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ANALYSIS OF THE CENTRAL HAWKE'S BAY SECTOR OF THE LATE NEOGENE FOREARC BASIN, HIKURANGI MARGIN, NEW ZEALAND

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“Happy is he who gets to know the reasons for things”.
-Virgil (70-19 BC)-

View of the Maungaharuru Range and Taraponui Trig from Bell Rock. Bluffs are formed of Titiokura Formation limestone and sandstone beds.

ABSTRACT

Hawke's Bay province lies within an extensive forearc basin in eastern North Island, New Zealand, that developed during the Late Miocene to present. An area of about 5 700 km^2 in central Hawke's Bay has been geologically mapped at 1:50 000 scale as part of an analysis of the Late Miocene-Early Pleistocene basin fill.

A substantially revised lithostratigraphic nomenclature is proposed for the Neogene succession, particularly for the latest Miocene-Early Pleistocene part (Mangaheia Group). The Tolaga Group is extended into central Hawke's Bay from the north, and incorporates the Early Miocene-Early Pliocene succession. It is proposed that the Hawke's Bay, Petane, Napier, and Poporangi Groups be abolished, and incorporated into a geographically expanded Mangaheia Group. The Petane Group is demoted to Petane Formation. Most formations within the group are now redefined as members, with the exceptions of the Esk Mudstone and Kaiwaka Formations, which are retained as separate formations.

An age model has been developed for the basin fill, chiefly using molluscan biostratigraphy. The Tongaporutuan-Kapitean boundary occurs in the Waitere Formation, and the Kapitean-Opoitian boundary occurs within the Mokonui Sandstone. The Opoitian-Waipipian boundary probably occurs in the Titiokura Formation, and the Waipipian-Mangapanian boundary in the Te Waka and Pohue Formations. The Mangapanian-Nukumaruan boundary has been identified at many localities, and occurs in several stratigraphic units, including the Papakiri Member (Matahorua Formation) and Sentry Box Formation. Geochemical analysis of glass shards in the Hikuroa Pumice Member (Petane Formation) suggests a correlation to tephra in the ODP 1124 record, and an inferred age of c. 2.15 Ma is suggested for this unit. The Plio-Pleistocene boundary is located in the Waipatiki Limestone Member (Petane Formation), and the top of the Olduvai paleomagnetic subchron occurs in the overlying Devils Elbow Mudstone Member.

The geological structure of the basin is classified into four structural domains. The axial range domain involves the eastern parts of the North Island axial ranges and there is marked oblique-slip displacement on major faults within it. Some oblique-slip is accommodated in the adjacent range front contractional domain, although dip-slip displacement is more significant. The more easterly central forearc basin domain is comparatively undeformed with only minor reverse faulting and associated folding. The eastern contractional domain comprises the inboard margin of the accretionary wedge, and is characterised by imbricate reverse and thrust faults, and associated folding. The uppermost parts of the accretionary wedge are currently undergoing gravitationally-induced collapse, expressed as deep-seated landslides and normal faulting.

While significant unconformities in the Neogene succession possibly reflect early phases in the development of the major faults in the North Island Shear Belt, most deformation of the basin fill is relatively young (post-lowermost Nukumaruan, c. 2.4 Ma), and much of this has occurred since the Early Pleistocene (c. 1.8 Ma), when deformation apparently intensified. This intensification coincides with the initiation of volcanism and rifting in the Taupo Volcanic Zone. The amount of Pliocene-Recent dextral-slip on the Ruahine Fault is likely to be less than 10 km, and there is probably less than 1 km of dextral-slip on the Mohaka Fault. New dextral-slip faults are developing in the basin fill east of the main oblique-slip faults, possibly due to dextral rotation of eastern North Island and the Hikurangi margin.

Forty-one lithofacies within the Late Miocene-Early Pleistocene sedimentary succession have been identified and grouped into six lithofacies assemblages. Each assemblage generally corresponds to a broad depositional environment. Siltstone lithofacies (inner to outer shelf) dominate the succession, followed by sandstone (shoreface-inner shelf), bioclastic (inner to middle shelf), mixed siliciclastic-bioclastic (nearshore to middle shelf), conglomerate (non-marine to shoreface), and volcaniclastic (non-marine to outer shelf) facies in decreasing abundance. In addition, thirty molluscan biofacies associations and sub-associations have been identified, representing both *in situ* and transported assemblages, and paleoenvironments ranging from estuarine to outer shelf settings.

Vail-type sequences, typically 20-80 m thick, are best developed in "middle" Pliocene to Early Pleistocene strata. These sequences are dominated by coarsening-upward packages of siliciclastic-dominated sediments, although bioclastic facies increase in prominence in Upper Nukumaruan cycles. Sequences are typically stacked in a strongly aggradational pattern, and although some periods of accelerated

subsidence are recorded in the stratigraphic record, the aggradational nature of the succession shows that basin subsidence mostly kept pace with sediment flux during the Mangapanian to Upper Nukumaruan. Transgressive systems tracts (TSTs) typically comprise a combination of bioclastic and siliciclastic lithofacies. Highstand systems tracts (HSTs) are dominated by fine-grained siliciclastic-dominated facies. Regressive systems tracts (RSTs) may be either siliciclastic or bioclastic-dominated, although siliciclastic-dominated RSTs are most common. Lowstand systems tracts (LSTs) are mostly characterised by non-marine greywacke conglomerate beds. They sharply overlie shallow-marine rocks, and were deposited when high-bedload river systems prograded across a low-gradient coastal plain and exposed continental shelf.

Eight sequence motifs have been developed, each representing different positions across a paleoshelf. While these motifs share some similarities, unique combinations of subsidence, sediment flux, and sediment provenance have combined to differentiate them. An idealised "shoreline to slope" two-dimensional sequence model has been produced for the Nukumaruan part of the basin succession using the motifs. The model sequence illustrates the idealised distribution across a paleoshelf of the various lithofacies, macrofaunal associations, and sequence stratigraphic surfaces.

The Neogene geological history of central Hawke's Bay can be usefully subdivided into three major phases, each represented by one of the three lithostratigraphic groups documented. The Early Miocene-Early Pliocene (Otaian-Lower Opoitian) phase is represented by the Tolaga Group. This group comprises four deepening-upward bathyal-dominated packages with shelfal beds at their base. This succession is overlain by a thick sandstone (Mokonui Sandstone). Mokonui Sandstone is unconformably overlain by the Mangaheia Group (Upper Kapitean-Upper Nukumaruan), characterised by shelfal deposits with some cyclothemic intervals. Occasional upper bathyal beds occur, but appear to represent short-lived depositional phases. The uppermost Neogene phase is represented by the Middle Pleistocene (Castlecliffian) Kidnappers Group, characterised by thick non- to marginal-marine greywacke conglomerates.

The basin has been substantially inverted along its western side, involving movement on faults of the North Island Shear Belt. The stratigraphic record along the eastern margin of the forearc basin records the development of faulting and folding associated with the growth of the inboard part of the accretionary wedge, such that parts of the forearc basin succession have become involved in the accretionary wedge. The outcrop pattern of westward-younging Pliocene limestones demonstrates that the inboard margin of the accretionary wedge has migrated toward the centre of the basin over time. Younger limestone beds (e.g. Mason Ridge Formation) presently crop out close to the forearc basin axis and at lower elevations compared with older Pliocene limestone beds (e.g. Kairakau Limestone) located along the eastern margins of the basin.

Uplift of the accretionary wedge resulted in the development of a Pliocene interior seaway, which was most extensive during the Mangapanian and characterised by the development of prominent limestone formations (Te Aute lithofacies) along both margins. Although large volumes of siliciclastic sediment were entering the basin, strong tidal currents periodically swept the sea floor of siliciclastic sediment, allowing extensive "continent-attached" carbonate banks to develop along the western side of the basin. Thick "continent-detached" limestone beds developed along the eastern side of the basin due to the elevated positions of accretionary ridges. Breaches in the seaway were present at times in the areas of Kuripapango and the Manawatu Gorge. By the Lower Nukumaruan, the interior seaway became permanently closed to the south with uplift of the Mount Bruce block in northern Wairarapa.

The most important influence on the stratigraphic architecture of the Neogene succession has been the tectonic factor. In comparison with the well developed cyclothemic record in the adjacent Wanganui Basin, the cyclothemic record in the Hawke's Bay area is incomplete and poorly developed. In most parts of the succession, tectonic influences have overprinted glacio-eustatic sea-level fluctuations. Only a limited correlation can be achieved between rocks in the Mangaheia Group and the $\delta^{18}O$ record contained in deep-sea records, as the sequences are not well enough developed in general to allow for cycle-by-cycle correlations.

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Volume Two

ENCLOSURES

Enclosure 1: Sheets 1-6, 1:50 000 geological map of central Hawke's Bay

SHEET 1, MOHAKA

SHEET 2, MAUNGAHARURU

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Enclosure 2 - Legends for 1:50 000 Geological Maps

Enclosure 3 - Geological Cross-Sections

Enclosure 4 - Stratigraphic correlations: Mangaheia Group simplified composite stratigraphic columns

Enclosure 5 - Lithofacies and stratigraphic correlations of upper parts of the Mangaheia Group, Waikare River to Ohara Depression

Enclosure 6 - Paleogeographic Maps

Enclosure 7 - Geographic Information System Database Model

Enclosure 8 - Locality and Topographic Feature Map

CHAPTER ONE

INTRODUCTION

OVERVIEW

This study presents the first comprehensive stratigraphic investigation of the Late Miocene-Quaternary sedimentary succession within central Hawke's Bay in eastern North Island, New Zealand (Fig. 1.1). It aims to establish the structural and stratigraphic development of a forearc basin extending NE-SW through much of Hawke's Bay Province within the Australian-Pacific plate boundary zone.

In North Island, the Hikurangi margin is a classic ocean-continent convergent margin involving the interaction of the leading edge of the overriding Australia plate with subduction of the Pacific plate (see Fig. 2.2, Chapter Two). This margin has five main east to west components: 1) an accretionary prism, which underlies the continental shelf and slope, and coastal hills of Hawke's Bay and Wairarapa; 2) a forearc basin in northern Wairarapa-Hawke's Bay-Gisborne; 3) axial ranges (Ruahine-Raukumara); 4) a bounding zone of strike-slip faults (North Island Shear Belt); and 5) an active volcanic arc. While the structure and development of 1, 4, and 5 are reasonably well known, that of 2 and 3 are geologically very poorly known as a result of few modern investigations.

In Hawke's Bay, the succession contained in the forearc basin is thick (up to 5 km), highly variable in rock type, and ranges in age from Early Miocene to Holocene. Moreover, it has been obliquely truncated by several major strike-slip faults (e.g. Mohaka and Ruahine Faults). The basement underlying the North Island axial ranges has been uplifted on these faults, and in places the overlying sedimentary succession contained in the basin has been uplifted with the basement. This situation presents an outstanding opportunity to identify and quantify, on the one hand, local structural and tectonic signals pertaining to the subsidence of the basin, the timing and magnitude of fault growth, and the timing of uplift of the ranges, and on the other hand, global sea-level signals that may be preserved in the details of the thick sedimentary succession contained in the basin.

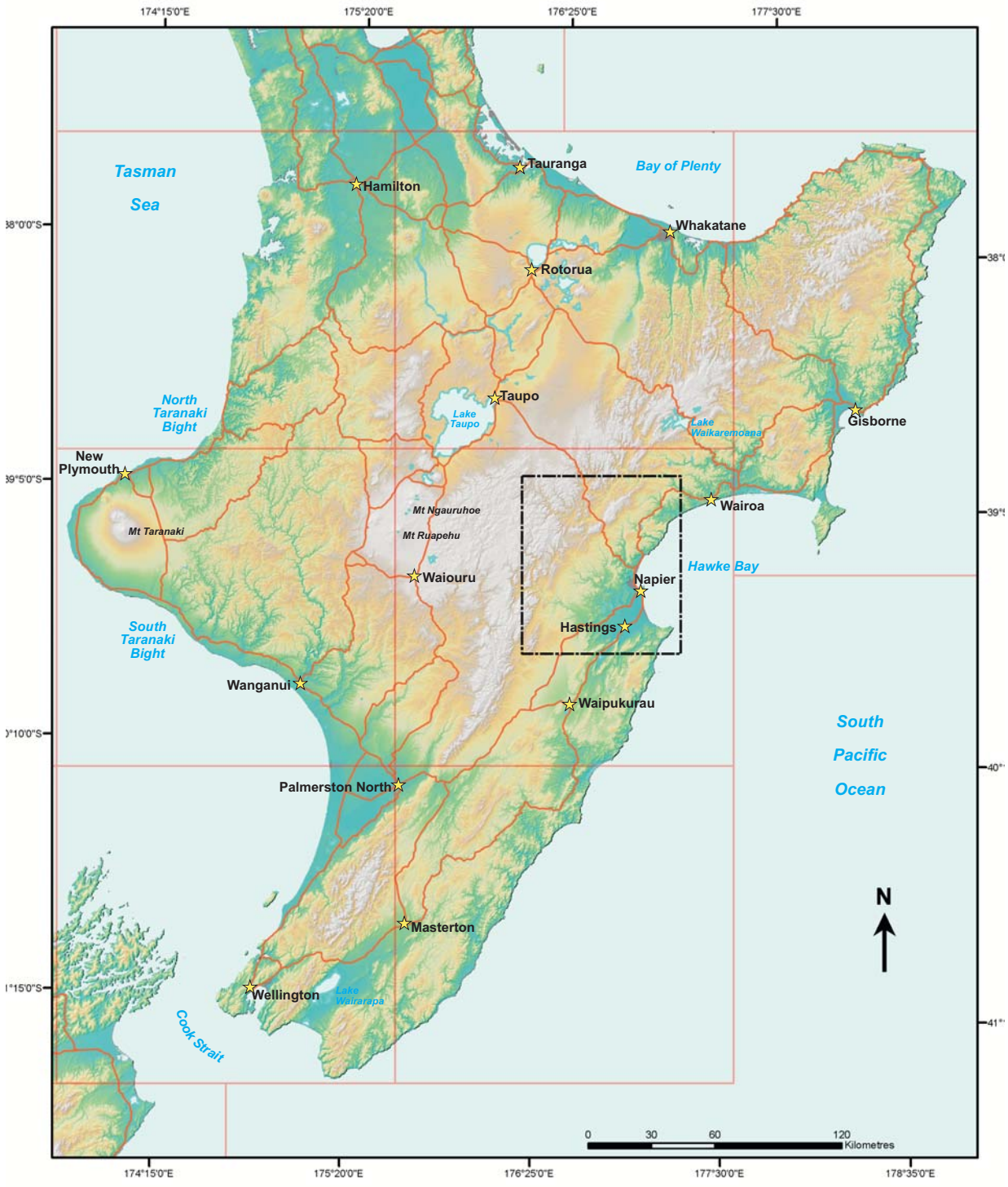

Fig. 1.1: Location of the central Hawke's Bay study area (dashed black box). Red boxes are the GNS Science QMAP sheet cut-up. Orange lines are state highways.

The successful isolation of the tectonic and sea-level signals would have significance for better understanding the development of the whole Hikurangi margin. An historical problem has been disparity between the age of formation of the accretionary prism (early Miocene, c. 22 Ma) versus the comparative youth of the modern volcanic arc (c. 2 Ma) in the Taupo Volcanic Zone (TVZ). A better understanding of the age and evolution of the intervening forearc basin and axial ranges

may help to answer this problem. Sediments of appropriate Miocene and Pliocene age are contained in the basin, and have been examined in this study to identify the timing of subduction-related subsidence, sedimentation, and deformation. In addition, western Hawke's Bay contains the only localities where parts of the basin succession occur on both sides of the major strike-slip faults, and careful examination of these records has enabled constraints to be placed on the magnitude and timing of horizontal and vertical offsets.

Parts of the basin fill contain thick cyclic-sequences modulated by sea-level changes driven by the formation and melting of ice sheets on land during the past 3 m.y. (e.g. Beu and Edwards 1984; Haywick *et al.* 1991; Bland *et al.* 2004). These sequences are thick because of the combined rates of sediment supply and basin subsidence. They represent end-member examples of cyclic sequences, and their stratigraphic architecture deserves to be better documented and interpreted so that the global sea-level signal can be accessed in other active margin basins.

THESIS OBJECTIVES

Specific objectives and aims of this project include:

1) Establish the stratigraphy of the sedimentary succession contained in central parts of Hawke's Bay. Geologically map the distribution of the stratigraphic units and structural features in this area (Chapter Three, Appendix I, Enclosures 1-4).

2) Develop a biostratigraphic and numerical chronology for the basin fill (Chapter Four).

3) Date the timing and displacement on the Mohaka and Ruahine Faults, and other structures in central parts of Hawke's Bay, from comparisons of the stratigraphy and chronology of sequences distributed and offset across the faults. Determine the timing and character of deformation of the inboard part of the accretionary wedge as it involves the forearc basin succession (Chapter Five, Enclosure 3).

4) Characterise the facies content and architecture of the deposits and interpret the related depositional paleoenvironments (Chapter Six, Appendix II, Enclosure 5).

5) Apply and develop sequence stratigraphic concepts to the succession and infer the record of relative sea-level changes, and correlate this record where possible with the global record of eustatic sea-level oscillations contained in deep-sea cores using the chronology established for the basin fill (Chapter Six).

6) Reconstruct the paleogeographic development of the basin, including the impact of global sea-level changes on the character of the basin fill and the record of strike-slip faulting and basement uplift along the western basin margin. Interpret the sedimentation

and deformation history of the basin in terms of the tectonic development of the various components of the Hikurangi margin (Chapter Seven, Enclosure 6).

THESIS OUTCOMES

The thesis research has resulted in a new stratigraphic model for the central Hawke's Bay basin, and a comprehensive analysis of its evolution has been undertaken, including characterising the influence of global eustatic sea-level changes on the architecture of the deposits. This has been achieved by detailed logging of outcrop sections, geological mapping, and analysis of the macrofaunal content of representative samples. The key output of this study is a new geological map showing the distribution of stratigraphic units, their geometry, and structure (fault and fold character). This map has been produced within a Geographic Information System (GIS) digital environment using ArcInfo 9.1. The new 1:50 000 scale geological map of central Hawke's Bay (covering about 5 700km^2) is presented as a series of six map sheets (Enclosure 1, Sheets 1-6). While presented as six separate map sheets in the thesis, the GIS database contains a seamless coverage of the study area and geological maps can easily be produced of any geographical area contained within the database. The new geological map displays the distribution of a substantially revised lithostratigraphy for Hawke's Bay. This lithostratigraphy has been proposed with a view to assisting the integration of the Raukumara (Mazengarb and Speden 2000) and Wairarapa (Lee and Begg 2002) QMAP sheets with the Hawke's Bay sheet.

COMMENTS ON THESIS STRUCTURE AND FORMAT

The results of this study have been written in a traditional thesis style, which has been compiled in three main parts. The eight text chapters in the main part of the thesis provide an overview of the study, discuss important issues, and present conclusions. Appendices provide important supporting descriptions for the interpretations presented in the main section of the thesis. Enclosures at the back of the thesis contain geological maps, cross-sections, stratigraphic correlations, and paleoenvironmental reconstructions. References cited within chapters are listed at the end of Chapter Eight.

The nature of this study has meant that detailed documentation of a large number of stratigraphic units and outcrops has been undertaken. As a result, the systematic documentation of stratigraphic units is very detailed, and makes for "tedious" reading. Consequently, Chapters Three and Six are written as "distillations" of much fuller descriptive chapters contained in Appendices I and II respectively, and focus on the main issues and results of the study.

When referring to international geological periods, epochs, and ages the qualifiers Early, Middle, and Late, capitalised, are used when such periods have been defined. If early, middle or late are used in lower case text, the terms are being used in an informal manner. For example, no "Middle" subdivision of the Pliocene epoch has been defined, therefore "middle" Pliocene is used informally. For New Zealand stages the terms "Lower" and "Upper" are used as qualifiers.

STATEMENT OF THE CONTRIBUTIONS MADE TO THIS THESIS BY THE AUTHOR AND EXTERNAL COLLABORATORS

A major component of this research project has involved the use of Geographic Information System (GIS) technology for the cataloguing, storage, manipulation and analysis of spatially referenced data collected and compiled during the course of the study. The extent of exisiting geological maps compiled and evaluated during this research is illustrated in detail in Appendix III (page A3-16). A large volume of spatially referenced data was collected during fieldwork, which was undertaken over a period of more than 50 weeks from December 2001 to October 2004. During fieldwork geological units were established and mapped at a field scale of 1:25,000 where possible, resulting for the first time in detailed geological maps of large parts of central Hawke's Bay. Over 1070 outcrops were described during this time, from which 117 stratigraphic columns, distributed through the study area, have been constructed (presented in Appendix IV). The schema of the GIS database utilised by this study was developed by Adam Vonk (PhD student, Department of Earth and Ocean Sciences, The University of Waikato) and the author, based on protocols developed by Rattenbury and Heron (1997) for the GNS Science QMAP GIS. All data entry into this database, and map production, was undertaken by the author.

Tephra samples analysed in this thesis were collected by the author. The extraction of glass shards from these tephra samples and the geochemical analysis of them (see Chapter Four, p. 114) was undertaken by Dr Brent Alloway (formerly GNS Science, Lower Hutt), using the electron microprobe housed at the University of Toronto, Canada. Doctor Brent Alloway also identified potential correlations between tephra analysed in this study and those from recent ODP drill cores.

The collection of 112 macrofaunal bulk samples during fieldwork, and the identification of taxa within them, was undertaken in collaboration with Austin Hendy (PhD student, University of Cincinnati, Ohio, USA). Census counts and collation of data from these bulk samples (see Chapter Six, p. 189) were undertaken by Austin Hendy. Cluster analysis of these data, and identification of the resulting macrofaunal associations, were carried out by the author. In addition to bulk sample analysis, 305 field observations of macrofaunal types and abundances were recorded by the author during fieldwork.

OUTLINE OF THESIS CHAPTERS

Chapter Two: Geological Setting and Physiography

Chapter Two provides an overview of the geological setting of the study area. It introduces the main morphotectonic elements that characterise the area, and summarises the geological history of eastern North Island. The chapter also discusses the physiography of the study area.

Chapter Three: Lithostratigraphic Overview and Issues

This chapter provides a brief overview of the geological map sheets in Enclosure One, describing their production, and the broad geological patterns they show. The chapter then discusses the five main "packages" of rocks in the study area (Torlesse composite terrane, Tolaga Group, Mangaheia Group, Kidnappers Group, and Late Quaternary deposits). The chapter focuses on the Mangaheia Group, discussing the major lithostratigraphic issues highlighted in this study, and their possible resolution. Lithostratigraphic details are contained in Appendix I.

Chapter Four: Biostratigraphy and Age

The purpose of this chapter is to develop an integrated biostratigraphy for the basin fill. The biostratigraphy is based on molluscan macrofossils, with some microfossil biostratigraphy, major element geochemical tephra analysis, and limited paleomagnetic analysis.

Chapter Five: Geological Structure

This chapter provides an overview of the geological structure on land in central parts of Hawke's Bay, extending from the North Island Shear Belt in the west to the accretionary wedge in the east. It describes the character of four structural domains that illustrate varying styles of deformation across the region, and places constraints on the timing and magnitude of deformation. The chapter concludes by attempting to place constraints on the timing of inception of the current phase of strike-slip faulting in the North Island Shear Belt.

Chapter Six: Paleoenvironments and Sequence Stratigraphy of the Mangaheia Group

This chapter has three main parts. The first two sections discuss the nature of the inferred depositional paleoenvironments in the Mangaheia Group, as revealed from lithofacies and biofacies analysis. A summary of the lithofacies and macrofaunal associations in the study area is presented in this chapter. More detailed descriptions are contained in Appendix II. The third part of the chapter discusses the character of the sequence stratigraphy of the Mangaheia Group. This section describes important unconformities and depositional patterns within the succession. The character of important sequence stratigraphic surfaces in the study area are described, as

are the systems tracts observed. Eight basic motifs of sequences are then defined and described. These motifs are combined in the final part of the chapter to produce an idealised source-to-sink model Nukumaruan sequence for the Mangaheia Group in Hawke's Bay.

Chapter Seven: Geological History and Basin Synthesis

This chapter outlines the inferred paleogeographic development of the basin, including the impact of global sea-level changes on the character of the basin fill and the record of strike-slip faulting and basement uplift along the western basin margin. It also demonstrates how accretionary wedge deformation has migrated inboard through time, and how eastern parts of the forearc basin succession have become progressively involved in deformation of the wedge. This chapter is supported by the paleogeographic maps in Enclosure 6.

Chapter Eight: Summary

Appendix I: Systematic Lithostratigraphy

This appendix provides systematic descriptions of all stratigraphic units geologically mapped in this study. A synthesis of this appendix chapter is presented in Chapter Three.

Appendix II: Paleoenvironmental Analysis

This appendix provides more detailed descriptions of the lithofacies and macrofaunal associations summarised in Chapter Six.

Appendix III: Geological Map Production Utilising a Geographic Information System

Outlines the geological database that underlies this study, and describes the methodology used to produce the geological maps in Enclosure 1. This appendix is accompanied by Enclosure 7.

Appendix IV: Stratigraphic Columns

Appendix V: Fossil Observation Datasheets

Appendix VI: "The early Pliocene Titiokura Formation: stratigraphy of a thick, mixed carbonate-siliciclastic shelf succession in Hawke's Bay Basin, New Zealand".

Enclosures

Seven enclosures are included in the back pocket of this thesis:

Enclosure 1: Sheets 1-6, 1:50 000 geological maps of central Hawke's Bay

Enclosure 2: Legends for 1:50 000 geological maps

Enclosure 3: Geological cross-sections

Enclosure 4: Stratigraphic correlations: Mangaheia Group simplified composite stratigraphic columns

Enclosure 5: Lithofacies and stratigraphic correlations of upper parts of the Mangaheia Group, Waikare River to Ohara Depression

Enclosure 6: Paleogeographic maps

Enclosure 7: Geographic Information System database model

Enclosure 8: Locality and Topographic Feature Map

PAPERS PRESENTED DURING THESIS RESEARCH

During the course of this thesis research the author has presented some preliminary results at both national and international conferences as either oral or poster papers. A manuscript has also been published in a peer-reviewed journal, and contributions have been made to field trip guides, and other papers. These are referenced below. In addition, several presentations have been given to interest groups within the University of Waikato, Hawke's Bay Regional Council, and the Geological Society of New Zealand.

Peer-reviewed journal articles

Bland, K. J.; Kamp, P. J. J.; Pallentin, A.; Graafhuis, R. B.; Nelson, C. S.; Caron, V., 2004: The early Pliocene Titiokura Formation: stratigraphy of a thick, mixed carbonate-siliciclastic shelf succession in Hawke's Bay Basin, New Zealand. *New Zealand Journal of Geology & Geophysics **47***. 675-695. (Copy included at the back of Chapter Three).

Kamp, P. J. J .; Vonk, A. J.; **Bland, K. J.**; Hansen, R.; Hendy, A. J. W.; McIntyre, A. P.; Ngatai, M.; Cartwright, S. J.; Hayton, S.; Nelson, C. S., 2004: Neogene stratigraphic architecture and tectonic evolution of Wanganui, King Country, and eastern Taranaki Basins, New Zealand. *New Zealand Journal of Geology & Geophysics **47***. 625-644.

Conference papers

Baggs, R. A.; Dyer, S. J. D.; Caron, V.; Pallentin, A.; **Bland, K. J**.; Graafhuis, R. B.; Nelson, C. S.; Kamp, P. J. J., 2002: Ongoing studies of Pliocene sedimentology in the Hawke's Bay region. Geological Society of New Zealand Annual Conference, Whangarei. *Geological Society of New Zealand Miscellaneous Publication **112A***. p. 4

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Bland, K. J.; Kamp, P. J. J.; Nelson, C. S., 2004b: Stratigraphic architecture, structure, and paleogeography of Hawke's Bay basin, Eastern North Island. Programme and Abstracts, Geological Society of New Zealand, New Zealand Geophysical Society, 26th Annual conference, Taupo. *Geological Society of New Zealand Miscellaneous. Publication **117A***. p. 9. (Invited plenary paper).

Bland, K. J.; Kamp, P. J. J.; Nelson, C. S., 2004c: New 1:50 000 scale geological maps of Hawke's Bay basin, eastern North Island. Programme and Abstracts, Geological Society of New Zealand, New Zealand Geophysical Society, 26th Annual conference, Taupo. *Geological Society of New Zealand Miscellaneous. Publication **117A***. p. 9

Bland, K. J.; Caron. V.; Nelson, C. S.; Kamp, P. J. J.; Pallentin, A., 2005: Continent-attached and continent-detached cool-water limestones in an actively deforming forearc basin, Hawke's Bay, New Zealand. Proceedings, 2005 Geological Society of America Annual Meeting & Exposition, Salt Lake City.

Bland, K. J.; Kamp, P. J. J., 2006: Geological structure of the forearc basin in central Hawke's Bay, eastern North Island. 2006 New Zealand Petroleum Conference, Sky City, Auckland. 13 p.

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Vonk, A. J.; **Bland, K. J**.; Pallentin, A.; Kamp, P. J. J., 2003: The use of GIS technology for geological mapping in basin analysis projects at the University of Waikato. Geological Society of New Zealand Inc. 2003 Annual Conference, Dunedin. *Geological Society of New Zealand Miscellaneous. Publication **116A***. p. 155

Field guides

Nelson, C. S.; Kamp, P. J. J.; Caron, V.; Pallentin, A; **Bland, K. J**.; Graafhuis, R. B., 2001: Sedimentology, diagenesis, and sequence stratigraphy of Plio-Pleistocene mixed siliciciclastic-carbonate forearc basin deposits, central Hawke's Bay, eastern North Island. In: *Fieldtrip Guides* (Ed. by R. T. Smith), Geological Society of New Zealand Annual Conference "Advances in Geosciences", University of Waikato, Hamilton. *GSNZ Miscellaneous Publication Vol. **110B**,* FT8. 45 p.

Litchfield, N.; **Bland, K**.; Hayward, B.; Page, M.; Langridge, R., 2005: Friends of the Quaternary Fieldtrip. Hawke's Bay 1st-3rd July, 2005. Co-organised through the Geological Society of New Zealand (GSNZ) and the Australasian Quaternary Association (AQUA). 19 p.

CHAPTER TWO

GEOLOGICAL SETTING AND PHYSIOGRAPHY

INTRODUCTION

The New Zealand subcontinent ("*Zealandia*") is an irregularly-shaped mass of continental crust lying along the convergent margin between the Pacific and Australia lithospheric plates (Fig. 2.1). This boundary contains three main tectonic sections. In the northern section oceanic crust of the Pacific plate is obliquely subducting beneath continental crust of the Australia plate. The Hikurangi trough (Fig. 2.1, 2.2, 2.4), extending from the Kermadec Trench in the north to Kaikoura in the south, marks where thickened, oceanic Hikurangi Plateau of the Pacific plate turns down beneath the Australia plate (Wallace *et al*. 2004). To the north the Hikurangi Plateau changes to a normal oceanic plate subducting at the Kermadec Trench (the northern continuation of the Hikurangi trough). In the northeast of South Island, subduction gives way to a strike-slip-dominated faulting system, with the Marlborough Fault System and Alpine Fault accomodating most of the Australia-Pacific relative motion (e.g. Van Dissen and Yeats 1991; Holt and Haines 1995; Nicol and Van Dissen 2002). Southwest of South Island, the Macquarie Ridge and Puysegur Trench (Fig. 2.1) mark a complex subduction and transform plate boundary. Along northern parts of this section of the plate boundary, Pacific plate crust overrides oceanic crust of the Australia plate. The central sector of the plate boundary is represented by a transform system where continental crust of the Pacific plate obliquely overthrusts continental crust of the Australia plate. The Alpine Fault occurs along this central section and is well known for the 480 km of Neogene-Quaternary dextral displacement, and associated overthrusting that has given rise to the Southern Alps (Kamp 1992).

The Hawke's Bay region, on the east coast of the North Island (Fig. 2.1), has been located in the convergent plate boundary zone since the subduction commenced during the early Miocene (Ballance 1993). Seismic reflection data indicate that the top of the subducted plate lies 15-25 km beneath Hawke Bay and dips northwestward at a shallow angle of about 6-12° as far west as the axial ranges, after which it dips more steeply northwestward (Ansell and Bannister 1996; Barnes *et al.* 2002).

The study area is located in the central Hawke's Bay part of a forearc basin (Fig. 2.2). The basin itself is a major Cenozoic sedimentary basin containing a c. 5 km-thick Miocene-Pleistocene succession. The forearc basin is one of five tectono-geomorphic elements in eastern North Island and has formed in response to the evolution of the convergent Australia-Pacific plate boundary

zone since the end of the Oligocene (Ballance 1993). The sedimentary fill of the basin is dominated by mudstone and flysch facies, with sandstone, limestone, and conglomerate facies more common in the Pliocene section. During the Plio-Pleistocene the marine forearc basin was differentially uplifted to form land.

TECTONIC SETTING

OVERVIEW

All of the North Island of New Zealand belongs to the upper (Australia) of the two plates involved with the modern plate boundary zone through the New Zealand subcontinent (Fig. 2.1, 2.2). Active tectonics in the North Island is dominated by subduction at the Hikurangi trough, back-arc rifting in the Taupo Volcanic Zone (TVZ), and strike-slip faulting in the North Island Shear Belt (Wallace *et al.* 2004). The plate boundary zone accommodates oblique subduction of the Pacific plate beneath the Australia plate (Fig. 2.1). The relative plate motion vector trends at c. 40°-70° to the general strike of the subduction margin and ranges from 38 to 50 mm/yr. Relative Australia-Pacific plate motion decreases in rate and takes on a greater margin-parallel component southward along the New Zealand margin (DeMets *et al.* 1990, 1994). Margin-parallel motion is minor in relation to the overall relative motion and appears to be accommodated by strike-slip faults bounding the eastern side of the axial ranges. Margin-normal motion is accommodated on reverse and thrust faults predominantly east of the axial ranges and within the subduction prism.

The term Hikurangi Margin is used here to describe all elements of the modern subduction zone of eastern North Island and northeastern South Island from the subduction interface west to the backarc region, including the modern volcanic arc (Fig. 2.2). The Hikurangi Margin corresponds to the southern termination of the Tonga-Kermadec subduction system (Fig. 2.1). The Hikurangi Margin has evolved over the last 25 m.y. as the Australia plate moved northwards relative to the Pacific plate, with the effect that the New Zealand continental block was sheared through the middle (Lewis and Pettinga 1993). The apparent dextral displacement along this part of the plate boundary totals about 480 km.

The morphostructural elements of the Hikurangi Margin, which are described below, are (in an arcward direction): the Hikurangi trough and subduction interface; the accretionary wedge; the forearc basin (including Hawke Bay); the structural ridge (incorporating North Island axial ranges and North Island Shear Belt); and the modern volcanic arc and back-arc region.

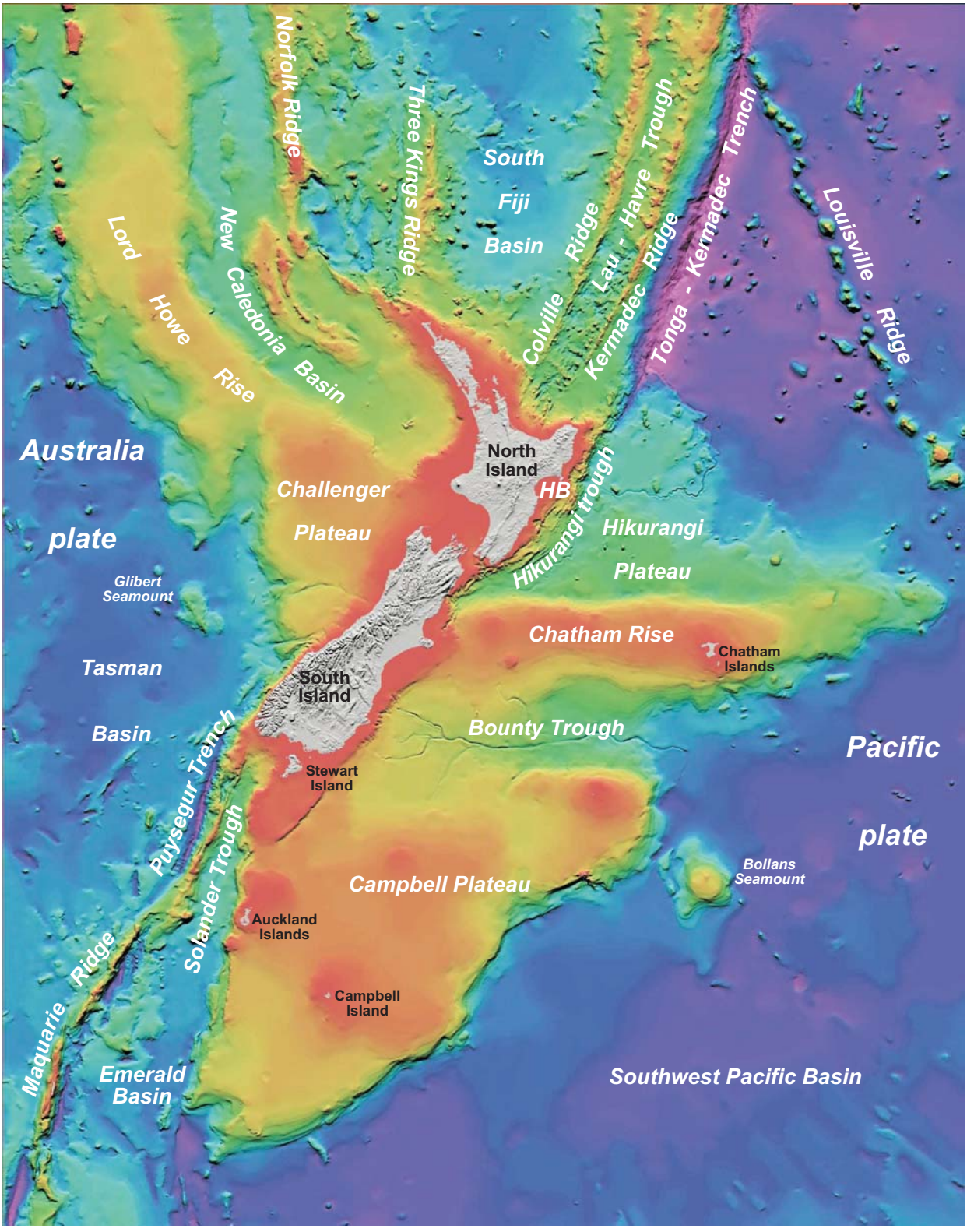


Fig. 2.1: The New Zealand subcontinent, showing the main bathymetric and tectonomorphic features. HB, Hawke Bay. Base image is the NIWA Undersea New Zealand map.

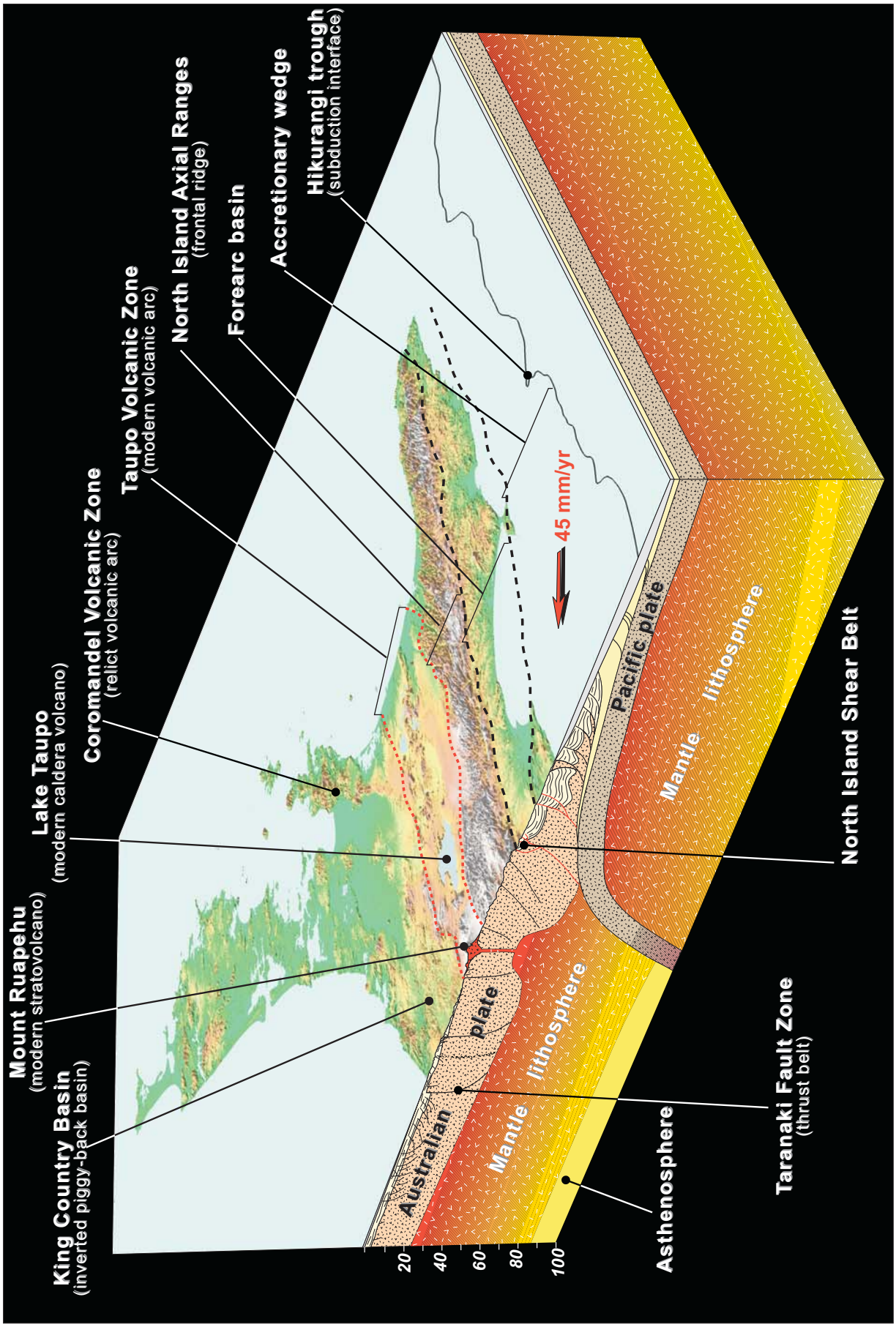
HIKURANGI TROUGH AND SUBDUCTION INTERFACE

The Tonga-Kermadec-Hikurangi subduction zone is a 3000 km-long plate boundary where oceanic crust of the Pacific plate is subducted beneath oceanic or continental crust of the Australia plate (Wallace *et al.* 2004) (Fig. 2.2). The Hikurangi trough (Fig. 2.1, 2.2, 2.4) is the southern part of this subduction system, and continues southwest to the Marlborough region in the northeast of the South Island from where the plate boundary becomes a zone of oblique continent-continent collision. Displacement on the plate boundary is transferred to the dextral Alpine Fault via the Marlborough Fault Zone.

The Hikurangi trough is a sediment-filled depression about 3000 m below sea level that marks the modern subduction boundary (deformation front) off the east coast of the North Island and northeastern South Island. It is approximately 4 km deep in the north and decreases to 1 km deep at its southwest end near Marlborough (Beanland 1995). At Hawke's Bay the deformation front, as recorded by the location of the Hikurangi trough, is approximately 175 km offshore, and near Wellington lies 75 km offshore. The Hikurangi trough comprises two separate zones: 1) a northern, sediment-flooded, volcanic knoll-studded, SSW trending structural continuation of the Kermadec Trench; and 2) a southern, more east-west trending transform boundary between central New Zealand and the downwarped continental crust of the Chatham Rise (Lewis 1980). The presence of seamounts suggests that the subducted crust is oceanic rather than continental (Uruski and Wood 1993). The Hikurangi trough southward becomes a zone of intracontinental transpression (Lewis 1985) and the boundary between these two zones remains relatively diffuse.

The convergent trench slope is characterised by rapid frontal accretion of Pliocene-Holocene turbidites south of Hawke Bay and by tectonic erosion and seamount subduction to the northeast (Lewis and Pettinga 1993; Collot *et al*. 1996). The Raukumara Peninsula is presently undergoing crustal extension, with listric faults and diapiric structures occurring in association with over-pressurised shales (Walcott 1987; Field *et al.* 1997; Mazengarb 1998).

Fig. 2.2 (facing page): Illustration of the tectonic setting of eastern North Island, New Zealand. Data used in this figure were derived from Beanland (1995), Field *et al.* (1997), Barnes and Nicol (2002), and Barnes *et al.* (2002).


Mount Ruapehu
(modern stratovolcano)
King Country Basin
(inverted piggy-back basin)
Lake Taupo
(modern caldera volcano)
Coromandel Volcanic Zone
(relict volcanic arc)
Taupo Volcanic Zone
(modern volcanic arc)
North Island Axial Ranges
(frontal ridge)
Forearc basin
Accretionary wedge
Hikurangi trough
(subduction interface)
45 mm/yr
Australian Plate
Mantle lithosphere
Pacific plate
Mantle lithosphere
North Island Shear Belt
Taranaki Fault Zone
(thrust belt)
Asthenosphere
20
40
60
80
100

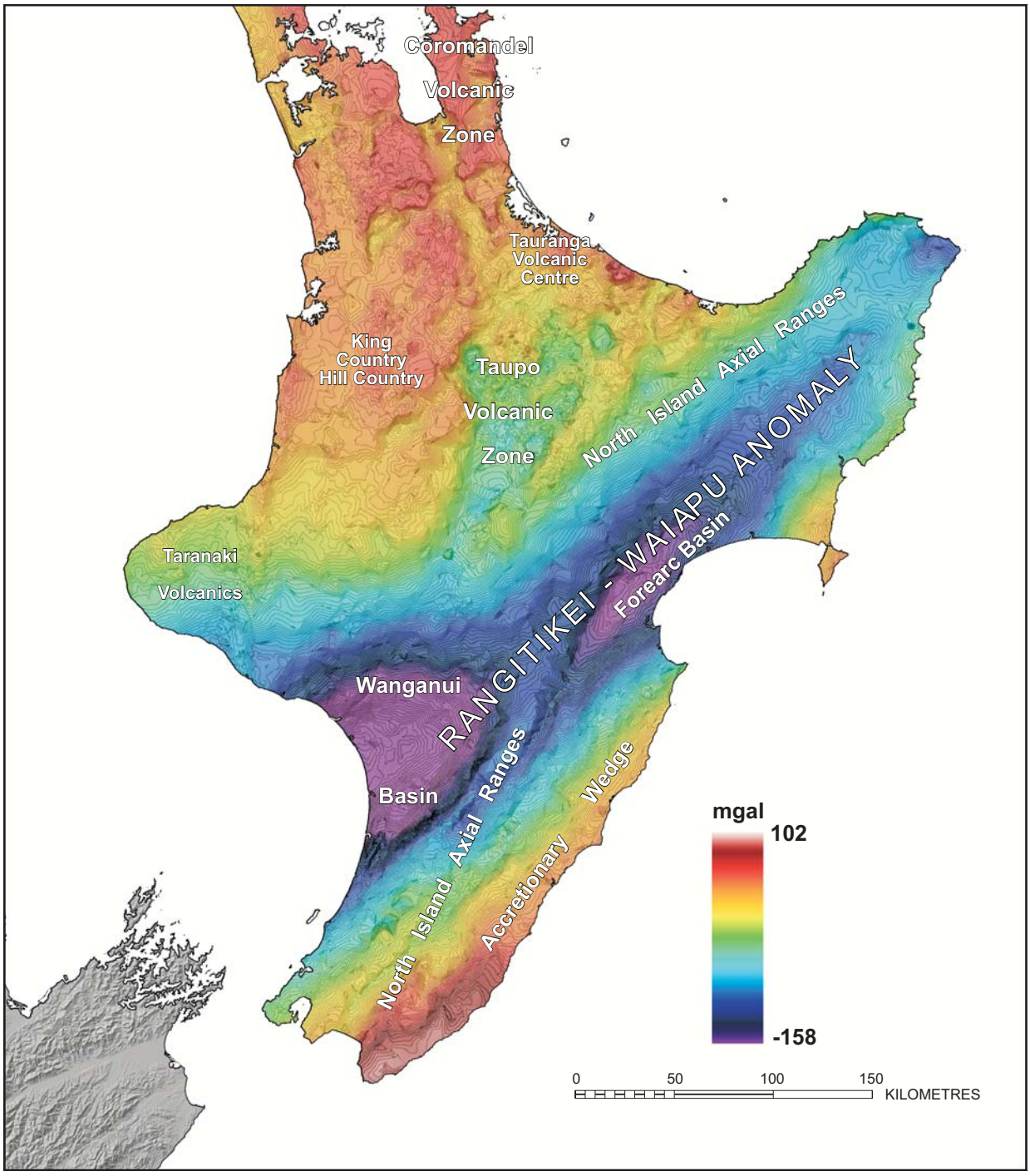


Fig. 2.3: Distribution of Bouguer gravity anomalies, North Island. Anomaly values are in mgal (10-5 N/kg); contour interval 1 mgal. Gravity values are in terms of the New Zealand Potsdam System (1959). Assumed density of topography (land) +2.67 Mg/m3, ocean -1.64 Mg/m^3. Data used in this figure are provided courtesy of GNS Science. The position of the Rangitikei-Waiapu gravity low (Robertson and Reilly 1958) is indicated. Note the strong coincidence of positive values (red and orange shades) with the accretionary wedge, and negative values (purple and blue shades) with the Plio-Pleistocene forearc basin and Wanganui Basin (Rangitikei - Waiapu anomaly).

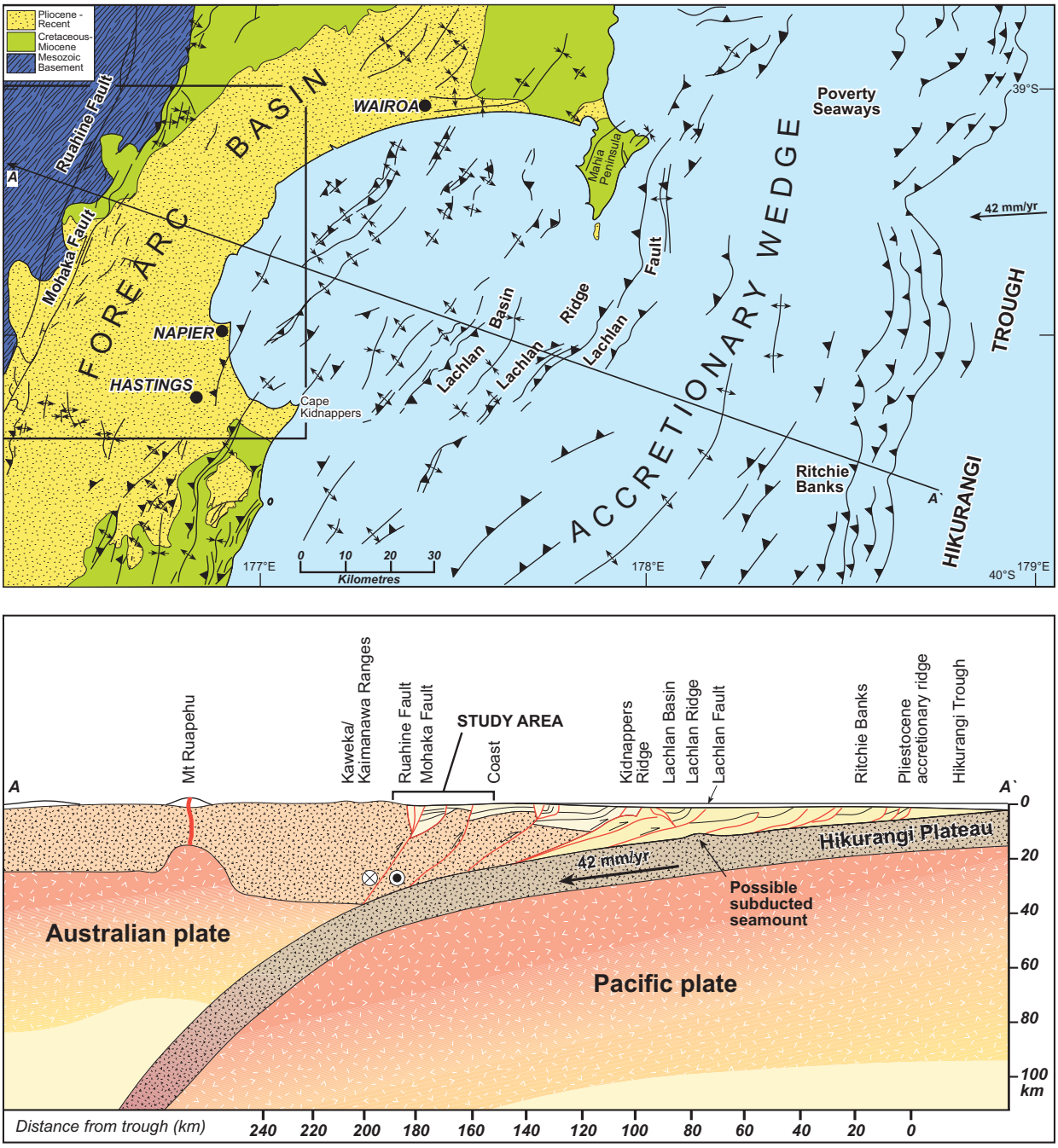


Fig. 2.4: Regional tectonic setting of the Hawke's Bay area, and the central part of the Hikurangi subduction zone. Location of the crustal cross section is indicated by line *A-A'*. The study area is shown by the black box on the map. Adapted from Barnes *et al.* (2002).

IMBRICATE ACCRETIONARY WEDGE

Arcward of the Hikurangi trough is a thrust fault-controlled region up to 160-180 km wide making up an imbricate frontal accretionary wedge that has developed during several phases of deformation and sediment offscraping (Chanier and Ferriére 1999; Fig. 2.2-2.4). This area is a zone of seaward-thinning imbricated sediments that forms a wedge-shaped sedimentary body frontal to the Australia plate and to the continental crust of New Zealand (Lewis and Pettinga

1993). This accrectionary wedge extends the whole length of the Hikurangi Margin and while mostly offshore, encroaches on land around Mahia Peninsula and south of Cape Kidnappers (Beanland 1995), south of which it is present for about 270 km (Pettinga and Lewis 1985; Ballance 1993; Lewis and Pettinga 1993) (Fig. 2.2).

The accretionary wedge comprises three main units: a) passive margin sediments; b) frontally accreted trench-fill; and c) slope basin infill. Late Cretaceous and Paleogene passive margin sediments and coeval tensional basin-fill represent a period of passive margin deposition between Early Cretaceous and Neogene phases of subduction and frontal accretion. These Late Cretaceous and Paleogene sediments have been rotated from a northwest strike along strike-slip faults, and because of this have been laterally accreted to the present margin where they form a zone about 80 km wide (Lewis and Pettinga 1993). Offscraped Neogene and Quaternary trench-fill is being frontally accreted to the seaward edge of the wedge and has reached a maximum width of over 80 km, and a thickness of 7 km in the central sector of the margin. Lewis and Pettinga (1993) viewed this as the accretionary wedge *sensu stricto*. Both the laterally and frontally accreted deposits are capped by numerous small, transitory, landward-tilting, turbidite-filled Neogene slope basins that are relocated as the basin-bounding thrusts relocate (Lewis and Pettinga 1993). All three units of the imbricate wedge are being "telescoped" into one body by imbricate-thrusting that elevates the seaward-verging, hanging-wall anticlines. The accretionary wedge is best developed in its central section offshore of Hawke's Bay and Wairarapa where it is at its widest, and the highest imbricate-thrust ridge and slope basins are emergent on land (Cole and Lewis 1981; Pettinga 1982).

The accretionary wedge comprises pre-existing passive margin sediments overlying basement rocks that have been thrust faulted and back-tilted during the past 25 million years (Pettinga 1982). Neogene slope basins in the accretionary wedge are generally aligned parallel to the trench axis (Lewis 1980; Berryman 1988). They are typically 5-30 km wide (Lewis 1980) and contain sediment fills between 200 and 2200 m thick (van der Lingen and Pettinga 1980; Pettinga 1982). Sediments filling slope basins have been progressively incorporated into the subduction complex, which includes zones of tectonic melange (Beanland 1995). The coastal hills of southern Hawke's Bay are characterised by complexly deformed and often truncated Upper Cretaceous to Lower Miocene sedimentary successions which are incorporated in three NNE-SSW-trending structural highs. Deformation styles in this area include tight recumbent and isoclinal folding, and reverse and/or thrust faulting (Pettinga 2004). The latter is often accompanied by narrow anastomosing zones of tectonic melange and broken formation. Miocene sediments of slope basin (alternating sandstone-mudstone) and slope (mudstone) environments, and Pliocene sediments of shelf (coquina limestone, calcarenite, and calcareous siltstone)

environments, are exposed on land in intervening broad synclinal structures (Pettinga 1980, 1982; Harmsen 1985; Kamp *et al*. 1988).

Late Quaternary landscape features indicate that folding, faulting, and uplift of the accretionary wedge on land continues to the present day. Such landscape features include uplifted and commonly tilted marine terraces, deeply incised and rejuvenating streams and rivers, and surface expression of active folds and faults (Pettinga 2004). Rates of Late Quaternary uplift of this region are variable, and range from <1 m/k.y. to about 3 m/k.y. (Lewis 1971; Hull 1985, 1987; Pillans 1986). In southeastern parts of North Island the boundary between the forearc basin and accretionary wedge is not clearly delineated (Beanland 1995).

The offshore part of the accretionary prism contains many actively growing fault-controlled anticlines and active faults (Field *et al.* 1997; Barnes and Nicol 2002; Barnes *et al.* 2002). These are mechanically linked to the structural telescoping of the accretionary prism (Ballance 1993; Lewis and Pettinga 1993; Beanland *et al.* 1998). One tectonically active ridge is the Lachlan Ridge (Barnes *et al.* 2002; Ricketts and Nelson 2004). Lachlan Ridge is the submarine extension of Mahia Peninsula and is an antiformal structure located above the hanging wall of an east-verging thrust, the Lachlan Fault. The fault itself extends to a detachment in Cretaceous or older strata (Field *et al.* 1997; Barnes *et al.* 2002).

FOREARC BASIN

The forearc basin (Fig. 2.2-2.4) represents the major topographic and structural depression associated with the complex, and is bounded to the west by a structural ridge of Mesozoic basement rocks (Torlesse composite terrane) which separates the forearc basin from the Taupo Volcanic Zone and back-arc region. The forearc basin extends from the axial ranges to the accretionary wedge and, with the exception of Hawke Bay, about half of the forearc is presently above sea level and is actively being uplifted (Beanland 1995). Its location coincides with a prominent area of low bouger anomalies (Fig. 2.3).

The forearc basin contains a Mio-Pliocene sedimentary fill that is moderately deformed by a series of reverse faults. Active deformation occurs throughout the forearc basin but varies in character and intensity in different structural domains (refer Chapter Five). The least deformed region is a zone through central parts of the basin bounded in the west by the North Island Shear Belt, a zone of active dip-slip and dextral faulting to the east (i.e. accretionary borderland). The greatest amount of deformation occurs in the region of the axial ranges where large dextral strike-slip and reverse faults have significantly offset the Mio-Pliocene basin fill.

Mesozioc basement rocks have been encountered in Te Hoe-1, Ongaonga-1, and Takapau-1 hydrocarbon exploration drillholes in western parts of the forearc basin. The eastern extent of indurated Mesozoic basement is not well known. For example, in Hawke Bay, it has not been unambiguously identified in seismic profiles (Uruski 1994; Field *et al.* 1997), and has not been intercepted in any drillhole east of the axial ranges (e.g. Hawke Bay-1, Hukarere-1, Whakatu-1).

Neogene sedimentary rocks generally dip 2°-25° to the southeast. Around Taradale beds dip 2°-4° northwest where they are involved in the Matapiro Syncline. At sites around the North Island Shear Belt, beds dip up to 70° to the northwest or southeast, and uncommonly may be overturned.

Hawke Bay

Hawke Bay proper (Fig. 2.1, 2.4) is the partially enclosed area of sea between Mahia Peninsula and Cape Kidnappers. Water depths are typically less than 120 m, with the 250 m isobath defining the edge of the continental shelf (Field *et al.* 1997). The origin of Hawke Bay remain poorly understood. Reyners (1989) postulated its origin as an upper plate structure that has formed above a tear in the subducted Pacific plate. Spörli and Ballance (1989) suggested it is a continuation of Wanganui Basin, and Uruski (1994) suggested it is a basin that formed as a result of regional bending of the strike-slip fault belt of the North Island.

Seismological data indicate that the top of the subducted Pacific plate lies 12-25 km beneath Hawke Bay (Bannister 1988; Ansell and Bannister 1996), with the plate interface dipping at a shallow angle of about 6°-12° northwest as far west as the axial ranges, before steepening further to the west (Barnes and Nicol 2002).

FRONTAL RIDGE: THE NORTH ISLAND SHEAR BELT AND THE AXIAL RANGES

The forearc basin is bounded to the west by a frontal ridge up to 1700 m high composed of Triassic to Early Cretaceous basement rocks assigned to the Torlesse composite terrane (Field *et al.* 1997; Fig. 2.2). The frontal ridge is geomorphologically expressed as the North Island axial ranges and is separated from the forearc basin by major dextral oblique-slip faults. In southern North Island the Wellington and Wairarapa Faults bound the axial ranges. Near Woodville, the Wellington Fault bifurcates into the Ruahine and Mohaka Faults, which continue northeast through the study area (Fig. 2.5). These faults commonly juxtapose basement rocks of the frontal ridge against Mio-Pliocene rocks of the forearc basin. The frontal ridge possesses a strong NNE-SSW structural and topographic alignment, with faulting more prominent along the eastern margins of the ridge. Vertical displacement since the early Pleistocene along the bounding faults is possibly as much as 2000 m (Berryman 1988).

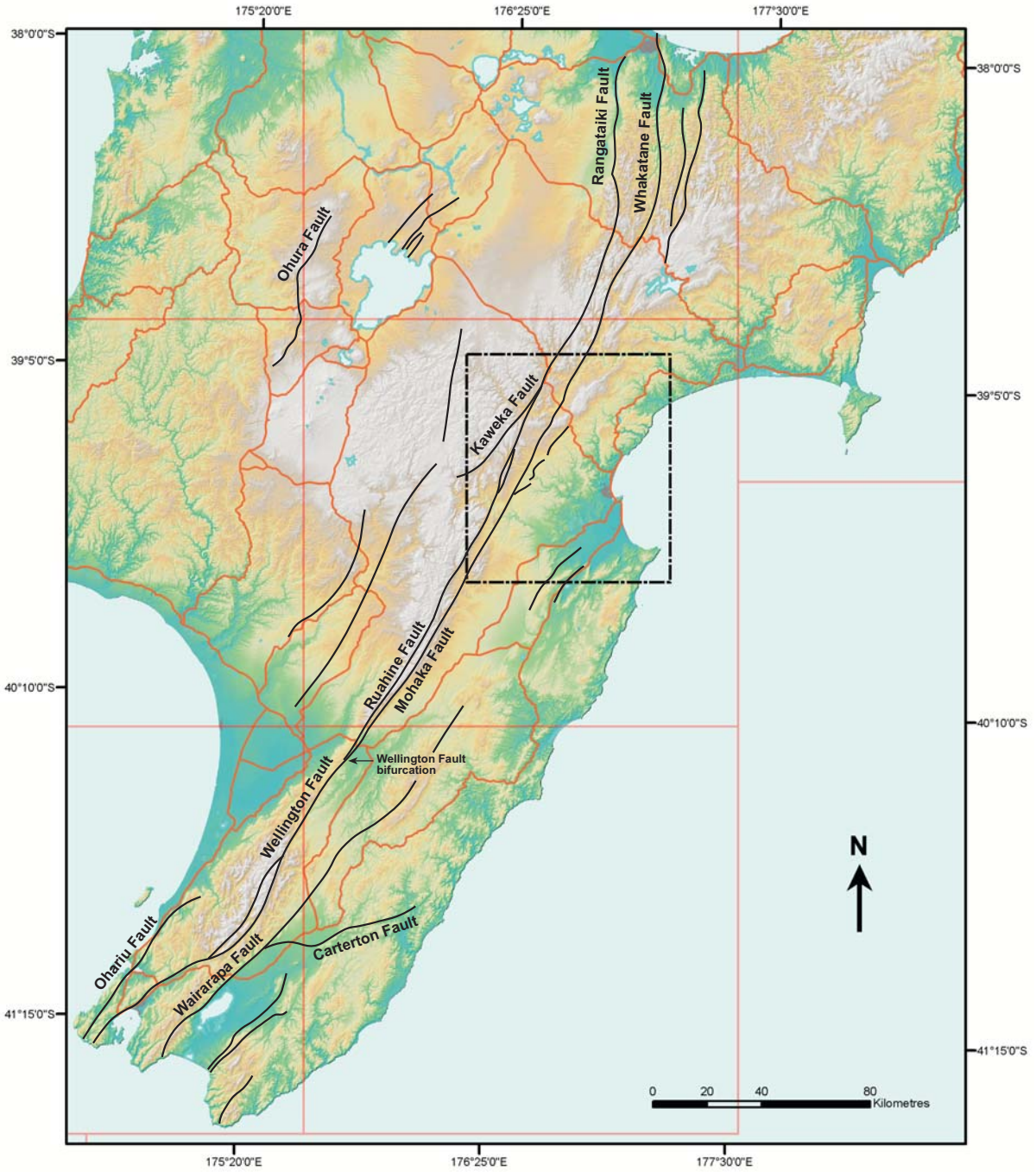


Fig. 2.5: Distribution of some major faults in southern and central North Island. The location of the Wellington Fault bifurcation (near Woodville) is indicated. Dashed box indicates the study area. Orange lines are QMAP sheet cut-ups; red lines are state highways.

The North Island Shear Belt acts to accommodate some of the modern plate motion through the North Island (Cashman *et al.* 1992; Beanland *et al.* 1998; Nicol and Van Dissen 2002; Wallace *et al.* 2004). The major dextral oblique-slip faults (e.g. Ruahine and Mohaka Faults) are inferred to accommodate a significant portion of the margin-parallel slip, whereas more basinward faults such as the Wakarara, Tukituki, and Poukawa Faults are inferred to have taken up more margin-normal slip. The significant dextral faults frequently mark the foot of mountain ranges with 1 - 1.7 km of

vertical relief (e.g. Erdman and Kelsey 1992; Beanland *et al.* 1995; Nicol and Van Dissen 2002), indicating that some degree of oblique-slip must be accommodated on them (e.g. Nicol and Van Dissen 2002).

Large areas of the axial ranges are characterised by summit height accordance or smooth topography, which has been interpreted as representing a remnant erosion surface (Wellman 1948; Berryman 1988).

VOLCANIC ARC AND BACK-ARC REGION

The Taupo Volcanic Zone (TVZ; Fig. 2.2, 2.3) is defined as the youngest and active (eastern) part of the Central Volcanic Region (Beanland 1995; Stratford and Stern 2006). It is a seismically active zone of Quaternary calc-alkaline volcanism and intra-arc rifting (Spinks *et al.* 2005) containing numerous closely-spaced northeast striking normal faults, half-grabens, and volcanic centres (Wilson *et al.* 1984). The TVZ marks the present location of intra-arc rifting related to an overall convergent setting within the North Island, and associated with a highly thinned crust of 15 km thickness (Bibby *et al.* 1995; Spinks *et al.* 2005).

Volcanic activity commenced in the TVZ at about 2 Ma (Houghton *et al.* 1995; Briggs *et al.* 2005), and the present area of active volcanism is concentrated in a NNE-SSW-trending zone 250 km long extending from White Island in the northeast to Mount Ruapehu in the southwest (Spinks *et al.* 2005). This area includes all activity in the past 300 k.y. (Houghton *et al.* 1995; Wilson *et al.* 1995). It can be divided into three parts along its length: a central region with several calderas extending from Okataina to Taupo including associated rhyolitic volcanism at the surface; and two extensions with Whakatane-White Island to the northeast and Tongariro-Ruapehu to the southwest with andesite-dacite stratovolcanoes (Houghton *et al.* 1995; Wilson *et al.* 1995). The central area is extremely productive with rhyolitic volcanic (c. 0.28 $m^3 s^{-1}$) and geothermal fluxes (the equivalent of c. 4200 MW) unequalled in the world (Wilson 1996).

TECTONOSTRATIGRAPHIC EVOLUTION OF THE EAST COAST REGION

MESOZOIC BASEMENT ROCKS

Basement rocks underlying the East Coast region are assigned to the Torlesse composite terrane (Fig. 2.6). This is one of several Late Paleozoic to Early Cretaceous fault-bounded tectonostratigraphic units of low grade metasedimentary rocks that constitute the Eastern

Province of New Zealand (Mazengarb and Speden 2000). Basement rocks of the East Coast region consist mainly of Triassic to Early Cretaceous indurated sandstone and mudstone (greywacke and argillite), and are assigned to the Rakaia, Pahau, and Waioeka terranes as part of the Torlesse composite terrane, in association with the Esk Head and Whakatane mélange zones (Fig. 2.6).

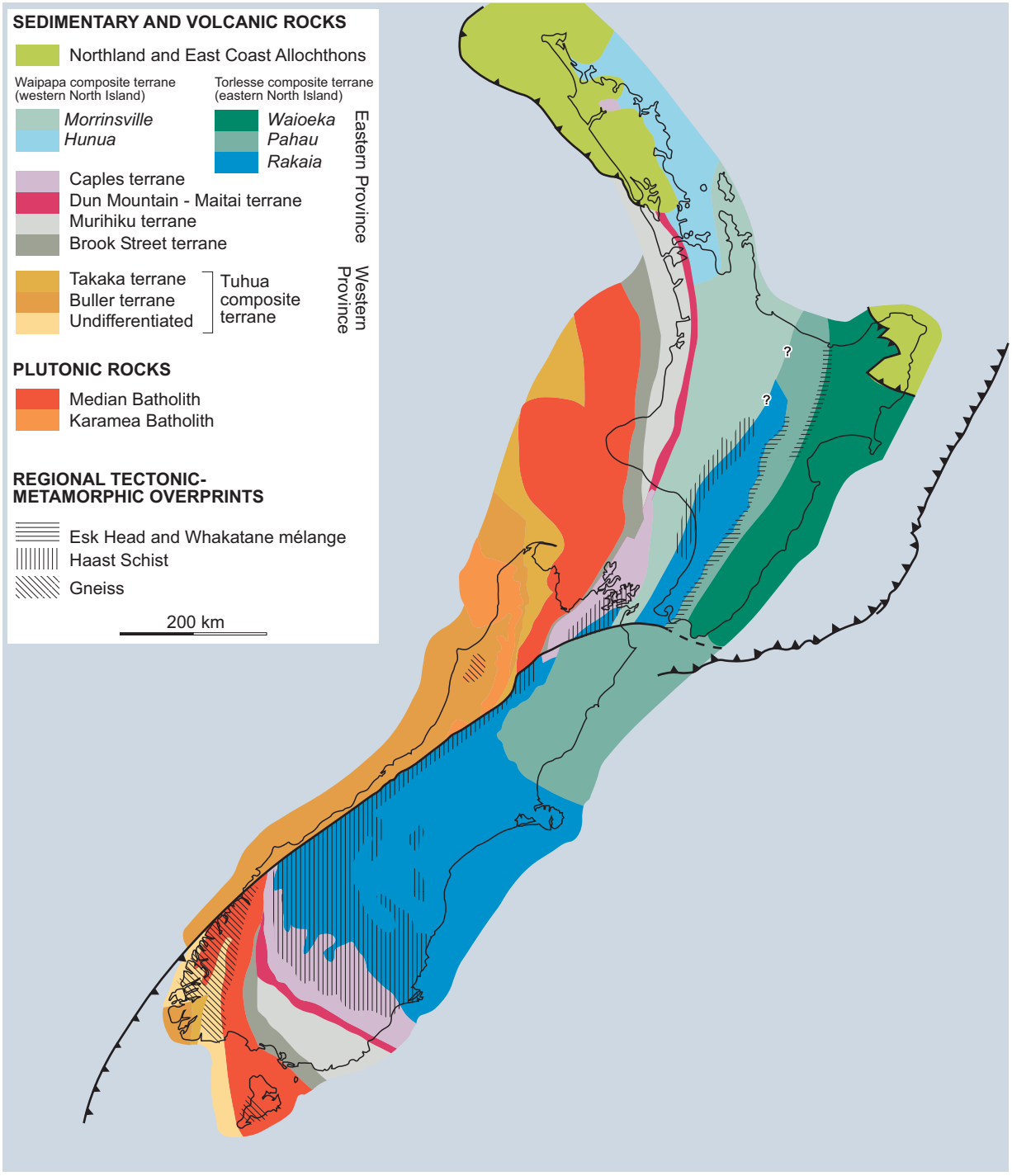


Fig 2.6: Tectonostratigraphic basement terranes of New Zealand, after Mortimer *et al.* (1999), adapted from Lee and Begg (2002). Basement rocks of the study area comprise Torlesse composite terrane, and the Esk Head and Whakatane mélange.

Rakaia terrane

The Rakaia terrane underlies the North Island axial ranges from Wellington to the Napier-Taupo Road and comprises relatively quartz-rich feldsarenites of mostly Triassic age (Mortimer 1995; Field *et al.* 1997). The sedimentary rocks grade into textural zone IIA schist in the Kaimanawa Range and western Wellington (Spörli 1978; Begg and Mazengarb 1996). Potassium-argon and rubidium-strontium whole-rock ages from both schistose and non-schistose Rakaia terrane rocks indicate two episodes of metamorphism and deformation, in the Early Jurassic and Early Cretaceous (Adams and Graham 1996).

Esk Head-Rimutaka mélange

This mélange separates the Rakaia and Pahau terranes. It is up to 15 km wide, but may be absent where faulted-out by Neogene faults such as the Mohaka Fault (Field *et al.* 1997). Basalts and Triassic limestones are common in the Esk Head-Rimutaka mélange (Silberling *et al.* 1988; Mortimer 1995). Whole rock K-Ar and Rb-Sr ages from the Rimutaka mélange near Wellington suggest deformation in the early Late Cretaceous (Adams and Graham 1996).

Pahau terrane

Pahau terrane underlies the northeastern South Island, the Aorangi, Rimutaka, eastern Tararuas and Ruahines, and the Ikawhenua ranges in the North Island. Lithologically it is very similar to the Rakaia terrane but the sandstones are of Late Jurassic to Early Cretaceous age and are less well-indurated (Mortimer 1995).

Whakatane mélange

Whakatane mélange was first proposed by Mortimer (1995) and has only been identified in the central North Island. It forms the tectonic contact between the Pahau and Waioeka terranes. As with the Esk Head-Rimutaka mélange, basalts and limestones are more common than in the adjacent terranes. The mélange is well exposed on the coast near Whakatane, in the Waimana Gorge, middle Whakatane River valley, and the Huiarau Range (Field *et al.* 1997).

Waioeka terrane

The Waioeka terrane forms the northeastern part of the Torlesse composite terrane, occurring east of the Whakatane Fault. While it comprises sandstone that is similar in age to the adjacent Pahau terrane, its compositions is quite different. Sandstone in the Waioeka terrane is relatively quartz-poor litharenite (Mortimer 1995).

Offshore of the east coast of the North Island the Hikurangi Plateau, a 300 000 km^2, 10-15 km thick region of oceanic crust is being subducted beneath the North Island. Petrological study of samples of basalt from the plateau appears to correlate the Hikurangi Plateau with other Early Cretaceous (115-130 Ma) Pacific Ocean plateaus such as the Ontong-Java and Manihiki plateaus (Mortimer and Parkinson 1996).

COVER ROCKS

Cover rocks in the East Coast region are of Cretaceous to Pleistocene age, and occur in three geographic areas (Raukumara Peninsula, southern Hawke's Bay/Wairarapa, and Marlborough). Neogene rocks are widespread across the region. Rocks of "middle" Pliocene age and younger are common south of Wairoa. The discussion of cover rock geological history in the following sections applies to the East Coast Basin as a whole, mostly as described by Field *et al.* (1997).

Cretaceous-Middle Paleocene

The late-Early Cretaceous (Aptian-Albian) was a time of major tectonic and igneous activity throughout much of New Zealand, reflecting the culmination of the Rangitata Orogeny (Bradshaw *et al.* 1981). The Torlesse composite terrane and other eastern province terranes are considered to have been juxtaposed at a convergent continental margin on the edge of the Gondwana supercontinent before the end of the Early Cretaceous (Bishop *et al.* 1985; Adams and Kelley 1998). In western parts of the Raukumara Peninsula Torlesse rocks were lithified, deformed, uplifted, eroded, and then buried by transgressive marine sediments during the Early Cretaceous (Mazengarb and Speden 2000). In the Raukumara region subduction-related deformation, including thrust faulting, may have continued throughout Early Cretaceous time and into the Late Cretaceous (Mazengarb and Harris 1994; Mazengarb and Speden 2000).

Uplift and deformation of Torlesse rocks in the East Coast region during the Early Cretaceous (Aptian-Albian) resulted in the development of a widespread angular unconformity that separates Torlesse rocks from overlying Albian "cover rocks" (Field *et al.* 1997). In the northeast of the East Coast region this pattern is locally complicated by possible continuous sedimentation from Torlesse into cover beds. Elsewhere, complications may arise from the presence of relatively old (Aptian) cover rocks. The oldest sedimentary cover rocks in the East Coast region are of Early Cretaceous age and are assigned to the Matawai Group. They consist of indurated fossiliferous sandstone, conglomerate, intraformational breccia, and minor mudstone (Koranga Formation) (Mazengarb and Speden 2000). These beds contain abundant fresh volcaniclastic sediments and are petrographically indistinguishable from sandstone of the underlying Waioeka terrane (Torlesse composite terrane).

Folding, faulting, uplift, and erosion in the Late Cretaceous was followed by renewed marine transgression (Mazengarb and Speden 2000). By the latest Cretaceous, slow accumulation of fine-grained clastic sediments and limestone was occurring over what is now the East Coast region (Field *et al.* 1997). Whangai Formation (of the Tinui Group), and its Marlborough equivalent the Herring Formation, are siliceous mudstone, that were deposited over virtually the entire East Coast region during the Late Cretaceous and Middle Paleocene. The Whangai Formation overlies transgressive sandstone of Piripauan to Lower Haumurian age. The Whangai Formation spans the Cretaceous-Tertiary boundary and reflects part of a stable pattern of sedimentation that continued through the Paleogene (Field *et al.* 1997). It typically consists of 300-500 m of non-calcareous and calcareous shale and mudstone of Haumurian-Teurian age. The formation may rarely be up to 600 m thick.

This pattern of sedimentation continued into the Paleocene and lasted in most areas until the late Oligocene. While there is some evidence for minor tectonism during this time, the condensed sedimentary record and character of the lithofacies suggest that most of the modern East Coast region was a passive continental margin during the Paleogene (Field *et al.* 1997; Mazengarb and Speden 2000). Rocks of this epoch comprise both the autochthonous and allochthonous cover rocks of the East Coast region (Mazengarb and Speden 2000).

Late Paleocene

The Waipawa Formation of Middle to Upper Teurian age (also known as the Waipawa Black Shale) is a widespread potential hydrocarbon source-rock that was deposited during the Late Paleocene (Field *et al.* 1997). Waipawa Formation conformably overlies the Whangai Formation, and is a regional marker bed consisting of very poorly bedded, dark brownish-grey to brownish-black moderately soft to hard, non-calcareous micaceous siltstone. The formation may be absent over much of southern and central Hawke's Bay. Leckie *et al.* (1992) interpreted the Waipawa Formation to represent a condensed section deposited at the peak of the Late Cretaceous to Paleocene marine transgression.

Latest Paleocene to Eocene

Eocene sedimentary rocks in eastern North Island are dominated by (slumped) smectitic mudstones of the Wanstead Formation. Wanstead Formation has been used as a general term for all fine-grained bentonitic (smectite-rich) sediments of Paleocene to Eocene age in eastern North Island (Moore and Morgans 1987). Other lithofacies include greensand, breccia, conglomerate, poorly to well-bedded glauconitic sandstone and mudstone, flysch, and siliceous units. The formation is known in all North Island east coast basins where Paleocene strata are

recorded (Field *et al.* 1997). It normally ranges in age from Teurian to Lower Whaingaroan but is more typically Teurian-Bortonian. Wanstead Formation is generally considered to represent the deepest-water depositional paleoenvironment of the Late Cretaceous-Paleogene in the East Coast, with average paleodepths of middle bathyal, although lower bathyal-abyssal depths are recorded in some parts. It was deposited coevally with the Amuri Formation in the Marlborough region (Field *et al.* 1997).

Oligocene

Throughout eastern North Island, rocks of Oligocene age are dominated by white-weathering marls and micritic mudstones, with minor flysch of the Weber Formation (Field *et al.* 1997). The Weber Formation usually conformably overlies Wanstead Formation, although in the Akitio River in southern Hawke's Bay 30 m of intensely bioturbated, bathyal, calcareous greensand of Kaiatan-Runungan age occurs at the base (Lee and Begg 2002). Weber Formation is generally a moderately hard, light grey, bioturbated, calcareous (40-70%) massive mudstone, although well-bedded sandstone does occur. The most common variation to this is massive, slightly glauconitic limestone. Thickness ranges from 30-900 m, but averages about 200-300 m. The most common Weber Formation facies are of Whaingaroan to Duntroonian age (Oligocene), although they may be as old as Bortonian-Lower Kaiatan (middle to late Paleocene) and as young as Lower Waitakian (Oligocene). The Weber Formation was possibly deposited at slightly shallower depths than the underlying Wanstead Formation, suggesting a slight regional regression (Field *et al.* 1997).

Miocene

The following sections overview the Neogene geological history of the East Coast Basin as a whole, as described mostly by Field *et al.* (1997). Changes in the style of sedimentation in the Early Miocene record the early phases of tectonism accompanying changes to the plate boundary system in the New Zealand region. Basal unconformities, facies changes, and deposition of flysch during the Waitakian and Otaian are inferred by Field *et al.* (1997) to mark the start of a new period of tectonism in the East Coast region, including large-scale faulting and the emplacement of allochthonous units (Mazengarb and Speden 2000). The style of sedimentation, sediment type, and tectonic style observed in the Raukumara area are similar to those observed in Northland. In both areas they are inferred to have developed from SW to SSW-directed subduction of the Pacific (oceanic) plate beneath the continental margin (Australia plate). The Late Cretaceous to Oligocene passive margin sequence, which had accumulated east and north of the Raukumara Peninsula, was dismembered into a series of thrust sheets and emplaced sequentially over the in-

place equivalent sequences. Obduction of the East Coast allochthon has juxtaposed rocks which were originally deposited far apart from each other (Mazengarb and Speden 2000).

The Miocene succession of the East Coast region consists mainly of bathyal mudstone and flysch punctuated by units comprising paralic conglomerate and nertitic sandstone and limestone (Field *et al.* 1997). Miocene units are up to 3500 m thick in northern Hawke's Bay and Cape Turnagain, but usually less than 1500 m thick in the Wairarapa. In Marlborough the Miocene succession is generally less than 1000 m thick, but reaches up to 2000 m thickness in the Awatere valley.

Early Miocene

Thick clastic-dominated sequences of Early Miocene age unconformably overlie thrust sheets of the East Coast allochthon and indicate that the SSW-directed obduction had ceased by this time (Mazengarb and Speden 2000). Over 100 m of Upper Waitakian mudstone and flysch mantled most of the East Coast region by the end of the Waitakian. The modern onshore areas and regions further east were mainly at bathyal water depths during the Upper Waitakian and into the Otaian. By the Lower Altonian most of the region was still at bathyal water depths with the possible exception of an area north of Lake Waikaremoana. Here, paralic and shelf sediments were deposited on Torlesse basement during the Altonian or Clifdenian suggesting that there was some uplift and erosion in the Lower Altonian (Field *et al.* 1997).

Middle Miocene

Deposition of Clifdenian sediments was greatest in the Raukumara Peninsula area where compacted thicknesses of over 1000 m are reported (Field *et al.* 1997). Over the Hawke's Bay and Wairarapa areas generally less than 100 m of Clifdenian rocks are present, although an anomalous thickness of up to 750 m occurs at Ruatahuna between two strike-slip faults. In the north of the East Coast area paleoenvironments generally deepened to the southeast, shelf sands were deposited in the west, and bathyal mudstones in the east with bathyal flysch deposited as slope aprons. Areas of uplift and subsidence together with localised faulting show that tectonism continued.

Paleogeographic reconstructions for the Lillburnian indicate a general onlap in the north of the East Coast Basin, in contrast to the basal Clifdenian succession. This probably resulted from both eustatic and tectonic influences. To the west of the modern main strike-slip fault belt Torlesse basement was probably exposed and eroding during the Lillburnian, as Waiauan and younger rocks lie directly on Cretaceous basement. By the end of Lillburnian time a large depocentre had formed in the north of the East Coast region, probably having the form of a west-facing, arcuate

sediment apron between the Raukumara Range and the coast. A distinct shallowing is evident in the south, with few Lillburnian rocks in the Marlborough area.

The Waiauan was characterised by dramatic periods of uplift and subsidence, perhaps indicating major faulting accompanied by two eustatic falls. These events combined to produce a mix of bathyal flysch and mudstone facies as well as paralic to neritic sandstone and limestone. No Waiauan rocks have been identified in outcrop in the study area, although they are present in places in the subsurface (see Chapter Seven, p. 258).

Late Miocene

Variations of sediment thickness and the distribution of paleoenvironments indicate that widespread faulting influenced sediment deposition during the Late Miocene, particularly in western areas and in the east of the present onshore region. Sediment thickness are greatest north of Hawke Bay. However, while sediments of Tongaporutuan age are thick, the long duration of the stage means that sedimentation rates were in places comparable to those in the Waiauan (Field *et al.* 1997). In the Middle to Late Miocene differential uplift formed a structural high around the area of modern Mahia Peninsula, and limited the eastern extent of the adjacent subsiding Wairoa Basin in which a thick sequence of sediments was being deposited (Mazengarb and Speden 2000). Throughout much of the Raukumara Peninsula during the Kapitean (latest Miocene) shallow-marine sediments were deposited.

Pliocene

In northern parts of the Raukumara Peninsula and in Marlborough the Pliocene succession is dominated by clastic sediments. Elsewhere the Pliocene is characterised by thick beds of bioclastic limestone ("Te Aute lithofacies"). Over 900 m of Plio-Pleistocene strata are estimated in the northern Raukumara area, 1700 m near Gisborne, about 2500 m along the Napier-Taupo Road, and up to 3000 m of Pliocene mudstone, sandstone, conglomerate, and limestone in the Wairoa Syncline in northern Hawke's Bay (Field *et al.* 1997).

The East Coast region was almost entirely submerged at the beginning of the Pliocene (Field *et al.* 2000). In many areas sedimentation appears to have continue across the Miocene-Pliocene boundary in the East Coast region, although "early-middle" Pliocene erosion at some localities has produced unconformities that give the impression of a Miocene-Pliocene boundary. This erosion has resulted in rocks of Opoitian age directly overlying Torlesse basement over a wide area from Wellington and the western Aorangi Range to Kuripapango, Waiouru, and Pakaututu. Subsidence occurred along the area of the modern axial ranges early in the Pliocene, evidenced by the deposition of widespread shallow-water facies such as those in the Matemateaonga

Formation on the northern Ruahine Range, on the Mangaohane Plateau, and near Kuripapango. Much of the Raukumara Peninsula became emergent during the "middle" Pliocene (Mazengarb and Speden 2000). No rocks of Mangapanian or Nukumaruan age are known from the Raukumara Peninsula or Marlborough areas, although they are well represented in Hawke's Bay (this study) and the Wairarapa (Field *et al.* 1997). Uplift of the axial ranges separated marine sedimentation in the East Coast region from Wanganui Basin during the Lower Nukumaruan, and marked uplift of the ranges has continued over the past million years.

During the latest Miocene and Pliocene, contraction in the accretionary wedge initiated shoaling around the coastal ranges of southern Hawke's Bay and the Wairarapa, resulting in deposition of Te Aute lithofacies limestones. From the Waipipian to Nukumaruan the uplifted coastal hills and rising axial ranges formed the margins of a seaway that extended from the Wairarapa to modern Hawke's Bay. Uplift of the Mount Bruce block in the Nukumaruan closed the seaway at its southern end and ceased deposition of the Te Aute lithofacies limestones. Wide, shallow-water marine platforms in central Hawke's Bay and southern Wairarapa promoted the deposition of strongly cyclic Nukumaruan successions when the influence of tectonism was less than that of eustatic sea-level change. Continued contraction resulted in the entire present onshore part of the East Coast region being uplifted above sea level near the end of the Nukumaruan. Minor non-marine sedimentation adjacent to the rapidly rising axial ranges, together with marginal-marine sedimentation at Cape Kidnappers and in the Wharekahika graben near East Cape occurred in the Middle Pleistocene. Within the past million years a structural high (Lachlan Ridge) immediately offshore from Mahia Peninsula has developed and is actively tilting the area WNW. This is one of a number of actively growing structures (such as the Kidnappers Anticline) and indicates continued deformation and uplift of the offshore part of the accretionary wedge (Mazengarb and Speden 2000).

PHYSIOGRAPHIC SETTING

The area under investigation in this study (Fig. 2.5, 2.7, 2.8; Enclosure 8) covers about 5,700 km^2 of central parts of Hawke's Bay, extending from the Ruahine and Kaweka Ranges in the west to the Pacific Ocean in the east, and bounded approximately to the north and south by the Waikare and Ngaruroro Rivers, respectively. The region is administered by the Hawke's Bay Regional Council, Hastings District Council, Wairoa District Council, and Napier City Council. The main human population is centred about the twin cities of Napier and Hastings (combined pop. approx. 110,000), of which Hastings is the larger. The next largest settlement is Havelock North near Hastings, with other significant towns including Flaxmere and Taradale. A number of other small towns and villages are scattered through the study area, including Te Haroto, Kotemaori, Putorino,

Bayview, Puketapu, Bridge Pa, Clive, Haumoana, and Te Awanga. Numerous small farming communities are present, the more significant of which include Maraekakaho, Tutira, Te Pohue, Rissington, Patoka, Puketitiri, Sherenden, Kuripapango, and Kereru (Fig. 2.7).



Fig. 2.7: Locations of some locality names referred to in this thesis.

Land use in the area has changed during recent years, and in many areas which once supported sheep and drystock farming there is now plantations of *Pinus radiata*, the largest of which occur in the Awahohonu, Te Haroto, Crohane, and Kaweka Forest areas. The recent dairy boom has also seen conversion of drystock farms to dairy units. The flat lowlands around the Ngaruroro

River, part of the Heretaunga Plains, are used for intensive horticulture, the most well-known product of which are the wines for which Hawke's Bay is famous. Fruit orchards are also common, particularly around Hastings and Havelock North, and in the Tutaekuri River valley near Dartmoor.

TOPOGRAPHY

The highest points in the study area occur on the Kaweka Range (Kaweka J, 1724 m) and the Maungaharuru Range (Taraponui, 1308 m). The Te Waka Range (highest point 1029 m) is also mostly over 900 m in elevation. The high ranges in western parts of Hawke's Bay are under snow for about 3 months in winter, and experience exceptionally strong winds during much of the year, but particularly during equinox periods. Annual rainfall at the coast (Napier) is approximately 850 mm, with a noticeable increase in precipitation west toward the main ranges.

The Kaweka, Ruahine, and Ahimanawa Ranges are part of the "greywacke" axial ranges of the North Island (Fig. 2.2, 2.8; Enclosure 8). The axial ranges define the western extent of the study area, and are typically bounded on their eastern side by the North Island Shear Belt. The western ranges comprise those ranges east of the North Island axial ranges, such as the Wakarara, Glenross, Maniora, Te Waka, and Maungaharuru Ranges. These ranges are generally bounded by the Mohaka Fault on their northwestern side and other faults, such as the Wakarara and Patoka, on their southeastern side.

The central hill country (Fig. 2.8) lies east of the main ranges, and north of the Heretaunga Plains and the fluvial terrace country. The area is mostly underlain by sandstone and mudstone. Notable geomorphic features are ridges and dipslopes held up by conglomerate and slightly cemented sandstone. Mudstone country is generally flatter, and the area as a whole is typically dissected by deeply-incised streams.

The Tangoio Block (as introduced by Haywick *et al.* 1991) (Fig. 2.8) is a coastal area of high topography (<600 m a.s.l). It is underlain by Nukumaruan rocks, and is held up by several well cemented limestone beds. Its elevation is not thought to be fault controlled.

The Ohara Depression (Fig. 2.8) is defined by the active Ruahine and Mohaka Faults. While Recent slip on these faults is dominated by strike-slip to oblique-slip displacement, long-term dip-slip displacement is responsible for the presence of the depression, and the bounding Ruahine and Wakarara Ranges.

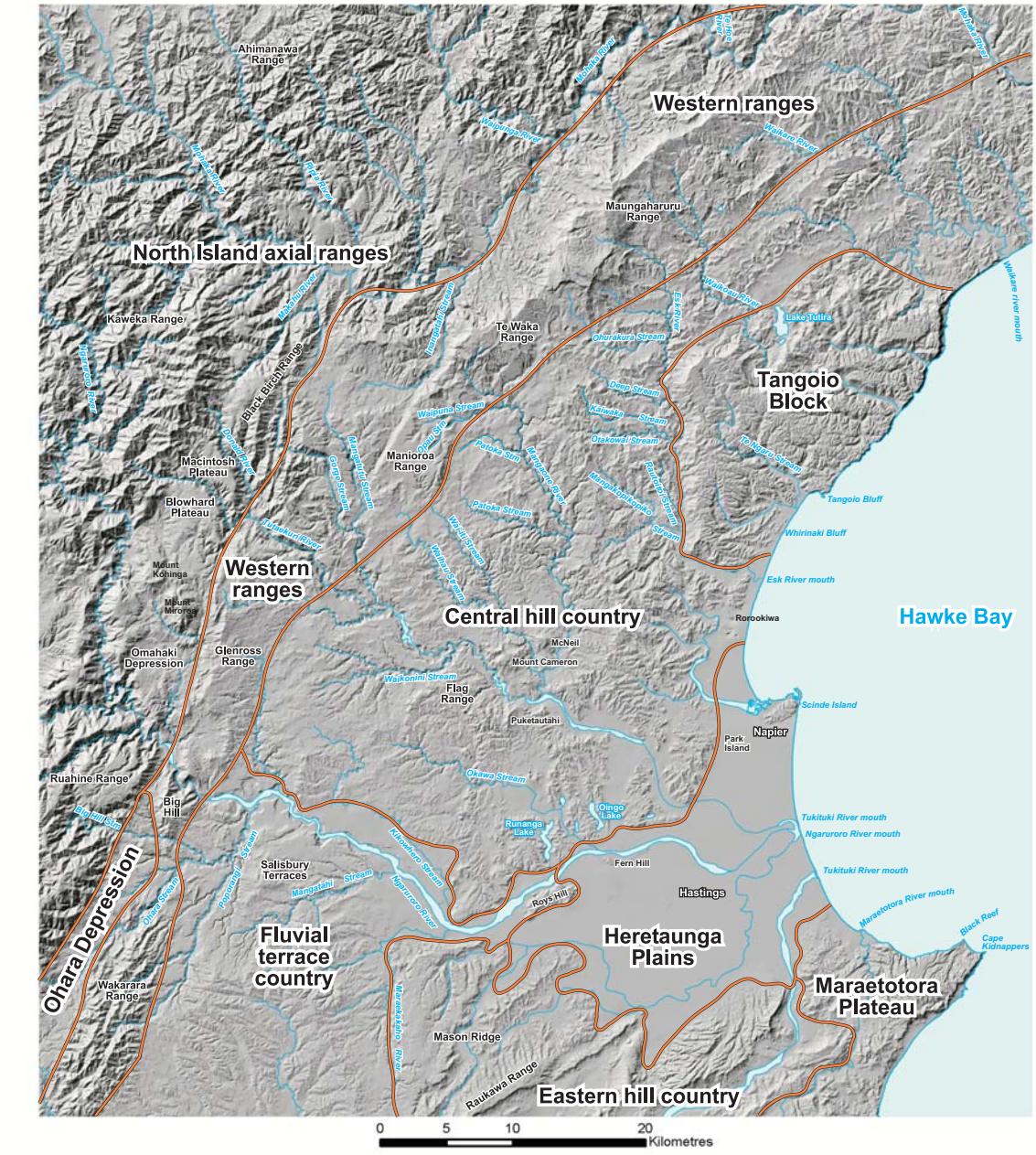


Fig. 2.8: Hillshade relief model of the study area illustrating the main physiographic areas in central parts of Hawke's Bay, and some other physical features referred to in this thesis.

The Heretaunga Plains represent the lower flood plains of the Tutaekuri, Ngaruroro, and Tukituki River systems, which all enter the Pacific Ocean within several kilometres of each other (Fig. 2.8). The major population centres of Hawke's Bay are all located on the Heretaunga Plains.

The eastern hill country (Fig. 2.8) represents the highest ridges of the accretionary wedge (Fig. 2.2, 2.3), It typically comprises an area of NE-SW trending fault-bounded hills, often capped by Te Aute limestone beds. The Maraetotara Plateau locates the same tectonomorphic position as the eastern hill country, and is the dominant landform of coastal southern Hawke's Bay. It is an

area with an average elevation of about 500 m, but rising in places up to 600 m a.s.l. (Pettinga 2004). The plateau is capped by relatively flat-lying erosion-resistant Early Pliocene limestones and calcareous sandstones (Lillie 1953; Pettinga 1980; Harmsen 1985; Beu 1995).
The fluvial terrace country (Fig. 2.8) comprises a series of gently dipping, relatively flat hills underlain by fluvial deposits derived from erosion of the adjacent Wakarara and Ruahine Ranges.

Hawke Bay is a major coastal indentation, and is the last remaining marine part of the forearc basin.

RIVER SYSTEMS

A number of large river systems drain the high range country bordering the study area and flow through Hawke's Bay (Fig. 2.8; Enclosure 8). The Mohaka River is the largest river in the study area, and one of the longest in the North Island (171 km long). It drains the eastern side of the Kaimanawa Range, flowing southeast towards the Kaweka Range, then swinging to the northeast before again flowing to the southeast and entering the Pacific Ocean at Mohaka, approximately halfway between Napier and Wairoa. Access to this river is restricted to a limited number of localities, with large portions of the river flowing through inaccessible, steep-sided river gorges. The river is crossed in its middle reaches by State Highway 5 (Napier-Taupo Road) between Te Pohue and Te Haroto, and by State Highway 2 (Napier-Wairoa Road) near Raupunga in its lowermost reaches. Good exposures are present throughout the river due to its incised nature. Relatively easy access to the river can be gained from Hot Springs Road, the Pakaututu Road bridge, Crohane Forest, McVicar Road and bridge, Waitara Road, Auroa Road, Pohokura Road at Waitere Station, and Willowflat Road, in addition to occasional farm tracks and other forest roads. Important tributaries of the Mohaka River in a geological sense include Inangatahi Stream, which drains the Puketitiri area and the northern side of the Te Waka Range.

The Ngaruroro River drains the southern Kaweka Range and flows in an easterly direction for nearly 120 km before reaching the Pacific Ocean near Clive. The river is typical of many in Hawke's Bay, characterised by a large braid plain in the middle and lower reaches, and confined in the upper reaches between steep-sided greywacke bluffs over 100 m high. The river has a high greywacke bedload. The river is crossed by Taihape Road in its upper reaches at Kuripapango. Access can also be gained from Whana Valley where it emerges from its gorge, and from a private farm track off Matapiro Road in its lower reaches. Access can also be gained by walking down the Ohara and Poporangi Streams from the Big Hill Road bridge to the confluence with the Ngaruroro River. The Ngaruroro River was rafted during this study from the Whana Cable downstream to Matapiro Station.

Several tributaries of the Ngaruroro River have been useful for accessing outcrops during this study, including Jumped Up Stream, Ohara Stream, Poporangi Stream, Big Hill Stream (Ohara Depression), and Kikowhero Stream, Okawa Stream.

The Tutaekuri River shares an estuary with the larger Ngaruroro River, and drains the central and northern portions of the Kaweka Range, and flows southeast to the Pacific Ocean. The Tutaekuri River is braided from where it emerges from the Kaweka State Forest Park to its mouth. The lower reaches are confined between a system of stop banks and other flood control works installed after the river altered its course following the 1931 Napier earthquake. The Tutaekuri River is accessible from forest roads in the Kaweka Forest, from the Dampney/Waldon Road ford, from Lower Flag Range Road, and from numerous access points from Dartmoor downstream to its mouth. The section of river from Waldon Road downstream to Dartmoor was rafted during this study.

The Mangaone River is the major tributary of the Tutaekuri River, flowing southeast from the Te Waka Range, and meeting the Tutaekuri River near Dartmoor. The upper and middle reaches are confined between steep-sided bluffs of sandstone and siltstone up to 150 m in height, before opening out onto a narrow floodplain near the small settlement of Rissington. The river is difficult to access with only a few farm tracks and one forest track in the uppermost reaches. It is crossed by Puketitiri Road at Rissington in its lower reaches and Dartmoor Road just above its mouth. Although difficult to access, the Mangaone River contains an excellent section for many kilometres through much of the Mangapanian and Lower Nukumaruan strata in this part of the forearc basin, and affords and excellent link between the high country to the north and the lower siltstone and limestone dominated stratigraphy to the south. Most of the river has been accessed during this study. An important tributary of the Mangaone River in this study is the Wai-iti Stream.

The Esk River is the major drainage system for the Maungaharuru Range and the western part of the Tangoio Block, starting from a series of small springs out of limestone facies on Rimu Station, near Ahuateatua Trig. Except for a few kilometres where the river leaves the Maungaharuru Range, the course of the Esk River can be either walked or floated down, and provides an excellent section through Mangapanian and Nukumaruan rocks in the area, displaying one of the most complete sections through the conglomeratic Matahorua Formation (Bland 2001). Although access points are limited, they occur up the river every few kilometres, allowing for most of the river to be logged. The easiest access is gained from Ellis Wallace Road, Island Farm, and Berry Road, and from there walking up or downstream from these points. Important tributaries of the Esk River that have aided determining the stratigraphy of this area include Kaiwaka, Deep, Rautoitoi, and Mangakopikopiko Streams. Deep and Kaiwaka Streams can be accessed from

farm tracks and forest roads off Old Coach Road near Trelinnoe Station. Rautoitoi Stream can be accessed from Ellis Wallace Road. Mangakopikopiko Stream can be entered from the Napier-Taupo Road.

The Waikoau River rises on the northern side of the Maungaharuru Range and flows east towards the Tangoio Block, from where it is known as the Aropaoanui River. Again, access points to this river are limited, but much of the river has been logged by Rhys Graafhuis as part of his MSc thesis on the area (Graafhuis 2001). The best access is gained from the Napier-Wairoa Road bridge and Waikoau Road. The lower reaches can be accessed from the Aropaoanui Beach access road.

The Waikare River drains the steep hill country to the north of the Maungaharuru Range and flows east through the village of Putorino to meet the Pacific Ocean at the northern end of the Tangoio Block. This river is characterised by very deep pools and steep-sided siltstone bluffs along its banks making access difficult in very remote terrain. Graafhuis (2001) logged much of the river as part of his MSc thesis. Access can be gained off the Napier-Wairoa Road and Heays Access Road. The lower reaches are accessed from roads leading downstream from Putorino village.

CHAPTER THREE

LITHOSTRATIGRAPHIC OVERVIEW AND ISSUES

INTRODUCTION

Although a number of lithostratigraphic schemes have been proposed for rocks in Hawke's Bay, from the early nomenclature of McKay (1886a, b, 1887), to the more recent schemes of Beu (1995), Field *et al. (*1997), Mazengarb and Speden (2000), and Lee and Begg (2002), no unified scheme is available at present and many names currently in use are either ambiguous, or poorly defined. This situation was also noted by Haywick (1990).

The objective of this chapter is to provide an overview of the stratigraphy of the Late Miocene-Early Pleistocene deposits in central parts of the forearc basin in Hawke's Bay, and to raise and attempt to resolve some of the lithostratigraphic issues surrounding them. The chapter also comments on the geological map series (Enclosure 1) inserted at the back of this thesis. It is not the intention in this chapter to provide exhaustive descriptions of the individual stratigraphic units; these are given in Appendix One: Systematic Lithostratigraphy.

This study (the extent of which is shown on Fig. 3.1) builds on the earlier work of many studies, including Lillie (1953), Kingma (1957, 1958a, b, 1962, 1971), Grindley (1960), Beu *et al.* (1980), Browne (1981), Haywick (1990), Haywick *et al.* (1991), Erdman and Kelsey (1992), Kelsey *et al.* (1993), Bland (2001), Graafhuis (2001), Baggs (2004), Bland *et al.* (2004), Browne (2004a), and Dyer (2005). Of particular note are the substantial contributions to understanding the lithostratigraphy of the study area by Kingma (1971), Haywick *et al.* (1991), and Beu (1995). Direct comparison of the lithostratigraphy erected in this study to that proposed by Beu (1995) is discussed within this chapter.

The chapter begins with a brief overview of the geological map series in this thesis, describing their production and the broad geological patterns they show. It then discusses the five main "packages" of rocks in the study area: Torlesse composite terrane, Tolaga Group, Mangaheia Group, Kidnappers Group, and Late Quaternary deposits. For each Group, descriptions of the historical nomenclature, lithostratigraphic framework, and geometry are provided, followed by discussion of the major lithostratigraphic issues this study has encountered, and their possible resolution.

GEOLOGICAL MAP

The fundamental product underpinning this study is a series of geological maps contained in Enclosure 1. Geological mapping was undertaken in an environment utilising Geographic Information System (GIS) technology. Full details of methodologies employed are contained in Appendix III. The GIS is a digital computer database that contains all geological and topographical information relevant to this study. In effect, it contains a seamless digital coverage of the geology of the study area. For this thesis a geological map at 1:50 000 scale is presented, cut-up into six sheets. These have been produced from the GIS and are contained at the back of this thesis as Enclosure 1, Sheets 1-6 (Fig. 3.2). Elements of the design of these maps sheets were derived from published GNS Science QMAP sheets, and Land Information New Zealand (LINZ) NZMS 260 series topographic map sheets.

The geological maps portray the surface distribution of mapping units, faults, folds, and other geological features identified during fieldwork. Accompanying geological cross-sections illustrate to some extent the sub-surface distribution of these features (Enclosure 3). A prominent theme evident from these map sheets is the strong NE-SW structural grain to the study area. Also evident is how the strike of the principal faults in the western part of the study area are slightly oblique to the average strike of the geological mapping units.

Clearly evident on the geological map is the degree of differentiation of mapping units in the upper part of the Mangaheia Group. Older stratigraphic units of the Tolaga Group tend to represent thick, relatively homogenous units many tens to hundreds of metres thick. The younger mapping units typically represent intervals up to 70 m thick, though more usually <40 m thick.

Five major intervals of stratigraphic units are presented on the map. The first and oldest comprises basement rocks of Mesozoic age. The second interval comprises the Tolaga Group, the oldest Cenozoic beds cropping out in the study area. The third interval comprises the Mangaheia Group, which is in turn overlain by the Kidnappers Group. The final group includes sediments of Late Quaternary age representing river and terrace deposits.

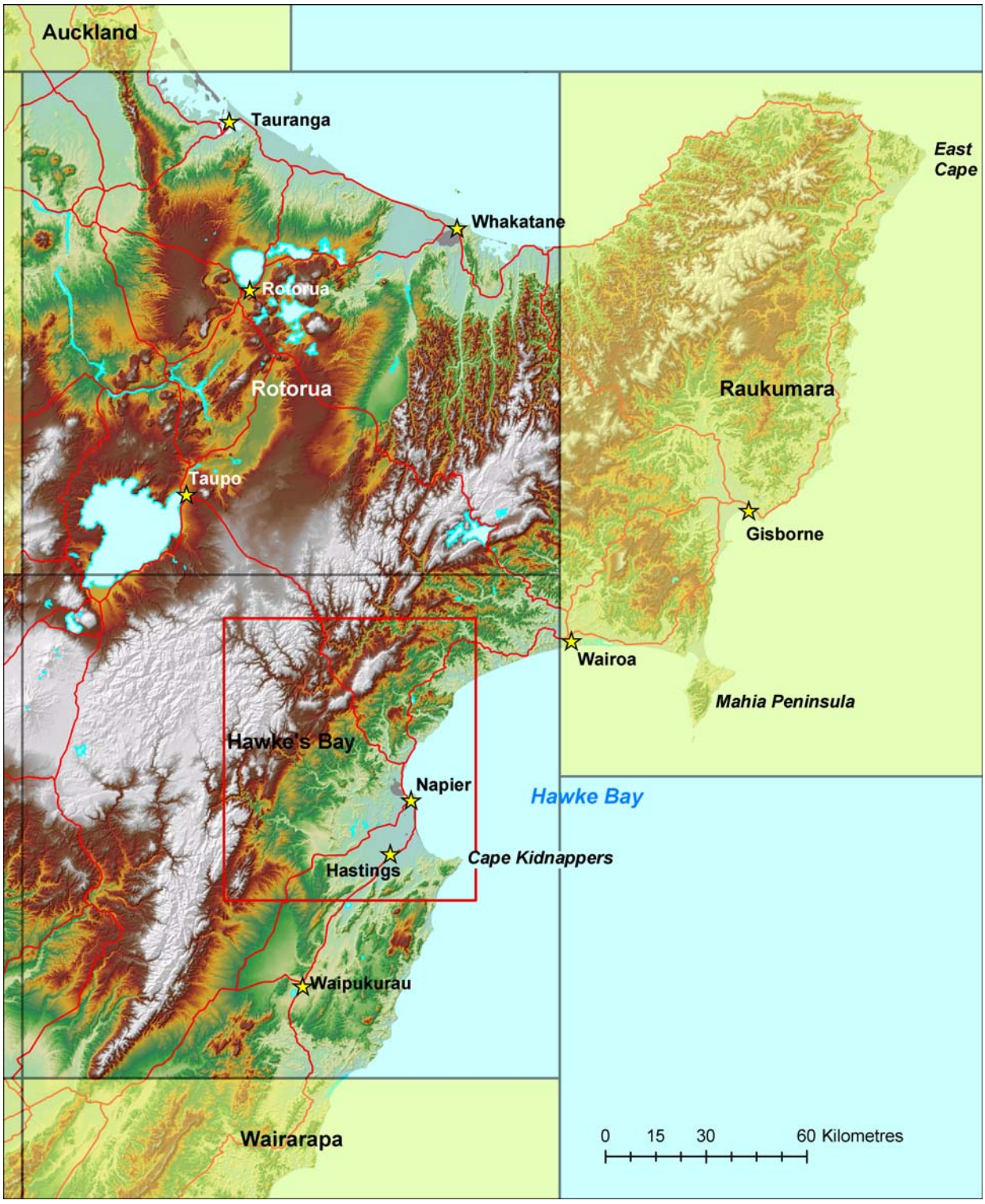


Fig. 3.1: Digital elevation and hillshade relief models of eastern North Island showing the location of the study area, and regions from which lithostratigraphic groups mapped in this study have been extended. Red box is the extent of Enclosure 1. Red lines are state highways. Black boxes are the boundaries of GNS Science QMAP sheets (sheet names indicated in larger font). Light yellow fill in these boxes indicate completed QMAP sheets at the time of printing. The Raukumara QMAP Sheet (Mazengarb and Speden 2000) is where the Tolaga and Mangaheia Groups have been extended into the current study area from.

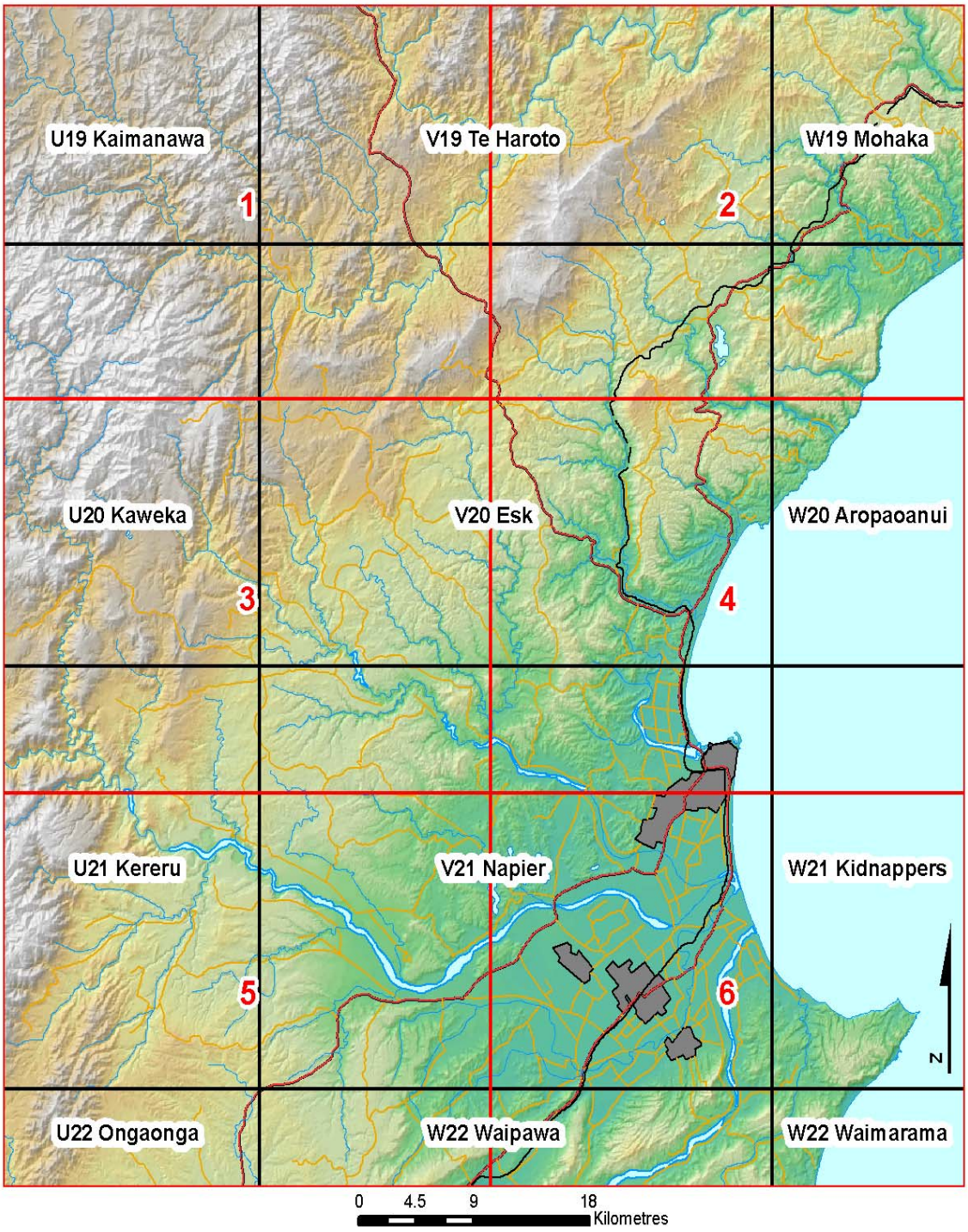


Fig. 3.2: Relationship between NZMS 260 series topographic map sheets and the geological map sheet cut-up in Enclosure 1 (this study) overlying a digital elevation model (DEM) and hillshade relief model. Black lines are NZMS topo sheets, red boxes are thesis geological map sheets. Black labels with white halos are NZMS topo sheet names. Large red numbers are the geological map sheets in Enclosure 1.

APPROACH TO GEOLOGICAL MAPPING

Geological units mapped and described as part of this project have, where possible, been mapped on the basis of broad lithological properties. Essentially this means that limestone-dominated facies have been mapped as being different to sandstone-dominated facies, and so on.

The cyclothemic nature of the Late Pliocene-Early Pleistocene strata in the study area allows for concurrent lithostratigraphic, allostratigraphic, and sequence stratigraphic subdivision. This combined lithostratigraphic-sequence stratigraphic approach has recently been applied by McIntyre (2002) in his study of the cyclothemic Mangapanian succession exposed in Wanganui Basin, and by Vonk *et al.* (2002) in eastern Taranaki for Late Miocene-Early Pliocene cyclothemic strata. Geological units in this study have been defined by conventional lithostratigraphic criteria, although conveniently for sedimentological analysis, coincidence of formation and/or member boundaries with sequence boundaries or systems tract boundaries has been noted.

While siliciclastic units ranging in age from Cretaceous to Quaternary are present in the study area, it is beds of Pliocene to earliest Pleistocene that are the main sedimentological and stratigraphic focus of this study. These beds are encompassed by the Mangaheia Group, and the greatest emphasis during fieldwork has been placed on them.

APPROACH TO NAMING UNITS

Where possible, historical usage has been acknowledged and names continued. Also, a lithostratigraphic qualifier has been added to the names of units mapped where suitable. In many parts of the basin different names have been applied to the same stratigraphic horizon or unit. This has led to the masking of relationships amongst beds through the study area, as well as generating a confusing number of names for the same units. Consequently, it has proven necessary to abandon the names for many units, a process that has simplified and strengthened the understanding of the lithostratigraphic development of this region.

Full descriptions and definitions of stratigraphic units are given in Appendix I. Only the most important or significant changes in the stratigraphic nomenclature of the forearc basin deposits are discussed here. The majority of these changes apply to strata in upper parts of the Mangaheia Group as described previously by Beu (1995).

DISTRIBUTION OF GEOLOGICAL UNITS

Geological units display a pronounced northeast-southwest strike with dips to the southeast (Fig. 3.3). The steepest dips occur adjacent to and within the North Island axial ranges, which corresponds to the area with the greatest amount of post-depositional deformation.

DISTRIBUTION OF STRUCTURAL ELEMENTS

Structural elements in the study area also have a strong northeast-southwest grain that approximately parallels the trend of the subduction margin. The strike of the major faults and folds is slightly oblique to that of the basin fill so that from northeast to southwest progressively younger beds are truncated by faults along the western margin of the study area. The character of deformation of the basin has been classified into five structurally distinctive domains detailed in Chapter Five. The most significant structural features occur along the western and eastern sides of the study area. The central part of the study area, representing the central part of the forearc basin in Hawke's Bay, is relatively undeformed.

STRATIGRAPHIC OVERVIEW

While the stratigraphic focus of this study is on the Late Miocene-Early Pleistocene sedimentary succession of central Hawke's Bay, in northern and western parts of the study area significant thicknesses of basement rocks and sedimentary beds of Miocene age occur. The general character of all of these units is described in the following sections.

The oldest rocks in the study area are Mesozoic metasedimentary greywackes, argillites, and minor conglomerates and cherts assigned to the Torlesse composite terrane. The overlying Neogene succession comprises three lithostratigraphic groups, the lower two of which have been extended south into the Hawke's Bay region from the Wairoa District where they were documented by Mazengarb *et al.* (1991) and Mazengarb and Speden (2000). The three groups are the Tolaga Group (Early Miocene-earliest Pliocene), Mangaheia Group (Late Miocene-Early Pleistocene), and Kidnappers Group (Middle Pleistocene). These intervals mark the three main phases of development in the forearc basin in Hawke's Bay, which correspond broadly to an overall regressive pattern that commenced with the inception of the modern plate boundary through the New Zealand region in the Early Miocene.

The Tolaga Group essentially represents outer shelf to middle/lower bathyal environments of deposition. The Mangaheia Group is almost entirely shelfal with uncommon non-marine and

upper bathyal beds. The Kidnappers Group represents marginal-marine to non-marine deposition.

The following sections describe the main characteristics of the basement rocks and the three Neogene groups. Far more detail, including definitions and comprehensive lithological descriptions, is contained in Appendix I.

MESOZOIC BASEMENT

HISTORICAL NOMENCLATURE

Mesozoic basement rocks are restricted to western parts of the study area where they underlie the main axial ranges (Fig. 3.3). The surface distribution of basement rocks was first mapped in some detail by Grindley (1960), who subdivided them into two major stratigraphic units, the Kaweka Greywacke and the Urewera Greywacke. The Kaweka Greywacke was mapped west of the Kaweka Fault and the Urewera Greywacke to the east. Urewera Greywacke was inferred to be of Jurassic age, and the Kaweka Greywacke of Jurassic-Triassic age. Basement rocks underlying the East Coast region are now assigned to the Torlesse composite terrane (e.g. Lee and Begg 2002), and the Kaweka and Urewera Greywackes nomenclature of Grindley (1960) has been discontinued. Torlesse composite terrane is one of several Late Paleozoic to Early Cretaceous fault-bounded tectonostratigraphic units of low grade metasedimentary rocks that constitute the Eastern Province of New Zealand (Mazengarb and Speden 2000). Basement rocks of the East Coast region consist mainly of Triassic to Early Cretaceous indurated sandstone and mudstone (greywacke and argillite).

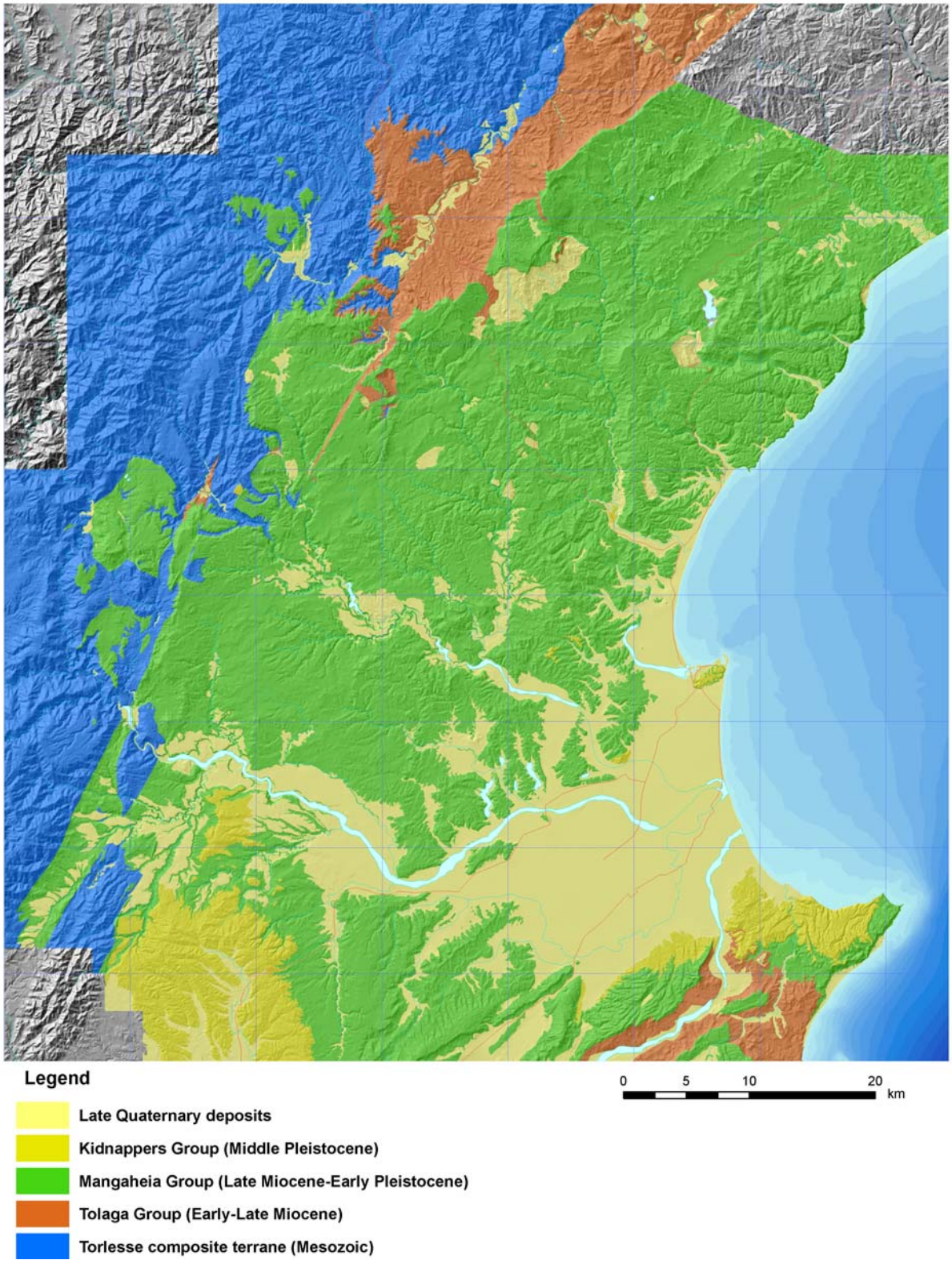


Fig. 3.3: Distribution of major rock units (groups) mapped in central Hawke's Bay superimposed on a hillshade relief model. Blue lines are 10 km NZMS 260 series gridlines. State highways (red lines), significant water bodies (blue lines and light-blue polygons) are shown.

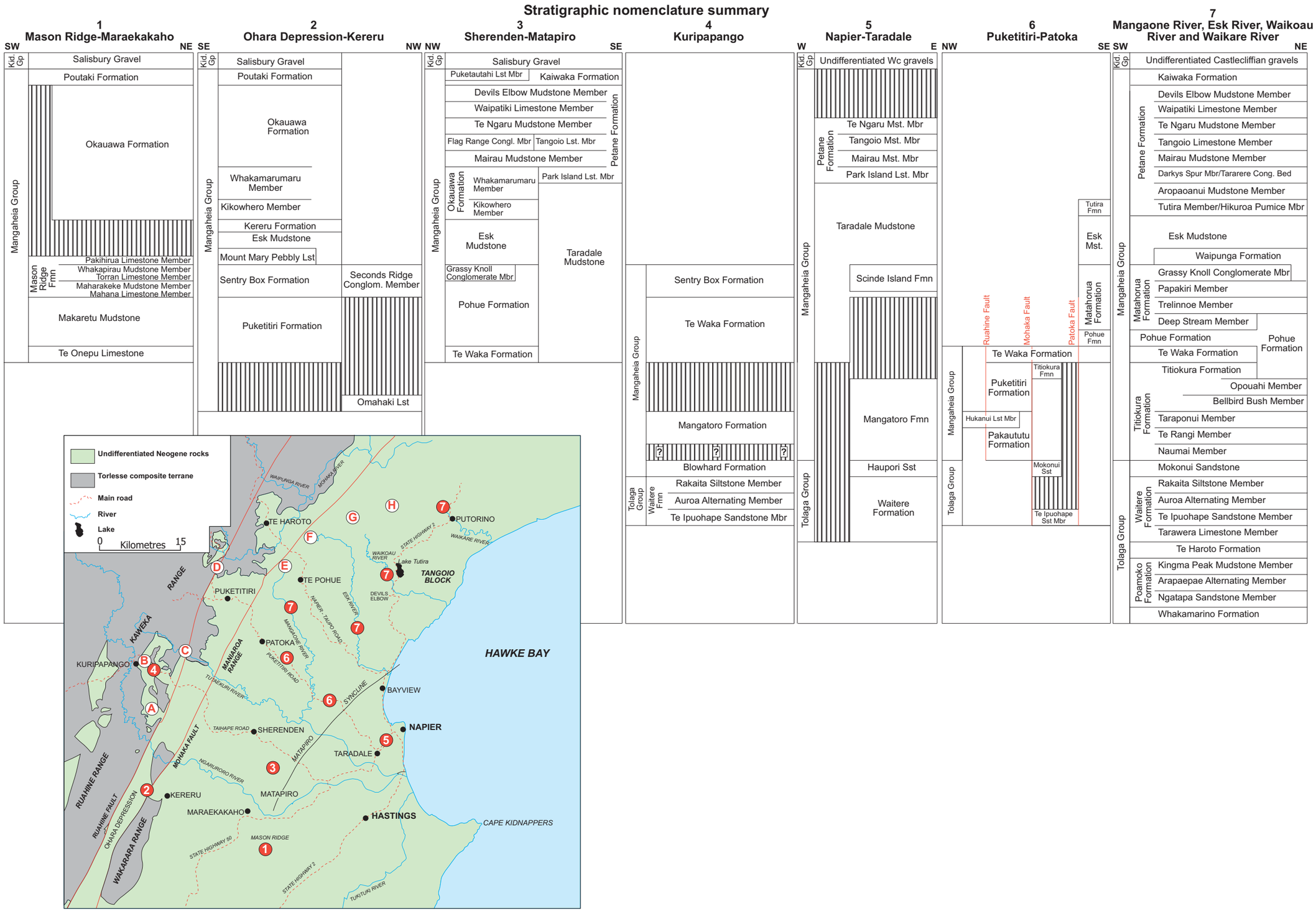


Fig. 3.4: Summary of the lithostratigraphic nomenclature proposed for central and western Hawke's Bay as a result of this study. Numbers 1-7 indicate the approximate locations of stratigraphic areas in this diagram. Letter codes A-H indicate the locations of areas illustrated in Fig. 3.7 and 3.8.

Mortimer (1995) subdivided the Torlesse rocks of eastern North Island on the basis of differences in sandstone petrography, age, bulk chemical composition and the known and inferred extent of mélange belts. He defined two major basement units east of the Taupo Volcanic Zone, namely the Pahau subterrane and a previously unrecognised Waioeka subterrane. Both are of Late Jurassic to Early Cretaceous age. The boundary between the two was placed at a major mélange that was inferred to extend from the modern Bay of Plenty coast to a point WSW of Lake Waikaremoana. This subdivision was accepted by Field *et al.* (1997). On the basis of their presumed geological origins Begg and Johnston (2000) elevated units formally known as subterranes (such as the Pahau subterrane) to full terrane status, and applied the name "Torlesse composite Terrane" to Torlesse rocks in general. Basement rocks of the East Coast region, North Island, are therefore assigned to the Rakaia, Pahau and Waioeka terranes as part of the Torlesse composite terrane, in association with two mélange zones (the Esk Head and Whakatane mélanges).

GEOMETRY

Mesozoic basement rocks are widespread through western parts of the study area, where they form the Ruahine, Wakarara, Kaweka, and Ahimanawa Ranges, among others. These are part of the North Island axial ranges. With the exception of an outlier near Patoka, and the Wakarara Range at Kereru, these beds do not crop out west of the Mohaka Fault. Basement rock (Torlesse composite terrane) distribution is illustrated in Fig. 3.3.

LITHOSTRATIGRAPHIC OVERVIEW

Basement rocks have been mapped as undifferentiated Torlesse composite terrane and any further analysis of them is beyond the scope of this study. Basement rocks are greywacke-dominated, although argillite, chipwacke, flysch, conglomerate and minor chert facies are also present. Flysch facies are common in the Wakarara Range, Pakaututu, and Puketitiri areas where they are moderately to highly deformed. In close proximity to major faults, basement rocks are highly shattered and fractured, with varying degrees of folding common.

The Rakaia Terrane is inferred to have accumulated as a turbiditic succession within an accretionary prism. Pahau Terrane has a similar lithologic content and structure to the Rakaia Terrane, although tuffaceous beds are more common in the Pahau Terrane. The Pahau Terrane probably represents trench deposits (Mortimer 2004). Volcaniclastic sediments are more common in the Waioeka Terrane than the Rakaia and Pahau Terranes (Lee and Begg 2002).

CENOZOIC SUCCESSION

Cenozoic rocks in the study area are contained within three lithostratigraphic groups, namely the Tolaga, Mangaheia, and Kidnappers Groups (Fig. 3.3, 3.4). The following sections of this chapter overview the main characteristics of these groups as well as lithostratigraphic issues pertaining to them. In addition to these groups the distribution of Late Quaternary deposits has also been mapped. The stratigraphy of the Neogene succession is summarised in Fig. 3.4. The study area has been divided into discrete regions, illustrating the variation in lithostratigraphy between them.

TOLAGA GROUP

HISTORICAL NOMENCLATURE

Tolaga Group was introduced and defined by Mazengarb *et al.* (1991) for sedimentary rocks of Waitakian to Upper Tongaporutuan (Miocene) age in the Tauwhareparae area inland from Tolaga Bay (Raukumara Peninsula), from where the name is derived. In the original definition of the Tolaga Group a mainly offshore, moderate to deep-water (outer neritic to ?upper bathyal) environment of deposition was inferred (Mazengarb *et al.* 1991, p. 33).

Only a limited extent and volume of shallow-water beds are present in the Tauwhareparae area and this suggests that shallow conditions only existed in localised areas for short periods. As defined by Mazengarb *et al.* (1991), Tolaga Group is unconformably overlain by the Late Miocene-Early Pliocene Mangaheia Group.

Mazengarb and Speden (2000) extended the definition of the Tolaga Group from the type locality to include all rocks of Early to Late Miocene age cropping out in the area of the Raukumara QMAP sheet. Beds of similar age, lithology, and inferred depositional environments crop out widely through northern parts of the study area and, until now, have not been included in any stratigraphic group. As in the original definition of Tolaga Group (Mazengarb *et al.* 1991), shallow-water beds of Early to Late Miocene age are limited in volume and extent in central Hawke's Bay, and the succession is dominated by massive deep-water mudstones with interbedded redeposited sandstones. The overlying Late Miocene-Pliocene Mangaheia Group of Mazengarb *et al.* (1991) was extended into the Wairoa region by Mazengarb and Speden (2000), and from there into the current study area where it is defined to unconformably overlie the Early to Late Miocene succession cropping out from the Napier-Taupo Road to Waitere Station in the Maungaharuru Range. The Mangaheia Group *sensu stricto* by definition overlies the Tolaga Group. It is viewed as consistent and appropriate that the Tolaga Group therefore be extended into the Hawke's Bay

region to include all Early to Late Miocene (to Early Pliocene) beds. Formations included here in the Tolaga Group are the Whakamarino Formation, Poamoko Formation, Te Haroto Formation, Waitere Formation, and Mokonui Sandstone.

OUTCROP AND SUBCROP GEOMETRY

The distribution of most of the Tolaga Group in the study area was documented in a series of maps produced in association with engineering investigations of potential hydro-electric dam sites (e.g. Cutten 1988), hydrocarbon exploration (e.g. Moore 1987, Francis 1993), or as summary geological reports (e.g. Grindley 1960; Scott *et al*. 1990a; Cutten 1994). The distribution of the Tolaga Group is illustrated in Fig. 3.3, and stratigraphic relationships are illustrated in Fig. 3.5. Rocks of the Tolaga Group are restricted in outcrop to western areas from Waitere Station in the northwest to Kuripapango in the central southwest. As the strike of the group is oblique to that of the North Island Shear Belt, at the southern end of the Te Waka Range the group is truncated by the Mohaka Fault. A small outlier of Tolaga Group (Te Ipuohape Sandstone Member, Waitere Formation) crops out in Opau and Waipunga Streams near Patoka. Here the group overlies basement, and is in turn overlain by Te Waka Formation (Late Pliocene, Mangaheia Group) across a spectacular angular unconformity. An outlier of Tolaga Group is also preserved in a fault-bounded block in the Kuripapango region. This is the southernmost outcrop of Tolaga Group. The lithology and Tongaporutuan age of this outlier means it has tentatively been assigned to the Waitere Formation.

LITHOSTRATIGRAPHIC OVERVIEW

Tolaga Group contains five formations and seven members (Fig. 3.4, 3.5) and is of Upper Otaian to Lower Opoitian (Early Miocene to Early Pliocene) age. The nature of facies in the group, and their ages and inferred depositional paleoenvironments, are comparable with Tolaga Group rocks in the original type locality (e.g. Mazengarb and Speden 2000). Tolaga Group comprises four deepening-upward cyclic packages consisting of a basal coarse-grained variably fossiliferous interval that passes up into mudstone. This contrasts with Cutten (1994) who described only three packages. Overlying the four cyclic packages is a thick interval of sandstone.

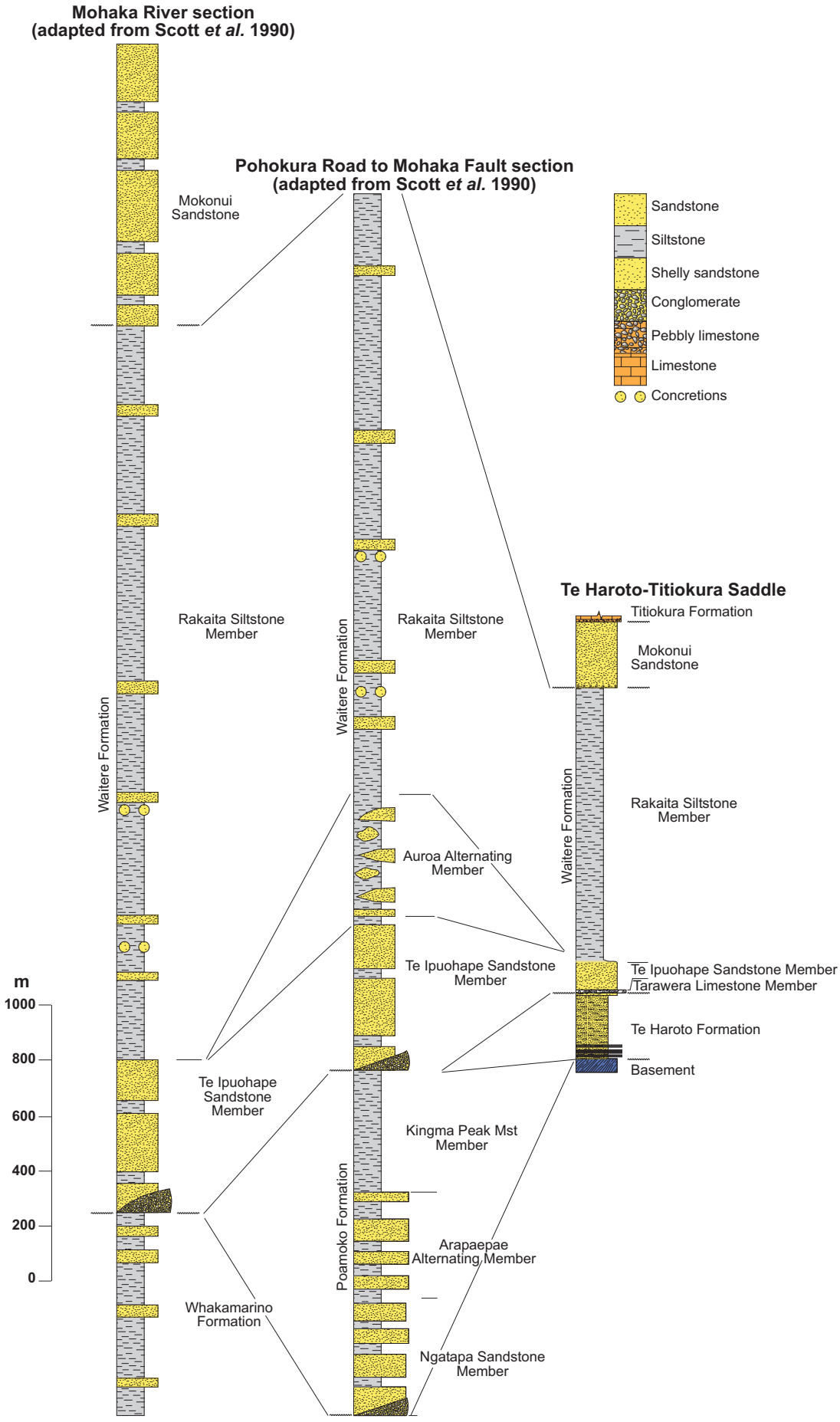
The basal formation of the Tolaga Group is the Whakamarino Formation (Early Miocene, Otaian) (Whakamarino Siltstone Formation in Cutten (1994)) (Fig. 3.5, 3.6A; Column Wi-3), and represents the lowermost of the four Tolaga Group sedimentary sequences. The Whakamarino Formation is overlain by the second cyclic interval in the Tolaga Group, the Poamoko Formation of Clifdenian to Upper Lillburnian age, that consists of three members: the Ngatapa Sandstone,

Arapaepae Alternating, and Kingma Peak Mudstone Members. (Fig. 3.5). The basal member (Ngatapa Sandstone Member, Fig. 3.6B, C) is a moderately to well cemented, highly fossiliferous sandstone containing abundant shallow-water macrofossils (Fig. 3.6C). An additional sequence to the three identified by Cutten (1994), the third one described here, is recognised in the Tarawera Station and Te Haroto areas, and is here named the Te Haroto Formation (Fig. 3.6D; Column Th-1). This unit comprises a basal concretionary, highly fossiliferous sandstone (Fig. 3.6D) that passes upsection into siltstone to sandy siltstone (Fig. 3.6E, F). The Te Haroto Formation unconformably overlies basement (Fig. 3.5), with other older formations of the Tolaga Group (Whakamarino and Poamoko Formations) absent. It is unconformably overlain by the Tarawera Limestone Member (Fig. 3.6E; Column Wi-2), the basal bed of the Waitere Formation, which is the fourth sequence in the Tolaga Group.

Tarawera Limestone Member comprises several metres of moderately well cemented pebbly fossiliferous limestone to shelly conglomerate rich in the gastropod *Zeacolpus*. In the Tarawera Station area the Tarawera Member overlies the Te Haroto Formation across an unconformable surface that displays decimetre-scale relief (e.g. V19/247220, Column Wi-2). Elsewhere the member may overlie basement, the Whakamarino Formation, or any member of the Poamoko Formation.

The Tarawera Limestone Member passes conformably upsection into the Te Ipuohape Sandstone Member, a 300 m-thick interval of non to slightly cemented, variably concretionary sandstone to sandy siltstone. Where Tarawera Limestone Member is absent, as in Crohane Forest, Te Ipuohape Sandstone Member unconformably overlies Torlesse basement. Te Ipuohape Sandstone Member passes conformably up into the Rakaita Siltstone Member, the stratigraphically highest member of the Waitere Formation. The transition from Te Ipuohape Sandstone to Rakaita Siltstone Members may either be direct, or via the Auroa Alternating Member. The Auroa Alternating Member involves alternating siltstone and sandstone (flysch) facies.

Fig. 3.5: Schematic stratigraphic columns illustrating the general stratigraphy of Tolaga Group rocks in the study area. Beds range in age from Otaian (Early Miocene, Whakamarino Formation) to Lower Opoitian (Early Pliocene, Mokonui Sandstone). Note how not all formations occur in all areas. The units of the Waitere Formation and Mokonui Sandstone are the most widespread formations in the Tolaga Group.


Mohaka River section
(adapted from Scott et al. 1990)
Pohokura Road to Mohaka Fault section
(adapted from Scott et al. 1990)
Te Haroto-Titiokura Saddle
Sandstone
Siltstone
Shelly sandstone
Conglomerate
Pebbly limestone
Limestone
Concretions
m
1000
800
600
400
200
0
Mokonui Sandstone
Rakaita Siltstone Member
Waitere Formation
Auroa Alternating Member
Te Ipuohape Sandstone Member
Kingma Peak Mst Member
Arapaepae Alternating Member
Poamoko Formation
Whakamarino Formation
Ngatapa Sandstone Member
Titiokura Formation
Tarawera Limestone Member
Te Haroto Formation
Basement


A


B


C


D


E
Tarawera Limestone Member
Te Haroto Formation


F

The stratigraphically highest formation in the Tolaga Group is the Mokonui Sandstone (Mokonui Sandstone Formation in Cutten (1994)). The Mokonui Sandstone conformably to disconformably overlies the Rakaita Siltstone Member (Waitere Formation) and is unconformably overlain by the Titiokura Formation (Mangaheia Group). The base of the Mokonui Sandstone is well exposed on the Napier-Taupo Road (V20/278152, Column Ti-1) and is marked by a slightly condensed section where fine sandstone of the Mokonui Formation overlies siltstone of the Rakaita Siltstone Member. The two units are separated by a 0.5 m-thick well cemented concretionary bed. The concretionary bed is overlain by a 0.2 m-thick interval containing abundant glauconite, and phosphate nodules and phosphatised macrofossils, including gastropods, bivalves, brachiopods, and notably shark teeth. This condensed section site has not been observed anywhere else in the study area. Cutten (1994) reported observing an angular unconformity between Rakaita Siltstone Member and Mokonui Sandstone at the Pohokura Road-Woodstock Road intersection on the Maungaharuru Range (V19/375276). This contact has not been satisfactorily relocated, and it appears at this site to in fact be conformable.

The origin of the Mokonui Sandstone remains unclear, and it is uncertain whether the formation records a regressive interval at the top of the Waitere Formation sequence, or a transgressive succession at the base of the Titiokura Formation. The condensed section at the base of the Mokonui Sandstone on the Napier-Taupo Road suggests that a transgressive origin is more likely in this area, but the coarsening-upward character of the formation at Pohokura Road suggests a regressive origin. As the condensed bed has only been observed at Titiokura Saddle, its significance is uncertain. The regressive origin for the Mokonui Sandstone is favoured at this time. The top of the Mokonui Sandstone marks the top of the Tolaga Group. The formation is unconformably overlain by the Titiokura Formation (Mangaheia Group).

Throughout the outcrop area, the base of the Titiokura Formation comprises a 0.5-6 m-thick conglomerate that usually displays decimetre-scale relief on its lower contact (e.g. Column Tw-3). At Hell's Hole on the Te Waka Range up to 30 m of relief is present on this contact (V20/235127). Because of the persistence of this erosional surface from the northern Maungaharuru Range to the southern Te Waka Range, the top of the Tolaga Group is clearly recognisable for a significant distance.

Fig. 3.6 (facing page): Field photographs of representative stratigraphic units within the Tolaga Group in western Hawke's Bay. **A)** Whakamarino Formation exposed in the Mohaka River, Waitere Station (V19/400356). **B)** Bluffs of Ngatapa Sandstone Member, Waitere Station (V19/400351 looking southwest). **C)** Highly fossiliferous boulder from Ngatapa Sandstone Member (Poamoko Formation), Waitere Station (V19/402354). **D)** Highly fossiliferous concretions within sandstone, cropping out on the Napier-Taupo Road near Te Haroto, basal Te Haroto Formation (V19/196265). **E)** Te Haroto Formation underlying Tarawera Limestone Member, Tarawera Station (V19/271246 looking south). **F)** Te Haroto Formation, Tarawera Station. White arrow denotes sharp contact between (lower) siltstone and (upper) sandstone parts of the formation (V19/246221).

This boundary between the Tolaga and Mangaheia Groups marks an important change in the character of the basin fill, with deep-water-dominated beds of the Tolaga Group replaced by shelfal sandstone, limestone, and siltstone beds of the Mangaheia Group.

MANGAHEIA GROUP

HISTORICAL NOMENCLATURE

Mazengarb *et al.* (1991) introduced Mangaheia Group in a geological map of the Tauwhareparae area north of Gisborne and inland from Tolaga Bay. The name of the group was redefined from the Mangaheia Formation of Steineke (1934). The name is derived from the Mangaheia River, which occurs immediately south of the Tauwhareparae area. The original definition of the Mangaheia Group (Mazengarb *et al.* 1991, p. 33) comprised shallow-water sandstone and limestone facies, with some deeper water slope mudstones of Kapitean to at least Opoitian age. Mazengarb and Speden (2000) extended the Mangaheia Group south from the Tauwhareparae area to encompass rocks of similar age and facies in the Wairoa and Mahia regions as part of the Raukumara QMAP sheet. In this definition the group was defined to incorporate rocks of Kapitean-Waipipian age. The top of the Mangaheia Group, as defined by both Mazengarb *et al.* (1991) and Mazengarb and Speden (2000), was marked by the youngest Cenozoic marine rocks present in their map areas.

Pallentin (in prep.) and Pallentin and Nelson (2001) recognised similarities between rocks of the Mangaheia Group in the Wairoa-Mahia area, and strata in the Maungaharuru-Willowflat-Putere Lakes area further south. Bland *et al.* (2000), Bland (2001), Graafhuis *et al.* (2000), and Graafhuis (2001) had included rocks of this area in a new group they named the Maungaharuru Group (a redefinition of the Maungaharuru Formation of Cutten (1994)). Recent fieldwork in the region between the current study area and the area of the Raukumara QMAP shows that prominent limestone intervals crop out consistently between the two areas. This indicates the two regions are linked in terms of their depositional history and stratigraphy. Given Mangaheia Group is an accepted and established stratigraphic name, and there are lithological and paleoenvironmental similarities between rocks in these two areas, it seems appropriate to extend the occurrence of Mangaheia Group south into the present study area. Mangaheia Group is defined in this study area to encompass rocks of Kapitean (Late Miocene) to Upper Nukumaruan (Early Pleistocene) age cropping out across most of the study area. It unconformably overlies deep-water-dominated beds of the Tolaga Group and is unconformably overlain by non- to marginal-marine rocks of the Kidnappers Group. The Mangaheia Group is defined in this study to include rocks previously

assigned to the Maungaharuru Subgroup (Bland *et al.* 2004) and the Petane Group of Haywick *et al*. (1991) and Beu (1995) and the Napier, Poporangi, and Hawke's Bay Groups of Beu (1995).

OUTCROP AND SUBCROP GEOMETRY

The Mangaheia Group is widespread throughout the study area, cropping out in a NE-SW trending belt from the Maungaharuru Range and Tangoio Block in the north to the Ohara Depression and Matapiro Syncline in the south (Fig. 3.3). In the northwest the Mangaheia Group is underlain by the Tolaga Group, and in the southwest it is overlain by the Kidnappers Group. Mangaheia Group rocks crop out to the north of the map boundary and continue into the Wairoa and Tiniroto regions into equivalent beds mapped by Mazengarb and Speden (2000). The Titiokura Formation in the current study area is equivalent to the Opoiti, Whakapunake, and Tahaenui Limestones cropping out around Te Reinga and the wider Wairoa region (Beu 1995; Bland *et al.* 2004).

LITHOSTRATIGRAPHIC OVERVIEW

Introduction

Twenty-two formations and 40 members of Kapitean to Upper Nukumaruan (Late Miocene to Early Pleistocene) age have been mapped and characterised in the Mangaheia Group in this study. While formations are defined based on their broad lithological features, in places formation and member boundaries coincide with sequence boundaries and systems tract boundaries. Because of this situation, some mapping units may represent part of a sea-level cycle, others the deposits of an entire sequence, and other mapping units multiple sequences. The Mangaheia Group is dominated by shelfal lithofacies throughout its succession, with the exception of parts of the Esk and Taradale Mudstones, indicating that subsidence mostly matched sediment deposition. Minor non-marine and upper bathyal beds occasionally punctuate the succession.

The stratigraphic nomenclature for the Mangaheia Group varies throughout the study area, as shown in Fig. 3.4. The most complete stratigraphic record is contained in the northern outcrop area of the group (Waikare, Esk, and Mangaone River sections). This area contains an uninterrupted sedimentary record of the entire Mangaheia Group from the Upper Opoitian to Upper Nukumaruan (Early Pliocene-Early Pleistocene). In other districts significant parts of the Mangaheia Group are absent due to non-deposition, erosion, or fault-truncation.

The following sections outline the broad stratigraphic trends in the Mangaheia Group in the study area for each of the major geographic areas on Fig. 3.4. For more detailed information about the stratigraphic units outlined here (such as definition, type sections, and depositional environments)

the reader is referred to Appendix I, Appendix IV: (Stratigraphic Columns), and Enclosures 1, 3, 4, and 5.

Waikare, Waikoau, Esk and Mangaone River sections (Maungaharuru Range, Te Waka Range, and Tangoio Block)

The basal formation of the Mangaheia Group varies throughout the study area in both age and lithology (Fig. 3.7), but generally comprises a limestone or sandstone bed. Throughout the Maungaharuru and Te Waka Ranges the base of the group corresponds to the base of the Titiokura Formation (Fig. 3.8). The basal contact of the Titiokura Formation is diachronous from northeast to southwest, and is of Upper Opoitian age in the northern Maungaharuru Range, but Waipipian age in the Te Waka Range (Bland *et al.* 2004). The basal beds of the Titiokura Formation always comprise a 0.5-6 m-thick conglomerate with clasts of varying lithologies. Decimetre-scale relief is present along the base, but at Hell's Hole in the Te Waka Range relief is as much as 30 m.

The character (e.g. Fig. 3.9D, E) and distribution of the Titiokura Formation was documented by Bland *et al.* (2004), a copy of which is included as Appendix VI (Volumne Two). The most notable feature of this formation is the way it dramatically thickens towards the northeast (Fig. 3.8). In the Maungaharuru Range the Titiokura Formation is conformably overlain by the Pohue Formation, a thick interval of siltstone and sandstone that becomes finer-grained to the northeast, such that by Willowflat Road it is siltstone-dominated (V19/518369). In the Te Waka Range the Titiokura Formation is conformably overlain by sandstone of the Te Waka Formation. Te Waka Formation comprises up to 80 m of fine to medium sandstone overlain by up to 20 m of interbedded concretionary sandstone and limestone beds (Fig. 3.9F). The thickest individual limestone bed at the type section is 8 m thick (V20/256129, Column Tp-3). Laterally (down-dip) the basal sandstone interval passes into a 40 m-thick limestone inferred to represent a channelised deposit (Fig. 3.11). This thick limestone forms the high bluff above Te Pohue village (V20/271106, Column Tp-1).

The Te Waka Formation is conformably overlain by Pohue Formation, which in the Te Pohue area consists of a cyclothemic series of shelfal siltstone and sandstone beds with occasional shellbeds. Pohue Formation is conformably overlain by the Matahorua Formation, the base of which is defined as the base of the first greywacke conglomerate bed above the Pohue Formation, the stratigraphic position of which varies across the study area. This point is illustrated on Enclosure IV. The Matahorua Formation is thickest in the wider Te Pohue and Patoka districts, particularly in the Mangaone River and Glengarry Forest areas. The Matahorua Formation involves up to four

cyclothemic units, each with a basal conglomerate overlain by siltstone and sandstone (Fig. 3.14). These units correspond more or less to the four members defined in the Matahorua Formation. The stratigraphically-lowest three members (Deep Stream, Trelinnoe, and Papakiri Members) consist of conglomerate-siltstone-sandstone cycles. The Papakiri Member is overlain by the Grassy Knoll Conglomerate Member, comprising solely a variably fossiliferous conglomerate bed 2-10 m thick.

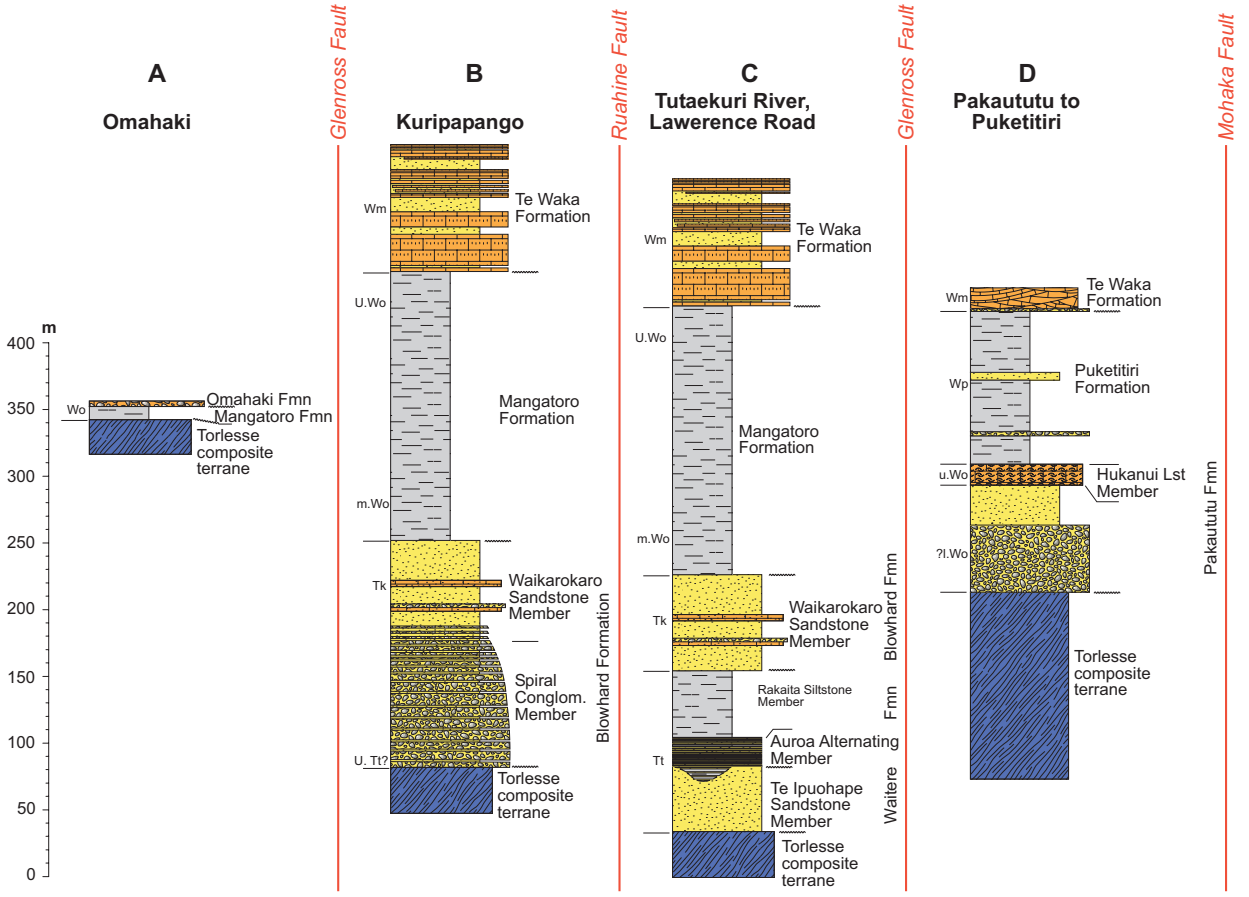


Fig. 3.7: Schematic stratigraphic columns (from southwest to northeast) of upper Tolaga Group and lower Mangaheia Group stratigraphic units cropping out west of the Mohaka Fault in the North Island Shear Belt. Note how the basal formation of the group varies between locations This figure highlights how in the Mangaheia Group the Te Waka Formation is the only unit present persistently across the shear belt. Column locations are shown on Fig. 3.4.

In the Waikare, Waikoau and Esk River sections the Matahorua Formation is overlain by the Waipunga Formation, an interval of shelfal sandstone and siltstone. The Waipunga Formation thins rapidly south of the Esk River section, and from Kaiwaka Stream south the Matahorua Formation is overlain by the Esk Mudstone (e.g. Column Tp-7). Where Waipunga Formation occurs (Enclosure 1, Sheets 2 and 4), it is conformably overlain by the Esk Mudstone. The Esk Mudstone (Fig. 3.10D) is in turn overlain by the Petane Formation (a redefined unit of the Petane Group of Haywick *et al.* 1991), a unit that contains up to five sedimentary cycles that incorporate

the well-documented (e.g. Beu and Edwards 1984) Darkys Spur and Devils Elbow sections in the Tangoio Block (Columns Tg-3 and Tg-4 respectively). Members defined in the Petane Formation in this area are the Tutira (Fig. 3.10F), Hikuroa Pumice (Fig. 3.10E), Aropaoanui Mudstone, Darkys Spur, Tararere Conglomerate, Mairau Mudstone, Tangoio Limestone (Fig. 3.10A), Te Ngaru Mudstone (Fig. 3.10A), Waipatiki Limestone (Fig. 3.10A, B), and Devils Elbow Mudstone. Analysis of major element geochemistry of glass shards in the Hikuroa Pumice Member provides a correlation to tephras 1124C 7H 3W 71-74 and 1124C 7H 3W 117-119 (AT-313 and AT-503) at ODP Site 1124 (Brent Alloway, GNS Science, pers. comm. 2004; see Chapter Four, p. 115). The two samples from ODP 1124 have been dated at 2.128 and 2.149 (paleomagnetic age model of Ian Hall) or 2.146 and 2.165 (paleomagnetic age model of Gary Wilson), providing an approximate age for the Hikuroa Pumice Member of about 2.15 Ma.

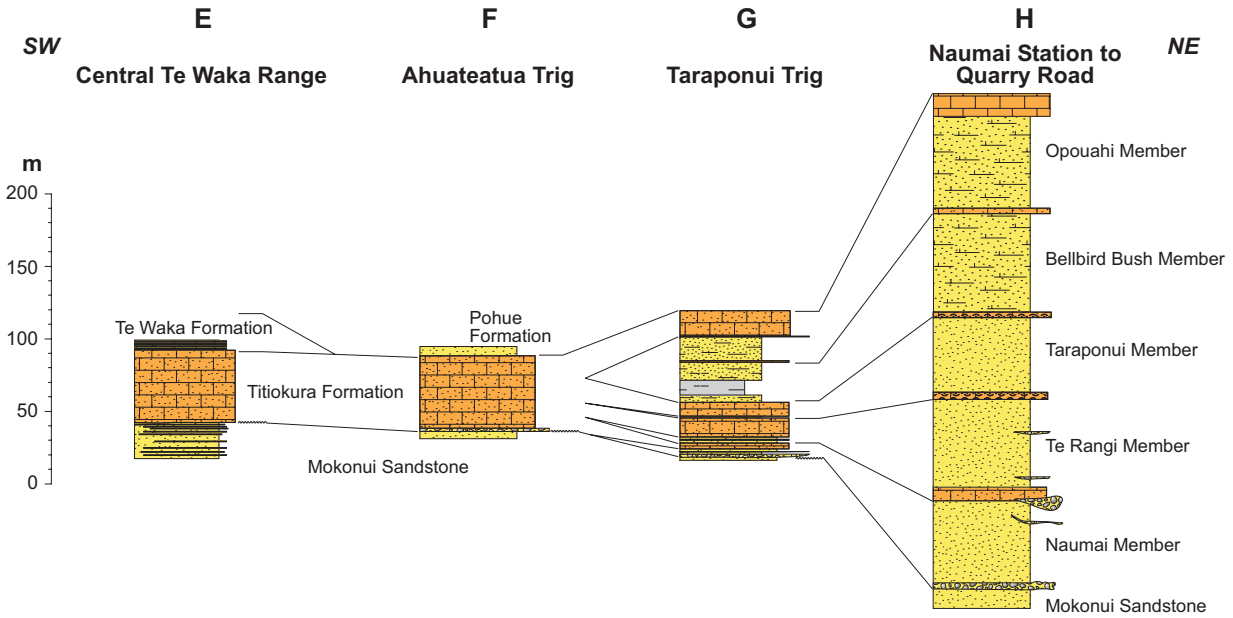


Fig. 3.8: Schematic distribution of the early to middle-Waipipian Titiokura Formation from the type section on the Te Waka Range northeast to the northern Maungaharuru Range. Note the way in which the formation dramatically thickens from southwest to northeast, reflecting the increase in prominence of interfingering siliciclastic beds. Column locations are shown on Fig. 3.4.

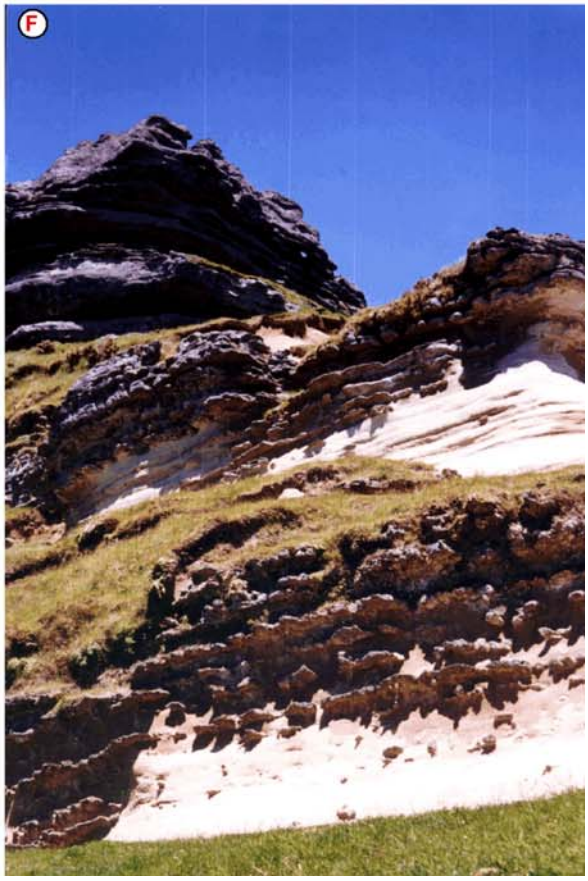
Fig. 3.9 (facing page): Field photographs of typical lithofacies within lower formations of the Mangaheia Group. **A)** Basal contact of the Mangaheia Group in a Kuripapango quarry with Torlesse basement overlain by Waikarokaro Sandstone Member (Blowhard Formation). Note the prominent relief on the contact (U20/047927). **B)** Waikarokaro Sandstone Member exposed in the lower slopes of Mount Miroroa, near Kuripapango. Person circled for scale (U20/008927). **C)** Hukanui Limestone Member (Pakaututu Formation, the basal formation of the Mangaheia Group in the Pakaututu and Puketitiri areas. The bivalves prominent in the image are *Tucetona laticostata* (V20/118113). **D)** Cross-bedded calcareous sandstone and minor limestone of the Te Rangi Member, Titiokura Formation, cropping out on Naumai Station, Maungaharuru Range (V19/390273). **E)** Thick limestone facies of the Opouahi Member, Titiokura Formation, cropping out beside Pohokura Road, Maungaharuru Range. Master weathering surfaces in the outcrop are arrowed (arrowed) (V19/410221). **F)** Concretionary sandstone and limestone beds of the Te Waka Formation cropping out at the type section, northern end of the Te Waka Range. Carbonate content increases up through this section (V20/252129).


A


B


C


D

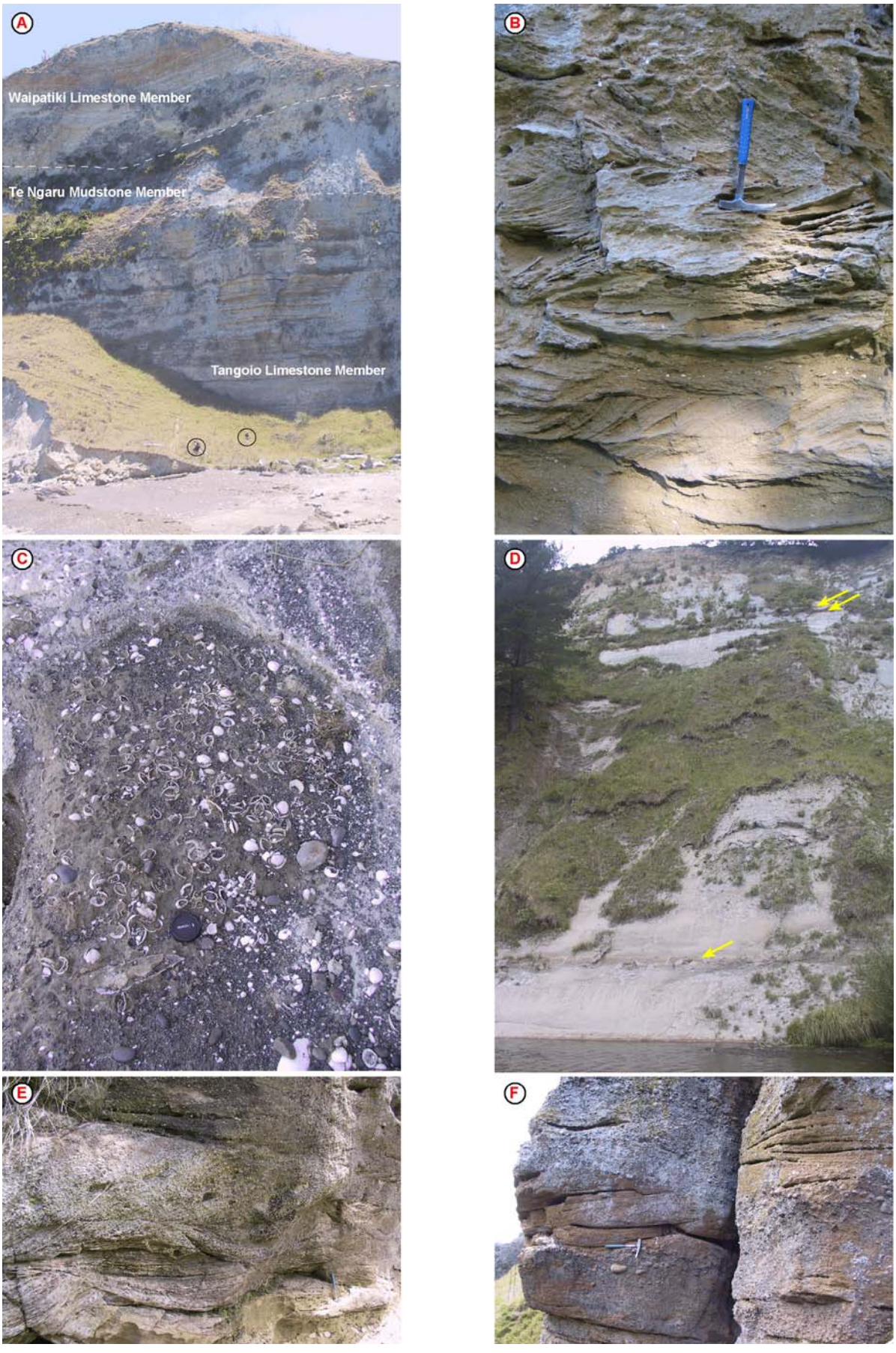

F


E

Puketitiri, Patoka, and Rissington

West of the Mohaka Fault in the Puketitiri and Pakaututu areas the basal formation of the Mangaheia Group is the Pakaututu Formation (Fig. 3.7D). The Pakaututu Formation comprises a distinctive 8-15 m-thick highly fossiliferous coarse-grained limestone (Hukanui Limestone Member; Fig. 3.9C) that overlies either basement (west of Ruahine Fault) or thick (<50 m) greywacke conglomerate and concretionary sandstone (30 m thick). Where present, the conglomerate and sandstone facies are included in the Pakaututu Formation (Column Pa-1). The thick conglomerate interval thins rapidly away from the Ruahine Fault. The Hukanui Limestone Member is distinctive as it contains very abundant valves of the large dog cockle *Tucetona laticostata* (Fig. 3.9C), among other thick-shelled molluscs. The presence of small *Phialopecten marwicki* supports an Opoitian age for this unit. The Pakaututu Formation is overlain by the Puketitiri Formation, a 120 m-thick massive to slightly laminated siltstone to sandy siltstone of inferred Waipipian age that is punctuated by occasional 2-3 m-thick beds of greywacke conglomerate and breccia. The nature of the contact with the underlying Pakaututu Formation is inferred to be conformable, but field exposure is poor. The Puketitiri Formation is unconformably overlain by the Te Waka Formation (Fig. 3.7D), with the contact exposed in several places including Hukanui Station (V20/155114, Column Pu-2), Rocky Hill Station (V20/139059, Column Pu-4), and near Puketitiri (V20/173068, Columns Pu-5 and Pu-6). On Hukanui Station the Te Waka Formation at its base has a 0.5 m-thick very coarse-grained and poorly sorted breccia with common large *Crassostrea ingens* oyster shells. While the basal breccia is similar to that at the base of the Titiokura Formation, the presence of the Mangapanian index pectinid *Phialopecten thomsoni* in the limestone above the basal breccia confirms that this unit is Te Waka Formation. Te Waka Formation in the Puketitiri area is characterised by the presence of giant-scale cross-beds up to 20 m across. Near the axial ranges to the west of the Mohaka Fault, Te Waka Formation comprises highly fossiliferous pebbly limestone, and unconformably overlies Torlesse basement.

Fig. 3.10 (facing page): Field photographs of typical lithologies in upper parts of the Mangaheia Group. **A)** Sea-cliff outcrop of the Tangoio Limestone, Te Ngaru Mudstone and Waipatiki Limestone Members of the Petane Formation. People circled for scale. Photo location W20/521229, south of Waipatiki Beach. **B)** Herringbone, trough and tabular cross-stratification in Waipatiki Limestone Member, Okawa Stream, V21/250781. **C)** Highly fossiliferous greywacke conglomerate, Flag Range Conglomerate Member (Petane Formation), Kikowhero Stream, V21/192726. **D)** Esk Mudstone with interbedded tephra layers (arrowed). Lower reaches of Mangaone River above Rissington, V21/305897. **E)** Cross-stratified tephric interval in the Hikuroa Pumice Member (Petane Formation), cropping out near Beattie Road, V20/360968. **F)** Trough cross-stratified greywacke conglomerate, Tutira Member (Petane Formation) near Glengarry Road, Tiokapu Station, V20/136987.


A
Waipatiki Limestone Member
Te Ngaru Mudstone Member
Tangoio Limestone Member
B
C
D
E
F

East of the Mohaka Fault in the Puketitiri and Patoka areas the basal formation of the Mangaheia Group is usually the Te Waka Formation which normally unconformably overlies the Mokonui Sandstone, although may overlie Torlesse basement and Te Ipuohape Sandstone Member (Opau Stream, Fig. 3.11H; V20/207049, Column Pt-2; Katz 1973). In one locality near Patoka at "The Gorges" (Fig. 3.11I; V20/186011, Column Pt-8) inferred Titiokura Formation crops out, and although the base is not exposed it probably unconformably overlies Mokonui Sandstone. In this locality Titiokura Formation is conformably overlain by a cyclothemic interval of the Te Waka Formation (Fig. 3.11I). The Mangapanian Te Waka Formation is the oldest Mangaheia Group unit to crop out either side of the Ruahine and Mohaka Faults (Fig. 3.7, 3.11), and therefore has important implications for determining the displacement history of faults in the North Island Shear Belt.

The formation crops out in a nearly continuous NE-SW belt from the type section at Te Waka Trig, through Patoka, Mangatutu Station, Kuripapango, and Glenross Range to Awapai Station. In the Kuripapango area Te Waka Formation unconformably overlies Torlesse basement, Blowhard Formation (Kapitean), or Mangatoro Formation (Upper Opoitian) (Fig. 3.7). No Waipipian beds are present in this area. On Awapai Station the formation interdigitates with the Puketitiri Formation (Mangapanian) and eventually passes laterally into it (Fig. 3.11A). In most cases, however, Te Waka Formation is conformably overlain by the Pohue Formation, which is then conformably overlain by the Matahorua Formation. The Matahorua Formation is in turn overlain by the Esk Mudstone (Fig. 3.10D). In the Patoka, Puketitiri, and Rissington areas no Tutira, Aropaoanui Mudstone, or Darkys Spur Members are present, having passed laterally into the Esk Mudstone. The Esk Mudstone grades into the Mairau Mudstone which is in turn overlain by the Flag Range Conglomerate Member (Fig. 3.10C), a lateral but coarser-grained and shallower water equivalent of the Tangoio Limestone Member (Fig. 3.10A). The Flag Range Limestone Member is overlain by the Te Ngaru Mudstone and then the Waipatiki Limestone Member (Fig. 3.10B), Devils Elbow Mudstone Member, and a variably fossiliferous coarse-grained conglomerate that marks the base of the Kaiwaka Formation.

Fig. 3.11 (facing page): Schematic stratigraphic columns illustrating the distribution of the Te Waka Formation from the type section on the Te Waka Range (northeast) to Awapai Station (southwest). Of note is how the Te Waka Formation overlies a number of stratigraphic levels from Mesozoic basement to "middle" Pliocene limestone.

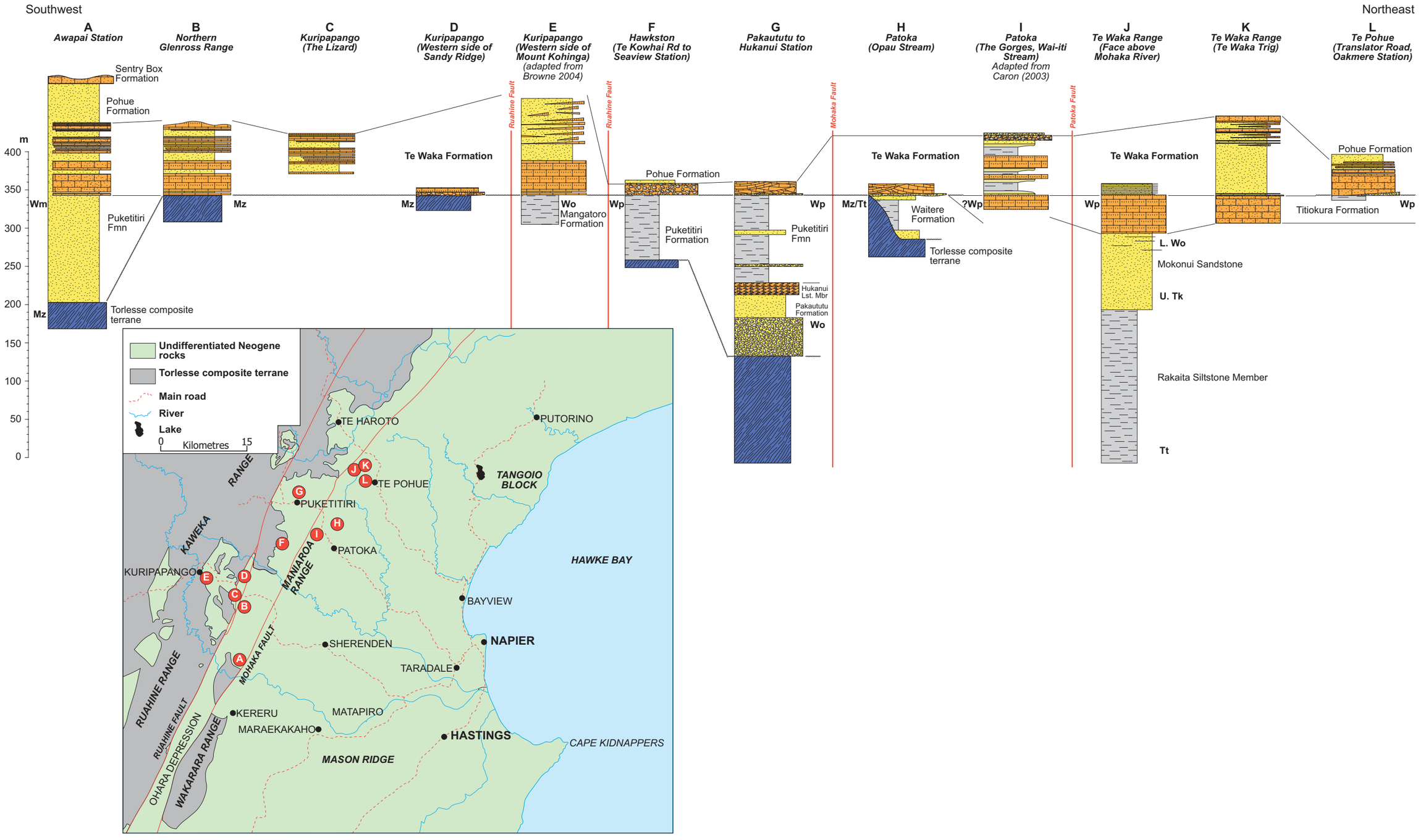


Fig. 3.11: Schematic stratigraphic columns illustrating the distribution of the Te Waka Formation from the type section on the Te Waka Range (Te Waka Trig, northeast) to Awapai Station (southwest). Of note is how the Te Waka Formation overlies a number of stratigraphic levels from Mesozoic Torlesse composite terrane (basement) to "middle" Pliocene limestone and mudstone. MZ, Mesozoic; Tt Tongaporutuan; U. Tk, Upper Kapitean, L. Wo, Lower Opoitian, Wp, Waipipian; Wm, Mangapanian.

Napier-Taradale

The stratigraphy of the Napier-Taradale area (Fig. 3.4) is in part a southward continuation of that in the Tangoio Block and Rissington areas. The stratigraphically oldest unit cropping out is the Scinde Island Formation, of Lower Nukumaruan age (Beu 1995). Stratigraphic issues pertaining to this formation are discussed later.

The stratigraphy below the Scinde Island Formation was determined from the Hukarere-1 Drillhole (Westech Energy New Zealand Ltd 2001, PR 2656). The Scinde Island Formation is a lens in the Taradale Mudstone, itself a mudstone-dominated formation with a minimum thickness of 860 m. Taradale Mudstone is of Waipipian to "middle" Nukumaruan age, and unconformably overlies Eocene sedimentary rocks at depth in Taradale-1 drillhole (Darley and Kirby 1969). Uppermost parts of the Taradale Mudstone contain the co-occurrence of the gastropods *Pelicaria acuminata* and *Pelicaria convexa* (Beu 1995), inferring a "middle" Nukumaruan age for its top. The Taradale Mudstone is gradationally overlain by the Park Island Limestone Member, a lateral equivalent of the Darkys Spur Member. The Park Island Limestone Member is abruptly overlain by the Mairau Mudstone Member, Tangoio Limestone Member, and a thin erosional remnant of Te Ngaru Mudstone Member (Fig. 3.15E).

Sherenden-Matapiro

Rocks cropping out in the Sherenden-Matapiro area (Fig. 3.12) record a transition from the lithostratigraphic units of the Tangoio Block to those of the Ohara Depression. The stratigraphically oldest unit in this district is the Te Waka Formation (Mangapanian), exposed on the upthrown (southeastern) side of Mohaka Fault near Willowford and Waiwhare. The Te Waka Formation is overlain by, and interdigitates with, the Pohue Formation, which is much thinner here than in the Maungaharuru Range and Te Pohue areas. The Pohue Formation is in turn overlain by the Grassy Knoll Conglomerate Member, the only member of the Matahorua Formation to occur in this area. This conglomerate is overlain by the Esk Mudstone, and in turn by the Okauawa Formation.

The Okauawa Formation has been geologically mapped northeast from the Ohara Depression (where first defined by Erdman and Kelsey (1992)) and represents a unit transitional between beds of the Tangoio Block and Ohara Depression. The Okauawa Formation contains two conglomerate-siltstone-sandstone cycles (Kikowhero and Whakamarumaru Members), and while these two cycles have been defined as members they are not differentiated on the geological maps. The Okauawa Formation is overlain by the Mairau Mudstone Member, and in turn by the Flag Range Conglomerate Member, both of the Petane Formation. The Flag Range

Conglomerate Member (Fig. 3.10C) enters the subcrop in the Matapiro district on the western limb of the Matapiro Syncline and re-emerges near Omahu and Puketapu as the Tangoio Limestone Member. These two beds are overlain by the Te Ngaru Mudstone Member, Waipatiki Limestone Member (Fig. 3.10A), Devils Elbow Mudstone Member, and Kaiwaka Formation. The Kaiwaka Formation overlies the Devils Elbow Mudstone Member across a transgressive surface of erosion, above which is a highly fossiliferous *Tawera*-dominated shellbed resembling that at the base of the Kaiwaka Formation in the Tangoio Block. This shellbed is overlain by siltstone, which passes upsection into a thick, well cemented limestone. This is the stratigraphically highest bed in the Mangaheia Group in this area and is named the Puketautahi Limestone Member.

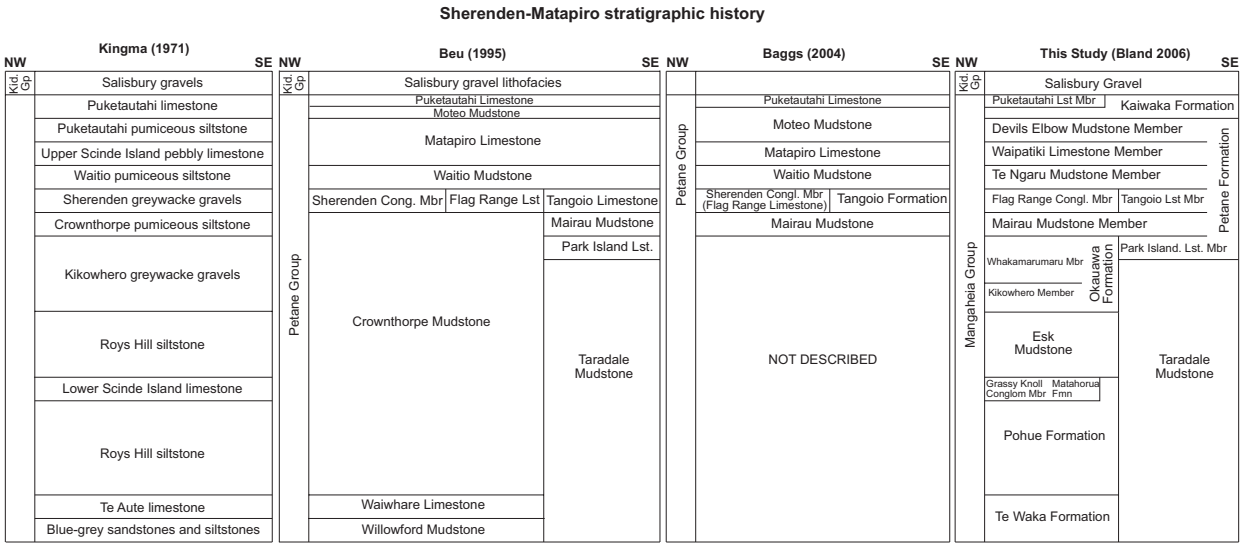


Fig. 3.12: Summary of the history of stratigraphic nomenclature for the Sherenden and Matapiro areas by Kingma (1971), Beu (1995), Baggs (2004), and this study.

Laterally all beds below the Park Island Limestone Member pass southeastwards into the Taradale Mudstone. Beds above the Taradale Mudstone are the same units as exposed in the Napier-Taradale region.

Kuripapango

The stratigraphic nomenclature of the Kuripapango area is summarised in Fig. 3.13. In this area the basal formation of the Mangaheia Group is the Blowhard Formation of Kapitean (Late Miocene) age (Fig. 3.9A, B) (Browne 2004a). This formation normally unconformably overlies either Torlesse basement, or more rarely Rakaita Siltstone Member (Waitere Formation, Tolaga Group). The Spiral Conglomerate and Waikarokaro Members, included in the Blowhard Formation by Browne (2004a), are retained here (Fig. 3.7B). Spiral Conglomerate Member comprises >100 m of poorly sorted greywacke conglomerate with thinner fine to medium sandstone and rare siltstone beds (Browne 2003). The member always overlies basement. The

Waikarokaro Sandstone Member (Fig. 3.9B) overlies the Spiral Conglomerate Member, although when the latter is not present the Waikarokaro Sandstone Member overlies Torlesse basement. Waikarokaro Sandstone Member comprises up to 70 m of very well sorted sandstone with conglomerate and limestone interbeds. Blowhard Formation is inferred to be unconformably overlain by the Mangatoro Formation of Upper Opoitian age (Browne 2004a). Mangatoro Formation consists of muddy to silty very fine to fine sandstone. The exact thickness of the unit is unknown as the basal contact is not exposed, and the formation is always in fault contact with older units. It is estimated from geological cross-sections to be up to about 200 m thick, although may be up to 550 m thick.

Kuripapango stratigraphic history

Browne (1981)	Beu (1995)	Browne (2004)	This Study (Bland 2006)
Te Aute Formation: Feldspathic litharenite/Lutite lithofacies	Sentry Box Limestone	Sentry Box Formation	Mangaheia Group: Sentry Box Formation
Te Aute Formation: The Miroroa Pebbly Biosparite Lithofacies			
Te Aute Formation: The Upper Alternating Biosparite-Litharenite Lithofacies	Te Waka Limestone	Kaumatua Formation	Te Waka Formation
Te Aute Formation: The Lower Biosparite Lithofacies			
Te Aute Formation: The Basal Sublitharenite Lithofacies		Te Waka Formation	
Mangatoro Formation	Mangatoro Formation	Mangatoro Formation	Mangatoro Formation
Blowhard Fmn: Undifferentiated Waikarikari Member	Owhakao limestone	Blowhard Fmn: Waikarokaro Sandstone Mbr	Blowhard Fmn: Waikarokaro Sandstone Mbr
Blowhard Fmn: Spiral Conglomerate Member		Blowhard Fmn: Spiral Conglomerate Member	Blowhard Fmn: Spiral Conglomerate Member
			Tolaga Group: Waitere Fmn: Rakaita Siltstone Member
			Tolaga Group: Waitere Fmn: Auroa Alternating Member
			Tolaga Group: Waitere Fmn: Te Ipuohape Sandstone Mr

Fig. 3.13: Summary of the history of stratigraphic nomenclature in the Kuripapango area from Browne (1981), Beu (1995), Browne (2004a), and this study.

Mangatoro Formation is unconformably overlain by the Te Waka Formation of Mangapanian age. No Waipipian rocks occur in the Kuripapango area, or the adjacent Ruahine Range, even though they are thick in other parts of the study area and in the Hawke's Bay region, and in the neighbouring Wanganui Basin. Basal Te Waka Formation at Kuripapango comprises a thick limestone bed that unconformably overlies Torlesse basement (Glenross Range and Sandy Ridge), Waikarokaro Sandstone Member, Mangatoro Formation (Mount Kohinga), or conformably overlies Puketitiri Formation (central and southern Glenross Range). This limestone passes up into a succession of at least three cyclothems consisting of mixed siliciclastic-bioclastic sandstone and shellhash sandy limestone (Fig. 3.11B, C). These cyclic units form the crest of The Lizard (U20/034911, Column Ku-2) and the summit of the Glenross Range (U20/040903, Column Gr-1). The youngest Mangaheia Group unit in the Kuripapango area is the Sentry Box Formation of lowermost Nukumaruan age (Beu *et al.* 1977; Beu 1995). Sentry Box Formation here comprises fine sandstone to gravelly limestone and fossiliferous sandstone with abundant concretions and carbonaceous debris (Browne 2003). It crops out at the Gentle Annie (U20/953954), in a fault-bounded sliver on Mount Kohinga (U20/981948), and along the summit ridge of Mount Miroroa below the Miroroa Thrust (U20/006923) (Browne 1986, 2004). At the Gentle Annie it rests on

basement across an angular unconformity (Browne 2004a, b), and on Mount Miroroa unconformably over Waikarokaro Sandstone Member (Fig. 3.11B). The basal Nukumaruan age of Sentry Box Formation is confirmed by the presence of *Zygochlamys patagonica delicatula* and *Jacquinotia edwardsii* (Beu *et al.* 1977, 1981; Beu 1995; Browne 2004a). In the Ngaruroro River around Kuripapango, deposits of Holocene Taupo Pumice are common.

Omahaki Depression

The Omahaki Depression contains a limited thickness of Neogene (Opoitian) sedimentary rocks that unconformably overlie basement (Fig. 3.7A). Approximately 20 m of fine-grained thin-bedded to massive Mangatoro Formation overlies Torlesse basement and is in turn unconformably overlain by conglomeratic limestone of the Omahaki Formation (Column Om-1).

Ohara Depression-Kereru

While accumulating in paleoenvironments similar to those of the beds in the Tangoio Block, the stratigraphy of the Ohara Depression and Kereru District (Fig. 3.14, 3.15A, B, 3.16) does show considerable differences. Beds there accumulated during active uplift of adjacent fault-bounded basement blocks, and this is reflected in the stratigraphy.

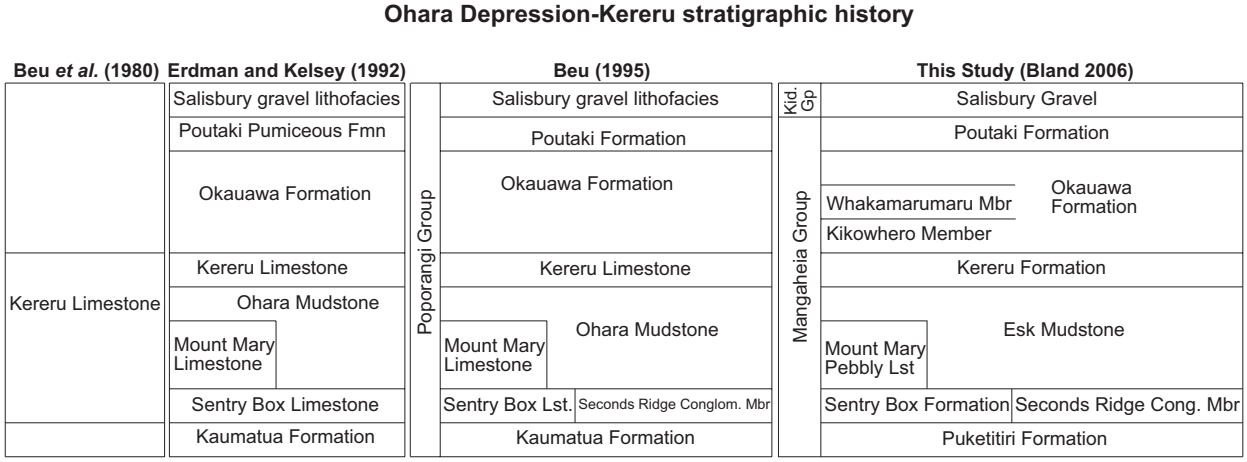
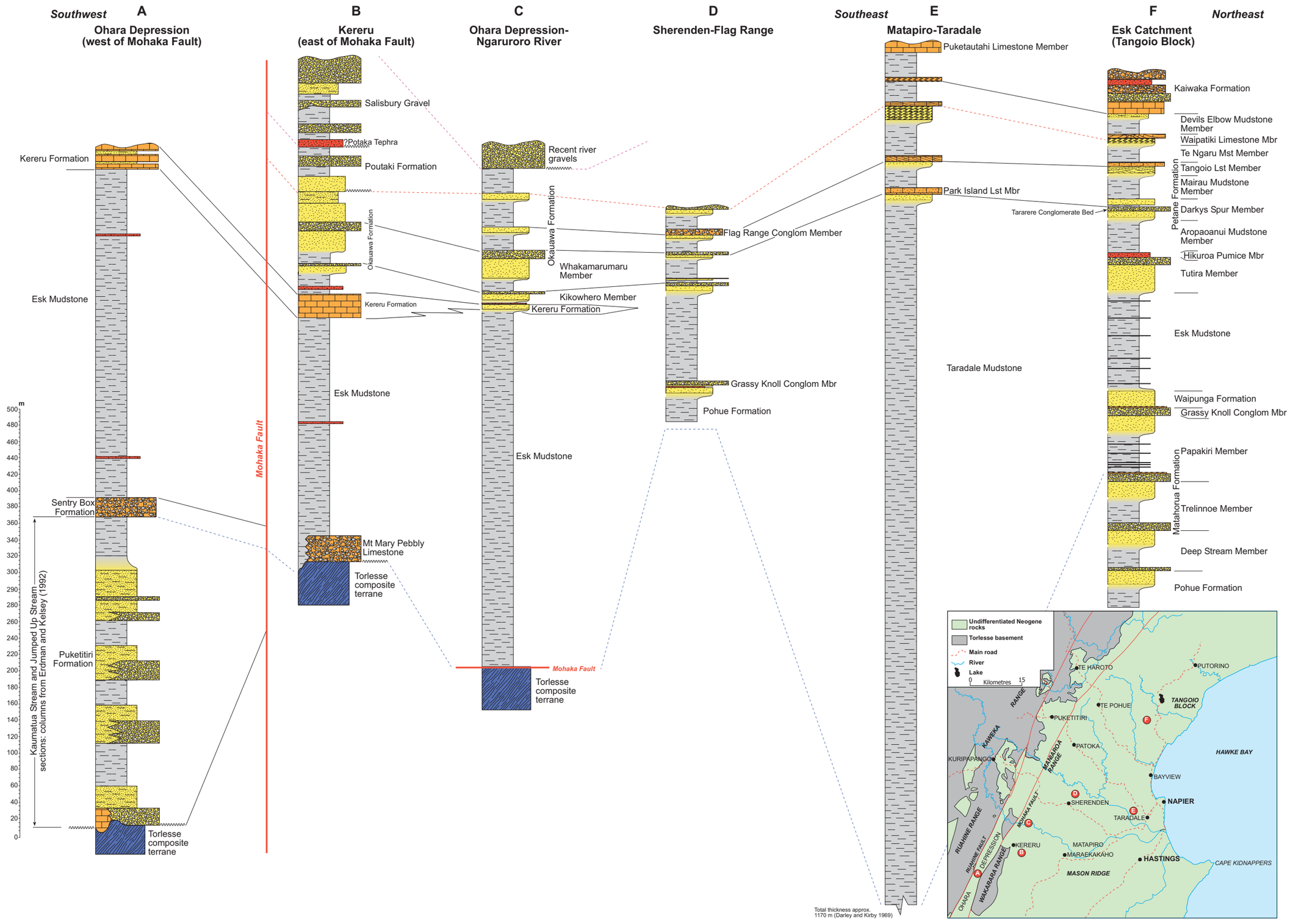


Fig. 3.14: Summary of the history of stratigraphic nomenclature of the Ohara Depression from Beu *et al.* (1980) to the present study. The diagram illustrates the stratigraphic nomenclature adopted, mainly from Erdman and Kelsey (1992).

Fig. 3.15 (facing page): Summary stratigraphic columns of the Nukumaruan succession in central parts of Hawke's Bay from the Ohara Depression (southwest) to the Esk River catchment (northwest, Tangoio Block). Geological mapping in this study has confidently correlated rocks from the Tangoio area to the Ohara Depression, resulting in a more unified Nukumaruan lithostratigraphy for this part of Hawke's Bay. The blue line marks the Mangapanian-Nukumaruan boundary, the red line the Pliocene-Pleistocene boundary, and the purple line the base of the Castlecliffian succession.


Southwest
A
Ohara Depression
(west of Mohaka Fault)
Kereru Formation
Esk Mudstone
Sentry Box Formation
Puketitiri Formation
Kaumatua Stream and Jumped Up Stream sections: columns from Erdman and Kelsey (1992)
m
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
Torlesse composite terrane
Mohaka Fault
B
Kereru
(east of Mohaka Fault)
Salisbury Gravel
?Potaka Tephra
Poutaki Formation
Okauawa Formation
Kereru Formation
Esk Mudstone
Mt Mary Pebbly Limestone
Torlesse composite terrane
C
Ohara Depression-
Ngaruroro River
Recent river gravels
Okauawa Formation
Whakamarumaru Member
Kikowhero Member
Kereru Formation
Esk Mudstone
Mohaka Fault
Torlesse composite terrane
D
Sherenden-Flag Range
Flag Range Conglom Member
Grassy Knoll Conglom Mbr
Pohue Formation
Southeast
E
Matapiro-Taradale
Puketautahi Limestone Member
Park Island Lst Mbr
Taradale Mudstone
Total thickness approx. 1170 m (Darley and Kirby 1969)
Northeast
F
Esk Catchment
(Tangoio Block)
Kaiwaka Formation
Petane Formation
Devils Elbow Mudstone Member
Waipatiki Limestone Mbr
Te Ngaru Mst Member
Tangoio Lst Member
Mairau Mudstone Member
Darkys Spur Member
Aropaoanui Mudstone Member
Hikuroa Pumice Mbr
Tutira Member
Tararere Conglomerate Bed
Esk Mudstone
Waipunga Formation
Grassy Knoll Conglom Mbr
Matahorua Formation
Papakiri Member
Trelinnoe Member
Deep Stream Member
Pohue Formation
Undifferentiated Neogene rocks
Torlesse basement
Main road
River
Lake
0 Kilometres 15
TE HAROTO
PUTORINO
TE POHUE
PUKETITIRI
PATOKA
KURIPAPANGO
BAYVIEW
SHERENDEN
NAPIER
TARADALE
KERERU
MATAPIRO
MARAEKAKAHO
HASTINGS
CAPE KIDNAPPERS
MASON RIDGE
HAWKE BAY
TANGOIO BLOCK
RANGE
KAWEKA
MANAROA RANGE
MOHAKA FAULT
RUAHINE RANGE
RUAHINE FAULT
DEPRESSION
WAKARARA RANGE
OHARA
A
B
C
D
E
F

Limestone beds are prominent in the Ohara-Kereru succession, particularly in the Lower Nukumaruan part of the record. This is in contrast to the Tangoio area where greywacke conglomerate, sandstone, and siltstone beds are present. These limestones are best developed around the margins of the Ohara Depression on the flanks of the Ruahine and Wakarara Ranges, and presumably record the positions of paleohighs away from a high siliciclastic sediment input. The stratigraphic record in the Ohara Depression also contains greywacke conglomerate and thick mudstone and sandstone beds. The stratigraphic nomenclature employed is that of Erdman and Kelsey (1992), with emendments made based on correlations from geological mapping during the current study (Fig. 3.15, 3.16).

The basal formation of the Mangaheia Group in the Ohara Depression-Kereru area is the Puketitiri Formation (Fig. 3.15A, 3.16). This formation is a minimum of 100 m thick and comprises massive sandy mudstone, alternating interbeds of sandstone and mudstone, and pebbly limestone and conglomerate beds (Kelsey *et al.* 1993). It has not been observed in outcrop east of the Mohaka Fault although the Kereru-1 drillhole suggests it does underlie this area at depth (Johnston and Francis 1996). In southern and central Ohara Depression the Puketitiri Formation is conformably overlain by the Sentry Box Formation (e.g. U21/934665, Column Ke-3). In northern Ohara Depression the contact between the two is unconformable (e.g. U21/971717, Column Ke-6) (Erdman and Kelsey 1992). The Sentry Box Formation is a thick pebbly barnacle limestone to fossiliferous muddy limestone with interbeds of massive mudstone and granule to pebble conglomerate. A distinguishing feature of the Sentry Box Formation is the common subantarctic macrofauna comprising among other taxa *Zygochlamys patagonica delicatula* and *Jacquinotia edwardsii* (Erdman and Kelsey 1992; Beu 1995). Laterally the formation grades into fine sandstone containing *Z. delicatula,* although the formation is still present in sporadic localities as a limestone on Mount Kohinga, Mount Miroroa, Seconds ridge (Ruahine Range), Whanawhana, and the Gentle Annie (Napier-Taihape Road). In the Ohara Depression-Kereru area Sentry Box Formation is restricted in outcrop to the western side of the Ohara Depression adjacent to the Ruahine Fault (Fig. 3.15A), although the Kereru-1 drillhole suggests a lateral correlative is present at depth (Johnston and Francis 1996). Coarse-grained conglomerate containing *Z. delicatula* on the northern end of the Ruahine Range, named the Seconds Ridge Conglomerate by Beu (1995) is included in this study as a member of the Sentry Box Formation (Seconds Ridge Conglomerate Member).

The Sentry Box Formation is conformably overlain by the Esk Mudstone (e.g. U21/934665, Column Ke-3). Fauna from 1 m above this contact indicate a bathyal environment of deposition for the lower Esk Mudstone in the Ohara Depression (Beu 1995), in contrast to the inner shelf environment inferred for the Sentry Box Formation. Around the margins of the Wakarara Range,

Mount Mary Pebbly Limestone directly overlies basement and is overlain by the Esk Mudstone. Where Mount Mary Pebbly Limestone is absent, Esk Mudstone directly overlies Torlesse basement (Erdman and Kelsey 1992). Mount Mary Pebbly Limestone is dominantly a pebbly, well cemented limestone composed of shellhash and greywacke pebbles. On Mount Mary (the type section, U21/981948) the formation crops out as a single pebbly unit, although laterally towards the centre of the Ohara Depression analogous carbonate fingers appear as a set of at least three interbedded conglomerate and limestone beds separated by mudstone, reflecting interdigitation with the Esk Mudstone, into which the formation eventually passes. It appears as though the Mount Mary Pebbly Limestone occupies a similar stratigraphic position to the Sentry Box Formation (as it underlies and interdigitates with the Esk Mudstone), but lacks all the diagnostic Lower Nukumaruan taxa common in the Sentry Box Formation. This could either be because it accumulated at a time slightly younger than the Sentry Box Formation, or because the paleoenvironment was too shallow for the index fauna (evidenced by the paucity of intact, easily identifiable macrofauna in the Mount Mary Pebble Limestone). The Esk Mudstone in the Ohara Depression is up to 412 m thick (Erdman and Kelsey 1992), significantly thicker than the 120 m observed in the Tangoio Block and reported by Haywick *et al.* (1991). The Esk Mudstone is conformably overlain by the Kereru Formation, a package of three pebbly limestone and sandy oyster beds that tend to crop out in strongly dipping ridges along most of the eastern edge of the Wakarara Range, and on several small platforms and ledges west of the Mohaka Fault on the western edge of the Wakarara Range (e.g. U21/968684). The limestone and shelly parts of the Kereru Formation are best developed adjacent to the Wakarara Range, and towards the west into the centre of the Ohara Depression quickly pass into sandstone and shellbed facies. In the cliffs of the Ngaruroro River north of the Wakarara Range only one sandstone bed is present that can be correlated with the Kereru Formation, the remainder of the formation having passed into the Esk Mudstone. On the eastern side of the Wakarara Range, Kereru Formation dips at up to 90° due to the influence of the Wakarara Thrust (see Chapter Five, p. 160).

Kereru Formation is the stratigraphically highest Mangaheia Group unit cropping out in the Ohara Depression (Fig. 3.16). To the east of the Ohara Depression Poutaki Formation is the highest unit in the Mangaheia Group (Fig. 3.16). To the east of the Mohaka Fault, Kereru Formation both interdigitates with, and is conformably overlain by, the Okauawa Formation (Erdman and Kelsey 1992). Kereru Formation is at least 20 m thick. The Okauawa Formation is at least 100 m thick and comprises highly fossiliferous sandstone, siltstone, and variably fossiliferous conglomerate beds. The two principal conglomerate beds (upper parts of the Kikowhero and Whakamarumaru Members, respectively) are restricted to lower parts of the formation and crop out from Ohara Stream (Columns Ke-4, Ke-5, Ke-7), through the Ngaruroro River to the Sherenden area. They are inferred to be lateral correlatives of conglomerate in the Tutira Member and the Tararere

Conglomerate Bed (Darkys Spur Member) in the Petane Formation (Fig. 3.15C, F), although lateral continuity cannot be demonstrated. They are therefore maintained as separate units. The Okauawa Formation is overlain by the Poutaki Formation, which consists of 60-100 m of coarse pumiceous sandstone, pumice granule to cobble conglomerate, siliciclastic sandstone, and mudstone (Beu 1995). The lower contact of the Poutaki Formation is defined as the first 1-1.5 m-thick pumiceous sandstone at the top of the Okauawa Formation (Beu 1995). The Poutaki Formation is unconformably overlain by the Salisbury Gravel of the Kidnappers Group. The Salisbury Gravel is the only mapping unit differentiated in the Kidnappers Group in the study area. The Salisbury Gravel comprises thick conglomerate and pumiceous sandstone beds overlying a 6 m-thick distal ignimbrite assumed to be the Kidnappers Ignimbrite (Wilson *et al.* 1995).

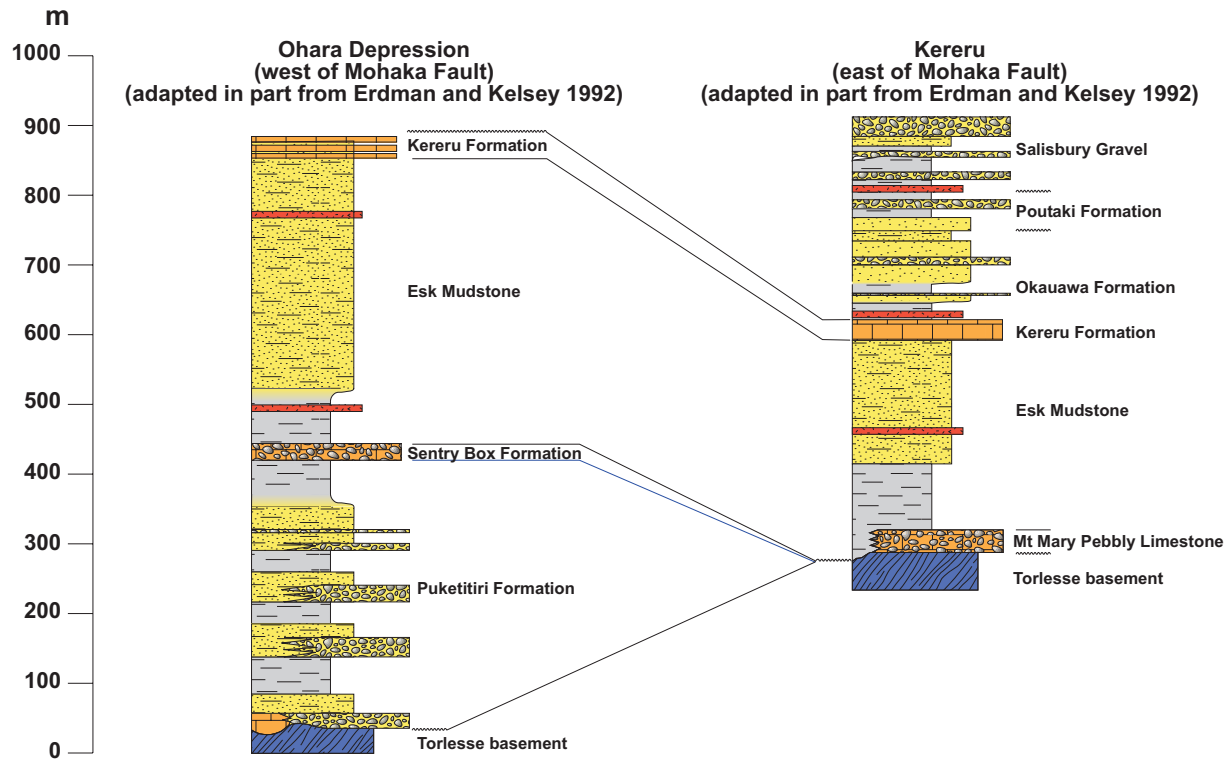


Fig. 3.16: Correlation of Mangapanian to Castlecliffian units cropping out in the Ohara Depression with those east of the Mohaka Fault. Within the Ohara Depression the Kereru Formation (Mangaheia Group) is the stratigraphically highest unit. East of the Mohaka Fault the Salisbury Gravel (Castlecliffian, Kidnappers Group) forms the stratigraphically highest beds.

Mason Ridge-Maraekakaho

The relationship between the stratigraphy of the Mason Ridge area (Fig. 3.17) and a similar succession immediately south of the Ngaruroro River in the Maraekakaho and Mason Ridge areas has been a stratigraphic issue this study has attempted to resolve. The issue itself is discussed in the following section, while the stratigraphic nomenclature for the Mason Ridge area is presented here. The stratigraphy of this area has recently been documented by Dyer (2005), and

her scheme is adopted here. The stratigraphically lowest unit cropping out in the wider Mason Ridge area is the Raukawa Mudstone which is in turn overlain by the Te Onepu Limestone, the classic "Te Aute Limestone" of historical usage. Both the Raukawa Mudstone and Te Onepu Limestone are not considered further in this study. The Te Onepu Limestone is overlain by the Makaretu Mudstone, which in turn is overlain by Mason Ridge Formation, a cyclic succession of limestone beds separated by mudstone. Each limestone and mudstone interval in the Mason Ridge Formation was given member status by Dyer (2005). The basal member of the Mason Ridge Formation is the Mahana Limestone Member, which gradationally overlies the Makaretu Mudstone. It is in turn overlain by the Maharakeke Mudstone Member, Torran Limestone Member, Whakapirau Mudstone Member, and Pakihirua Limestone Member. The Mason Ridge Formation is unconformably overlain by Okauawa Formation, Poutaki Formation, and in places a thin veneer of Kidnappers Group gravels.

Maraetotara Plateau-Raukawa Range

The geology of this area is not described in detail in this study, but for completeness these units appear on geological maps in southeastern parts of the study area. Formations in this area accumulated on a growing accretionary wedge as part of the "continent-detached" succession outlined in Caron *et al.* (2004a). These units are eastern equivalents to the "early-middle" Pliocene succession cropping out along the western margin of the study area. The basal unit is the "lower to middle" Mangatoro Formation, which is in turn overlain by the Upper Opoitian Kairakau Limestone (equivalent to lowermost parts of the Titiokura Formation, and the Hukanui Limestone Member). Kairakau Limestone is then overlain by a succession comprising Mokopeka Sandstone, Tuki Bell limestone (informal, Caron 2002), Mokopeka Sandstone, "middle" Waipipian Awapapa Limestone (which forms Te Mata Peak), Pukekura Calcarenite, Upper Waipipian Rotookiwa Limestone, Raukawa Mudstone, Mangapanian Te Onepu Limestone, the Makaretu and Mahanga Mudstones, the basal Nukumaruan Pakipaki Limestone, and the Mason Ridge Formation. For more detailed descriptions of these units the reader is referred to Beu (1995), Caron (2002), and Caron *et al.* (2004a).

Fig 3.17 (facing page): Summary of historical stratigraphic nomenclature in the Mason Ridge and Maraekakaho areas by Kingma (1971), Beu *et al.* (1980), Harmsen (1985), Kelsey *et al.* (1993), Beu (1995), Dyer (2005), and this study.

Mason Ridge-Maraekakaho stratigraphic history

LITHOSTRATIGRAPHIC ISSUES IN THE MANGAHEIA GROUP

This section aims to address lithostratigraphic issues pertaining to the Mangaheia Group. These are issues that have been identified during the course of, or as a result of, geological mapping in this study. The section documents and attempts to resolve key points relating to the distribution, correlation, and character of the Mangaheia Group in terms of some of the key stratigraphic units. In concluding remarks, Beu (1995, p. 185) outlined several points he regarded as important in improving the reliability of his Pliocene limestone distribution maps in eastern North Island. These points, summarised here, included: 1) The distribution of limestones between the Napier-Taupo and Napier-Taihape Roads needs accurate mapping; 2) Understanding the "mysterious" contact between the Titiokura Limestone and Maungaharuru Formation in the Te Waka and adjacent Maungaharuru Ranges, respectively, was needed; 3) A detailed study of the Big Hill area is warranted to better understand the relationship between Neogene rocks north and south of the Big Hill block; 4) Detailed 1:50 000 scale mapping of the Matapiro Syncline is needed to be certain of correlations between the main areas of Nukumaruan rock outcrop; and 5) Understanding limestone deposition in eastern North Island would be greatly improved by sequence stratigraphic analysis.

This research has addressed most of these points in some way. In particular, detailed geological mapping in this study has greatly improved the understanding of the region between the Napier-Taupo and Napier-Taihape Roads, firmed up correlations between units in the Matapiro Syncline and other areas of Nukumaruan outcrop, and proposed a strong correlation between limestones in the Te Waka and Maungaharuru Ranges (see Bland *et al.* 2004, included as Appendix VI, Volume One, Part Two). These and other points are discussed in the following sections.

Relationship between limestone beds in the Maungaharuru and Te Waka Ranges

Beu (1995) commented that more work was needed to understand the relationship between "early and middle" Pliocene limestone units cropping out in the Te Waka and Maungaharuru Ranges. The relationship between these limestones was discussed by Bland *et al.* (2004). The Te Waka Range is capped by two prominent limestone intervals assigned to the Titiokura and Te Waka Formations. Titiokura Formation thickens to the northeast, and thins to the southwest. Bland *et al.* (2004) demonstrated that limestones in the Maungaharuru Range were equivalent to the Titiokura Formation cropping out in the Te Waka Range. Geological mapping by Graafhuis (2001) and this study clearly demonstrates that Te Waka Formation does not occur in the Maungaharuru Range, the formation having passed laterally into fine sandstone and siltstone of the Pohue Formation.

Abolition of the Petane Group: Extension of the Mangaheia Group into the Nukumaruan

Understanding the distribution and nature of the Petane Group (Haywick *et al.* 1991; Beu 1995) has been a key focus of this study. The Petane Group was introduced by Haywick (1990) and formally defined by Haywick *et al.* (1991), formalising the long usage of the name "Petane" for the rocks cropping out in the Tangoio area (e.g. McKay 1886a). Haywick *et al.* (1991) tentatively placed the base of the group at the base of the Waipunga Formation in their study (Haywick *et al.* 1991, p. 215). The top of the Petane Group was placed at the top of the Kaiwaka Formation, which coincided either with the modern land surface, or an unconformable contact with Castlecliffian (Middle Pleistocene) Kidnappers Group gravel. Bland (2001) and Graafhuis (2001) extended the base of the Petane Group to the base of the Matahorua Formation, a cyclothemic package with prominent thick conglomerate beds that underlies the Waipunga Formation. This definition was supportable and easily recognisable in the Esk and Waikoau River catchments of which the Tangoio Block is part.

Fieldwork during this study has demonstrated that the base of the group, as defined by Haywick *et al.* (1991) and Beu (1995) cannot be consistently or accurately defined away from the Tangoio Block (i.e. the base of the group, as defined in the type locality cannot be geologically mapped away from this area). Formations within parts of the Petane Group of Haywick *et al.* (1991), such as the Tangoio and Waipatiki Limestone Members, have been confidently mapped from the Tangoio Block southwest to Taradale and Puketapu near Napier. The succession in the Napier area comprises Taradale Mudstone, overlain by the Park Island Limestone, Mairau Mudstone, and formations above this (Fig. 3.15E; Enclosure 1, Sheet 4). The stratigraphic record here is supported by the stratigraphic record from Taradale-1 drillhole (Darley and Kirby 1969) and from outcrop. The Matahorua Formation does not occur in the vicinity of Napier, there having passed laterally into the Taradale Mudstone, as have the Esk Mudstone, Tutira Member, and Aropaoanui Mudstone Member (Fig. 3.15E). Beu (1995) placed the base of the Petane Group in the Taradale area at the inferred position of the base of the Nukumaruan Stage derived from Taradale-1 drillhole. A problem with defining a group boundary in this way is that it is not based on lithology, and the Taradale Mudstone appears to continue with no noticeable change in lithology for a further 550 m below this level to beds of Waipipian age. This is one example of how the base of the Petane Group cannot be consistently or accurately defined away from the type locality. A conclusion of this study is that the maintenance of Petane as a group name is unsustainable. Consequently, it is proposed that Petane Group be demoted to formation status and become incorporated into the Mangaheia Group. The status of formations within the Petane Group varies with some of them retained as discrete formations, and others becoming members of a new Petane Formation (Fig. 3.4). Petane Group was only first defined in 1991 (Haywick *et al*. 1991)

from mapping in the Tangoio Block, and so converting it to a formation will not undermine, but rather help strengthen and simplify, the regional lithostratigraphy.

Petane is retained as a formation name for much of the succession in the Tangoio Block and its lateral equivalents, because of historical usage of the name "Petane" (e.g. McKay 1886a), and because the interval can still be usefully subdivided and geologically mapped. The new definition of Petane Formation (see Appendix I, p. A1-136) encompasses an interval comprising five shelfal cycles containing sandstone, siltstone, limestone, and conglomerate facies. This is consistent with other formations in the Mangaheia Group that also represent intervals with multiple cycles and similar lithologies, such as the Titiokura Formation, Matahorua Formation, Mason Ridge Formation, Kereru Formation, and Okauawa Formation. The thickness and diversity of stratigraphic units in the Kaiwaka Formation of Haywick *et al.* (1991), the stratigraphically highest unit of the old Petane Group, means that it warrants being retained as a separate formation. The internal composition of the Kaiwaka Formation, and the lateral continuity of constituent beds also remain poorly-resolved at this point, and it is desirable to maintain it as a separate formation at this stage. The Kaiwaka Formation sharply overlies the Petane Formation across a transgressive surface of erosion at the top of the Devils Elbow Mudstone Member near Devils Elbow on the Napier-Wairoa Road. Likewise, the Esk Mudstone is retained as a formation due to its significant stratigraphic thickness and lateral persistence across the entire study area from Putorino in the north to the Ohara Depression in the south. The Esk Mudstone gradationally underlies the Petane Formation. All other formations defined by Haywick *et al.* (1991) and Beu (1995) in the Petane Group cropping out in the Tangoio Block are now incorporated as members in the Petane Formation. These are the **Devils Elbow Mudstone Member, Waipatiki Limestone Member, Te Ngaru Mudstone Member, Tangoio Limestone Member, Mairau Mudstone Member, Tararere Conglomerate Bed, Darkys Spur Member, Aropaoanui Mudstone Member, Hikuroa Pumice Member,** and **Tutira Member** (Fig. 3.4, 3.15F). In addition to these members, the Petane Formation is defined to incorporate beds that geological mapping has demonstrated are lateral equivalents to units in the Tangoio Block. These include the **Park Island Limestone Member** (Darkys Spur Member equivalent) and **Flag Range Conglomerate Member** (Tangoio Limestone Member equivalent).

Lithostratigraphic correlation of the Tangoio Block to the Ohara Depression

The relationships between all Nukumaruan stratigraphic units from north to south in the study area are summarised in Fig. 3.15 and Fig. 3.18. These diagrams illustrate that many of the stratigraphic units are in reality common to several parts of the study area, and that they are not necessarily geographically restricted. Fig. 3.20 also records the proposed Nukumaruan

lithostratigraphy for central parts of Hawke's Bay. Key to correlating beds of upper parts of the Mangaheia Group has been mapping of the Waipatiki Limestone Member, stratigraphically the second highest member of the Petane Formation. This member is important because, while it is involved in the folding associated with the Matapiro Syncline, it does not completely enter the subsurface, whereas all underlying members of the Petane Formation do. The effect of this is that there is a marker horizon on which to "hang" stratigraphy cropping out on either limb of the Matapiro Syncline. On the eastern limb of the Matapiro Syncline (western limb of the Taradale Anticline) the Waipatiki Limestone Member is underlain by the Te Ngaru Mudstone Member, Tangoio Limestone Member, Mairau Mudstone Member, Park Island Limestone Member, and Taradale Mudstone. The stratigraphic position of the Park Island Limestone Member here is equivalent to that of the Darkys Spur Member in the Tangoio Block. No other coarse-grained Pliocene units occur below the Park Island Limestone Member based on the succession contained in Taradale-1 drillhole (Darley and Kirby 1969).

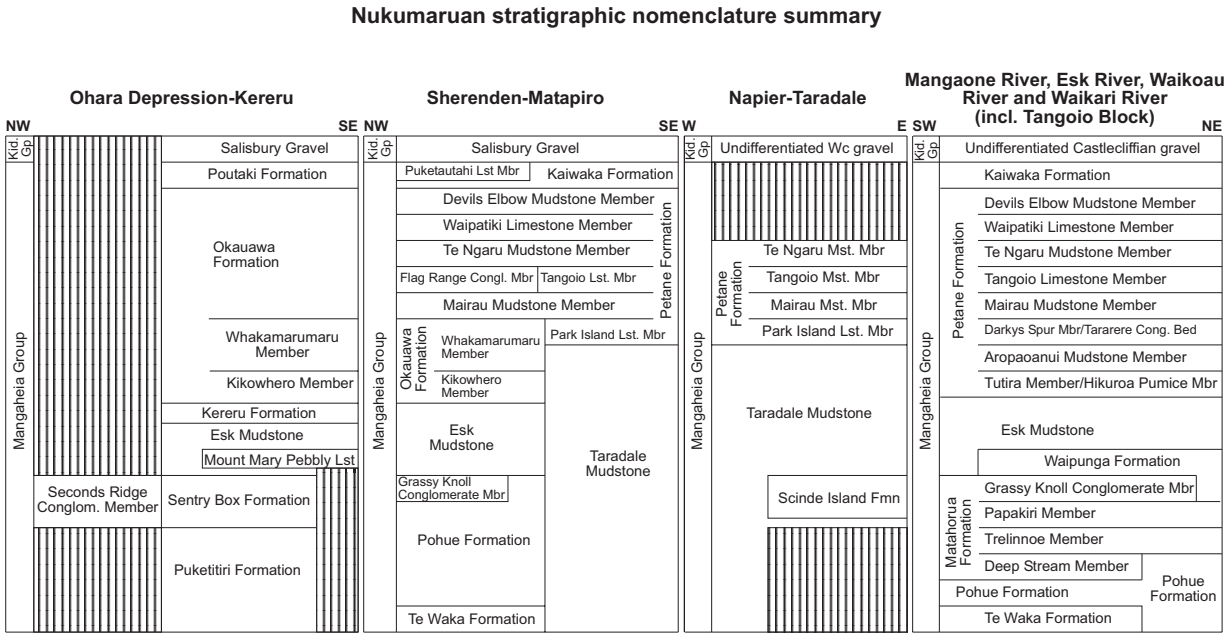


Fig. 3.18: Summary of the stratigraphic nomenclature employed for the Nukumaruan succession from the Tangoio Block to the Ohara Depression.

The western limb of the Matapiro Syncline occurs in the Sherenden, Matapiro, and Crownthorpe districts (Fig. 3.12). Underlying the Waipatiki Limestone Member on this limb are the Te Ngaru Mudstone Member, Flag Range Conglomerate Member, and two cycles with greywacke conglomerates at their base (Columns Sh-1, Sh-2, Sh-3). The stratigraphic position of the Flag Range Conglomerate Member is correlative with that of the Tangoio Limestone Member cropping out in both the Tangoio Block and on the eastern limb of the Matapiro Syncline (Fig. 3.15D-E). The first conglomerate bed below the Flag Range Conglomerate Member is inferred to be

stratigraphically equivalent to both the Darkys Spur Member and Park Island Limestone Member. The second conglomerate bed is inferred to be stratigraphically equivalent to the Tutira Member cropping out in the Tangoio Block and Esk River catchment. The interval of siltstone between the two conglomerates is therefore a lateral equivalent of the Aropaoanui Mudstone Member. The conglomerate beds have been confidently mapped through Whana Valley in the Ngaruroro River into the Ohara Depression where they crop out prominently in Ohara and Poporangi Streams. The conglomerates in the Ohara Depression were included by Erdman and Kelsey (1992) in the Okauawa Formation, and therefore this name has been applied to the beds cropping out below the Flag Range Conglomerate Member and above the Esk Mudstone. The names Tutira Member, Aropaoanui Mudstone, and Darkys Spur Members have not been applied to the beds in the Sherenden-Matapiro and Otamauri areas because although they occupy the same stratigraphic positions they are not laterally continuous with each other. They can be traced directly to beds in the Okauawa Formation, and therefore this name is preferred. In the Kereru district the conglomerates of the Okauawa Formation are overlain by a series of cycles consisting of basal shellbed, intervening siltstone, and overlying sandstone facies. It is inferred that the Flag Range Conglomerate, Te Ngaru Mudstone, Waipatiki Limestone, and Devils Elbow Mudstone Members of the Petane Formation in the Matapiro Syncline pass laterally into upper cycles of the Okauawa Formation. However, individual Petane Formation members cannot be differentiated in the Kereru district. Geological mapping clearly demonstrates that Ohara Mudstone of Erdman and Kelsey (1992) and Beu (1995) in the Ohara Depression is the same as the Esk Mudstone of Haywick *et al.* (1991). Given the priority of usage (Smith 1877) the name "Esk" is preferred over "Ohara" and the name Ohara Mudstone of Erdman and Kelsey is now abandoned.

In the Sherenden area (Fig. 3.12) the lower conglomerate bed of the Okauawa Formation is underlain by the Esk Mudstone, and in turn by a further greywacke conglomerate bed. Geological mapping demonstrates that this latter conglomerate is equivalent to the Grassy Knoll Conglomerate Member (top of Matahorua Formation). Based on stratigraphic position and macrofaunal content this member is inferred to have been deposited about 41 k.y. into the Nukumaruan stage (see Chapter Four, p. 125), and provides an important marker horizon southwest of Mangaone River into Tutaekuri River. The Grassy Knoll Conglomerate Member is overlain by the Esk Mudstone, a thick, almost monotonous interval of siltstone to sandy siltstone cropping out from Putorino in the northeast of the study area to the Ohara Depression in the south. It is punctuated occasionally by centimetre to decimetre-thick layers of pumiceous ash. The Esk Mudstone consistently overlies marginal-marine to inner shelf facies throughout its outcrop extent, and occupies the same stratigraphic position as the Ohara Mudstone of Erdman and Kelsey (1992). Esk Mudstone is therefore another stratigraphic horizon which can be used to link the Tangoio Block to the Ohara Depression.

Abolition of the Poporangi and Napier Groups and revision of the Nukumaruan stratigraphic nomenclature

In his attempt to review the Nukumaruan stratigraphy of eastern North Island, Beu (1995) defined three lithostratigraphic groups to encompass the Nukumaruan stratigraphy in central Hawke's Bay, two of which, the Napier and Poporangi Groups, were introduced in his study (Fig. 3.18, 3.19). The most widespread group was the Petane Group (as defined by Haywick *et al.* 1991). As discussed elsewhere in this chapter, even though Petane Group can be defined in Tangoio Block, accurate and consistent definition of the base of the group in other areas is very difficult. This study has proposed that Petane Group be demoted to Petane Formation and that it be incorporated into the Mangaheia Group. Beu (1995, p. 135) introduced the Napier Group to encompass Lower Nukumaruan limestone and siliciclastic beds comprising several formations including the Scinde Island Formation, Pakipaki Limestone, and Whanawhana Limestone. Beu considered the Late Pliocene-Early Pleistocene stratigraphy in the Ohara Depression (as mapped by Erdman and Kelsey 1992) as being lithologically and geographically distinct from beds of similar age elsewhere in the basin, and introduced the name Poporangi Group to encompass them (Beu 1995, p. 140). The previous section has argued to the contrary and that beds in the Ohara Depression can be confidently and accurately correlated to beds elsewhere in the basin, such as those cropping out in the Tangoio Block and Matapiro Syncline (e.g. Fig. 3.15A-F, 3.18).

Introduction of the Napier and Poporangi Groups, together with maintenance of the Petane Group, has produced an unnecessarily complex Nukumaruan stratigraphy in central parts of Hawke's Bay. Based on field mapping in the current study the groups established by Beu (1995) cannot be sustained as members and formations can readily be correlated between them. Beu (1995) focused on the faunal content of stratigraphic units and his lithostratigraphic group divisions have not been supported by the new geological mapping in this research.

Although Beu (1995) introduced and defined the Napier and Poporangi Groups, he designated no type or reference sections and provided no stratigraphic columns, making comparison of areas of Nukumaruan outcrop difficult. The creation of a lithostratigraphic group based soley on geographic areas of outcrop and some variations in macrofaunal content can be suspect. This is particularly true when geological mapping demonstrates that rocks of one group conformably underlie and interfinger with rocks of another group. Beu (1995) assigned to the Poporangi and Napier Groups geological units, such as the Sentry Box and Whanawhana Formations respectively, which sometimes crop out in locations less than 10 km from each other. In this example, in addition to some minor difference in lithofacies, justification for doing this was mostly because *Phialopecten triphooki* in the Whanawhana Limestone consist of both "typical" wide-ribbed and narrow-ribbed forms (Beu 1995, p. 139), while *P. triphooki* in the Sentry Box Formation

seemed to comprise only "typical" wide-ribbed forms. Both formations contain the key basal Nukumaruan index pectinid *Z. delicatula*, and both are limestone-dominated and of similar thickness. The two units are viewed in this study as merely representing slightly different depositional paleoenvironments, and should be described as being part of the same formation, in the same group.

The Nukumaruan part of the basin fill in the study area contains no significant unconformities or dramatic widespread facies changes, so it seems reasonable therefore to maintain the same lithological group throughout. Stratigraphy from the underlying Mangapanian part of the Mangaheia Group appears to continue uninterruptedly into the Nukumaruan, so a conclusion of this study is that all Nukumaruan rocks in the study area should be incorporated into the Mangaheia Group. Unifying the Nukumaruan stratigraphy across the central part of Hawke's Bay is an important step toward a more regional lithostratigraphy, especially as the GNS Science QMAP programme extends into Hawke's Bay. As the Petane Group is now incorporated as Petane Formation into the Mangaheia Group, beds of Beu's (1995) Napier and Poporangi Groups are also included in the Mangaheia Group, and the Napier and Poporangi Groups become obsolete names.

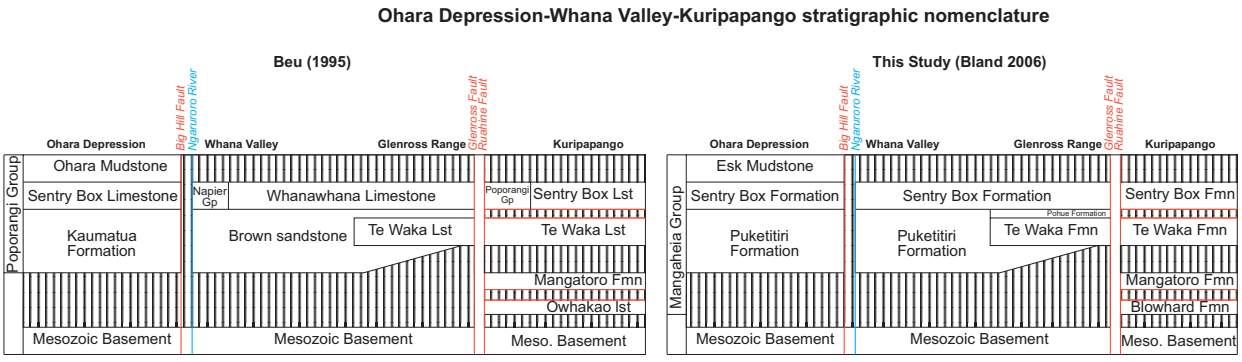


Fig. 3.19: Comparison of stratigraphic units of the Mangaheia Group from the Ohara Depression through Whana Valley to the Kuripapango area. Shown for comparison is the nomenclature scheme of Beu (1995) and that adopted in this study. Vertical black lines indicate areas of non-deposition or erosion.

Implications for basal Nukumaruan stratigraphy from distribution of Sentry Box Formation

Rocks of lowermost Nukumaruan age along southwestern margins of the study area are characterised by coarse-grained shelly limestone to fossiliferous sandstone containing the diagnostic Lower Nukumaruan index pectinid *Z. delicatula.* This is similar to coarse-grained Lower Nukumaruan rocks cropping out in the adjacent Wanganui Basin, such as the Hautawa Shellbed (Fleming 1953; McIntyre 2002). Nukumaruan rocks in the study area were assigned by Beu (1995) to the Sentry Box Limestone (Fig. 3.19), Seconds Ridge conglomerate (informal), and Whanawhana Limestone, among others. He examined Sentry Box Limestone in the Ohara

Depression and on Mount Miroroa and the Gentle Annie at Kuripapango. Seconds Ridge conglomerate was mapped at the northern end of Ruahine Range, and Whanawhana Limestone occurred between the two areas of Nukumaruan limestone outcrop.

All Nukumaruan limestone, fossiliferous sandstone, and conglomerate units occurring along western margins of the study area and containing *Z. delicatula* are assigned to the Sentry Box Formation in this study. Although the Sentry Box Formation overall is inferred to have been deposited in shallow-water high-energy environments, different lithofacies within the formation reflect diversified subenvironments on a lowermost Nukumaruan Hawke's Bay paleoshelf.

Implications from the base of Esk Mudstone on timing of deformation

Based on stratigraphic position and macrofaunal content, the Grassy Knoll Conglomerate Member is inferred to have been deposited some 40 k.y. into the Nukumaruan stage (base Nukumaruan 2.4 Ma; Cooper 2004), and provides an important marker horizon southwest of the Mangaone River towards rocks exposed in Tutaekuri River cliffs (an age of approximately 2.36 Ma). Away from the Tangoio Block, Grassy Knoll Conglomerate Member is sharply overlain by the Esk Mudstone. In the Ohara Depression the Esk Mudstone rapidly overlies the Lower Nukumaruan Sentry Box Formation. The Sentry Box Formation contains a molluscan macrofauna consistent with an inner shelf environment of deposition. At Jumped Up Stream, Esk Mudstone approximately 1 m above the Sentry Box Formation contains a 0.1 m-thick shellbed containing a diagnostic upper-bathyal molluscan fauna (Beu 1995). In the Tutaekuri River the Esk Mudstone overlies non- to marginal-marine conglomerate facies of the Grassy Knoll Conglomerate Member, as it does in the Mangaone and Esk Rivers. Haywick (pers. comm. 2002) reported observing redeposited sandstone beds in the lower parts of the Esk Mudstone in the Esk River, and Kamp (pers. comm. 2006) has observed turbidites in the Esk Mudstone in the Waikoau River cliffs. It is inferred that the lower Esk Mudstone records a period of rapid and significant deepening across the study area a short time into the Lower Nukumaruan. The timing of this deepening is marked by the age of the top of the Grassy Knoll Conglomerate Member and appears to have occurred at c. 2.36 Ma.

Stratigraphic position of the "Matapiro Limestone" and "Puketautahi Limestone"

The Matapiro Limestone was introduced by Beu (1995) for an Upper Nukumaruan limestone cropping out in the Matapiro and Okawa areas. Many studies of Hawke's Bay limestones, including Hood (1993), Beu (1995), Caron (2002), Caron *et al.* (2003; 2004a, b), Nelson *et al.* (2003), and Baggs (2004), have analysed the well-exposed Upper Nukumaruan (Late Pliocene-Early Pleistocene) limestone-dominated section cropping out on Ohiti Road (V21/300733). These studies have all included the two limestone units here, separated by several metres of fine-grained

tephric calcareous mudstone, in the Matapiro Limestone. The succession exposed on Ohiti Road clearly comprises two sedimentary cycles. Geological mapping in this study demonstrates that the lower limestone, a prominently cross-stratified unit, is laterally equivalent to the Waipatiki Limestone Member cropping out in surrounding hills and road cuttings. The overlying mudstone interval is equivalent to the Devils Elbow Mudstone Member, and the upper limestone is equivalent to the basal beds of the Kaiwaka Formation. In *no* known location does the Waipatiki Limestone Member contain multiple cycles, and it is viewed that previous studies of the Ohiti Road section may have stratigraphically misinterpreted this section. The siltstone overlying the basal cross-stratified limestone is included here in the Devils Elbow Mudstone Member. This siltstone is sharply overlain by a prominent *Tawera*-dominated shellbed, similar to the shellbed that marks the base of the Kaiwaka Formation in the Devils Elbow section. On the basis of stratigraphic position, basal contact nature, and lithology, this shellbed is therefore assigned to the Kaiwaka Formation, as are the overlying siltstone, sandstone, and limestone beds. The upper limestone bed (not exposed in the Ohiti Road succession) had previously been assigned to the Puketautahi limestone (informal, Kingma 1971) and Puketautahi Limestone (formal, Beu 1995). Based on stratigraphic position it is assigned to the Kaiwaka Formation and named Puketautahi Limestone Member. It represents the stratigraphically highest unit in the Mangaheia Group south of the Napier-Taupo Road (Fig. 3.12).

Distribution of the Matahorua Formation, and relationship to conglomerates in the Ohara Depression

Matahorua Formation is a distinctive stratigraphic unit in the Upper Mangapanian-Lower Nukumaruan part of the basin fill. The formation contains a succession of up to four greywacke conglomerate beds each up to 15 m thick that crop out from the Waiwhare area in the south to at least as far north as Willowflat Road. These conglomerates are inferred to represent progradation of a fluvial braid-plain across central parts of Hawke's Bay during periods of sea level lowstand. In the most down-dip parts of outcrop highly fossiliferous conglomerates occur and are inferred to mark the position of the lowstand shoreline (e.g. Kaiwaka Stream (V20/366052), Esk River (V20/378067)). The conglomeratic succession of the Matahorua Formation is at its thickest in the Te Pohue and Patoka areas around the Mangaone River, Glengarry Forest, and Esk River. Southwest and northeast of these areas conglomerate beds of the formation progressively pass into sandstone and mudstone facies of the Esk Mudstone and Waipunga Formation. Down-dip, the Matahorua Formation is inferred to pass into the Taradale Mudstone. The distribution of each conglomerate bed in the Matahorua Formation differs. The lowermost conglomerate, part of the Deep Stream Member, is the least widely distributed. At Willowflat Road in the northeast of the study area only the two middle conglomerates (part of the Trelinnoe and Papakiri Members) can

be differentiated. In the Sherenden area only the uppermost member (Grassy Knoll Conglomerate Member) of the Matahorua Formation occurs, although shallow-marine sandstone beds equivalent to conglomerates in the Trelinnoe and Papakiri Members can be differentiated. The conglomerate at the base of the Papakiri Member contains the lowest occurrence of the basal Nukumaruan index pectinid *Phialopecten triphooki* and is therefore laterally equivalent at least in part to the lower Sentry Box Formation. The Grassy Knoll Conglomerate Member also contains *P. triphooki* and is inferred to be a lateral equivalent of Lower Nukumaruan formations such as the lower Mason Ridge Formation, Scinde Island Formation, and Sentry Box Formation.

McLennan (1990) correlated conglomerates in the Te Pohue region (Matahorua Formation) directly with conglomerates cropping out in Poporangi and Ohara Streams in the Ohara Depression (Kikowhero and Whakamarumaru Members, Okauawa Formation). This study clearly demonstrates that conglomerates cropping out in these two areas are *not* lateral equivalents (Fig. 3.15 A-F). Conglomerate beds of the Matahorua Formation cropping out around Te Pohue are probably equivalent to the uppermost Puketitiri Formation (in the Ohara Depression), Sentry Box Formation and possibly Mount Mary Pebbly Limestone in the Ohara Depression. Conglomerates in the Okauawa Formation (parts of the Kikowhero and Whakamarumaru Members) are inferred lateral equivalents, based on stratigraphic position, of conglomerates in the Tutira Member and Darkys Spur Member (Tararere Conglomerate Bed), Petane Formation (Fig. 3.15).

Relationship between the Mason Ridge Formation, the Matapiro Syncline, and the Kereru district

South of the Ngaruroro River, in the Maraekakaho area, rocks of Lower Nukumaruan age form the southward-trending hill country known as Mason Ridge. These beds are assigned to the Mason Ridge Formation and face Upper Nukumaruan limestone and siltstone beds cropping out on the north side of the river. The distribution of the Mason Ridge Formation has recently been mapped by Dyer (2005). Rocks on the north side of the Ngaruroro River have been mapped by Baggs (2004). It is inferred that these two areas are separated by a significant fault, named here the Ngaruroro River Fault. The presence of a fault in this part of the basin was inferred by Kingma (1971) and Beu (1995). Mason Ridge Formation is restricted to the Mason Ridge area, the presence of which is inferred to record the location of a Lower Nukumaruan structural high. Mason Ridge Formation comprises three cycles of Lower Nukumaruan age. The age is constrained by the occurrence of *Phialopecten triphooki* in all three limestone members of the formation (Dyer 2005). This means that Mason Ridge Formation is laterally equivalent to the Scinde Island and Sentry Box Formations, the Pakipaki Limestone, and the conglomerate members of the Matahorua Formation. The distribution of the Mason Ridge Formation appears

restricted to the area of Mason Ridge, a series of southward-trending structurally-controlled ridges inferred to be cored by reverse faults. It is probable that the formation accumulated on a series of structural highs during the Lower Nukumaruan, on a transgressive seafloor bathymetrically above any significant input of siliciclastic sediments. Although age equivalent to many other stratigraphic units, it is preferred to maintain the Mason Ridge Formation as a distinct formation due to its well-constrained geological distribution, distinctive cyclothemic character, and lack of continuation with other Lower Nukumaruan formations. The Taradale-1 and Kereru-1 drillhole records demonstrate that the formation does not crop out in the subsurface in these areas, and is therefore not continuous with either the Sentry Box Formation, Pakipaki Limestone, Scinde Island Formation, or Matahorua Formation conglomerate beds.

A conclusion of this study is that limestone units facing each other across the Ngaruroro River near Roys Hill are of different ages. The Ngaruroro River Fault separates Upper Nukumaruan Tangoio Limestone Member, Waipatiki Limestone Member (Petane Formation), and Puketautahi Limestone Member (Kaiwaka Formation) on the north side from Lower Nukumaruan limestones of the Mason Ridge Formation on the southside. Another fault between Roys Hill and Mason Ridge separates Mason Ridge Formation from "middle" Nukumaruan Park Island Limestone Member (Petane Formation). The Ngaruroro River Fault also separates Park Island Limestone Member from the Tangoio, Waipatiki, and Puketautahi Limestone Members. In this area the Ngaruroro River deviates abruptly from its southeast course to a northeast course (around V21/ 212670). It is inferred that the Ngaruroro River Fault is also acting to control the course of the river in this reach.

Resolving the stratigraphic position of Scinde Island Formation

The stratigraphic position of the Scinde Island Formation has been a matter of contention since the geology of Scinde Island was first documented by Buchanan (1870). Scinde Island Formation underlies the prominent topographical feature at Napier city in the form of Scinde Island, now known as Bluff and Hospital Hills.

Correlations in the past have linked Scinde Island Formation with Park Island Limestone Member (Kingma 1971), the lowermost limestone bed (Mahana Limestone Member) at Mason Ridge (Beu 1995), and limestones cropping out in the hills above Te Pohue (e.g. McKay 1877a, b, 1886a, b; Hutton 1886; Hill 1887). Scinde Island Formation is assigned a confident Lower Nukumaruan age on the basis of macro- and microfossil content (Beu 1995), with lower parts of the formation the type locality for *Phialopecten triphooki* (Zittel), a scallop whose presence indicates Lower Nukumaruan time. The presence of *P. triphooki* indicates that limestones at Scinde Island are

significantly younger than the uppermost Opoitian-Waipipian age for the Titiokura Formation, and the uppermost Waipipian-Mangapanian age for the Te Waka Formation at Te Pohue. The Titiokura and Te Waka Formations contain pectinids ancestral to *P. triphooki*, namely *P. marwicki* (Upper Opoitian to Waipipian in eastern North Island, Beu (1995)) and *P. thomsoni* (Mangapanian), respectively. Likewise, the occurrence of *P. triphooki* also indicates that Scinde Island Formation is clearly older than the age demonstrated for Park Island Limestone Member based on that member's lack of *P. triphooki*, stratigraphic position, and other biostratigraphic indicators. Beu (1995) correlated the lower beds at Scinde Island to the lowermost of the three limestone beds (Mahana Limestone Member) in Mason Ridge Formation at Mason Ridge on the basis of the occurrence of *P. triphooki* in both of these units. He assumed that the upper two limestone beds at Mason Ridge lacked *Phialopecten* and assigned them "middle" and "upper" Nukumaruan ages as a consequence. Both Caron (2002) and Dyer (2005) have collected *P. triphooki* from both the lowest and highest limestones at Mason Ridge, indicating that all three beds are in fact of probable Lower Nukumaruan age. Clearly, Beu's restriction of the name "Scinde Island Limestone" to only the lowermost limestone at Mason Ridge based on his reported *Phialopecten* occurrence is not supportable. As the records of Taradale-1 and Whakatu-1 drillholes have demonstrated, Scinde Island Formation and Mason Ridge Formation are not laterally continuous in the subsurface, and it is preferred to maintain them as separate formations, although they do appear to have accumulated at similar times under similar conditions on fault-bounded structural highs. The presence of such a paleohigh beneath Scinde Island Formation is illustrated by the siting of the hydrocarbon exploration hole Hukarere-1 at Napier Port, which targeted an anticlinal structure associated with the adjacent subsurface Napier Fault (Enclosure 3; Westech Energy New Zealand Ltd 2001, PR2656). This anticline was clearly active in the Lower Nukumaruan.

Although no limestone facies were intercepted in Taradale-1, a regional council water well at Onekawa (near Scinde Island) intercepted a lens of limestone at moderate depth (A. Beu, GNS Science pers. comm. 2004). This demonstrates that Scinde Island Formation is not laterally continuous beneath the wider Napier and Taradale areas. The conclusion of this study is that Scinde Island Formation is effectively a large lens of limestone that prior to erosion interfingered with the Taradale Mudstone, and is geographically restricted to a small area around Scinde Island and Napier city. Its current distribution reflects uplift and deformation caused by the subsurface Napier Fault, the trace of which lies immediately west of Scinde Island. The Lower Nukumaruan age of the Scinde Island Formation demonstrates that it was deposited concomitantly with conglomerate facies of the Matahorua Formation, and thick limestone beds adjacent to the axial ranges and locally in the axis of the forearc basin. Conglomerate facies of the Matahorua Formation crop out only 20 km from Scinde Island and the presence of thick, non-marine fluvial

deposits in the Matahorua Formation must have meant that significant volumes of siliciclastic sediment were being fed into a paleo-Hawke Bay. The fact that the Scinde Island Formation could accumulate during this time suggests that some form of structural high existed in the Scinde Island area, upon which carbonate factories could develop. This situation appears to be typical of other Lower Nukumaruan limestones in the study area, such as those in the Pakipaki Limestone and Mason Ridge Formations which are also currently cropping out in association with topographic highs.

Relating the stratigraphy of Beu (1995) to the current Mangaheia Group - a summary

Beu (1995), in a major stratigraphic investigation involving the Hawke's Bay region, attempted to reconcile the stratigraphic relationships between carbonate-dominated rocks of Late Miocene-Early Pleistocene age throughout eastern North Island. This work was undertaken in association with a revision of Late Neogene pectinid biostratigraphy in eastern North Island, and its use in determining the stratigraphy of East Coast Basin successions. The study of Beu (1995) was significant as it firstly updated stratigraphic knowledge of eastern North Island, but more importantly it updated knowledge about the lineage of many genera of pectinids (e.g. *Phialopecten, Mesopeplum, Sectipecten*) and other biostratigraphically-important molluscan macrofauna, such as *Pelicaria* spp.

Beu (1995) formally defined many new groups, formations, and members for limestones in eastern North Island, commonly formalising long-used but otherwise informal names for stratigraphic intervals. During the course of this current research it has become necessary to re-evaluate the stratigraphy of Beu (1995) and to emend it where appropriate (Fig. 3.20). A key finding is that many of the stratigraphic units defined by Beu are duplicated in different parts of the basin, which was not apparent to him as there was no geological mapping in his work. Many sections in this chapter have discussed proposed changes to this stratigraphy based on detailed new mapping and correlations. The lithostratigraphy established by Beu (1995), however, remains the most modern published record of the basin fill, and was adopted in the Cretaceous-Cenozoic Project (CCP) bulletin of the East Coast Basin by Field *et al.* (1997).

Revision of Beu's stratigraphy is most apparent in the Nukumaruan part of the basin record. This section of the chapter discusses how the stratigraphy established by Beu (1995) relates to the stratigraphy defined in this study (Fig. 3.20).

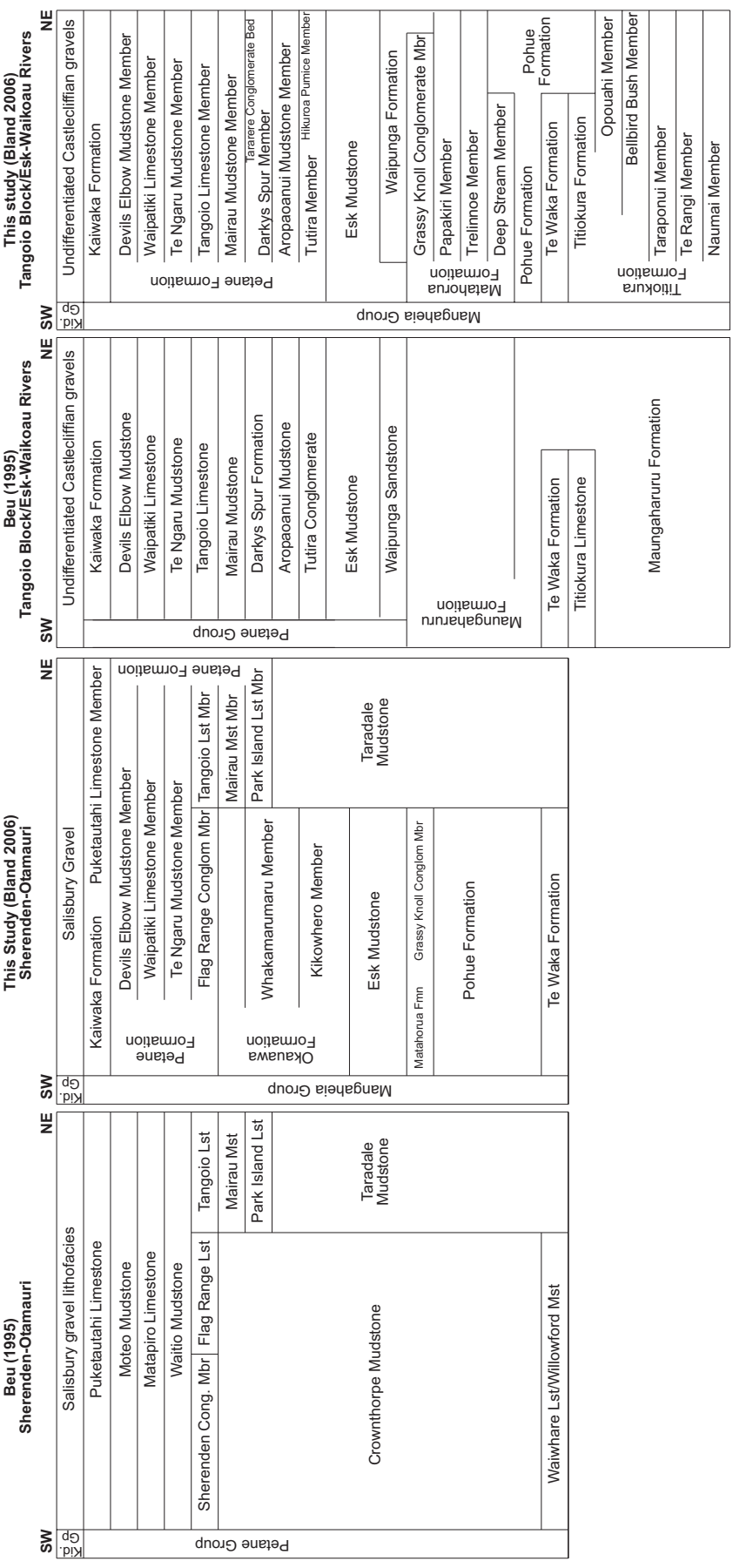


Fig. 3.20: Comparison of the stratigraphy of Beu (1995) and that proposed in this study for the Sherenden-Otamauri and Tangoio Block areas.

Summary of revision of Beu (1995) stratigraphy

Kapitean to Mangapanian stratigraphy

All formations defined and mapped by Beu (1995) in the study area are now incorporated in the Mangaheia Group. This has had the result of simplifying the number of lithostratigraphic groups from four to one. Reasons and justifications for abolishing Beu's group names are provided elsewhere in this chapter and in Appendix I. He renamed the Blowhard Formation of Browne (1981, 1986) the informal Owhakao limestone; it is returned to Blowhard Formation in this study. The lower limestone-bearing part of the Maungaharuru Formation of Beu is now mapped as Titiokura Formation, and five members have been formally defined within it (Naumai, Te Rangi, Taraponui, Bellbird Bush, and Opouahi Members) (Bland *et al.* 2004). Middle and upper parts of the Maungaharuru Formation are now mapped as Pohue and Matahorua Formations.

Nukumaruan stratigraphy

Beu (1995) defined new nomenclature for much of the Nukumaruan stratigraphy in the study area, particularly that portion with limestone beds. This stratigraphy included previously defined formations (mostly from Beu and Edwards (1984) and Haywick *et al.* (1991)) together with many new groups, formations, and members, as summarised in Fig. 3.20. Beu (1995) subdivided the Nukumaruan stratigraphy in central parts of Hawke's Bay into three areas and developed a separate stratigraphy for each, while suggesting possible correlations across the areas. Geological mapping in this study has demonstrated a clear continuum between stratigraphic units in each of Beu's three outcrop areas. This has the result of simplifying the stratigraphy of the region by removing redundant names, as well as improving the understanding of the paleogeography and geological evolution of the area as a whole. The Poporangi, Napier, and Petane Groups of Beu (1995) are now all included into the Mangaheia Group. It is also suggested that his Hawke's Bay Group be incorporated into the Mangaheia Group, although detailed analysis of Hawke's Bay Group rocks is beyond the scope of this current study. The Tutira, Aropaoanui, Darkys Spur, Mairau, Tangoio, Te Ngaru, Waipatiki, and Devils Elbow formations of Beu's Petane Group are now all mapped as members of the Petane Formation. The Waipunga, Esk, and Kaiwaka Formations, also part of Beu's Petane Group, are retained as discrete formations, though now within the Mangaheia Group. Flag Range Limestone and Sherenden Conglomerate Member of Beu (1995) are mapped together as the Flag Range Conglomerate Member (Petane Formation). The Puketautahi Limestone of Beu (1995) is included here as a member of the Kaiwaka Formation (Puketautahi Limestone Member). The Whanawhana Limestone and Seconds Ridge conglomerate (informal) are mapped as Sentry Box Formation, with the Seconds Ridge Conglomerate now defined as a member. Crownthorpe Mudstone is included in both the Okauawa Formation and Mairau Mudstone Member. The Ohara Mudstone is now incorporated into the Esk Mudstone. The Matapiro Limestone is now mapped as part of the Waipatiki

Limestone Member. Willowford Mudstone is included in the Esk Mudstone. Park Island Limestone is emended to Park Island Limestone Member, and included as part of the Petane Formation. Waitio Mudstone is now mapped as Te Ngaru Mudstone Member and the Moteo Mudstone is now mapped as Devils Elbow Mudstone Member.

KIDNAPPERS GROUP

Kidnappers Group is the stratigraphically highest lithostratigraphic group in the study area, and records the emergence of much of the study area from a marine environment into a terrestrial one during the Middle to Late Pleistocene (Early Quaternary). The definition of Kidnappers Group is extended in this study to incorporate all rocks of Castlecliffian age cropping out in the study area (Fig. 3.3).

HISTORICAL NOMENCLATURE

Kidnappers Group is named after Cape Kidnappers at the southern end of Hawke Bay. Kingma (1971) formalised the long usage of the name “Kidnappers” in reference to the well-exposed section between Clifton and Black Reef. The name itself was introduced by Hill (1887) who referred to the strata in this area as the Kidnapper Beds or Kidnappers Section, and in 1891 as the Kidnapper Conglomerates and the Kidnapper Pumice and Conglomerate Beds. The definition of Kingma (1971) is retained, and extended to incorporate the prominent thick Castlecliffian gravel beds cropping out adjacent to the northern Ruahine and Wakarara Ranges (Erdman and Kelsey 1992). These more westerly beds are inferred to represent proximal non-marine equivalents of the marginal-marine strata exposed in the Clifton-Black Reef Section (Beu 1995).

OUTCROP AND SUBCROP GEOMETRY

The Kidnappers Group mostly crops out in two widely separated areas, those being the Salisbury Terraces at Kereru in the west, and the Maraetotara Plateau and Cape Kidnappers area in the east (Fig. 3.3). Isolated thin veneers of Castlecliffian gravels crop out in central parts of the study area, particularly above rocks of Nukumaruan age. The Salisbury Gravel dips gently to the east and are relatively undeformed by post-depositional faulting and folding. Beds cropping out in the Kidnappers section dip northwest, forming the eastern limb of the Napier Syncline and lie to the west of the Kidnappers Anticline. Beds in the Kidnappers section are commonly cut by normal faults as part of the eastern contractional domain (see Chapter Five, p. 173). Throw on these faults is usually less than 10 m and reverse faults are uncommon. Some remnants of Kidnappers Group rocks have been lifted to significant elevations, particularly those on the crest of hills in the

Mason Ridge and Dartmoor areas. Kidnappers Group crops out sporadically in coastal areas, such as at Scinde Island, Petane Corner, and Whirinaki Bluff. Thick gravels overlying the Opoitian-aged (Early Pliocene) Pakaututu Formation in the Ripia River area may be of Castlecliffian age (and therefore Kidnappers Group), although their age cannot be confirmed.

Two hundred and thirty-two metres of Kidnappers Group was intercepted in Whakatu-1 drillhole where it unconformably overlay Taradale Mudstone of Mangapanian age (Ozolins and Francis 2000). No Kidnappers Group was intercepted in other nearby exploration wells (e.g. Hukarere-1, Mason Ridge-1, and Kereru-1). Although no Kidnappers Group rocks were intercepted in Taradale-1 (Darley and Kirby 1969), steeply-dipping beds of undifferentiated Kidnappers Group crop out nearby at Waiohiki in a small outlier beside the Tutaekuri River.

LITHOSTRATIGRAPHIC OVERVIEW

Kidnappers Group unconformably overlies the Mangaheia Group (Fig. 3.3). The Salisbury Gravel forms a series of high-level terraces east of Kereru and the Wakarara Range in the southwest of the study area. The base of the Salisbury Gravel is marked by a thick ignimbrite that unconformably overlies the Poutaki Formation (Mangaheia Group). This ignimbrite was inferred to be the Kidnappers Ignimbrite by Kamp (1990) and Wilson *et al.* (1995).

The Salisbury Gravel is therefore of comparable age to Kidnappers Group rocks of marginal-marine origin cropping out in the coastal section between Clifton and Black Reef at the southern end of Hawke Bay, and probably are deposits from the fluvial systems that fed the Cape Kidnappers area with siliciclastic sediment.

Beds in the Kidnappers section have been subdivided into several stratigraphic intervals (e.g. Kingma 1971; Kamp 1978), but for the purposes of this study they have been mapped as undifferentiated Kidnappers Group. In the Kidnappers section the basal formation of the Kidnappers Group is the Maraetotara Sandstone which overlies the Waipipian (Late Pliocene) Black Reef Calcareous Sandstone across an angular unconformity. The base of the highly fossiliferous Maraetotara Sandstone contains examples of reworked macrofauna from the underlying Black Reef Calcareous Sandstone, including highly abraded fragments of the "early to middle" Pliocene-restricted pectinid *Phialopecten marwicki*.

LATE QUATERNARY DEPOSITS

Late Quaternary deposits are thickest and best developed beneath the Heretaunga Plains where the Ngaruroro and Tutaekuri Rivers enter their braidplains, although they also occur throughout the study area (Fig. 3.3). Late Quaternary deposits are 75 m thick in Whakatu-1 drillhole (Ozolins and Francis 2000) and 45 m thick in Taradale-1 (Darley and Kirby 1969). Hukarere-1 drilled through approximately 8 m of reclamation fill and no Late Quaternary sediments (Westech Energy New Zealand Ltd 2001). Extensive sets of elevated terraces are well developed in the Ohara Depression and Kereru areas where they are underlain by greywacke gravels. Flights of well-developed terraces are also present in the lower reaches of the Waikare River.

SUMMARY

This study proposes significant revision to the lithostratigraphy of central parts of Hawke's Bay based on new detailed geological mapping and section description, in an attempt to simplify a confusing and unwieldy stratigraphy. Revision of lithostratigraphic nomenclature is most apparent in the Nukumaruan part of the basin record. Where possible, previously defined groups, formations, and members have been extended into the study area in an attempt to work towards a more unified regional lithostratigraphy.

It is proposed that all Early Pliocene-Early Pleistocene rocks in central and northern Hawke's Bay be incorporated in the Mangaheia Group. These beds are underlain by a geographically expanded Early Miocene-Early Pliocene Tolaga Group (after Mazengarb *et al*. 1991), and overlain by the Middle Pleistocene (Middle Castlecliffian) Kidnappers Group (after Kingma 1971). Expanding the Tolaga Group into central Hawke's Bay incorporates formations that have previously been part of no stratigraphic group. Expanding the Mangaheia Group into central Hawke's Bay reduces the number of Early Pliocene-Early Pleistocene lithostratigraphic groups from four to one.

Beu (1995) defined new nomenclature for much of the Nukumaruan stratigraphy in the study area, particularly that portion with limestone beds. This stratigraphy included previously defined formations (mostly from Beu and Edwards (1984) and Haywick *et al*. (1991)) together with many new groups, formations, and members, as summarised in Fig. 3.20. Beu (1995) subdivided the Nukumaruan stratigraphy in central parts of Hawke's Bay into three areas and developed a separate stratigraphy for each, while suggesting possible correlations across the areas. Geological mapping in this study has demonstrated a clear continuum between stratigraphic units in each of Beu's three outcrop areas. This has resulted in the simplification of stratigraphy in

central Hawke's Bay by removing redundant names, as well as improving the understanding of the paleogeography and geological evolution of the area as a whole. The Petane, Poporangi, and Napier Groups are included in the Mangaheia Group, and the names "Poporangi" and "Napier" abandoned. "Petane" is retained as a formation name. Although detailed analysis of Hawke's Bay Group rocks is beyond the scope of this current study it is also suggested that the Hawke's Bay Group be incorporated into the Mangaheia Group and the name "Hawke's Bay" be abandoned.

Kaumatua Formation (after Erdman and Kelsey 1992) has been abandoned as a name, and the rocks within it incorporated as part of the Puketitiri Formation. With the Petane Group demoted to Petane Formation, the Tutira, Aropaoanui, Darkys Spur, Mairau, Tangoio, Te Ngaru, Waipatiki, and Devils Elbow formations of the Petane Group are now all mapped as members of the Petane Formation. Also included in the Petane Formation are the Park Island Limestone and Flag Range Conglomerate Members. The Waipunga, Esk, and Kaiwaka Formations, also part of the former Petane Group, are retained as discrete formations, but now within the Mangaheia Group.

Detailed geological mapping in this study has demonstrated that many formations defined by Erdman and Kelsey (1992) and Beu (1995) are in fact lateral equivalents to formations previously defined by others (such as Haywick *et al*. 1991), and proposes applying these previously existing names to them. The Whanawhana Limestone and Seconds Ridge conglomerate (informal), originally defined by Beu (1995), are now included within the Sentry Box Formation (after Erdman and Kelsey 1992), with the Seconds Ridge Conglomerate defined as a member of that formation. The Ohara Mudstone (after Erdman and Kelsey 1992) and Willowford Mudstone (after Beu 1995) are now incorporated into the Esk Mudstone, and the names "Ohara" and "Willowford" abandoned. Park Island Limestone is emended to Park Island Limestone Member, and included as part of the Petane Formation. Crownthorpe Mudstone (after Beu 1995) is equivalent to both the Okauawa Formation and Mairau Mudstone Member (Petane Formation) and has now been included as such; the name "Crownthorpe" is abandoned. The Flag Range Limestone and Sherenden Conglomerate Member of Beu (1995), lateral equivalents of the Tangoio Limestone Member (as suggested by Beu 1995, and demonstrated in this study), are mapped together as the Flag Range Conglomerate Member (Petane Formation), with the name "Sherenden" abandoned. The Matapiro Limestone is now mapped as part of the Waipatiki Limestone Member, Waitio Mudstone is now Te Ngaru Mudstone Member, and the Moteo Mudstone is now mapped as Devils Elbow Mudstone Member (all part of the Petane Formation), as initially suggested by superposition by Beu (1995). The names "Matapiro", "Waitio", and "Moteo" are all abandoned. The Puketautahi Limestone of Beu (1995) is emended here as the uppermost member of the Kaiwaka Formation (Puketautahi Limestone Member) in the Matapiro area.

CHAPTER FOUR

BIOSTRATIGRAPHY AND AGE

INTRODUCTION

In New Zealand, the Miocene to Recent is subdivided into several local stages (Fig. 4.1), traditionally defined on the basis of foraminiferal and molluscan and bioevents (Fig. 4.2).

The purpose of this chapter is to develop an integrated biostratigraphy and chronostratigraphy for the basin fill. The age control developed is based mostly on the biostratigraphy of molluscan macrofossils, supported where possible by microfossil biostratigraphy, major element composition of tephra and related correlations, and on limited paleomagnetic data.

Because no one section contains all the age datums identified within the study area, stratigraphy and geological mapping provide the correlation framework for the integrated biostratigraphy. This has been facilitated by the many cyclothemic limestone and conglomerate beds cropping out in the study area, especially those in the Late Pliocene-Early Pleistocene part of the basin fill. These prominent mappable horizons allow for regional correlations to be made, and therefore considerable effort has been placed on accurate mapping and correlation of them.

One limitation of using molluscan bioevents for determining a relative stratigraphy in the study area is facies control on their distribution, a factor discussed by McIntyre (2002, p. 115) for Late Pliocene beds in Wanganui Basin. Most biostratigraphically-useful bioevents occur within shellbeds that are present at ~ 20-60 m stratigraphic intervals in cyclothemic strata. They are separated by massive mudstone and sandstone facies that form the bulk of sequences in terms of thickness and inferred time. This means that the location of a stage boundary can be imprecise as the bioevents that mark a particular stage boundary may not have occurred while accumulation of the shellbed took place. A consequence is that stage boundaries could either be placed at the base of the shellbed containing the first occurrence of a new species, or at the top of the preceding shellbed where the last occurrence of an older species occurs. Both the Waipipian-Mangapanian (Wp-Wm) and Mangapanian-Nukumaruan (Wm-Wn) Stage boundaries in this study are placed at the base of the shellbeds containing the lowest occurrence (L.O.) of new species (e.g. L.O. of *Phialopecten thomsoni* and *Phialopecten triphooki/Zygochlamys patagonica delicatula* respectively), and the dual occurrence of lowest and highest (H.O.) occurrences together in the same shellbed (e.g. H.O. *Crassostrea ingens* and *P. thomsoni* with L.O. *P. triphooki* and *Z. delicatula* in the Sentry Box Formation).

While the latest Pliocene-Pleistocene (uppermost Mangapanian-Nukumaruan) part of the basin fill is richly fossiliferous with numerous bioevents, the remainder of the succession is generally sparsely fossiliferous, and bioevents useful for identifying stages in other New Zealand sedimentary basins (e.g. L.O. *P. marwicki*, H.O. *Sectipecten grangei, S. wollastoni*) are unsuitable in central Hawke's Bay. An example of this is *P. marwicki*, which is not known in rocks older than Upper Opoitian in eastern North Island, even though it is important in defining the base of the Opoitian in Wanganui and Taranaki basins.

BIOSTRATIGRAPHY

This part of the chapter describes bioevents that aid the identification of the relative age position of a stratigraphic unit in the basin fill. Only the Tongaporutuan to Nukumaruan part of the basin fill is described in this chapter as this interval is the focus for this study. For further discussion on biostratigraphic events in pre-Tongaporutuan stratigraphy in the study area the reader is referred to Scott *et al.* (1990a), Cutten (1994), and Field *et al.* (1997). Biostratigraphic datums presented here are mostly derived from molluscan macrofossils collected during the course of field work. Macrofossils are common throughout the sedimentary succession, although the Plio-Pleistocene portion of the basin fill in particular contains a richly fossiliferous macrofaunal content. Rapidly evolving macrofauna such as the pectinid genus *Phialopecten*, and gastropoda such as *Austrofusus, Pelicaria,* and *Struthiolaria,* have proven to be very useful taxa for determining Plio-Pleistocene New Zealand stages in the study area.

A limited number of microfossil samples have been collected and analysed during this study, and use has been made of microfossil records from both paleontological reports and the New Zealand Fossil Record File (FRF). Microfossil analysis of the Tolaga Group north of the Napier-Taupo Road was undertaken by Scott *et al.* (1990a). Microfossil samples collected during this study have come from siltstone intervals adjacent to the North Island Shear Belt from Puketitiri to Omahaki.

Tongaporutuan

The Tongaporutuan Stage is the lowest of the Late Miocene New Zealand stages (10.92-6.5 Ma; Crundwell *et al.* 2004). The term was first used informally by Marwick (1924) for the Tongaporutu Formation (series) of Grange (1922) in North Taranaki. Allan (1933) proposed a Taranakian System that included the Tongaporutuan and overlying Urenuian (Urenui Formation). In their final review of the Cenozoic stage classification, Finlay and Marwick (1947) abandoned the Urenuian because of uncertainty about the defining molluscan and foraminiferal criteria, and included it in an expanded Tongaporutuan, the sense in which the stage is used today (Crundwell *et al.* 2004).

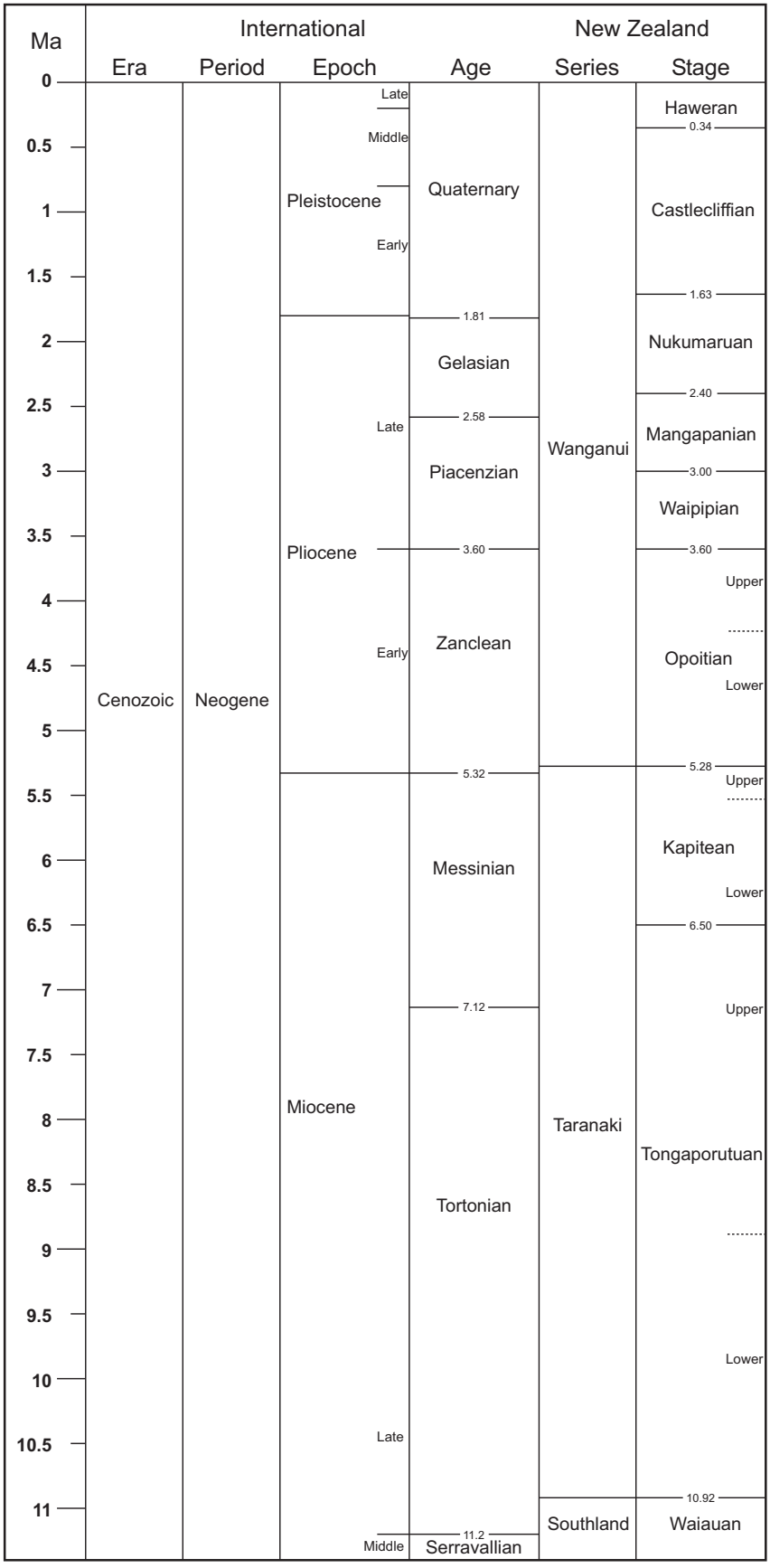


Fig. 4.1: Summary of part of the Neogene geological time scale showing the relationship between international ages and the New Zealand stage classification scheme. Adapted from Cooper (2004).

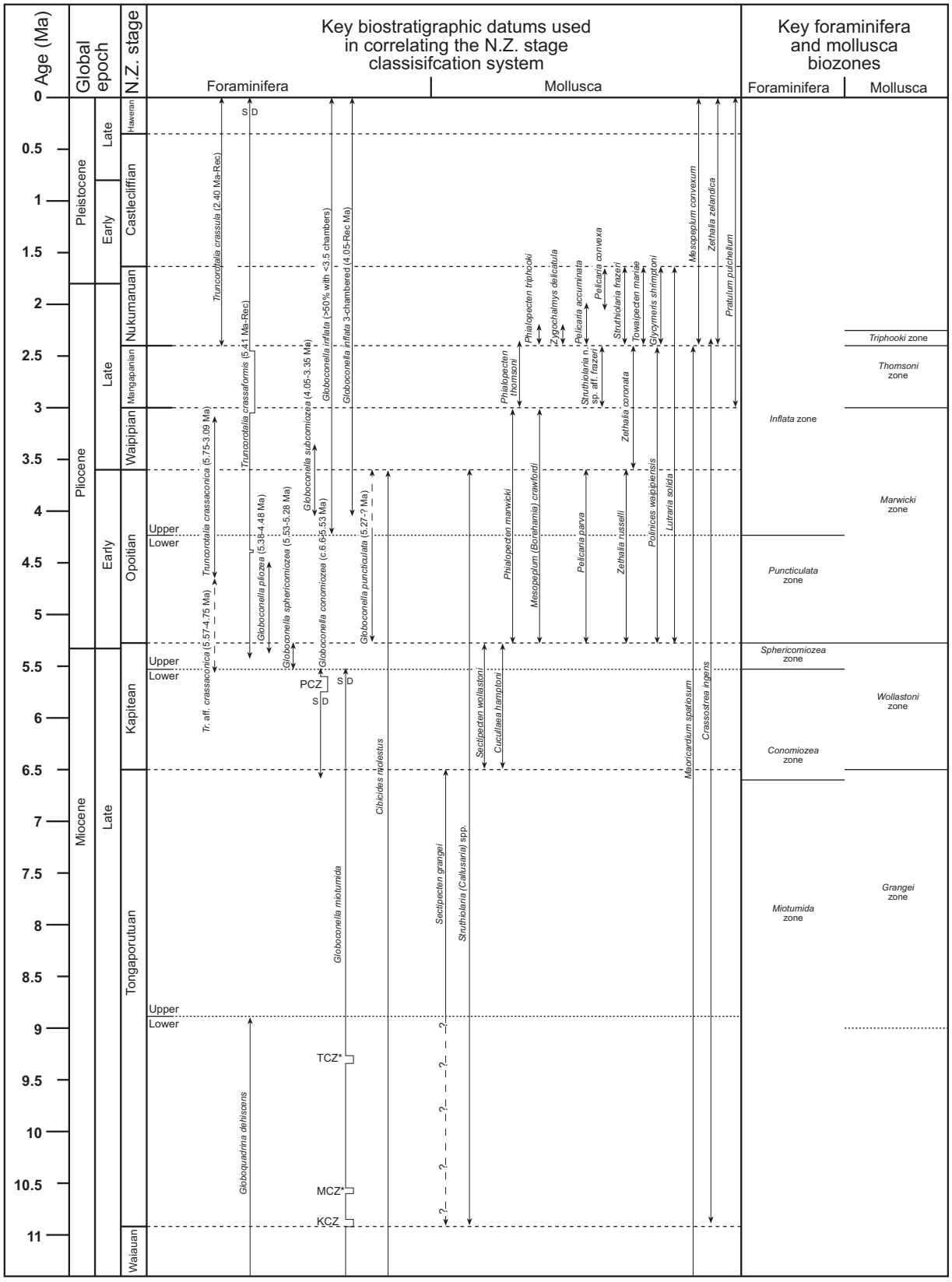


Fig. 4.2: Summary of the New Zealand stage classification system integrated with age ranges of key foraminifera and mollusca of biostratigraphic importance in the Late Miocene to Recent interval. Figure is adapted from Hendy (2002). Fossil age ranges are compiled from Beu and Maxwell (1990), Beu (1995), Beu *et al.* (2004), and Crundwell *et al.* (2004).

The base of the Tongaporutuan is defined by Crundwell *et al.* (2004) as the base of the Kaiti Coiling Zone, a coiling event in populations of the *Globoconella miotumida* foraminiferal lineage. The stratotype for this event is located at Kaiti Beach, Gisborne.

Molluscs

Twenty-one genera of marine molluscs last appear in New Zealand in the Tongaporutuan, although by this time many of them had become too rare to be useful for biostratigraphy, probably due in part to changes in lithofacies (A. Hendy, pers. comm. 2006). Only *Bartrumina, Tropicolpus,* and *Echinophoria* remained moderately common (Crundwell *et al.* 2004). By the Tongaporutuan most of the "middle Cenozoic" warm water genera of New Zealand had become extinct. The evolutionary radiation of scallops from the genus *Mesopeplum* had begun, reflecting selection pressures exerted by temperature change and rapid tectonic changes caused by motion on the plate boundary (Beu 1995). Species last recorded in Tongaporutuan rocks in New Zealand include *Eucrassatella ampla, Circomphalus speighti, Struthiolaria (Callusaria) callosa, Austrofusus gamma, Zelandiella calcarata,* and *Cominella hendersoni.* Restricted species include *Sectipecten grangei, Zeacolpus taranakiensis, Struthiolaria praenuntia,* and *Austrofusus cliftonensis.* Genera first recorded in the Tongaporutuan include *Xenostrobus, Pelicaria,* and *Oenopota.* Species first occurring include *Cucullaea hamptoni, Crassostrea ingens, Pratulum quinarium,* and *Conus hendersoni* (Table 4.1) (Beu and Maxwell 1990; Beu 1995; Crundwell *et al.* 2004).

Most rocks of Tongaporutuan age in the study area are of inferred deep-water (outer shelf to bathyal) origin, and age diagnostic macrofossils are not common. Shallow-water sandstone facies of Tongaporutuan age commonly contain highly fossiliferous concretionary bodies. Macrofauna in them are usually rich in the gastropod genera *Struthiolaria (Callusaria)* and *Struthiolaria (Struthiolaria).* Where molluscan macrofauna are present, the Tongaporutuan Stage in the study area is most easily identified by the presence of the pectinid *Sectipecten grangei.* However, *Sectipecten grangei* is very uncommon in Tongaporutuan rocks in Hawke's Bay, and has only been observed and collected from shallow-water concretionary sandstone beds in the Tutaekuri River in Kaweka Forest Park (Fig. 4.3). Although *Sectipecten* is known in rocks of Waiauan age (*S. diffluxus*), *S. grangei* has not been collected from Lower Tongaporutuan rocks, rather appearing during the Upper Tongaporutuan (Boreham 1961, cited in Hendy 2002, p. 48). This most likely reflects a paucity of shallow-water lithofacies in Lower Tongaporutuan rocks in Taranaki and East Coast Basins.



Fig. 4.3: *Sectipecten grangei* (circled), a Tongaporutuan index scallop in a strongly cemented highly fossiliferous shellbed in the Te Ipuohape Sandstone Member, Tutaekuri River, Kaweka Forest Park. The bulk of the fossiliferous material in this shellbed comprises shellhash and biostratigraphically undiagnostic *Crepidula radiata* and *Patro undatus.*

Table 4.1: List of molluscan taxa most useful for recognising the Tongaporutuan Stage in the study area. Adapted from Beu and Maxwell (1990), Beu (1995) and Crundwell *et al.* (2004). * Denotes taxa of highest biostratigraphic utility and reliability.

Restricted	Last occurrence	First occurrence
*Sectipecten grangei**	*Serripecten*	*Cucullaea (Latiarca) hamptoni*
	Bassina speighti	*Crassostrea ingens*
	Tropicolpus	*Pratulum quinarium*
	*Penion crawfordi**	
	*Struthiolaria (Callusaria) callosa**	

Foraminifera

The base of the Tongaporutuan is defined as the base of the Kaiti Coiling Zone (coiling direction change in *Globoconella miotumida*), which lies in close proximity to the lowest New Zealand occurrences of the *Bolivinita quadrilatera* group and the highest common occurrence of *Neogloboquadrina mayeri s.l.* (as defined by a 5% abundance threshold) (Crundwell *et al.* 2004). The Tongaporutuan Stage is characterised by populations of *Globoconella miotumida* (Jenkins 1967). Members of the foraminiferal genus *Bolivinita* have been used to subdivide the Tongaporutuan into biozones. *Bolivinita quadrilaterata, B. pohana,* and *B. compressa* were inferred to relate to the lower, middle, and upper Tongaporutuan respectively (Hornibrook *et al.*

1989). However, these events do not always maintain consistent homotaxial order, and the tripartite subdivision cannot generally be recognised in shallow shelf or deep-bathyal environments (Crundwell *et al.* 2004). The regional disappearance of the warm water planktic foraminifer *Globoquadrina dehiscens* has been used to subdivide the Tongaporutuan into upper and lower parts (Scott 1992), and is useful in the study area.

Micropaleontology samples U20/f150 and V20/f442 (Appendix V) were collected from Tongaporutuan rocks during this study. They contain typical planktic and benthic foraminifera, including *Globoconella miotumida, Neogloboquadrina pachyderma, Bolivinita* c.f. *pliobliqua,* and *B. pohana*. The relative abundance of *Globigerinoides* and the apparent absence of *Globoquadrina dehiscens* in V20/f442 led M. Crundwell (pers. comm. 2004) to suggest an age of 8.8-8.0 Ma for this sample.

The two Tongaporutuan samples analysed in this study compliment microfossil analysis of samples from Tongaporutuan rocks in the north of the study area by Scott *et al.* (1990a) and B.D. Field (Fossil Record File data). The presence of *Bolivinita pohana* in poorly preserved, low-diversity foraminiferal assemblages near the base of the Te Ipuohape Sandstone Member, and of *Globoquadrina dehiscens* in higher levels, indicated Lower Tongaporutuan deposition for this unit (Scott *et al.* 1990a; Cutten 1994). The absence of *Globoquadrina dehiscens* in middle and upper beds of the Waitere Formation supported deposition during the post-Lower Tongaporutuan (Cutten 1994).

Kapitean

The Kapitean is the uppermost of the New Zealand Miocene stages (6.5-5.28 Ma). The Kapitean lies within a distinct latest Miocene and earliest Pliocene faunal interval during which there were fluctuating values of $\delta^{18}O$ and $\delta^{13}C$ on a scale comparable to the Pleistocene (Crundwell *et al.* 2004).

The Kapitean Stage was first defined by Finlay and Marwick (1947), with a brief description of the type locality at Kapitea Creek in Westland. They defined the base of the stage as being marked by the L.O. of the scallop *Sectipecten wollastoni,* and also *Austrofusus tuberculatus* (=*A. coerulescens*). The molluscan biostratigraphy on which the Kapitean Stage is based (e.g. *Sectipecten wollastoni*) is confined to neritic facies, with foraminifera used more commonly for stage identification in deep-water successions (Crundwell *et al.* 2004).

Molluscs

The Kapitean Stage includes the last records in New Zealand of typical Miocene genera, such as *Cucullaea, "Lentipecten"* (new genus, Beu and Maxwell (1990)), *Kuia, Notocorbula, Falsicolus,* large species of *Cypraea* and *Conus,* and the nautiloid *Aturia* (Crundwell *et al.* 2004). Molluscs restricted to the Kapitean include *Sectipecten wollastoni* and *Phialopecten tolagaensis.* First occurrences recorded in New Zealand during the Kapitean include the bivalves *Ostrea chilensis, Patro undatus, Dosinia (Kereia) greyi, Maorimactra chrydaea,* and *Marama murdochi,* the gastropod *Struthiolaria (Callusaria) obesa,* and the scaphopod *Antalis pareoraensis* (Table 4.2) (Beu and Maxwell 1990; Beu 1995; Crundwell *et al.* 2004).

Kapitean rocks crop out over limited extent in the study area, and are generally non to sparsely fossiliferous. This makes field-based identification of Kapitean beds difficult. The Waikarokaro Sandstone Member (Blowhard Formation) in the Kuripapango region does contain a sparse to moderate molluscan macrofauna including the Kapitean index scallop *Sectipecten wollastoni* and also *Maorimactra chrydaea.* Kapitean rocks in the study area may also contain *Struthiolaria (Callusaria)* spp., although no species in this genus are restricted to the Kapitean in the study area. Where both micro- and macrofossils are absent, or age diagnostic species are lacking, identification of Kapitean beds has mostly been based on stratigraphic position.

Table 4.2: Molluscan taxa most useful for recognising the Kapitean Stage in the study area. The list is adapted from Beu and Maxwell (1990), Beu (1995), and Crundwell *et al.* (2004). * Denotes taxa of highest biostratigraphic utility and reliability.

Restricted	Last occurrence	First occurrence
*Sectipecten wollastoni**	*Mesopeplum (M) burnetti**	*Trachycardium (Ovicardium)**
*Phialopecten tolagaensis**	*Cucullaea**	*Aneator (Aneator)*
	*Kuia**	*Eumarcia (Atamarcia) benhami*
	*Notocorbula**	*Dosinia (Kereia) greyi*
		Patro undatus
		Atrina pectinata zelandica
		Ostrea chilensis
		*Maorimactra chrydaea**
		*Struthiolaria (Callusaria) obesa**
		*Hartungia typica**

Foraminifera

A paucity of foraminiferal events near the base of the Kapitean Stage reflects a period of relatively stable oceanic conditions and evolutionary stasis amongst planktic foraminifera (Crundwell *et al.* 2004). This is a characteristic feature of global planktic zonations in the period prior to the Mediterranean salinity crisis (e.g. Berggren *et al.* 1995).

The lowest occurrence of the planktic foraminifera *Globoconella conomiozea* is most commonly used as a Kapitean Stage indicator, although it is subject to taxonomic uncertainty (Crundwell *et*

al. 2004). Some biostratigraphers consider it to be a Late Miocene anageneitc derivative of *Globoconella miotumida* (e.g. Kennett 1966; Malmgren and Kennett 1981; Crundwell *et al.* 2004), whereas others consider it to be a reduced-chambered intraspecific variant within the normal variation field of *Globoconella miotumida* (e.g. Scott *et al.* 1990b).

No microfossil analysis has been undertaken on rocks of Kapitean age during this study. Scott *et al.* (1990a) and Cutten (1994) undertook microfossil analysis of the Tolaga Group succession in the north of the study area where they sampled the upper beds of the Waitere Formation (upper part of Rakaita Siltstone Member) and the lower Mokonui Sandstone. Sample V19/f80 from upper parts of the Rakaita Siltstone Member near The Organs was assigned a Kapitean age based on the presence of *Bolivinita pliozea* and *Globoconella miotumida* (Scott *et al.* 1990a). Collections V19/f46, f47 and f113 from the Mokonui Sandstone in the Mohaka River section contained poorly preserved variants of *G. miotumida*. Some individuals with elevated umbilical faces (axial orientation) resembled *conomiozea* morphotypes, and other small, compact specimens resembled *G. puncticulata sphericomiozea*. A peripheral keel was observable on adequately preserved specimens, and this population was assigned to *G. miotumida*. These three collections were dated as Lower Kapitean, possibly adjacent to the Upper Kapitean datum marked by the entry of *G. puncticulata sphericomiozea* (Scott *et al.* 1990a).

Opoitian

The Opoitian is the first of the Pliocene New Zealand stages (5.28-3.60 Ma; Beu *et al.* 2004). Opoitian rocks in New Zealand are similar to those of the Kapitean and Waipipian Stages in their relatively wide variation in both lithology and thickness. The name Opoiti "series" (i.e. formation) was proposed by Ongley (1928, p. 7) for a 1050 m-thick succession between Late Miocene and "Waitotoran" strata in the area inland from Wairoa, northern Hawke's Bay. The Opoitian Stage was proposed by Finlay (1939, p. 530) for this Early Pliocene succession (quoted by Fleming 1959, p. 280), and was characterised by its foraminiferal fauna. The stage was adopted and more fully defined by Finlay and Marwick (1940) (Beu *et al.* 2004).

Molluscs

Twelve molluscan genera are first recorded in New Zealand during the Opoitian, including *Dosinia (Phacosama), Zygochlamys, Protothaca, Irus (Notirus),* and *Zethalia.* According to Cooper (2004), common and widespread species first recorded in New Zealand during the Opoitian include *Perna canaliculus, Phialopecten marwicki, Mesopeplum (Borehamia) crawfordi, Pteromyrtea dispar, Lutraria solida, Maoricolpus roseus, Zeacolpus vittatus, Polinices waipipiensis,* and *Austrofusus pagoda* (Table 4.3). Most "typical" Miocene molluscs (e.g. *Cucullaea*) became extinct at the end of the Kapitean, and only a few of the taxa (e.g. *Struthiolaria*

(Callusaria) obesa) extended into the Opoitian, but no further (Beu and Maxwell 1990; Beu *et al.* 2004).

Opoitian rocks are widespread along western margins of the study area from the Maungaharuru Range to the Omahaki Depression. Rocks of Opoitian age are identified mostly by the presence of the pectinid *Phialopecten marwicki,* often in association with the gastropod genus *Struthiolaria (Callusaria)* spp. Where diagnostic macrofauna are absent, the stage may be identified by microfauna. This has been necessary for mapping the distribution of the fine-grained Mangatoro Formation.

Restricted to shallow-water facies of Opoitian age are *Pelicaria parva* and *Zethalia russelli*. The first occurrence of *Phialopecten marwicki* in the study area is inferred to have occurred in the Upper Opoitian (Early Pliocene) (Beu 1995) and is recorded in the base of the Te Rangi Member of the Titiokura Formation at Naumai Station, and in the Hukanui Limestone Member (Pakaututu Formation), near Puketitiri and the Ripia River. It is also inferred to have appeared coevally in the Upper Opoitian Kairakau Limestone on the emerging eastern margin of the Hawke's Bay inland seaway (Te Mata Peak to Cape Turnagain) (Beu 1995).

The end of the Opoitian marks the extinction of the gastropod subgenus *Struthiolaria (Callusaria)* in the study area, a distinctive gastropod common in coarse-grained, shallow-water facies of Tongaporutuan to Opoitian age. Only *Struthiolaria (Struthiolaria)* is present in rocks younger than Opoitian.

Table 4.3: Molluscan taxa most useful for recognising the Opoitian Stage in the study area. The list is adapted from Beu and Maxwell (1990), Beu (1995) and Beu *et al.* (2004). * Denotes taxa of highest biostratigraphic utility and reliability.

Restricted	Last occurrence	First occurrence
*Towaipecten ongleyi**	*Myrtea*	*Phialopecten marwicki**
*Zethalia russelli**	*Struthiolaria (Callusaria)**	*Mesopeplum (Borehamia)*
*Pelicaria parva**	*Struthiolaria (Callusaria) obesa**	*crawfordi*
	Xenostrobus altijugatus	*Zethalia**
		Perna
		*Lutraria solida**
		Dosinia (Phacosama)
		*Pelicaria canaliculata**
		Polinices waipipiensis
		Semicassis (Kahua) fibrata
		Austrofusus pagoda
		Maoricolpus roseus
		Zeacolpus vittatus
		Pteromyrtea dispar

Foraminifera

Several long-ranging lower and middle bathyal species of foraminifera disappear in the Opoitian, although this may have been the result of facies change rather than extinction (Beu *et al.* 2004). The Opoitian contains the first occurrences of several planktic foraminifera, including *Globoconella puncticulata s.s., Globoconella inflata, Hirsutella margaritae,* and *Truncorotalia crassaconica,* and the last occurrences of the planktic foraminifera *Truncorotalia juanai* and *Globoconella mons.* The lowest occurrence of *T. crassaformis* occurs in the uppermost Kapitean, just below the first occurrence of *G. puncticulata s.s.* (Beu *et al.* 2004).

Microfossils identified in samples collected from Opoitian rocks in the study area include the planktic foraminifera *Globoconella puncticulata, G. pliozea* and *Truncorotalia juanai* (U21f87).

A collection (V19/f160) from about 100 m above the base of the Mokonui Sandstone on Pohokura Road included *Truncorotalia crassiformis, Globoconella pliozea,* and *G. puncticulata* and was assigned a Lower Opoitian age (Scott *et al.* 1990; Cutten 1994).

Waipipian

The name Waipipi was first used by Marshall (1919, p. 249) for the Waipipi “series” (i.e. formation) of Pliocene blue-grey sandstone with several prominent highly fossiliferous shellbeds that crop out on the South Taranaki coast south of Waverly, between Hawera and Wanganui. The name was adopted by Morgan (in Withers 1924) for a suggested subdivision of Thomson’s (1916) Waitotoran Stage. Fleming (1953, p. 102) adopted the name Waipipian for the lower substage of the Waitotoran, recognising the distinctive nature of the molluscan fauna.

Distinguishing Mangapanian rocks from Waipipian strata in the study area is relatively simple. However, distinguishing Waipipian rocks from Opoitian beds is more difficult. Reasons for this are discussed in the following section.

Molluscs

Seventeen molluscan genera are last recorded in New Zealand during the Waipipian, including *Eucrassatella* and *Miltha,* together with the last occurrence of common species such as *Mesopeplum (Borehamia) crawfordi, Phialopecten marwicki, Maorimactra chrydaea,* and *Pelicaria canaliculata* (Beu and Maxwell 1990; Beu 1995; Beu *et al.* 2004).

Four genera are first recorded in this stage, including *Aulacomya* and *Barytellina,* as well as common species including *Glycymerita (Manaia) manaiaensis, Eumarcia plana,* and *Zethalia*

coronata (Table 4.4). Restricted Waipipian species include *Pelicaria zelandiae* and *Amalda (Baryspira) oraria*.

Table 4.4: Taxa most useful for recognising the Waipipian Stage in the study area. The list is adapted from Beu and Maxwell (1990), Beu (1995), and Beu *et al.* (2004). * Denotes taxa of highest biostratigraphic utility and reliability.

Restricted	Last occurrence	First occurrence
*Pelicaria incrassata**	*Glycymerita*	*Aulacomya*
*Pelicaria zelandiae**	*Eucrassatella**	*Barytellina*
Alcithoe (Leporemax) gatesi	*Miltha**	*Glycymerita (Manaia)*
	Pratulum finlayi	*manaiaensis*
	Pratulum quinarium	*Bassina yatei*
	*Maorimactra chryaea**	*Eumarcia plana**
	Antalis pareorensis	*Xenostrobus huttoni*
	*Hartungia typica**	*Zethalia coronata**
	Pelicaria canaliculata	*Stircolpus symmetricus*
	*Phialopecten marwicki**	
	*Mespeplum (B) crawfordi**	

The Waipipian succession in the study area typically comprises relatively monotonous mudstone facies punctuated with occasional limestone beds. It is difficult to distinguish rocks of Waipipian age from those of Opoitian age in the study area for several reasons. Firstly, mudstone facies of Waipipian age are generally non to sparsely fossiliferous, and few age-diagnostic macro and microfossils have been identified from them. Secondly, most of the bivalve and gastropod macrofossils encountered in the limestone beds tend to be of aragonitic composition, and they have been variably lost through diagenesis. Fossils with calcitic composition are preferentially preserved. Macrofossils with calcitic shells include oysters (*Crassostrea, Ostrea*), barnacles (*Tasmanbalanus, Austromegabalanus*), brachiopods (*Neothyris*), and the biostratigraphically important pectinids (*Phialopecten, Towaipecten, Sectipecten, Mesopeplum*). Although the pectinids are typically preserved, many biostratigraphically useful macrofossils with aragonitic compositions (e.g. *Pelicaria, Struthiolaria*) are often absent or difficult to identify in the limestone facies. A third reason that makes identification of the Waipipian Stage difficult is that key index pectinids present in the Waipipian Stage are the same species as those used to identify the Opoitian Stage; *Phialopecten marwicki* and *Mesopeplum (Borehamia) crawfordi* both occur in Upper Opoitian rocks (Beu 1995). *Mesopeplum (Borehamia) crawfordi* was regarded as a Waipipian-restricted species (e.g. Beu and Maxwell 1990). However, *M. crawfordi* has been identified in rocks of known Opoitian age (Beu 1995) and is now of little use in identifying soley Waipipian-aged beds. The most useful macrofossil for identifying the Waipipian Stage in the study area is *P. marwicki.* Although this species first evolved in the Lower Opoitian (in Wanganui-Taranaki Basins), it progressively became larger through time, with Waipipian forms typically bigger than Opoitian forms. Opoitian *P. marwicki* are rarely over 100 mm high while Waipipian *P. marwicki* are larger than 115 mm high (Beu 1995, p. 64). Typical Waipipian forms of *P. marwicki*

have only been collected from the top of the Titiokura Formation along the crest of the Te Waka Range.

The H.O. of *Phialopecten marwicki* has been identified along the crest of the Te Waka Range near Te Waka Trig and is a very useful identifier of the end of Waipipian time. *Phialopecten marwicki* is common in the uppermost beds of the Titiokura Formation in this area.

Foraminifera

The discrimination of Opoitian from Waipipian rocks through the use of foraminifera remains poorly resolved (Beu *et al.* 2004). The highest occurrence of the benthic foraminifer *Cibicides molestus* has sometimes been used as a proxy for the top of the Opoitian Stage (Fig. 4.2). The base of the Waipipian Stage as provisionally defined by Beu *et al.* (2004) lies just below the highest occurrence of the planktic foraminifer *Globoconella subconomiozea* (Hornibrook *et al.* 1989; Beu *et al.* 2004).

Microfossil samples collected from rocks of Waipipian age in the study area are constrained by the presence of several planktic foraminifera, including *Truncorotalia crassaformis, Globoconella inflata, G. inflata triangula, G. puncticulata, G. subconomiozea,* and *G. pliozea*.

Mangapanian

The Mangapanian Stage (3.0-2.4 Ma) is the second of three Late Pliocene New Zealand stages. Mangapanian marine rocks are only known in Wanganui Basin, eastern North Island, and North Canterbury. The Mangapanian was originally introduced by Fleming (1953, p. 102) as an informal younger substage of the now obsolete Waitotoran Stage, based on the “type locality” at Mangapani (Mangapunipuni Stream), Waitotora valley, Wanganui district (Beu *et al.* 2004). Later authors (Fleming 1962, p. 82, 1975; Vella 1963, p. 38) recognised all Fleming’s (1953) substages as full stages, and replaced the Waitotoran with Waipipian (older) and Mangapanian (younger) Stages.

In nearshore to moderately shallow-water facies, distinguishing between Waipipian and Mangapanian molluscan faunas is relatively easy, and significantly easier than distinguishing between the Opoitian and Waipipian Stages (Beu *et al.* 2004).

The base of the Mangapanian Stage is defined by the L.O. of the mollusc *Phialopecten thomsoni.* In deep-water successions the base of the stage is approximated by the base of the *Truncorotalia oceanica* dextral coiling zone.

Table 4.5: Taxa most useful for recognising the Mangapanian Stage in the study area. The list is adapted from Beu and Maxwell (1990), Beu (1995), and Beu *et al.* (2004). * Denotes taxa of highest biostratigraphic utility and reliability.

Restricted	Last occurrence	First occurrence
*Phialopecten thomsoni**	*Maoricardium**	*Pratulum pulchellum*
*Towaipecten katieae**	*Polinices**	*Bassina parva**
Struthiolaria n.sp. aff. *frazeri*	*Austrofusus pliocenicus**	*Pelicaria* n.sp. aff. *zelandiae*
	*Austrofusus pagoda**	*Alcithoe brevis*
	*Zethalia coronata**	*Alcithoe arabica*
		*Aoteadrillia alpha**

Molluscs

The Mangapanian Stage represents a relatively short interval (c. 600 k.y.) between the disappearance of almost all of the last remaining warmer water Miocene-early Pliocene molluscs (such as *Maoricardium spatiosum, Polinices waipipiensis,* and *Crassostrea ingens*) and the appearance of cold water *Zygochlamys delicatula* fauna at the beginning of the Nukumaruan (Beu *et al.* 2004). The boundary is also characterised by the transition from the Waipipian-Mangapanian *Zethalia coronata* to the presently extant *Z. zelandica*, abundant in shallow-water sandstone facies. Restricted Mangapanian molluscs included the large scallop *Phialopecten thomsoni, Towaipecten katieae,* and the distinctive gastropod *Struthiolaria* n.sp. aff. *frazeri* (Beu and Maxwell 1990; Beu 1995) (Table 4.5). Common species first recorded in Mangapanian rocks are *Pratulum pulchellum* and *Tawera subsulcata.*

The base of the Mangapanian Stage is difficult to accurately define in the study area. Biostratigraphically it is marked by the extinction of *Phialopecten marwicki* and *Mesopeplum (Borehamia) crawfordi* and the appearance of *Phialopecten thomsoni*. *Phialopecten thomsoni* is common and widespread in limestone facies of the Te Waka Formation, particularly from the Patoka area southwest to Awapai Station. It has not, however, been observed in the common shallow-water sandstone facies of the Pohue Formation. The top of the stage is well-defined at several localities, and geological mapping has confidently correlated it across areas of little or poor outcrop. A useful indicator of the Mangapanian in the study area is the small, common to abundant gastropod *Zethalia coronata* (Wp-Wm). This species is a descendant of the Opoitian *Z. russelli,* and is ancestral to the Nukumaruan to Recent *Z. zelandica.* However, the shallow-water sandstone lithofacies that *Zethalia* are commonly associated with is often not conducive to preservation of the morphological details required for the discrimination of these species. In shallow-water facies the presence of the large gastropod *Struthiolaria* n.sp. aff. *frazeri* is a more reliable indicator of the Mangapanian (Beu 1995).

The extinction of several species provides a useful indicator of the end of the transition from the uppermost Mangapanian to basal Nukumaruan in the study area. These include *Maoricardium spatiosum, Crassostrea ingens, Phialopecten thomsoni,* and *Polinices waipipiensis.*

Foraminifera

The upper dextral coiling zone of the planktic foraminifer *Truncorotalia oceanica* is a proxy for the Waipipian-Mangapanian stage boundary in deep-water sediments. This coiling zone occurs high in the Kaena Subchron (C2An.1r) in ODP site 1123, with an interpolated age of 3.05 Ma (G.H. Scott, pers. comm., cited in Beu *et al.* 2004). The almost coeval highest occurrence of *Truncorotalia crassula* (interpolated at 2.40 Ma in ODP 1123; G.H. Scott, pers. comm., cited in Beu *et al.* 2004) and the top of the upper dextral coiling zone of *T. oceanica* is a useful proxy for the Mangapanian-Nukumaruan boundary. The Mangapanian Stage in New Zealand is therefore almost equivalent to the upper dextral coiling zone of *T. oceanica* (Beu *et al.* 2004).

No microfossil analysis of Mangapanian rocks has been undertaken. One microfossil sample (V20/f444) was collected from inferred Mangapanian-aged Puketitiri Formation near Puketitiri, but it contained no calcareous material (M. Crundwell, pers. comm. 2004).

Nukumaruan

The Nukumaruan Stage (2.40-1.63 Ma) occurs across the Late Pliocene and Early Pleistocene (including the Plio-Pleistocene boundary at 1.8 Ma) (Beu *et al.* 2004) (Fig. 4.1). Nukumaruan marine rocks are limited to the young sedimentary basins in the plate boundary zone in central New Zealand. Highly fossiliferous shellbeds are common in these Nukumaruan beds, and the abundant highly diverse molluscs in these shallow-water deposits has allowed for the development of a well-understood molluscan biostratigraphy (Beu *et al.* 2004). Rocks of Nukumaruan age are very widespread in central and southern Hawke's Bay, and significant effort has been put into the analysis of molluscan macrofossils in them during this study.

Molluscs

The most important and distinctive faunal characteristic of Nukumaruan time is the basal Nukumaruan migration to central New Zealand of a cold water fauna characterised by the subantarctic scallop *Zygochlamys patagonica delicatula* and the large subantarctic crab *Jacquinotia edwarssi.* During this migration, plankto-trophic larvae of *Zygochlamys* were transported passively in ocean currents at least 600 km north of the present northern limit of common shallow-water specimens off Otago Peninsula (Orpin *et al.* 1998; Beu *et al.* 2004). Fossils of *Zygochlamys* are abundant as far north as Dannevirke and become less common

towards the Napier-Taihape Road in the study area, and the Hautawa Shellbed in Wanganui Basin (Beu *et al.* 1981; Beu 1995).

Table 4.6: Taxa most useful for recognising the Nukumaruan Stage in the study area. The list is adapted from Beu and Maxwell (1990), Beu (1995) and Beu *et al.* (2004). * Denotes taxa of highest biostratigraphic utility and reliability. l.n., lowermost Nukumaruan; u.n., upper Nukumaruan

Restricted	Last occurrence	First occurrence
*Phialopecten triphooki** l.n.	*Crassostrea ingens** l.n.	*Pratulum pulchellum*
*Towaipecten mariae**	*Patro undatus**	*Bassina parva**
*Zygochalmys patagonica delicatula** l.n.		*Pelicaria* n.sp. aff. *zelandiae*
		Alcithoe brevis
?Mesopeplum (M.) convexum		*Alcithoe arabica*
Struthiolaria frazeri		*Aoteadrillia alpha**
Glycymeris (s.s.) *shrimptoni**		*Austrofusus glans*
*Spisula (Spisuloma) crassitesta**		*Xymene expansus*
*Pelicaria accuminata**		*Zethalia zelandica**
*Pelicaria convexa** u.n.		*Austrovenus crassitesta*
*Pelicaria rugosa**		
Aoteadrillia finlayi		
Cominella kereruensis		
Austrofusus taitae		

The base of the Nukumaruan Stage is well-defined across the study area as it is marked by both the extinction and appearance of many molluscan macrofauna. Beu and Maxwell (1990) noted that 5% of New Zealand molluscan genera became extinct at the end of the Mangapanian, although the arrival of subantarctic fauna boosted the number of genera present in paleo-New Zealand waters from 257 in the Mangapanian to 312 in the Nukumaruan (McIntyre 2002).

Genera first recorded in New Zealand in the Nukumaruan include *Semicassis (sensu stricto)* and *Paracomitas*, as well as common species such as *Mesopeplum convexum, Austrovenus crassitesta, Xymene expansus, Zethalia zelandica, Austrofusus taitae,* and *Aeneator marshalli.* Nukumaruan restricted species include *Glycymeris shrimptoni, Towaipecten mariae, Phialopecten triphooki, Struthiolaria frazeri, Pelicaria acuminata, Pelicaria convexa,* and *Paracomitas protransenna* (Table 4.6). The many common mollusca becoming extinct at the end of the Nukumaruan include the genera *Glycymeris (sensu stricto), Towaipecten, Patro, Neopanis, Pteromyrtea, Spisula (Spisularia), Lutraria, Dosinia (Raina), Eumarcia (Eumarcia), Eumarcia (Atamarcia),* and *Taxonia,* and the species *Marama murdochi.*

Of particular note in Nukumaruan biostratigraphy are the numerous species that either became extinct or first appeared *during* various parts of the stage. A characteristic basal Nukumaruan molluscan fauna includes *Zygochlamys delicatula, Phialopecten triphooki,* and the last recorded examples of *Crassostrea ingens, Maoricardium spatiosum,* and *Phialopecten thomsoni*. A distinctive Upper Nukumaruan molluscan macrofauna was reported by Beu (1995), and included *Amalda mucronota* forma *erica, Aeneator comptus, Glaphyrina plicata*, and *Cominella excoriata*.

The L.O. of three pectinid species are important in determining the position of the Mangapanian-Nukumaruan boundary; namely *Phialopecten triphooki, Zygochlamys patagonica delicatula,* and *Towaipecten mariae.* Other notable first occurrences in the Nukumaruan include *Glycymeris shrimptoni, Dosinia (Austrodosinia) anus, Pelicaria convexa, Austrofusus taitae, Struthiolaria frazeri* and *Zethalia zelandica.* Although reported as having been in New Zealand waters since the Tongaporutuan (Late Miocene) (Beu and Maxwell 1990), the extant small pectinid *Mesopeplum convexum* appears as a very common component in coarse shellbed facies from the base of the Nukumaruan, whereas it appears to be absent in rocks older than Nukumaruan. McIntyre (2002) and Beu *et al.* (2004) regarded the appearance of *M. convexum* as an indicator of the Nukumaruan.

The first occurrences of *Phialopecten triphooki* and *Towaipecten mariae* have been accurately located at several sites through the study area. In the Esk River section the L.O. of *P. triphooki* (V20/371084, Column Tp-4) is underlain by sandstone containing the H.O. of the Mangapanian-restricted gastropod *Struthiolaria* n.sp. aff. *frazeri* (A. Beu, GNS Science pers. comm. 2004). The L.O. of *P. triphooki* has also been observed in Deep Stream (V20/361073, Column Tp-5); the Napier-Taupo Road at Glengarry Hill (V20/309038, Column Gg-1); Glengarry Forest (V20/293023); Huiarangi Road near Patoka (Fig. 4.4; V20/259002, Column Pt-4); the base of the Scinde Island Formation at Scinde Island, Napier (type locality of *Phialopecten triphooki*, V21/460843; Beu 1995); Mason Ridge; Sentry Box Formation at Awapai Station, Whanawhana (U21/040806, Column Wh-3); and the base of the Sentry Box Formation in Jumped Up Stream (U21/934665, Column Ke-3).

The L.O. of *Zygochlamys patagonica delicatula* has only been observed in the base of the Sentry Box Formation in the Jumped Up Stream section (U21/934665, Column Ke-3), although it has been reported at other sites in the study area (Beu *et al.* 1977; Beu 1995; Browne 2004a).

The L.O. of *Phialopecten triphooki* occurs in several horizons across the study area. This is inferred to reflect changing facies and habitats through the Lower Nukumaruan, indicating that the persistence of *P. triphooki* in the study area may be strongly facies controlled. This point is discussed in more detail later in this section. In the area around Deep Stream, the Esk River and Kaiwaka Stream including the top of the Grassy Knoll Conglomerate Member in Deep Stream, the the L.O. of *P. triphooki* occurs in the base of the Papakiri Member, and the H.O. in the Grassy Knoll Conglomerate Member. In the Glengarry and Patoka areas, both the L.O. and H.O. of *P. triphooki* occur in the Papakiri Member and have been located at Glengarry Hill, in Glengarry Forest, and beside Huiarangi Road (Fig. 4.4). The overlying Grassy Knoll Conglomerate Member in these areas comprises lithofacies that were unsuitable for *Phialopecten* (e.g. non-marine to

estuarine). In the Ohara Depression the H.O. of *Phialopecten triphooki* coincides with the top of the Sentry Box Formation. In the Mason Ridge area the H.O. occurs in the Pakihirua Limestone Member (Mason Ridge Formation).



Fig. 4.4: Shellbed in the Papakiri Member (Matahorua Formation) containing the L.O. of *Phialopecten triphooki* and *Glycymeris shrimptoni* in the study area, exposed beside Huiarangi Road near Patoka (GR NZMS260/259002). A basal Nukumaruan age of 2.4 Ma is assigned to this horizon. The black dotted line marks the abrupt transition from shallow-water *G. shrimptoni*-dominated conglomerate into shelfal pebbly siltstone dominated by *Neilo* and *Dosinia (Kereia) greyi*. This shellbed has been geologically mapped into the Te Pohue region and the Esk River. The locations of some *P. triphooki* valves are circled.

The extinction of the large oyster *Crassostrea ingens* occurred during the lowermost Nukumaruan (Beu 1995). Co-occurrence of *Z. delicatula* and *P. triphooki* with *P. thomsoni* and *Crassostrea ingens* in Jumped Up Stream demonstrates a reliable very basal Nukumaruan age (Beu 1995). This co-occurrence has also been noted in the Hautawa Shellbed in Wanganui Basin by McIntyre (2002).

The lineage of species of the gastropod genus *Pelicaria* has proven to be useful to understanding the Nukumaruan stratigraphy of the study area. Two species and one form of *Pelicaria* occur in siltstone facies in Nukumaruan rocks in the study area, these being *P. acuminata* and its successors, *P. convexa* and *P. convexa* form *fossa.*

Struthiolaria frazeri is a large distinctive Nukumaruan-restricted gastropod that characterises shallow-water sandstone facies of Nukumaruan age. It is most common in sandstone beds of middle to upper Nukumaruan age in the Tangoio Block and in the Kereru area. Prominent *S. frazeri*-rich shellbeds crop out in the Darkys Spur Member at Darkys Spur, and in the Okauawa Formation opposite the Whanakino Station entrance gate.

An interesting point of pectinid biostratigraphy identified in the study area is the lack of *Phialopecten* and *Towaipecten* in rocks younger than Lower Nukumaruan. *Phialopecten* has preferentially occupied environments associated with the accumulation of coarse-grained limestone to conglomeratic facies. Specimens of *Phialopecten triphooki,* the youngest *Phialopecten* species, have been collected from a maximum of three cycles into the Nukumaruan Stage. Although apparently suitable substrates and depositional settings were present for Phialopecten in the middle and upper Nukumaruan (such as the Flag Range Conglomerate Member), no *Phialopecten* or *Zygochlamys* have been observed. The extinction of the two genera in Hawke's Bay seems to have occurred during lowermost Nukumaruan time, perhaps 120 000 years into the stage. This may be due to one of two reasons. Firstly, the base of the Nukumaruan marks an influx of subantarctic faunas such as *Zygochlamys* and *Jacquinotia,* among others. The influx of cooler waters that introduced larvae of these genera to Hawke's Bay coincided with the speciation from *P. thomsoni* (Mangapanian) to *P. triphooki*, as well as *Towaipecten katieae* to *T. mariae.* It appears that the subantarctic faunas only survived in Hawke's Bay for a short interval, perhaps only 80 to 120 k.y., similar to the length of time that *Phialopecten triphooki* survived in the Nukumaruan. It may be that as waters warmed slightly after the basal Nukumaruan they became intolerable for *Phialopecten and Zygochlamys,* which then became extinct in the Hawke's Bay area. A second factor is the availability of suitable substrate for these pectinids. After the Lower Nukumaruan a rapid basin-wide deepening appears to have occurred, recorded by the Esk Mudstone. Shelf limestone of the Sentry Box Formation in the Ohara Depression, rich in *Phialopecten triphooki* and *Zygochlamys delicatula,* is abruptly overlain by mudstone containing a bathyal fauna (Beu 1995). In the areas from the Tangoio Block south through the Esk Catchment to the Ngaruroro River, non- to marginal-marine conglomerate beds (with common *Phialopecten triphooki*) of the Matahorua Formation are overlain by outer shelf mudstone facies. Immediately north of the study area, shelfal rocks of Upper Mangapanian age are overlain by upper bathyal mudstones at the mouth of the Mohaka River. Throughout the study area *Zygochlamys, Phialopecten,* and *Towaipecten* of Nukumaruan age have only been observed and collected from coarse-grained pebbly limestone to shelly conglomerate facies. In the Esk and Mangaone catchments such facies only occur for two cycles into the Nukumaruan. It is inferred that the Sentry Box Formation may record up to four cycles into the Nukumaruan before it is overlain by bathyal mudstone. It could be that a dramatic change in environment occurred in the

Lower Nukumaruan that was unfavourable for *Phialopecten* and other scallops, and that these genera became extinct in the Hawke's Bay. Even though suitable facies are widespread in the middle and upper Nukumaruan in the study area, they were not recolonised by *Phialopecten* as it was already extinct. *Zygochlamys* could not re-colonise these beds as water temperatures were probably too warm for it to migrate northwards as it had done during the basal Nukumaruan. It is probable that a combination of rising water temperatures and change in sea-floor habitat (mostly substrate change) led to the extinction of both *Phialopecten and Zygochlamys* in the study area. It is important to keep in mind that while *Phialopecten* is extinct in the modern environment, *Zygochlamys patagonica delicatula* is still widespread in deep waters on the Otago shelf where it is commercially harvested.

Foraminifera

Notorotalia zelandica is typical of Nukumaruan rocks in eastern North Island, although it is rare in the Nukumaru Coast section (Beu *et al.* 2004). Hornibrook *et al.* (1989) nominated the first occurrence of *Truncorotalia crassula* as the best available proxy for the base of the Nukumaruan Stage (Fig. 4.2). Beu *et al.* (2004) comment, however, that while the L.O. of *T. crassula* is still used as a stage proxy in deep-water sequences where age-diagnostic benthic foraminifera and mollusca are lacking, the biostratigraphic events on which the stage correlation is based are subject to facies control and may not necessarily be homotaxial.

Planktics and benthics identified in Nukumaruan rocks in this study include *Globoconella inflata, Globoconella inflata triangula, Truncorotalia crassaformis, T. truncatulinoides, T. crassula, T.* cf. *crassula,* and *Notorotalia zelandica* (M. Crundwell, GNS Science pers. comm. 2004) (Appendix V).

TEPHRA GEOCHEMISTRY

The Late Pliocene-Pleistocene (Nukumaruan-Castlecliffian) part of the sedimentary succession in Hawke's Bay Basin contains a large number of macroscopic tephra layers. Seventeen tephra samples from rhyolitic pumiceous beds were collected from rocks of Nukumaruan age during this study (Fig. 4.5). Glass shards from these samples were extracted and analysed for major element geochemistry by B.V. Alloway (GNS Science, Lower Hutt). Tephra layers are preferentially located in siltstone beds, although thick pumiceous units may also be associated with non- to marginal-marine conglomerate beds. Preservation is generally good. Tephras are generally white to pale-pink in colour, fresh-looking, and comprise fine to medium ash, though lapilli-sized clasts are common in ignimbrite and mass flow deposits. The tephras are typically sharp based, although upper contacts tend to be gradational and contain an admixture of ash and terrigenous

grains from the overlying unit. Burrows commonly extend from the overlying siltstones into the tephras and are filled dominantly with siltstone.

The purpose of geochemical tephra analysis was to try and identify possible correlatable horizons between regions in the study area, and to try and obtain possible absolute age markers within the succession.

Methods

A total of 334 analyses were made on 17 tephra samples, averaging around 19 per tephra. Analysis was undertaken using a CAMEBAX SX-50 microprobe housed at the University of Toronto by Brent Alloway (formerly GNS Science). The microprobe was operated at 15kv, beam current at 10nA, and in scanning mode. All elements were calculated on a water-free basis, with H_20 by difference from 100%. All Fe is expressed as FeO. All samples were normalised against glass standard UA-5831.

Results

Seven discrete populations can be delineated although there may be some intermixing between populations (Fig. 4.6). Silica contents for the 17 tephras range from 73.60 to 77.59% (Table 4.7), typical for rhyolitic tephras. Al_2O_3 are between 12.99 and 13.18%, K_2O from 3.03 to 3.31% and Na_2O from 3.93 to 4.14%. These values are typical for rhyolitic tephras (Le Maitre 1984).

A good correlation has been obtained for six tephra samples taken from the Matahorua Formation between the Te Pohue and Patoka districts (Fig. 4.5, 4.6). These samples were collected from positions near the inferred Mangapanian-Nukumaruan boundary (both below and above the inferred boundary; Fig. 4.5, 4.6).

The major element geochemistry of samples WP-260 and WP-324, collected from the Hikuroa Pumice Member (Table 4.7), is indistinguishable from that of two tephras (AT-313 and AT-503) in the ODP 1124 tephra record (1124C 7H 3W 71-74 and 1124C 7H 3W 117-119) (Brent Alloway, GNS Science, pers. comm. 2004). The two samples from ODP 1124 have been dated at 2.128 and 2.149 Ma (paleomagnetic age model of Ian Hall) or 2.146 and 2.165 Ma (paleomagnetic age model of Gary Wilson) (B. Alloway, pers. comm. 2003). This correlation provides a potentially valuable age marker for the Nukumaruan succession in the study area and its implications are discussed later in the chapter.

Table 4.7: Major element glass compositions of Plio-Pleistocene tephra layers from central Hawke's Bay The compositions of the ODP-tephra correlatives (AT-313 and AT-503) of the Hikuroa Pumice Member are included in this table.

Sample	SiO	TiO_2	Al_2O_3	Fe	MgO	MnO	Ca	Na_2	K_2O	Cl	H_2O	*n*
WP-1012	77.36	0.12	12.47	1.14	0.13	0.06	1.13	3.33	4.02	0.2	6.94	1
	0.24	0.10	0.11	0.24	0.07	0.03	0.25	0.21	0.60	0.0	1.04	
WP-872	77.59	0.17	12.17	1.28	0.15	0.03	1.21	3.52	3.61	0.2	6.28	1
	0.28	0.09	0.21	0.18	0.05	0.03	0.24	0.13	0.52	0.0	0.50	
WP-1011	75.80	0.06	13.12	1.80	0.07	0.03	1.33	3.82	3.81	0.1	6.65	1
	0.24	0.06	0.13	0.07	0.03	0.03	0.09	0.13	0.22	0.0	1.24	
WP-1001	77.70	0.08	12.41	1.32	0.08	0.05	1.20	3.79	3.21	0.1	5.45	1
	0.22	0.05	0.10	0.05	0.03	0.03	0.06	0.12	0.11	0.0	0.89	
WP-201a	75.65	0.20	13.18	1.80	0.22	0.04	1.46	4.14	3.12	0.2	6.02	1
	0.23	0.06	0.10	0.09	0.03	0.03	0.05	0.11	0.16	0.0	0.76	
WP-201b	75.65	0.20	13.18	1.84	0.21	0.05	1.50	4.14	3.03	0.2	6.36	1
	0.23	0.06	0.14	0.10	0.04	0.05	0.06	0.08	0.13	0.0	0.94	
WP-221	75.85	0.22	13.10	1.78	0.20	0.04	1.43	4.04	3.12	0.2	6.52	1
	0.62	0.05	0.22	0.13	0.03	0.04	0.15	0.54	0.43	0.0	1.01	
WP-221a	75.77	0.17	13.11	1.79	0.19	0.05	1.42	4.06	3.23	0.2	6.10	1
	0.55	0.09	0.25	0.19	0.05	0.03	0.21	0.25	0.45	0.0	1.18	
WP-1013	75.66	0.19	12.99	1.88	0.21	0.05	1.56	3.93	3.31	0.2	7.16	1
	0.18	0.06	0.13	0.09	0.03	0.04	0.09	0.12	0.18	0.0	1.17	
WP-1014	75.70	0.18	13.13	1.80	0.22	0.04	1.52	4.05	3.15	0.2	7.76	1
	0.21	0.08	0.18	0.07	0.02	0.03	0.06	0.13	0.24	0.0	2.63	
WP-868	77.47	0.12	12.39	1.18	0.11	0.04	1.09	3.49	3.90	0.2	5.99	1
	0.42	0.05	0.10	0.12	0.03	0.03	0.15	0.30	0.39	0.0	0.74	
WP-877	77.51	0.08	12.49	1.11	0.11	0.04	1.07	3.33	4.02	0.2	6.46	1
	0.33	0.07	0.12	0.05	0.02	0.03	0.04	0.38	0.15	0.0	0.36	
Wp-1001a	74.48	0.16	13.67	2.23	0.13	0.08	1.23	4.39	3.43	0.1	6.58	1
	0.24	0.08	0.14	0.07	0.03	0.05	0.06	0.09	0.11	0.0	0.69	
WP-1000b	74.38	0.18	13.60	2.26	0.13	0.07	1.18	4.56	3.42	0.2	6.01	1
	0.20	0.05	0.09	0.08	0.02	0.04	0.06	0.17	0.13	0.0	0.83	
WP-1000a	73.60	0.22	13.84	2.53	0.22	0.06	1.44	4.51	3.36	0.2	6.07	1
	1.62	0.09	0.45	0.72	0.19	0.05	0.51	0.16	0.23	0.0	0.88	
pop.1	74.49	0.18	13.60	2.16	0.12	0.06	1.16	4.54	3.48	0.2	6.11	1
	0.32	0.06	0.09	0.13	0.02	0.05	0.09	0.13	0.13	0.0	0.81	
pop.2	71.72	0.28	14.39	3.25	0.46	0.07	2.07	4.53	3.07	0.1	5.47	3
	0.18	0.09	0.32	0.15	0.13	0.06	0.14	0.09	0.11	0.0	0.83	
WP-324	77.42	0.08	12.25	1.42	0.06	0.04	0.94	3.84	3.72	0.2	4.46	1
	0.20	0.06	0.12	0.09	0.01	0.04	0.06	0.08	0.12	0.0	0.43	
WP-260	77.48	0.10	12.21	1.40	0.06	0.04	0.91	3.83	3.73	0.2	4.56	1
	0.23	0.08	0.10	0.11	0.02	0.03	0.07	0.10	0.16	0.0	0.58	
AT-503	76.95	0.11	12.60	1.43	0.08	0.04	0.94	4.18	3.48	0.1	6.15	1
1124C 7H 3W 71-74	0.47	0.03	0.20	0.12	0.03	0.03	0.12	0.17	0.18	0.0	0.54	
AT-313	77.44	0.11	12.37	1.42	0.06	0.03	0.90	3.98	3.50	0.2	6.25	1
1124C 7H 3W 117-	0.11	0.04	0.09	0.09	0.01	0.02	0.05	0.10	0.20	0.0	0.51	
UA-5831	74.91	13.15	0.07	1.59	0.04	0.07	0.77	3.99	5.05	0.3	1.31	4
Glass Standard	0.23	0.11	0.06	0.07	0.02	0.05	0.06	0.19	0.08	0.0	0.44	

Analyses were made using a CAMEBAX SX-50 microprobe housed at the University of Toronto by B.V. Alloway. The microprobe was operating at 15kV, beam current at 10nA, and in scanning mode. All elements calculated on a water-free basis, with H_2O by difference from 100%. All Fe expressed as FeO.

The Hikuroa Pumice Member comprises up to 15 m of pumiceous ash and lapilli, and appears to represent a significant eruptive event. The thickness of the inferred correlatives in the ODP 1124 record, located several hundred kilometres off the eastern North Island coastline (AT-313, 0.3 m thick and AT-503 0.2 m thick), further suggest large eruptive events. Samples from the Hikuroa Pumice Member, and its ODP correlatives, have similar geochemical compositions to samples of the Ohingaiti Tephra described by Naish (1996) and Naish *et al.* (1996), and may also be related to the "two closely spaced tephras interbedded in a marine succession of comparable age exposed at Waikoau Stream, central Hawke's Bay" described by Naish and Kamp (1994).

No other correlations have been made between samples collected in this study, and samples analysed from the ODP records.

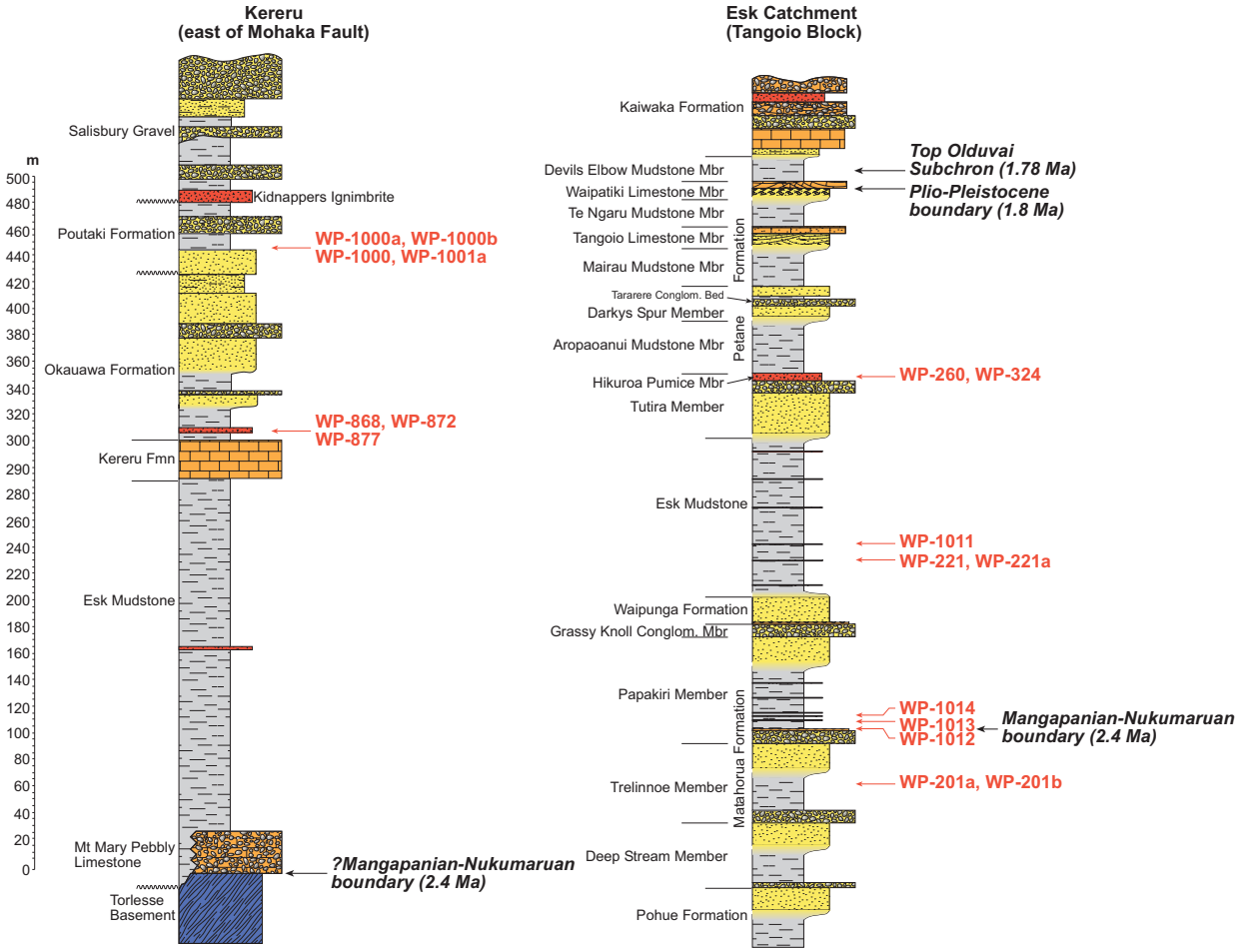


Fig. 4.5: Simplified stratigraphic columns showing the stratigraphic position of tephra samples (red sample numbers with arrows) analysed in this study. The inferred positions of absolute age markers in these composite sections are also indicated. Samples WP 260 and WP 324 are possible correlatives of samples AT-313 and AT-503 (Table 4.7).

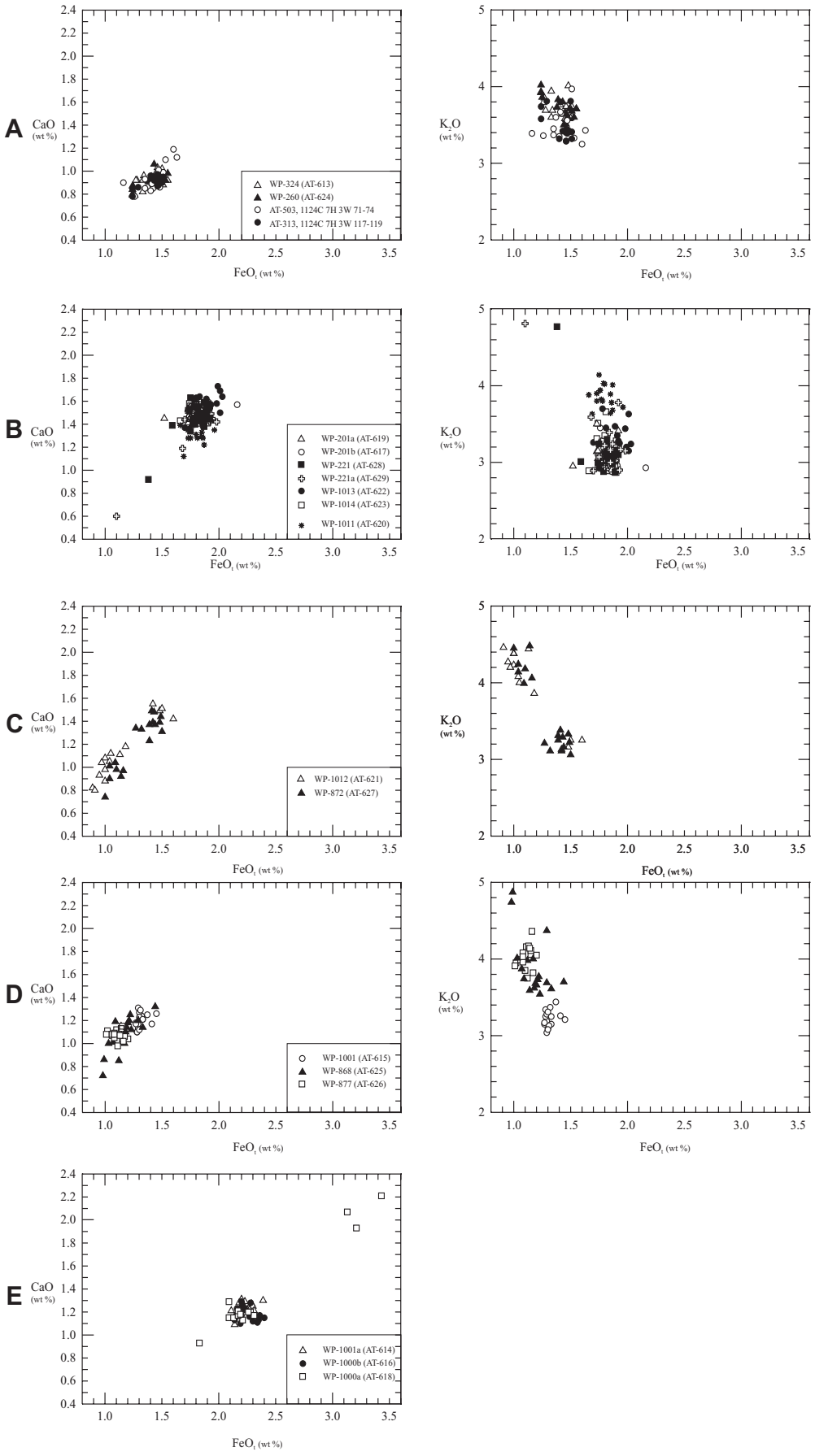


Fig. 4.6: Plots of populations of tephra samples collected from the Nukumaruan stratigraphy in the study area as determined by major element geochemistry. The geochemical comparison of the Hikuroa Pumice Member and potential correlative beds from ODP 1124 is shown in Group A.

Erdman and Kelsey (1992) reported major element geochemistry for several tephras collected from the Okauawa Formation in the Ohara Depression. Silica contents of these tephra were between 76.32 and 77.45%, Al_2O_3 between 12.42 and 13.03%, K_2O from 3.93 to 4.24%, and Na_2O from 3.59 to 3.79%. The geochemistry of these samples appears to correlate well with samples collected in this study from the Okauawa Formation.

PALEOMAGNETIC DATING

No new paleomagnetic analysis has been undertaken in this study.

Plio-Pleistocene boundary

The position of the Plio-Pleistocene boundary was identified by Beu and Edwards (1984) in the Waipatiki Limestone Member (Petane Formation) in the Tangoio Block on the basis of the first occurrence of the microfossil *Gephyrocapsa sinuosa* near the base of the underlying Te Ngaru Mudstone Member. Geological mapping has confidently correlated the Waipatiki Limestone Member across the study area from the Tangoio Block into the Matapiro district and Ngaruroro River. The Waipatiki Limestone Member is conformably, although abruptly, overlain by the Devils Elbow Mudstone Member. The top of the Olduvai paleomagnetic subchron (1.78 Ma) has been located in this mudstone (P. Kamp, University of Waikato unpublished data). The position of this paleomagnetic transition correlates well with the inferred position of the Plio-Pleistocene boundary in the unit underlying Waipatiki Limestone Member (as located by Beu and Edwards (1984)).

OVERVIEW OF RELATIVE CHRONOLOGIES FOR AREAS IN CENTRAL HAWKE'S BAY

Relative chronology of the Te Hoe and Te Haroto areas

This area contains the oldest Neogene rocks cropping out in the study area, all of which are encompassed in the Tolaga Group. A robust chronology for this group is lacking, and the relative chronology has been achieved through microfossil biostratigraphy (Scott *et al.* 1990a; Cutten 1994). The basal and oldest formation in this region is the Whakamarino Formation. The Whakamarino Formation is overlain by the Middle Miocene Poamoko Formation. Te Haroto Formation is a Lower Tongaporutuan (possibly Upper Waiauan) formation cropping out only in the Te Haroto and Tarawera Station area. The Te Haroto and Poamoko Formations are unconformably overlain by the Waitere Formation of Lower Tongaporutuan to Lower Kapitean age. The basal member of the Waitere Formation (Tarawera Limestone Member, Lower Tongaporutuan) contains a distinctive macrofauna dominated by the gastropods *Zeacolpus* sp. and *Struthiolaria (Callusaria)* sp. The Tarawera Limestone Member passes up into the Te

Ipuohape Sandstone Member. Basal concretionary beds of this member are often rich in *S. (Callusaria).* The Te Ipuohape Sandstone Member (Lower to Upper Tongaporutuan) passes through the Auroa Alternating Member into the Rakaita Siltstone Member. No macrofossils have been observed in the Rakaita Siltstone Member. Microfossils infer an Upper Tongaporutuan to Lower Kapitean age.

Relative chronology of the Maungaharuru and Te Waka areas

The chronology in these areas remains poorly resolved compared with the refinement achieved in the Nukumaruan succession during this study. At best only a relative position within a New Zealand stage has been achieved (i.e. "lower", "middle", "upper"). Dating rocks in this region is mostly based on molluscan biostratigraphy, particularly the lineage of scallops in the genus *Phialopecten*.

The oldest formation of this area is the Waitere Formation of Lower Tongaporutuan to Lower Kapitean age (Late Miocene). Waitere Formation is conformably to unconformably overlain by the Kapitean to Lower Opoitian (Late Miocene to Early Pliocene) Mokonui Sandstone (Scott *et al.* 1990a; Cutten 1994). Macrofauna in the Mokonui Sandstone are very rare to absent, and relative dating of it is based on foraminifera and stratigraphic position. Microfossil sample V19/f46 from the Mokonui Sandstone in the Mohaka River (V19/432321) contains *Globoconella miotumida* (with *conomiozea* morphotypes) and is dated as Lower Kapitean, possibly near the Upper Kapitean boundary. Sample V19/f160 from Pohokura Road near Woodstock Road (V19/376274) includes *Truncorotalia crassiformis, Globoconella puncticulata,* and *G. pliozea,* with a Lower to "Middle" age Opoitian (Cutten 1994).

Mokonui Sandstone is unconformably overlain by the "early to middle" Pliocene Titiokura Formation. The L.O. of *Phialopecten marwicki* in this part of the basin occurs in the Te Rangi Member of the Titiokura Formation at Naumai Station on the Maungaharuru Range. These specimens resemble the typical Opoitian form characterised by small size and numerous ribs, placing them in the Opoitian field of Beu (1995, Fig. 9, p. 27). The Kapitean to Lower Opoitian age of the underlying Mokonui Sandstone, suggests an Upper Opoitian age for the base of the Titiokura Formation in the Maungaharuru Range.

The position of the Opoitian-Waipipian boundary in the Maungaharuru and Te Waka ranges remains uncertain, although it is inferred to lie in the Bellbird Bush Member of the Titiokura Formation. Macrofossils are sparse in this area, and age-diagnostic species even rarer. Three microfossil samples collected from the Bellbird Bush and Opouahi Members (Titiokura Formation) along Pohokura Road provide mixed Upper Opoitian and Lower Waipipian ages (Beu *et al.* 1980;

Beu 1995; V19/f8529 collected by N. de. B. Hornibrook, A.G. Beu, and T.L. Grant-Taylor; V19/f8615 and f8616 by R. Stonely). Sample V19/f8529 was assigned an Opoitian-Waipipian age, although comments on this sample suggest the age is more probably Waipipian. Sample V19/f8615 was assigned a Waipipian age, and sample V19/f8616 a "Waitotoran" (Waipipian/Mangapanian) age. These ages suggest that the Opouahi Member is Lower Waipipian in age, and that the underlying Bellbird Bush Member is of Upper Opoitian-Lower Waipipian age.
The base of the Te Waka Formation at the type section on the Te Waka Range (V20/258133) may be uppermost Waipipian in age. Sparse scallops observed in middle to upper beds of Te Waka Formation at the type section resembled typical Waipipian *Phialopecten marwicki* rather than the expected Mangapanian *Phialopecten thomsoni* (Bland 2001). Additionally, small specimens of *Phialopecten* observed in these beds shares morphological characteristics of both *P. marwicki* and *P. thomsoni* (A. McIntyre, pers. comm. 2000; Bland 2001). Uppermost beds of Te Waka Formation in the Te Waka Range are of Mangapanian age, based on the occurrence of the Mangapanian index pectinid *Phialopecten thomsoni* (Beu 1995). These beds also contain *Maoricardium spatiosum* (Bland 2001), and therefore cannot be younger than Mangapanian age.

The Te Waka and Titiokura Formations are both overlain by the Pohue Formation. In the area of the Maungaharuru Range the Pohue Formation is of Lower Waipipian to Upper Mangapanian age. In the Te Waka Range and Patoka areas the Pohue Formation is of middle to upper Mangapanian age. The decrease in age of the Pohue Formation towards the south reflects interdigitation with Te Waka Formation.

Relative chronology of the Pakaututu, Puketitiri, and Patoka areas

In most parts of the Puketitiri and Patoka areas the oldest Neogene rocks are Upper Opoitian (Early Pliocene), although small areas of Tongaporutuan beds are present. The ages of the Opoitian rocks are constrained by the sparse to moderately common occurrence of Opoitian forms of *P. marwicki* in coarse shelly limestone of the Hukanui Limestone Member (Pakaututu Formation). Concretionary beds immediately underlying the Hukanui Limestone Member contain gastropods identified by Austin Hendy (Univ. Cincinnati) as *Struthiolaria dolorosea*, an Opoitian-restricted species (Beu and Maxwell 1990). The Pakaututu Formation is overlain by the Puketitiri Formation. No age diagnostic molluscs have been observed in this latter formation, and its inferred Waipipian age is based mostly on stratigraphic position. Two micropal samples (V20/f444 and V20/f445) were collected during this study in an attempt to constrain the age of the Puketitiri Formation. Sample V20/f444 contained no foraminifera, although common sponge spicules, radiolarians, and rare fish teeth were observed. Sample V20/f445 was assigned a Waipipian age based on planktic foraminifera, including *Truncorotalia crassaformis, Globoconella inflata, G. inflata triangulata, G. puncticulata, G. subconomiozea,* and *G. pliozea* (M. Crundwell, GNS

Science, pers. comm. 2004). This sample confirms the inference that at least some part of the Puketitiri Formation is of Waipipian age. The Puketitiri Formation is unconformably overlain by the Te Waka Formation. In the Puketitiri and Patoka areas Te Waka Formation is of Mangapanian age, constrained by common *Phialopecten thomsoni*. The Te Waka Formation is in turn overlain by middle to upper Mangapanian Pohue Formation, its age constrained by the presence of *Polinices waipipiensis* and the Mangapanian-restricted gastropod *Zethalia coronata*.

In two small areas, rocks of Tongaporutuan age are preserved. Microfossil sample V20/f442 was collected from basal parts of a siltstone unit near an unconformable contact with Torlesse basement in Gorge Stream, Te Kowhai Forest. A Tongaporutuan age is inferred by the presence of *Globoconella miotumida, Neogloboquadrina pachyderma,* and *Bolivinita pohana*. The relative abundance of *Globigerinoides* and the apparent absence of *Globoquadrina dehiscens* suggest an age of 8.8-8.0 Ma for this sample (M. Crundwell, GNS Science, pers. comm. 2004). The second Tongaporutuan area of outcrop is preserved in the Opau and Waipunga Stream area, near Patoka. Here sandstone and siltstone of Tongaporutuan age unconformably overlie Torlesse basement, and are in turn unconformably overlain by Mangapanian Te Waka Formation. The basal sandstone beds contain concretions rich in the gastropod *Struthiolaria (Callusaria) ?calcar*. Overlying siltstone beds contain a Tongaporutuan microfauna (Katz 1973).

Relative chronology of the Kuripapango and Omahaki areas

The stratigraphy of these areas lies across the North Island Shear Belt, and is punctuated by common unconformities. No absolute ages have been determined in these areas, and the relative chronology developed is based entirely on micro- and macrofossil biostratigraphy.

Kuripapango area

Neogene rocks of Tongaporutuan to lowermost Nukumaruan age crop out in the Kuripapango area, although no rocks of Waipipian age are known. Tongaporutuan rocks are restricted in outcrop to the Tutaekuri River near the Donald River confluence, with their age constrained by both the common presence of the Tongaporutuan index scallop *Sectipecten grangei*, and by both planktic and benthic foraminifera, including *Globoconella miotumida, Neogloboquadrina pachyderma,* and *Bolivinita pliobliqua* (U20/f150). These Tongaporutuan beds are unconformably overlain by shallow-water sandstone and minor limestone of the Waikarokaro Sandstone Member (Blowhard Formation). The age of this unit is constrained by the presence of sparse *Sectipecten wollastoni*, the Kapitean index scallop (Beu 1995; Crundwell *et al.* 2004). In places the Waikarokaro Sandstone Member may be underlain by the Spiral Conglomerate Member. A palynological sample from this member (U20/f129) was dominated by *Nothofagidites lachlaniae*, indicating an age of Tongaporutuan and younger (D.C. Mildenhall, GNS Science, pers. comm., cited in Browne 2004a). As the Spiral Conglomerate Member is overlain by Kapitean Waikarokaro

Sandstone Member, Browne (2004a) adopted a Tongaporutuan age for it. However, the presence of bathyal to shelfal Tongaporutuan rocks nearby in the Tutaekuri River suggests that a Kapitean age is more likely for the Spiral Conglomerate Member.

The Blowhard Formation is inferred to be unconformably overlain by the Mangatoro Formation. In the study area Mangatoro Formation contains no visible macrofossils, although foraminifera are abundant and well preserved (Browne 2004a). A middle to upper Opoitian age is assigned to the Mangatoro Formation based on foraminifera (M. Crundwell, GNS Science, pers. comm. cited in Browne 2004a). The Mangatoro Formation is unconformably overlain by the Mangapanian Te Waka Formation, an age confidently assigned on the basis of the presence of common *Phialopecten thomsoni*. No Waipipian rocks are known or exposed in either the Kuripapango or Omahaki Depression areas.

Preserved in several fault-bounded blocks are small areas of the basal Nukumaruan Sentry Box Formation. The age of this formation is tightly constrained to the basal Nukumaruan by the presence of common subantarctic macrofauna including, *Zygochlamys patagonica delicatula* and *Jacquinotia edwarssi*.

Omahaki Depression

The only Neogene rocks cropping out in the Omahaki Depression are of Opoitian age, their ages constrained by both foraminifera and molluscs. The basal beds in this region unconformably overlie Torlesse basement and are alternating fine sandstone and mudstone assigned to the Mangatoro Formation (Appendix I, p. A1-47). They contain an Opoitian planktic foraminiferal content constrained by *Globoconella puncticulata, Globoconella pliozea,* and *Truncorotalia juanai* (U21/f87). The Mangatoro Formation is overlain by fossiliferous conglomerate to pebbly limestone of the Omahaki Formation, which contains the Kapitean-Opoitian gastropod *Struthiolaria (Callusaria) obesa* (Beu 1995).

Relative chronology of the Tangoio and Esk areas

The rocks cropping out in this area conformably overlie the youngest beds in the Maungaharuru Range, Te Waka Range, and Te Pohue areas (see above). Detailed geological mapping of many closely-spaced horizons in this part of the study area has improved the understanding of the relative chronology of the area. The geochemical matching of glass shards in the Hikuroa Pumice Member to tephras in the ODP 1124 record, described earlier in this chapter, helps age sequences in the Tangoio Block and the chronology of the Nukumaruan succession in central Hawke's Bay.

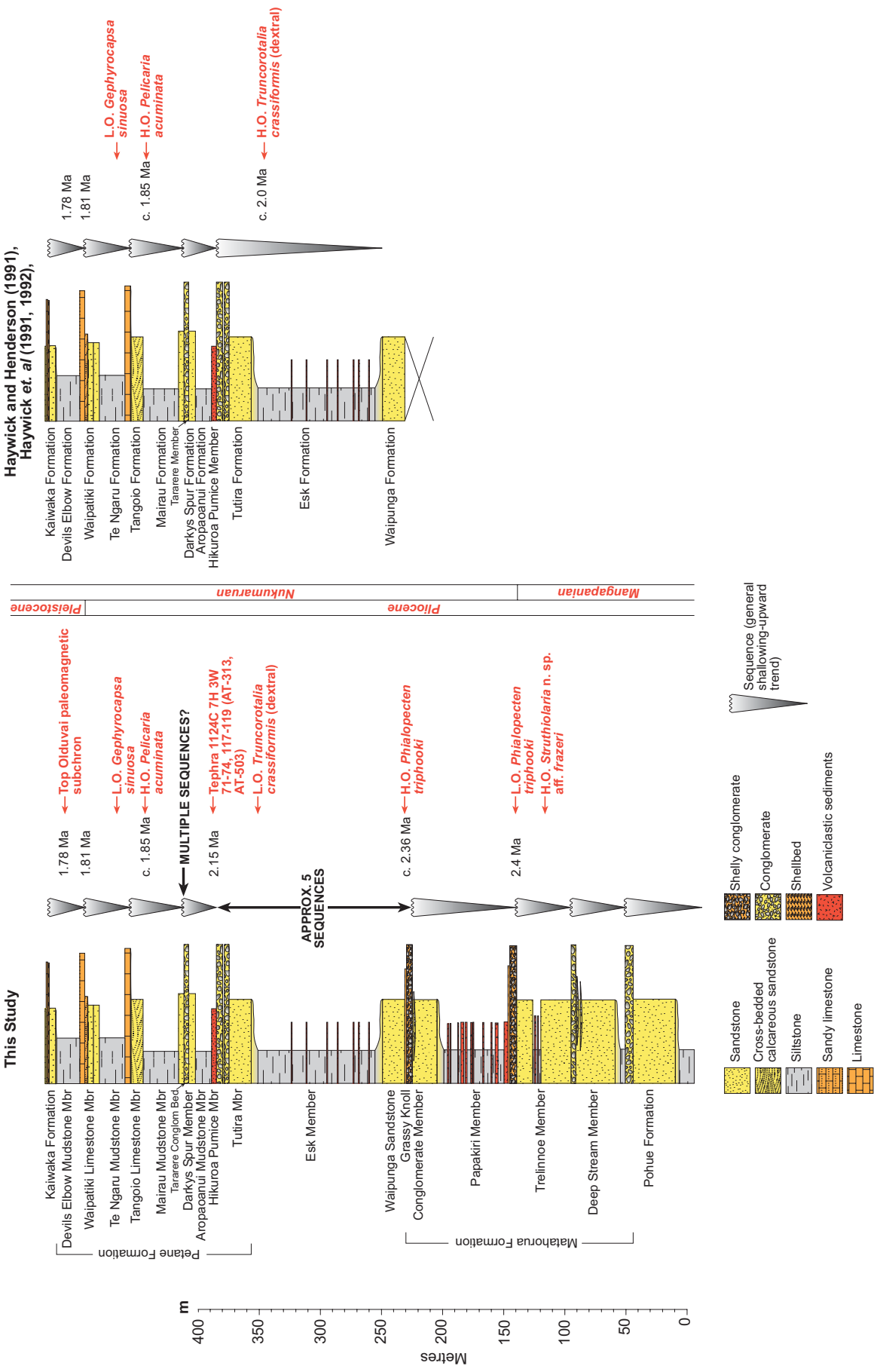


Fig. 4.7: Relative chronology of Nukumaruan strata as determined in this study compared with the chronology of Haywick *et al.* (1991). Biostratigraphic and other markers are shown in red.

The stratigraphy of the Tangoio Block was regarded by Beu and Edwards (1984), Haywick *et al.* (1991), and Beu (1995) as a continuous, uninterrupted succession up to 550 m thick of middle to upper Nukumaruan age. These beds accumulated during a known period of obliquity-controlled sea-level cycles with a duration of 41 k.y. (e.g. Naish and Kamp 1997). Haywick *et al.* (1991), Haywick and Henderson (1991), and Haywick (2000) assigned all beds in the Tangoio Block to an uninterrupted period comprising five distinct cyclothems, each with a duration of 41 k.y. The inference of this is that the Tangoio Block succession accumulated over approximately 205 k.y. (Fig. 4.7).

The conglomerate bed in the Papakiri Member of the Matahorua Formation contains the L.O. of *Phialopecten triphooki* and *Towaipecten mariae,* and marks the base of the Nukumaruan Stage at 2.40 Ma. Sandstone immediately underlying the conglomerate bed contains the H.O. of the large gastropod *Struthiolaria* n. sp. aff. *frazeri* (Beu 1995; A. Beu, GNS Science, pers. comm. 2001) (Fig. 4.7). The Grassy Knoll Conglomerate Member (itself overlain by either Waipunga Sandstone or Esk Mudstone) overlies the Papakiri Member and also contains *P. triphooki.* The top of this member is therefore assigned an age 41 k.y. younger than the base Nukumaruan (c. 2.36 Ma). This means that where the Waipunga Sandstone is absent the age of the base of the Esk Mudstone is approximately 2.36 Ma. Where Waipunga Sandstone is present the age of the base of the Esk Mudstone is likely to be about 2.32-2.28 Ma.

The L.O. of *Gephyrocapsa sinuosa* near the base of the Te Ngaru Mudstone Member (Beu and Edwards 1984; Beu 1995) indicated that the Plio-Pleistocene boundary (1.81 Ma) lies within the overlying Waipatiki Limestone Member (Beu 1995) (Fig. 4.7). This therefore provided an age marker in the upper part of the Nukumaruan succession for the work of Haywick (1990). At least one “cyclothem” occurs above this boundary, and four below, meaning that the oldest beds in this succession, as described by Haywick, are by inference approximately 1.97 Ma, and the youngest 1.77 Ma. The age of the top of the succession (1.77 Ma), together with the position of the Plio-Pleistocene boundary, correlates well with the inferred position of the top of the Olduvai paleomagnetic subchron (1.78 Ma; Cooper 2004) in the Devils Elbow Mudstone above the Plio-Pleistocene boundary (P. Kamp, University of Waikato, unpubl. data).

A geochemical correlation of glass shards in the Hikuroa Pumice Member to tephra in the ODP 1124 record (Fig. 4.6) provides an age of approximately 2.14 Ma for the Hikuroa Pumice Member. The age of the base of the Kaiwaka Formation is approximately 1.76 Ma. Therefore, an interval of 380 k.y. is inferred between the Hikuroa Pumice Member and the Kaiwaka Formation. If this interval was the result of four 41 k.y. cyclothems, the interval covered should in theory cover 164 k.y. This study suggests that in the Tangoio Block succession a period of 216 k.y. is effectively

"missing". It is inferred that this "missing time" may be accommodated in cyptic sequences within the Darkys Spur and Mairau Mudstone Members.

The Esk Mudstone is a minimum of 120 m thick in the Tangoio Block, and up to 420 m thick in the Ohara Depression Fig. 4.7, 4.8). The thickness of the Esk Mudstone as a single HST is anomalous with the thickness of all other HST deposits identified in the study area which are typically 10-40 m thick. It is also anomalously thick when compared to other Plio-Pleistocene HST facies in New Zealand such as those in the Rangitikei River section in Wanganui Basin (Naish and Kamp 1997). Also, the 2.36 Ma inferred age at the base of the formation in the Esk and Waikoau River catchments, and the 2.14 Ma age for the overlying Tutira and Hikuroa Pumice Members (Petane Formation) gives a period of approximately 220 k.y. in which the Esk Mudstone appears to have accumulated. Clearly, in the Esk and Waikoau River sections Esk Mudstone probably represents up to five 41 k.y. sea-level cycles (Fig. 4.7). This study also concludes that the succession in the Tangoio Block did not accumulate as the result of only five, uninterrupted sea-level cycles (Fig. 4.7).

Relative chronology of the Napier, Taradale, and Puketapu areas

Stratigraphy cropping out in the Taradale and Puketapu areas is mostly an extension of the stratigraphy exposed in the Tangoio Block to the northeast. The oldest rocks cropping out are of Lower to early-Upper Nukumaruan age (Late Pliocene), and the youngest are Upper Nukumaruan (Early Pleistocene). The oldest Neogene beds recorded in the Taradale area were intercepted in the Taradale-1 drillhole (Darley and Kirby 1969). These are of Eocene (Mangaorapan to Waipawan) age. Most of the rocks intercepted in Taradale-1 are part of the Taradale Mudstone of Waipipian to "middle" Nukumaruan age. *Truncorotalia crassula* and a few *T. crassaformis* (coiling predominance unclear) occur throughout the Nukumaruan part of the Taradale Mudstone in Taradale-1 (G.H. Scott, pers. comm., cited in Beu 1995). In outcrop, above the level of rocks in Taradale-1, the Taradale Mudstone is only of Nukumaruan age. The formation here contains the Lower Nukumaruan index gastropod *Pelicaria acuminata* and the Lower Nukumaruan planktic foraminiferal assemblage of *T. crassula* and dextral *T. crassaformis* (Beu 1995). This planktic assemblage is also present low in the Scinde Island Formation at Scinde Island (see below). The Taradale Mudstone is conformably overlain by members of the Petane Formation from the Park Island Limestone Member upsection to the Devils Elbow Mudstone Member. The Petane Formation is overlain by the Kaiwaka Formation.

Stratigraphy of the Taradale area is separated from that in the Napier area by the Napier Fault (see Chapter Five, p.174; Enclosure 3, line D-D'). The only Neogene rocks cropping out in the Napier area are of Late Pliocene Scinde Island Formation and a possible thin veneer of Middle

Pleistocene Kidnappers Group rocks at Scinde Island. The oldest rocks documented in the Napier area were intercepted by the Hukarere-1 drillhole (Westech Energy NZ Ltd 2001) and are of Haumurian (Late Cretaceous) age. These beds are overlain by strata of Paleocene, Eocene and Early Oligocene age. They are separated by a significant unconformity from overlying rocks of Late Miocene (Tongaporutuan to Kapitean) age. The Late Miocene beds are overlain by "early to middle" Pliocene rocks of Opoitian to Waipipian age. No Mangapanian strata were reported in Hukarere-1. Over 380 m of Lower Nukumaruan mudstone overlies the Opoitian-Waipipian succession (Westech Energy NZ Ltd 2001). This mudstone is inferred to be overlain by Scinde Island Formation, exposed at Scinde Island itself. Scinde Island is the type locality of the Lower Nukumaruan index scallop *Phialopecten triphooki*.

Two FRF samples from near the base of the Scinde Island Formation have yielded reliable planktic foraminiferal faunas (V21/f6005, type locality of *P. triphooki*, Milton Road, Scinde Island; V21/f3, drillhole at Onekawa) (Beu 1995). Both faunas contained the Lower Nukumaruan zonal species *Truncorotalia crassula* and dextral *T. crassaformis* (Beu 1995). *Phialopecten triphooki* is restricted to only the lower limestone bed (Member A) of the Scinde Island Formation, so therefore a confident Lower Nukumaruan age can only be applied to this horizon.

The ages of the two upper limestones of the Scinde Island Formation at Scinde Island remains unresolved, although the lack of *Phialopecten triphooki* suggests a "middle" Nukumaruan age is probable. It may be that these limestones are lateral equivalents of the Park Island and Tangoio Limestone members of the Petane Formation, although biostratigraphy and geological mapping at this stage cannot resolve this.

Relative chronology of the Matapiro and Sherenden areas

The Grassy Knoll Conglomerate Member (upper member of the Matahorua Formation) has been confidently mapped from the Waikoau River section southwest through the Te Pohue, Patoka, and Waihau areas, into the Tutaekuri River section, and from there to Taihape Road near Willowford. The stratigraphic position of this bed is well established in the Esk River section where it is one sequence above the base of the Nukumaruan Stage (2.40 Ma), defined by the L.O. of *Phialopecten triphooki.* This means that the age of the Grassy Knoll Conglomerate Member is likely to be c. 2.36 Ma, which helps constrain the age of the overlying Esk Mudstone in the Sherenden and Waihau areas. The Esk Mudstone in the Sherenden area is overlain by the Kikowhero Member (Okauawa Formation), which itself has been correlated through geological mapping to the Tutira Formation (c. 2.14 Ma).

The inferred age of the Hikuroa Pumice Member leads to the possibility that several sequences may be "tied-up" in the Darkys Spur Member, Mariau Mudstone Member, and their lateral equivalents. This is supported by other geological sections in the study area, such as in the Darkys Spur section and the Flag Range area, where cryptic, "masked" cycles with poorly-developed shellbeds have been observed. The stratigraphic level representing the Darkys Spur Member has been correlated from the type section to the Park Island Limestone Member at Napier, and the uppermost conglomerate bed of the Okauawa Formation (top of the Whakamarumaru Member; Enclosure 5), which itself crops out from Mount Cameron (Column Da-1) southwest through Flag Range, to the Ngaruroro River and into the Ohara Depression near Big Hill (Columns Ke-4, Ke-5). At Flag Range the Whakamarumaru Member is overlain by the Mairau Mudstone and then in turn by the Flag Range Conglomerate Member (Petane Formation). In a private road cutting (Column Sh-3) on Flag Range, anomalous shellbeds have been described that resembled TSTs, but could not be correlated into nearby river and stream sections. It is possible that these shellbeds may mark poorly-developed sequences, or even sequences that were removed by erosion prior to deposition of the Flag Range Conglomerate Member.

Geological mapping in this study has demonstrated that the Waipatiki Limestone Member cropping out in the Tangoio Block is the same stratigraphic unit as the Matapiro Limestone of Beu (1995) and Baggs (2004) (see Chapter Three, p. 79, and Appendix I, p. A1-172 for more detail). The presence of the Plio-Pleistocene boundary in the Waipatiki Limestone Member in the Tangoio Block (Beu and Edwards 1984; Haywick *et al.* 1991) provides a marker horizon (1.81 Ma) for determining the chronology of beds south of this area. Throughout the Matapiro region strata are broadly folded into a structure named the Matapiro Syncline (see Chapter Five, p. 172). The Waipatiki Limestone Member is often the stratigraphically highest unit involved in the Matapiro Syncline, and although it reaches ground level the unit doesn't completely enter the subsurface. This is in contrast to horizons below the Waipatiki Limestone Member which enter the subsurface on either limb of the syncline. Because the Waipatiki Limestone Member remains in outcrop throughout the syncline, it provides a horizon which can be used to correlate stratigraphy on either limb of the syncline. On the eastern limb of the Matapiro Syncline the Waipatiki Limestone Member is underlain by the Te Ngaru Mudstone, Tangoio Formation, Mairau Mudstone, and Park Island Limestone Members (Petane Formation). The ages of these units are the same as those assigned to the formations and members cropping out in the Tangoio Block. On the western limb of the syncline the Waipatiki Limestone Member is underlain by the Te Ngaru Mudstone Member, Flag Range Conglomerate Member (Petane Formation), Whakamarumaru and Kikowhero Members (Okauawa Formation), and Esk Mudstone. The Flag Range Conglomerate Member is assigned an age of 1.77 Ma, and the Kikowhero Member 2.14 Ma. The age of the Whakamarumaru Member lies somewhere between these ages, and is inferred to be c. 2.01 Ma.

The 240 k.y. "missing" between the Whakamarumaru Member and Flag Range Conglomerate Member is inferred to be tied up in poorly-developed sequences, or sequences that have been removed through erosion. This is similar to the situation in the Tangoio Block.

Relative chronology of the Ohara Depression and Kereru area

This study has refined the chronology for the Tangoio Block stratigraphy, which has then allowed for the re-evaluation of Nukumaruan chronology elsewhere in the basin. Geological mapping of horizons from the Tangoio Block southwest into the Kereru and Ohara Depression areas has also refined the age of the succession here (Fig. 4.8, 4.9). The Darkys Spur Member has been correlated with the top of the Whakamarumaru Member (Okauawa Formation). The top of the Tutira Member (marked by the Hikuroa Pumice Member, 2.15 Ma) has been correlated with the top of the Kikowhero Member of the Okauawa Formation. The Kikowhero Member is underlain by the Kereru Formation, which is in turn underlain by the Esk Mudstone which crops out in a NE-SW belt from the Tangoio Block to the Ohara Depression. The Esk Mudstone is underlain by the Sentry Box Formation, a unit that contains both *Phialopecten triphooki* and *Zygochlamys patagonica delicatula*. Neither of these pectinids are known in rocks in the North Island younger than about 2.28 Ma (approx. three 41 k.y. sequences above base Nukumaruan), providing an uppermost limit to the age of the base of the Esk Mudstone and the top of the Sentry Box Formation. The base of the Sentry Box Formation contains a very diagnostic basal Nukumaruan fauna consisting of *Zygochlamys patagonica delicatula, Phialopecten triphooki, Phialopecten thomsoni, Maoricardium spatiosum,* and *Crassostrea ingens.* The base of the Nukumaruan Stage is 2.4 Ma (Beu *et al.* 2004). Based on molluscan macrofossils the underlying Puketitiri Formation (Fig. 4.8) is of Mangapanian age.

The top of the Esk Mudstone increases in age from the Tangoio Block southwest to the Ohara Depression, together with an over three-fold increase in thickness (Fig. 4.9). The base of the formation in the Ohara Depression (top Sentry Box Formation) is inferred to be approximately 2.36 Ma, although there is little biostratigraphic or other chronological control to refine this. Lithologically the contact is marked by a change from coarse-grained shelfal limestone to bathyal mudstone (Erdman and Kelsey 1992; Beu 1995). The contact also marks the last occurrence of *Phialopecten* and *Zygochlamys* in this part of the basin. The base of the Esk Mudstone could be younger than 2.36 Ma based on the thickness of the underlying Sentry Box Formation, and the highest-known occurrence of *Phialopecten* (approx. 2.28 Ma) in the study area. The Esk Mudstone in the Ohara Depression and Kereru areas is overlain by the Kereru Formation which lies stratigraphically below the lateral equivalent of the Tutira Member. Up to three discrete sequences have been observed in the Kereru Formation, each of which is inferred to represent a 41 k.y. sea-level oscillation. The Tutira Member is assigned an age of approximately 2.15 Ma.

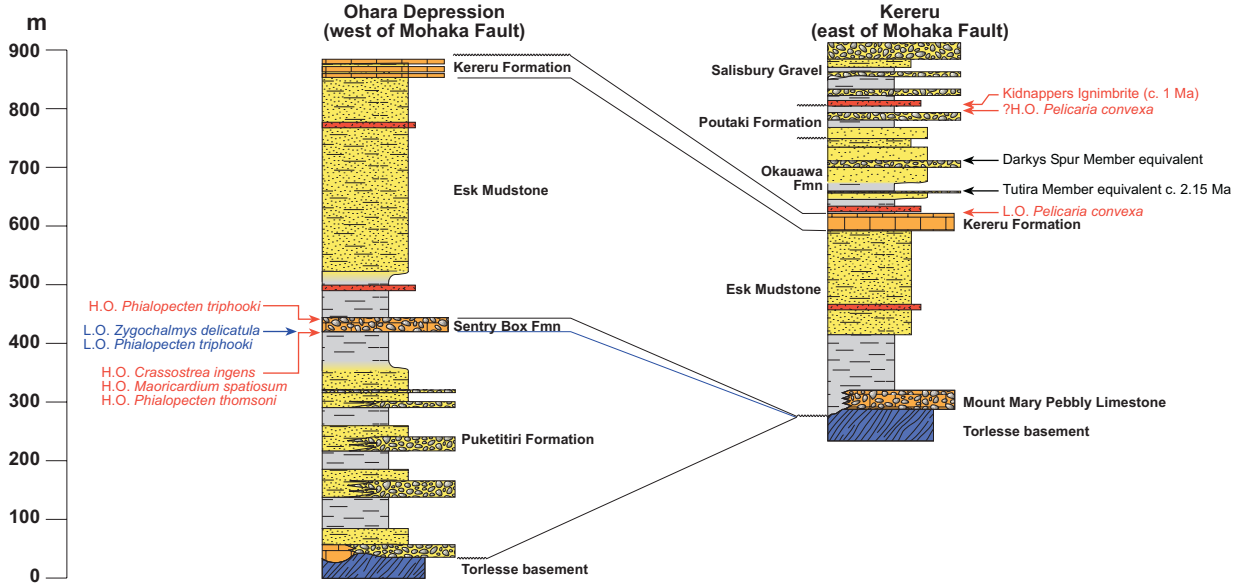
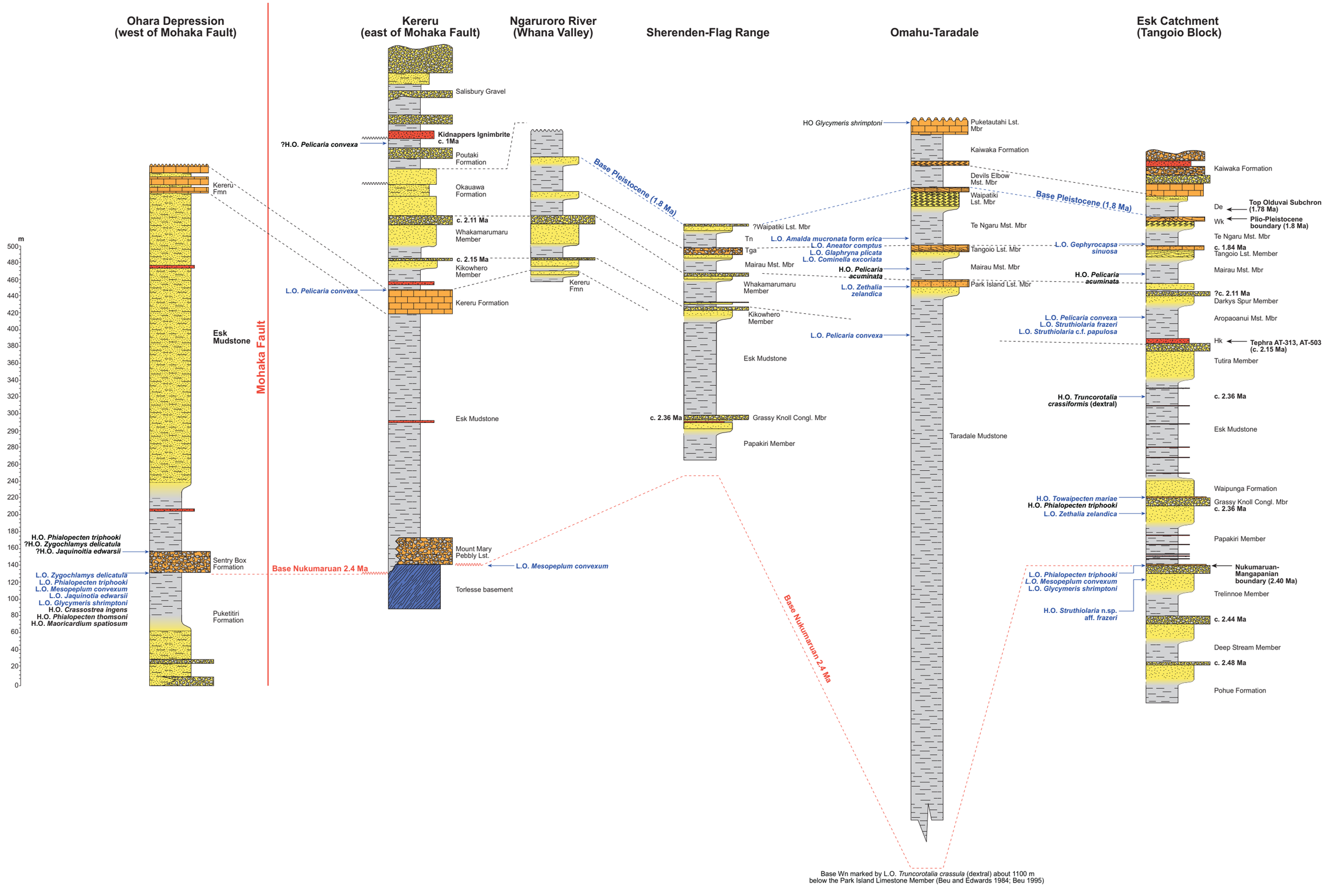


Fig. 4.8: Simplified stratigraphic columns illustrating the inferred relationships between stratigraphic units in the Ohara Depression and the Kereru area. Stratigraphic columns are adapted from Erdman and Kelsey (1992). Also illustrated are the locations of key biostratigraphic and other correlation markers in this area.

The presence of the three inferred 41 k.y. sequences in the underlying Kereru Formation would therefore imply an age of approximately 2.26 Ma for the top of the Esk Mudstone (and base of the Kereru Formation) in the Ohara Depression. The net result of this is that Esk Mudstone in the Ohara Depression seems to have accumulated over a period of only 100 k.y., contrasting with the up to 220 k.y. inferred for the Esk and Waikoau River catchments further northeast. This has important implications for sedimentation rates (see Fig. 7.10, Chapter Seven). Esk Mudstone in the Ohara Depression is up to 420 m thick (Erdman and Kelsey 1992), whereas Esk Mudstone around the Esk and Waikoau areas is only 120 m thick (Haywick *et al.* 1991; Bland 2001). The inference is therefore that sedimentation rates during deposition of the Esk Mudstone were 4.2 m/k.y. in the Ohara Depression, but 0.5 m/k.y. in the Esk and Waikoau areas. Deposition of the Taradale Mudstone (Waipipian to "middle" Nukumaruan) infers a sedimentation rate of about 0.7 m/k.y. These values have important implications in terms of Lower Nukumaruan paleogeography and sediment supply vectors.

Fig. 4.9 (facing page): Simplified stratigraphic columns of the Nukumaruan stratigraphy described in this study. The positions of biostratigraphic lowest occurrences are shown in blue font; biostratigraphic highest occurrences are shown in black font. Other markers are shown in black bold font. The red dashed line is the Nukumaruan-Mangapanian boundary. The blue dashed line is the Plio-Pleistocene boundary. De (Devils Elbow Mudstone Member); Hk (Hikuroa Pumice Member); Tga (Flag Range Conglomerate Member); Tn (Te Ngaru Mudstone Member); Wk (Waipatiki Limestone Member). Some fossil datums in the Esk Catchment section are based on Beu and Edwards (1984) and Haywick *et al.* (1991). Ohara Depression and Kereru stratigraphic columns are adapted from Erdman and Kelsey (1992).


Ohara Depression (west of Mohaka Fault)
Kereru (east of Mohaka Fault)
Ngaruroro River (Whana Valley)
Sherenden-Flag Range
Omahu-Taradale
Esk Catchment (Tangoio Block)
m
500
480
460
440
420
400
380
360
340
320
300
290
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
Kereru Fmn
Esk Mudstone
Mohaka Fault
H.O. Phialopecten triphooki
?H.O. Zygochlamys delicatula
?H.O. Jaquinoitia edwarsii
L.O. Zygochlamys delicatula
L.O. Phialopecten triphooki
L.O. Mesopeplum convexum
L.O. Jaquinotia edwarsii
L.O. Glycymeris shrimptoni
H.O. Crassostrea ingens
H.O. Phialopecten thomsoni
H.O. Maoricardium spatiosum
Sentry Box Formation
Puketitiri Formation
Base Nukumaruan 2.4 Ma
Salisbury Gravel
?H.O. Pelicaria convexa
Kidnappers Ignimbrite c. 1Ma
Poutaki Formation
Okauawa Formation
c. 2.11 Ma
Whakamarumaru Member
c. 2.15 Ma
Kikowhero Member
L.O. Pelicaria convexa
Kereru Formation
Esk Mudstone
Mount Mary Pebbly Lst.
L.O. Mesopeplum convexum
Torlesse basement
Kereru Fmn
Base Pleistocene (1.8 Ma)
?Waipatiki Lst. Mbr
Tn
Tga
L.O. Amalda mucronata form erica
L.O. Aneator comptus
L.O. Glaphryna plicata
L.O. Cominella excoriata
Mairau Mst. Mbr
H.O. Pelicaria acuminata
Whakamarumaru Member
L.O. Zethalia zelandica
Kikowhero Member
L.O. Pelicaria convexa
Esk Mudstone
c. 2.36 Ma
Grassy Knoll Congl. Mbr
Papakiri Member
HO Glycymeris shrimptoni
Puketautahi Lst. Mbr
Kaiwaka Formation
Devils Elbow Mst. Mbr
Waipatiki Lst. Mbr
Te Ngaru Mst. Mbr
Tangoio Lst. Mbr
Mairau Mst. Mbr
Park Island Lst. Mbr
Taradale Mudstone
Base Nukumaruan 2.4 Ma
Base Wn marked by L.O. Truncorotalia crassula (dextral) about 1100 m
below the Park Island Limestone Member (Beu and Edwards 1984; Beu 1995)
Base Pleistocene (1.8 Ma)
L.O. Gephyrocapsa sinuosa
H.O. Pelicaria acuminata
L.O. Pelicaria convexa
L.O. Struthiolaria frazeri
L.O. Struthiolaria c.f. papulosa
H.O. Truncorotalia crassiformis (dextral)
Kaiwaka Formation
De
Top Olduvai Subchron (1.78 Ma)
Wk
Plio-Pleistocene boundary (1.8 Ma)
Te Ngaru Mst. Mbr
c. 1.84 Ma
Tangoio Lst. Member
Mairau Mst. Mbr
?c. 2.11 Ma
Darkys Spur Member
Aropaoanui Mst. Mbr
Hk
Tephra AT-313, AT-503 (c. 2.15 Ma)
Tutira Member
c. 2.36 Ma
Esk Mudstone
Waipunga Formation
H.O. Towaipecten mariae
H.O. Phialopecten triphooki
L.O. Zethalia zelandica
Grassy Knoll Congl. Mbr
c. 2.36 Ma
Papakiri Member
Nukumaruan-Mangapanian boundary (2.40 Ma)
L.O. Phialopecten triphooki
L.O. Mesopeplum convexum
L.O. Glycymeris shrimptoni
Trelinnoe Member
H.O. Struthiolaria n.sp. aff. frazeri
c. 2.44 Ma
Deep Stream Member
c. 2.48 Ma
Pohue Formation

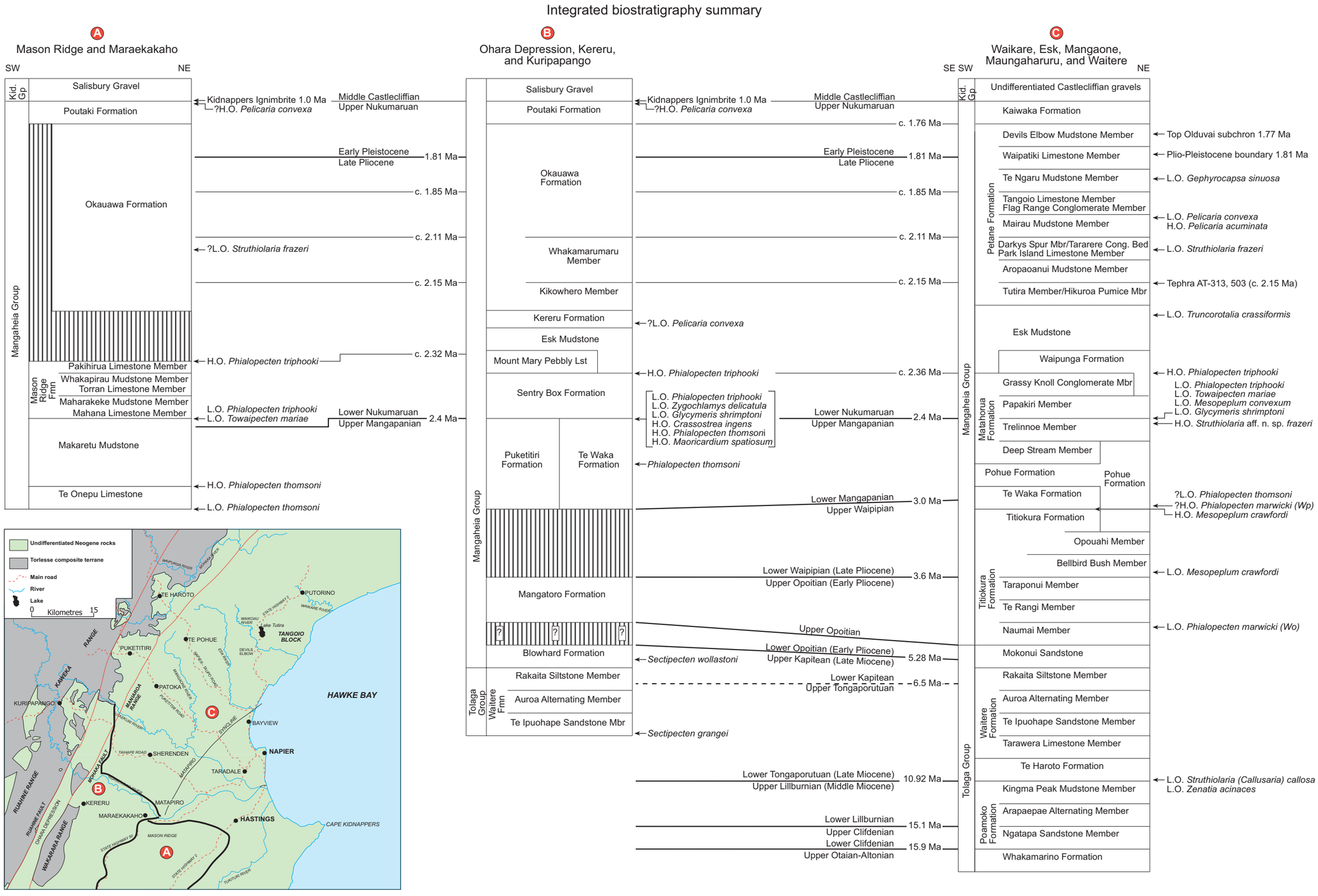


Fig. 4.10: Diagrammatic summary of the integrated biostrigraphy and age model developed for the basin fill in central Hawke's Bay.

The presence of basal Nukumaruan Sentry Box Formation has implications for the timing of the current phase of uplift of the North Island axial ranges. Similarly, refining the age of the Esk Mudstone and Kereru Formation has allowed more accurate constraints to be placed on the re-inception of displacement on the Mohaka and Wakarara Fault systems in the Late Pliocene. These implications are discussed in more detail in Chapter Five.

Relative chronology of the Mason Ridge area

Previous workers have attempted to correlate Lower Nukumaruan limestone at Scinde Island with limestones cropping out at Mason Ridge (e.g. Beu *et al.* 1980; Beu 1995; see Chapter Three, p. 86, and Appendix I, p. A1-124, for more discussion on this issue). Unlike the Scinde Island Formation where only the lowermost of the three limestone members contains *Phialopecten triphooki* (Beu 1995), both the lowermost and uppermost of the three limestone members of the Mason Ridge Formation contain *P. triphooki* (Caron 2002; Dyer 2005). The Mason Ridge Formation is therefore entirely of Lower Nukumaruan age based on the presence of *P. triphooki*. Chronologically it is probable that the Mason Ridge Formation is equivalent to the lowermost Scinde Island Formation limestone member (Member A), the Sentry Box Formation, upper beds of the Matahorua Formation, and the Pakipaki Limestone south of Hastings. Mason Ridge Formation conformably overlies the upper Mangapanian to Lower Nukumaruan Makaretu Mudstone, which itself overlies the Mangapanian Te Onepu Limestone. The Te Onepu Limestone (the classic "Te Aute Limestone") contains common to abundant Mangapanian-restricted *Phialopecten thomsoni* and is therefore well constrained in terms of its age. The Mason Ridge Formation is unconformably overlain by both the middle to upper Nukumaruan (Late Pliocene) Okauawa and Poutaki Formations, the ages of which are discussed in the previous section (Chronology of the Ohara Depression and Kereru area).

SUMMARY

By integrating macrofossil and microfossil biostratigraphy, correlation of tephra, and a paleomagnetic datum, an age model has been established for the Neogene succession in the study area. This relative chronology is summarised in Fig. 4.10, which presents a simplified lithostratigraphy for the study area, together with a summary of the integrated biostratigraphy and relative chronology developed. It shows the locations of macrofossil and microfossil datums used in dating the sedimentary succession, together with other useful marker horizons. For purposes of clarity, the Opoitian (Early Pliocene) beds cropping out in the Pakaututu and Omahaki areas, the Taradale Mudstone (Waipipian-"middle" Nukumaruan (Late Pliocene)), and Scinde Island Formation (Lower Nukumaruan (Late Pliocene)) have been omitted from this diagram. These areas have, however, been discussed elsewhere in this chapter.

CHAPTER FIVE

GEOLOGICAL STRUCTURE

INTRODUCTION

Eastern North Island, of which Hawke's Bay province is a part, lies within the forearc region of the subduction zone associated with the obliquely convergent Australia-Pacific plate boundary zone (Fig. 5.1). The North Island Shear Belt which lies within the western part of the study area is a zone in which strain is expressed in a series of dip-slip (more outboard position) and strike-slip (inboard) faults. Uplift has been greater within the North Island Shear Belt than the main part of the forearc basin. Locally dips on Late Neogene rocks within the NISB are up to 70°, but generally range from 40-30°, and gradually decrease to 4-2° towards the east (coast).

Beanland (1995) and authors of other papers have characterised the character of the North Island Shear Belt. Cashman *et al*. (1992) and Erdman and Kelsey (1992) studied strain partitioning across southern parts of the study area. Structural elements of the Esk catchment were documented by Leith (2003), and of the middle reaches of the Mohaka River around the confluence with the Te Hoe River by Cutten (1994).

The purpose of this chapter is to provide an overview of the onshore geological structures in central parts of Hawke's Bay, mainly those involving the forearc basin, but also extending west to the main structural ridge and east into the accretionary wedge. It describes the character of four structural domains in the study area (Fig. 5.2), the style of deformation within them, and considers constraints on the timing and magnitude of deformation. The information builds on several earlier structural studies, especially those by Cashman *et al.* (1992), Erdman and Kelsey (1992), Beanland (1995), Beanland and Haines (1998), and Beanland *et al.* (1998).

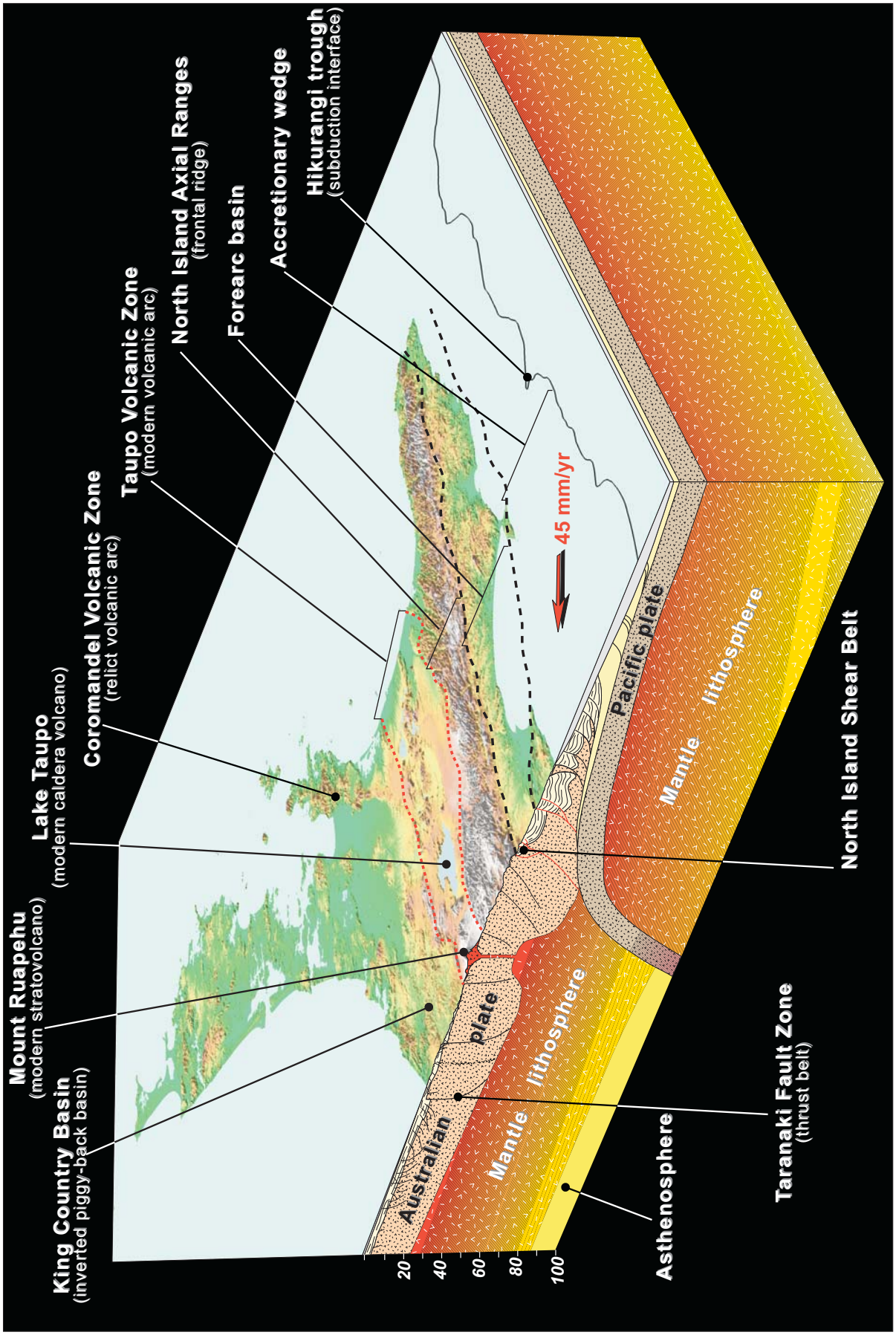


Fig. 5.1: Illustration of the tectonic setting of eastern North Island, New Zealand. Data used are derived from Beanland (1995), Field *et al.* (1997), and Barnes *et al.* (2002).

GEOLOGICAL SETTING AND STRUCTURAL OVERVIEW

Hawke's Bay contains a forearc basin bounded to the east by the inboard part of an uplifted and semi-emergent accretionary wedge, and on its western side by an elevated fault-bounded frontal ridge underlain by indurated Mesozoic basement (Fig. 5.1). Hawke Bay is a major coastal indentation, representing the submarine portion of the forearc basin. The frontal basement ridge in the west contains along its eastern side a zone of dip-slip and dextral oblique-slip faults collectively known as the North Island Shear Belt. Major faults in this zone, principally the Ruahine and Mohaka faults, represent the northeastern continuation of the Wellington Fault. The present study area extends from the frontal ridge across the forearc basin succession to the inboard margin of the accretionary wedge. The forearc basin in its present configuration began to develop in the Late Miocene, and was at its greatest extent as a depocentre in the "middle and late" Pliocene. While much of the basin is now inverted and subaerially exposed, part remains submarine in Hawke Bay, and active non-marine deposition is occurring in the Heretaunga Plains. During the Pleistocene, accretionary processes have resulted in the eastern margin of the forearc basin becoming involved in the accretionary prism, while the faults bordering the axial ranges have extended into the basin succession on the western side.

The study area, and the wider East Coast Basin in general, displays a strong NE-SW structural grain that is roughly parallel to the modern plate boundary zone (Fig. 5.3). The regional strike of the beds making up the sedimentary fill of the basin is more easterly than the oblique-slip fault system, meaning that progressively younger beds are truncated to the south in western parts of Hawke's Bay by these faults.

STRUCTURAL DOMAINS

The onshore structural elements of Hawke's Bay can be usefully classified into four structural domains following the approach of Cashman *et al.* (1992) and Beanland *et al.* (1998) (Fig. 5.2). Each domain reflects a different style and degree of deformation that allows it to be differentiated from adjacent areas. The four domains (from west to east) are the axial range domain, the range front contractional domain, the central forearc basin domain, and the eastern contractional domain.

AXIAL RANGE DOMAIN: AN OVERVIEW

The axial range domain (Fig. 5.2) is characterised by strike-slip faults, and contains the Wellington, Ruahine, Mohaka and Whakatane Faults, and related structures. These structures

have prominent active traces that at a broad scale are almost linear and extend up to 400-500 km in a NNE direction (Beanland *et al.* 1998).

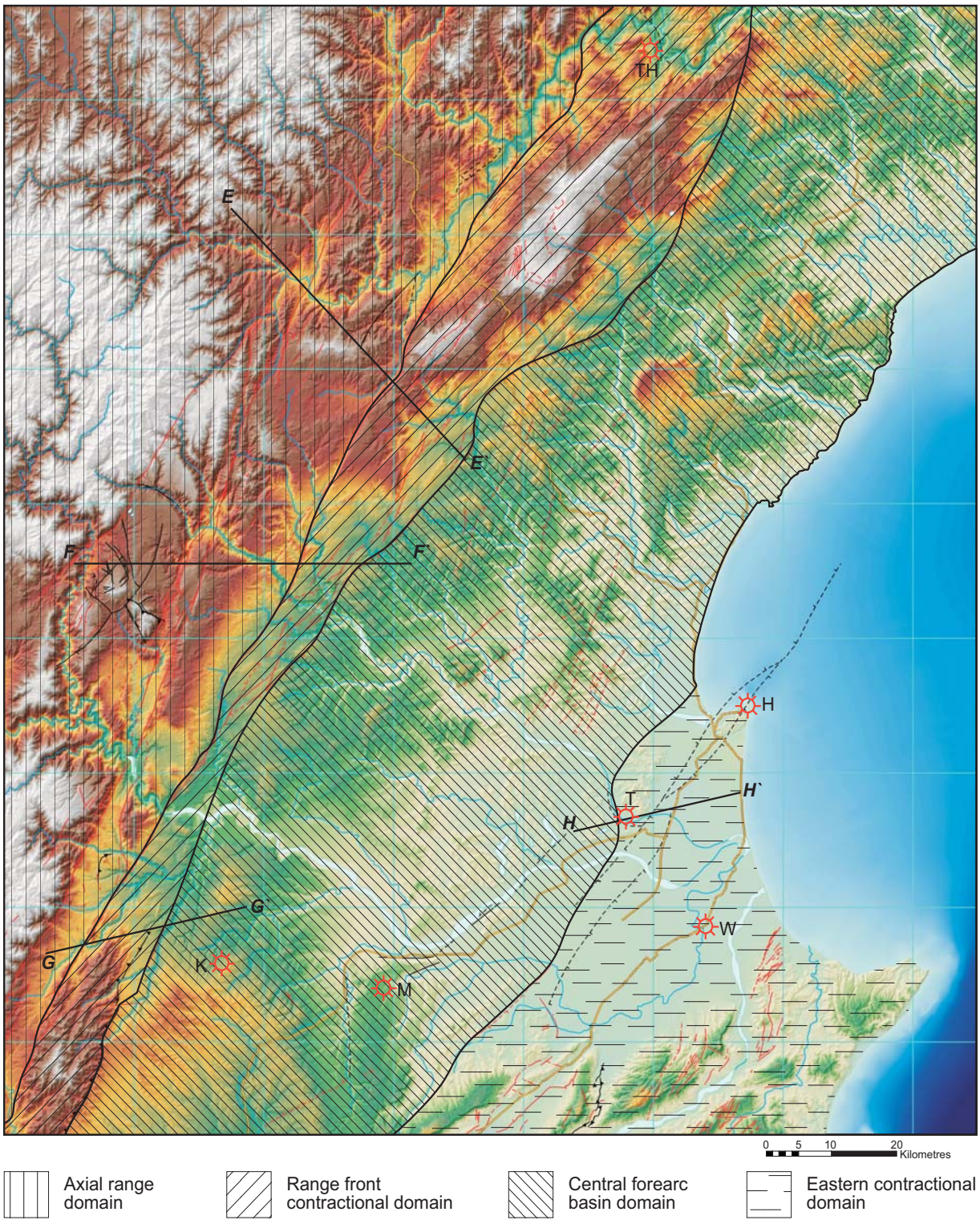


Fig. 5.2: The four structural domains defined in this study (overlay patterns). Transect lines E-E‘ through H-H‘ correspond to geological cross-sections presented in Fig. 5.5, 5.7, 5.12 and 5.15. Red symbols indicate the location of hydrocarbon exploration wells in the study area: TH, Te Hoe-1; K, Kereru-1; M, Mason Ridge-1; H, Hukarere-1; T, Taradale-1; W, Whakatu-1. Vertical and horizontal blue lines are 10 km NZMS 260 series gridlines. State highways (orange lines), and significant water bodies (blue lines and light-blue polygons) are also shown.

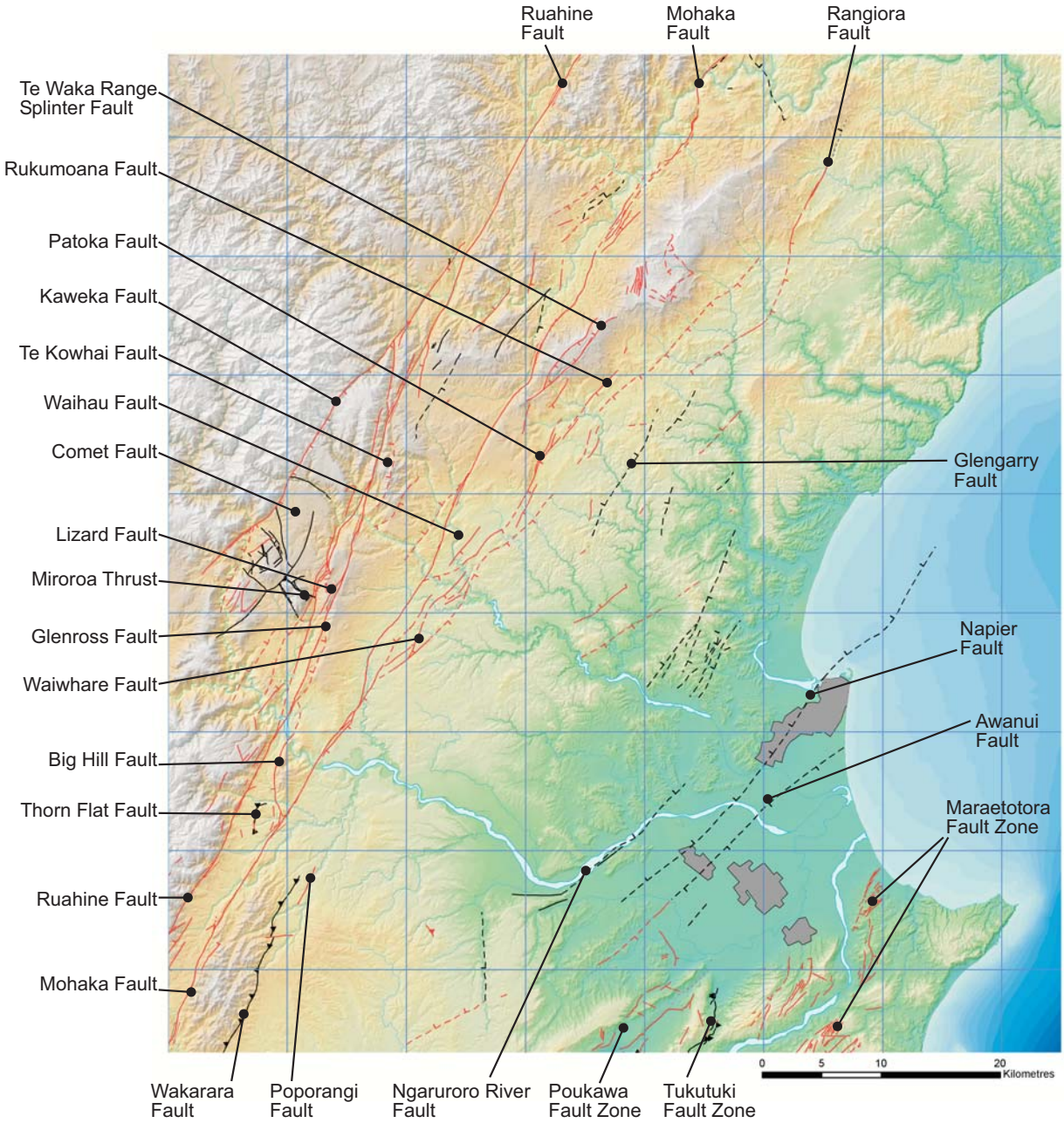


Fig. 5.3: Locations of major faults and fault zones in the study area. Red lines indicate known or inferred active faults, black lines indicate other faults. Note the northeast-southwest structural grain. Vertical and horizontal blue lines are 10 km NZMS 260 series gridlines. Significant water bodies (blue lines and light-blue polygons), and major residential areas (grey polygons) are also shown.

The Ruahine (Fig. 5.3, 5.4) and Mohaka Faults (Fig. 5.3) are the most significant faults in the study area in terms of lateral continuity and amount of displacement. They are both presently oblique-slip structures that parallel each other striking about 030°. Although they have a component of vertical offset as indicated by striae on the fault planes (Erdman and Kelsey 1992), this is typically much less than strike-slip displacement. The estimated ratio of horizontal to vertical offset on Late Quaternary topographic features on the Mohaka Fault in the Ohara Depression ranges between >1:1 to 8:1 (Erdman and Kelsey 1992). For the Ruahine Fault the ratio was estimated at 2.1:1.

These two faults are dramatic because they mostly form the geological boundary at the surface between Torlesse basement underlying the axial ranges and adjacent Neogene sedimentary rocks of the forearc basin. However, as shown on geological cross-sections, basement occurs on both sides of these faults and underlies most of the forearc basin (Fig. 5.5, 5.7, 5.11; Enclosure 3).

Although characterised by oblique-slip faults, the axial range domain also contains numerous dip-slip (reverse-dominated) faults of varying throw. Between the Ruahine and Mohaka Faults folding and reverse faulting dominate modern deformation. The Kaweka Fault, located west of the Ruahine Fault (Fig. 5.3), is the main structure on which uplift of basement in the Kaweka Range has occurred (Fig. 5.7). Both the Mohaka and Ruahine Faults continue outside the boundaries of the study area. The Kaweka Fault appears to stop between the Mohaka-Ripia River confluence and the Napier-Taupo Road. Many of the significant faults along the axial ranges, such as the Kaweka and Glenross Faults (Fig. 5.3), are inferred to merge at depth with the Ruahine and Mohaka Faults (e.g. Fig. 5.7). Many faults in the adjacent range front contractional domain, such as the Patoka Fault, are also inferred to merge at depth with the Mohaka Fault, although they mostly appear to be dip-slip in character.

Faults

Ruahine Fault

The Ruahine Fault (Fig. 5.4, 5.6) is the western of two branches of the Wellington Fault, the other being the Mohaka Fault. The Wellington Fault bifurcates into these two parts near the Manawatu Gorge (Langridge *et al.* 2005). Throughout the study area, the Ruahine Fault lies within or immediately adjacent to the axial ranges, and its generally straight trace indicates a steeply dipping fault plane (Browne, 1981; Beanland, 1995). The Ruahine Fault occurs as a nearly continuous trace from the southwestern to northeastern parts of the study area.

Vertical dips were measured on the Ruahine Fault by Beanland (1995) in southern and central parts of the study area. In the Ohara Depression (see Fig. 5.9) the fault plane strikes 032°, and dips vertically. Striae on the plane trend 32° and plunge 25° (Erdman and Kelsey 1992). In the Omahaki area and near the upper Tutaekuri River (Kuripapango) the fault plane dips 75°SE and Late Quaternary motion is almost pure strike-slip (Beanland 1995). Offset on an early Holocene terrace riser across the Ruahine Fault at Puketitiri indicates a slip rate of 0.7-1.5 mm/yr for Beanland (1995). Although not considered reliable by Beanland (1995) it does provide an order of magnitude estimate for the slip rate on the Ruahine Fault. There are no data to constrain the

slip rate on the Ruahine Fault in the Ohara Depression. Beanland and Berryman (1987) estimated present day slip on the whole Ruahine Fault at 1-2 mm/yr

.

Dextrally offset streams crossing the Ruahine Fault are prominent in the Puketitiri and Pakaututu areas (Fig. 5.4B). Recent movement appears to have resulted in upthrow on the western side of the fault, although geological cross-sections through this area suggest that since the Early Pliocene there has been substantial uplift of the eastern block of at least 300 m. This is indicated by the presence of Early Pliocene Pakaututu Formation on Torlesse basement around the Ruahine Fault in the Puketitiri and Pakaututu areas.

Vertical offset on the Ruahine Fault in the area of the Tutaekuri River is likely to be several hundred metres. Estimates of offset are hampered however by the lack of stratigraphic marker horizons across the fault. Oblque-slip displacement in the Ohara Depression on the Ruahine Fault has resulted in substantial uplift of Torlesse basement since the Lower Nukumaruan (c. 2.4 Ma) resulting in the formation of the Ruahine Range. An outlier of Sentry Box Formation preserved at Seconds Ridge on the northern end of the range demonstrates about 300 m of vertical offset on the fault since 2.4. Ma, with uplift on the western side.

The nature of the active trace of the Ruahine Fault changes in character through the study area depending on the proximity of the axial ranges to the fault. This is most noticeable in the Puketitiri area. In cases where the ranges are very close to, or indeed on the fault (such as at Baldy Quarry; Fig. 5.6), a prominent series of sag ponds are visible, with upthrown ridges on the eastern side of what has previously been viewed as the modern fault trace (Fig. 5.4A, C). Where ranges are further away from the fault (such as beside Hot Springs Road), a prominent bench occurs (higher on the western side), with offset streams across the fault marking dextral strike-slip movement (Fig. 5.4B, D). Few sag ponds are present along these parts of the fault trace. This situation appears analogous to that reported by Eusden *et al.* (2005) for fault structures in North Canterbury bounding the foothills of the Southern Alps in the South Island.

Erdman and Kelsey (1992) suggest that displacement on the Ruahine Fault may have commenced as early as the Opoitian. This is consistent with stratigraphy preserved adjacent to the modern fault trace near Pakaututu. Geological mapping near the northern end of the Kaweka Range suggests that the proto-Ruahine Fault was active during the Early Pliocene. Thick greywacke conglomerates and breccias of Opoitian age occur adjacent to the modern fault trace, and rapidly thin away from the structure. These conglomerates are inferred to be possible indicators of uplift of Torlesse basement on the Ruahine Fault in the Early Pliocene. No

constraints can be placed on the fault as to whether this displacement was of dip-slip or strike-slip character, although the former is likely.

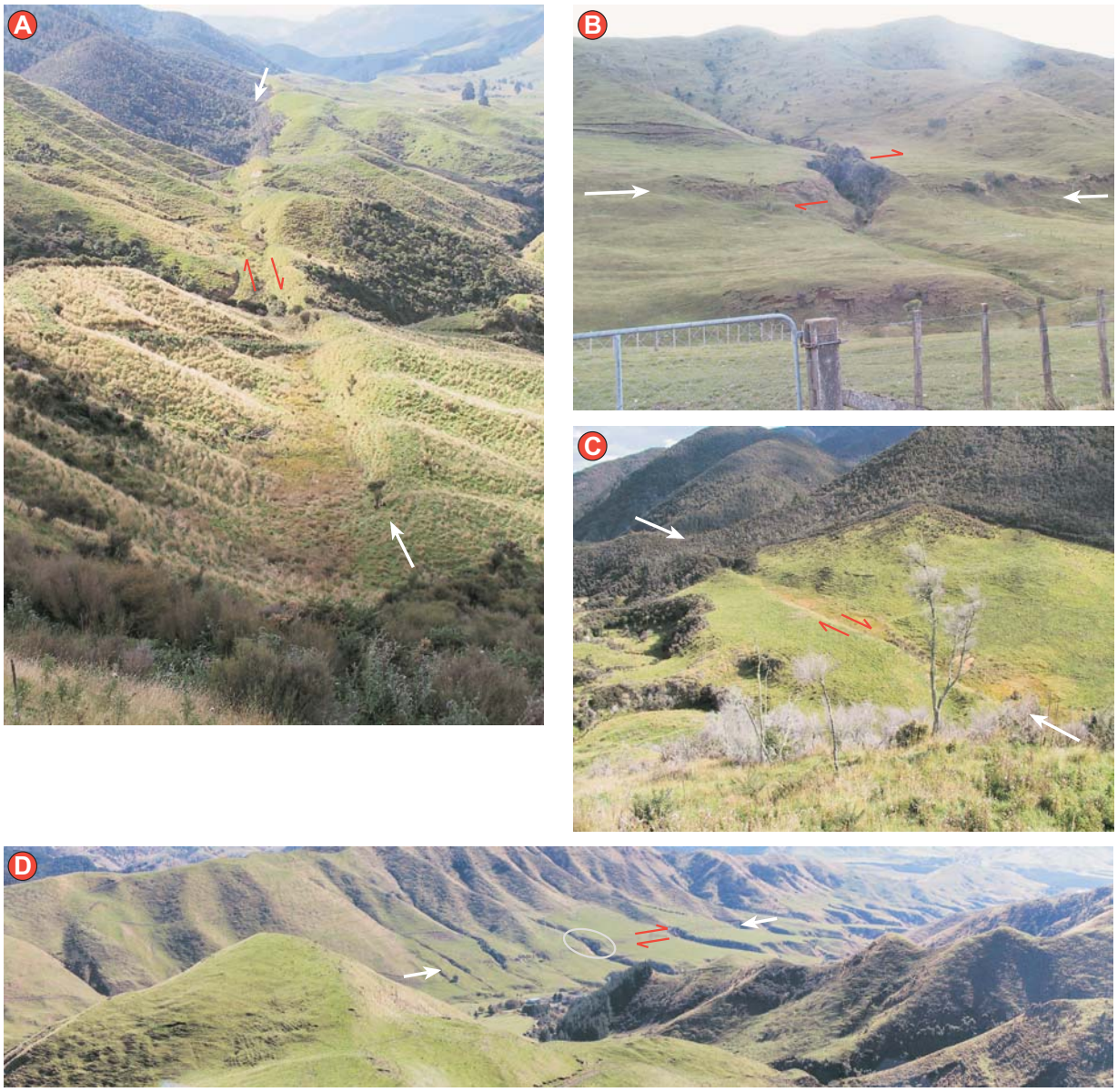
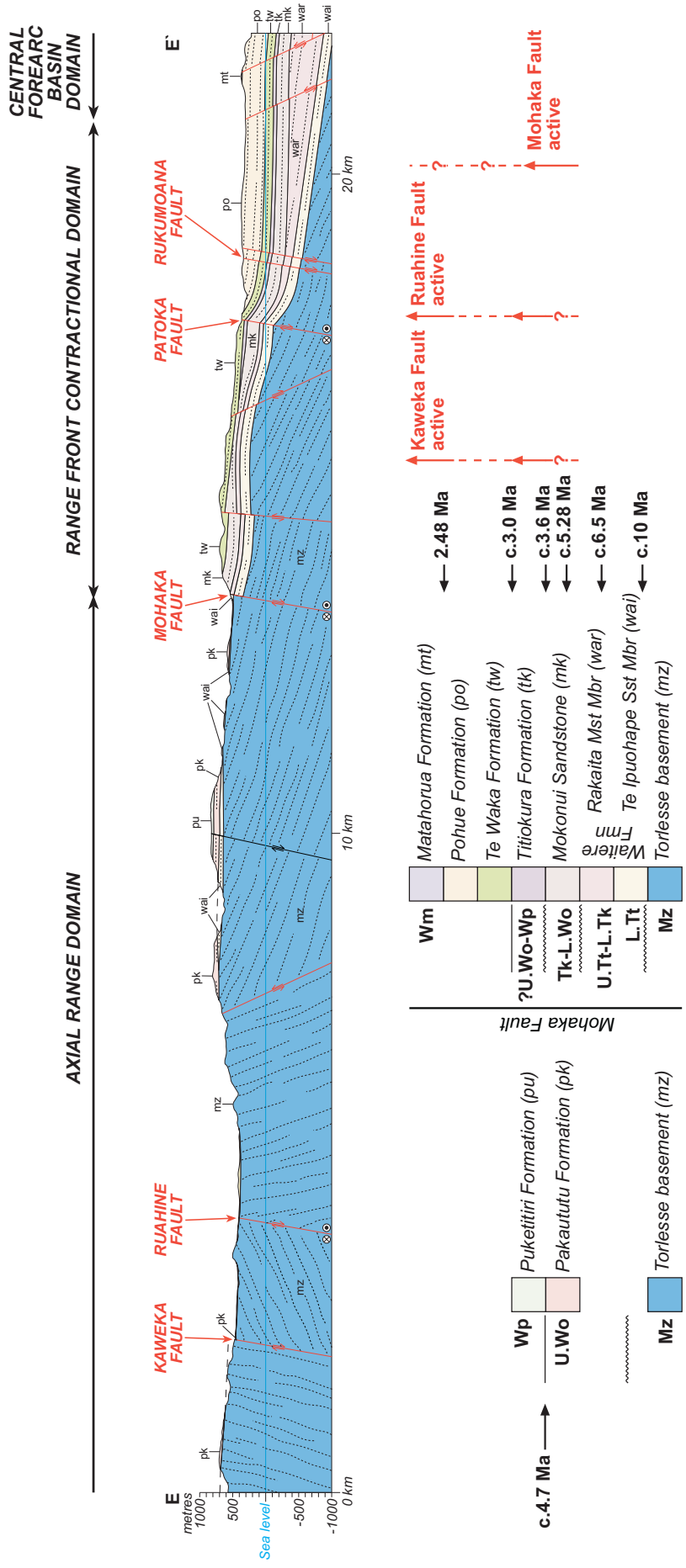


Fig. 5.4 (above): Photographs of active traces of the Ruahine Fault (white arrows) in the Puketitiri area, western parts of Hawke's Bay. Note in these images how the expression of the fault changes from that of a topographic furrow to a ridge along strike. This is inferred to reflect the relative closeness of the fault to significant hills and ranges. Ranges lie across or against the fault in images A and C, and are set back from the fault in B and D. Red arrows indicate direction of dextral offset. **A)** View looking northeast from Baldy Quarry, Whittle Road. Photo location: U20/090976. **B)** View looking west from Hot Springs Road at a dextrally offset stream across the fault. The offset stream is highlighted by the white circle in image D. Photo location: V20/124144. **C)** View looking southwest from Lucknow Road, Kaweka Forest Park. Photo location: U20/085069. **D)** View of the Ruahine Fault from Hukanui Station, looking northwest across Hot Springs Road. Photo taken from V20/120117.

Fig. 5.5 (facing page): Geological cross-section across the axial range and range front contractional domains in the Pakaututu area (line E-E' in Fig. 5.2, western part of line B-B' on Enclosure 3). Note the change in stratigraphy across the Mohaka and Patoka Faults, and the degree of vertical displacement on Torlesse basement. Inferred periods of active displacement of faults in this cross-section are indicated.


CENTRAL FOREARC BASIN DOMAIN
RANGE FRONT CONTRACTIONAL DOMAIN
AXIAL RANGE DOMAIN
E
E`
KAWEKA FAULT
RUAHINE FAULT
MOHAKA FAULT
PATOKA FAULT
RUKUMOANA FAULT
metres
1000
500
Sea level
-500
-1000
0 km
10 km
20 km
Kaweka Fault active
Ruahine Fault active
Mohaka Fault active
2.48 Ma
c.3.0 Ma
c.3.6 Ma
c.5.28 Ma
c.6.5 Ma
c.10 Ma
Matahorua Formation (mt)
Pohue Formation (po)
Te Waka Formation (tw)
Titiokura Formation (tk)
Mokonui Sandstone (mk)
Rakaita Mst Mbr (war)
Te Ipuohape Sst Mbr (wai)
Torlesse basement (mz)
Wm
?U.Wo-Wp
Tk-L.Wo
U.Tt-L.Tk
L.Tt
Mz
Waitere Fmn
Mohaka Fault
c.4.7 Ma
Wp
U.Wo
Puketitiri Formation (pu)
Pakaututu Formation (pk)
Mz
Torlesse basement (mz)

As with other structures in the study area the current phase of strike-slip displacement on the Ruahine Fault probably commenced some time after 2 Ma, coinciding with initial rfiting in the Taupo Volcanic Zone. This is constrained by distribution and deformation of Neogene rocks in the North Island Shear Belt (see Chapter Seven, p. 242-253 for more discussion on this). Late Neogene oblique-slip displacement on the Ruahine Fault appears to have commenced before deformation on the Mohaka Fault. This is consistent with the idea that the faults step east over time into the forearc basin, as suggested by their lesser vertical offset in cross-sections (e.g. Fig. 5.5). Based on correlation of basal Nukumaruan sandstone and limestone beds across the Ruahine Fault, Beu (1977) estimated 20 km of dextral offset during the Pleistocene. Beanland (1995) viewed this amount as too large, and suggested 7-10 km as a more probable horizontal offset since the Early Pliocene. Based on the proximity of distinctive limestone beds (Hukanui Limestone Member, Pakaututu Formation) either side of the Ruahine Fault in the Puketitiri and Pakaututu areas, this study infers less than 10 km of dextral offset on the Ruahine Fault since the Early Pliocene (Chapter Three; Enclosure 1, Sheet 1).

From the Ngaruroro River near McIndoe Flat north toward Kuripapango, the Ruahine Fault splays into at least two northeast-trending splinter faults, of which Glenross Fault is the most significant one.

Glenross Fault

Glenross Fault (Fig. 5.3) was named and mapped in its central and northern parts by Browne (1981), the name being derived from the Glenross Range, which the fault mostly bounds. The surface trace of the Glenross Fault is inferred to splinter from the Ruahine Fault near McIndoe Flat in the northern Ohara Depression and merges again north of the Tutaekuri River. The Glenross Fault defines the eastern margin of the Omahaki Depression and, with the Ruahine Fault, bounds the Glenross Range.

While the fault plane has not been observed, a wide zone of strongly sheared and shattered greywacke occurs where the Glenross Fault is inferred to cross Lizard Road in Kaweka Forest (U20/038909). Strongly shattered greywacke, and a series of prominent defects are also visible where the fault crosses the Tutaekuri River downstream of the Lawrence Road swing-bridge (U20/063980). The inferred trace of the Glenross Fault, striking about 020° is usually well defined by a series of steeply northwest-dipping (30°-65°) outcrops of Te Waka Formation. These outcrops lie adjacent to both the eastern and western sides of the fault from Awapai Station northeast to The Lizard. Further to the east of the Glenross Fault (c. 1-2 km), Te Waka Formation dips more gently at 15-25° to the southeast as part of the Glenross Range.

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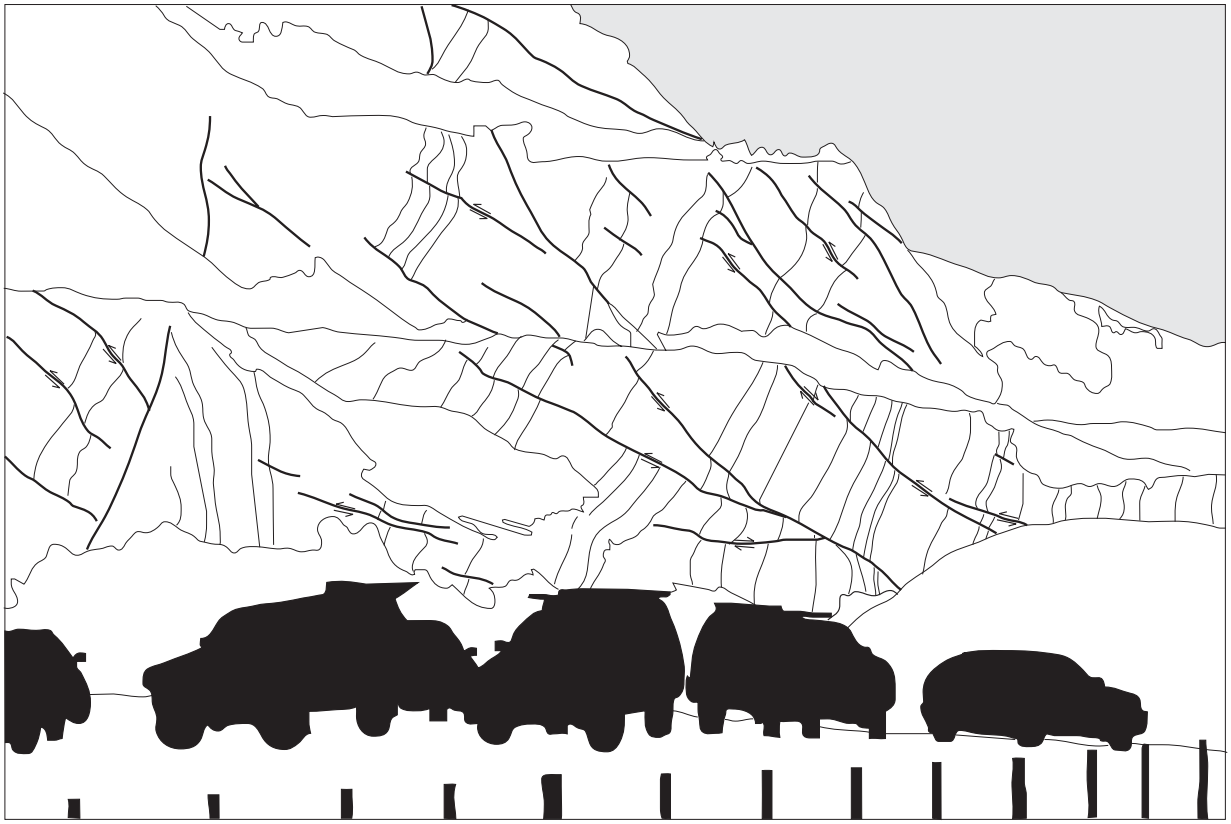


Fig. 5.6: Ruahine Fault Zone exposed in the face of Baldy Quarry (excavating Mesozoic Torlesse basement), Kaweka Forest Park. The main trace of the fault lies around 100 m to the east (left) of this photograph. Photo location: U20/090076.

Lizard Fault

The Lizard Fault (Fig. 5.3) comprises a short trace that strikes about 027° and converges towards the Glenross Fault around The Lizard, Kaweka Forest. It was first mapped and described by Browne (1981). The interaction between the Lizard and Glenross Faults is responsible for the steeply dipping Te Waka Formation that forms The Lizard. To the east of the Lizard Fault, Te Waka Formation dips at over 60° to the northwest. To the west of the fault the Te Waka Formation dips 25° to the southeast. The dip decreases towards the Lizard Fault.

Comet Fault

The Comet Fault (Fig. 5.3) was first mapped by Kingma (1957). Browne (1986) inferred the Comet Fault to be a near-vertically dipping structure based on is rectilinear outcrop trace. It lies several kilometres northwest of the Ruahine Fault and truncates the northern end of the Miroroa Fault. Approximately 9 km southwest of Mount Miroroa the Comet Fault downthrows to the northwest by about 200 m an erosion surface developed on Torlesse basement (Browne 1986). Kingma (1957) estimated 1 km of throw on the Comet Fault but gave no criteria for this estimate. Browne (1981) estimated 30 m of throw at The Blowhard. East of the Burns Range the fault displaces the Blowhard Formation to the east, opposite to the direction of throw at Comet Range and Mount Miroroa. The fault cannot be mapped north of the Tutaekuri River and appears to die out (Browne 1986). No estimates of strike-slip displacement are possible for the Comet Fault as no displacement markers are known along its length (Browne 1986).

Miroroa Thrust

The Miroroa Thrust (Fig. 5.3) was first identified by Kingma (1957) and was studied in more detail by Browne (1981, 1986). The Miroroa Thrust, as with the adjacent Comet Fault, is an inactive structure. It is named after Mount Miroroa (Cattle Hill) south of the Napier-Taihape Road. The fault trends NW-SE (strike about 123°), and separates Torlesse basement from Lower (basal) Nukumaruan (Late Pliocene) sandstone, siltstone and limestone. Although surface outcrops indicate a fault plane dipping at 45° the dip probably steepens at depth as its outcrop trace is linear along its 3 km length (Browne 1986). The Miroroa Thrust links the dextral Ruahine Fault with the Comet Fault located 3 km to the northwest, perhaos acting as a transfer structure between the Ruahine and Comet Faults. On the northern slopes of Mount Miroroa, Torlesse basement is separated from basal Nukumaruan rocks by a 2-5 cm-thick dark-grey gouge orientated 107/45° SE (Browne 1986). The overthrust Torlesse basement indicates displacement after the Lower Nukumaruan, and may record the inception of strike-slip displacement on the Ruahine Fault at around 2 Ma.

Kaweka Fault

The Kaweka Fault (Fig. 5.3) is a relatively short but significant structure in the North Island Shear Belt. It extends from Kuripapango to Pakaututu, diverges southwestwards from the Ruahine Fault, and may represent a transfer tear structure. The Kaweka Fault bounds the east side of the Kaweka Range with a very steep escarpment (Beanland 1995). Beanland (1995) measured a dip of 80° on the fault plane near Kuripapango, and observed slickensides with shallow plunges (045/ 10°SE). This suggested that the fault may accommodate a significant component of strike-slip motion. Through the Kuripapango and Pakaututu areas the fault strikes 035° and is characterised by steep, triangular faceted spurs. The Kaweka Fault diminishes in throw rapidly northwards from Kuripapango, and the trace cannot be identified much north of the Ripia River at Pakaututu. Measured vertical offset on Upper Opoitian limestone beds (Hukanui Limestone Member, Pakaututu Formation) on basement at the northern end of the Kaweka Range is about 120 m (upthrow to west of fault). This contrasts with the nearly 1000 m of west-side-up throw estimated at Kuripapango by Browne (1981, 2004). Browne's estimate seems anomalously high compared to other faults in the domain. It was based on inferred displacement of Torlesse basement underlying Early Pliocene Mangatoro Formation, which Browne (1981, 2004) estimated as being up to 1500 m thick. This study has suggested that a thickness of less than 550 m is more likely (see Appendix I, p. A1-48), and in the immediate Kuripapango area is probably only 200-300 m thick. This reduces the inferred throw on the Kaweka Fault to several hundred metres. In the northernmost area near Makahu River, triangular-faceted spurs are present, although not as well developed as those to the south. The western side of the fault is consistently upthrown. No data exist for modern slip rates on the Kaweka Fault.

Mohaka Fault

The Mohaka Fault (Fig. 5.3) represents the eastern branch of the northern continuation of the Wellington Fault (Langridge *et al.* 2005), and is a major structural feature through the study area. It is currently a dextral oblique-slip fault (Raub 1985; Beanland *et al.* 1998), although it was probably initially a dip-slip fault. It marks the boundary between the axial range domain to the west and the range front contractional domain to the east. Geological mapping in this study suggests that rather than being characterised by a single continuous fault trace, the Mohaka Fault often comprises a series of sections, each up to several kilometres long, that occupy the same general trend. In southern and central parts of the study area the Mohaka Fault is near vertical in dip, as indicated by the straightness of the fault trace (Beanland 1995). In northern parts of the study area the dip at the surface is much shallower (Cutten 1994). The modern expression of the Mohaka Fault as a dextral-slip structure is likely to be a relatively new feature in terms of the geological history of the study area. The presence of many discrete sections suggests that it has not yet

become a through-going fault. Also, variations in strike along these sections further suggest the insufficient time has passed for the fault to "straighten out" its kinks (e.g. Wesnousky 1988).

Mohaka River to Napier-Taupo Road

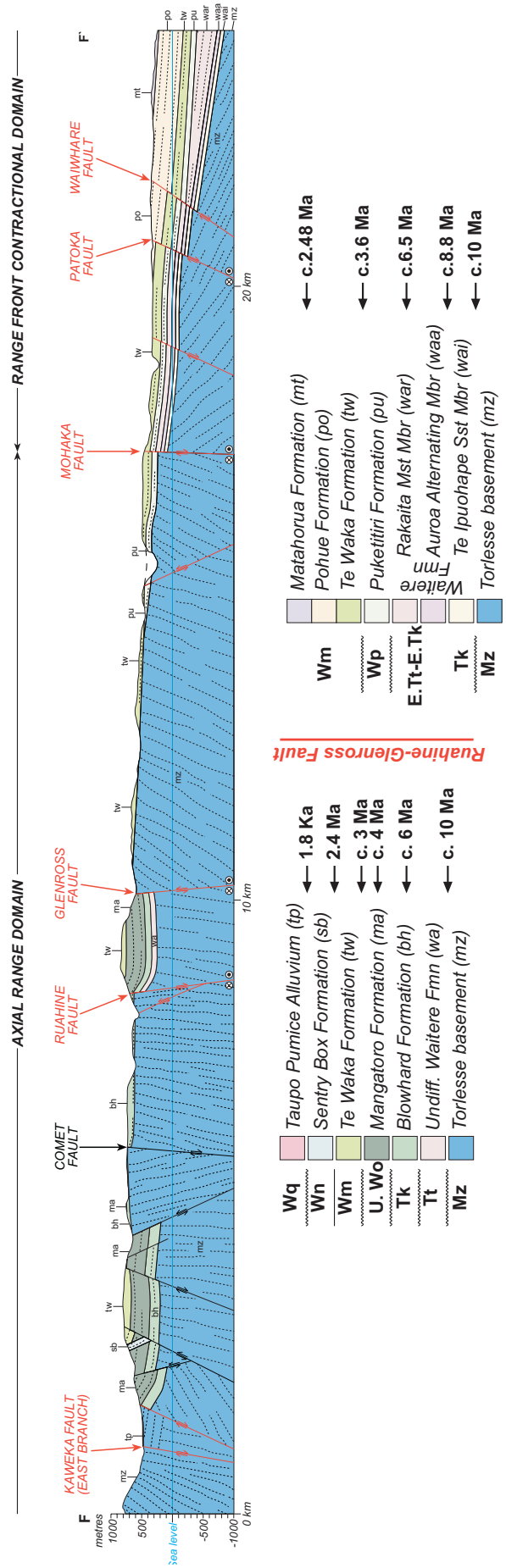
The Mohaka Fault through this region often comprises several active traces, especially in the area around Waitara Road. There is a combination of uplift along both western and eastern sides of the numerous fault traces. Around northern parts of the study area, traces of the Mohaka Fault are arranged in a left-stepping pattern, separated by more northerly-striking segments (Cutten 1994; Beanland 1995). The surface dip on the fault plane in this sector is shallower than reported in southern sectors.

Hawkston Station to Napier-Taupo Road

This section of the Mohaka Fault extends from Hawkston Station near Patoka to the Napier-Taupo Road, including the range fronts of the Te Waka and Maniaroa Ranges. Throw along the fault steadily decreases from the Te Waka Range to Hawkston Station, and is reflected in the topographic lowering of the summit ridges of the Te Waka and Maniaroa Ranges. Uplift is to the east of the fault. The Maniaroa Range, immediately east of the Mohaka Fault represents an uplifted fault scarp, with Mangapanian Te Waka Formation repeated on both sides of the fault. It is difficult to estimate the amount of strike-slip displacement along this sector of the Mohaka Fault as similar lithologies occur on either side of the trace. Kingma (1958a) reported no evidence of strike-slip displacement on the Mohaka Fault through the Patoka-Puketitiri area, but estimated about "700 ft" (c. 210 m) of vertical displacement, consistent with displacement inferred in this study. Active traces of the fault in this area are difficult to locate.

Greywacke basement is exposed immediately west of the Mohaka Fault near Potter Road on Cherry Block Station. Although modern uplift on the fault involves a substantial degree of east-side-up displacement (as shown by the presence of the Maniaroa Range), no basement crops out to the east of the fault in this area. This suggests that the current phase of uplift to the east has occurred since the Late Pliocene, and significant uplift to the west has occurred during the Neogene, elevating basement.

Fig. 5.7 (facing page): Geological cross-section through the axial range and range front contractional domains in the Kuripapango area (line F-F' in Fig. 5.2, western part of line C-C' on Enclosure 3). Note the change in stratigraphy across the Ruahine Fault, the presence of Mangapanian ("middle" Pliocene) Te Waka Formation across much of the area, and the degree of displacement on Torlesse basement.


AXIAL RANGE DOMAIN
RANGE FRONT CONTRACTIONAL DOMAIN
F
F'
KAWEKA FAULT (EAST BRANCH)
COMET FAULT
RUAHINE FAULT
GLENROSS FAULT
MOHAKA FAULT
PATOKA FAULT
WAIWHARE FAULT
metres
1000
500
sea level
-500
-1000
0 km
10 km
20 km
Ruahine-Glenross Fault
Wq
Wn
Wm
U. Wo
Tk
Tt
Mz
Taupo Pumice Alluvium (tp)
Sentry Box Formation (sb)
Te Waka Formation (tw)
Mangatoro Formation (ma)
Blowhard Formation (bh)
Undiff. Waitere Fmn (wa)
Torlesse basement (mz)
1.8 Ka
2.4 Ma
c. 3 Ma
c. 4 Ma
c. 6 Ma
c. 10 Ma
Wm
Wp
E.Tt-E.Tk
Tk
Mz
Matahorua Formation (mt)
Pohue Formation (po)
Te Waka Formation (tw)
Puketitiri Formation (pu)
Rakaita Mst Mbr (war)
Waitere Fmn
Auroa Alternating Mbr (waa)
Te Ipuohape Sst Mbr (wai)
Torlesse basement (mz)
c.2.48 Ma
c.3.6 Ma
c.6.5 Ma
c.8.8 Ma
c.10 Ma

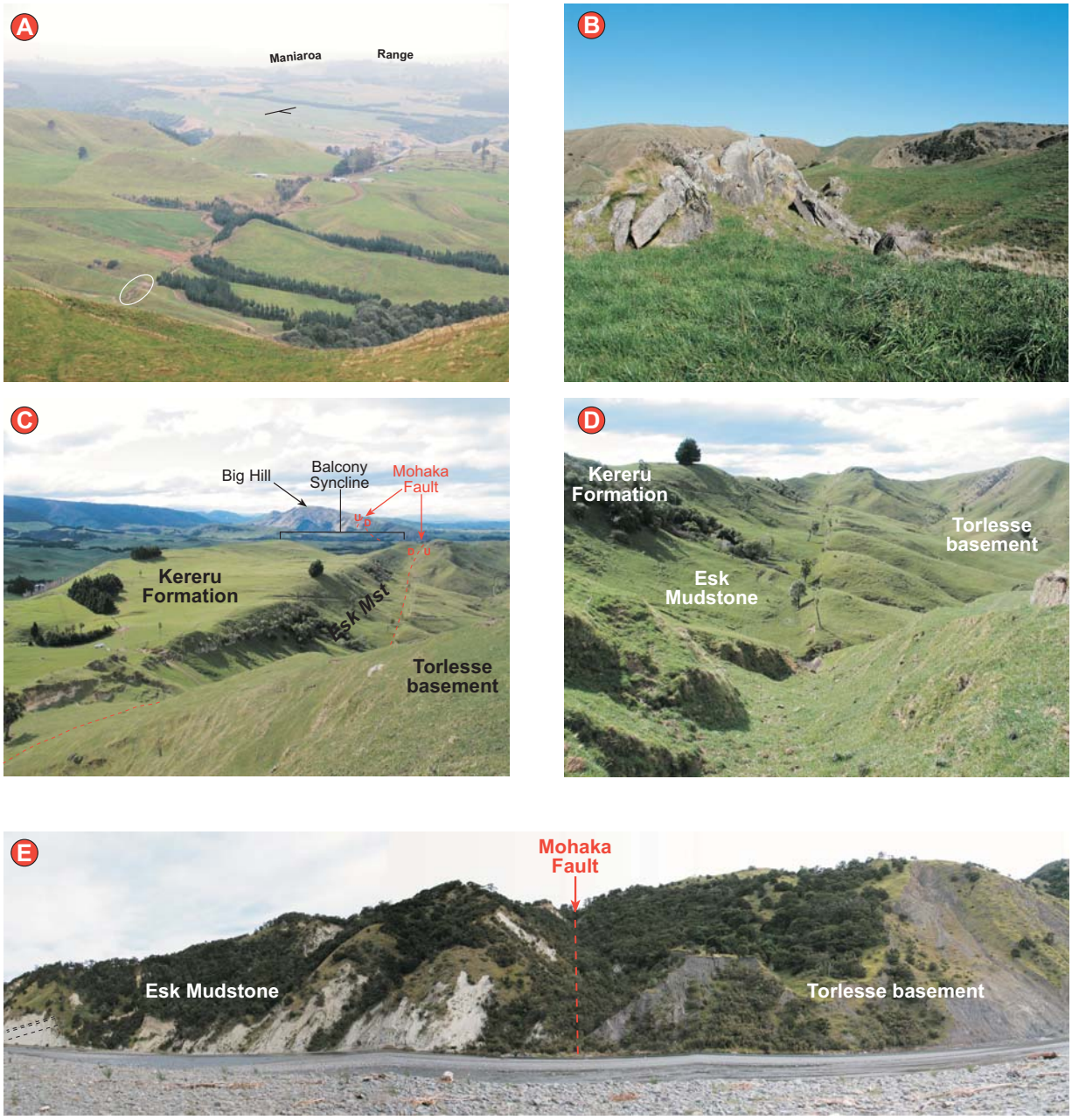


Fig. 5.8: Views of active traces of the Mohaka Fault from the Ohara Depression to Puketitiri area. **A)** Fault trace viewed from Mangatutu Station looking north. The direction of dip on the top of the Mangapanian Te Waka Formation on the western side of the fault is indicated. The white oval indicates the outcrop in the centre of image B. Photo taken from V20/134966. **B)** Strongly recrystallised limestone of probable Te Waka Formation cropping out immediately to the east of the active trace of the Mohaka Fault, Hawkston Station. Nearby shutter ridges and offset streams indicate recent strike-slip displacement on this section of the fault. Photo location: V20/134979. **C)** Fault trace (highlighted) viewed from the slopes of Mount Mary, Glendale Farm, Ohara Depression. Late Pliocene Esk Mudstone and Kereru Formation are folded in the adjacent Balcony Syncline, constraining the post Lower Nukumaruan timing and magnitude of displacement of this part of the fault. Torlesse basement is juxtaposed against Late Pliocene sediments across the fault. Photo taken from U21/969681, looking northwest. **D)** View of the Mohaka Fault from the active trace. Note the presence of shutter ridges and offset streams across the fault. Relative uplift is to the east (right) side of the fault. Photo location: U21/968682. **E)** Exposure of the Mohaka Fault in the Ngaruroro River, Whana Valley. Torlesse basement is juxtaposed against Late Pliocene Esk Mudstone, indicating uplift on the western side (right) of the fault post-"middle" Nukumaruan. This exposure of the fault is less than 15 km from the exposures in images C and D, both of which display uplift on the eastern side of the fault. Photo location: U21/022770.

Big Hill to Hawkston Station

This part of the Mohaka Fault extends from Awapai Station in the southwest to Hawkston Station in the northeast. Upthrow is greatest at the southwestern end of the zone along the eastern front of Big Hill, and diminishes steadily to the northeast. The upthrown side is to the west of the fault, the opposite sense of displacement to that of parts of the fault immediately to the north and south.

Around Big Hill, Torlesse basement is juxtaposed against Late Pliocene beds of the Mangaheia Group (Fig. 5.8E). Vertical displacement on the Mohaka Fault in the Big Hill area is probably at least several hundred metres. The fault trace is well exposed on Hawkston Station (Fig. 5.8A, B), and clearly evident on aerial photos trending through the Whana Valley area. On Hawkston Station the fault trace is marked by a series of steeply dipping, well cemented limestone ridges that parallel the fault trace and its associated sag ponds and offset streams. Prominent splays of the main Mohaka Fault trace are clearly evident through the Whana Valley area from aerial photographs.

The Mohaka Fault is very well expressed in the Ngaruroro River at Kohatunui Station where the river emerges from its deep greywacke gorge (Fig. 5.8E). Broken formation consisting of strongly shattered basement (upstream) and Lower Nukumaruan Esk Mudstone (downstream) occurs for approximately 120 m upstream and downstream of the vertical fault plane of the Mohaka Fault. Vertical displacement at this site is a minimum of 600 m upthrown to the west since the Lower Nukumaruan (Late Pliocene). This degree of throw diminishes rapidly northeast to Hawkston Station. Near the Mangatutu Stream bridge on Hawkston Road, displacement of the Mangapanian (Late Pliocene) Te Waka Formation reaches 0 m on this part of the fault. Northeast of this area the sense of throw reverses quickly to a substantial degree of east-side-up along the Maniaroa and Te Waka Ranges (see above).

Ohara Depression to Big Hill

This region contains that part of the Mohaka Fault from the southern boundary of the study area north to Awapai Station. The Mohaka Fault is the major structural boundary in this area. The preservation of Plio-Pleistocene strata in the Ohara Depression is due to vertical offset on the fault. There is substantial strike-slip displacement and only minor shortening west of the fault, and dominantly contractional deformation east of it (Erdman and Kelsey 1992). Prominent stratigraphic differences in cover beds are evident either side of the Mohaka Fault in this area. In only one locality east of the fault is the base of the Neogene succession known to be exposed. That locality is on Mount Mary, where greywacke-pebbly-rich facies of the Mount Mary Pebbly Limestone overlies Torlesse basement (U21/969681). To the west of the Mohaka Fault, Neogene rocks are commonly observed to onlap basement.

The fault plane at the surface in this area strikes 029° and dips 89°±5°SE (Beanland 1995). South of the Ohara Depression, Raub (1985) and Raub *et al.* (1987) measured four dips on the Mohaka Fault ranging from 84°NW to 90°. Slickensides on the fault plane trend 032° and 030° and plunge 25° and 47° (Erdman and Kelsey 1992). The sense of motion from these data is dextral with a minor southeast-side-up component (Beanland 1995). Two estimates of slip rate by Raub (1985) were made on this part of the Mohaka Fault at the southern end of the Ohara Depression. From terrace riser and channel offsets cut into aggradational terraces, he determined slip rates of 3.0±0.7 and 3.1±0.5 mm/yr for the past 35 and 11 k.y. respectively.

The Mohaka Fault trace is very well exposed on Glendale Farm in the Ohara Depression, where it strikes 030° and marks the western face of the Wakarara Range (Fig. 5.8C, D). Torlesse greywacke crops out on the eastern side of the fault (occasionally overlain by Mount Mary Pebbly Limestone), with Kereru Formation and Esk Mudstone cropping out on the western side of the fault. From Glendale Farm to Mangleton Road the active trace of the Mohaka Fault is well expressed with a prominent series of sag ponds, swampy intervals and shutter ridges along the trace.

The Big Hill Fault trends off the Mohaka Fault at the southern end of Big Hill and acts to transfer strike-slip motion from the Mohaka to the Ruahine Fault (Erdman and Kelsey 1992). North of the Big Hill Fault, Plio-Pleistocene strike-slip displacement seems to have been more significant on the Ruahine Fault than the Mohaka Fault.

Fault displacement

Average Late Quaternary slip on the Mohaka Fault in the south of the study area is estimated at about 3-7 mm/yr (Raub *et al.* 1987). It is difficult to determine the total horizontal offset along the Mohaka Fault as there are few if any appropriate horizontal displacement markers. North of the Ohara Depression the Ruahine Fault appears to be the dominant strike-slip fault. South of this point the Mohaka Fault may be the dominant strike-slip feature. Offset streams and shutters ridges are common along the Mohaka Fault in the Ohara Depression, and are rare north of Hawkston Station. As shown in the above sections, the sense of vertical offset on the Mohaka Fault varies throughout the study area. The lack of appropriate marker horizons across the Mohaka Fault hinders the identification of the total amount of dextral-slip on the fault. It is estimated, based on similarities of lithofacies across the fault, that in the study area total horizontal displacement across the Mohaka Fault is less than 5 km, with most of this movement during the past 500 k.y. It is possible that total displacement may only be in the order of 1-2 km, although this is poorly constrained. It is consistent with the estimate made by Beanland *et al.* (1998) of 2 km of horizontal offset on the Mohaka Fault since 3 Ma.

Vertical displacement on the Mohaka Fault since the Early Pliocene varies along the strike of the fault. From the north of the study area to Hawkston Station vertical offset since the Early Pliocene typically appears to be around 100-200 m, although may be greater in more northern areas. Uplift is on the western side of the fault. Through this area displacement is shown by offset on "middle" Pliocene Te Waka Formation, and expressed as the Maniaroa Range. Near Hawkston Station there is no vertical offset of this formation. South of Hawkston Station the amount of vertical displacement across the fault steadily increases, and by the Ngaruroro River and Big Hill, displacement is at least several hundred metres, with uplift on the western side of the fault. Accurate estimates of total vertical offset cannot be gained due to a lack of marker horizons across the fault. South of Big Hill in the Ohara Depression vertical offset is also at least several hundred metres since the Early Pliocene, but again a lack of marker horizons means that accurate constraints on total displacement cannot be gained. Uplift in this southern area is to the east.

North of Hawkston Station the active trace of the Mohaka Fault becomes less well defined. This may reflect displacement being preferentially taken up on the Ruahine Fault, or other faults to the east (Patoka Fault Zone and Rangiora Fault). A series of reverse and strike-slip faults splinter off the Mohaka Fault from left-stepping jogs in its trace near Corbin Road (Waiwhare and Waihau Faults), the Tutaekuri River (Patoka Fault Zone) and at Puketitiri Road (Te Waka Range Splinter Fault). These faults are described in more detail below as part of the range front contractional domain. The Rangiora Fault is inferred to splinter off the Mohaka Fault in the area of the southern Maungaharuru Range.

Big Hill Fault

Big Hill Fault (Fig. 5.3) was named by Erdman and Kelsey (1992), the name being derived from Big Hill, a prominent greywacke block at the northern end of the Ohara Depression. The southern portion of the Big Hill Fault trends south-southeast, and is a reverse fault responsible for uplift of the Big Hill block (Enclosure 1, Sheet 5 Kereru). Towards the Ngaruroro River the trend of the fault becomes more northerly and the dominant sense is more of a strike-slip fault (Erdman and Kelsey 1992). The Big Hill Fault transfers motion from the Mohaka to the Ruahine Faults in the northern Ohara Depression (Erdman and Kelsey 1992). Total vertical displacement on the fault is at least 200 m since the Late Pliocene, and expressed in the topography of the Big Hill massif.

Thorn Flat Fault

The Thorn Flat Fault is a reverse fault with an active trace that occurs in the Ohara Depression near Rocky Outcrop (Fig. 5.9). It strikes between 005° and 070° with an arcuate surface trace. There are no constraints on slip rates or recurrence intervals. West-north-west shortening across

the Ohara Depression induced by the transfer of strike-slip motion from the Mohaka Fault to Ruahine Fault along the Big Hill Fault was inferred by Erdman and Kelsey (1992) as the driving mechanism behind the formation of the Thorn Flat Fault and the adjacent Herricks Anticline and Herricks Syncline (see below). They suggested that the Thorn Flat Fault formed and propagated to the surface after initial formation of the Herricks Anticline and Syncline.

Folds

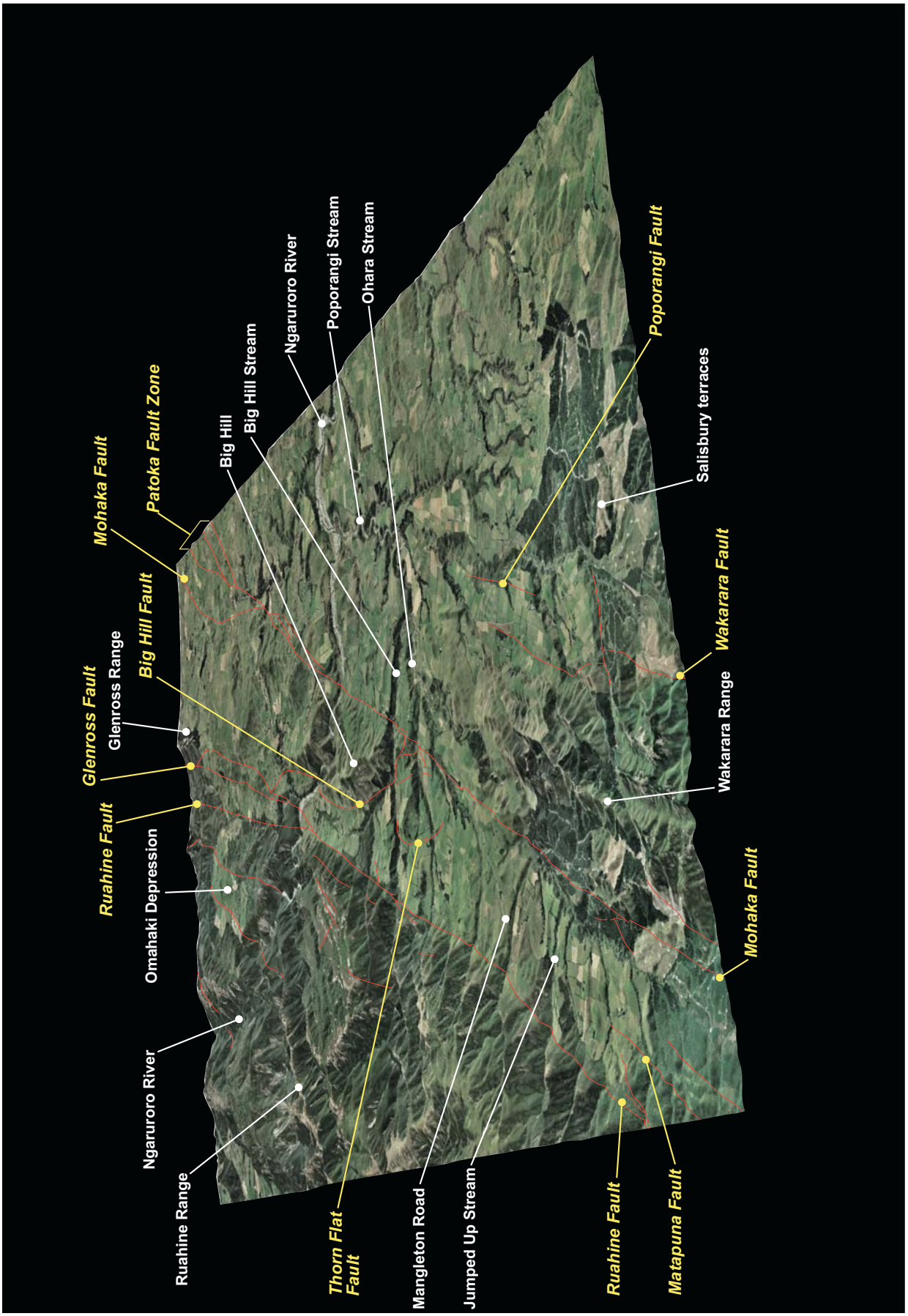
Herricks Anticline

The Herricks Anticline is located in the Ohara Depression between the Ruahine and Mohaka Faults near the southern end of the Big Hill Fault (Fig. 5.10). The Herricks Anticline is associated with a dome-shaped basement uplift (Beanland 1995) and lies immediately east of the surface trace of the Thorn Flat Fault, an active reverse fault (Erdman and Kelsey 1992). Greywacke lies less than 100 m below the ground surface at the Herricks Anticline, determined from the presence of strong reflectors in a seismic line (Beanland 1995). The anticline is cored by basement and involves Puketitiri Formation. Surface expression of the anticline is defined by the Sentry Box Formation which dips moderately to steeply on both limbs of the fold (up to 55° on the western limb and 21° on the eastern limb; Kelsey *et al.* 1993). The fold axis trends 175°. East of the Herricks Anticline beds dip southeast toward the Mohaka Fault. West of the anticline beds are deformed by the Herricks Syncline.

Herricks Syncline

Herricks Syncline (Fig. 5.10) lies west of the Herricks Anticline, and 1-1.5 km east of the Ruahine Fault. The fold is cored by Esk Mudstone. The fold axis trends about 019°. Its western limb is truncated by the Ruahine Fault with basement juxtaposed against Esk Mudstone.

Fig. 5.9 (facing page): Oblique reconstructed aerial view of the Ohara Depression and Kereru district illustrating the surficial distribution of faults in the axial range and range front contractional domains in this area. Also indicated are the major topographic features of the area. The view in this figure is from the south. The locations of active faults are shown with red lines. Note the way the Ruahine and Mohaka Faults define the Ohara Depression. Aerial photos used in this figure are derived from the LINZ NZMS260 U21 orthophoto database. Elevation is derived from the LINZ NZMS260 digital topographic dataset.


Mohaka Fault
Patoka Fault Zone
Big Hill
Big Hill Stream
Ngaruroro River
Poporangi Stream
Ohara Stream
Poporangi Fault
Salisbury terraces
Glenross Fault
Glenross Range
Big Hill Fault
Wakarara Fault
Ruahine Fault
Omahaki Depression
Wakarara Range
Mohaka Fault
Ngaruroro River
Ruahine Range
Thorn Flat Fault
Mangleton Road
Jumped Up Stream
Ruahine Fault
Matapuna Fault

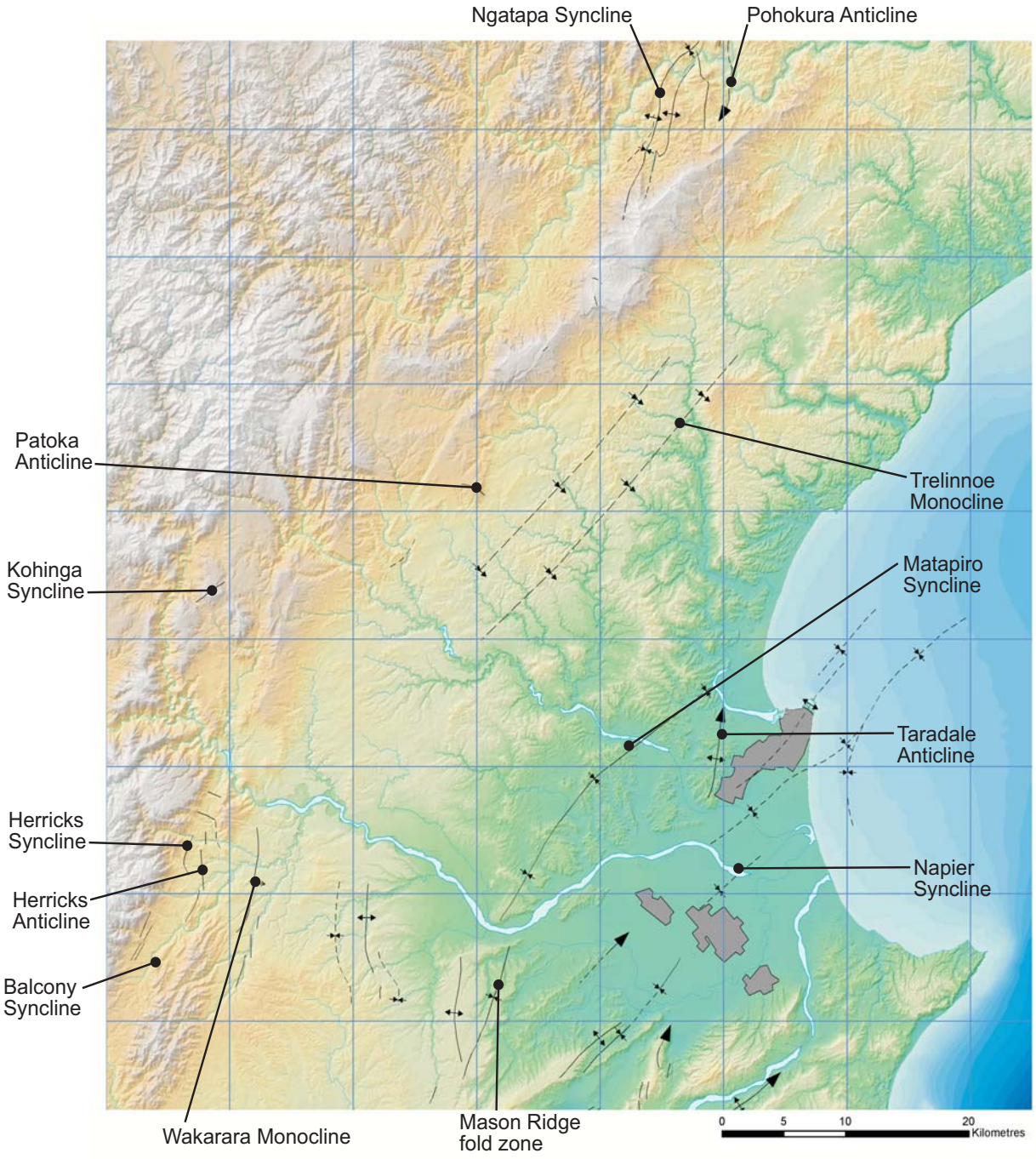


Fig. 5.10 (above): Locations of major folds in the study area. Many of these folds are the surface expression of blind reverse faults.

Balcony Syncline

The Balcony Syncline (Fig. 5.8C, 5.10) occurs on the western face of the Wakarara Range below Mount Mary, and is bounded along its eastern margin by a well developed active trace of the Mohaka Fault. It is cored by Esk Mudstone and Kereru Formation and is a prominent topographic feature viewed from Mount Mary. Limbs on the syncline dip moderately at about 30-35°, and the fold axis trends 030°, nearly parallel to the trend of the Mohaka Fault. Southwest of the Balcony Syncline similar deformation along the western edge of the Mohaka Fault can be observed in

Kereru Formation. The formation of the Balcony Syncline relates to re-activation of the Ohara Depression sector of the Mohaka Fault. Because the syncline is cored by Kereru Formation, development of the syncline must post-date its deposition, inferred to have occurred at about 2.2-2.0 Ma.

Kohinga Syncline

The Kohinga Syncline (Fig. 5.10) is a prominent feature forming the summit of Mount Kohinga above Kuripapango. It is a strongly faulted feature, reflecting the often complex deformation in parts of this structural domain. The northwestern limb of the Kohinga Syncline dips at up to 55°SE, and the southeastern limb at up to 24°NW (Browne 1981). The axis of the syncline plunges towards the NE. The northwestern limb of the syncline is commonly displaced by normal faults with throws of up to 40 m. The fold is cored by "middle" Pliocene Te Waka Formation.

RANGE FRONT CONTRACTIONAL DOMAIN: AN OVERVIEW

Range-front structures mostly comprise reverse faults with associated monoclines (e.g. Wakarara Monocline, Fig. 5.10) and anticlines in a zone located west of the Mohaka Fault (Fig. 5.2). Some strike-slip faulting is evident in the domain. The principal faults in this domain are the Wakarara, Patoka, Rukumoana and Rangiora Faults. In the south of the study area (Kereru district) the domain is on average 5 km wide (Beanland *et al.* 1998), increasing to 13 km wide in the north of the study area (Maungaharuru Range area). This increase in width reflects the widening of the forearc basin north of the latitude of Napier and the Ohara Depression, and the lack of emergence above sea level of the accretionary wedge north of Cape Kidnappers. The topography in this domain, as well as the adjacent axial range domain is strongly controlled by structural features, as illustrated in Fig. 5.11. While range front domain structures commonly form the boundary between uplifted Torlesse basement and Neogene sedimentary rocks of the forearc basin in the study area (e.g. Fig. 5.11), they also extend into the basin fill succession. Of note from geological cross sections (Fig. 5.5, 5.7, 5.11; Enclosure Three) is the way in which Mesozoic basement rocks at or near the surface in the domain are abruptly down-faulted to significant depths immediately east of the domain. This is also reflected in the dramatic increase in preserved thickness of the Late Neogene basin fill from the axial range domain into the range front contractional and central forearc basin domains. The depths at which basement rocks underlie the central forearc basin domain (>1.5 km) indicates the large degree of vertical displacement accommodated on the faults in the range front contractional domain.

Faults

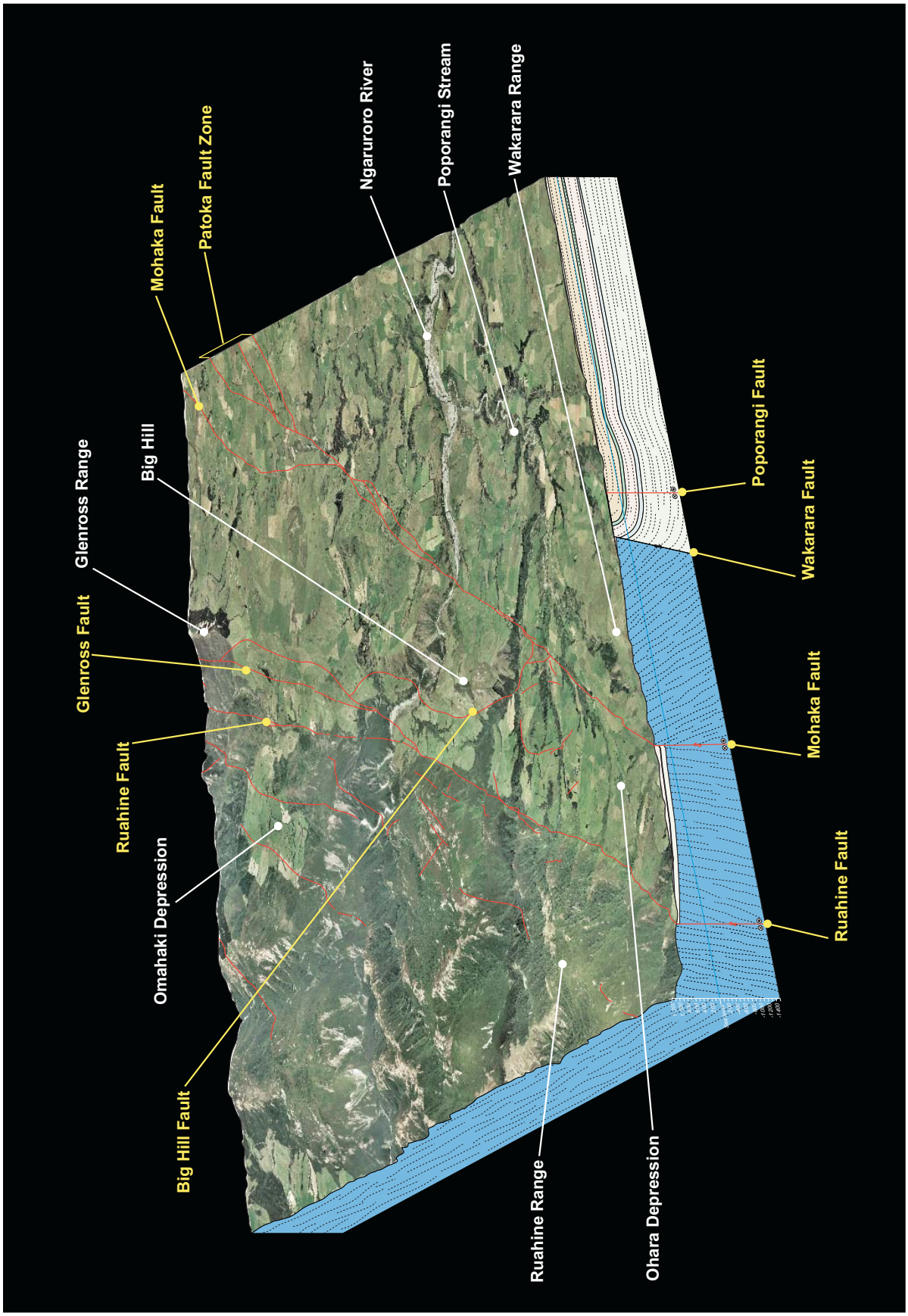
Wakarara Fault

The Wakarara Fault (Fig. 5.3, 5.11, 5.12) is a reverse fault that has accommodated a significant amount of dip-slip displacement, and possibly a small amount of strike-slip offset. The fault displaces Torlesse basement by at least 1100 m. There are no Late Quaternary traces along the fault and Beanland (1995) reported no dextral offsets along it. Uncommon Holocene traces mapped in the Wakarara area by Raub (1985) are probably associated with cross faults and bedding-parallel faults (Beanland 1995). The location of the fault is marked by a series of steeply-dipping to near vertical ridges of Kereru Formation that crop out along the eastern side of the Wakarara Range (Fig. 5.11, 5.12). It does not appear to have ruptured in the past 30,000 years as aggradational gravels of that age are undeformed across the associated monoclinal fold in the north (Raub *et al.* 1987). The Wakarara Fault lies several kilometres east of the Mohaka Fault and bounds the Wakarara Range. Erdman and Kelsey (1992) measured the fault plane of the Wakarara Fault in four places. The fault plane dips at 60-80°W. Striations at several locations were reported by Erdman and Kelsey as being consistent with reverse faulting with a small amount of dextral slip.

The fault enters the subsurface north of the Wakarara Range near the axis of a monoclinal fold named the Wakarara Monocline (Erdman and Kelsey 1992) (Fig. 5.10). The Wakarara Fault parallels and locally overthrusts the axis of the Wakarara Monocline along the eastern front of the Wakarara Range (Grant-Taylor 1978).

The Rangiora, Rukumoana and Patoka Faults are inferred to splinter off the Mohaka Fault at depth (Fig. 5.5, 5.7), splaying off at the surface at locations of left-stepping jogs in the Mohaka Fault trace (e.g. Halliday *et al.* 2003). Recent displacement on the Rangiora and Patoka Faults indicates dextral-slip displacement (Cutten *et al.* 1988; Halliday *et al.* 2003).

Fig. 5.11 (facing page): Oblique aerial view of the Ohara Depression and the inferred relationship between structural elements exposed at the surface and features in the subsurface. The location of the lower cross-section in this figure is indicated in Fig. 5.2 (line G-G'). View is from the southwest, and the distance across the bottom of the image is approximately 20 km. Note the abrupt edge of the North Island axial ranges (Ruahine Range) as defined by the Ruahine Fault. Evident is the large vertical displacement on Torlesse basement (blue colour in cross sections) on faults of the range front and axial range domains. This figure also illustrates the thickness of Neogene sedimentary rocks east of the range front contractional domain in comparison with that preserved in the axial range and range front contractional domains. Note the large increase in dip on beds east of the Wakarara Fault. Aerial photographs used in this figure are derived from the LINZ NZMS 260 U21 orthophoto database. For geological unit colours refer to Fig. 5.12. Elevation is derived from the LINZ NZMS260 digital topographic dataset.


Mohaka Fault
Patoka Fault Zone
Ngaruroro River
Poporangi Stream
Wakarara Range
Glenross Range
Big Hill
Glenross Fault
Ruahine Fault
Omahaki Depression
Big Hill Fault
Ruahine Range
Ohara Depression
Poporangi Fault
Wakarara Fault
Mohaka Fault
Ruahine Fault

The origin of the eastward development of oblique-slip structures into the basin succession is not really known. It may be related to dynamics at the shallow subduction interface between the plates, but could also reflect wider tectonic forces such as the southward propagation of rifiting in the Taupo Volcanic Zone and associated dextral rotation of the frontal ridge and the East Cape area (e.g. Beanland and Haines 1998).

Poporangi Fault

The Poporangi Fault (Fig. 5.3, 5.11) was mapped by Erdman and Kelsey (1992) in the Kereru area to the east of the Wakarara Range. Its trace lies to the east of the Wakarara Fault in a position similar to structures of the Patoka Fault Zone further north. Erdman and Kesley (1992) indicated some degree of strike-slip displacement on the Poporangi Fault, although gave no estimates of the amount of displacement. They also inferred that the fault has developed in the last 500 k.y., perhaps in response to active uplift and thrust faulting on the adjacent Wakarara Fault.

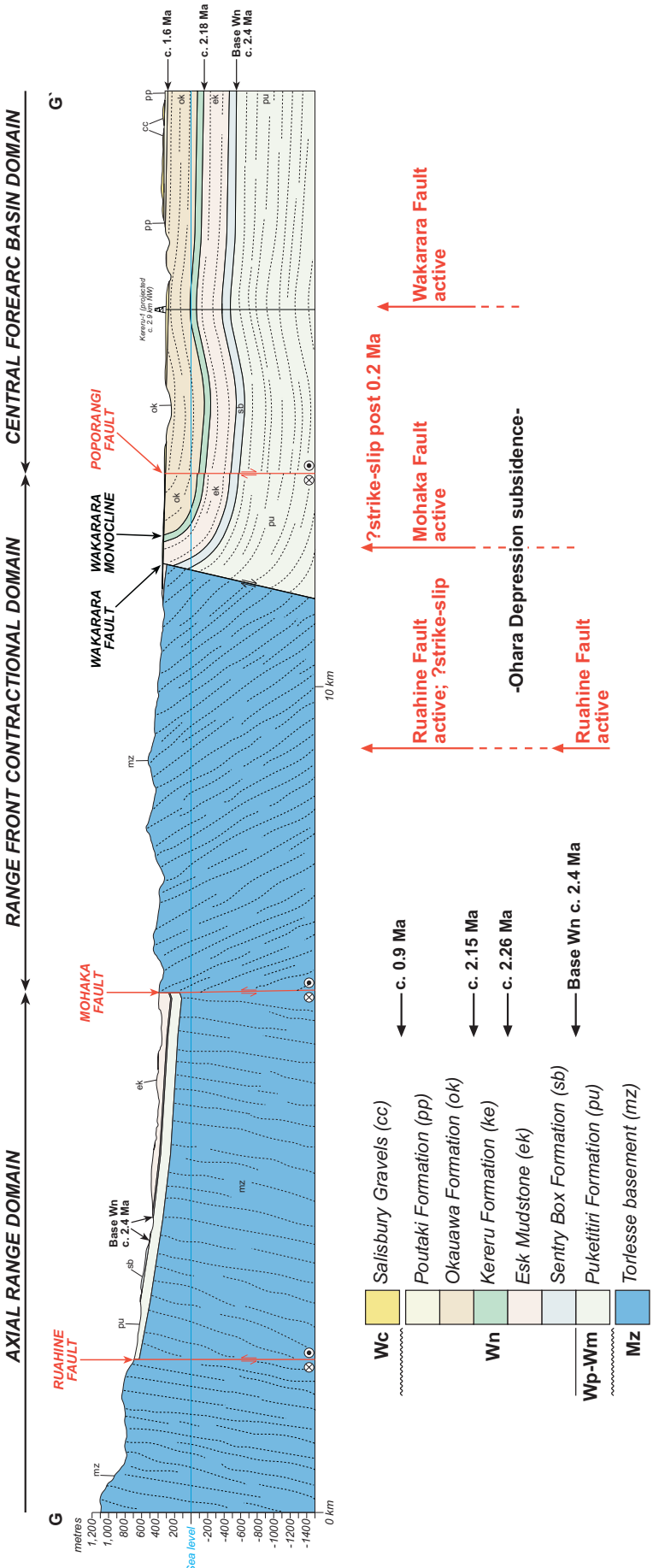
Te Kowhai Fault

Identification of the Te Kowhai Fault (Fig. 5.3) in this study is based in part from a trace mapped by Grindley (1960). Its trace as depicted in this study is mostly inferred. It strikes from Mangatutu Station to the northern edge of Te Kowhai Station along which it displaces basement and Te Waka Formation. Vertical offset is up to the west of the fault. On Mangatutu Station, Te Waka Formation is dramatically folded adjacent to the inferred location of the fault plane which itself has not been observed. The amount of throw on the Te Kowhai Fault is unknown, but is at least 100 m, and probably greater.

Patoka Fault and Patoka Fault Zone

The Patoka Fault Zone extends from Hawkston Station to at least as far as Te Pohue in the northeast, and consists of a series of reverse and dextral-slip faults that trend NE-SW. The Patoka Fault Zone comprises two principal structures, namely the Patoka and Rukumoana Faults (Fig. 5.3), and several other prominent fault traces and lineaments have been mapped. It is probable that the Rangiora Fault represents a northeastern extension on the Patoka Fault Zone.

Fig. 5.12 (facing page): Geological cross-section (line G-G‘ in Fig. 5.2, western part of line D-D‘ on Enclosure 3) across the axial range and range front contractional domains in the Ohara Depression and Kereru area. The large displacement on the Wakarara Fault is clearly evident, as is the folding associated with it that has produced the Wakarara Monocline. The Ohara Depression has formed in a down-faulted basin between Torlesse basement blocks uplifted by the Ruahine and Mohaka Faults. The relationship between structures and beds in this cross-section, and topography is illustrated in Fig. 5.11. Inferred periods of active displacement of faults in this cross-section are indicated.


AXIAL RANGE DOMAIN
RANGE FRONT CONTRACTIONAL DOMAIN
CENTRAL FOREARC BASIN DOMAIN
G
G`
RUAHINE FAULT
MOHAKA FAULT
WAKARARA FAULT
WAKARARA MONOCLINE
POPORANGI FAULT
Base Wn c. 2.4 Ma
c. 1.6 Ma
c. 2.18 Ma
Base Wn c. 2.4 Ma
Kereru-1 (projected c. 2.9 km NW)
metres
1,200
1,000
800
600
400
200
Sea level
-200
-400
-600
-800
-1000
-1200
-1400
0 km
10 km
mz
pu
sb
ek
ok
pp
cc
Ruahine Fault active; ?strike-slip
?strike-slip post 0.2 Ma
Mohaka Fault active
Wakarara Fault active
-Ohara Depression subsidence-
Ruahine Fault active
c. 0.9 Ma
c. 2.15 Ma
c. 2.26 Ma
Base Wn c. 2.4 Ma
Salisbury Gravels (cc)
Poutaki Formation (pp)
Okauawa Formation (ok)
Kereru Formation (ke)
Esk Mudstone (ek)
Sentry Box Formation (sb)
Puketitiri Formation (pu)
Torlesse basement (mz)
Wc
Wn
Wp-Wm
Mz

The Patoka Fault is an important boundary between Torlesse basement and forearc basin sediments to the east. No basement rocks crop out east of the Patoka Fault, or its northern equivalents the Rukumoana and Rangiora Faults. North of where the Patoka Fault splinters off the Mohaka Fault recent evidence of strike-slip displacement on the Mohaka Fault becomes less common. It is possible therefore that a significant portion of strike-slip motion on the Mohaka Fault further south is now accommodated on structures of the Patoka Fault Zone.

The Patoka Fault was first mapped and described by Kingma (1958). It has more recently been studied in detail by Halliday (2003) who mapped a 15 km-long surface trace of the fault including several traces at the northern and southern ends of the structure. The Patoka Fault is the principal element of the Patoka Fault Zone and trends along the base of Patoka hill, above Patoka Village from where the name derives. Sag ponds are visible along the fault trace from Puketitiri Road and in adjacent farms (Fig. 5.13). Although the fault plane has not been observed in this study, the fault trace has recently been trenched (Halliday *et al.* 2003).



Fig. 5.13: Views of the active trace of the Patoka Fault around V20/199997, Raumati Station. The uplifted shutter ridge is on the northwest side of the fault. Note the sag ponds in images B and C. This part of the Patoka Fault trace was trenched as part of the study by Halliday (2003) and Halliday *et al.* (2003).

Kingma (1958b) estimated a maximum vertical displacement of "400 ft" (c. 120 m) on the Patoka Fault about 3.2 km north of Patoka village, and commented that there was no evidence of strike-slip displacement. However, the recent work of Halliday (2003) and Halliday *et al.* (2003)

demonstrates significant strike-slip displacement on the fault. Holocene spurs and streams display dextral offset of up to 13 m (Halliday *et al.* 2003). At least three separate events in the past 5,300 years have been identified from trenching the fault trace at Patoka village (Fig. 5.13). Halliday *et al.* (2003) suggested that the Patoka Fault developed in the Holocene, but this is not consistent with the geology surrounding the fault. Halliday *et al.* (2003) inferred a maximum vertical slip-rate on the Patoka Fault of 0.21 mm/yr. The estimated maximum dextral slip-rate on the fault was estimated by Rob Langridge (*in* Litchfield *et al.* 2005) at 1.9-3.2 mm/yr, similar to that estimated for the Mohaka Fault. It is probable that the Patoka Fault represents the recent evolution of the North Island Shear Belt and, with the Rukumoana and Rangiora Faults (see below), is becoming important in the strike-slip deformation of the study area.

Waiwhare Fault

The name Waiwhare Fault is introduced for a structure in the Waiwhare region. It has not previously been mapped, although its trace is inferred in part from the geological map of Grindley (1960), and active traces contained in the GNS Science active faults database. It is the southernmost structure of the Patoka Fault Zone. It marks the eastern edge of the Te Waka Formation at Waiwhare and trends from Lee Road through the Napier-Taihape Road, River Road and Mangatutu Road, where the trace is inferred to end at Mangatutu Stream (Fig. 5.3). It is upthrown along its western edge.

Waihau Fault

The name Waihau Fault is introduced here for a newly mapped fault in the area around Waihau Road (Fig. 5.3). Its mapped trace is mostly inferred from discontinuous active traces, deformation of sedimentary rocks, and lineaments evident on digital elevation models and air photographs. The Waihau Fault is included as part of the Patoka Fault Zone. The fault marks the edge of Matahorua Formation outcrop from Puketitiri Road, through Waihau Road to the Waiwhare area. The Matahorua Formation is downthrown on the eastern side of fault. Total throw on the fault is uncertain, but is considered to be in the order of <100 m.

Rukumoana Fault

The Rukumoana Fault (Fig. 5.3) is the northeastern continuation of the Patoka Fault, and trends NE-SW along the foot of the Te Waka Range to Te Pohue. It was first identified by Stonely *et al.* (1958) and mapped by Francis (1991), Bland (2001) and Leith (2003). The Rukumoana Fault is the northernmost part of a 21 km-long series of active fault traces that extend NE-SW from Patoka to Te Pohue.

The fault plane has not been observed in the field, but the fault is imaged on seismic reflection profiles. The fault steepens at depth and is projected to intersect the Mohaka Fault (Wylie 1993). It has been inferred from surface investigations that the Rukumoana Fault has accommodated dextral strike-slip displacement in recent time (e.g. Begg *et al.* 1994), although little field evidence exists to confirm this. However, because the Rukumoana Fault is the northern continuation of the Patoka Fault some degree of dextral-slip displacement is probable on it. Vertical offset is estimated at a minimum of 60-100 m (Bland 2001), but is probably greater than this. There is a significant increase in the dip (c. 25°) of Te Waka Formation beds adjacent to the fault near Te Pohue indicating substantial dip-slip displacement (Bland 2001).

A strong lineament continues from the end of the Rukumoana Fault northeast along the base of the Maungaharuru Range, although it remains unresolved whether it represents a continuation of the Rukumoana Fault. Possible active fault traces have been observed in this area and may relate to this lineament (Rob Langridge, GNS Science, pers. comm. 2005). In places the lineament is obscured by landslide debris and no seismic line crosses this area to confirm its presence. However, the presence of the active Rangiora Fault (see below) on a similar trend to the Patoka/ Rukumoana Fault system strongly suggests that the lineament is part of the same fault zone. It is also likely to represent the large fault inferred to be driving uplift along the eastern side of the southern Maungaharuru Range and its consequential large-scale deep-seated gravitational collapse.

Te Waka Range Splinter Fault

Te Waka Range Splinter Fault (Fig. 5.3) strikes NE-SW along the crest of the Te Waka Range to the west of the microwave tower. It is a relatively minor structure that lies between the Mohaka and Rukumoana Faults. Around 15 km of strike-length has been mapped by Neall *et al.* (1995), and the fault has been described as an extensional splinter trace of the Mohaka Fault. In its southern section the fault has an orientation of 034/85° W, and can be traced to below Te Waka trig where it splays and appears to terminate (Leith 2003). The fault is normal, and may relate to minor gravitational collapse of the western face of the Te Waka Range into the Mohaka River valley. At Te Waka trig the western side of the fault is downthrown by 30 m. However, because this is near the terminus of the fault, total displacement is likely to increase towards the southwest. Possible maximum horizontal displacement is between 60-100 m, and faulting events have been identified both pre- and post- the 11 850 yr BP Waiohau Tephra (Neal *et al.* 1995). The fault may be responsible for the large landslide in the central Maniaroa Range in the headwaters of Waipunga Stream.

Rangiora Fault

The Rangiora Fault (Fig. 5.3) is a 14 km-long structure located about 40 km north of Napier and 13 km east of the Mohaka Fault. Although lateral continuity cannot be confidently demonstrated, it is inferred to represent the northernmost element of the Patoka Fault Zone based on its position near the Mohaka Fault and its style of deformation. A 5 km-long Late Quaternary trace occurs along the central section of the fault at Rangiora Station near the Waikare River (Cutten *et al.* 1988). The fault was first mapped by Grindley (1960), although he didn't note its Late Quaternary activity, and also by Cutten *et al.* (1988), Cutten (1994), and Graafhuis (2001). The trace is visible as a scarp up to 2 m high that shows reversals in the upthrown side. The fault strikes 030°, oblique to beds in the surrounding Mangaheia Group, which typically strike around 055°. Total throw on the fault is unknown, but is likely to be less than a few 10s of metres as there is no lithological contrast across it (Cutten *et al.* 1988; Graafhuis 2001). The linear trace of the fault over hill country, and changes in the upthrown side, indicate a very steep dip on the fault plane (Cutten *et al.* 1988), although it probably curves and merges with the Mohaka Fault at depth.

Beanland (1995) suggested that the Rangiora Fault is becoming important in terms of the development of the North Island Shear Belt. At the northern end of the fault trace, near the Waikare River, a series of river terraces are dextrally offset with progressive displacements of 5-15 m (Cutten 1994). Three faulting events were identified by Cutten *et al.* (1988) involving 4-6 m right lateral offsets, with one occurring between 3300 and 1900 years ago, and two in the last 1900 years. The Rangiora Fault is inferred to have an average late Holocene slip rate of 4.5 mm/yr (Cutten *et al.* 1998), comparable to that of the Mohaka and Ruahine Faults. The scale of offset on the Rangiora Fault estimated by Cutten *et al.* (1988) is consistent with offset on the Patoka Fault estimated by Halliday (2003).

Folds

Wakarara Monocline

The Wakarara Monocline has developed as a consequence of reverse offset on the Wakarara Fault (see above) (Erdman and Kelsey 1992) (Fig. 5.12). It is a major structural element of southwestern parts of the study area that extends for over 30 km. Along the face of the Wakarara Range the Wakarara Monocline trends about 035°. North of the range the trend becomes more westerly (190°). It is locally overturned along the eastern range front of the Wakarara Range, and dies out north of Ohara Stream. This is marked by steeply dipping ridges of Kereru Formation, examples of which are visible near Poporangi Road. The southern parts of the Wakarara Monocline were described in detail by Raub (1985). North of the Wakarara Range the Wakarara

Monocline represents the geomorphic expression of the subsurface continuation of the Wakarara Fault. The Wakarara Monocline is well exposed at the confluence of Ohara Stream and Big Hill Stream where beds of the Kereru and Okauawa Formations dip steeply in cliff faces (Fig. 5.14). Along the eastern face of the Wakarara Range Kereru Formation dips near vertically along the edge of the Wakarara Fault.



Fig. 5.14: Surface expression of the Wakarara Monocline in Ohara Stream, U21/026720. The monocline has formed as a surface response to displacement on the subsurface Wakarara Fault. Ticked filled circles indicate the changes in dip of the Okauawa Formation across the monocline.

Patoka Anticline

The Patoka Anticline was first described and named by Kingma (1958b) and is geomorphically expressed in Patoka Hill. This structure possibly records deformation induced by contraction between the Patoka and Mohaka Faults and is cored by Te Waka Formation. The eastern extent of the fold is truncated by the main trace of the Patoka Fault (Enclosure One, Sheet 3). The southern limb dips at about 13°SW, with the northern limb dipping up to 20°E. South of the anticline towards Price Cockburn Road, dips on Te Waka Formation steadily become more easterly, and by Mangatutu Station the Te Waka Formation is dipping 9°SE, more consistent with the regional dip.

Pohokura Anticline

The Pohokura Anticline (Fig. 5.10) is an asymmetric fold whose trend was mapped by Cutten (1994). It was previously named the Dam Site Anticline in Cutten (1988). The fold deforms Early Miocene rocks in the area around Waitere Station in the north of the study area. The hinge of the fold is well exposed in Anticline Creek at V19/405322. In this section beds of the eastern limb have a strike and dip of 205°/68°E and beds on the western limb 156°/49°W (Cutten 1994).

CENTRAL FOREARC BASIN DOMAIN: AN OVERVIEW

The modern forearc basin is a 400-500 km long narrow (10-40 km) region containing a thick Late Neogene succession bounded to the west by the range front contractional domain and to the east by the eastern contractional domain (Fig. 5.2). The domain is an area of relatively subdued topography, with the sedimentary succession underlying it relatively undeformed (Fig. 5.12). Deformation is mostly minor with NNE-trending reverse faults and folds and associated anticlines, which broadly parallel the basin trend. Reverse and normal faults are common, with vertical offsets typically less than 1 m, although displacements may be up to 20 m.

West of Hastings and Napier the sedimentary succession dips at about 20°-2° as part of the Hawke's Bay Monocline. The axis of the monoclinal folding is evident in the Tangoio Block north of Napier where beds in the northwest of the block dip at 10°SE while beds in the southeast dip 2°SE. A central syncline in the Heretaunga Plains, known as the Matapiro Syncline, involves on the western limb beds of the monocline, and on the eastern limb, beds in the vicinity of Hastings and Napier that dip up to 20°NW. The Matapiro Syncline extends from the north bank of the Ngaruroro River at Matapiro to approximately the Puketapu area and has folded Upper Nukumaruan rocks (less than 2.1 Ma) into a broad shallow (4°-2°) fold. The exploration well Kereru-1 (Fig. 5.2, 5.12) targeted an anticlinal structure in the central forearc basin domain.

Faults

Glengarry Fault

The Glengarry Fault (Fig. 5.3) displaces Matahorua Formation from Patoka to Trelinnoe Station through Glengarry Forest and across the Napier-Taupo Road. Its trace is mostly inferred, although outcrop patterns of Late Pliocene sedimentary rocks in the area strongly support its presence. No active traces have been observed. The position of the fault is very similar to that of the subsurface Eastern Patoka Fault inferred from seismic lines by Leith (2003) (see below), and strikes about 030°.

At Trelinnoe Station vertical displacement on the Glengarry Fault is less than 15 m with down-throw to the northwest. Displacement increases southwestward along the fault trace towards the Napier-Taupo Road and Glengarry Forest where it is at its greatest, diminishing again southward to Waihau Road. Vertical displacement in the Glengarry Forest area is difficult to accurately determine, but is about 80 m.

Ngaruroro River Fault

The Ngaruroro River Fault (Fig. 5.3) lies on the south bank of the Ngaruroro River near the small settlement of Maraekakaho and Roys Hill. It separates Lower Nukumaruan Mason Ridge Formation on the south side of the river (Mason Ridge block) from Upper Nukumaruan Petane and Kaiwaka Formations on the north side (Matapiro Block). Its trace was mapped by Kingma (1971). The course of the Ngaruroro River changes noticeably in this area. From Kuripapango and Whana Valley the river follows a mostly southeast course, until near Maraekakaho where it abruptly trends northeast. Once the river reaches Fern Hill its course becomes more easterly until reaching State Highway 2 and its lagoon. It is probable that the rivers position in this area is controlled by the Ngaruroro River Fault.

A further fault is inferred in this area which separates the isolated block of Roys Hill from both the Mason Ridge and Matapiro blocks. Roys Hill is formed from "middle" Nukumaruan Park Island Limestone Member which is not known from either the adjacent Matapiro or Mason Ridge blocks. Park Island Limestone Member probably underlies the Matapiro block, but was never deposited on the Mason Ridge block whose beds are older than the Park Island Limestone Member. It is probable that the Ngaruroro River Fault is a concealed structure, buried beneath Quaternary gravels of the Heretaunga Plains.

The structural position of Fern Hill is uncertain. Fern Hill lies on the immediate south bank of the Ngaruroro River at the locality of Fern Hill, adjacent to Omahu. As at Roys Hill, Fern Hill is formed from Park Island Limestone Member, although it is faced immediately across the river by prominent bluffs of younger Waipatiki Limestone Member. It is probable that a concealed fault separates Fern Hill from beds immediately north of the Ngaruroro River.

Subsurface faults

Many of the actively growing anticlines within the central forearc basin domain are inferred to be cored by reverse faults. Because of the unconsolidated nature of many near-surface sediments in coastal Hawke's Bay, many deeper faults have failed to propagate to the ground surface, and in such circumstances many faults are expressed at the surface as broad warps or force folds (Begg *et al.* 1994). The 1931 Napier earthquake demonstrated that these folds can develop in association with large earthquake events (Hull 1990; Begg *et al.* 1994).

Eastern Patoka Fault

The Eastern Patoka Fault was identified and named by Leith (2003), inferred from a strong, gently dipping reflector at about 2s TWTT (Two Way Travel Time) in seismic line EC91-4. This structure

correlated well with a similar reflector at the western end of line WEC97-2 that occurs immediately below a broad c. 5 km-wide anticlinal structure which dominates the profile. Leith (2003) inferred the Eastern Patoka Fault to be responsible for many of the defects and lineaments affecting the Esk River catchment at present.

The Eastern Patoka Fault has no surface trace. The zone above the terminus of the fault consists of many small faults, each with a vertical displacement of less than 20 m. The combined effect is "warping" of the modern land surface above the inferred termination of the Eastern Patoka Fault (Leith 2003). The warping of the land surface can be observed from river long-profiles which show streams across the structure flow above grade. This suggests that the fault is still active, as streams have not been able to cut down to grade. The position of the Eastern Patoka Fault as mapped by Leith (2003) is very similar to that of the inferred Glengarry Fault (see above), although any correlation between the two structures is uncertain. Leith (2003) suggested that a surface expression of the Eastern Patoka Fault is likely to consist mostly of many extensional structures, although it is unlikely that individual splays of the fault would extend to the surface due to the diffuse nature of the faulting.

Trelinnoe Fault

The Trelinnoe Fault was mapped as the "Wakarara Fault-Trelinnoe Sector" by Leith (2003). It is a subsurface structure inferred to be an important driving factor behind the active deformation and landsliding in the Esk River catchment. The presence of the fault was inferred from seismic lines by Leith (2003), who included the structure as part of the Wakarara Fault (see above) on the basis of similarity between seismic sections east of the Wakarara Range (Beanland *et al.* 1998) and east of the Te Waka-Maungaharuru Ranges. Geological mapping in the current study suggests that the Wakarara Fault *sensu stricto* and the "Wakarara Fault-Trelinnoe Sector" are not linked in any way. It has therefore been renamed the Trelinnoe Fault to avoid any confusion with the Wakarara Fault bounding the Wakarara Range.

The projected surface location of the fault is marked by a monocline named the Trelinnoe Monocline (Fig. 5.10). Seismic lines across the Trelinnoe Fault show little of the complex faulting above the adjacent Eastern Patoka Fault, and overlying sediments appear to have been deformed in a more ductile manner. To the east of the monocline upper parts of the sedimentary succession appear to be deformed by compressional thrust faults induced by shortening of the sediments in the tightening fold hinge (Leith 2003). These faults are well defined on seismic line WEC97-1, dip to the east and are spaced approximately 200 m apart. They appear to terminate sharply at depth on a horizon interpreted to be the top of the Grassy Knoll Conglomerate Member (Matahorua Formation) (Leith 2003).

Folds

Matapiro Syncline

The Matapiro Syncline (Fig. 5.10) is the major structural feature affecting the outcrop pattern of Nukumaruan rocks through central portions of the study area. Previously the syncline was mapped extending from the Ngaruroro River, through the Puketapu area, to the Esk River mouth (e.g. Grindley 1960; Kingma 1971; Beu 1995). Geological mapping in this study suggests that the Matapiro Syncline is not as extensive as previously shown, and extends from the Ngaruroro River to near Puketapu. Dips on beds in the syncline are typically 4°-2°. Development of the Matapiro Syncline occurred syn-depositionally, as evidenced by dip-changes between older and younger units. Lithological differences occur between units exposed on either limb of the syncline, reflecting a depositional gradient across a paleoshelf. It is possible that the eastern limb of the syncline, marked by the western limb of the Taradale Anticline, marks the encroachment of the accretionary wedge into the forearc basin succession. The western limb of the syncline reflects uplift driven by displacement on faults in the axial range and range front contractional domains. The Matapiro Syncline terminates abruptly at the Ngaruroro River near Roys Hill, and does not continue south into the Mason Ridge area. North of Napier and Puketapu the western limb of the Matapiro Syncline is referred to as the Hawke's Bay Monocline. This monocline dips at about 2°-35° to the southeast, with its axis in the western part of the Tangoio Block.

Trelinnoe Monocline

The Trelinnoe Monocline is the surface expression of the subsurface Trelinnoe Fault (Fig. 5.10). Across the Trelinnoe Monocline the dip of Late Pliocene sedimentary rocks above it increases. The axis of the monocline is also marked by a series of landslides which were mapped by Leith (2003). These landslides include the prominent Eland, Northlands and Deep Stream landslide complexes (Enclosure 1, Sheet 4). Dips across the monocline increase from approximately 8° to 15°. The increased dip on these poorly cemented sedimentary rocks increases the propensity for mass-movement events, hence the series of landslide complexes above the monocline.

Mason Ridge fold zone

The Mason Ridge area is characterised by a series of anticlines and synclines (Fig. 5.10), probably resulting from displacement on blind reverse or thrust faults. In the Late Pliocene (Lower Nukumaruan) these anticlines have been important in the development of the Mason Ridge Formation by providing paleo-seafloor relief upon which carbonate factories formed. The folds beneath Mason Ridge may represent the encroachment of the accretionary wedge into the forearc basin fill.

Other folds

The folds underlying Mason Ridge (Fig. 5.10) are part of a belt of anticlines and synclines that extends from the northern Wakarara Range east to the Raukawa Range (e.g. Fig. 3 in Cashman *et al.* 1992). Mapping by Kelsey *et al.* (1993) illustrates that many of the folds in this area are underlain by reverse or thrust faults at depth. This zone of folding appears to correspond to the area where the forearc basin narrows south of Hastings, perhaps indicating increasing contraction of the basin. This is probably due to the encroachment of the accretionary wedge into the forearc basin fill, with the subsequent narrowing of the basin resulting in fault and fold propagation.

In the area around Rautoitoi Stream, Tutira Member beds show evidence for blind faulting, driving the formation of a surface fold.

EASTERN CONTRACTIONAL DOMAIN: AN OVERVIEW

The eastern contractional domain (Fig. 5.2) comprises the coastal hill country in the southeastern part of the study area from the Raukawa Range east to the Maraetotara Plateau and offshore. It marks a zone of reverse faulting and related folding (Fig. 5.15). This domain includes the onland part of the accretionary wedge. A similar style of deformation underlies Hawke Bay (Barnes *et al.* 2002). Although the western margin of the domain is slightly diffuse, it is marked by more dense faulting and folding that includes the Longlands, Poukawa (Kelsey *et al.* 1998), and Tukituki Faults (Fig. 5.3). It is inferred that some degree of dextral-slip displacement is accommodated on structures in the western part of this domain, and structures in the eastern part accommodate principally contractional deformation (Cashman *et al.* 1992; Beanland 1995; Beanland *et al.* 1998).

Coastal parts of this domain (Maraetotara Plateau, Cape Kidnappers area) are cut by a network of Recent normal faults, 1-7 km long, that have vertical displacements of up to many tens of metres (Kingma 1971; Cashman and Kelsey 1990; Cashman *et al.* 1992). Fault traces in this area (Maraetotara Fault Zone) (Fig. 5.3), are discontinuous and the zone varies in width from several hundred metres to about 8 km (Begg *et al.* 1994). Normal faults bound both east- and west-dipping fault blocks. Fault-slip indicators show nearly pure dip-slip displacement (Cashman *et al.* (1992). The relationship between the normal faults in the domain and the major reverse faults of the accretionary wedge at depth is poorly known, as is the depth to which the faults extend (Begg *et al.* 1994). The relationships between normal faults and deeper reverse faults is however better understood in offshore areas (e.g. Barnes and Nicol 2002; Barnes *et al.* 2002). Both Pettinga (1982) and Cashman *et al.* (1992) suggested that normal faults in this domain are a surface response to uplift and arching through contraction of the underlying accretionary wedge, and not

representative of deformation at deeper levels. This was supported by Pettinga (2004) in a study of the character of large-scale gravitational collapse of the Maraetotara Plateau. In the Cape Kidnappers area Late Pleistocene marginal-marine sediments have been uplifted nearly 150 m above sea level, tilted to the northwest and cut by dominantly normal faults with displacements of up to 9 m. Cashman *et al.* (1992) suggested that normal faulting in the Cape Kidnappers area began during the Late Pleistocene and continues to the present day. These extensional faults continue into Hawke Bay (Begg *et al.* 1994).

Several recent hydrocarbon exploration wells (e.g. Whakatu-1, Hukarere-1; Fig. 5.2) have targeted anticlinal structures in the eastern contractional domain. Hawke Bay-1 targeted an anticlinal structure in the offshore extension to the north of this domain.

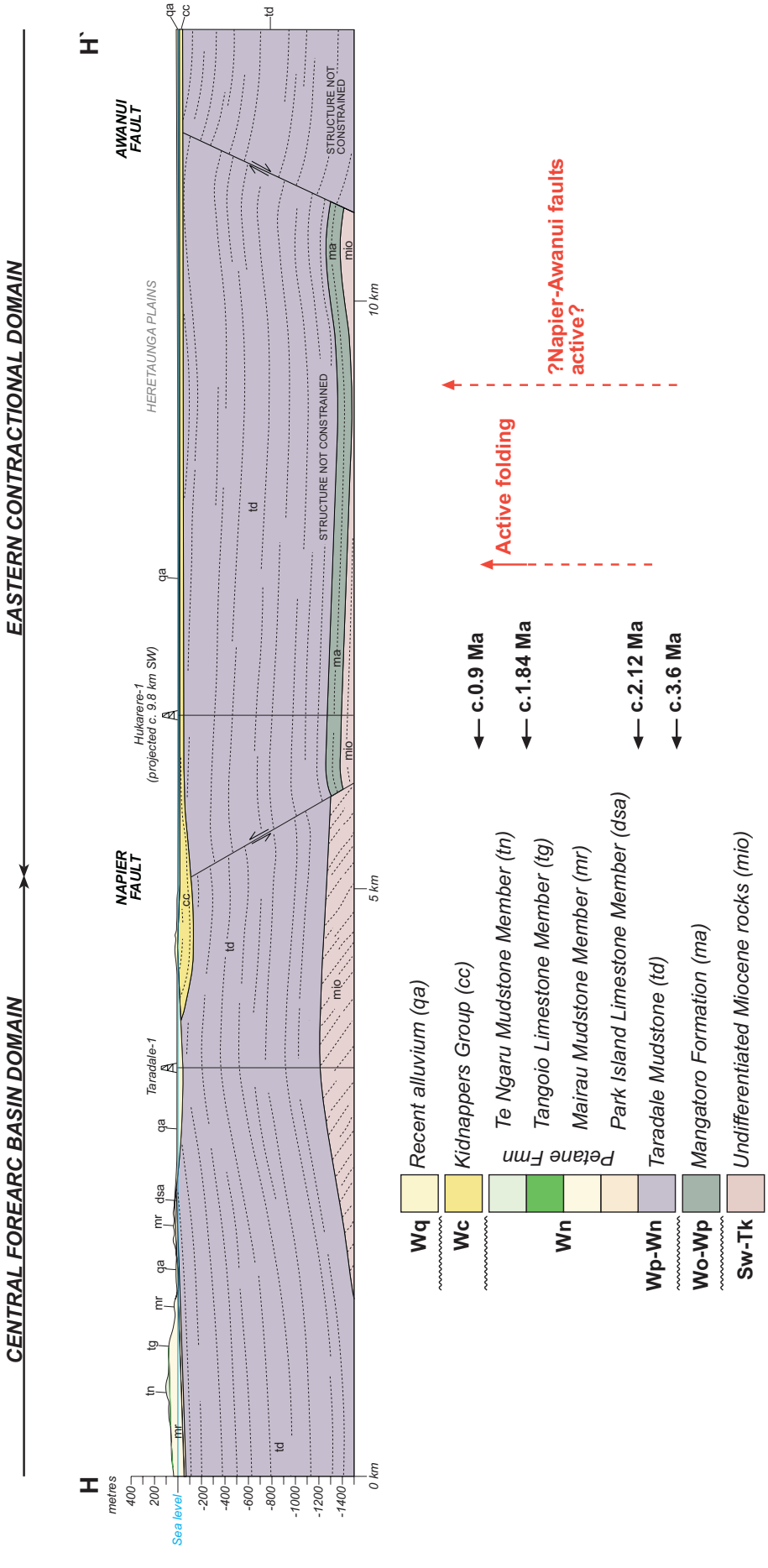
Faults

Napier Fault

The Napier Fault is a northeast-trending subsurface structure identified from seismic lines that extends from at least Bridge Pa (and perhaps almost as far southwest as Tikokino), beneath Te Awa and Taradale, and offshore from the Port of Napier (Hull 1990; Begg *et al.* 1994) (Fig. 5.3, 5.15). The fault lies to the west of Scinde Island, its location here constrained by seimic data aquired and processed as part of the Hukarere-1 drilling programme (Westech Energy New Zealand Ltd). The Napier Fault is inferred to be reverse in nature with a strike-slip component (Begg *et al.* 1994) and may mark the inboard margin of the accretionary prism. It is inferred that displacement on the Napier Fault during the Pliocene was responsible for creating a paleohigh upon which carbonate facies of the Scinde Island Formation accumulated. This suggests that it has been active since at least the Lower Nukumaruan (Late Pliocene, c. 2.4 Ma). The offshore trend of the Napier Fault is probably reflected in the location of Pania Reef.

The Napier Fault was inferred to be the subsurface continuation of the Poukawa Fault Zone by Begg *et al.* (1994). However, a significant step-over would be required for this to be the case. It appears as though Begg *et al.* (1994) have confused the Napier Fault with the Awanui Fault, which lies further east (see below).

Fig. 5.15 (facing page): Geological cross-section (line H-H‘ in Fig. 5.2, eastern part of line D-D‘ on Enclosure 3) through the Taradale-Napier area. This cross-section illustrates the transition from the central forearc basin to eastern contractional domains. Significant offset on the Napier Fault is inferred from exploration well data in Hukarere-1 and Taradale-1. Also evident are the anticlinal structures targeted in Taradale-1 and Hukarere-1.


CENTRAL FOREARC BASIN DOMAIN
EASTERN CONTRACTIONAL DOMAIN
H
H`
metres
400
200
Sea level
-200
-400
-600
-800
-1000
-1200
-1400
0 km
5 km
10 km
tn
tg
mr
ga
dsa
cc
td
mio
ma
Taradale-1
Hukarere-1
(projected c. 9.8 km SW)
NAPIER FAULT
AWANUI FAULT
HERETAUNGA PLAINS
STRUCTURE NOT CONSTRAINED
STRUCTURE NOT CONSTRAINED
?Napier-Awanui faults active?
Active folding
c.0.9 Ma
c.1.84 Ma
c.2.12 Ma
c.3.6 Ma
Recent alluvium (qa)
Kidnappers Group (cc)
Te Ngaru Mudstone Member (tn)
Tangoio Limestone Member (tg)
Mairau Mudstone Member (mr)
Petane Fmn
Park Island Limestone Member (dsa)
Taradale Mudstone (td)
Mangatoro Formation (ma)
Undifferentiated Miocene rocks (mio)
Wq
Wc
Wn
Wp-Wn
Wo-Wp
Sw-Tk

Awanui Fault

The Awanui Fault (Fig. 5.15) is an inferred subsurface structure extending from near Bridge Pa, beneath Flaxmere, to the coast at Awatoto. Based on the surface and subsurface distribution of faults reported by Hull (1990), Beanland *et al.* (1998), and Westech Energy New Zealand Ltd (2001), the Awanui Fault is likey to be a subsurface continuation of the Poukawa Fault Zone. It is uncertain whether the Awanui Fault merges with the Napier Fault at depth, the inferred trace of which lies to the west. Rupture on the Poukawa Fault and its inferred northern continuation, the Awanui Fault, is inferred to have been responsible for the 1931 Napier earthquake (Hull 1990). The line of zero elevation change of the land surface around Napier/Hastings as a result of the 1931 earthquake, extending from Bridge Pa to Awatoto, is currently regarded as the most accurate location of the surface projection of the Napier Fault (Henderson 1933; Haines and Darby 1987; Hull 1990). This location is supported by the presence of a series of springs, presumably the consequence of disruption of an aquifer (Begg *et al.* 1994).

Maraetotara Fault Zone

The Maraetotara Plateau and Cape Kidnappers area is cut by a discontinuous network of 1-7 km-long normal faults that have vertical displacements up to many tens of metres (Cashman and Kelsey 1990; Cashman *et al.* 1992) (Fig. 5.3), and bound both east- and west-dipping fault blocks. The fault zone varies in width from several hundred metres to about 8 km (Begg *et al.* 1994). Fault-slip indicators show nearly pure dip-slip displacement (Cashman *et al.* 1992). The relationship between these normal faults and the major reverse faults is unknown, as is the depth to which the faults extend (Begg *et al.* 1994). Both Pettinga (1982) and Cashman *et al.* (1992) suggested that normal faults in this domain are a surface response to uplift and arching through contraction of the underlying accretionary wedge, and are not representative of deformation at deeper levels. In the Cape Kidnappers area, Late Pleistocene marginal-marine sediments have been uplifted to over 150 m above sea level, tilted to the southwest and cut by dominantly normal faults with a displacement of up to 9 m. Cashman *et al.* (1992) suggested that faulting began in the Cape Kidnappers area during the Castlecliffian and continues to the present day. The northern extension of the Maraetotara Fault Zone can be identified in seismic profiles from Hawke Bay (Begg *et al.* 1994).

Poukawa Fault Zone

The Poukawa Fault Zone (Fig. 5.3) consists of a highly segmented series of 15 anastomising and en-echelon right and left-stepping dextral strike-slip, thrust and normal faults (Kelsey *et al.* 1993, 1998). Active folding accompanies faulting in this zone, and fold axes often parallel the trends of associated faults (Cashman *et al.* 1992). Companion hanging wall anticlines are present in

association with faults in the zone (Kelsey *et al.* 1998). The geomorphically expressed length of the fault zone is 34 km, although on the basis of co-seismic deformation associated with the 1931 Napier earthquake, and the presence of blind faults north of the expressed length, the seismogenic length of the fault zone may be a much as 130 km (Kelsey *et al.* 1998). This means that the subsurface Awanui Fault may be a northeastern continuation of the Poukawa Fault Zone.

The northernmost part of the Poukawa Fault Zone occurs in southern parts of the study area between the Kaokaoroa and Raukawa Ranges in a region of locally downwarped basins, and uplifted folded hills. The Poukawa and Otane Basins, and two fault-bounded anticlinal hills (Waikareao and Glenforsa Anticlines), constitute the main structural elements of the wider fault zone (Cashman *et al.* 1992) and are south of the study area.

Faults in the Poukawa Fault Zone typically strike NNE and dip from 45-75°NW (Beanland *et al.* 1998). Cashman *et al.* (1992) inferred a Quaternary strike-slip displacement rate of 7-9 mm/yr for the Poukawa Fault Zone, though this was refuted by Beanland (1995). The fault zone is actively growing towards the east and the north beneath the Heretaunga Plains (Kelsey *et al.* 1998).

Tukituki Fault Zone

The Tukituki Fault Zone (Fig. 5.3) lies several kilometres east of the Poukawa Fault Zone, and encroaches into southernmost parts of the study area. It comprises a series of NW-dipping reverse faults that trend NNE to NE. Most of the Tukituki Fault Zone lies outside the study area.

Folds

Taradale Anticline

On his geological map of the Matapiro-Napier area, Kingma (1971) showed an anticline in the hills immediately west of Taradale. Subsequent studies have made no mention of the presence of this structure (e.g. Beu *et al.* 1980; Beu 1995). Geological mapping as part of this current study confirms the presence of this feature (Fig. 5.10). The anticline is defined by Park Island Limestone Member which near Puketapu follows Puketitiri Road uphill towards Taradale, before dipping steeply down to Park Island reserve. The Taradale Anticline is a north to northeast-plunging anticline that forms the eastern limb of the Matapiro Syncline. It is inferred to be cored by a reverse fault. Beds dip at up to 7° on the western limb, and 1°-4° on the eastern limb. The anticline cannot be traced north of The Outfall.

It is probably related to a structure at depth targeted by the hydrocarbon exploration hole Taradale-1 (Fig. 5.2). The Taradale Anticline is inferred to mark the most inboard expression of deformation associated with the accretionary wedge, and the boundary between the central forearc basin and eastern contractional structural domains.

Napier Syncline

The Napier Syncline (Fig. 5.15) reflects deformation associated with the inboard margin of the accretionary wedge, and probably developed during the Pliocene and perhaps Early Pleistocene. Its approximate location was documented by Hull (1986, 1990). As the limbs of the syncline are truncated by Quaternary deposits (e.g. Middle Castlecliffian Kidnappers Group and Recent alluvium), little post-Pliocene deformation on it is inferred. It is bounded on its western side by the Awanui Fault. The anticline associated with its eastern limb was targeted as a hydrocarbon prospect by Whakatu-1 (Fig. 5.15). The Napier Syncline may be a continuation of the unamed syncline mapped by Beanland *et al.* (1998) to the east of Pakipaki ridge and the Longlands Fault.

LINEAMENTS

Lineaments have been defined from analysis of air photos and DEMs and are depicted on the geological maps in Enclosure One. Most lineaments observed have the same trend as the main structural grain of the study area. They display a variable trace length. Features have been mapped as lineaments when they cannot be confirmed as being a fault.

SUMMARY OF TIMING OF FAULT DISPLACEMENT

Figure 5.18 summarises the inferred temporal distribution of fault activity in central Hawke's Bay for part of the Late Neogene. It is difficult to conclude exactly when the current phase of strike-slip displacement commenced in Hawke's Bay. This study suggests that most deformation of the forearc basin fill in central Hawke's Bay is young, and probably of post-latest Pliocene ("middle" Nukumaruan, c. 2 Ma) age. Earlier phases of deformation can also be identified in the study area. Uplift and erosion occurred in several fault blocks in the axial range and range front domains in the Late Miocene and Early Pliocene (Upper Kapitean to "middle" Opoitian, 5.3-4 Ma). Uplift and erosion during the "early-middle" Pliocene (Waipipian, 3.5-3 Ma) occurred in the axial range and eastern contractional domains. More widespread uplift of the proto-axial ranges occurred during the Late Pliocene (uppermost Mangapanian to lowermost Nukumaruan, 2.8-2.36 Ma) as inferred from the influx of thick non-marine braidplain deposits. Rapid basin-wide subsidence seems to have occurred during the Late Pliocene (Lower Nukumaruan, c. 2.3 Ma).

Thick conglomerate beds at the base of the Pakaututu Formation suggest Early Pliocene (Upper Opoitian) dip-slip displacement on the Ruahine Fault (Fig. 5.16). In the Kuripapango area the Te Waka Formation is the only Neogene stratigraphic unit occurring on both sides of the North Island Shear Belt. It is therefore a useful horizon to constrain the timing of deformation along this part of the shear belt. Rocks of middle to upper Opoitian age are present in the Kuripapango area, but Waipipian rocks are absent. The Mangapanian Te Waka Formation overlies the Opoitian beds, indicating a phase of uplift and erosion along the North Island Shear Belt during the Waipipian. Waipipian unconformities are also present in Taradale-1 (Darley and Kirby 1969), Ongaonga-1 (Leslie 1971a), and Takapau-1 (Leslie 1971c). The subaerial unconformity at the base of the Titiokura Formation near Te Waka trig is also of probable Waipipian age.

The most recent phase of deformation in the study area appears to have commenced at about 2.0-1.8 Ma, and continued up to the present (Fig. 5.16). This more regional deformation coincides with the timing of initiation of rifting in the Taupo Volcanic Zone (Beanland and Haines 1998, Carter *et al.* 2003, 2004). Offset of the Late Neogene basin fill in central Hawke's Bay on the Ruahine and Mohaka Faults has also mostly occurred since 2 Ma.

The presence of Lower Nukumaruan (Late Pliocene, c. 2.4 Ma) marine Sentry Box Formation on the flanks of the Ruahine and Kaweka Ranges demonstrates that the basement under these ranges was mostly submarine at this time. Deformation of Late Pliocene sedimentary units adjacent to the Ruahine and Mohaka Faults, particularly those in the Ohara Depression, indicates intensification of fault activity at approximately 2.0-1.8 Ma (Fig. 5.16). It is uncertain whether this marks the onset of strike-slip displacement on these faults. The presence of "middle" Nukumaruan Kereru Formation (c. 2.2 Ma) around the flanks of the Wakarara Range shows that this now highly-elevated (up to 1000 m) block of basement was still mostly submarine until after 2 Ma. The Kereru Formation forms the core of the Balcony Syncline on the western flank of the Wakarara Range. The Balcony Syncline is effectively a drag structure formed from the easterly uplift of the adjacent Mohaka Fault (Fig. 5.8C), and its formation helps to constrain the timing of the start of dip-slip displacement on the North Island Shear Belt to after 2 Ma. In the Ngaruroro River where it crosses the Mohaka Fault, Lower Nukumaruan (c. 2.2 Ma) Esk Mudstone is in fault contact with Torlesse basement, clearly demonstrating vertical offset on this fault after deposition of the Esk Mudstone.

Throughout the study area rocks of Upper Nukumaruan age (c.1.8 Ma and younger) display common soft-sediment deformation structures, including water-escape structures. Such features are relatively uncommon throughout most of the sedimentary succession in the basin. It is inferred

that the appearance of these deformation structures supports the onset of the current phase of accelerated deformation from about 2 Ma and more prevalent earthquake activity.

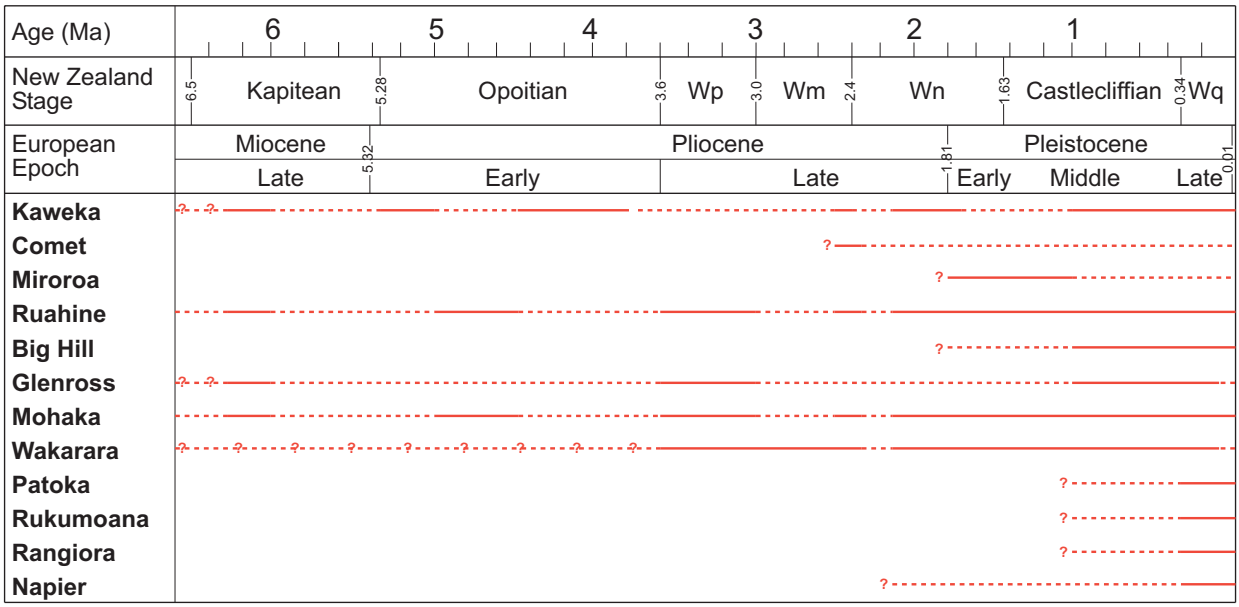


Fig. 5.16: Summary of inferred temporal distribution of activity on major faults in the study area during deposition of the Mangaheia and Kidnappers Groups. Solid lines indicate that fault activity is probable; dashed line, fault activity likely, but lithologic data are lacking; queried dashed lines indicate uncertain activity due to insufficient data. Some data adapted from Erdman and Kelsey (1992, p.190). Time scale from Cooper (2004).

Total horizontal offset on the Ruahine and Mohaka Faults since the Early Pliocene (Upper Opoitian), estimated from offset of sedimentary rocks either side of the faults, is likely to be less than 10 km. Most of this has probably been accommodated since the Late Pliocene (Upper Nukumaruan). The nature of the modern traces of the Mohaka and Ruahine Faults are consistent with limited through-going displacement on them. Traces are often discontinuous, display frequent reversals in their sense of displacement and have common bends. It is inferred that not enough displacement has occurred to both "straighten out" the fault traces and to join the various fault sections together into a single through-going mature fault. Total strike-slip displacement on the Ruahine Fault in central Hawke's Bay appears to be greater than that on the Mohaka Fault, and it is also probable that the Ruahine Fault began accommodating strike-slip displacement before the Mohaka Fault (about 2-1.8 Ma). Beanland *et al.* (1998) concluded that total strike-slip displacement on the Mohaka Fault since 3 Ma is likely to be less than 2 km.

CHAPTER SIX

PALEOENVIRONMENTS AND SEQUENCE STRATIGRAPHY OF THE MANGAHEIA GROUP

INTRODUCTION

This chapter addresses the nature of the inferred depositional paleoenvironments in the Late Miocene-Early Pleistocene (Kapitean-Nukumaruan) Mangaheia Group, as revealed by lithofacies, biofacies, and sequence stratigraphic analysis. It first establishes the lithofacies types and molluscan macrofaunal associations of the sedimentary succession in the study area. Details about these attributes are given in Appendix II (Paleoenvironmental Analysis), but a summary is included here. The chapter then documents the character of sequence stratigraphic elements, including key surfaces and systems tracts. The lithofacies and faunal associations are important for the characterisation of the systems tracts within sequences. Eight basic motifs of sequences are identified and described, and used to produce an idealised model sequence for the Nukumaruan part of the Mangaheia Group in central parts of Hawke's Bay.

LITHOFACIES ANALYSIS

INTRODUCTION

Examination and description of 1244 discrete outcrops during fieldwork in this study has led to the description of 41 separate lithofacies which have been grouped into six broad facies assemblages on the basis of dominant lithology, namely sandstone, siltstone, conglomerate, volcaniclastic, bioclastic and mixed bioclastic-siliciclastic assemblages. Each assemblage excepting the volcaniclastic one, generally corresponds to a broad depositional environment. Conglomerate facies are mostly of non- to marginal-marine origin. Sandstone facies represent shoreface/ nearshore to inner shelf settings, whereas siltstone facies are usually of middle to outer shelf origin. Bioclastic and mixed siliciclastic-bioclastic facies accumulated mostly in inner to middle shelf settings. The Hawke's Bay part of the forearc basin is a siliciclastic-dominated sedimentary system that contains only a small volume of bioclastic facies. Although of subordinate volume, these bioclastic beds are nevertheless conspicuous in the landscape as they tend to be moderately to well cemented and form prominent ranges, strike ridges, and hilltops. Siltstone lithofacies dominate the succession, followed by sandstone, bioclastic, mixed siliciclastic-bioclastic, and conglomerate facies in decreasing abundance. Volcaniclastic facies are least

common, and are mostly restricted to the Late Pliocene part of the basin fill. It should be kept in mind that transitions between various lithofacies and lithofacies groups are obvious and important. The lithofacies schemes of previous workers (e.g. Bland 2001; Graafhuis 2001; Caron 2002) have been used as a basis for this study. Where relevant, facies schemes from other basins have also been used, especially where analogues to depositional systems present in the study area occur. For example, the work of Browne and Naish (2003) on Late Quaternary deposits in Canterbury represents a good analogue for the Late Pliocene conglomerate units described in this project.

Table 6.1 summarises the characteristics of the lithofacies identified in this study. Further details about these lithofacies are contained in Appendix II (Paleoenvironmental Analysis).

SILICICLASTIC–DOMINATED LITHOFACIES

Sandstone lithofacies

Sandstone lithofacies are common throughout the sedimentary succession, comprising about 25-30% of the basin fill. Twelve sandstone lithofacies have been identified (Table 6.1). Sandstone lithofacies are usually from 1-40 m thick, and typically overlie siltstone lithofacies (e.g. Z_3 or Z_9). They are in turn usually overlain by conglomerate and limestone lithofacies. The massive sandstone (S_1) and silty sandstone (S_4) lithofacies are most common, with ripple and flaser-bedded sandstone (S_8) the least common. Macrofossils are common in many sandstone facies (e.g. S_3, S_4, S_{11}), particularly those in the Late Pliocene part of the succession. Macrofauna are typically shallow-water infaunal genera such as *Dosinia* (*D. (Austrodosinia)* and *(D. Phacosama)*), *Tawera, Atrina,* and *Zethalia*. Deposition of sandstone lithofacies is inferred mostly to have occurred at shoreface to inner shelf water depths.

Siltstone lithofacies

Siltstone lithofacies dominate the sedimentary succession in the study area, occupying about 60% of the basin fill. Eleven siltstone lithofacies have been defined (Table 6.1) and mostly represent shelfal deposits, although they are associated with bathyal and non-marine deposits as well. Siltstone units are usually 0.5-60 m thick, although facies Z_1 may be up to 1000 m thick. Siltstone lithofacies are typically moderately fossiliferous, with diverse macrofaunal taxa, mostly being infaunal bivalves (e.g. *Pratulum, Atrina, Dosinia (Kereia)*), although firm-ground development is recorded where epifauna such as oysters (e.g. *Ostrea*), pectinids (e.g. *Talochlamys*), and brachiopods (e.g. *Tegulorhynchia*) are common. Siltstone lithofacies normally underlie sandstone, limestone, or conglomerate facies, often through a transitional unit such as facies Z_3 or Z_9.

Conglomerate lithofacies

While conglomerate lithofacies occur throughout the basin fill, they are most common in the Late Pliocene-Pleistocene strata in the basin. They account for 1-5% of the basin fill. The conglomerate clasts are almost entirely derived from adjacent Torlesse basement. Some of the conglomerate lithofacies described by Browne and Naish (2003) from the Canterbury Plains have been identified in the Hawke's Bay basin fill. Seven conglomerate lithofacies types have been identified and described (Table 6.1). They are usually 1-15 m thick, are underlain by sandstone facies (e.g. S_3, S_9), and overlain by siltstone facies (e.g. Z_5). Conglomerate facies defined here represent deposition in non- to marginal-marine settings, typically as part of a fluvial braid-plain system. Facies Cg_1-Cg_3 are inferred to represent different positions within paleo-river channels in a braided river system. Although almost always non fossiliferous, facies Cg_4 represents shingle beach environments on an open marine coastline. Facies Cg_5 contains fauna typical of estuarine environments, whereas facies Cg_6 and Cg_7 are typical of modern harbour channels and rocky shoreline environments.

Volcaniclastic lithofacies

The volcaniclastic lithofacies assemblage, comprising less than 1% of the basin fill, is the least common of the four siliciclastic lithofacies groups identified in this study. Occurrence is mostly restricted to strata of uppermost Mangapanian age and younger. Three volcaniclastic lithofacies types are identified (Table 6.1), and likely represent a spectrum from airfall tephra (V_1) to reworked volcaniclastic beds (V_3). Airfall tephra (V_1) are normally 0.05-0.5 m thick, and are interbedded with siltstone facies Z_8. Lithofacies V_2 and V_3 are typically 0.1-10 m thick, representing pyroclastic flow deposits and reworked volcaniclastic deposits. Fossil content and stratigraphic position of these lithofacies are consistent with non-marine to marginal-marine deposition, often in estuarine environments.

BIOCLASTIC-DOMINATED LITHOFACIES

Although accounting for only about 5% of the total volume of the Late Miocene-Pliocene fill of the Hawke's Bay, the preferential cementation and consequent resistance to erosion of the bioclastic facies makes them prominent features throughout Hawke's Bay. It is the presence of limestone beds in the Te Waka and Maungaharuru Ranges, and in Te Mata Peak that gives these topographical features their elevation and prominence in the landscape. Seven bioclastic lithofacies have been identified in this study (Table 6.1).

Table 6.1: Lithofacies in the Neogene succession cropping out in the forearc basin in western and central parts of Hawke's Bay (continued on next page). R, rare; UC, uncommon; S, some; C, common; A, abundant.

Lithofacies		Description	Inferred environment of deposition	Typical faunal associations
Sandstone		**Siliciclastic-dominated**		
S_1	Massive sandstone (C)	Massive, non cemented non fossiliferous slightly micaceous very well-sorted fine to medium sandstone.	Shoreface to nearshore	None
S_2	Massive to cross-stratified sandstone (C)	Massive to cross-stratified non cemented very well-sorted fine to medium sandstone.	Shoreface to inner shelf	None
S_3	Massive to cross-stratified fossiliferous sandstone (C)	Massive to cross-stratified non cemented very well-sorted moderately to highly fossiliferous fine to medium sandstone. Macrofossils commonly concentrated into densely-fossiliferous lenses.	Shoreface to inner shelf	*Dosinia, Zethalia, Fellaster*
S_4	Silty sandstone (C)	Non cemented non to sparsely fossiliferous massive to laminated well-sorted fine sandstone to silty sandstone.	Lower-inner to middle shelf	*Atrina, Maorimactra, Dosinia (Kereia), Patro*
S_5	Calcareous sandstone (S)	Non to well cemented non to sparsely fossiliferous slightly to moderately calcareous fine sandstone with prominent concretions and cemented horizons. May contain a noticeable bioclastic content.	Lower-inner to middle shelf	*Atrina*
S_6	Interbedded sandstone-siltstone (S)	Non to well cemented non to sparsely fossiliferous fine sandstone to sandy siltstone with common concretionary horizons and prominent sandstone and silstone interbeds.	Inner shelf	*Dosinia (Kereia), Atrina*
S_7	Sandstone with siltstone stringers (UC)	Non to well cemented fine sandstone to sandy siltstone with common mudstone stringers. Beds are faintly to strongly laminated.	Marginal-marine to sheltered nearshore	*Austrovenus, Patro*
S_8	Ripple and flaser-bedded sandstone (R)	Non to slightly fossiliferous ripple, flaser- and cross-bedded fine to medium sandstone with common interbeds and detached lenses of siltstone.	Estuarine	*Austrovenus*
S_9	Pebbly sandstone (S)	Non cemented, non to moderately fossiliferous massive to cross-stratified to laminated sandstone with common to abundant greywacke pebbles and conglomerate lenses.	Shoreface to nearshore	*Dosinia, Zethalia*
S_{10}	Concretionary sandstone (S)	Non to slightly cemented non- to sparsely-fossiliferous moderately to strongly laminated and cross-stratified fine to medium sandstone with common to abundant concretionary horizons.	Nearshore to inner shelf	*Atrina*
S_{11}	Sandstone with fossiliferous concretions (S)	Slightly to well cemented fine to medium sandstone with moderately to highly fossiliferous, moderately to well cemented concretionary bodies up to 1 m thick.	Nearshore to inner shelf	*Struthiolaria (Callusaria), Zeacolpus*
S_{12}	Laminated to convolutedly-bedded sandstone (R)	Strongly laminated to cross-stratified to convolutedly-bedded fine to medium sandstone bodies in a series of stacked packages up to 0.5 m thick. Contains common to abundant tephric sediments.	Inner shelf	Null
Siltstone				
Z_1	Massive siltstone (A)	Non fossiliferous, massive to weakly laminated non to slightly cemented siltstone. May contain concretions up to 1 m across.	Outer shelf to bathyal	None
Z_2	Fossiliferous siltstone (A)	Slightly to moderately fossiliferous, massive to laminated non cemented firm bioturbated siltstone.	Middle to outer shelf	*Pratulum, Neilo, Ostrea, Tawera-Patro, Talochlamys, Tegulorhynchia-Talochlamys*
Z_3	Fossiliferous sandy siltstone	Slightly to moderately fossiliferous massive to laminated bioturbated siltstone.	Lower-inner to middle shelf	*Atrina, Patro, Dosinia (Kereia), Stiracolpus-Talochlamys, Tawera-Patro*
Z_4	Siltstone with sandstone interbeds (UC)	Non to moderately fossiliferous, fine-grained siltstone with sandstone interbeds and stringers. Ripple and flaser-bedded units are common.	Estuarine	*Austrovenus*
Z_5	Pebbly siltstone (C)	Non cemented, slightly to moderately fossiliferous, slightly to moderately pebbly siltstone to sandy siltstone.	Inner to middle shelf	*Stiracolpus-Talochlamys, Ostrea, Neilo*
Z_6	Siltstone-sandstone couplets	Slightly to strongly laminated planar-bedded non cemented, fine to large-scale alternating fine siltstone/sandstone couplets.	Upper bathyal	None
Z_7	Channelised siltstone-sandstone couplets (S)	Strongly-laminated non cemented alternating fine-grained siltstone-sandstone couplets in large packages with sharp, highly erosional and channelised bases.	Upper bathyal	None
Z_8	Siltstone with tephra beds (S)	Non to slightly fossiliferous non cemented sandy siltstone to siltstone with prominent discrete tephra beds.	Middle to outer shelf	*Pratulum, Atrina, Talochlamys*
Z_9	Alternating siltstone-sandstone (C)	Alternating beds of non to slightly fossiliferous non cemented sandy siltstone interbedded with fine-grained well sorted non fossiliferous sandstone.	Inner to upper-middle shelf	*Dosinia (Kereia), Atrina*
Z_{10}	Siltstone with plant remains (R)	Non cemented fine grained grey brown laminated siltstone with some to abundant plant remains	Non- to marginal-marine	None
Z_{11}	Muddy shellbed (C)	Non to weakly cemented, massive siltstone to silty sandstone, matrix-dominated bed containing a concentration of molluscan macrofauna. May be noticeably pebbly in places. Inferred to occur above downlap surfaces.	Middle to outershelf	*Ostrea, Ostrea*-glycymerid

Table 6.1 (continued from previous page)

Lithofacies		Description	Inferred environment of deposition	Typical faunal associations
Conglomerate				
Cg_1	Massive conglomerate (C)	Non-to moderately cemented, poorly to moderately sorted non fossiliferous massive to weakly laminated greywacke conglomerate. Clasts are of granule to boulder-size.	Fluvial braid-plain, river channels	None
Cg_2	Conglomerate with sand and silt lenses (C)	Non to slightly cemented massive to laminated and cross-stratified greywacke conglomerate with interbeds of sandstone and siltstone to 0.5 m thick.	Fluvial braid-plain, major and adjacent channels	None
Cg_3	Cross-stratified conglomerate (S)	Non to slightly cemented, poorly to well-sorted tabular to trough cross-stratified greywacke conglomerate.	Fluvial braid-plain, river channel bars	None
Cg_4	Laminated conglomerate (C)	Strongly-laminated very well-sorted alternating coarse sand/fine-pebble - medium/coarse pebble greywacke beds.	Shoreface, shingle beach	None
Cg_5	Slightly-fossiliferous conglomerate (UC)	Non to moderately cemented clast-supported, slightly fossiliferous greywacke conglomerate.	Marginal marine to estuarine	*Austrovenus*
Cg_6	Fossiliferous conglomerate (S)	Non to moderately cemented, moderately to well sorted, moderately to highly fossiliferous greywacke conglomerate.	Nearshore, harbour and tidal channels, inner shelf	*Paphies, Zethalia, Tawera, Ostrea*-glycymerid, *Tucetona, Ostrea-Purpurocardia, Struthiolaria (Callusaria), Zeacolpus*
Cg_7	Fossiliferous breccia (R)	Non to moderately cemented, poorly to slightly cemented, moderately to highly fossiliferous coarse-grained breccia. Clasts are dominated by greywacke with a sandy and gravelly matrix.	Nearshore to shoreface with a rocky coastline.	*Crassostrea*
Volcaniclastic				
V_1	Airfall tephra (R)	Non-welded, massive to laminated fine-ash with occasional fine to medium lapilli-sized clasts in beds up to 0.6 m thick. Commonly strongly burrowed.	Volcanic airfall into middle- to outer-shelf water depths	None
V_2	Ignimbrite (R)	Non- to slightly-welded, massive to laminated to cross-stratified fine ash with occasional medium lapilli-sized clasts.	Non-marine to marginal-marine pyroclastic flow	None
V_3	Laminated to cross-stratified volcaniclastics (R)	Non-welded massive to strongly-laminated and cross-stratified fine ash to medium lapilli-sized volcaniclastic sediments that display evidence of current re-working. Convolute bedding and water-escape structures are common.	Non-marine to estuarine	None
		Bioclastic-dominated		
BC_1	Stacked medium to coarse skeletal beds (C)	Moderately to well cemented, sparsely fossiliferous medium to coarse-grained stacked skeletal sheets 0.1-0.3 m thick.	Inner to middle shelf	*Neothyris*
BC_2	Fossiliferous stacked medium to coarse skeletal beds (C)	Moderately to well cemented moderately to highly fossiliferous stacked skeletal beds 0.1-0.3 m thick. Fauna are almost exclusively epifaunal and semi-infaunal taxa.	Inner to middle shelf	*Crassostrea-Phialopecten, Neothyris*
BC_3	Shelly limestone (C)	Slightly to well cemented moderately to highly fossiliferous shelly medium to coarse-grained limestone with common to very abundant biomoulds.	Nearshore to inner shelf	*Tucetona, Tawera, Eumarcia*
BC_4	Fossiliferous shell-gravel (S)	Slightly to moderately cemented highly fossiliferous cross-stratified shell-gravel-dominated coarse-grained sandstone with abundant intact macrofossils.	Nearshore to inner shelf	*Tawera-Crepidula, Crepidula-Sigapatella*
BC_5	Giant cross-stratified limestone (UC)	Slightly to moderately cemented non to sparsely fossiliferous limestone with stacked beds as part of giant, metre-scale trough and sigmoidal cross-beds.	Inner to middle shelf with strong sea-floor currents	*Crassostrea-Phialopecten, Neothyris*
BC_6	Pebbly limestone (S)	Slightly to well cemented, sparsely to moderately fossiliferous alternating skeletal grainstone and mixed bioclastic-siliciclastic packstone as sheets up to 0.3 m thick with common to abundant greywacke pebbles.	Inner shelf, strong bottom currents	*Crassostrea-Phialopecten*
BC_7	Cross-stratified sandy limestone (S)	Moderately to well cemented tabular to sigmoidal cross-stratified sandy limestone. Contains sparse to common macrofauna, which are usually present as biomoulds.	Inner shelf, moderate to strong bottom currents	*Tawera*
		Mixed bioclastic-siliciclastic-dominated		
MX_1	Bioclastic-siliciclastic sandstone (C)	Non to slightly cemented, medium-grained siliciclastic-bioclastic sandstone. Commonly cross-stratified with mudstone lenses and stringers to 0.3 m thick.	Innermost shelf	*Tawera, Tawera-Crepidula, Crepidula-Sigapatella*
MX_2	Coarse-grained mixed conglomerate (R)	Pebble to cobble-dominated conglomerate with rare clasts up to boulder-size and common valves of robust epifaunal and infaunal bivalves in a coarse-grained bioturbated matrix of mixed bioclastic-siliciclastic sediments. Contains Mesozoic and Cenozoic clasts.	Nearshore, tidal channels	*Crassostrea-Phialopecten*
MX_3	Conglomeratic limestone (S)	Moderately to well cemented, massive to cross-stratified medium to coarse-grained bioclastic-dominated beds with common to abundant pebble to cobble-sized clasts of greywacke, sandstone and mudstone lithologies.	Nearshore, harbour and tidal channels, inner shelf	*Tawera, Paphies, Maoricolpus, Tucetona, Ostrea*-glycymerid, *Struthiolaria (Callusaria), Zeacolpus, Ostrea-Purpurocardia*
MX_4	Alternating bioclastic-silciciclastic bodies (C)	Slightly to well cemented, sparsely fossiliferous alternating skeletal grainstone and mixed bioclastic-siliciclastic packstone as sheets up to 0.3 m thick.	Inner to middle shelf with strong tidal currents	*Neothyris*

Bioclastic facies accumulated on a carbonate-dominated, continent-attached shelf (e.g. Caron *et al.* 2004a), subjected to moderate to strong tidal currents at inner to middle shelf water depths. These tidal currents transported siliciclastic sediment across the shelfal sea floor and bypassed it to deeper waters. The presence of greywacke clasts implies an emergent basement hinterland, and provided coarse sea floor substrate to which bryozoans, bivalves, and brachiopods could attach. Bioclastic lithofacies are inferred to have accumulated in water depths of about 10-60 m. Barnacle plates and fragments are common within these facies, reflecting the strong tidal current flow. The composition and discontinuous nature of individual sheets of facies BC_3 indicate a wave-dominated environment on an open shelf. The skeletal beds represent storm-emplaced sheets mobilised from carbonate factories and dispersed across a shelf characterised by mixed bioclastic-siliciclastic sedimentation. Facies BC_1 is also thought to represent sedimentation in a current-swept environment with individual skeletal sheets being products of sediment remobilisation off carbonate factories during storm events. The occurrence of burrows extending from overlying into underlying sheets, and sharp bases to beds in facies BC_1 and BC_2, indicate that deposition of the sheets occurred as discrete sedimentation events.

MIXED BIOCLASTIC-SILICICLASTIC LITHOFACIES

Mixed bioclastic-siliciclastic facies contribute about 2-5% to the sedimentary succession in the field area. Four mixed bioclastic-siliciclastic lithofacies have been described (Table 6.1). They mainly represent deposition in shallow-water, nearshore to inner shelf environments under regimes of moderate to strong current flows. Macrofauna within these facies typically include robust, epifaunal and semi-infaunal taxa such as *Tucetona, Crassostrea, Phialopecten,* and species of the glycymerid family (e.g. *Glycymeris shrimptoni*). Deposition has often occurred near a rocky coastline with exposed Torlesse basement, or gravel beaches and tidal channels.

MACROFOSSIL ANALYSIS

INTRODUCTION

Biofacies are the relicts of paleocommunities. Macrofaunal associations have been grouped from the macrofossil populations preserved in the rocks. They have proven to be useful aids in identifying paleoenvironments within deposition systems (systems tracts) of sequences (e.g. Abbot and Carter 1997; Hendy and Kamp 2004; Kondo *et al.* in review). Understanding the spectrum and environmental preferences of biofacies within the study area enables the rates and magnitudes of paleoenvironmental change to be quantitatively estimated.

DATA ACQUISITION

Macrofaunal data were acquired during fieldwork at outcrops (semi-quantitative), or in the lab from analysis of bulk samples (Fig. 6.1). The main focus of this study is the Mangaheia Group and therefore sampling effort and analyses have been concentrated in this interval.

Bulk samples

One hundred and twelve bulk samples were collected during the course of geological mapping and stratigraphic logging of the study area in collaboration with paleontological research by A. Hendy (University of Cincinnati). Census counts and collation of data from these bulk samples were undertaken by Austin Hendy. Cluster analysis of these data, and identification of the resulting macrofaunal associations, were carried out by the author. Collection and analysis of bulk samples followed the methodology of Hendy and Kamp (2004). An attempt was made to collect bulk samples from as wide a variety of lithofacies as possible, although the dataset reveals that there is an over-representation of samples from coarse-grained shellbeds of regressive and transgressive systems tracts. The reasons for this are two-fold. First, the typical highly fossiliferous nature of these horizons makes them obvious targets for sampling. Second, these horizons are typically better cemented than their siliciclastic counterparts and therefore better exposed in the landscape, making them more accessible to investigation and collection. Samples were located within logged stratigraphic sections and their spatial positions marked using a GPS unit. Bulk samples were typically 3-5 kg in size and were extracted using sledgehammer, pick-axe, or cold chisel, or where samples were uncemented by pick-axe or spade. Bulk samples were collected from individual horizons that were typically < 0.1 m thick and placed in bags labelled with the collection location and stratigraphic position for later analysis. The preservation, and degree of articulation, fragmentation, encrustation and boring were also noted.

Macrofossils were identified to the finest taxonomic scale possible. This was usually to species level, but the degree of cementation often meant that only identification to genus level was possible. Consequently, due to difficulties in the identification of often poorly-preserved assemblages, data analysis in this study was undertaken at genus level.

Field observations

Field observations provide a combination of binary (presence-absence) and semi-quantitative field-based data estimations for 305 localities across the study area (Fig. 6.1). As far as possible, the identification and relative abundances of macrofossils was documented while at the outcrop. Where specimens could not be identified in the field they were brought back to the laboratory for identification.

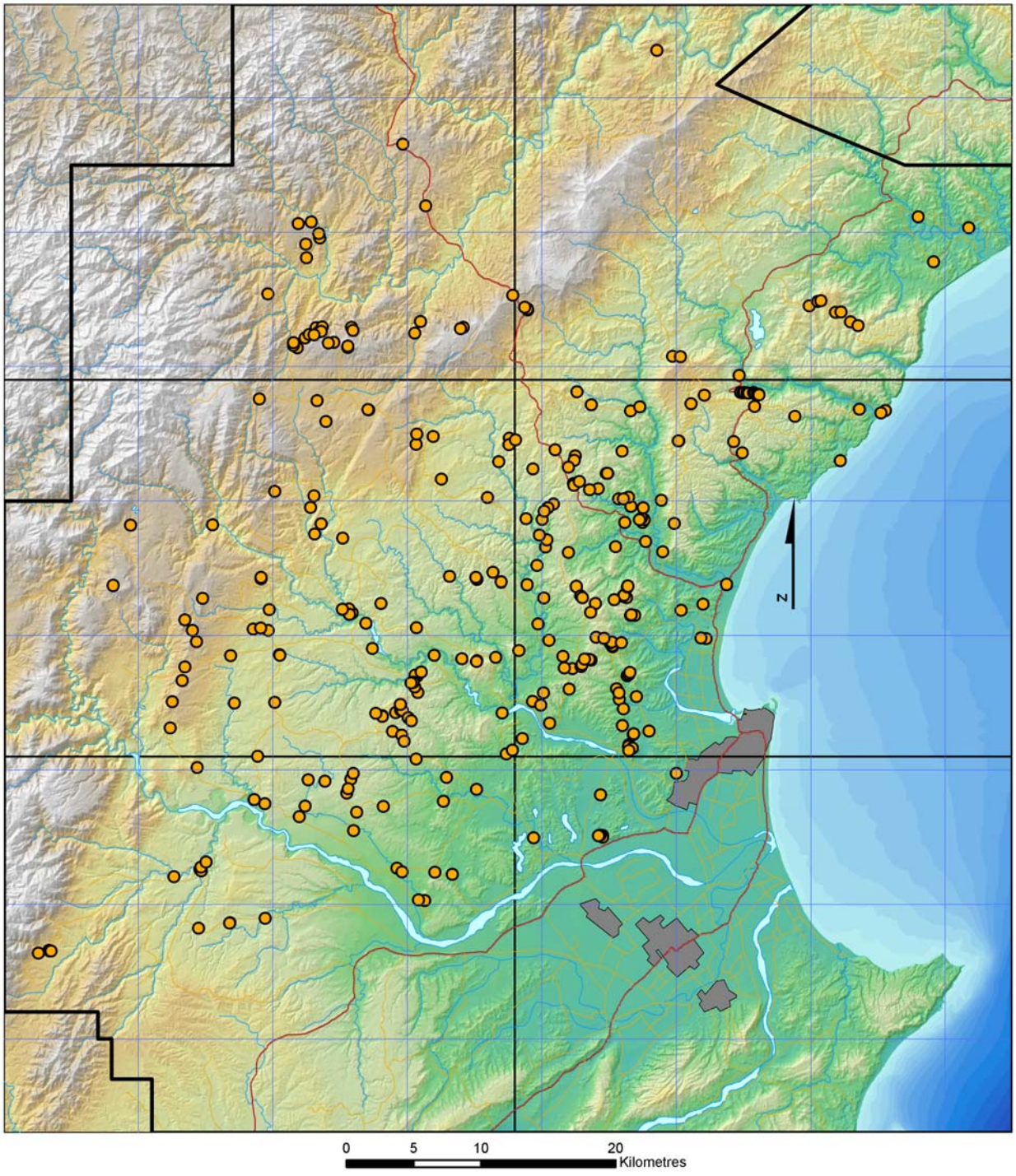


Fig. 6.1: Map showing the distribution of fossil data sites across the study area (orange circles). Sites shown (305 in total) represent both bulk sample and field observation locations. The thick black line is the extent of geological mapping in this study. The thinner black lines represent the extent of the six map sheets in Enclosure 1.

DATA ANALYSIS

Methodology

A combination of quantitative and semi-quantitative analyses were used to discriminate macrofaunal associations present in the study area.

Cluster analysis

Analyses were based on census counts of bivalve, gastropod, brachiopod, and echinoderm specimens using both Q-mode cluster analysis and field-based observations. Fragments of bivalves were only counted if they incorporated the umbo, or if the complete posterior and anterior margins were present. For gastropods, the aperture had to be present. The number of articulated bivalve and brachiopod specimens was halved as bivalves can produce twice the number of countable skeletal parts compared with other groups such as gastropods (Hendy and Kamp 2004). Echinoderm counts were divided by five, given the multiple skeletal elements that these taxa contribute to death assemblages (Hendy and Kamp 2004).

Data were analysed using Q-mode cluster analysis to determine biofacies using the PC programme PRIMER, following the methodology of Hendy and Kamp (2004). Cluster analysis is a commonly utilised method for the identification of paleoecological groups in multivariate datasets. Cluster analyses form discrete groupings based on the degree of similarity between the composition of samples and the co-occurrence of taxa. It provides a rapid and reproducible mechanism for establishing a classification of biofacies from the data (Hendy 2002). All analyses were undertaken at genus or subgenus level. The Q-mode analysis used the arithmetic averages of a Bray-Curtis distance matrix to produce a dendrogram classification of samples (Fig. 6.2).

Macrofaunal associations from siltstone to sandy siltstone facies typically displayed the highest faunal diversity. By contrast, associations from sandstone, conglomerate, and limestone facies typically had low macrofaunal diversity. In effect, the closer to the inferred paleoshoreline a sample was collected, the less diverse the macrofaunal content tended to be.

Field observations

The identification of biofacies from field observations is a legitimate process for the identification of biofacies where bulk sampling is not possible (Hendy 2002). This is necessary because often macrofossils are sparsely distributed through a unit, the collection of a bulk sample is impractical, or the rock is so cemented that a suitable sample cannot be removed.

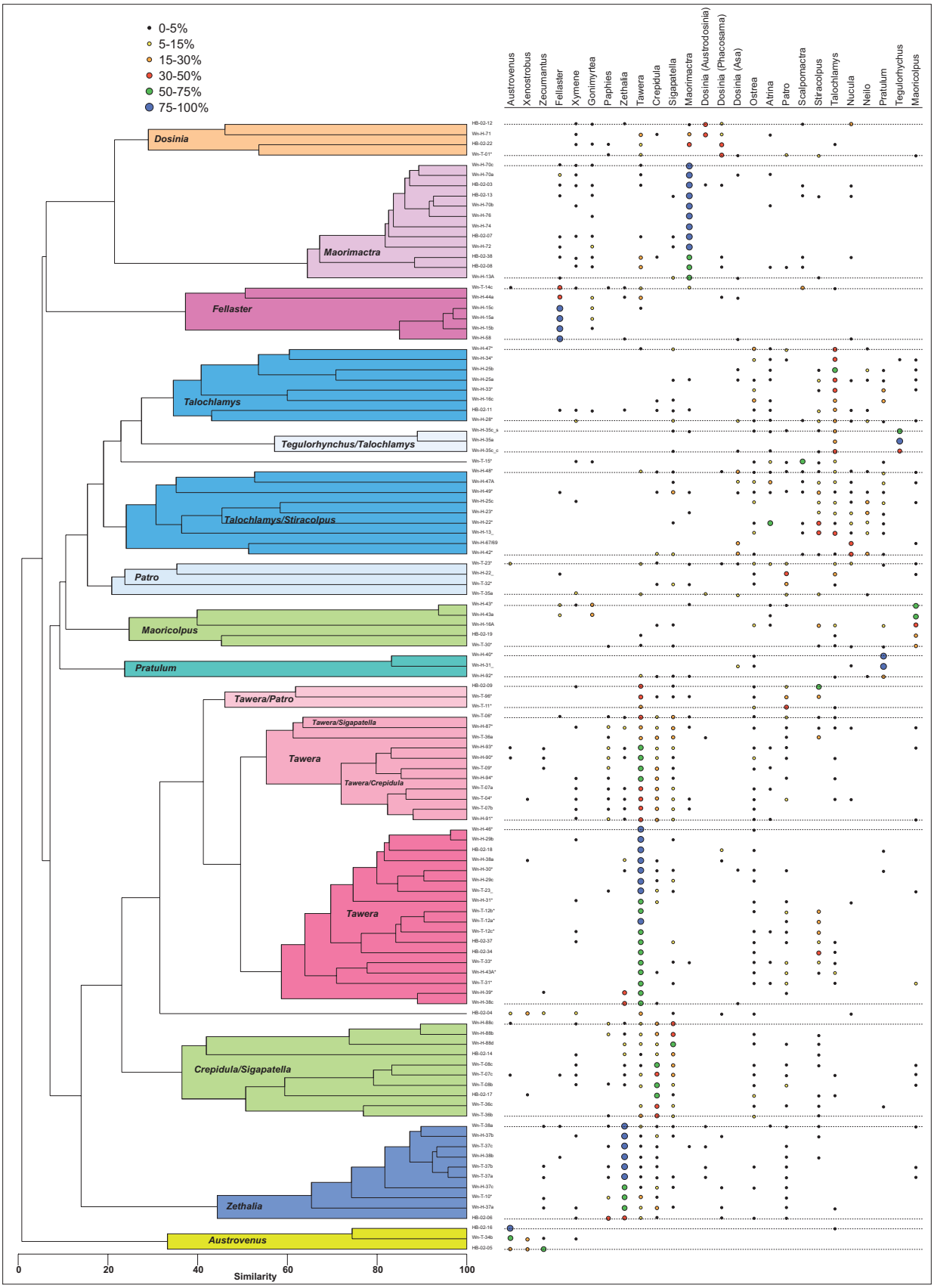


Fig. 6.2: Q-mode cluster analysis of macrofossil bulk samples collected from Nukumaruan (Late Pliocene) rocks in central Hawke's Bay.

Results

Macrofaunal associations (Table 6.2) have been identified from a combination of over 300 field observations and cluster analysis of 112 Nukumaruan bulk samples during this study, as well as using several dozen field observations from Bland (2001). Thirty macrofaunal associations and six sub-associations have been differentiated. Sixteen of these groupings have been defined from cluster analysis, the remainder having been defined from field observations where bulk sampling was not possible. More detailed descriptions of faunal associations are contained in Appendix II. Compositions of the associations are summarised in Table 6.2.

Q-mode cluster analysis (Fig. 6.2) produced 16 groupings (comprising three or more samples), here recognised as faunal associations (Fig. 6.3, Table 6.2). Two major subsets can be delineated on the basis of abundance of the bivalve genera *Tawera* and *Talochlamys.* The *Tawera*-dominated subset consists of three discrete clusters characterised by: 1) the overall dominance of *Tawera subsulcata*; 2) the dominance of *Tawera subsulcata* with common *Crepidula radiata* and *Sigapatella novaezelandiae* (*Tawera-Crepidula* sub-association); and 3) the dominance of *Tawera subsulcata* with common *Patro undatus* and *Sigapatella* spp. The *Talochlamys*-dominated subset consists of three smaller clusters characterised by: 1) the dominance of *Talochlamys gemmulata*; 2) common *Talochlamys gemmulata* and *Stiracolpus* spp.; and 3) common *Talochlamys gemmulata* and the brachiopod *Tegulorhynchia niagricans.* Nine smaller subsets are recognised that are distinctly separated from the larger subsets. These include clusters dominated by *Dosinia, Maorimactra, Fellaster, Patro, Maoricolpus, Pratulum, Crepidula-Sigapatella, Zethalia,* and *Austrovenus.* With the exception of the *Patro* and *Pratulum*-dominated clusters, these smaller subsets are typically present in shallow-water sandstone, conglomerate, and shellbed facies of regressive and transgressive systems tracts. The *Pratulum* and *Patro* associations are typical of siltstone to silty sandstone facies of highstand systems tracts.

The faunal associations identified represent a combination of *in situ* (life position) and transported assemblages. Macrofauna from *in situ* associations tend to be well preserved, bivalves are often articulated, and shells are largely unbroken. Faunal diversity in such associations tends to be low to moderate. Reworked assemblages tend to have a higher degree of faunal diversity, but due to the reworked and redeposited nature of taxa within them there is often significant overlap in composition between faunal associations (e.g. Haywick 1990). Macrofauna in reworked associations have a high proportion of broken and disarticulated shells, and are usually preserved in cross-stratified patterns. Abrasion of shells is common, particularly of estuarine faunas (such as *Austrovenus stutchburyi*) when they have been mixed with open-marine fauna.

Table 6.2: Macrofaunal associations identified in this study.

Macrofaunal association	Typical macrofauna	Inferred environment of deposition	Typical lithofacies	Typical age range
Austrovenus (au)	Very low faunal diversity dominated by *Austrovenus stutchburyi* and *Austrovenus crassitesta.* Occasionally *Zeacumantus lutuentus, Xenostrobus huttoniana* and *Barytellina crassidens*	Estuarine	S_7, S_8, Z_4, Cg_5,	Wm-Wc
Fellaster (ze)	Low faunal diversity dominated by *Fellaster zelandiae*	Beach, very shallow-water nearshore	S_3,	Wm-Wn
Zethalia (ze)	Low faunal diversity with *Zethalia* spp. dominant. Occasionally contains *Lutraria solida* and *Dosinia spp.*	Very shallow-water beaches, tidal harbour channels	S_3, S_9, Cg_6	Wm-Wn
Paphies (ph)	Very low faunal diversity, almost exclusively *Paphies australis,* with rare *Ostrea chilensis and Lutraria solida*	Very shallow-water estuaries, harbours with some current flow	Cg_6, MX_3	Wn
Crepidula-Sigapatella (cr-sg)	Moderate faunal diversity, characterised by the co-dominance of *Crepidula radiata* and *Sigapatella novaezelandiae.*	Nearshore to inner shelf environments on a firm-ground shellhash substrate. Moderate to strong tidal currents	BC_4, MX_1	Wn
Tawera (tw)	Dominated by *Tawera subsulcata*. Faunal diversity is moderate to high	Nearshore to inner shelf environments on sandy to shell-gravel substrates with a strong current influcene	Cg_6, BC_3, BC_7, MX_1, MX_3	Wn
Tawera-Sigapatella sub-association *(tw-sg)*	Moderately high faunal diversity dominated by *Tawera subsulcata* with common *Sigapatella novaezelandiae. Crepidula radiata* also common	Tide-dominated near-shore to innermost shelf on a coarse shell-gravel substrate	BC_4, MX_1	Wn
Tawera-Crepidula sub-association *(tw-cr)*	Moderately high faunal diversity dominated by *Tawera subsulcata* with common *Crepidula radiata. Sigapatella novaezelandiae* also common	Tide-dominated nearshore to innermost shelf on a coarse shell-gravel substrate	BC_4, MX_1	Wn
Tawera-Patro sub-association *(tw-pt)*	Low to moderate faunal diversity, co-dominance of *Tawera subsulcata* and *Patro undatus*	Lower-inner to upper-middle shelf on a semi firm-ground sandy to silty substrate	Z_3, Z_4	Wn
Dosinia (do)	Moderate faunal diversity, characterised by *Dosinia (Phacosama) subrosea* and *Dosinia (Austrodosinia) anus.* Also common are *Rexithaerus spenceri, Tellinota edgari, Peronaea gaimardi,* and *Austromegabalanus decorus*	Sandy substrates at shoreface to inner shelf (0-30 m), mostly above fair-weather and storm wavebase	S_3, S_4, S_9	Wm-Wn
Maoricolpus (mc)	Low to moderate faunal diversity, characterised by *Maoricolpus roseus*	Hard bottom coarse shell debris substrate in harbour and tidal channels. More shoreward than the *Tawera* association	MX_3	Wm-Wn
Ostrea-glycymerid *(os-gl)*	Low to moderate faunal diversity, characterised by *Ostrea chilensis* in association with glycymerid bivalves such as *Glycymeris* spp. and *Tucetona laticostata.* May also contain *Phialopecten* spp. and *Mesopeplum convexum*	Nearshore to innermost shelf on a firm sandy to gravelly substrate. Strong tidal currents swept fine siliciclastic sediment away from substrate	Cg_6, MX_3	Wo-Wn
Eumarcia (eu)	High faunal diversity characterised by *Eumarcia plana.* Also may include *Paphies australis, Fellaster zelandiae, Mactra discors, Zethalia* spp., *Bassina* spp., *Dosinia (Asa) lambata, Glycymeris shrimptoni, Gari lineolata, Scalpomactra scalpellum, Divaricella huttoniana, Myadora stepnahiae, Purpurocardia purpurata,* and *Tawera subsulcata.*	Shallow-water nearshore to innermost shelf environment under a regime of strong tidal currents	BC_3	Wm-Wn
Ostrea-Puropurocardia (os-pu)	High faunal diversity characterised by *Ostrea chilensis* and *Purpurocardia purpurata*. Taxa typically thick-shelled robust epifaunal and semi-infaunal species such as *Lutraria solida* and *Alcithoe arabica* with some *Glycymeris shrimptoni* and *Tucetona laticostata*	Nearshore to innermost shelf on gravelly substrates. Sea-floor swept by strong tidal currents	Cg_6, MX_3	Wn
Tucetona (tu)	Moderate faunal diversity characterised by robust semi-infaunal and epifainal bivalves. Dominated by *Tucetona laticostata*. May include common *Ostrea chilensis, Crassostrea ingens, Oxyperis komakoensis, Phialopecten* spp., and *Eucrassatella* sp.	Nearshore settings on very coarse sandy to gravelly substrates, probably in tidal channels. Proximal to exposed rocky greywacke coastline	Cg_3, BC_3, MX_3	Wo-Wn
Maorimactra (mm)	Low to moderate faunal diversity dominated by *Maorimactra ordinaria*	Soft fine sand to silty sand substrates at inner to middle shelf water depths (20-60 m). More open marine than *Dosinia (Kereia)* association	S_4	Wn

Table 6.2 (continued)

Macrofaunal association	Typical macrofauna	Inferred depositional environment	Typical lithofacies	Typical age range
Dosinia (Kereia) (dk)	Low to moderate faunal diversity dominated by *Dosinia (Kereia) greyi*, with common *Atrina pectinata zelandica, Pratulum pulchellum, Ostrea chilensis, Talochlamys gemmulata, Stiracolpus* spp., *Alcithoe* spp., *Austrofusus* spp., and *Pelicaria* spp.	Fine silty sand substrates at inner to middle shelf (10-50 m) water depths	S_4, S_6, Z_3, Z_9	Wm-Wn
Ostrea (os)	Low faunal diversity dominated by *Ostrea chilensis*. Usually monospecific although may contain *Zeacolpus vittatus* and *Dosina* spp.	Silty firm-ground sunstrate at lower inner- to outer-shelf water depths, probably association with sediment starvation. Often present on top of downlap surfaces	Z_2, Z_5, Z_{11}	Wm-Wn
Patro (pt)	Low faunal diversity dominated by *Patro undatus*	Lower-inner to middle shelf water depths on fine sandy silty firm-grounds	S_5, S_7, Z_3	Wm-Wn
Zeacolpus (zc)	Typically monospecific, dominated by *Zeacolpus* spp.	Shallow-water nearshore to inner shelf environments on a sandy to slightly gravelly substrate	S_{11}, Cg_6, MX_3	Tt
Struthiolaria (Callusaria) (st)	Low to moderate faunal diversity, dominated by *Struthiolaria (Callusaria)* spp., with common *Zenatia acinaces* and *Zeacolpus* sp. May also contain *Sectipecten grangei* and *Crepidula radiata*.	Nearshore to inner shelf setting on sandy to slightly gravelly substrates. Proximal to rocky greywacke coastline	S_{11}, Cg_6, MX_3	Tt-Wo
Crassostrea (cs)	Low faunal diversity, dominated by *Crassostrea ingens*. Other robust epifaunal and semi-infaunal taxa are present including *Maoricardium spatiosum, Tucetona laticostata,* and *Phialopecten* spp.	High-energy shoreface to nearshore settings on hard-grounds adjacent to a rocky greywacke coastline	Cg_7	Wo-Wm
Crassostrea-Phialopecten sub-association *(cs-pp)*	Low faunal diversity, charactersied by the abundance of *Crassostrea ingens* and *Phialopecten thomsoni*. *Patro undatus* is also common. Barnacle fragments and plates are very common among the bivalves	Nearshore to inner shelf water depths on a gravelly mixed bioclastic-siliciclastic hardground	BC_2, BC_5, MX_2	Wm
Neothyris (ne)	Low faunal diversity, charactersied by the abundance of *Neothyris* aff. *obtusa.* The association commonly contains *Phialopecten* spp. and almost always *Ostrea chilensis*. Barnacle fragments and plates are very common among the bivalves	Firm shell-gravel to sandy firm-ground at lower-inner to middle shelf water depths. Sea-floor swept of strong tidal currents	BC_2, BC_5, MX_4	Wm
Talochlamys (ta)	High faunal diversity, charactersied by *Talochlamys gemmulata*, with common *Atrina pectinata zelandica* and *Pelicaria* spp.	Fine-grained silty firm-ground at middle to outer shelf water depths. Firm-ground development may represent periods of sediment starvation	Z_8	Wm-Wn
Stiracolpus-Talochlamys sub-association *(sc-ta)*	Moderate to high faunal diversity characterised by co-dominance of *Stiracolpus* spp. and *Talochlamys gemmulata*. *Nucula* sp. and *Neilo* sp. are common secondary taxa	Middle to outer shelf water depths (50-150 m) on fine silty substrates	Z_3, Z_5	Wm-Wn
Tegulorhynchia-Talochlamys sub-association *(tg-ta)*	Moderate faunal diversity characterised by the dominance of *Tegulorhynchia niagricans*	Firm-ground at lower-inner to middle shelf water depths. Firm-ground development may represent periods of sediment starvation	Z_2	Wn
Atrina (at)	Typically monospecific association containing *Atrina pectinata zelandica*	Inner shelf to upper-middle shelf waer depths with a silty sand substrate with a moderately high siliciclastic sediment input	S_4, S_5, S_6, S_{10}, Z_3, Z_8, Z_9	Wm-Wn
Neilo (ni)	Low faunal diversity characterised by *Neilo* spp., with common *Notocallista multistriata, Calliostoma* sp., *Talochlamys gemmulata, Pleuromeris* sp., and Nuculanids.	Middle to outer shelf, fine sandy silt and silty substrates, often with a fine pebble content	Z_2, Z_5	Wm-Wn
Pratulum (pr)	Very low to moderate faunal diversity characterised by *Pratulum pulchellum*. May be monospecific, or contain *Talochlamys gemmulata, Ostrea chilensis, Dosinia (Kereia) greyi, Zenatia acinaces, Antalis nana, Pelicaria* spp., and *Austrofusus* spp.	Lower-inner to outer shef water depths on a sea-floor characterised by soft incoherent silty sediments	Z_2, Z_8	Wm-Wn

Interpretations as to the inferred environment of accumulation have been determined from integrating data on macrofaunal content, sedimentary structures, and lithofacies of the enveloping sedimentary rocks, and comparisons of the association with modern equivalents (where possible).



Fig. 6.3: Histograms showing the mean relative abundances of molluscan macrofauna in the 16 macrofaunal associations defined from Q-mode cluster analysis. Numerical values are percentages.

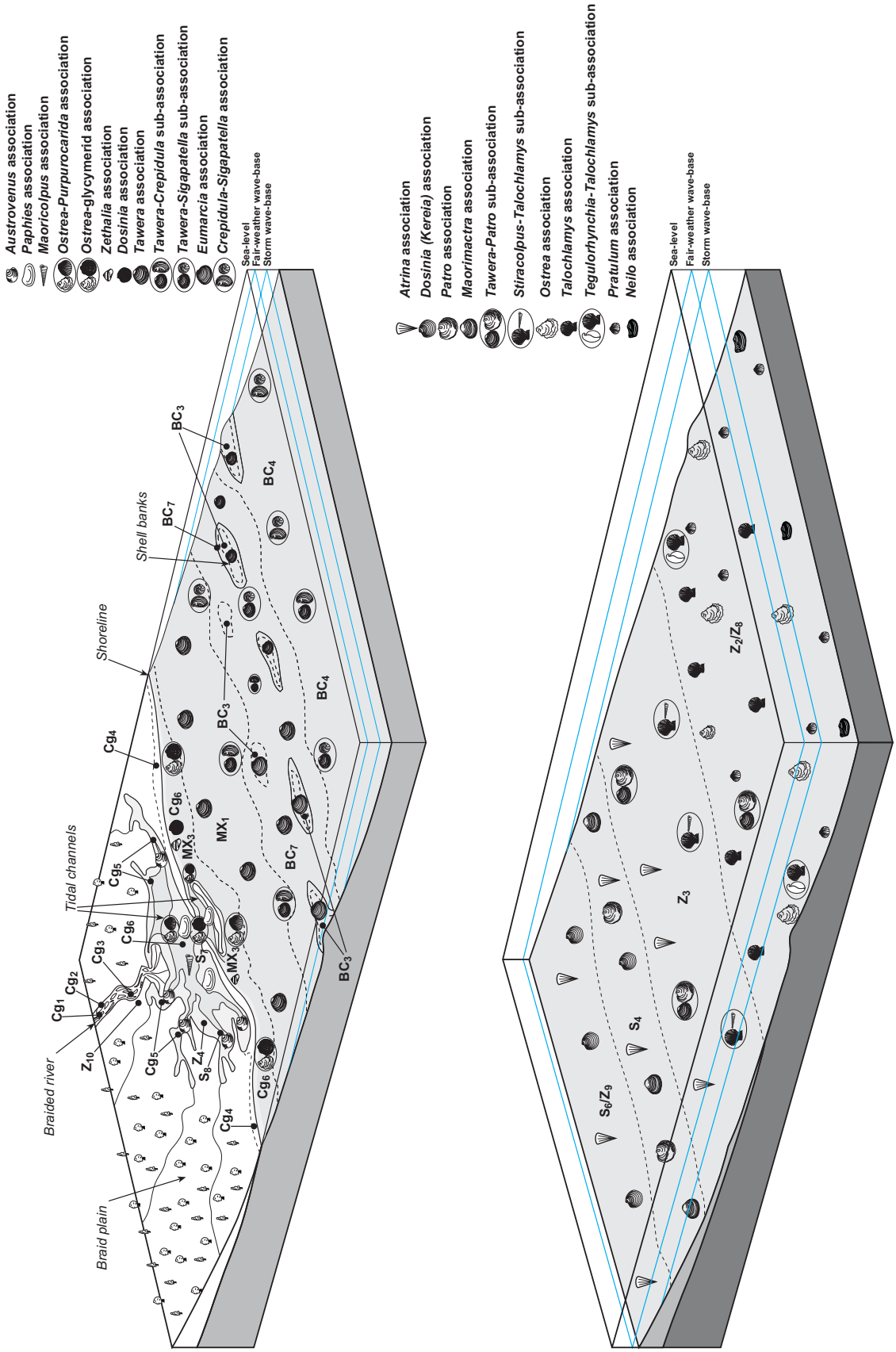


Fig. 6.4: Schematic illustrations showing the idealised distribution of lithofacies and macrofaunal associations on an inferred paleoshelf in the Nukumaruan. The upper figure is drawn for sea-level lowstand, the lower figure for sea-level highstand. Symbols are facies codes (Table 1). Fossil symbols represent macrofaunal associations identified in the legend.

Many macrofossils and associations in the study area have extant analogues to which direct comparisons can be made. The *Austrovenus* association is almost identical to modern *Austrovenus*-dominated communities in New Zealand estuaries (Beu and Maxwell 1990). Some modern *Tawera* and *Maoricolpus*-dominated communities currently living in the Manukau and Waitemata Harbours strongly resemble the *Tawera* and *Maoricolpus* associations described in this study (Powell 1937; McKnight 1969). Modern communities resembling the *Maorimactra* association are common on the New Zealand shelf in water depths of 20-60 m (McKnight 1969), and the *Pratulum* association is comparable to modern New Zealand communities reported by Dell (1951a, b), Estcourt (1967), Grace and Hayward (1980), and Hayward *et al.* (1984).

DISTRIBUTION OF PALEOENVIRONMENTS IN THE MANGAHEIA GROUP

Figures 6.4 and 6.5 illustrate the inferred distribution of lithofacies and macrofaunal associations across a shoreline-shelf setting during deposition of the Mangaheia Group. The main factors affecting the distribution of lithofacies during the Late Miocene-Early Pleistocene have been: 1) the general change from an irregular rocky basement coastline to an indented coastline with harbours, embayments, and (in the Upper Nukumaruan) a hinterland comprising a low-gradient coastal plain; 2) an increase in width of the paleoshelf; 3) the progressive constriction of the basin during the Pliocene, resulting in increased strength of tidal flows; and 4) the progradation of fluvial braidplain systems in two periods during the Late Pliocene. It appears that an increase in the variety of lithofacies and macrofaunal associations occurred through the Pliocene. Variations in lithofacies were more prominent during periods of relative sea-level lowstand, as illustrated in Fig 6.4.

Latest Miocene-Early Pliocene lithofacies in the Mangaheia Group reflect the presence of a rocky basement coastline and a narrow paleoshelf (Fig. 6.5A). The distribution of lithofacies and macrofaunal associations suggests that the coastline was highly irregular with embayments and harbours, and probably resembled the modern Coromandel and Northland east coasts. Bioclastic lithofacies were restricted to shore-parallel belts along the margins of the basin during this time. Bioclastic facies along the western margin are rich in greywacke clasts, reflecting basement provenance. Coeval lithofacies along eastern margins of the basin reflect mobilisation of shell debris off structural highs. Towards the axis of the basin bioclastic beds pass rapidly into sandstone and then massive mudstone lithofacies.

In the Late Pliocene ("middle" Mangapanian, Fig. 6.5B) progressive uplift along both margins of the basin induced a constriction of tidal flows in the forearc basin. Shore-parallel shell banks occurred along both margins of the basin, although massive mudstone lithofacies were still

accumulating in the axis of the basin during this time. The western coastline was probably still very irregular and rocky. Mixed siliciclastic-bioclastic lithofacies are common in this area. Emergent islands of basement occurred in several places, around which pebbly limestone and fossiliferous breccia were deposited. Along the western margin of the basin, bioclastic beds are generally restricted to the area southwest of the Napier-Taupo Road, with fine sandstone and massive mudstone occurring to the northeast.

In both Lower and Upper Nukumaruan beds, relative highstand lithofacies occur in shore-parallel belts (Fig. 6.4). A cross-shelf transition occurs from shoreface sandstone to silty sandstone and siltstone facies. The distribution of lithofacies during times of regressive and lowstand conditions changed markedly between the Lower to Upper Nukumaruan (Fig. 6.4C, D).

Basal Nukumaruan lithofacies (Fig. 6.5C) in outcrop are characterised by prominent conglomerate and limestone beds interbedded with thick sandstone and mudstone facies. Upper Nukumaruan paleoenvironments include conglomerate braidplain (Cg_1-Cg_3), conglomerate shoreline (Cg_4), fossiliferous conglomerate nearshore (Cg_5-Cg_6, MX_3), and pebbly limestone and cross-stratified limestone (e.g. BC_3 and BC_7). From Sherenden to the northeast, lithofacies generally occur in broadly shore-parallel belts, adjacent to a fluvial braid-plain system. South of Sherenden, where there was likely no braidplain, the coastline was rocky and irregular, and probably adjacent to exposed basement rocks. Lithofacies occur in a more sporadic pattern in this area, reflecting the more variable nature of the coastline.

Where the braidplain was present, the position of the lowstand shoreline can be estimated by mapping the distribution of Cg_4 conglomerate lithofacies, inferred to represent shingle beach deposits. The braidplain itself is characterised by Cg_1-Cg_3 lithofacies. A transition from non-marine conglomerates through fossiliferous conglomerate to mixed bioclastic-siliciclastic beds occurred perpendicular to the shoreline. It is inferred that the paleoshelf during the basal Nukumaruan was relatively narrow, and because of this coarse-grained shallow-water lithofacies rapidly pass into massive mudstone and flysch lithofacies. It is inferred that the paleocoastline and shelf where the braidplain was present during the basal Nukumaruan perhaps resembled the modern Napier coastline.

A large embayment, surrounded by a rocky basement coastline, is inferred to have been present in the Kuripapango and Awapai Station areas. Lithofacies in this embayment comprise coarse-grained fossiliferous conglomerate and limestone units. Conglomeratic lithofacies are more common close to the rocky coastline, with limestone deposits in central parts of the embayment. Coarse-grained lithofacies pass into massive mudstone facies in central parts of the basin.

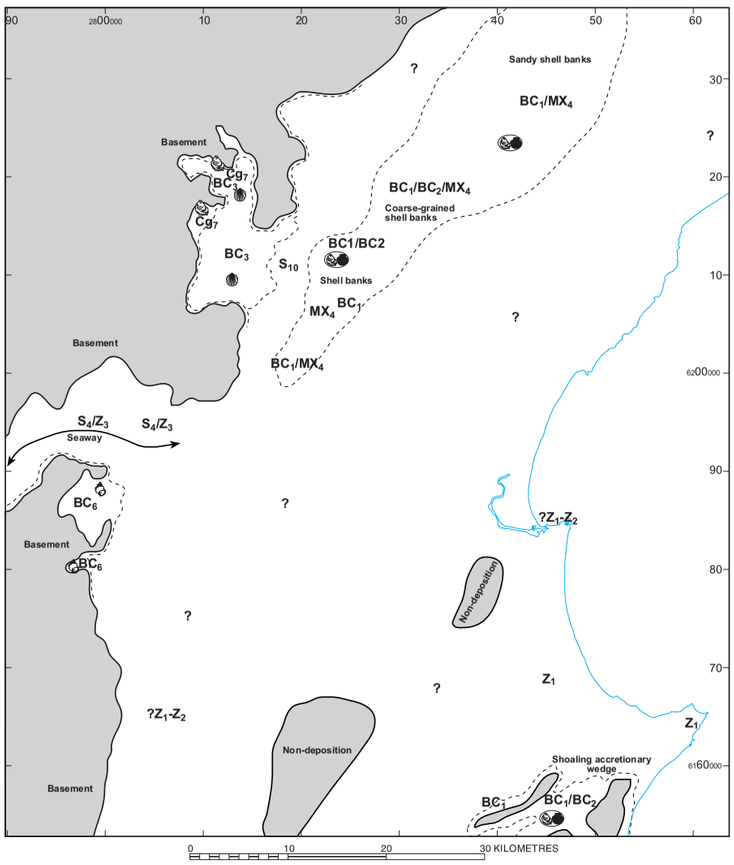
Coarse-grained pebbly limestone lithofacies were also deposited in the Ohara Depression. The presence of emergent greywacke to the east (Wakarara Range) and west (Ruahine Range) of the depression probably constricted tidal flows through the area, winnowing fine siliciclastic sediments. Limestone and conglomerate lithofacies are thickest and best developed along the margins of the depression, and pass into sandstone and siltstone facies in central parts. Pebbly limestone units were also deposited along the eastern side of the Wakarara Range. These beds also pass laterally into sandstone and siltstone facies.

Structural highs around Scinde Island, Mason Ridge, and Pakipaki allowed for deposition of limestone facies in these areas. Giant cross-bedded limestone at Scinde Island indicates strong tidal currents over this site. Bioclastic deposits at Scinde Island pass rapidly into massive mudstone lithologies in all directions.

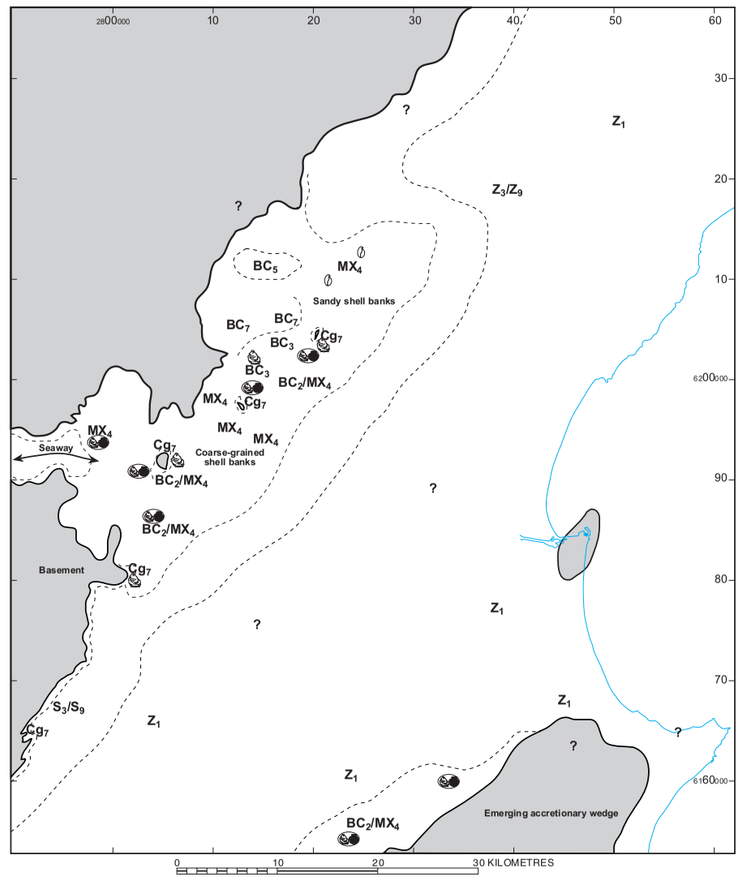
Upper Nukumaruan periods of regressive to lowstand sea level comprised highly variable lithofacies (Fig. 6.5D). Rather than broadly parallel bands, facies often occur sporadically. Relative sea-level lowstand lithofacies in the Upper Nukumaruan conspicuously comprise common limestone beds. The inner shelf probably comprised shell banks that were swept by strong tidal flows and storm wave-base. Tidal channels, and bars probably occurred along the western margins of the basin during this time. Bidirectional cross-stratification in limestone facies indicates that strong ebb and flood currents swept the shelf. Haywick *et al.* (1992) suggested that the Tangoio Block area was typical of mesotidal settings and was subjected to 2-4 m tides.

Fig. 6.5 (facing page): Inferred lithofacies and macrofaunal distribution for the Upper Opoitian, "middle" Mangapanian, basal Nukumaruan and Upper Nukumaruan. The different scales of the maps reflect the different outcrop patterns of rocks in each of these periods. Grey areas depict land or non-deposition. The locations of lithofacies codes and macrofaunal association symbols on these figures are based on outcrop position. Dashed lines mark the approximate distribution of lithofacies types. A) Upper Opoitian. Most rocks of this age in the study area are coarse-grained shallow-water units, preserved along the margins of the basin. This period records the early shoaling of the accretionary wedge along eastern margins the basin, and the possible re-opening of a seaway connecting Wanganui and East Coast Basins (Kuripapango Strait). Limited outcrop of Opoitian rocks in central parts of Hawke's Bay means that control on lithofacies distribution is poor. B) "Middle" Mangapanian. This period records the greatest development of the "Ruataniwha Strait" through central parts of the forearc basin. The seaway was open to Wanganui Basin through the Kuripapango Strait during this time. Coarse-grained limestone-dominated units accumulated adjacent to both margins of the basin. The variety of lithofacies along the western margin reflects an exposed basement hinterland, uplifted Neogene sedimentary units, and a highly irregular coastline. C) Basal Nukumaruan. The map is drawn for late lowstand-early transgressive sea level when the first period of fluvial fan-delta progradation in central parts of Hawke's Bay was occurring. D) Upper Nukumaruan, during deposition of the Tangoio Limestone Member, Flag Range Conglomerate Member, and correlative beds c. 1.8 Ma. The map is drawn for late lowstand-early transgressive sea level conditions.

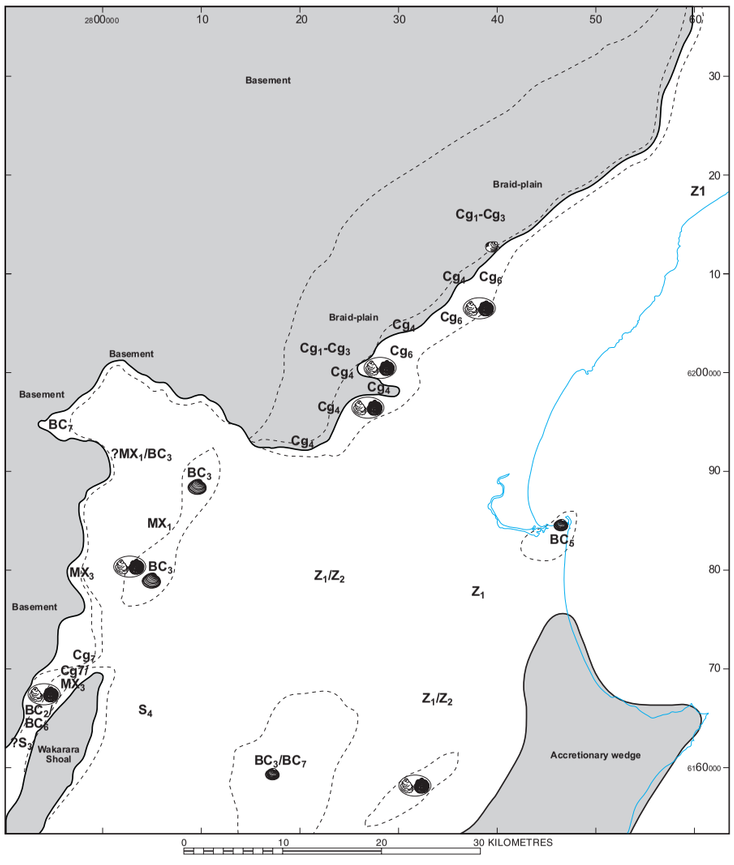
A) Upper Opoitian lithofacies distribution (c. 4 Ma)



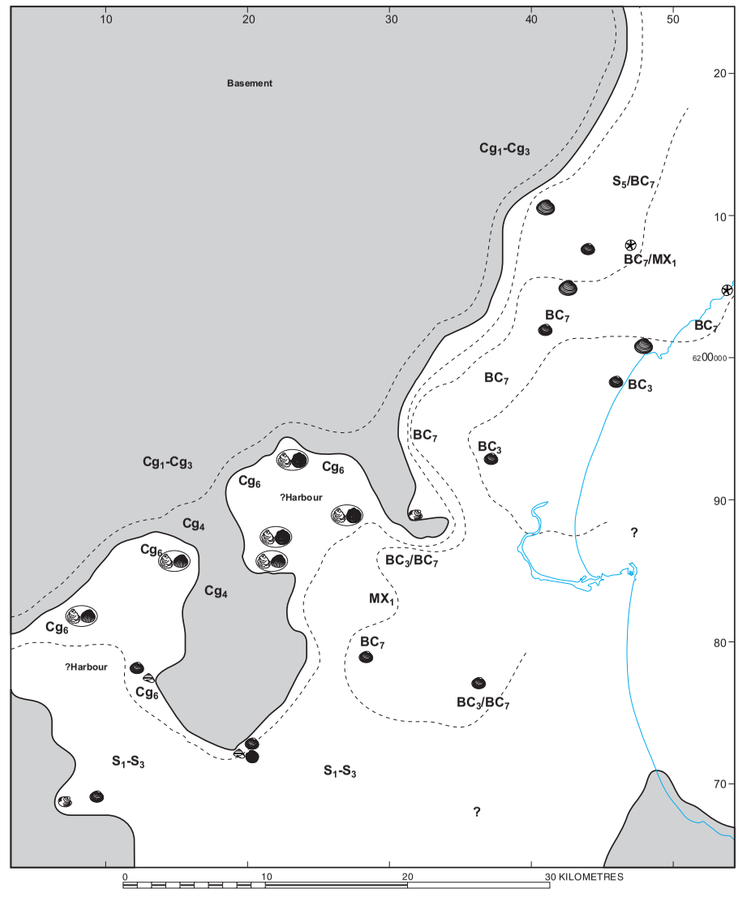
B) Middle Mangapanian lithofacies distribution (c. 2.8 Ma)



C) Basal Nukumaruan, late lowstand-early transgression sea-level (c. 2.4 Ma)



D) Upper Nukumaruan lithofacies distribution, lowstand sea-level (c. 1.8 Ma)



Legend

- *Austrovenus* association
- *Crassostrea* association
- *Crassostrea-Phialopecten* sub-association
- *Dosinia* association
- *Eumarcia* association
- *Fellaster* association
- *Neothyris* association
- *Ostrea*-glycymerid association
- *Ostrea-Purpurocardia* association
- *Struthiolaria (Callusaria)* association
- *Tawera* association
- *Tucetona* association
- *Zethalia* association

The distribution of lithofacies and macrofaunal associations during the Upper Nukumaruan indicates that the lowstand shoreline was strongly embayed (Fig. 6.5D). This is consistent with the nature of the lowstand shoreline inferred for the Tangoio Block by Haywick *et al.* (1992). Large embayments and/or harbours with tidal channels were present in the Sherenden and Matapiro areas. Lithofacies in these areas are dominated by shallow-water fossiliferous conglomerates rich in taxa such as *Tucetona, Ostrea, Dosinia, Zethalia, Purpurocardia,* and *Austrovenus*. These molluscs are common in shallow-water, high-energy environments, such as harbours and tidal channels around the modern New Zealand coastline. Around the Tangoio Block fossiliferous conglomerate lithofacies are inferred to have been less widespread, and pass rapidly from pebbly limestone units into shelly limestone beds.

SEQUENCE STRATIGRAPHY

INTRODUCTION

This section of the chapter introduces sequence stratigraphic concepts, applies them to the study area, and, using the lithofacies and macrofaunal associations defined in this chapter, develops a sequence stratigraphic model for the Mangaheia Group portion of the basin fill. Sequence stratigraphy is a technique that involves the identification of chronostratigraphically-related discontinuities, thereby allowing for sedimentary deposits to be grouped into discrete packages (or sequences). Milankovitch orbital variations of 21 k.y. (precession), 41 k.y. (obliquity), and 100 k.y. (eccentricity) duration have combined to produce changes in the amount of solar radiation reaching the surface of the Earth (Pillans *et al*. 1998). These variations in the wobble of the Earth about its axis control the amount of solar radiation reaching critical latitudes, thereby affecting the build up and melting of ice onland, which in turn influences sea level through changes in ice volumes in polar regions. In deep ocean environments, where calcareous ooze has accumulated, changes in ocean volume (and by proxy sea level) are recorded in oxygen isotope records of fossil shells (e.g. Shackleton *et al.* 1995; Nelson and Cooke 2001; Cooke *et al.* 2002). In continental margin settings, sea-level changes may be recorded in the form of lateral changes in facies types and sediment stacking patterns (sequences and systems tracts).

Much of the lithologic succession in the study area was deposited as a consequence of the interplay between tectonic influences on the basin (subsidence, uplift), a high siliciclastic sediment flux to parts of the area, and climatically-driven changes in sea level. Accumulation of sediments in the study area occurred during a time of known periodic sea-level change, as reported by studies such as Haywick *et al.* (1992), Shackleton *et al*. (1995), Naish and Kamp (1997), and Kamp and McIntyre (1998).

Many sequence stratigraphic studies in New Zealand have focused on Wanganui Basin in southern North Island. This basin has preserved an exceptionally sensitive record of 5th and 6th order (i.e. 100 k.y. and 41 k.y.) glacio-eustatically-driven cyclothems within a 5 km-thick Plio-Pleistocene sedimentary succession (Naish and Kamp 1997; Carter and Naish 1998; Abbot *et al.* 2005). Studies by Vella (1963), Beu and Edwards (1984), Haywick (2000), Haywick and Henderson (1992), Haywick *et al.* (1991, 1992), and Bland *et al.* (2004) have demonstrated the presence of cyclothems in Plio-Pleistocene rocks in Hawke's Bay Basin. The cyclothemic nature of many units in the Mangaheia Group has been noted by previous workers and attributed to orbital variations of 41 k.y. (Haywick, 2000; Haywick *et al.* 1992; Haywick and Henderson 1991; Beu 1995). The sequences identified share characteristics with the well-documented siliciclastic-dominated cyclothems in the adjacent Wanganui and Taranaki Basins (e.g. Naish and Kamp, 1997; Kamp and McIntyre, 1998; Vonk *et al.* 2002).

Sequences, whose development has been attributed to glacio-eustatically-driven changes in relative sea level, are best developed in "middle" Pliocene to Early Pleistocene strata in the study area. Caron (2002), Caron *et al.* (2003, 2004b), and Bland *et al.* (2004) recognised sequences within limestone formations in the Mangaheia Group (e.g. Te Waka and Titiokura Formations), and Bland (2001) noted the presence of sequences within the Pohue Formation. Sequences in the study area are dominated by coarsening-upward packages of siliciclastic sediments, with bioclastic facies increasing in prominence in younger, Upper Nukumaruan cycles. The identification of cyclothemic intervals in the study area has allowed for the correlation of stratigraphic horizons across the study area. This allows for the chronology established in one area to be applied in another. Because of this, careful attention has been paid to the accurate correlation of stratigraphic horizons during field mapping. The Plio-Pleistocene sequences in the study area are typically 20-80 m thick, are siliciclastic-dominated, and are stacked in a strongly aggradational pattern. Models of sequences in New Zealand have often depicted a strongly progradational stacking pattern for sequences (e.g. Naish *et al.* 2005), a situation very different to Hawke's Bay during the Plio-Pleistocene. The aggradational nature of the succession shows that basin subsidence mostly kept pace with sediment flux for significant periods of time. The inference therefore is that between 20-80 m of subsidence was occurring in the basin every 40 k.y during the Plio-Pleistocene. Times of accelerated subsidence are recorded in the stratigraphic record (e.g. the Esk Mudstone, which lacks obvious sequences), but, in general, from the Mangapanian to the Upper Nukumaruan, subsidence and deposition were balanced.

SURFACES

Sequence stratigraphy is a method of subdividing a sedimentary succession on the basis of key surfaces. These surfaces may be erosional unconformities, condensed horizons, or their correlative conformities. The following section discusses the surfaces of relevance for determining the sequence stratigraphy of the study area. The positions of surfaces and inferred stratal patterns important in this study are illustrated in Fig. 6.6.

Sequence boundary (SB)

The sequence boundary is the fundamental surface in classifying sequences as it bounds them (Fig. 6.6). Complications have arisen where clearly identifiable non-marine strata are present in a sequence, such as the conglomerate beds in the Matahorua, Petane and Okauawa Formations. Non-marine beds in the study area are sharp-based, and their lower contact displays decimetre-scale relief. Haywick (2000), observing the erosional base of non-marine deposits in the Tangoio Block, and the resulting lithofacies transition from marine to non-marine sedimentation, placed the sequence boundary at this surface. He also restricted non-marine facies to the lowstand of sea level (lowstand systems tract, LST), by inference assuming that no non-marine beds were deposited during the highstand (highstand systems tract, HST) or regressive (regressive systems tract, RST) phases of a sea-level cycle. Studies by Browne and Naish (2003) and Naish *et al.* (2005) also placed the sequence boundary at the base of non-marine LST beds.

This study infers that the non-marine beds in Plio-Pleistocene sequences in Hawke's Bay could have accumulated in any of the highstand, regressive, or lowstand systems tract, depending on their position on the paleoshelf. This means that at a given point in time a non-marine deposit can be linked by a chronological surface (or time plane) to nearshore and offshore facies basinward on the paleoshelf (Fig. 6.7, 6.8). Even though the base of the non-marine beds appears strongly erosional and an appropriate place to put a sequence boundary, the surface is only present because of the expected fluvial incision from a fan-delta system, and not strongly related to widespread shelf ravinement, condensation, or planation. Furthermore, marine rocks that have accumulated farther basinward of the area of non-marine deposition can be linked through this erosional surface by the hypothetical time planes mentioned above (Fig. 6.8).

This study therefore views the *top* of non-marine beds to be the most appropriate place to locate a sequence boundary (Fig. 6.9, 6.10A). This surface also corresponds to a transgressive surface of erosion (TSE) (see below), produced by wave planation during sea level rise. Across this surface the linkages between facies breaks down; that is, strata above and below the surface cannot be linked to one another by time planes. This means that strata above and below the

sequence boundary and TSE are related to separate depositional sequences. The base of the LST is described informally here as a "subaerial exposure surface". The strongly diachronous nature of this surface means that it probably has little importance in terms of delimiting systems tracts. Also, the conglomerate braidplains indicate long term deposition and not erosion.

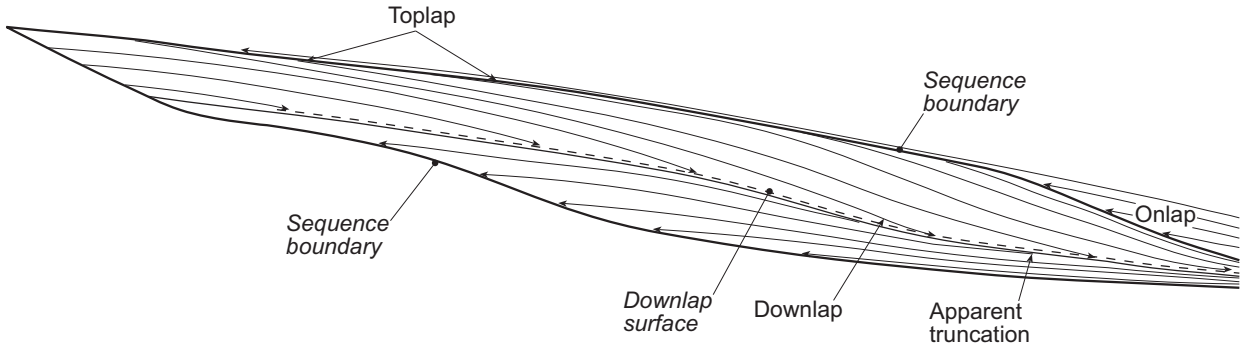


Fig. 6.6: Diagram illustrating sequence boundaries (unconformities), downlap (maximum flooding) surfaces, and other stratal terminations in a single idealised sequence. Apparent truncation refers to stratal termination by depositional thinning. Adapted from Boggs (1995, p. 548) after Vail (1987).

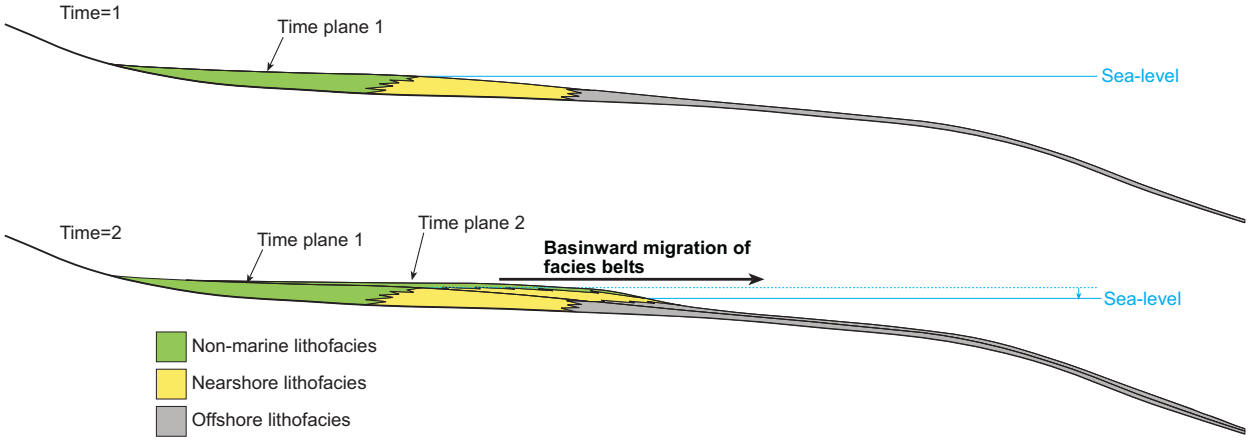


Fig. 6.7: Conceptual diagram illustrating the basinward migration of facies belts during relative sea level fall. In the study area, non-marine lithofacies comprise greywacke conglomerate beds, nearshore lithofacies are shelly conglomerates and sandstones, and offshore lithofacies are silty sandstones and siltstones.

Transgressive surface of erosion (TSE)

Transgressive surfaces of erosion (TSEs) are formed during sea level rise and correspond to the process of erosional translation of the shoreface profile upwards and landwards (Nummedal and Swift 1987). This involves intense reworking and winnowing of pre-existing deposits by the action of wave and storm currents (Caron *et al.* 2004b). TSEs in the study area are usually sharp and commonly support relief up to 0.5 m. They typically underlie deepening-upward bioclastic and mixed bioclastic-siliciclastic deposits and overlie shoreface to nearshore sandstone, shellhash limestone, or non-marine greywacke conglomerates. Where TSEs overlie non-marine

conglomerates, such as in the Matahorua Formation (e.g. Fig. 6.10A), the exact position of the TSE may be difficult to locate. This is because greywacke clasts in the non-marine part of the conglomerate are reworked into the overlying marine conglomerate, with the TSE between them. In such cases the contact may appear to be gradational over about 0.1 m, and has developed as a result of rapid flooding. In all other cases the TSE is a sharp contact between lithofacies (Fig. 6.10B-G). In this study the TSE is in effect the sequence boundary.

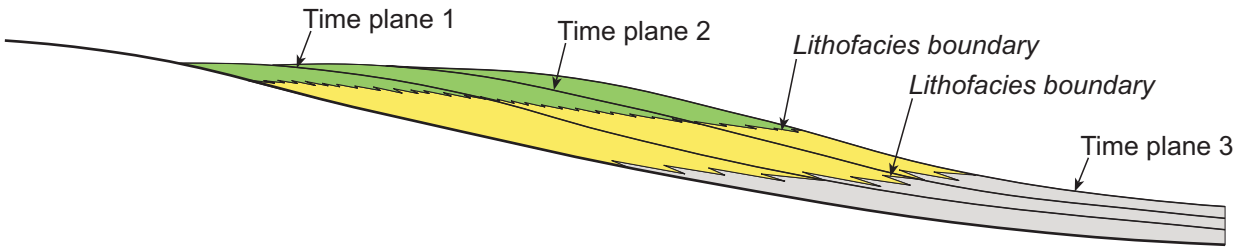


Fig. 6.8: Conceptual relationship between lithofacies boundaries and time planes during a period of relative sea level fall, and ensuing basinward migration of lithofacies belts. Non-marine lithofacies are represented by the green fill, nearshore lithofacies by the yellow fill and offshore lithofacies by the grey fill. Note in the diagram how time planes cut through facies belts. This illustrates how the boundaries that separate lithofacies within a sequence are almost always diachronous. As systems tracts represent "linked depositional systems", the lithofacies boundaries that separate them are also diachronous, and these surfaces cross time planes. This means that the four systems tracts (TST-HST-RST-LST) will comprise many different linkages of lithofacies belts (depositional systems) on a shelf-slope profile at any given time.

Downlap surface (DS)

At the seismic-scale the downlap surface records the transition from retrogradational to progradational stratal geometries (Fig. 6.6). In the field these changes in stratal geometry cannot be observed as the dips are too shallow, and where present the downlap surface typically marks the sharp transition from bioclastic TST deposits to siliciclastic siltstone. In effect the downlap surface marks the top of the TST and will be close to the point of maximum sea level rise attained during a sequence. It therefore is usually coincident with the maximum flooding surface (MFS). The downlap surface may be underlain by a shellbed named the backlap shellbed (e.g. Naish and Kamp 1997; Kondo *et al.* 1998), and overlain by a downlap shellbed. These shellbeds are discussed in more detail below.

Regressive surface of erosion (RSE)

Regressive surfaces of erosion mark the base of forced regressive systems tracts (FRST) (Hunt and Tucker 1992). These systems tracts develop when the rate of sea level fall exceeds the rate of basin subsidence and an erosional surface is produced through wave-based scour of the sea floor (Nummedal and Swift 1987). Over time, with continued sea level fall, the shoreline migrates seaward over the RSE, typically resulting in well sorted beach and nearshore sandstones sharply overlying shelf siltstones. The underlying siltstones are assigned to the highstand systems tract,

and the overlying sandstones to the forced regressive systems tract. In the study area the transition from highstand to regressive systems tracts is almost always gradational, and the contact between the two systems tracts is virtually impossible to locate. Regressive surfaces of erosion are very rare in the study area, and have only been observed in Rautoitoi Stream where sandstone of the Tutira Member (Petane Formation) sharply overlies siltstone of the Esk Mudstone. Haywick (2000) reports the presence of RSEs in the Kaiwaka Formation.

SYSTEMS TRACTS

Systems tracts are defined as linked depositional systems that can be correlated on the basis of their bounding unconformities or flooding surfaces (Walker, 1992). The four systems tracts discussed in this study (TST, HST, RST, and LST) each imply an interval in a sea-level cycle (Fig. 6.9). The following section will discuss the characteristics of each systems tract in the study area, and how, if possible, they can be distinguished from one another. Although in theory depositional systems (systems tracts) are linked across the coastal plain-shoreline-shelf-slope-basin between bounding surfaces, this study demonstrates that in practice this can be difficult to determine due to limited down-dip exposure.

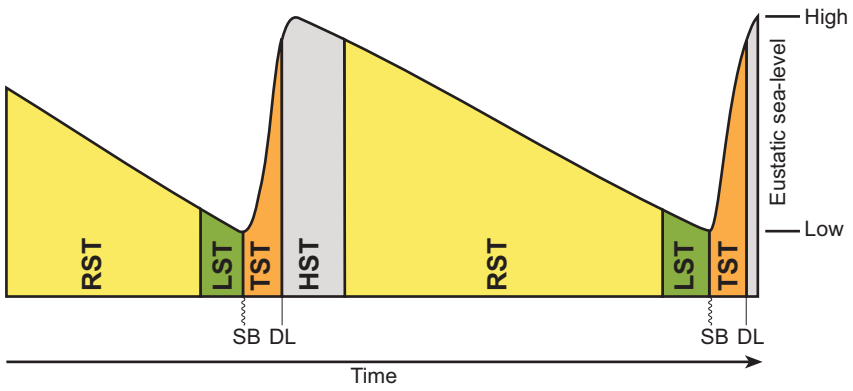


Fig. 6.9: Model illustrating the timing of systems tracts within a eustatic oscillation of sea level rise and fall. SB denotes the sequence boundary, DL denotes the downlap surface. RST - regressive systems tract; LST - lowstand systems tract; TST - transgressive systems tract; HST - highstand systems tract.

Transgressive Systems Tract (TST)

The TST comprises all contemporaneous strata deposited during the interval of rapid rise in relative sea level. The architecture of the TST is controlled mostly by the rate of relative sea level rise and the flux of terrigenous sediment. The base of the TST is marked by a transgressive surface of erosion (TSE) in shelf successions, and commonly erodes or lowers the sequence boundary. Typically, the TST is overlain by a maximum flooding surface, approximated by the downlap surface. During the transgressive phase, siliciclastic sediment may accumulate in retrogradationally-stacked shoreline-connected wedges (Naish and Kamp, 1997; Kamp and

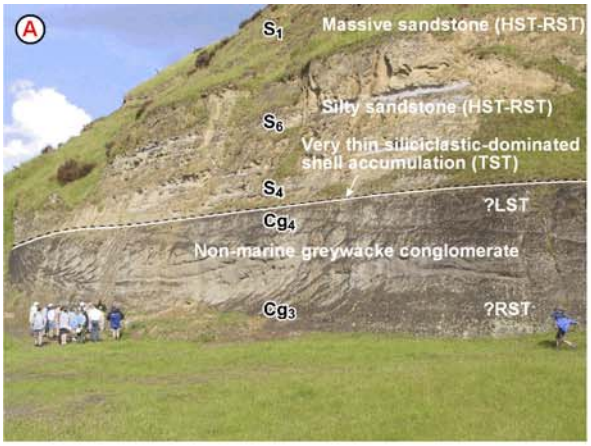
McIntyre, 1998). TSTs in Wanganui and Taranaki Basins typically comprise moderately to highly fossiliferous shellbeds of 0.5-5 m thickness overlying a transgressive surface of erosion (Naish and Kamp, 1997; Kamp and McIntyre, 1998; Vonk *et al*. 2002). This contrasts with the Hawke's Bay situation where TSTs are mainly very thin (<0.5 m thick) units.

The collapse of ice sheets in the early parts of an interglacial and the consequential sea level rise generally occur rapidly (e.g. Petit *et al.* 1999). By contrast, the building-up of ice sheets and the subsequent sea level fall during a glacial are typically prolonged events. The net effect is that sea level rise into an interglacial occurs rapidly, and sea level fall out of an interglacial occurs at a slower rate. Geological mapping and lithofacies analysis in this study have led to the conclusion that the continental shelf in the study area during the Plio-Pleistocene was narrow (about 10-30 km wide) with low gradient. A consequence of this is that transgressions occurred rapidly. This rapid rate of inundation contrasts with the slower rate of withdrawal of the sea from the coastal plain and across the shelf during periods of sea level fall. The rapid landward migration of the shoreline across the shelf and coastal plain during the TST was a contributing factor to the thin TSTs preserved in the study area.

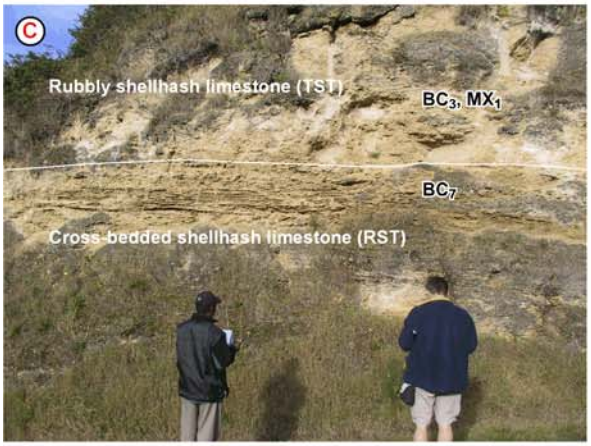
Also acting to limit the thickness of TSTs in the Nukumaruan succession in the study area was the high terrigenous sediment flux into Hawke's Bay Basin during the Pliocene. This flux limited carbonate production by saturating the continental shelf with siliciclastic sediment. The combined effect of all of these factors (rapid sea level rise, low-gradient shelf, and high siliciclastic sediment input) is that Pliocene TSTs in the basin are often thin, poorly-developed, and siliciclastic sediment-rich.

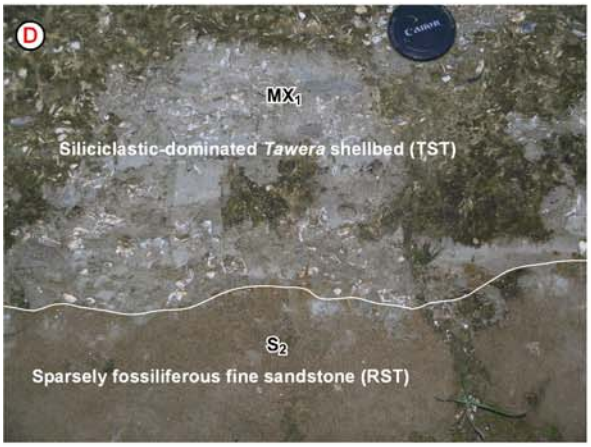
TSTs in the study area typically comprise a combination of bioclastic and siliciclastic lithofacies of pebbly sandstone and moderately fossiliferous pebbly shellbeds (e.g. Cg_5, Cg_6, BC_3, MX_3). Pebbles in the TST are mainly derived from erosion of underlying conglomerate lithofacies in the previous sequence. These pebbles are usually well rounded and very well sorted, and decrease rapidly in size up through the TST. Macrofauna present are generally indicative of a high-energy environment and are dominated by robust, thick-shelled species such as *Tucetona laticostata, Glycymeris shrimptoni, Ostrea chilensis, Crassostrea ingens, Patro undatus,* and *Phialopecten* spp. (typically of the *Austrovenus, Ostrea*-glycymerid, *Ostrea-Purpurocardia, Eumarcia,* and *Tawera* macrofaunal associations). A progression is often noticeable from nearshore faunas at the base of a TST (e.g. *Tawera, Paphies,* and *Zethalia* associations) into deeper water species near the top (e.g. *Phialopecten* in the *Ostrea*-glycymerid association), reflecting a continued rise of sea level.

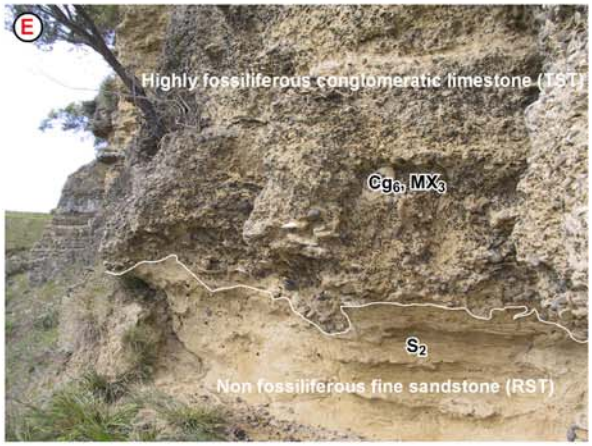
Fig. 6.10 (facing page): Typical field expressions of sequence boundaries in the Mangaheia Group across the study area. Solid white lines denote the sequence boundary (and TSE), dotted black lines indicate the inferred position of the downlap surface. **A)** Non-marine conglomerate lithofacies overlain by silty sandstone, Trelinnoe Member, Matahorua Formation. The conglomerate is sharply truncated by a TSE, over which lies a very thin, siliciclastic-dominated TST shellbed. The top of the shellbed is inferred to represent the downlap surface. The thickness of the conglomerate and the nature of the overlying silty sandstone suggest that this outcrop represents a landward position on the paleoshelf with respect to other down-dip localities. The conglomerate may represent at least in part both the RST and the LST. Matahorua Road gravel pit (V19/490206). **B)** Slightly bioclastic sandstone sharply overlain by a moderately well cemented limestone, Te Waka Formation. The sequence boundary displays decimetre-scale relief, and is extensively burrowed. Glenross Range near Kaweka Forest headquarters (U20/087904). **C)** Strongly cross-bedded sandy limestone (RST) overlain by rubbly shellhash limestone (TST), Waipatiki Limestone Member. The two intervals are separated by the sequence boundary. Cross-bedding in the lower interval is mostly small to moderate-scale tabular and herringbone cross-stratification. Such bedding is mostly absent in the overlying interval. Macrofauna are sparse in the RST, but are more common in the TST, and are dominated by the *Eumarcia* association. Ohiti Road (V21/299732). **D)** Sequence boundary displaying centimetre-scale relief separating sparsely fossiliferous fine sandstone (RST) from moderately to highly fossiliferous sandstone (TST), Kaiwaka Formation. Macrofauna in the TST shellbed are typical of the *Tawera* association, and the fragmented nature of many valves, together with the high siliciclastic content is typical of onlap shellbeds. Ohiti Road (V21/232721). **E)** Highly fossiliferous TST greywacke conglomerate of the Flag Range Conglomerate Member overlying a TSE displaying decimetre-scale relief. Below the conglomerate is sparsely fossiliferous fine sandstone of the Mairau Mudstone Member. No non-marine conglomerate is present at this locality, which is inferred to be near the position of the lowstand shoreline. Macrofauna in the TST are typical of the *Ostrea*-glycymerid association. Mount Cameron (V21/251881). **F)** Cross-bedded shellhash limestone (RST) underlying a sequence boundary. Above the sequence boundary is more massive, biomouldic limestone of the TST. Macrofauna are sparse in the RST, and are more common in the TST limestone (*Tawera* association). Both units are part of the Waipatiki Limestone Member. Photo Location: Hedgley Station (V20/368915). **G)** Waipatiki Limestone Member cropping out in Okawa Stream. The sequence boundary separates cross-bedded to slump-bedded shelly limestone (RST) from more massive, biomouldic limestone of the TST. Macrofauna in the RST are characterised by the *Tawera, Tawera-Crepidula*, and *Tawera-Sigapatella* associations and sub-associations. Macrofauna in the TST are dominated by the *Tawera* association. Although the siliciclastic content of the RST at this site is probably too high to be a true toplap limestone, nearby localities exposing this interval (e.g. V21/273811, V21/293749) represent toplap shellbeds. Okawa Stream near Pukehaumoamoa School (V21/250781).


A
S_1
Massive sandstone (HST-RST)
Silty sandstone (HST-RST)
S_6
Very thin siliciclastic-dominated shell accumulation (TST)
S_4
?LST
Cg_4
Non-marine greywacke conglomerate
Cg_3
?RST

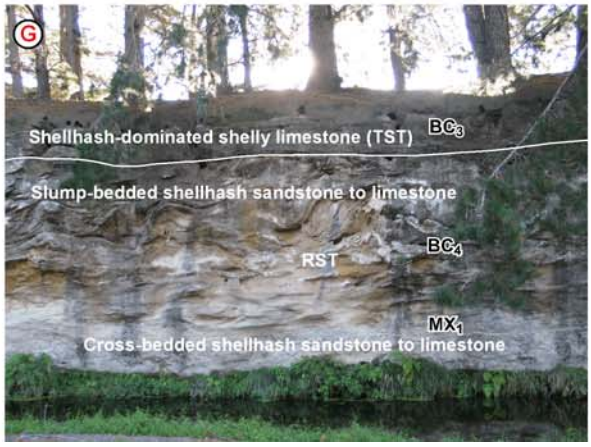

B
Shellhash limestone (TST)
BC_3
Slightly bioclastic sandstone (RST)
S_5


C
Rubbly shellhash limestone (TST)
BC_3, MX_1
BC_7
Cross-bedded shellhash limestone (RST)


D
MX_1
Siliciclastic-dominated *Tawera* shellbed (TST)
S_2
Sparsely fossiliferous fine sandstone (RST)


E
Highly fossiliferous conglomeratic limestone (TST)
Cg_6, MX_3
S_2
Non fossiliferous fine sandstone (RST)


F
Shelly limestone (TST)
BC_3
BC_7
Cross-bedded shellhash sandstone to limestone (RST)


G
Shellhash-dominated shelly limestone (TST)
BC_3
Slump-bedded shellhash sandstone to limestone
BC_4
RST
MX_1
Cross-bedded shellhash sandstone to limestone

Highstand Systems Tract (HST)

HSTs comprise sediments deposited during the late rise, stillstand, and early fall of a relative sea-level cycle, and represent the "roll-over" from transgressive to regressive phases of sea level. At seismic scale this change is represented by a change from retrogradational to progradational stratal geometries (Naish and Kamp 1997), the base of which is marked by the downlap surface. In effect, HSTs are deposits formed in the deepest water environments encountered during a sea-level cycle. The base of the HST in rare occasions may be marked by a sparsely fossiliferous shell accumulation referred to as the downlap shellbed.

HSTs are dominated by fine-grained siliciclastic-dominated facies that accumulated in wave and storm-dominated environments on a continental shelf (e.g. lithofacies S_4, Z_1, Z_2, Z_3, Z_8, and Z_9). They are normally 10-60 m thick. In rare cases, where the shoreward-edge of a sequence has been preserved, sandstone-dominated HSTs have been inferred. Macrofauna are generally relatively sparse to moderately common throughout the HST, and are dominated by soft-sediment-dwelling infaunal bivalves such as those in the *Pratulum, Neilo, Dosinia (Kereia),* and *Atrina* associations, and the epifaunal *Talochlamys* association, and *Talochlamys-Stiracolpus* and *Tegulorhynchia-Talochlamys* sub-associations. These macrofauna indicate an environment of relatively low-energy, in middle to outer shelf water depths with soft substrate. The presence in some places of abundant *Talochlamys* and the brachiopod *Tegulorhynchia niagricans* suggest intermittent firm-ground development. The HST typically coarsens upwards and passes gradationally into overlying nearshore and shoreface sandstone lithofacies. Only very rarely is the transition marked by a sharp surface, inferred to be a regressive surface of erosion (RSE) (e.g. in Rautoitoi Stream at the base of the Tutira Member).

Regressive Systems Tract (RST)

The RST represents sediments deposited during a period of falling relative sea level and the resulting basinward progradation of sediments in response to this base-level fall. In the traditional sequence stratigraphic model, no sedimentation was inferred to occur during sea level fall, as this was viewed as a time of erosion (Pillans *et al.* 1998). However, with the right balance of basin subsidence and sediment flux, shelf sedimentation can occur during falling sea level (Hunt and Tucker 1992; Naish and Kamp 1997). Studies of Plio-Pleistocene rocks in New Zealand have demonstrated that thick shallowing-upward deposits have accumulated during times of sea level fall (e.g. Haywick (2000) and Haywick *et al.* (1991; 1992) in Hawke's Bay; and Naish and Kamp (1997), Carter and Naish (1998), Carter *et al.* (1998), Kamp and McIntyre (1998), and Kondo *et al.* (1998) in Wanganui Basin). Naish and Kamp (1997) suggested that all progradational strata accumulating during rapid relative sea level fall be classified as the RST. They also noted that the

base of the RST does not have to be erosional, but can be gradational with respect to the underlying HST. This is in contrast to the *forced regressive systems tract* (FRST) of Hunt and Tucker (1992) that displays an erosive base (regressive surface of erosion). Strata are assigned to the RST when they are inferred to have accumulated during a time of falling sea level, but contain no diagnostic features that allow them to definitively be assigned to the FRST. This is the situation with virtually all potential RSTs in the study area. Because the transition from "typical" HST siltstone to "typical" RST sandstone is gradational, the positioning of the systems tract boundary is time transgressive basinward. For convenience in this study it is typically placed mid-way between dominantly-siltstone and dominantly-sandstone intervals.

RSTs in the study area can be either siliciclastic- or bioclastic-dominated, the former being most common (facies S_1, S_2, S_3, S_9). The presence of bioclastic-dominated RSTs in the study area differs from RSTs in the adjacent Wanganui and Taranaki Basins, where they are almost exclusively siliciclastic-dominated (e.g. Naish and Kamp 1997; Kamp and McIntyre 1998; Vonk *et al.* 2002). Regressive facies are typically coarser-grained than underlying HST facies, and in many cases contain a significantly higher bioclastic content. They may also display prominent cross-stratification, although usually appear massive due to the very well sorted nature of the sandstone.

Where sediment starvation in an RST can be demonstrated, shellbeds may be termed toplap shellbeds (Kidwell 1991; Naish and Kamp 1997; Kondo *et al.,* 1998; facies BC_4). Macrofauna in toplap shellbeds are of the *Crepidula-Sigapatella* association, and the *Tawera-Sigapatella* and *Tawera-Crepidula* sub-associations. More typically, however, RSTs in Hawke's Bay are often characterised by prominent, highly fossiliferous shell-rich lenses, 0.5-2 m long, occurring in massive to cross-bedded fine to medium sandstone (facies S_3). These shellbeds have developed during discrete storm events and have not developed from stratigraphic condensation. Such shellbeds have been termed event concentrated shellbeds (Hendy *et al.* 2006). Macrofauna are normally tightly-packed, concave-down, bivalve-dominated, and the shellbeds themselves sharply-based. Event-concentrated shellbeds are most evident in upper levels of a RST, for example in the Darkys Spur Member, Petane Formation (V20/407105, Column Tg-3). Fauna in these shellbeds are typically dominated by the *Dosinia*, *Zethalia*, and *Fellaster* associations. Where the RST is dominantly bioclastic, such as those present in the Tangoio and Waipatiki Limestone Members (Petane Formation), the interval is classed as a toplap shellbed, produced through wave-base induced sea-floor scour and winnowing, resulting in the concentration of bioclastic sediments over siliciclastic sediments. The toplap shellbed in these members is characterised by poorly cemented, highly fossiliferous beds of *Tawera, Crepidula*, and *Sigapatella*, in total up to about 5 m thick. These gradationally overlie significantly less

fossiliferous siltstone and sandy siltstone lithofacies, and are sharply truncated at their tops by a TSE (sequence boundary). They are overlain by more strongly cemented limestone of the next TST. Both the toplap and event-concentrated shellbed types are discussed in more detail in following sections of this chapter.

In contrast to the rapid collapse of ice sheets that occurs during transgressive periods, the build-up of ice sheets during a regressive phase is typically a much slower process (e.g. Petit *et al.* 1999). A key effect of this is that regressive phases of sedimentation are usually longer-lived than the transgressive phase. This partially explains the greater thickness of RST deposits over TST deposits in the study area. The higher siliciclastic sediment flux that occurs during the regressive phase also contributes to the greater thickness of RST deposits. RSTs in the middle and upper Mangaheia Group are typically up to 40 m thick, reflecting the combination of a long period of sea level regression (in contrast to rapid sea level rise during transgression) and a high siliciclastic sediment input. The length of regression reflects the interplay between continued, rapid basin subsidence and a high terrigenous sediment flux sourced from an actively rising hinterland.

It is highly probable that some upper parts of RSTs in the study area are represented by non-marine conglomerate beds, such as those in the Matahorua, Petane, and Okauawa Formations. The basal erosional surface of these conglomerates is strongly diachronous across the paleoshelf, and it is likely that landward areas of conglomerates accumulated during RST time. There are no surfaces within the conglomerates to allow differentiation between the RST and LST, and it is probable that only those conglomerates near the lowstand shoreline can confidently be assigned to the LST. The only surface of sequence stratigraphic importance within the conglomerate beds is the TSE which separates non-marine from marine beds, and is superimposed within the sequence boundary.

Lowstand Systems Tract (LST)

The LST marks sediment accumulation during the lowest stage of sea level during a sea-level cycle and underlies the sequence boundary. The general sequence stratigraphic model predicts "cessation of widespread fluvial deposition" and "stream rejuvenation and incision" (Posamentier *et al*. 1988) during lowstand conditions. It has, however, been demonstrated by a number of workers (e.g. Browne and Naish 2003) that rivers do not necessarily incise during sea level lowstand if they flow out onto a coastal plain flanked by a low-gradient shelf. In these cases subaerial fluvial aggradation may occur where rivers with a high sediment bedload emerge from their hinterland onto a plain and shelf with a much lower gradient (Woolfe *et al.* (1998). This means that of fundamental importance to producing non-marine LSTs in the study area is the

presence of rivers with a high sediment load (preferably coarse sand and gravel), and a low-gradient coastal plain and adjacent continental shelf. The Hawke's Bay Basin during the Late Pliocene is inferred to have contained these elements.

Lowstand deposits in the study area are inferred to mostly be characterised by non-marine greywacke conglomerate beds of 2-15 m thickness. Non-marine lowstand deposits (e.g. facies Cg_1-Cg_3) sharply overlie shallow-marine rocks of dominantly sandstone lithology (facies S_1-S_3, S_9). These deposits were produced when high-bedload river systems emerged from a proto-North Island axial range belt onto a low-gradient coastal plain and exposed continental shelf. This process led the river systems to debouch their sediment load producing a low gradient fan-delta system, much in the manner that the modern braided river systems of the Canterbury Plains and central Hawke's Bay do today.

Lowstand deposits in Hawke's Bay record a high sediment flux throughout the regressive and lowstand phases of a number of sea-level cycles that, coupled with falling sea level, drove the basinward progradation of a braid-plain system across the exposed continental shelf. As would be expected from a fluvial system, the base of the LSTs are channel erosional, and usually marked with a transition from nearshore sandstone to non-marine conglomerate lithofacies. The coarse-grained fluvial sediments of the Matahorua Formation mark the commencement during the Upper Mangapanian of a significant phase of aggradation and progradation of a braided fan-delta system, probably due to rapid uplift and erosion of a greywacke basement hinterland. The conglomerate lithofacies that represent LST deposits are sharp-based and non fossiliferous, except for uncommon plant fossils. Fossiliferous conglomerates (facies Cg_5, Cg_6) are assigned to the TST.

SHELLBEDS

Condensed deposits, especially shellbeds, play important roles as indicators of sequence architecture in siliciclastic shelf successions (e.g. Kidwell 1991; Abbott and Carter 1994; Naish 1996). Shellbeds are regarded as stratigraphic intervals that contain "above background" amounts of macrofossils. Stratigraphic condensation can occur anywhere that stratal surfaces converge. This is often along surfaces of onlap, downlap, backlap, or toplap, which are usually characterised by slow net terrigenous sediment accumulation that encourages favouring the formation of a shellbed. Such horizons are common and widespread through the study area. Shellbeds may be differentiated on the basis of the stratigraphic and stratal position they occupy (Fig. 6.11, Table 6.3).

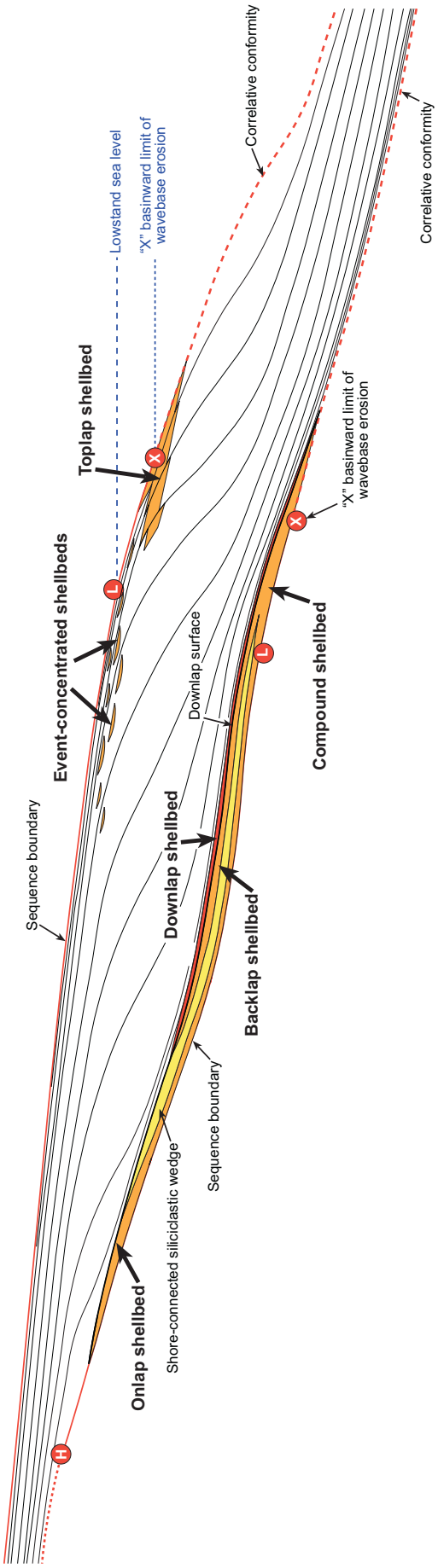
The condensed deposit nomenclature adapted in this study is derived from that used in studies by Kidwell (1991), Naish and Kamp (1997), Kondo *et al.* (1998), Hendy and Kamp (2004), and Hendy *et al.* (2006).

Onlap shellbed

Onlap refers to the termination of strata in a landward direction against an initially sloping surface (Fig. 6.11). Shellbeds that form in the context of onlap (Fig. 6.6, 6.11) are inferred to accumulate at or above contemporary wave-base. They are shell (macrofossil)-rich, and contain reworked and fresh, poorly to moderately preserved, innermost shelf to shoreface fauna (Naish and Kamp 1994, 1997).

Onlap shellbeds in the study area are usually characterised by a shellhash-dominated interval with abundant infaunal to semi-infaunal, shallow-marine fauna of any of the *Tawera, Ostrea*-glycymerid*, Ostrea-Purpurocardia, Tucetona, Paphies, Austrovenus,* or *Maoricolpus* faunal associations*.* Fauna of the *Tawera* association are most typical. When underlain by greywacke conglomerate facies, the onlap shellbed is pebbly, and comprises robust semi-infaunal molluscs of the *Maoricolpus*, *Ostrea*-glycymerid, *Ostrea-Purpurocardia,* or *Tucetona* macrofaunal associations. Macrofossils in onlap shellbeds are usually abraded and fragmented. Onlap shellbeds comprising the *Austrovenus* association usually occur above greywacke conglomerate beds of the Matahorua Formation and Tutira Member, although may overlie RST sandstone in the Okauawa Formation. Fauna in onlap shellbeds often display a deepening-upward pattern, with oysters and brachiopods common in upper parts. Where facies are favourable, upper portions of onlap shellbeds may contain significant accumulations of pectinids such as *Phialopecten marwicki* and *P. triphooki.* The onlap shellbed may be separated from a backlap shellbed through a siliciclastic interval termed the shore-connected wedge. In more distal locations the onlap and backlap shellbeds may merge into a single unit termed the "compound shellbed" (see below).

Fig. 6.11 (facing page): Idealised cross-shelf profile and sedimentary sequence illustrating the inferred positions of shellbeds within it. With the exception of the event-concentrated shellbed, all shellbeds are inferred to have developed through some form of sediment starvation. The former type is inferred to have originated as a consequence of storm and wave-induced scour and sediment winnowing. **H**, highstand shoreline; **L**, lowstand shoreline; **X**, limit of lowstand wave-base.


Correlative conformity
Lowstand sea level
"X" basinward limit of wavebase erosion
Correlative conformity
Toplap shellbed
"X" basinward limit of wavebase erosion
Event-concentrated shellbeds
Downlap surface
Compound shellbed
Sequence boundary
Downlap shellbed
Backlap shellbed
Sequence boundary
Shore-connected siliciclastic wedge
Onlap shellbed

The basal surface of an onlap shellbed is abrupt to erosional, and is inferred to represent a transgressive surface of erosion (TSE) and the sequence boundary (Fig. 6.6). Where LST deposits are not represented, a sequence boundary is superimposed on this surface. In nearshore examples, the upper surface is gradational into siltstone of the overlying HST. In more shelfal examples, the upper surface is sharp and may be overlain by siliciclastic sediments of a shore-connected wedge. In more distal settings the onlap shellbed may merge with the backlap shellbed, thereby forming a compound shellbed.

In many cases in the upper Mangaheia Group, onlap shellbeds are strongly cross-stratified with small- to moderate-scale sigmoidal, tabular, and trough cross-beds (e.g. lithofacies BC_3, BC_7). Where the *Austrovenus* association comprises the onlap shellbed, flaser and ripple-bedded siltstone (lithofacies Z_4) and sandstone (lithofacies S_7, S_8) are commonly interbedded with macrofossils. On the basis of macrofossils and interbedded sedimentary facies, onlap shellbeds accumulated at shoreface to inner shelf water depths with a strong influence from wave action and tidal currents.

Backlap shellbed

The term "backlap" was introduced by Kidwell (1991) and refers to the termination of beds at the distal, basinward edge of a retrogradational facies succession (Naish and Kamp 1994, 1997). This occurs during marine transgression. Sediment starvation under "backlap" conditions may produce a backlap shellbed (Fig. 6.11). Backlap shellbeds occur below the downlap surface, and may be overlain by a downlap shellbed. Backlap shellbeds can be differentiated from downlap shellbeds as the matrix sediments in the former are normally bioclastic-dominated as opposed to the siliciclastic-dominated nature typical of the latter. The backlap shellbed is often separated from the onlap shellbed by an interval of shoreline-connected siliciclastic sediment that is usually non- to sparsely fossiliferous. Upper limestone facies of the Waipatiki Formation in the Glengarry Road region can be subdivided into onlap and backlap portions.

Backlap shellbeds are often rich in whole shells, and they contain much less siliciclastic sediment than the onlap shellbed. Epifauna such as oysters, pectinids, and brachiopods are more common in backlap shellbeds than onlap shellbeds. This reflects a combination of factors including: 1) the development of firm-grounds; 2) reduced terrigenous sediment input; and 3) increasing water depth as marine transgression continues. The *Eumarcia* association is common in upper Mangaheia Group backlap shellbeds, particularly those in the Tangoio Limestone Member, Waipatiki Limestone Member, and Kaiwaka Formation.

Table 6.3: Characteristics of shellbed types in Mangaheia Group cyclothemic strata.

Shellbed type	Description	Condensation process	Typical[1] macrofaunal associations	Typical[2] lithofacies	Stratal relationships	Depositional environment	Typical examples
Onlap	Highly fossiliferous, infauna dominated. Typically sharp lower contact. Upper contact abrupt to gradational. Siliciclastic matrix. Rich in shellhash. Disartculated macrofauna are common. Commonly rich in Torlesse pebbles. Typically up to 2 m thick	Sediment bypassing and starvation during transgression. Inferred to form at or above contemporary wave base.	*tw, os-gl, tu, os-pu, au, mc, ph*	BC_3, BC_7	Base of TST. Overlies TSE. Overlain by TST sandstone (shore-connected sediment wedge), backlap shellbed, or downlap surface	Shoreface to inner shelf	Waipatiki Limestone Member, Puketitiri Road (Column Gg-2); Papakiri Member, Huiarangi Road (Column Pt-4)
Backlap	Highly fossiliferous, infaunal to epifaunal benthos. Bioclastic matrix. Articulated macrofauna common. Up to 2 m thick	Sediment starvation during deepening. Form below contemporary wave-base	*eu, os*	BC_3	Base of TST. Overlies TST sandstone (shore-connected sediment wedge). Overlain by downlap surface	Inner- to middle-shelf	Waipatiki Limestone Member, Puketitiri Road (Column Gg-2)
Compound	Highly fossiliferous, epifauna dominated. Bioclastic matrix. Articulated macrofauna common. May have a silty matrix	Sediment starvation during deepening. Forms in offshore environments and comprises elements of both onlap and backlap shellbeds	*eu, os*	BC_3	TST. Overlies TSE. Overlain by downlap surface	Inner- to middle-shelf	Waipatiki Limestone Member, Whirinaki Beach (Column Tg-5)
Downlap	Sparsely- to moderately-fossilifeorus. Siliciclastic matrix dominated. Articulated epifauna common. Macrofauna typically well preserved. Usually up to 0.5 m thick	Sediment starvation in the distal toes of prograding clinoforms. Form below contemporary fair-weather and storm wave-base	*os*	Z_{11}	Base of HST. Overlies downlap surface. Passes gradationally into HST siltstone	Middle- to outer-shelf	Base Te Ngaru Mudstone, Whirinaki Beach (Column Tg-5)
Toplap	Highly fossiliferous, tightly packed. Dominated by Infauna. Up to 5 m thick	Reworking and condensation of shells during multiple events, below fair-weather wave base but above storm wave-base	*cr-sg, tw-cr, tw-sg*	BC_4	Upper parts of RST, usually below lowstand shoreline. Gradational lower contact with RST sandstone. Top truncated by TSE	Inner shelf	Waipatiki Limestone Member, Ngamahanga Station (Column Ok-1)
Event-concentrated	Highly fossiliferous, sharp based, lensoidal. Bivalve dominated, moderately to typically packed, mostly concave down. Sandy matrix, shellhash common	Reworking and redeposition of shells during storm events, winnowing of siliciclastic sediment. Form above contemporary wave base	*do, ze, fe*	S_3, S_9	Upper parts of RST, usually interbedded with sandstone	Inner shelf to shoreface	Darkys Spur Member, Darkys Spur Road (Column Tg-3)
Rapid-burial	Sparsely to moderately fossiliferous, matrix dominated. Infaunal to epifaunal benthos	Episodic burial of *in situ* macrofauna by siliciclastic sediment	*pr, dk, ta, at, os, pt*	S_4, Z_2, Z_3, Z_8	Usually interbedded with HST siltstone and sandy siltstone	Inner- to outer-shelf	Devils Elbow Mudstone Member, Devils Elbow, SH2 (Column Tg-4)

[1] See Table 6.1
[2] See Table 6.2

Compound shellbed

On a sediment-starved shelf basinward of the shoreline siliciclastic wedge, shell material condensed during backlap may become mixed with, or superimposed directly upon, shell material condensed during marine onlap. The result in that the entire TST is represented by condensed deposits (Naish and Kamp 1994). This resulting shellbed is named the compound shellbed (Fig. 6.11). The compound shellbed represents a concentration of bioclastic sediments where the onlap and backlap shellbeds lie in direct contact with each other and are not separated by an interval of siliciclastic sediment (shore-connected wedge). A deepening-upward profile is evident in compound shellbeds from macrofauna, with infauna more common near the base, and epifauna (oysters, pectinids) more common near the top. Upper parts of a backlap shellbed are normally bioclastic-dominated, well cemented, and contain a molluscan macrofauna typical of the *Ostrea* association. Oysters such as *Ostrea chilensis* dominate and are commonly articulated. In beds of Opoitian to Lower Nukumaruan age, backlap shellbeds may contain common pectinids such as *Phialopecten* spp., *Mesopeplum* spp., *Talochlamys gemmulata,* and *Zygochlamys patagonica delicatula,* in addition to the dominant *Ostrea chilensis.* Brachiopods such as *Neothyris* spp., *Tegulorhynchia niagricans,* and *Waltonia inconspicula* are also common. In backlap shellbeds younger than Lower Nukumaruan, *Ostrea* still dominates with common brachiopods (*Neothyris,*

Tegulorhynchia, and *Waltonia*), *Talochlamys,* and rare *Dosina*. Matrix sediments consist of siltstone to sandy siltstone. The upper surface is abrupt with the overlying downlap shellbed.

Downlap shellbed

Condensed deposits associated with downlap (Fig. 6.11) occur within the distal, basinward portion of progradational siliciclastic sediments of the highstand systems tract (Naish 1996; Naish and Kamp 1997). The downlap shellbed overlies the downlap surface and, where it has developed, a compound shellbed (Fig. 6.11). Because the downlap shellbed is matrix-dominated, it is usually readily distinguished from backlap shellbeds. Molluscan macrofauna are typical of the *Ostrea* association (e.g. base Te Ngaru Mudstone Member at Whirinaki Beach, column Tg-5). Macrofauna in downlap shellbeds are sparsely packed, are often articulated, well-preserved, and show little abrasion. Some encrustation by serpulids and bryozoans may be present.

The downlap shellbed is siliciclastic sediment-dominated, with oyster and pectinid fossils. They commonly occur on top of transgressive limestone beds in the Petane and Mason Ridge Formations, are faunally dominated by the *Ostrea* association, and are normally 0.1-0.5 m thick.

Toplap shellbed

Toplap shellbeds (Fig. 6.11) develop in response to sediment starvation, due most probably to siliciclastic sediment bypass. They occur in RSTs and should not be confused with event concentrated shellbeds that may occupy the same stratal position (see below). Toplap shellbeds are restricted to the western (shoreward) margin of RSTs in the Waipatiki Limestone Member, reflecting a nearshore to innermost-shelf environment of deposition. Siliciclastic sediment in toplap shellbeds is usually restricted to granule to fine pebble-sized, well sorted, and well rounded clasts of greywacke. The base of the toplap shellbed is usually gradational with an underlying siliciclastic sandstone. The top surface is usually sharp and represents a TSE produced through wave-planation during a subsequent marine transgression.

The mechanism of condensation is inferred to be winnowing resulting from wave-base action on the sea floor. The *Crepidula-Sigapatella* and *Tawera-Crepidula* associations are inferred to have developed due to the processes that produce toplap shellbeds, and are common in the Waipatiki Limestone Member in many areas. The macrofauna in these associations have been winnowed and concentrated due to the influence of storm wave-base on the sea floor, and the removal of siliciclastic sediments. These toplap shellbeds are normally up to 5 m thick.

Other shellbed types

Event concentrated shellbeds

Although they may theoretically occupy any stratal position in a sequence, event concentrated shellbeds in the study area are almost entirely restricted to upper parts of shallow-water RST sandstone deposits (Fig. 6.11). While event concentrated shellbeds occupy the same stratal position as toplap shellbeds, the mechanism that produced them is different. Event concentrated shellbeds are products of single, discrete sedimentation events, such as storms, whereas toplap shellbeds are produced through sediment starvation and stratigraphic condensation (Hendy *et al.* 2006). Concentration of macrofauna in event concentrated shellbeds is probably due to the winnowing effects of wave and bottom-floor currents during storm events. The presence of these shellbeds interbedded in typically thick (>20 m) nearshore sandstone facies illustrates that sediment starvation is not occurring.

Macrofauna of the *Dosinia, Zethalia,* and *Fellaster* associations are most commonly represented in event concentrated shellbeds in the study area. These shellbeds are most often observed in upper parts of the Pohue Formation and in the Matahorua Formation, although they occur throughout the study area, typically in shallow-water, nearshore sandstone facies. Event concentrated shellbeds have sharp, scoured bases, and usually abrupt tops. They are normally interbedded with very well sorted, clean, non cemented siliciclastic sandstone. Molluscs in them are mostly bivalve-dominated, with shells moderately to tightly packed, disarticulated and concave-down. Intact valves are common, as is shellhash. The individual shellbeds are typically 0.1-0.5 m thick, and lenses may be up to 1.5 m across. The base of event concentrated shellbeds represent scours induced by strong bottom-floor currents, probably due to storm wave events. These shellbeds are inferred to have accumulated at shoreface to innermost-shelf water depths (0-20 m) during regressive sea level conditions.

Rapid-burial shellbeds

Rapid-burial shellbeds were described by Hendy (2002) in Late Miocene-Early Pliocene Matemateaonga Formation in Wanganui and Taranaki Basins. Rapid-burial shellbeds are restricted to finer-grained siltstone to silty sandstone facies in highstand and to a lesser degree regressive systems tracts. Typical fauna in these shellbed types include the *Pratulum, Atrina, Dosinia (Kereia), Talochlamys, Neilo,* and *Patro* associations.

Rapid-burial shellbeds are typically dispersed throughout the systems tract, and are not concentrated in any one area. Based on their macrofaunal content, rapid-burial shellbeds

accumulated at lower-inner to outer shelf water depths in environments with a high siliciclastic sediment input.

SEQUENCE MOTIFS

This study has defined eight basic architectural forms, or "motifs", of sequences for the shelfal sedimentary succession in western and central Hawke's Bay (Fig. 6.12). While these motifs share some similar characteristics, unique combinations of subsidence, sediment flux, and sediment provenance have combined to produce each distinctive motif. Lateral transitions do occur between several of these motifs, and by linking surfaces in them an idealised "shoreline to slope" sequence model can be produced for the Nukumaruan part of the basin succession.

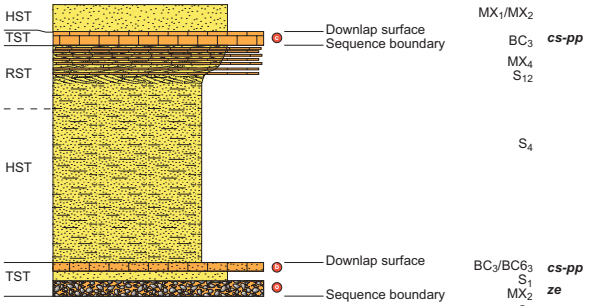
Naumai motif

Although sea level was rhythmically rising and falling during the Opoitian and Waipipian (as demonstrated by Kamp *et al.* 2002, 2004; Vonk *et al.* 2002), cyclothems are difficult to identify in rocks of this age in the study area, such as the Titiokura Formation (Bland *et al.* 2004). This is possibly due to a highly-complicated paleogeography during this time in western and northern parts of Hawke's Bay, lithofacies unsuitable for the formation of sequences on the shelf, and poor preservation of rocks of Opoitian-Waipipian age in western parts of the study area. Sequences have been documented in correlative beds in eastern parts of the Hawke's Bay region in the Kairakau, Awapapa, and Rotookiwa Limestones by Caron *et al.* (2003, 2004b). In the current study area, Graafhuis (2001) attempted to model sequences he identified in the northern Maungaharuru Range area in the Titiokura Formation. The Naumai motif is derived from this succession.

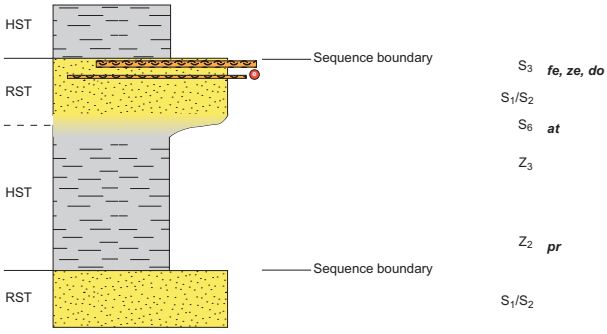
The basal sequence boundary of the Naumai motif (Fig. 6.12) is inferred to be a TSE which truncates underlying limestone facies. Above the TST is typically an interval of variably fossiliferous pebbly limestone, inferred to represent an onlap shellbed. Macrofossils are generally uncommon although shellhash is abundant in the matrix among the pebble- to cobble-sized clasts. The gravel clasts are variable in composition, and although they are greywacke-dominated, mudstone, sandstone, and pumice are locally common. The pebbly bed is overlain by a thin (<0.5 m) sandstone bed which is in turn overlain by a mixed bioclastic-siliciclastic backlap shellbed. The top of the backlap shellbed is marked by a downlap surface, overlying which is a downlap shell bed < 0.2 m thick (usually of the *Ostrea* association).

Fig. 6.12 (facing page): Sequence motifs defined for the Mangaheia Group in the study area. Each motif represents a repetitive pattern of lithofacies stacking observed in the field reflecting differing influences of basin subsidence, sediment flux, and rate of sea-level change across a paleoshelf. Typical lithofacies and macrofossil associations related to each motif are indicated. Lithofacies codes are defined in Table 6.1, macrofaunal association codes are defined in Table 6.2.

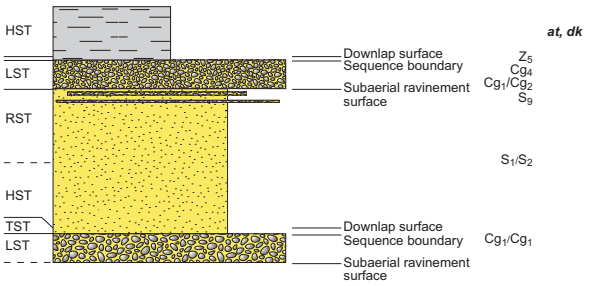
Naumai Motif
Example: Te Rangi Member, Naumai Station



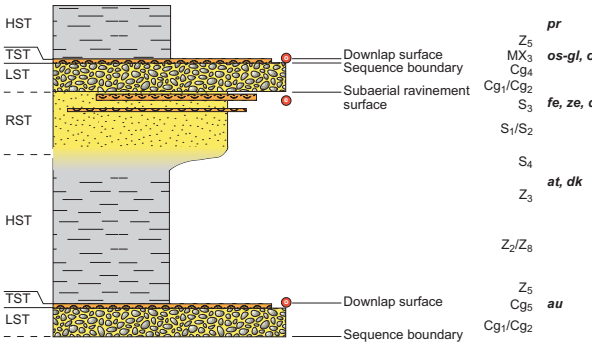
Pohue Motif
Example: Pohue Formation, upper Mangaone River



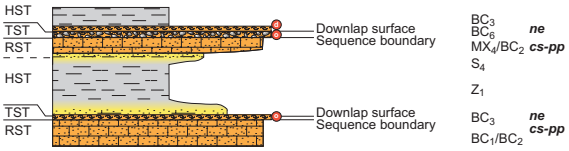
Trelinnoe Motif
Example:Trelinnoe Member, Esk River



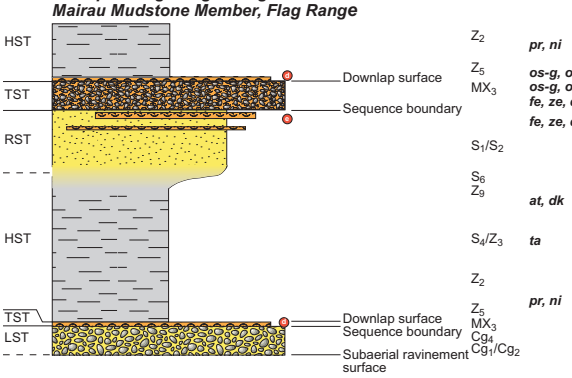
Matahorua Motif
Example: Papakiri Member, Esk River



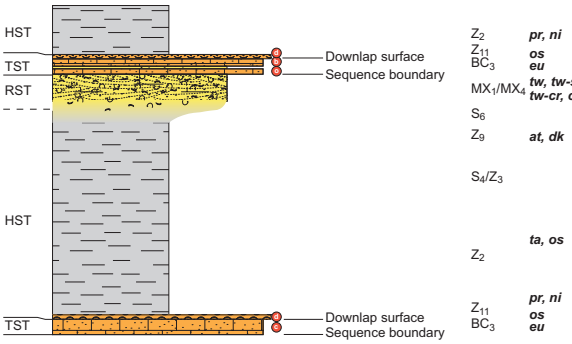
Patoka Motif
Example: Te Waka Formation, Wai-iti Stream



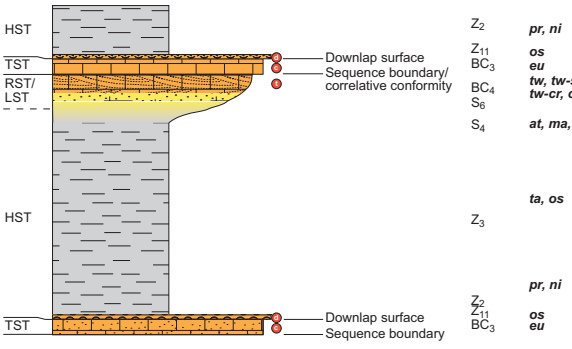
Kikowhero Motif
Example: Flag Range Conglomerate Member & Mairau Mudstone Member, Flag Range

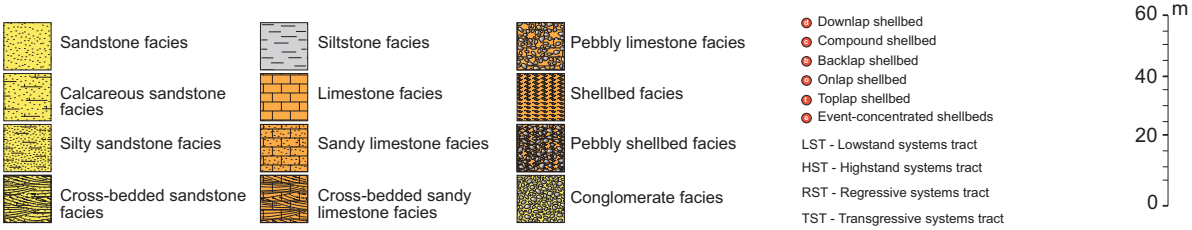


Tangoio Motif
Example: Waipatiki Limestone Member & Te Ngaru Mudstone Member, Waipunga Road



Waipatiki Motif
Example: Waipatiki Limestone Member & Te Ngaru Mudstone Member, Matapiro district





The downlap shellbed is abruptly overlain by silty sandstone, often containing well-developed and preserved sedimentary structures such as tabular and sigmoidal cross-bedding, convolute bedding, and burrows. In upper parts of the sandy siltstone the bioclastic content increases and alternating bioclastic-siliciclastic beds occur. These beds are commonly decimetre- to metre-scale cross-stratified. No boundary between the HST and RST can be identified in the field and its position is inferred. The interbedded interval is sharply overlain by the onlap shellbed of the subsequent sequence. The sharp surface is inferred to be a TSE and occupies the sequence boundary.

Patoka motif

Although the Patoka motif (Fig. 6.12) contains elements of the Matahorua, Kikowhero and Tangoio motifs, it is restricted in outcrop to the Te Waka Formation in western parts of the study area near the axial ranges. The Patoka motif has only been observed in rocks of Mangapanian age.

The base of the sequence is represented by a very pebbly limestone which is assigned to the TST. The base of the pebbly limestone is the sequence boundary, and is inferred to be a TSE produced by wave-scour during marine transgression. The TST is sparsely to moderately fossiliferous with occasional disarticulated oyster and *Phialopecten* valves. The TST is gradationally to abruptly overlain by sandy siltstone of the HST. Macrofauna are very uncommon in this interval which coarsens upsection into bioclastic-dominated beds. These beds comprise stacked units about 0.3 m thick and represent the RST. It is inferred that no lowstand deposits are recorded in this motif, although the greywacke clasts in the TST are probably derived from erosion and reworking of non-marine gravels deposited during lowstand conditions.

Pohue motif

The Pohue motif is similar to Nukumaruan sequences described by Naish and Kamp (1997) in the Rangitikei River section in Wanganui Basin, although it differs in having a much lower macrofossil content. It is easily distinguished from other associations in the study area as it lacks limestone and conglomerate lithofacies, and is instead represented by variably fossiliferous siltstone and sandstone facies. This motif has only been observed in the Mangapanian Pohue Formation.

The sequence boundary is normally very difficult to accurately locate because in this motif siliciclastic sandstone is overlain by siliciclastic siltstone. There are no limestone or conglomerate beds to obviously separate sequences. In the upper Mangaone River, fine to medium sandstone is sharply overlain by siltstone. This contact is inferred to be a sequence boundary. No obvious TST shellbeds are present in this motif. The siltstone bed is variably fossiliferous with the deepest

water paleoenvironments present in lowermost parts. The siltstone coarsens upsection, passing gradationally into fine sandstone. The sandstone also coarsens slightly upsection, and is mostly non fossiliferous. In uppermost parts, highly fossiliferous event-concentrated shellbeds of the *Zethalia* and *Dosinia* associations are present. This sandstone is in turn sharply overlain by siltstone of the subsequent sequence. No HST-RST boundary can be identified in the field and its position in the motif is inferred

Trelinnoe motif

The Trelinnoe motif (Fig. 6.12) represents the landward edge of a depositional sequence. No clearly identifiable TST deposits are evident, which presumably reflects the strongly landward, sediment-saturated environment of deposition of this motif. The upper sequence boundary is at the top of the non-marine greywacke conglomerate at the top of the sequence. A channelised surface that often displays centimetre to decimetre-scale relief is clearly evident as a continuous, erosional surface at the base of the conglomerate. Clasts derived from the underlying sandstone bed are frequently incorporated into the basal parts of these non-marine conglomerates and presumably reflect incision and erosion during progradation of a fluvial braid-plain during sea level fall.

The base of the conglomerate bed represents the top of a coastal plain to shoreface environment. The top of the conglomerate is overlain by siliciclastic sandstone, and no shellbed is present. Identification of the TST is difficult as facies typical of this systems tract, such as shellbeds, are not present.

Matahorua motif

This motif (Fig. 6.12) is common within formations of the upper Mangaheia Group and crops out widely in the study area in the Matahorua and Okauawa Formations. It also occurs sporadically in the Petane and Kaiwaka Formations. This motif is distinct from others described in this study due to the presence of thick non-marine conglomerate deposits, reflecting sedimentation over innermost shelf to shoreface to estuarine facies.

A channelised surface is placed at the base of the lowstand systems tract (LST) which comprises a non-marine greywacke conglomerate, 2-15 m thick. The LST is overlain by a pebbly shellbed to fossiliferous conglomerate, 0.3-3 m thick, across a transgressive surface of erosion (TSE). These pebbly onlap shellbeds are assigned to the TST and record a return to marine deposition during rapid sea level rise. The thickest such shellbeds occur in the Crownthorpe and Sherenden areas. These areas presumably mark accumulation near the lowstand shoreline. It is more

common, however, for the TSTs in this motif to be less than 0.5 m thick, as observed throughout the Te Pohue and Patoka areas. Macrofauna may comprise any of the *Austrovenus, Tucetona, Maoricolpus, Ostrea-Purpurocardia,* or *Ostrea*-glycymerid faunal associations. The different associations present reflect different subenvironments on the paleoshelf, though all are between estuarine to inner shelf water depths. The TST passes gradationally over 0.1-0.6 m into the siltstone of the overlying HST through a pebbly siltstone interval. The pebbles, reworked from the underlying TST, rapidly become smaller in size upwards and less common. The final transition from pebbly siltstone to siltstone is inferred to mark the top of the TST and the downlap surface. The HST siltstone is massive to weakly laminated, non to moderately fossiliferous, and occasionally contains tephric intervals from 0.05-1.5 m thick. The HST varies in thickness from 5-60 m. The HST coarsens upsection, and grades into the overlying sandy RST. In almost all cases no RSE is present and hence the overlying sandstone is assigned to an RST rather than a FRST. In Rautoitoi Stream regressive sandstone of the Tutira Formation sharply overlies HST mudstone of the Esk Mudstone. This sharp surface is inferred to be an example of an RSE and the sandstone is therefore assigned in this case to a FRST. The position of a non-marine conglomerate bed several metres above the base of the sandstone strongly suggests the sharp surface is an RSE and not a TSE. This example is the only case of an FRST identified in the any motif.

Kikowhero motif

The Kikowhero motif (Fig. 6.12) links the non-marine conglomerate lithofacies of the Trelinnoe and Matahorua motifs with the limestone lithofacies in the Tangoio and Waipatiki motifs. The fossiliferous conglomerate bed that characterises the Kikowhero motif is inferred to represent the approximate position of the lowstand shoreline. The Kikowhero motif is usually represented by the Mairau Mudstone and Flag Range Conglomerate Members (Petane Formation), although is also present in rare occasions in the upper Matahorua Formation. This motif can be distinguished from the lithologically similar Matahorua motif as it contains no obvious non-marine lithofacies. All conglomerate lithofacies in it are 2-5 m thick, variably fossiliferous, are sharp based, and overlie fine to medium sandstone. The sharp base is inferred to be a transgressive surface of erosion. The conglomerate therefore represents deposition at or immediately basinward of the lowstand shoreline. Beach, nearshore, and harbour paleoenvironments can all be identified, and a number of faunal associations are present, including the *Ostrea*-glycymerid, *Maoricolpus, Paphies, Ostrea-Purpurocardia,* and *Tucetona* associations. In a direction shoreward of the lowstand shoreline, where non-marine conglomerate deposits are present, the TSE is inferred to overstep the LST beds (Matahorua motif).

The fossiliferous conglomerate grades over 0.5 m through a pebbly siltstone into variably fossiliferous siltstone of an inferred middle shelf depositional environment. The top of the pebbly siltstone interval is taken as the top of the TST and therefore the approximate position of the downlap surface. No downlap shellbed is present in this motif. The siltstone coarsens upsection into fine to medium sandstone. No surface occurs to separate the HST from the RST, and its position in the motif is inferred. The sandstone may contain macrofauna of the *Dosinia* and *Zethalia* associations, and has an inferred shoreface to nearshore environment of deposition. The sandstone is sharply overlain by a TSE, marking the top of the sequence.

Waipatiki motif

This sequence motif (Fig. 6.12) is inferred to have formed at a location on the shelf near or below lowstand wave-base. The basal TST is characterised by shelly limestone, which is relatively siliciclastic-poor in comparison with other sequence motifs. The top of the TST is marked by a downlap surface, which is in turn overlain by a downlap shellbed. This shellbed is siliciclastic-dominated, with macrofauna of the *Ostrea* association. The downlap shellbed passes rapidly into siltstone of the HST. Macrofauna in the lower parts of this siltstone are typical of the *Neilo* and *Pratulum* associations, representing deposition at outer shelf water depths (~100-150 m). The siltstone coarsens upsection, reflecting falling sea level, and passes conformably into fine sandstone. The shallowing upsection is also recorded in changes in the macrofaunal associations through the sequence. The fine sandstone becomes increasingly bioclastic-rich upsection, and passes gradationally into a coarse-grained shelly limestone inferred to represent a toplap shellbed. Macrofauna in this shellbed are dominated by the *Tawera* and *Crepidula-Sigapatella* associations. The upper surface of the toplap shellbed may be marked by a sharp surface, inferred to be produced by wave-base scour. The sequence boundary is placed at this surface. In situations where deposition is inferred to have occurred below lowstand wave-base, no sharp surface is present, and a correlative conformity is inferred. In these cases RST and LST limestone beds are conformably overlain by transgressive (TST) limestone. A lithofacies change is still recorded however, with typically cross-bedded, coarse-grained shellhash-dominated RST and LST limestone beds overlain by a more massive limestone TST containing more common intact bivalves, and macrofauna of the *Eumarcia* and *Ostrea*-glycymerid associations.

Tangoio motif

The Tangoio motif (Fig. 6.12) shares characteristics with Wanganui style cyclothems documented by Naish and Kamp (1997) and Kamp and McIntyre (1998). The basal sequence boundary is represented by a TSE, above which lies an onlap shellbed comprising a coarse-grained shellhash-dominated limestone bed, often containing scattered pebbles of greywacke. Siliciclastic sand is

also noticeable in the shellbed. Biomoulds are common, and macrofauna are normally part of the *Eumarcia* or *Tawera* associations. The onlap shellbed is in turn overlain by a thin (0.1-0.5 m thick) backlap shellbed. Macrofauna in this shellbed are typically more intact than in the underlying onlap shellbed, and siliciclastic sediment is virtually absent. Macrofauna are typical of the *Eumarcia* and *Ostrea*-glycymerid associations. The top of the backlap shellbed is marked by a downlap surface, above which may be a matrix-supported downlap shellbed (0.1-0.5 m thick). This shellbed will normally comprise both articulated and disarticulated valves of the *Ostrea* association.

The downlap shellbed passes gradationally into variably fossiliferous siltstone, inferred to represent the HST. The deepest depositional paleoenvironments occur in lowermost parts of the siltstone, shallowing upsection. The siltstone interval passes gradationally into several metres of fine sandstone. An increase in bioclastic content occurs upsection with the fine sandstone passing gradationally into 5-10 m of cross-stratified shellhash limestone, or alternating bioclastic-siliciclastic-dominated beds from 0.1-0.3 m thick. Macrofauna are typical of the *Tawera* and *Crepidula-Sigapatella* associations. A high siliciclastic content is normally present in the bioclastic interval. The top of the bioclastic interval is marked by a sharp erosional surface that may display decimetre-scale relief. This surface is inferred to be a TSE and is the upper sequence boundary.

DEVELOPMENT OF A MODEL SEQUENCE

Introduction

The eight "sequence motifs" (Fig. 6.12) described in this study are inferred to represent outcrop windows of different positions across a paleoshelf. Not all of a sequence is preserved in the rock record due to the effects of differential uplift and erosion. In these cases, to produce an idealised sequence model (Fig. 6.13), correlating between the outcrop windows helps to better understand the character of a sequence across the shelf. Outcrop windows in the study area extend from positions near the highstand shoreline (e.g. the Trelinnoe motif), to positions below the lowstand shoreline (e.g. the Waipatiki motif). The most basinward parts remain in subcrop and are therefore not accessible in the field. By developing an idealised sequence model for the study area it is possible for outcrops described in isolation to be placed at some position on a paleoshelf.

The model sequence developed in this study for Plio-Pleistocene cyclothems in Hawke's Bay is shown in Fig 6.13. This model has been derived from examples of Hawke's Bay sequences, and the motifs described during this study. Figure 6.14 illustrates the inferred distribution of lithofacies and macrofaunal associations in a model sequence.

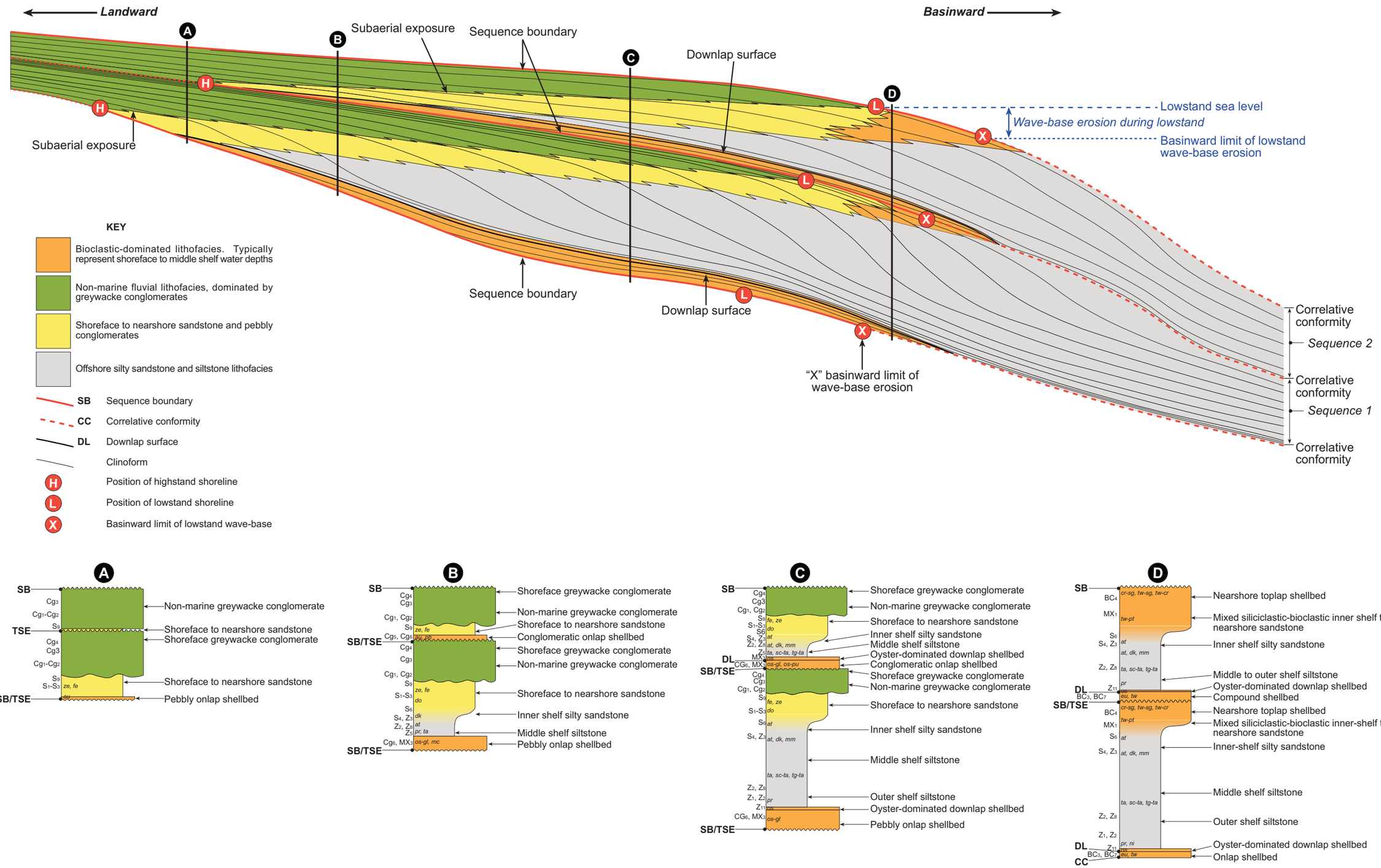


Fig. 6.13: Model sequences for Nukumaruan (Late Pliocene) rocks in Hawke's Bay. Note the aggradational stacking pattern of the sequences in this model. The stick columns indicate the inferred outcrop pattern of rocks at different positions across the paleoshelf. These columns also illustrate the slightly progradational stacking pattern in this model. Typical lithofacies and macrofossil assocations are indicated by codes on each column, and are defined in Table 6.1 and 6.2. This model is based in part on those of McIntyre (2001) and Naish *et al.* (2005).

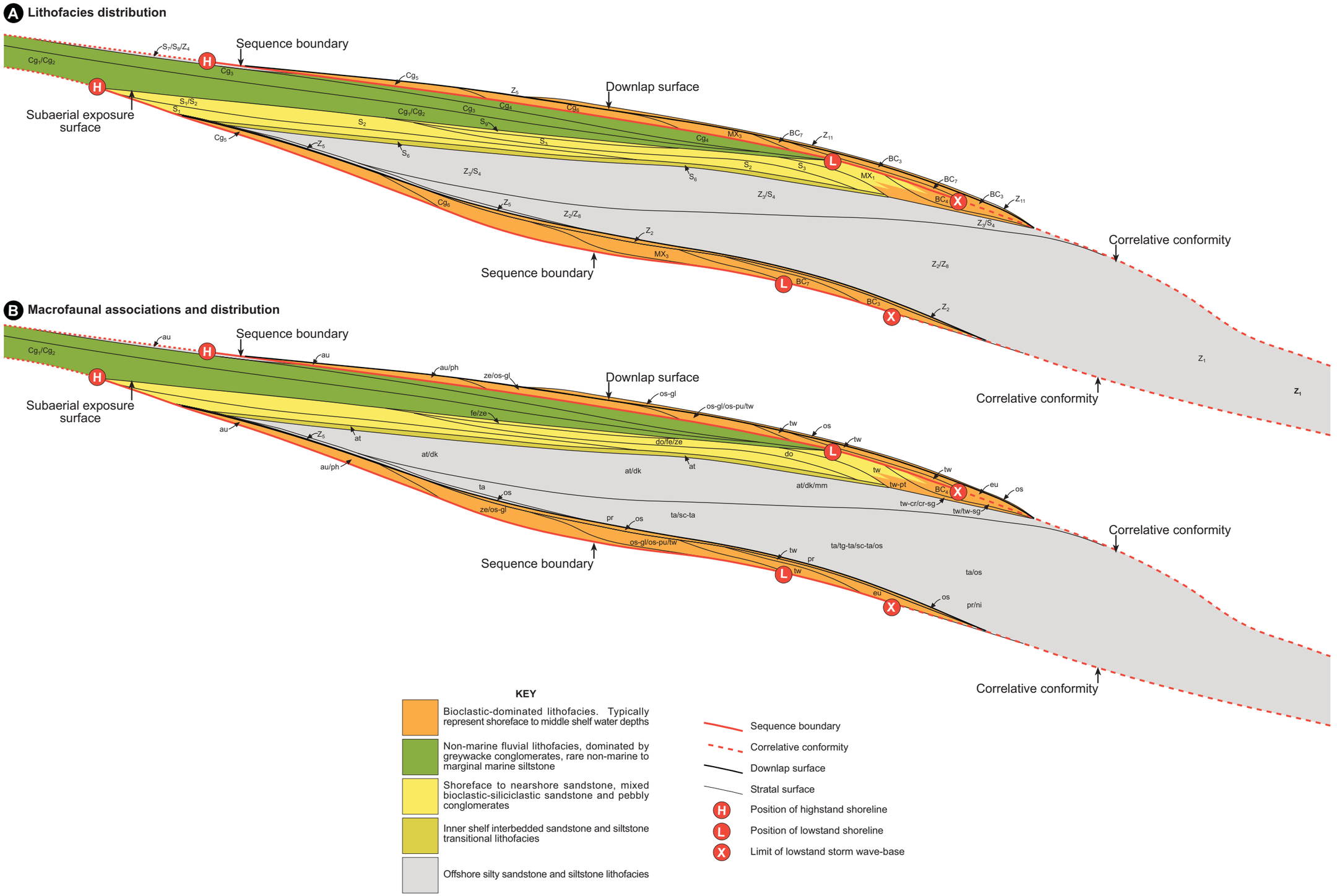


Fig. 6.14: Depositional architecture for an idealised sequence in upper parts of the Mangahiea Group, illustrating the inferred distribution of lithofacies (upper sequence, A) and macrofaunal associations (lower sequence, B). Lithofacies codes are described in Table 6.1. Macrofaunal association codes are described in Table 6.2.

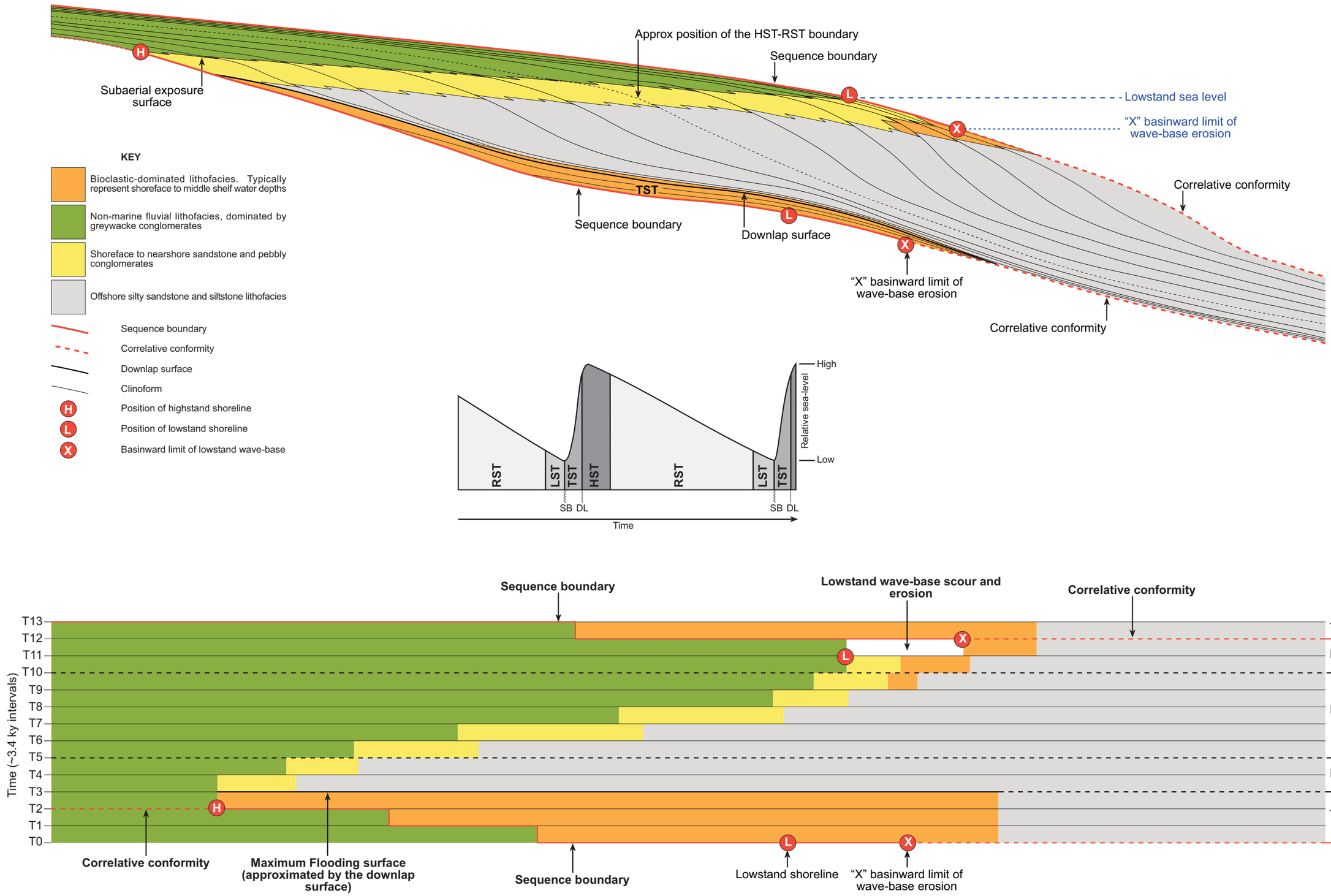


Fig. 6.15: Generic model sequence for Nukumaruan (Late Pliocene) rocks in Hawke's Bay, with expected lithofacies in their relative basinward position. This diagram is based on that of McIntyre (2001, p.289).

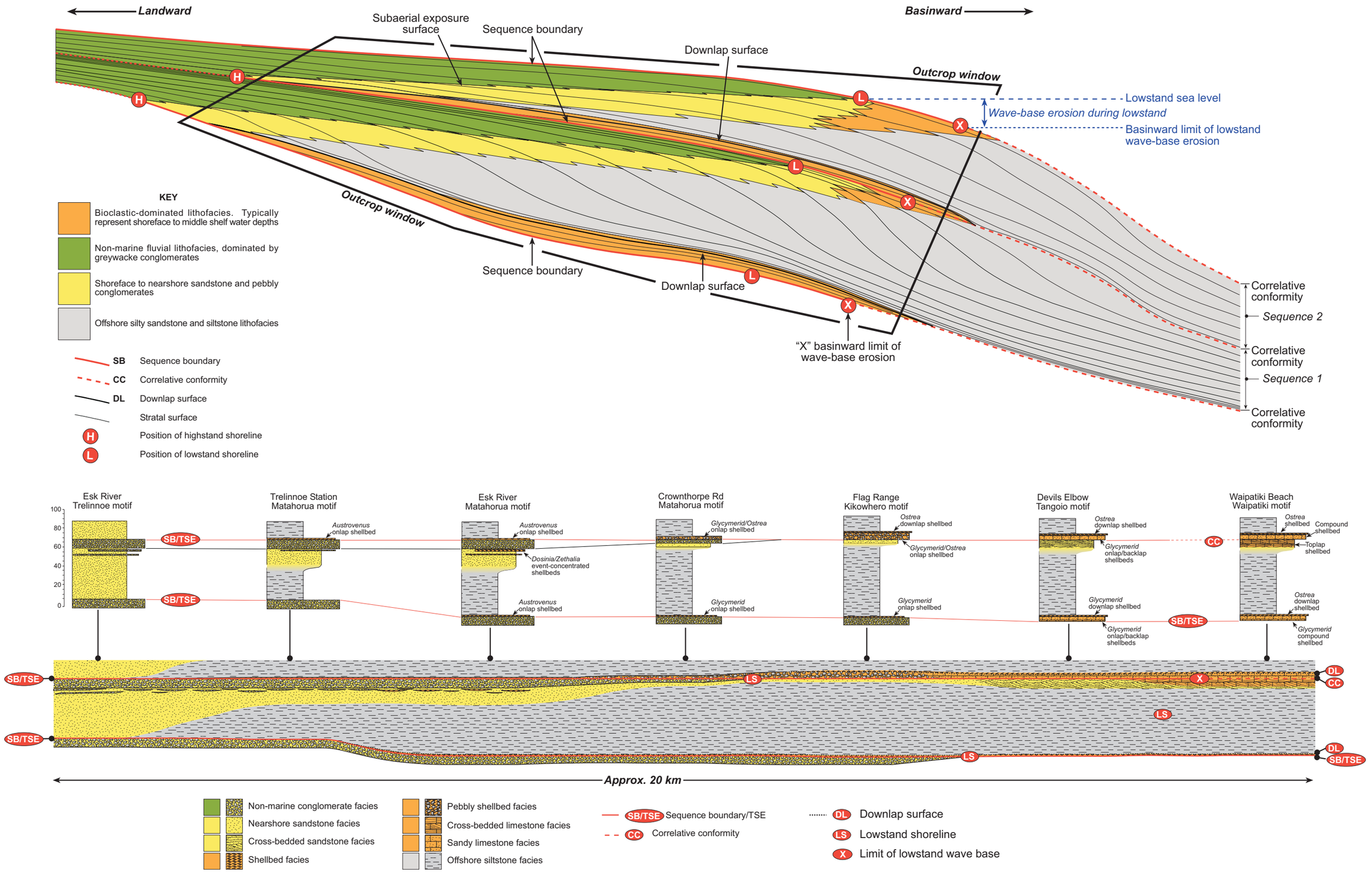


Fig. 6.16: Correlation of motifs for a model sequence (Nukuamaruan deposits). The upper diagram shows the general facies/depositional environment distribution within a model sequence.

The conceptual diagram in Fig. 6.15 attempts to break the model sequence down into equal time slices, thereby showing how different depositional environments were occurring at different positions across the paleoshelf at different points in time. The outcrop window preserved in the study area does not contain the entire extent in a single sequence, as depicted in the models of Fig. 6.13-6.15. The idealised outcrop window across a sequence, produced from the correlation of sequence motifs from the inferred landward to basinward edges of the paleoshelf, is shown in Fig. 6.16. A series of conceptual block diagrams illustrating a cross-shelf profile during the formation of an idealised Hawke's Bay Nukumaruan cyclothem sequence is depicted in Fig. 6.17.

Overview of formation of a model sequence

Transgressive Systems Tract (TST)

Where the shoreline moves landwards over LST conglomerate facies during transgression, pebbly shellbeds are produced. These are thickest towards the lowstand shoreline, and thin toward the highstand shoreline. Immediately basinward of the lowstand shoreline, TST deposits comprise moderately- to highly fossiliferous pebbly shellbeds. In a basinward direction these shellbeds become progressively less pebbly and pass into bioclastic TSTs. The base of TSTs basinward of the lowstand shoreline and above "point X" is sharp, reflecting the influence of wave-base and current scour during the lowstand. The increase in eustatic sea level during a transgression is inferred to allow TST development in two main ways. First, the increased water depth raises the level of wave-base, meaning that scour and removal of sediment becomes less common, resulting in net sediment accumulation. Second, during regressive and lowstand phases a high siliciclastic sediment flux is inferred, acting to limit bioclastic carbonate production. During a transgression, siliciclastic sediment typically becomes tied-up in a backstepping shore-connected wedge. This means that a more favourable environment for shellbed-forming biota is created. Adding to this, a reduction in sediment generation is likely as revegetation occurs in the basin hinterland, reflecting warming conditions out of the previous glaciation.

LST deposits that form shoreward of the lowstand shoreline appear to often be gradationally based, although some sharp surfaces may be preserved in places. The gradational base is inferred to reflect wave-induced reworking of the underlying non fossiliferous conglomerate beds into lower parts of the TST pebbly shellbeds. Macrofauna in these shellbeds are robust epifauna and semi-infauna such as glycymerids (e.g. *Tucetona, Glycymeris*), *Maoricolpus,* oysters, and pectinids.

TST deposits basinward of the lowstand shoreline may comprise two parts (onlap and backlap shellbeds; Fig. 6.11, Table 6.3), often separated by sandstone facies of the shore-connected

wedge. Shellhash is common in the lower parts of TST, reflecting a high energy environment during early transgression with wave-scour and sometimes strong bottom tidal currents. Macrofauna are often dominated by nearshore taxa such as *Tawera* and *Zethalia.* Siliciclastic sediment comprises a moderate part of the TST. The upper part of the TST is typically characterised by a greater percentage of intact shells, less siliciclastic sediment, and taxa such as *Ostrea* and *Phialopecten*, more indicative of slightly deeper water depths. The lower siliciclastic content results from siliciclastic sediment starvation.

The very top of the TST accumulates near the point of maximum sea level during a sequence, especially for 41 k.y. cycles. Siliciclastic sediment starvation across the shelf is high because revegetation reduces its flux, and because it tends to be trapped in retrogradational shore-connected wedges in the nearshore setting. This starvation often leads to the development of thin (0.1-0.5 m thick) oyster-dominated shellbeds in the uppermost parts of the TST, particularly in backlap and compound shellbeds. These oyster-shellbeds overlie the backlap shellbed part of the TST, and are typically present in TSTs that have formed basinward of the lowstand shoreline where water depths are greater, and the distance from a siliciclastic sediment source is larger.

Highstand Systems Tract (HST)

The TST is usually overlain by a HST, which in outcrop is normally inferred to be represented by sparsely to moderately fossiliferous siltstone. The two systems tracts can be separated by the downlap surface. Its position in a sequence is inferred from the observation of a downlap shellbed which overlies the downlap surface. The HST represents the late rise, stillstand, and early fall of a sea-level cycle. In most positions landward of the lowstand shoreline the HST commonly overlies 0.5 m of siltstone containing significant amounts of very well sorted, very well rounded fine greywacke granules and pebbles that have been reworked from the underlying TST. In areas near the highstand shoreline, such as those typified by the Trelinnoe motif, the HST comprises fine to medium sandstone. The reason for this is that even during sea level highstand, water depths are never deep enough for silt to be deposited. This setting limits the accommodation space and sediment accumulation is always proximal to a shoreline.

Regressive Systems Tract (RST)

The change from highstand to regressive deposition is recorded by a change from retrogradational to progradational sedimentation. In shoreward settings the fall of sea level reduces accommodation space and, coupled with typically high siliciclastic sediment input, effectively forces nearshore and shoreline facies basinward. In the most shoreward of positions HST sandstone facies are effectively overlain by RST sandstone facies (Trelinnoe motif). In more

basinward directions (e.g. Matahorua motif) HST siltstone facies are overlain by RST sandstone. The relatively thin sandstone facies in the Tangoio and Waipatiki motifs may reflect their more basinward positions on the paleoshelf, in contrast to the thicker sandstones in the more shoreward Matahorua and Kikowhero motifs. Even as the nearshore sand belt progrades basinward during sea level fall, driven by the reduction in accommodation space, basinward parts of the shelf near the lowstand shoreline will still be undergoing siltstone deposition (e.g. the Tangoio and Waipatiki motifs). The HST-RST boundary in a time sense will therefore pass through lithofacies. In a lithological sense the transition between HST and RST deposits appears to be commonly marked by several metres of alternating siltstone-sandstone beds, each about 0.05-0.3 m thick. The appearance of sandstone beds reflects shoreline migration in response to falling sea level and the progressive basinward shift of these facies aided by storm emplacement. Eventually, sea level falls to a point where sandstone deposition dominates over siltstone. Because in almost all cases no RSE is present, the positioning of the HST-RST boundary is difficult to place; in this study it is conveniently placed about mid-way between the main “typical” HST siltstone and “typical” RST sandstone beds. Upper beds in RST sandstone deposits commonly contain highly fossiliferous event-concentrated shellbeds (Fig. 6.11, Table 6.3) reflecting the increased influence of wave scour and sediment winnowing as sea level falls. In some basinward positions below the lowstand shoreline (Tangoio motif) sediment starvation caused by wave-base winnowing may produce the highly fossiliferous toplap shellbeds (Fig. 6.11, Table 6.3) present in lower parts of the Tangoio and Waipatiki Limestone Members. As sea level continues to fall, an influx of greywacke conglomerate lenses and stringers occurs. This is inferred to record flood-events supplying greywacke bedload from river mouths into the nearshore environment, and the progradation of the non-marine fluvial deposits across a progressively more exposed continental shelf.

Lowstand Systems Tract (LST)

Eventually, as a result of eustatic sea level fall and sediment progradation, relative sea level falls to such a point that the continental shelf becomes exposed and a fluvial braid-plain progrades across it with net sediment aggradation. Thick non-marine greywacke conglomerate beds are deposited on the now exposed continental shelf. Narrow belts of marginal-marine and beach conglomerates are deposited, but they are not inferred to extend too far from the shoreline, perhaps only to water depths of less than 20 m. The low-gradient of the continental shelf, coupled with the high bedload of the river systems, mean that fluvial aggradation occurs. This occurs because high-energy river systems, on leaving the basement hinterland, emerge onto a region of greatly reduced gradient and are forced to drop their sediment load. This process currently occurs on the Canterbury Plains of the South Island, and to a lesser degree in the Ruataniwha and Heretaunga Plains of modern Hawke’s Bay. Estuaries and small harbours develop on the

seaward fringe of such a braidplain system, reflected in the abrupt facies changes that may be observed between outcrops in LST deposits.

Fluvial processes of channel cutting and filling associated with the braidplain, particularly in the early stages, may produce an erosion "surface" of sorts. However, this is just a local feature and cannot be regarded as a fundamental element in any model. The preference in this study is, where non-marine deposits are present, that the sequence boundary is placed at the *top* of the non-marine conglomerate. During sea level fall in landward position non-marine deposits will be accumulating while further out on the shelf marine sandstone and siltstone will be deposited. With subsequent sea level fall the basinward progradation of the non-marine lithofacies belt occurs, with non-marine deposits overlying sediments deposited previously in a marine setting. Even though the sharp base present at the base of the non-marine beds can be traced in outcrop, the surface is diachronous across the shelf. The key inference from this is that in this sequence model during almost all of the HST, RST, and LST, non-marine deposits will be accumulating at some location on the paleoshelf and coastal plain. This means that the surface at the base of the non-marine beds cannot be used as a systems tract boundary, and certainly not as a sequence boundary as it strongly cuts through time planes (Fig. 6.6, 6.13). The position where the time-plane linkages "breaks down" is at the top of the non-marine beds where a return to marine deposition occurs and is recorded by the presence of a TSE (Fig. 6.6, 6.13). This surface illustrates that the marine beds overlying the non-marine lithofacies below cannot be "linked" to the siltstone-sandstone-conglomerate succession below, and is therefore part of another phase of deposition, and therefore belongs to a distinct sequence.

The Kikowhero, Tangoio, and Waipatiki motifs are inferred to have in part accumulated in positions below the lowstand shoreline (e.g. Haywick 2000). Therefore they are likely to have been influenced by wave-base erosion and winnowing during lowstand time. The exception to this is in some expressions of the Waipatiki motif. Part of the limestone package in upper parts of this motif is inferred to represent sedimentation below lowstand wave-base erosion (Haywick 2000), referred to as point "X" by McIntyre (2002). No erosional surfaces can be observed within these limestones and continuous sedimentation during lowstand time is inferred. A change in the character of the limestone package in this situation can be used to indicate a return to the TST, and therefore the base of the subsequent sequence. As no erosional surfaces separate the two sequences, the boundary between them is represented by a correlative conformity.

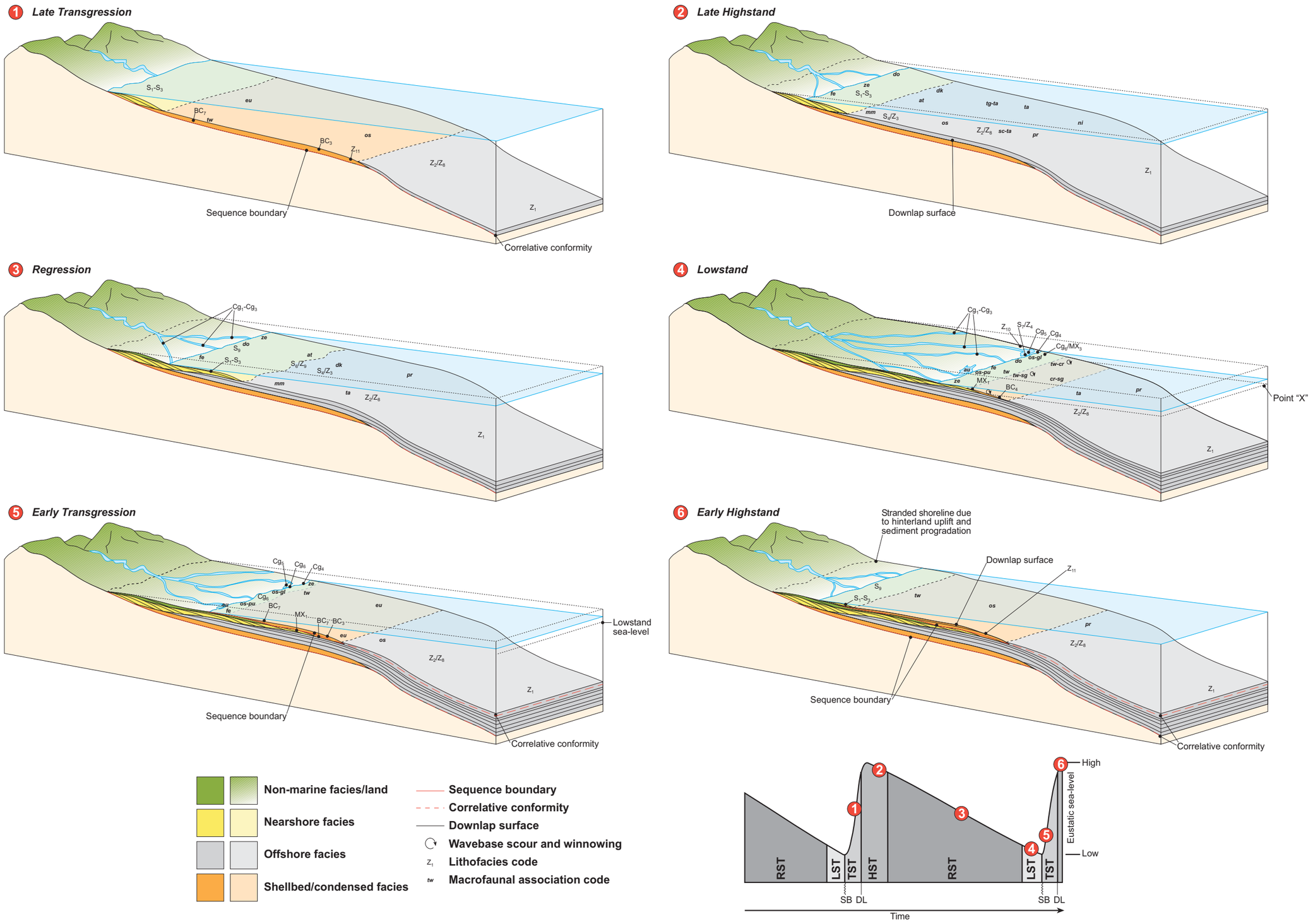


Fig. 6.17: Cartoon illustrating the idealised development of a Late Pliocene (Nukumaruan) sequence in Hawke's Bay. See Table 6.1 for lithofacies descriptions and Table 6.2 for macrofaunal association descriptions.

CHAPTER SEVEN

GEOLOGICAL HISTORY AND BASIN SYNTHESIS

INTRODUCTION

This chapter aims to integrate the lithostratigraphic, paleontologic, structural, and sequence stratigraphic data and interpretations presented in this thesis into a unified paleogeographic evolution of the forearc basin in western and central parts of Hawke's Bay It also discusses how relative sea-level fluctuations, tectonism and sediment supply have controlled sedimentation in the Hawke's Bay area during the Neogene.

Paleogeographic reconstructions of a general nature covering eastern North Island were presented by Field *et al.* (1997). New data presented in this study suggest that reinterpretation of the Neogene paleogeographic development of the Hawke's Bay area is required. Consequently, new paleogeographic maps are presented in Enclosure 6. The paleogeography is discussed in the last section of this chapter.

Chapter One described a series of thesis objectives and questions, including the following:

> 1) Develop and apply sequence stratigraphic concepts for the Neogene succession and infer the record of relative sea-level changes, and correlate this record with the global record of eustatic sea-level oscillations contained in deep-sea cores.
>
> 2) Date the timing and establish the displacement on the Mohaka and Ruahine Faults from comparisons of the stratigraphy and chronology of sedimentary successions distributed across and offset by these faults. Determine how the North Island Shear Belt and accretionary wedge have deformed the sedimentary fill of the basin.
>
> 3) Reconstruct the paleogeography of the basin, including the impact of global sea-level changes on the character of the basin fill and the record of strike-slip faulting and basement uplift along the western basin margin. Interpret the sedimentation and deformation history of the basin in terms of the tectonic development of the various components of the Hikurangi margin.

This chapter discusses these three objectives. It begins by showing how the stratigraphy documented in Chapters Three, Four, and Six, can be used to better understand the development of the North Island Shear Belt and accretionary wedge (as described in Chapter Five). It then discusses if the basin fill can be correlated to the global record of sea-level oscillations. The

chapter concludes by describing the paleogeographic evolution of the Hawke's Bay region. This final part of the chapter is associated with Enclosure 6 (Paleogeographic Maps).

GEOLOGICAL HISTORY

The Neogene geological history of central parts of Hawke's Bay can be usefully subdivided into three major phases, each represented by one of the three lithostratigraphic groups documented in Chapter Three. The overall Neogene succession analysed in this study essentially represents a broadly transgressive-regressive, Miocene-Pleistocene megasequence. The first phase, of Early to Late Miocene age, is represented by the Tolaga Group (Fig. 7.1), which mostly comprises deep-water bathyal rocks. The group comprises four deepening-upward packages (each a separate formation), with shelfal beds at the base passing up-section into bathyal units. The overlying Late Miocene-Early Pleistocene Mangaheia Group, which represents the second major Neogene phase, is dominated by shelfal deposits with some cyclothemic intervals. Occasional upper bathyal beds occur, although these appear to be short lived. The uppermost phase is represented by the Middle Pleistocene Kidnappers Group. Beds in this group are mostly non-marine, with marginal-marine rocks preserved at Cape Kidnappers.

In many parts of the basin, Neogene rocks lie either side of major faults forming the North Island Shear Belt, and so can help constrain the timing and magnitude of fault displacement. The stratigraphy in eastern parts of the basin helps to record the inboard encroachment and emergence of the accretionary wedge. The following sections of the chapter attempt to characterise the deformational history of the North Island Shear Belt and the accretionary wedge as revealed by the stratigraphic record.

NORTH ISLAND SHEAR BELT

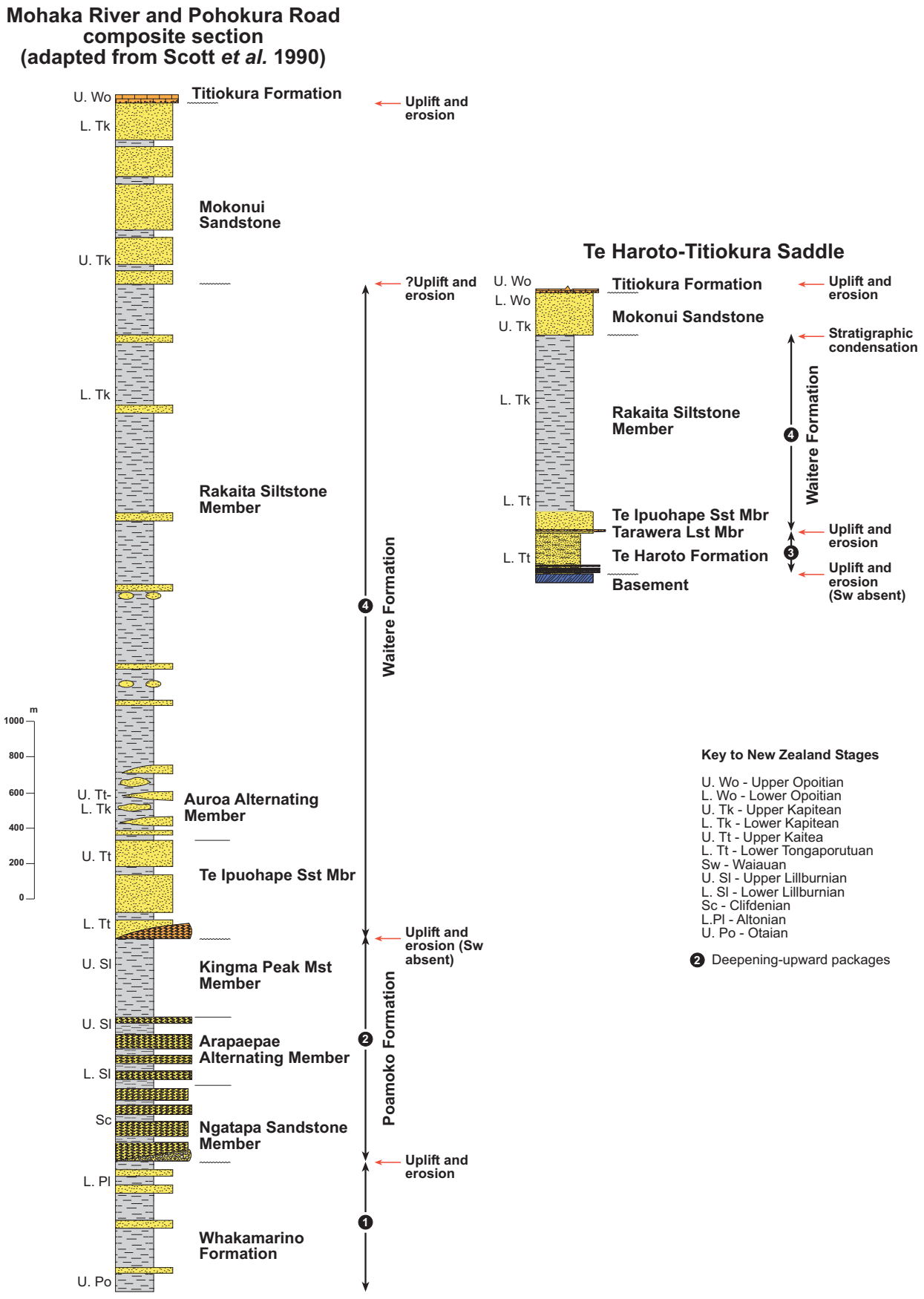
The western margin of the forearc basin, coinciding with the present location of the North Island Shear Belt, has had a dynamic history of uplift and subsidence that apparently intensified in the Late Pliocene (Nukumaruan). It is likely that these phases of uplift and subsidence were focused on larger structures in the shear belt, although the mechanisms driving these events are uncertain. The character of individual faults within the North Island Shear Belt was discussed in Chapter Five. The shear belt comprises faults and folds in the axial range and range front contractional domains. Several of these faults, such as the Ruahine and Mohaka Faults, have probably been active as reverse faults throughout deposition of the succession in the study area. Other faults, such as the Comet Fault, have been active in the past with significant offsets across them, but are inactive at present. Faults such as the Poporangi, Patoka, and Rangiora Faults appear to be

young features. At present, the basin is significantly inverted along its western margin with uplift focused in the North Island Shear Belt.

The oldest Neogene rocks mapped in the North Island Shear Belt are part of the Whakamarino Formation, which unconformably overlies Paleogene beds (see Appendix I, p. A1-9). During the Lower Clifdenian the western basin margin was uplifted, some erosion occurred, and renewed subsidence resulted in deposition of the Poamoko Formation. Waiauan uplift then occurred, resulting in the formation of a widespread unconformity along the western side of the basin. The Pohokura Anticline (see Chapter Five, p. 168) was probably growing by this time, and was likely to have been emergent in parts. Tongaporutuan subsidence then occurred, before differential uplift occurred in the "middle" Kapitean. This uplift was greatest along southern parts of the shear belt (Ohara-Kuripapango), and apparently lessened from the Te Pohue area to the Te Hoe area. Again subsidence occurred along the margin, before further differential uplift occurred in the Lower to "middle" Opoitian. The degree of uplift during this time resulted in a larger area becoming emergent than during the Kapitean, with probable subaerial erosion extending from the Omahaki-Kuripapango area to the Maungaharuru Range. These unconformities were overlain by shelfal rocks of Upper Opoitian age. Widespread differential uplift along the North Island Shear Belt occurred in the Lower Waipipian. No Waipipian rocks are known to crop out from the Ohara Depression and Kuripapango areas, although Waipipian rocks do occur in the Puketitiri area. The Lower Waipipian uplift was followed by differential subsidence in the Upper Waipipian to Lower Mangapanian as evidenced by the deposition of the Te Waka Formation across the shear belt at Kuripapango, the Puketitiri Formation in the Ohara Depression, and Te Aute lithofacies limestone on Torlesse basement in Ongaonga-1 (Leslie 1971a) and Takapau-1 (Leslie 1971c).

Emergence and erosion of an extensive basement hinterland occurred in the Upper Mangapanian, with shoaling over the Wakarara Range and around the eastern margins of the Ruahine and Kaweka Ranges. This resulted in the deposition of conglomerate beds in the Matahorua Formation (see Appendix I, p. A1-105).

Lower Nukumaruan subsidence occurred across western and central Hawke's Bay, indicated by shelfal rocks overlain by upper bathyal to outer shelf mudstone. Subsidence was greatest adjacent to the Ruahine Fault in the Ohara Depression, where over 400 m of Esk Mudstone accumulated over shelfal Sentry Box Formation. The amount of subsidence was less toward the Tangoio Block, where 120 m of Esk Mudstone was deposited. It is likely that subsidence also occurred in the vicinity of the Mohaka River mouth, where Lower Nukumaruan flysch is preserved.


Mohaka River and Pohokura Road composite section (adapted from Scott et al. 1990)
U. Wo
L. Tk
Titiokura Formation
Uplift and erosion
Mokonui Sandstone
U. Tk
?Uplift and erosion
L. Tk
Rakaita Siltstone Member
Waitere Formation
4
m
1000
800
600
400
200
0
U. Tt-
L. Tk
Auroa Alternating Member
U. Tt
Te Ipuohape Sst Mbr
L. Tt
Uplift and erosion (Sw absent)
U. Sl
Kingma Peak Mst Member
U. Sl
Arapaepae Alternating Member
2
Poamoko Formation
L. Sl
Sc
Ngatapa Sandstone Member
Uplift and erosion
L. Pl
1
Whakamarino Formation
U. Po
Te Haroto-Titiokura Saddle
U. Wo
L. Wo
Titiokura Formation
Uplift and erosion
Mokonui Sandstone
U. Tk
Stratigraphic condensation
L. Tk
Rakaita Siltstone Member
4
Waitere Formation
L. Tt
Te Ipuohape Sst Mbr
Tarawera Lst Mbr
Uplift and erosion
3
L. Tt
Te Haroto Formation
Uplift and erosion (Sw absent)
Basement
Key to New Zealand Stages
U. Wo - Upper Opoitian
L. Wo - Lower Opoitian
U. Tk - Upper Kapitean
L. Tk - Lower Kapitean
U. Tt - Upper Kaitea
L. Tt - Lower Tongaporutuan
Sw - Waiauan
U. Sl - Upper Lillburnian
L. Sl - Lower Lillburnian
Sc - Clifdenian
L.Pl - Altonian
U. Po - Otaian
2 Deepening-upward packages

One of the most significant periods in the Late Neogene history of the North Island Shear Belt, and a matter of debate, was when dextral-slip began on the main North Island Shear Belt faults in eastern North Island.

There is a coincidence of the intensification of deformation in the North Island Shear Belt and the migration of volcanism from the Tauranga (2.7-1.9 Ma) and Kaimai (2.9-2.1 Ma) Volcanic Centres in the Coromandel Volcanic Zone (Briggs *et al.* 2005), to the Taupo Volcanic Zone (1.6 Ma-present) (Carter *et al.* 2003, 2004; Briggs *et al.* 2005). Soft-sediment deformation structures are abundant in the Waipatiki Limestone Member (c. 1.8 Ma) and younger units, possibly indicating more frequent earthquakes in the forearc area. The involvement of Kereru Formation in the Balcony Syncline and Wakarara Monoclines limits formation of these structures until after c. 2.15 Ma. Likewise, the involvement of Okauawa Formation in the Wakarara Monocline suggests deformation after Okauawa deposition, at about 1.7 Ma. Juxtaposition of Esk Mudstone beside Torlesse basement in the Ngaruroro River means uplift of the Big Hill Block after 2.3 Ma. These stratigraphic controls record the intensification of deformation along structures of the North Island Shear Belt from about 2.2-1.8 Ma.

A change from reverse to dextral displacement in the North Island Shear Belt has occurred since the Late Pliocene, and is inferred to be due to clockwise rotation of the eastern North Island (Fig. 7.2) (Beanland and Haines 1998; Wallace *et al.* 2004; Reyners *et al.* 2006), possibly induced by slab rollback and evolution of the subduction system (Stratford and Stern 2006). This rotation has apparently been matched with the southeast translation of the active andesitic volcanic arc south of Coromandel at about 4 Ma to its present day location at the eastern margin of the Taupo Volcanic Zone (TVZ) (Stern and Davey 1987). It is inferred that rifting of the TVZ in the latest Pliocene-Pleistocene is linked to the inception of dextral-slip on the North Island Shear Belt.

Fig. 7.1 (facing page): Composite stratigraphic column for the Tolaga Group. This group crops out mostly north of the Napier-Taupo Road, in an area that lies within the North Island Shear Belt (axial range and range front contractional domains), and deposition of the stratigraphy here has been strongly linked to fault displacements. Significant events in the uplift and subsidence history of this area are indicated. Numbers 1-4 refer to the four main deepening-upward packages identified within the Tolaga Group.

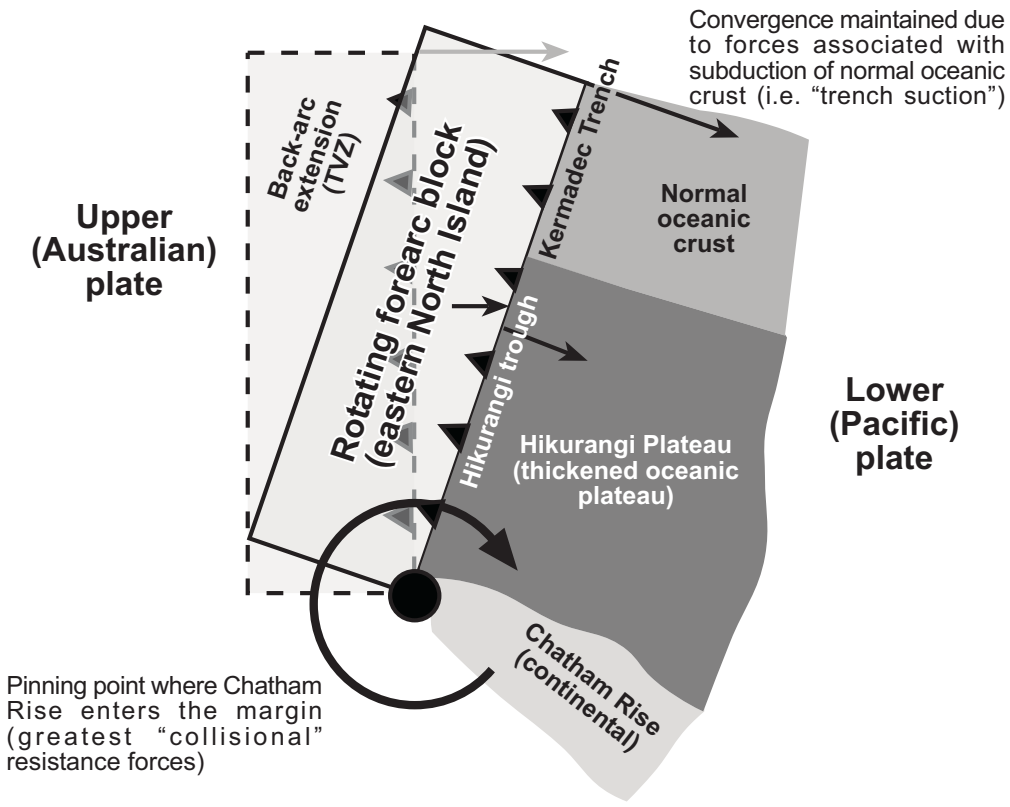


Fig. 7.2: Schematic diagram illustrating the possible rotation of eastern North Island, resulting in the inception of the current phase of dextral-slip in the North Island Shear Belt. The various structural blocks in eastern North Island rotate relative to the Pacific plate about a pole of rotation adjacent to where the Chatham Rise impinges on the Hikurangi margin. This rotation is inferred to have caused the inception of dextral-slip on several faults in the North Island Shear Belt. Adapted from Wallace *et al.* (2004, p. 18).

Present day extension rates in the TVZ, modelled from GPS data, indicate that the TVZ is opening at 8 ± 2 mm/yr at the southern end of the graben, and 15 ± 2 mm/yr at the northern end (Wallace *et al.* 2004), consistent with a model of a dextral rotation of eastern North Island. In western Hawke's Bay, it appears that the Ruahine Fault began accommodating dextral displacement in the latest Pliocene-Pleistocene, before other faults in the shear belt, possibly because it is the most inboard of the major through-going faults in the shear belt. The faults in the shear belt appear to have become progressively active to the east. This suggests that with continued rotation of the eastern North Island, dextral displacement has continued to migrate outboard to the Mohaka Fault in the Late Pleistocene, and then to the Patoka Fault Zone and Rangiora Fault in the Holocene.

The Wallace *et al*. (2004) model (Fig. 7.2) is new, and has some significance because the TVZ was opening at the same time as intensification of displacement on the North Island Shear Belt faults was occurring. The model may not be comprehensive, but it may have some usefulness in relating different aspects of North Island geology. Other models, such as those of Walcott (1987),

Cashman *et al.* (1992), and Beanland and Haines (1998) invoke strain-partitioning of the motion from the oblique approach of the Pacific plate to describe why dextral-slip displacement occurs in the North Island Shear Belt, and not on other faults in the basin. However, these models still require a mechanism for why the North Island Shear Belt became particularly active after 2 Ma, and why dextral-slip displacement appears to be a relatively young feature of the shear belt.

Kaweka Fault

Pliocene stratigraphy in the Pakaututu-Puketitiri area suggests displacement on the Kaweka Fault may have occurred from about 6 Ma (Fig. 7.3). In the Kuripapango area (Fig. 7.4) there is no direct evidence for offset on the Kaweka Fault before about 2.5 Ma, as Neogene stratigraphy older than this is absent. However, older Neogene displacement is probable, as Late Miocene-Pliocene stratigraphy occurs nearby. There is little evidence for strike-slip displacement on the Kaweka Fault. Triangular faceted spurs along the fault trace near the Makahu River suggest that dip-slip displacement has remained dominant.

Ruahine Fault

Dip-slip displacement was occurring on the Ruahine Fault by the Kapitean (c. 6 Ma), based on the absence of any rocks older than Opoitian west of the fault at Pakaututu and Puketitiri (Fig. 7.3). At Kuripapango, Lower Kapitean rocks are apparently absent, and “middle” Tongaporutuan Waitere Formation is overlain by Upper Kapitean Blowhard Formation (Fig. 7.4), inferring motion on the Ruahine Fault since at least the Kapitean. Dip-slip displacement on the fault in the Ohara Depression has occurred since at least the Opoitian (Fig. 7.5). Older dip-slip displacement along the fault is probable, but the lack of pre-Late Miocene stratigraphic markers across it means such motion cannot be constrained.

Contractional structures began to form in the Ohara Depression and along the front of the Wakarara Range at about 2.2-2 Ma. These appear to indicate renewed displacement on the Ruahine Fault, and possibly the onset of dextral-slip on the fault. Growth of contractional structures in the Ohara-Kereru area, such as the Herricks Anticline, Herricks Syncline, and Wakarara Monocline, occurred after 1.6 Ma (Erdman and Kelsey 1992). Strike-slip displacement was almost certainly being accommodated on the Ruahine Fault by this time.

In the Ohara Depression, total vertical offset on the Ruahine Fault since 2.4 Ma is about 2-3 km. Since about 4 Ma, vertical offset may have been as much as 4 km in this area, and probably decreased northeast along the trace (Beanland *et al.* 1998). Total inferred Neogene dextral offset on the Ruahine Fault is difficult to accurately constrain, but is probably in the order of 5-10 km (e.g.

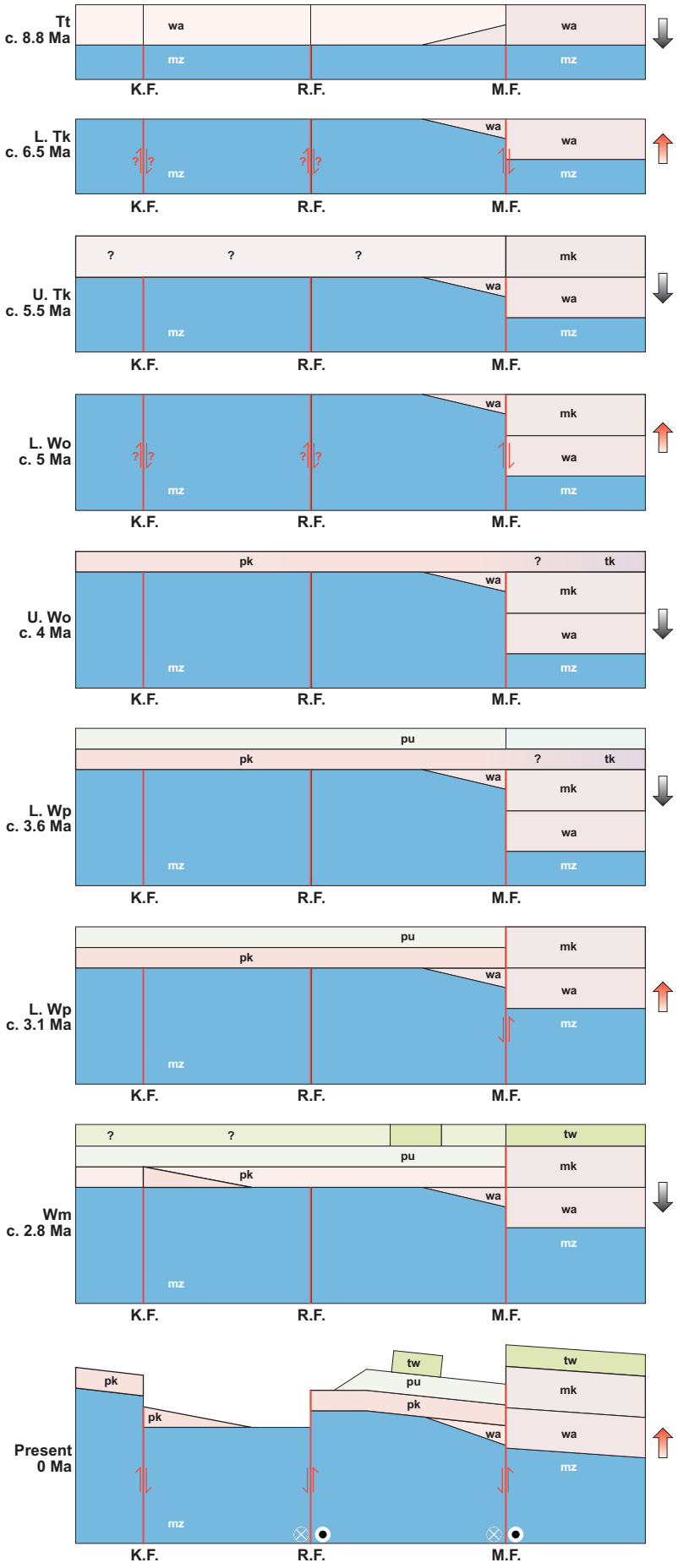
Bland and Kamp 2006). This is more than the apparent offset of about 300 m estimated for the Mohaka Fault (e.g. Beanland *et al.* 1998). This supports the notion that the Ruahine Fault began accommodating dextral slip before the Mohaka Fault.

Mohaka Fault

The section of the Mohaka Fault north of the Napier-Taupo Road was active before the Tongaporutuan, judging by the presence of fault gouge at The Organs overlain by undisturbed Te Ipuohape Sandstone Member (Cutten 1994). It is uncertain when this fault gouge was formed, and whether it relates to early stages in the formation and migration of the current plate boundary through New Zealand, or whether is was produced at a later time. The thickness and width of fault gouge at The Organs is suggestive of a substantial amount of deformation on the fault at some point. The presence of growing anticlinal structures, and uplift of the western margin of the basin in the Early and Middle Miocene, indicate that contraction was occurring across the basin during this time. Some of this contraction may have been accommodation on the Mohaka Fault. In the Pakaututu area (Fig. 7.3) dip-slip displacement on the fault has probably occurred since the Kapitean (c. 6 Ma). There is no clear evidence that the section of the Mohaka Fault in the Kuripapango-Willowford area was active before 2.4 Ma (Fig. 7.4), although the modern trace there indicates Recent displacement. In the Ohara-Kereru area (Fig. 7.5), the fault has been active since at least the Opoitian, and very well developed active traces demonstrate Recent displacement.

Formation of the Balcony Syncline, essentially a drag structure west of the Big Hill-Ohara Depression section of the Mohaka Fault, occurred after deposition of the Kereru Formation. This constrains renewed offset along this part of the fault to after c. 2.2 Ma. The Big Hill-Ohara Depression section of the fault possibly became active again after 2 Ma, and was most probably active by 1.6-1 Ma, as suggested by Erdman and Kelsey (1992). Uplift on this section of the fault was to the west, in contrast to the eastern uplift on the Big Hill-Ohara Depression part of the fault. While the Big Hill-Ohara Depression part of the Mohaka Fault was active again at about 2.2 Ma, it is uncertain whether the Big Hill-Hawkston section was. Esk Mudstone is in fault contact with Torlesse basement at the southern end of this sector of the fault, constraining uplift until after 2.2 Ma.

Fig. 7.3 (facing page): Schematic diagrams illustrating the possible uplift and subsidence history of the Pakaututu area, over the past 9 m.y., as revealed by the stratigraphy preserved across the North Island Shear Belt in this area. This figure is modelled on the western part of cross-section B-B‘ (Enclosure 3).



Wm - Mangapanian
U. Wp - Upper Waipipian
L. Wp - Lower Waipipian
U. Wo - Upper Opoitian
L. Wo - Lower Opoitian
U. Tk - Upper Kapitean
L. Tk - Lower Kapitean
Tt - Tongaporutuan

tw - Te Waka Formation
pu - Puketitiri Formation
tk - Titiokura Formation
pk - Pakaututu Formation
mk - Mokonui Sandstone
wa - Waitere Formation
mz - Torlesse basement

K.F. - Kaweka Fault
R.F. - Ruahine Fault
M.F. - Mohaka Fault

⊗ ⊙ Dextral strike-slip

General uplift

General subsidence

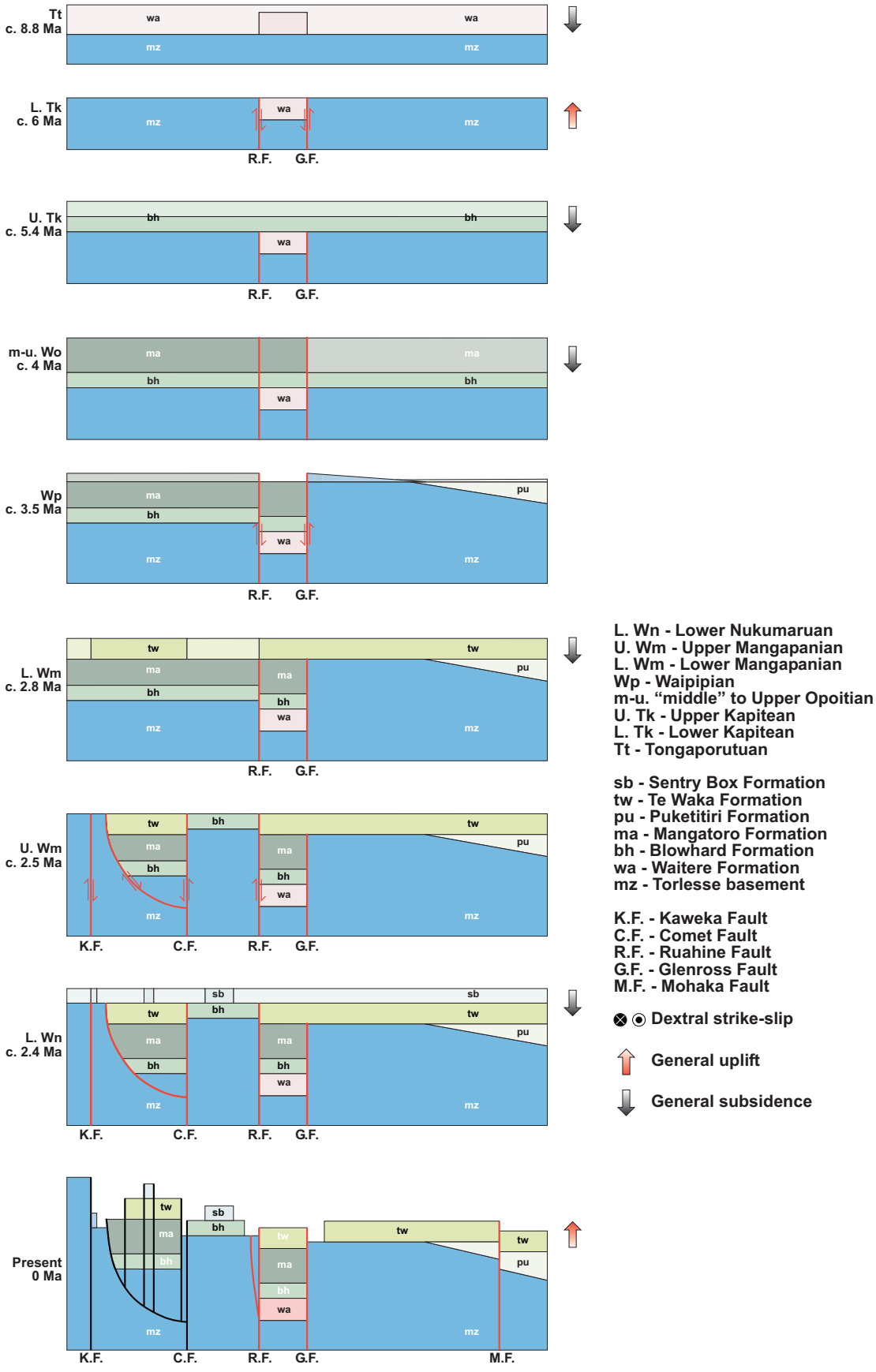
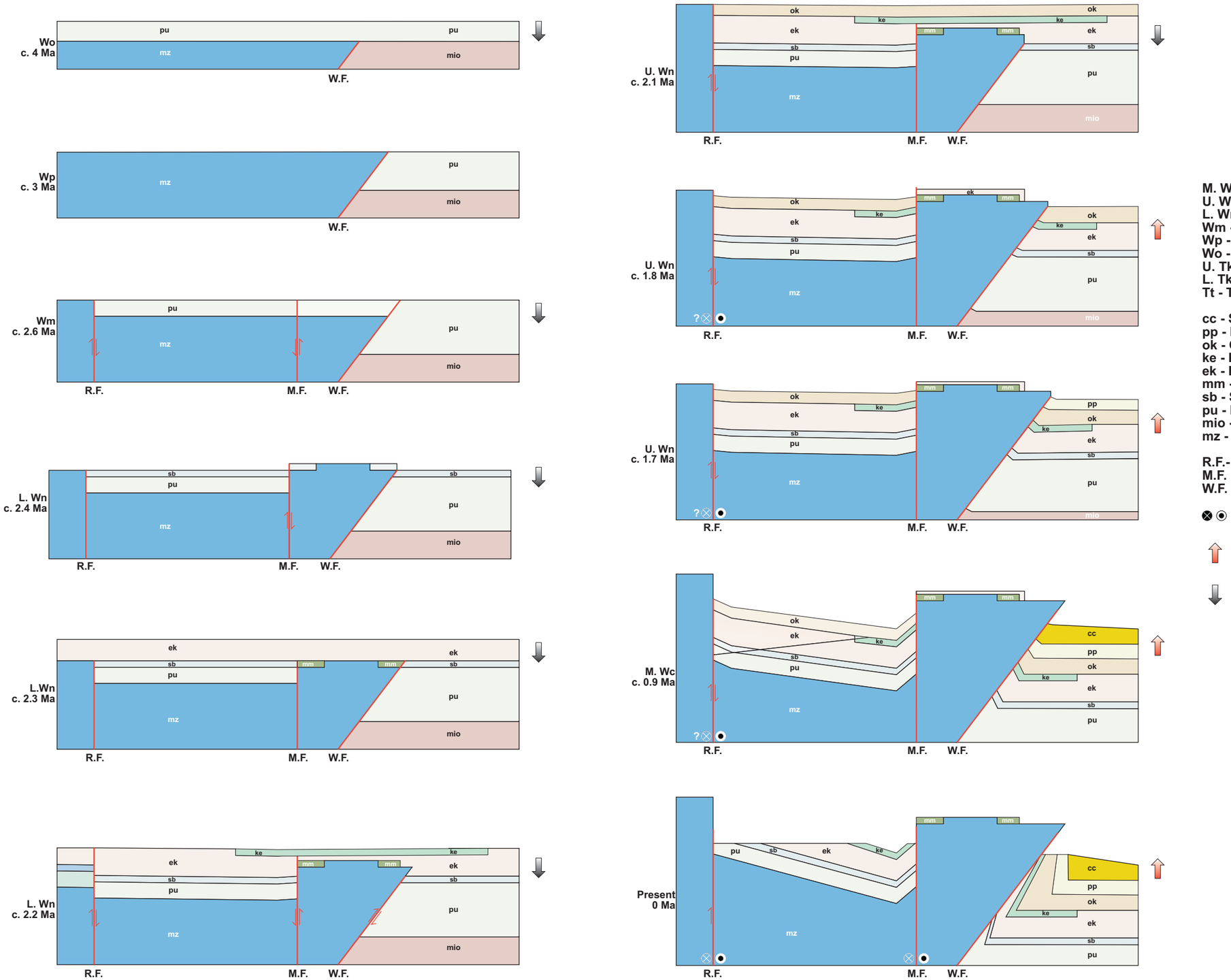


Fig. 7.4: Schematic diagram illustrating the possible uplift and subsidence history of the Kuripapango area over the past 9 m.y., as revealed by the stratigraphy preserved across the North Island Shear Belt in this area (modelled on the western part of cross-section C-C', Enclosure 3).



M. Wc - Middle Castlecliffian
U. Wn - Upper Nukumaruan
L. Wn - Lower Nukumaruan
Wm - Mangapanian
Wp - Waipipian
Wo - Opoitian
U. Tk - Upper Kapitean
L. Tk - Lower Kapitean
Tt - Tongaporutuan

cc - Salisbury Gravel
pp - Poutaki Formation
ok - Okauawa Formation
ke - Kereru Formation
ek - Esk Mudstone
mm - Mount Mary Pebbly Limestone
sb - Sentry Box Formation
pu - Puketitiri Formation
mio - undifferentiated Miocene
mz - Mesozoic basement

R.F.- Ruahine Fault
M.F. - Mohaka Fault
W.F. - Wakarara Fault

⊗ ⊙ Dextral strike-slip

General uplift

General subsidence

Fig. 7.5: Schematic diagrams illustrating the possible uplift and subsidence history of the Ohara Depression-Kereru area over the past 4 m.y., as revealed by the stratigraphy preserved across the North Island Shear Belt in this area. This figure is modelled on the western parts of cross-section D-D' (Enclosure 3).

With inferred continued clockwise rotation of the forearc (Beanland and Haines 1998; Wallace *et al.* 2004; Reyners *et al.* 2006), strike-slip displacement on the Mohaka Fault was probably not initiated until after 1 Ma (Beanland *et al.* 1998). The inception of the current phase of dextral-slip on the Mohaka Fault is inferred to reflect the migration of some dextral-slip from the Ruahine Fault outboard onto the Mohaka Fault. This pattern has apparently continued into the Late Quaternary, with dextral-slip migrating further outboard from the Mohaka Fault onto the Rangiora (Cutten *et al.* 1988) and Patoka (Halliday 2003) Fault systems. As described in Chapter Five, the estimated total strike-slip offset across the Mohaka Fault is relatively small. Beanland *et al.* (1998) estimated less than 300 m of dextral offset across the fault in the Ohara Depression. At current rates of displacement, such an offset can be accommodated in the Late Quaternary.

ACCRETIONARY WEDGE

The inboard margin of the accretionary wedge encroaches into southeastern parts of the study area, and is structurally represented by the eastern contractional domain, the character of which was documented in Chapter Five. The stratigraphic record along the eastern margin of the forearc basin records the progressive encroachment of the accretionary wedge into the forearc basin, so that through time, parts of the forearc basin succession have become involved in the accretionary wedge. Figure 7.6 shows the probable extent of the wedge at present in the Hawke's Bay region. The outcrop pattern of westward-younging Pliocene limestones demonstrates that the inboard margin of the accretionary wedge has migrated toward the centre of the basin over time. Younger limestone beds (e.g. Mason Ridge Formation) presently crop out close to the forearc basin axis and at lower elevations compared with the older Pliocene limestone beds (e.g. Kairakau and Awapapa Limestones) located at the outer margins of the basin (Beu 1995; Caron *et al.* 2004a).

Sedimentary deposits about the accretionary wedge were dominated by bathyal units until at least the Late Miocene (e.g. Pettinga 1982). In the Lower Opoitian it appears that the accretionary wedge had developed enough that it began to encroach inboard into the forearc basin succession. Initial shoaling of the wedge to shelf water depths by the Upper Opoitian is recorded by deposition of the Kairakau Limestone (Pettinga 1980; Beu 1995). It is uncertain whether the wedge by this time was emergent, but more probably it resembled a series of shallow-marine platforms extending from Te Mata Peak to at least as far south as Cape Turnagain and Patangata (Beu 1995). Waipipian Taradale Mudstone overlies Eocene rocks in Taradale-1 (Darley and Kirby 1969), indicating subsidence around this area in the Waipipian.

The stratigraphic record in the Napier and Matapiro areas records an apparent intensification of deformation along inboard parts of the accretionary wedge during the Upper Nukumaruan at about

2.1-1.8 Ma. The Taradale Anticline began to accumulate carbonate lithologies after deposition of the Taradale Mudstone, as did structural highs at Roys Hill and Fern Hill. This period coincides with the intensification of deformation along the North Island Shear Belt, and the appearance of abundant soft-sediment deformation structures in carbonate lithofacies. Deformation of stratigraphy in the Taradale and Napier areas appears consistent with the migration of the accretionary wedge inboard into the forearc basin, and the progressive involvement of the basin fill in the wedge.

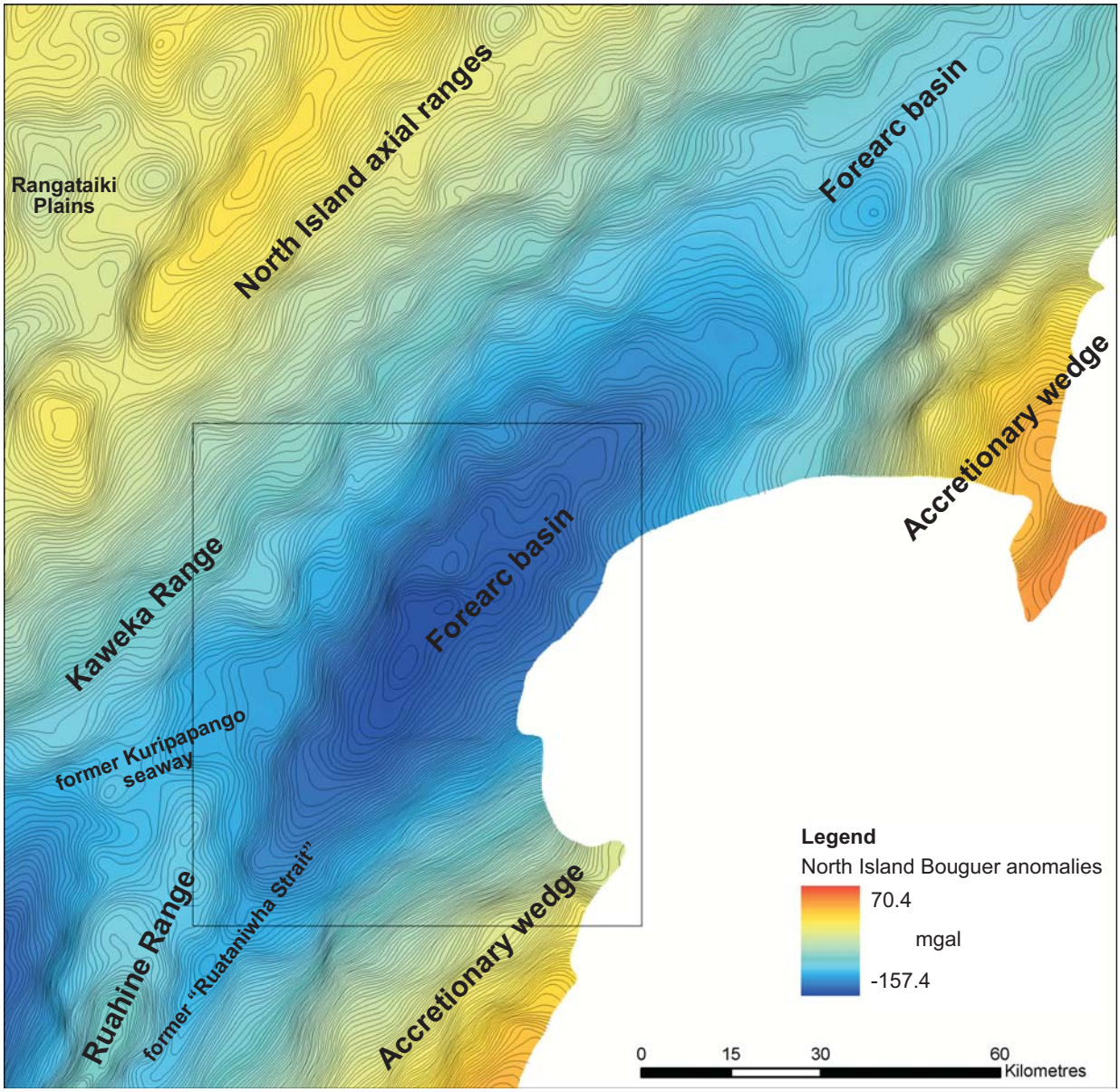


Fig. 7.6: Gravity map showing Bouguer anomalies at 500 m above sea level. Anomaly values in mgal (10-5 N/kg); contour interval 1 mgal. Gravity values in terms of N.Z. Potsdam System (1959). Assumed density of topography +2.67 Mg/m3 (land); -1.64 Mg/m3 (ocean). Data digitised from DSIR 1:250 000 Bouguer anomaly maps (Sheets 3 - 12; Woodward (1971a,b); Woodward and Boyle (1972); Reilly (1972); Woodward and Ferry (1973, 1974); Ferry *et al*. (1974); Whiteford (1974); Doone and Ferry (1974); Whiteford and Woodward (1974)). Note the coincidence of positive values (red and orange shades) with the accretionary wedge, and negative values (purple and blue shades) with forearc basin.

Significant deformation has been accommodated across the Napier Fault and the Napier Syncline and its bounding fault, the buried Awanui Fault. Pliocene Mangatoro Formation and Taradale Mudstone have become involved in the syncline, indicating deformation since at least the Late Pliocene. Mangatoro Formation is offset by several hundred metres across the Napier Fault, and to a lesser degree across the Awanui Fault (see Fig. 5.15, Chapter Five). Uplift on the Napier Fault in the Upper Mangapanian-Lower Nukumaruan is inferred to have produced the paleohigh that the Scinde Island Formation accumulated on during the lowermost Nukumaruan.

IMPRINT OF GLOBAL SEA-LEVEL RECORD ON THE BASIN FILL

OVERVIEW

As documented in Chapter Six, parts of the basin fill, particularly the Mangaheia and Kidnappers Group succession (Kapitean-Castlecliffian), accumulated during a known period of high-frequency, glacio-eustatically-driven, oscillations in sea level. A question resulting from this is why the forearc basin succession does not contain the excellent Kapitean-Castlecliffian record of this cyclicity, as preserved in the neighbouring Wanganui and Taranaki Basins? While parts of the forearc basin succession do contain well developed cyclothemic strata, in general the stratigraphic record lacks obvious cyclothems. This reflects the involvement of the forearc basin in the Hikurangi subduction margin. Although eastern and western North Island sedimentary basins were linked for long periods of time by seaways, they contain very different sedimentary records and have undergone different sedimentation histories due to their tectonic positions. It appears as though there are three main factors which contributed to the lack of cyclothem development in the Hawke's Bay region, each driven directly or indirectly by tectonics: 1) a high siliciclastic sediment flux; 2) water depths were often too deep to record sea-level oscillations; and 3) local tectonics, where different structural blocks underwent different sedimentation histories.

Sediment flux

The siliciclastic sediment flux into the basin may have contributed to the lack of cyclothem development (see Fig. 7.10 for Nukumaruan sediment flux). For parts of the Mangaheia Group, sediment flux may have been too high to allow obvious cyclothems to be identified, such as in parts of the Pohue Formation. This is because parts of the formation, such as that in the upper Esk River, are overwhelmingly dominated by sandstone, meaning that the identification of important sequence stratigraphic surfaces is difficult. Conversely, a very low siliciclastic accumulation rate, such as during periods when beds of the Te Aute limestone lithofacies were

deposited, also hindered the development of obvious cyclothems. Again, this is because the identification of surfaces important in defining sequences is difficult. Caron *et al.* (2004a, b) demonstrate that the identification of sequences in these limestones often needs detailed petrographic analysis, and such classification often cannot be done easily in the field. The fact the obvious sequences can be identified in parts of the Mangaheia Group is often due to the presence of prominent bioclastic beds within siliciclastic-dominated intervals. The fact that bioclastic beds could form at all in this siliciclastic-dominated system is due mostly to the presence of a Pliocene interior seaway (refer to Paleogeographic Evolution, this chapter). The seaway constrained tidal currents which were able to periodically sweep the sea floor of siliciclastic sediment (Beu *et al.* 1980), and allow for net carbonate production, often during regressive and transgressive periods of sea level (refer Chapter Six). Haywick *et al.* (1991) also proposed periods of siliciclastic sediment bypassing on the paleoshelf in the Tangoio area, also allowing for net carbonate production. In units such as the Titiokura Formation at Te Pohue, winnowing of bioclastic deposits has effectively condensed the sedimentary succession into a relatively thin interval, making field-based identification of cyclothems difficult. Such condensation and stacking of bioclastic sediments also occurred along the accretionary wedge in formations such as the Awapapa and Te Onepu Limestones (Caron *et al.* 2004a, b).

Water depth

While the Mangaheia Group mostly comprises rocks of inner to middle shelf origin, occasional incursions to outer shelf and upper bathyal water depths occurred. These events are preserved in units such as the Mangatoro Formation, Esk Mudstone, and Taradale Mudstone. With sea-level fluctuations during the Plio-Pleistocene in the order of 60-70 m, these formations often accumulated at water depths too great to record obvious cyclothems through lithofacies variations.

Local tectonic influence

The Mangaheia Group accumulated during a period of differential uplift and subsidence, with different basement blocks undergoing different sedimentation histories. Rates of subsidence may have been at times too high for development of cyclothems, or periods of uplift and emergence meant that cyclothems could not form. In many areas along the North Island Shear Belt, stratigraphic intervals are absent due to non-deposition and erosion (e.g. “middle” Kapitean and Waipipian), while areas that were submarine during these times may have been in situations unfavourable for cyclothem development and preservation, as described above. A complete record of Late Neogene cyclothems cannot therefore not be attained for parts of the basin fill.

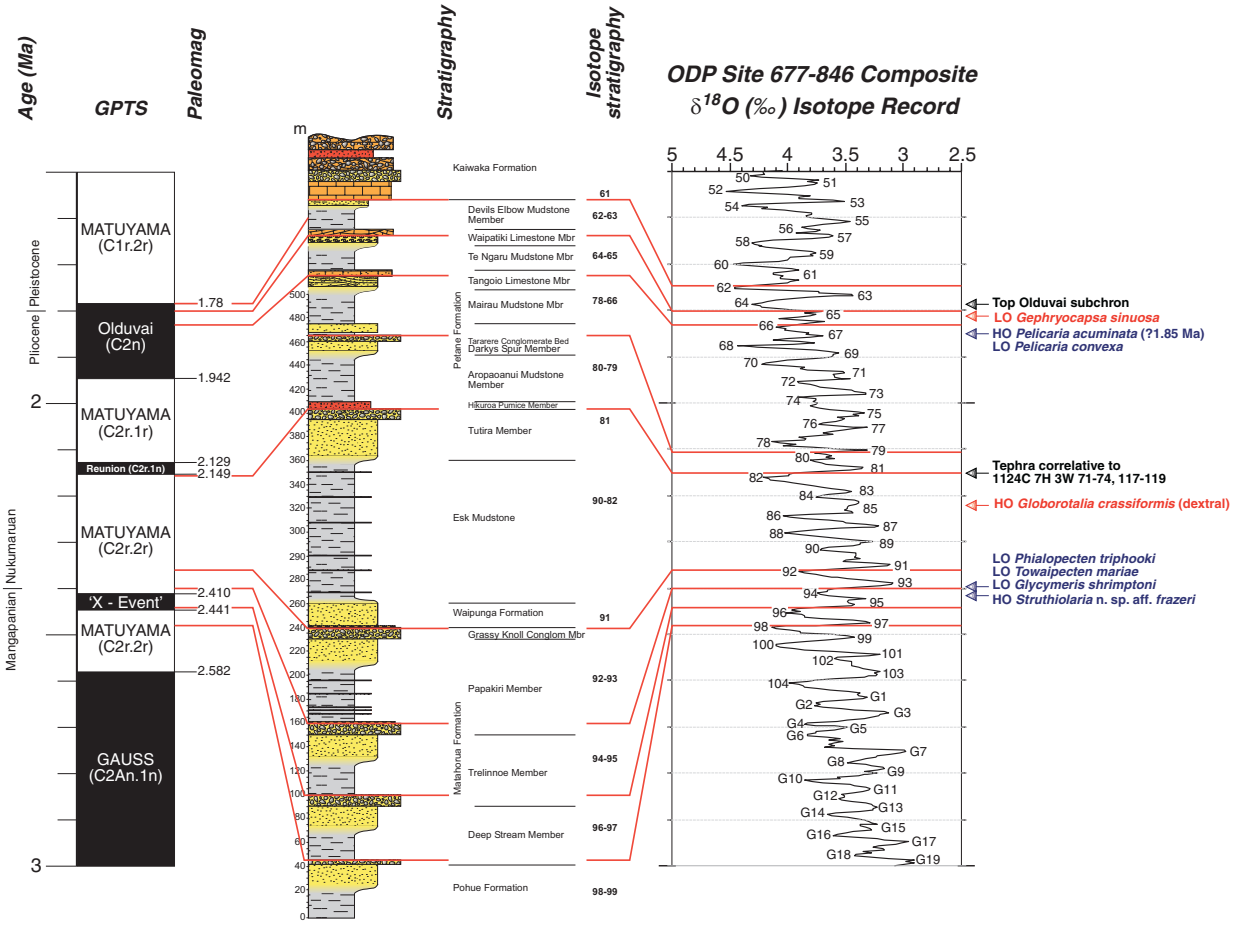


Fig. 7.7: Correlation of stratigraphy cropping out in the Esk-Tangoio area with the $\delta^{18}O$ record for ODP sites 667 and 846. Positive correlations can be made to the ODP record with the Papakiri Member (Matahorua Formation), and the Waipatiki Limestone Member and Devils Elbow Mudstone Member (Petane Formation). Correlations between other stratigraphic units remain uncertain. The shellbed near the base of the Papakiri Member is inferred to be a correlative of the Hautawa Shellbed in Wanganui Basin. $\delta^{18}O$ records derived from Shackleton and Hall (1989), and Shackleton *et al.* (1995). Base Nukumaruan (2.4 Ma), after Cooper (2004).

CORRELATION TO THE GLOBAL SEA LEVEL RECORD

Cyclothemic rocks, whose formation can be attributed to glacio-eustatic sea-level changes, are generally only present in the Late Pliocene Mangaheia Group (Chapter Six). For the reasons described above, only a limited correlation between the Mangaheia Group and ODP records is possible. There are too many breaks in the sedimentary record to allow for cycle-by-cycle correlations, such as those achieved for Pliocene strata in Wanganui Basin by Naish and Kamp (1997), McIntyre and Kamp (1998), McIntyre (2002), and Naish *et al.* (2005).

Cycles can be observed in isolation in parts of the Pohue Formation (such as in the Mangaone River and at Te Pohue), but cannot be correlated across interfluves. There is a possibility of correlation between the three cyclothems differentiated in the Te Waka Formation from Patoka to

Kuripapango to the southern Glenross Range near Awapai Station, but the degree of faulting in the North Island Shear Belt between these areas make any correlations far from certain. Three cyclothems occur in the Mason Ridge Formation, and at least three occur in the Okauawa Formation. However, the cyclothemic record in these two areas is too fragmented to allow confident correlation to ODP records, and absolute dating of the succession is also problematic. It is only in upper parts of the Mangaheia Group, in the Esk and Tangoio areas, that any tentative correlation can be made to the oxygen isotope record (Fig. 7.7).

As illustrated in Fig. 7.7, the identification of the Mangapanian-Nukumaruan boundary (2.4 Ma) in lower parts of the Papakiri Member provides one tie to the deep-sea record, as does the identification of the Plio-Pleistocene boundary in the Waipatiki Limestone Member (Beu and Edwards 1984), and the position of the top Olduvai subchron in the Devils Elbow Mudstone Member (P. Kamp, Univ. of Waikato, unpublished data). Between the cyclothemic Matahorua and Petane Formations lies the Esk Mudstone, a unit which is inferred to contain geological time as mudstone across several 41 k.y. sea-level cycles, demonstrating the fragmented character of the cyclothemic record in the forearc basin.

EVOLUTION OF THE FOREARC BASIN IN CENTRAL PARTS OF HAWKE'S BAY

EARLY AND MIDDLE MIOCENE

Otaian-Waiauan (21.7-10.92 Ma)

The oldest Neogene rocks cropping out in the study area are of the Otaian-aged Whakamarino Formation (Fig. 7.1). The unit was deposited after the inception of the modern plate boundary through the New Zealand subcontinent. This event marked the cessation of passive-margin sedimentation along eastern North Island, and the commencement of deposition of Tolaga Group. The Whakamarino Formation records the start of turbidite deposition in the study area. Whakamarino Formation is unconformably overlain by Poamoko Formation. Submergence is recorded in the Clifdenian by deposition of the shelfal Ngatapa Sandstone Member, followed by the bathyal Arapaepae Alternating Member and Kingma Peak Mudstone Members (Upper Lillburnian). Water depths during deposition of the Arapaepae Alternating and Kingma Peak Mudstone Members were probably as great as middle bathyal (Cutten 1994).

No Waiauan rocks are known to crop out in the study area, indicating a possible period of emergence and erosion focused along the North Island Shear Belt. This may be related to the

presence of fault gouge along the Mohaka Fault, preserved beneath undeformed Te Ipuohape Sandstone Member (Tongaporutuan) at The Organs (Cutten 1994). However, while western parts of the basin were probably emergent, the presence of Waiauan rocks in subcrop, as demonstrated by several hydrocarbon exploration wells in the wider Hawke's Bay region, shows that sedimentation continued in other areas. In the Wairoa-Mahia area, Waiauan Makaretu-D equivalent sandstone (Tunanui Formation, Mazengarb and Speden 2000) was recorded in Tuhara-1 (Ian R Brown and Associates 1998d), and in Opoho-1, Waiauan Tangihau Mudstone and Makaretu-D equivalent sandstone was reported (Ian R Brown and Associates Ltd 1999c). No Waiauan rocks are reported in other exploration wells in the Wairoa area, although they do crop out in the hill country around Lake Waikaremoana, and inland from Wairoa and Ruakituri (Mazengarb and Speden 2000). In central parts of Hawke's Bay, Waipipian Taradale Mudstone overlies steeply-dipping Waiauan flysch in Mason Ridge-1 (Leslie 1971b). Waiauan Waipuna Limestone was recorded in Whakatu-1 by Ozolins and Francis (2000), and shelfal sandstone of Waiauan age was reported from Hawke Bay-1 (BP Shell Aquitane Todd Petroleum Development Ltd 1976). Rocks of Upper Whaingaroan to possibly Upper Tongaporutuan age are absent in Hukarere-1 (Westech Energy New Zealand Ltd 2001), and beds of Mangaorapan to Waipipian age are absent in Taradale-1 (Darley and Kirby 1969). It is likely therefore that western parts of the study area were subaerial for much of the Waiauan and remained so until the Lower Tongaporutuan. Central and eastern parts of the basin were deep-marine, with flysch and other redeposited units accumulating. It is inferred that the absence of Waiauan rocks in Hukarere-1 and Taradale-1 reflect later phases of uplift and erosion.

LATE MIOCENE

Tongaporutuan (10.92-6.5 Ma)

Tongaporutuan rocks are widespread in outcrop in northwestern parts of the study area, and in the subsurface throughout the Hawke's Bay region. The Tongaporutuan is broadly characterised by submergence of the western basin margin during the lower parts of the stage (Enclosure 6, Map 1), and continued deep-marine sedimentation into the Kapitean (Enclosure 6, Map 2). Most Tongaporutuan rocks show deep-marine sedimentation across the study area, with minor shelfal beds.

Most of the western margin of the study area was emergent during the lowermost Tongaporutuan, with the exception of the Tarawera Station and Te Haroto areas where the Te Haroto Formation was deposited. A short period of uplift followed deposition of this unit, and then, probably in the "middle" Tongaporutuan, the entire western margin subsided, reflected in deposition of the shelfal

Tarawera Limestone Member, and coarse-grained, highly fossiliferous lower beds of the Te Ipuohape Sandstone Member (both Waitere Formation). All pre-Tongaporutuan Neogene rocks are absent in the Te Haroto and Tarawera Station areas, most probably eroded during the Waiauan. The region continued to subside during the Tongaporutuan, and by the Upper Tongaporutuan most of the study area was at upper bathyal water depths. The Auroa Alternating and Rakaita Siltstone Members were deposited during this time. The axial range area was mostly submarine, and an open marine connection existed between East Coast and Wanganui Basins. This period of deep-water sedimentation continued uninterruptedly into the Lower Kapitean.

Substantial growth of the Pohokura Anticline with associated erosion had occurred before deposition of the Waitere Formation, with units near the crest of the fold removed. Te Ipuohape Sandstone Member (Waitere Formation) was deposited over the Whakamarino Formation, and all three members of the Poamoko Formation (Cutten 1994) across the anticline. Waitere Formation subsequently became involved in the Pohokura Anticline, indicating that the fold continued to grow after the Tongaporutuan.

A similar pattern of Tongaporutuan subsidence is preserved in the Wairoa area where several hydrocarbon exploration wells (Kiakia-1, Makareao-1, Kauhauroa-1, -2, -5, Awatere-1, Tuhara-1) have intercepted late Lower and Upper Tongaporutuan strata. Middle bathyal Pindari Mudstone was intercepted in all the wells mentioned above, as well as middle bathyal Poha Formation. These formations are most probably lateral equivalents of the Waitere Formation preserved in the study area. Intermittent development of turbidite fan complexes are represented by the Makareao Sandstone Member in the Poha Formation. Ratios of planktic to benthic foraminifera in this member from Makareao-1 led Ian R Brown and Associates Ltd (1998b) to suggest that a shelf barrier east of Hawke's Bay existed somewhere between Mahia Peninsula and Cape Kidnappers that partially restricted the water mass. The exploration well Hawke Bay-1 is located in this area, and foraminifera from Tongaporutuan mudstones in this hole indicate an outer shelf environment (BP Shell Aquitane Todd Petroleum Development Ltd 1976). Hawke Bay-1 was drilled into the location of an inferred diapiric structure that had been active since the Early Miocene, effectively bathymetrically raising the area above the nearby sea floor. This structure may have contributed to forming the partially restricted water mass observed in Makareao-1.

Along eastern margins of the study area, deep-marine sedimentation continued (Pettinga 1982). Tongaporutuan beds are recorded in Whakatu-1 (Ozolins and Francis 2000). It is uncertain whether Tongaporutuan rocks are recorded in Hukarere-1 due to poor paleontological results, although they are certainly absent in nearby Taradale-1 (Darley and Kirby 1969) and Mason Ridge-1 (Leslie 1971b). It is likely that Tongaporutuan beds were deposited over the sites of all

four of these wells, and that a post-Tongaporutuan erosion event, probably in the Opoitian (Beu *et al.* 1980), removed them from Taradale-1 and Hukarere-1. Thick turbidite successions were deposited over the accretionary wedge (Pettinga 1982), accumulating in fault-bounded basins. Mudstone was deposited at outer shelf depths about Hawke Bay-1 (BP Shell Aquitane Todd Petroleum Development Ltd 1976).

Kapitean (6.5-5.28 Ma)

The Kapitean (Enclosure 6, Maps 2 and 3) was typically characterised by a transition from the mostly deep marine beds of the Tolaga Group to the shelfal beds of the Mangaheia Group. Marine sedimentation continued uninterruptedly across the Tongaporutuan-Kapitean boundary in western Hawke's Bay, with deposition of Rakaita Siltstone Member (Waitere Formation). The marine connection between East Coast and Wanganui Basins remained open into the Lower Kapitean. During the "middle" Kapitean it appears as though the western margin was uplifted, followed in upper parts of the Kapitean by subsidence. This uplift produced the unconformity between Rakaita Siltstone Member and Mokonui Sandstone cropping out at the Napier-Taupo Road. Water depths were greater to the northeast in the Maungaharuru Range, and the transition here appears to be gradational. Mokonui Formation was deposited over the Maungaharuru and Te Waka Ranges from the "middle" Kapitean into the Lower Opoitian. By the Upper Kapitean, the Kuripapango region had subsided to shallow shelf water depths, and the Blowhard Formation deposited, mostly over Torlesse basement. The presence of Tongaporutuan sediments at Kuripapango, preserved in a down-faulted block between the Ruahine and Glenross Faults, indicates uplift and possible erosion in this area prior to deposition of the Blowhard Formation. Bathyal water depths were certainly present here before deposition of the Blowhard Formation. The seaway connection between Wanganui and East Coast probably became closed to very restricted during the "middle" and upper parts of the Kapitean, and opened for a short period of time in the uppermost Kapitean (Enclosure 6, Map 3). Coevally, Matemateaonga Formation was deposited along western parts of the axial ranges.

Outer shelf to bathyal deposition continued over the accretionary wedge during the Kapitean, and outer shelf to upper bathyal deposition was recorded in Hawke Bay-1 (BP Shell Aquitane Todd Petroleum Development Ltd 1976).

EARLY PLIOCENE

Sedimentation during the Pliocene was typically more varied and localised than that in the Miocene. Stratigraphic units became more diverse, and the widespread, thick, relatively monotonous formations typical of the Tolaga Group were replaced by rapidly interdigitating shelf-

dominated formations of the Mangaheia Group. Displacement on structures of the North Island Shear Belt began to exert a greater control on the sedimentary history of the study area, and neighbouring structural blocks in the North Island Shear Belt often had different sedimentation histories.

Opoitian (5.28-3.6 Ma)

The Opoitian (Enclosure 6, Maps 4 and 5) records the deposition of the first Te Aute lithofacies limestones, along the margins of a developing interior seaway ("Ruataniwha Strait"; Beu 1995). The eastern margin of this seaway probably comprised a series of shoaling, shelfal platforms, perhaps with a small number of islets. The western shelf of the basin was narrow, probably only several kilometres wide. It was bounded by a Torlesse basement hinterland of relatively low gradient. This resulted in the earliest constriction of tidal currents through the seaway.

The western basin margin continued to shallow from the Kapitean. The Kuripapango area was probably emergent by the Lower Opoitian, while bathyal Mangatoro Formation was accumulating nearby in the Omahaki Depression, and the Mokonui Sandstone was progressively shallowing upsection from the Patoka to Te Hoe areas (Enclosure 6, Map 4). Shallowing of the Mokonui Sandstone was greatest in the Te Waka Range area, and by late in the Lower Opoitian it was subaerially exposed here, producing the spectacular paleorelief preserved at Hells Hole (see Fig. 15D, F, Appendix I). Erosion of the Mokonui Sandstone occurred from the Te Waka Range to at least as far northeast as the northern end of the Maungaharuru Range.

Lower Opoitian uplift of the Kaweka Range area occurred, resulting in a period of erosion across western hinterland parts of study area. This was followed by "middle" Opoitian subsidence, and deposition of the Mangatoro Formation. Possible "middle" Opoitian uplift on Ruahine Fault in the Pakututu area occurred, resulting in the generation of localised thick greywacke conglomerate in basal beds of the Pakututu Formation. In the Lower Opoitian, Opoiti Limestone Member and Ormond Limestone were deposited in the Wairoa-Tiniroto and Gisborne areas, respectively (Beu 1995; Mazengarb and Speden 2000).

During the Upper Opoitian (Enclosure 6, Map 5), Titiokura Formation accumulated along northwestern margins of the study area as part of a continent-attached carbonate depositional system (Bland *et al.* 2004, 2005; Caron *et al.* 2004a). Upper Opoitian parts of the Titiokura Formation were deposited from at least the Putere Lakes in the northeast, to the central parts of the Maungaharuru Range in the southwest. Kairakau Limestone accumulated along the eastern margin of the seaway from Te Mata Peak to as far south as Patangata. Accumulation of Pakututu Formation (including the Hukanui Limestone Member) in the Puketitiri area, occurred

adjacent to a rocky coastline, probably in a large embayment. Mangatoro Formation continued to accumulate at Kuripapango, Omahaki, the accretionary wedge (Cape Kidnappers, Maraetotara Plateau,) and southern Hawke's Bay (Leslie, 1953; Harmsen 1985). Upper Opoitian shallowing is recorded in the Omahaki Depression, where upper bathyal Mangatoro Formation is overlain by shallow-water Omahaki Formation. Mangatoro Formation at Kuripapango remained shelfal through this time.

Lower Opoitian Haupori Sandstone crops out in the Maraetotara Plateau and Cape Kidnappers area (Francis 1993), and was reported in Hukarere-1 (Westech Energy New Zealand Ltd 2001). Haupori Sandstone was deposited at about middle shelf depths in the Maraetotara area (Francis 1993), and near the shelf break in Hukarere-1 (Westech Energy New Zealand Ltd 2001). Haupori Sandstone was then overlain by Mangatoro Formation, which represents the remainder of the Opoitian in these areas. During the Opoitian, outer shelf to upper bathyal mudstone was deposited over Hawke Bay-1 (BP Shell Aquitane Todd Petroleum Development Ltd 1976).

LATE PLIOCENE

Waipipian (3.6-3.0 Ma)

The Waipipian (Enclosure 6, Maps 6 and 7) was characterised by the development of carbonate banks in the northwest and southeast of the study area, and uplift and erosion along the North Island Shear Belt from Patoka to at least as far south as the Takapau Plains. Waipipian beds are not very widespread in outcrop in the study area, reflecting in many places a period of non-deposition and erosion. The eastern basin margin was partially emergent by this time, and probably consisted of an archipelago. Along the western margin the shoreline was irregular and rocky, with an emerging basement hinterland, and areas of uplifted Cretaceous, Paleogene, and Neogene sediments. The western continental shelf continued to grow in the Waipipian, reflecting general uplift of the basin margin and progradation of the sedimentary pile. Widespread uplift occurred across central parts of the forearc basin during this time. Subaerial exposure is recorded in Ongaonga-1 and Takapau-1 where Mangapanian limestone overlies Torlesse basement. Extensive carbonate banks developed along western and eastern margins of the basin. Continued growth of fold structures in the Wairoa area allowed for deposition of the Whakapunake and Tahaenui Limestones. There was probably no connection through to Wanganui Basin in the Kuripapango Strait at this time with the seaway closed.

During the Lower Waipipian (Enclosure 6, Map 6) deposition of Puketitiri Formation over Pakaututu Formation occurred in the Puketitiri area. In the Maungaharuru Range during this time,

deposition of the Titiokura Formation stopped, and Pohue Formation began to accumulate. Titiokura Formation accumulated about the Te Waka Range. Around Napier and Taradale, the Taradale Mudstone began to accumulate, overlying Eocene rocks (Darley and Kirby 1969).

Uplift of the Kuripapango area occurred, followed by a period of erosion and non-deposition. Uplift appears to have been focused on the Ruahine and Glenross Faults. The Maungaharuru Range remained submarine, with a progressively deepening pattern towards the north of the range. A depocentre was present around the Raupunga and Willowflat areas in the northeast, and the Taradale-Hastings area in the southeast.

Waipipian erosion occurred in the Ohara Depression, with almost total removal of Opoitian Mangatoro Formation. Uplift occurred on the Ruahine, Mohaka, and probably the Wakarara Faults. Sedimentation continued to the east of the Wakarara Block as Waipipian rocks were recorded in Kereru-1 (Johnston and Francis 1996).

The accretionary wedge continued to shoal, resulting in tidal currents becoming more constricted in the seaway. There was probable emergence along parts of the accretionary wedge as it continued to encroach inboard into the basin fill. Along this rising ridge the Awapapa and Rotookiwa Limestones accumulated as detached carbonate factories atop reverse-fault-cored anticlines and thrust ridges (Caron *et al.* 2004a). The Awapapa Limestone accumulated in the Lower Waipipian and Rotookiwa Limestone in Upper Waipipian, with the Pukekura Calcarenite deposited between the two units. Black Reef Calcareous Sandstone was deposited around the Cape Kidnappers area as the northern end of the Maraetotara Plateau began to shoal. This may have been due to growth of the Kidnappers Anticline. It is uncertain when the Cape Kidnappers area emerged, but it had probably occurred by the Nukumaruan.

Although it remains unclear when the Opau Stream area was uplifted, the area was certainly emergent during the Waipipian, before subsiding again in the Lower Mangapanian.

Mangapanian (3.0-2.4 Ma)

During the Mangapanian (Enclosure 6, Maps 8 and 9), the interior seaway was at its most extensive, with significant areas of carbonate banks accumulating along both margins. Large volumes of greywacke conglomerate began entering the basin in the Upper Mangapanian. The inboard margin of the accretionary wedge was by this time becoming well exposed and, as in the Waipipian, probably constituted an archipelago. It was probably shallow enough between islets and islands to constrict tidal flow through the interior seaway, which itself was open at both its northern and southern ends. The continent-attached western shelf was becoming more extensive

due to uplift of the western margin of the basin, and progradation of siliciclastic sediments. The western side of the basin was swept by strong tidal currents, with giant cross-bedded limestone deposited at Hukanui hill (Puketitiri). Continent-detached carbonate factories, developing on structural highs in the accretionary wedge, were also swept by these currents. Seaway connections were open between East Coast Basin and Wanganui Basins through the Kuripapango and Manawatu Straits, with a semi-emergent basement island present around the modern Ruahine Range (Enclosure 6, Maps 8 and 9). The Kaweka Range was probably partially exposed, and basement around the Ahimanawa, Ikawhenua, and Huiarau Ranges was also emergent. The strong tidal currents through the basin acted to transport significant amounts of siliciclastic sediment north into the Waikare and Raupunga areas. These areas remained depocentres throughout the Mangapanian, with outer shelf to uppermost bathyal beds deposited. Shelfal deposition occurred about the lower reaches of the Mohaka River (Beu and Maxwell 1990).

In the Lower Mangapanian (Enclosure 6, Map 8), a rocky greywacke coastline extended from the Ohara Depression to at least as far north as Hawkston Station. Northeast of these areas the coastline was probably more regular, with uplifted Late Neogene sediments exposed in the hinterland. Puketitiri Formation was deposited on basement from the Ohara Depression to the Glenross Range (e.g. Fig. 7.8). This reflects submergence of the basement block underlying the Ohara Depression, and infers displacement on the Ruahine, Glenross, and Mohaka Faults. The Puketitiri Formation in the Ohara Depression continued to accumulate at shelf depths until the Sentry Box Formation was deposited during the lowermost Nukumaruan, probably after a small period of uplift.

The Te Waka Formation represents a succession of carbonate banks that migrated southwest through time, so that the oldest beds occur at the type section in the northeast (Te Waka Trig), and the youngest beds occur in the southwest (Awapai Station). At Sandy Ridge (Kuripapango), Hawkston Station, and Opau Stream, Te Waka Formation accumulated over basement, as well as overstepping the various formations that had been uplifted and eroded during the Waipipian in the Kuripapango area. Along the Glenross Range, Te Waka Formation also overlay parts of the Puketitiri Formation, before grading into it at Awapai Station at the southern end of the Glenross Range. No Te Waka Formation is evident south of the Ngaruroro River indicating that the Mangapanian western margin carbonate banks did not develop this far south. However, while Te Waka Formation continued to accumulate into the Upper Mangapanian around Kuripapango and Awapai Station, Puketitiri Formation accumulated in the Ohara Depression (Fig. 7.8). During this time, to the northeast, Pohue and Matahorua Formations were deposited. Along the Te Waka Range, Te Waka Formation continued to accumulate.

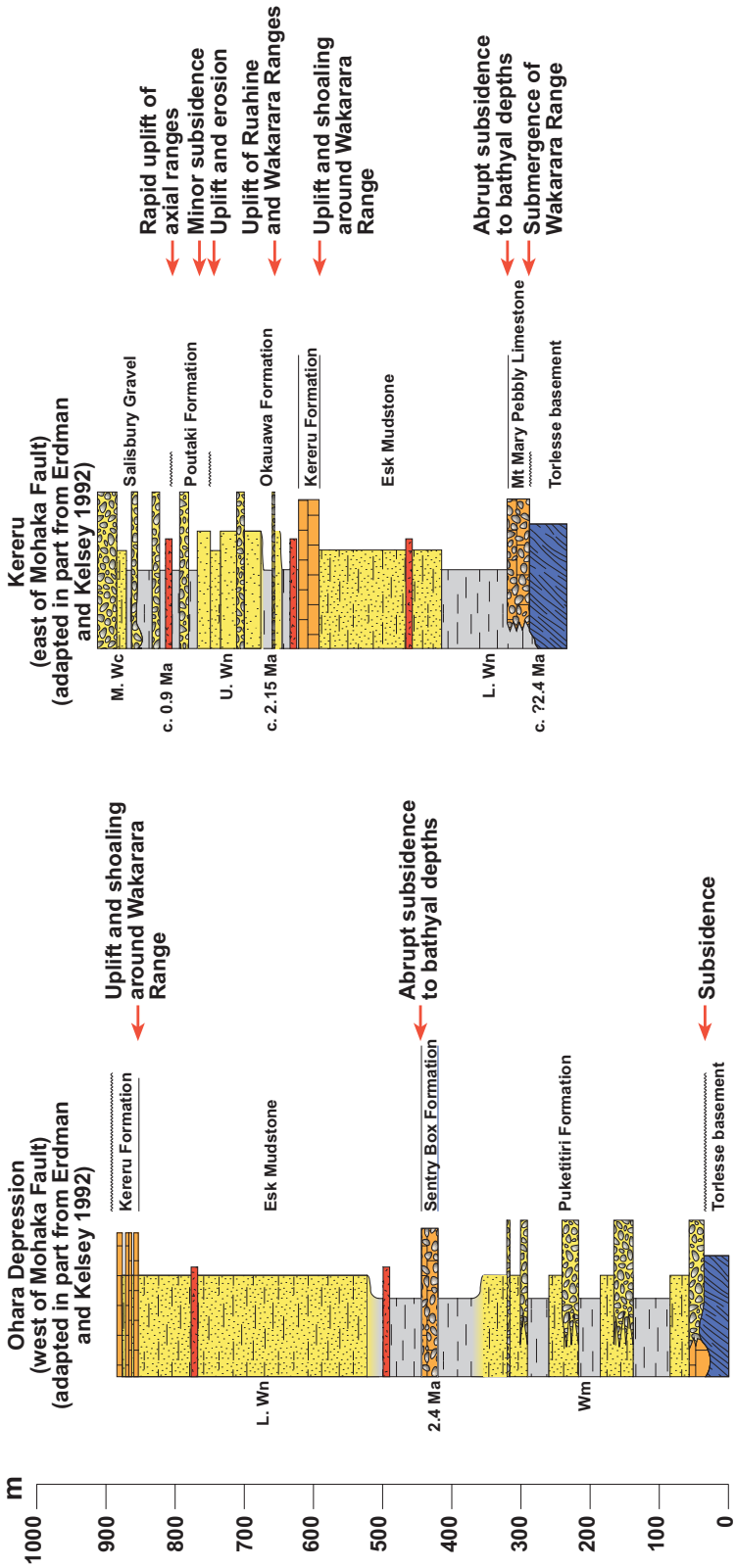


Fig. 7.8: Composite stratigraphic columns of the Ohara Depression (axial range domain) and Kereru area (range front contractional domain), illustrating significant events in the geological history of this part of the basin. These areas record the Late Pliocene-Castlecliffian intensification of deformation on the North Island Shear Belt.

Subsidence of the western margin of the basin in the Lower Mangapanian occurred outside of the study area, as indicated by the deposition of limestone beds overlying basement in Ongaonga-1 and Takapau-1. In Hawke Bay-1, middle shelf deposition continued uninterruptedly from the Waipipian. Mangapanian rocks in this well are mostly sandy siltstone lithofacies, although a 12 m-thick interval of coquina limestone was reported, suggesting the development of a carbonate factory on the structure (BP Shell Aquitane Todd Petroleum Development Ltd 1976).

The axial ranges were progressively becoming more uplifted during this stage, and by the Upper Mangapanian (c. 2.48 Ma) the first major influx of Torlesse greywacke conglomerate deposits entered the basin, represented by the Deep Stream Member (Matahorua Formation) (Fig. 7.9; Enclosure 6, Map 9). These conglomerate beds, of which four in total have been identified, were associated with the basinward progradation of fluvial braidplain systems during periods of eustatic sea level fall and lowstand. With each successive progradation, the extent of the braidplain increased, and by the lowermost Nukumaruan extended from the Tutaekuri River in the south, to Willowflat Road in the north.

The Te Waka Formation is overlain by the Pohue Formation which, like the Te Waka Formation, also youngs to the southwest. The Pohue Formation began accumulating in the Lower Waipipian in the Maungaharuru Range, while Titiokura Formation was accumulating around the Te Waka Range. By the Lower Mangapanian, Te Waka Formation had been deposited on the Te Waka Range, and was overlain by the Pohue Formation.

Although some cyclothemic rocks are evident in Upper Opoitian-Lower Waipipian parts of the Titiokura Formation (Bland *et al.* 2004), prominent cyclothemic intervals became evident in sedimentary record in the Te Waka and Pohue Formations.

During the Upper Mangapanian the southeastern margin of the study area continued to rise, and the underlying accretionary wedge progressively migrated inboard. The Te Onepu Limestone was deposited along the rising Raukawa Range during this time (Enclosure 6, Map 9).

LATEST PLIOCENE-PLEISTOCENE

Nukumaruan (2.4-1.63 Ma)

The Nukumaruan (Enclosure 6, Maps 10-13) was characterised by the development of prominent cyclothemic intervals, and by the dramatic intensification of deformation in both the North Island Shear Belt and accretionary wedge. Regular sea-level oscillations of about 60-70 m occurred

throughout this stage (Beu 1995). The eastern margin was probably a relatively elevated, continuous landmass by this time. The interior seaway was open at its northern and southern ends in early parts of the Nukumaruan, although the southern end was closed by the Upper Nukumaruan. Limestone deposition is recorded from both the lowermost and upper parts of the stage, although is absent from middle parts. Sediment flux was high throughout the stage, from about 0.3-2.6 m/k.y. (Fig. 7.10). The basal Nukumaruan records the short-lived northward migration of a subantarctic fauna into southern North Island (Orpin *et al.* 1998; Beu 1995).

In the lowermost Nukumaruan (Enclosure 6, Map 10), limestone of the Sentry Box Formation was deposited along the western margin of the basin from the Ohara Depression (Fig. 7.8) to Kuripapango. Further north, cyclothemic shelfal beds of the Matahorua Formation (Papakiri and Grassy Knoll Conglomerate Members) were deposited. The presence of shallow-marine Sentry Box Formation, preserved on the Ruahine and Kaweka Ranges, demonstrates that these ranges were mostly submarine in basal Nukumaruan time. In the Ohara Depression, Sentry Box Formation overlies Puketitiri Formation. The contact is gradational in central parts of the depression, and unconformable in northern parts, indicating shallower water depths in the northern area (Erdman and Kelsey 1992). The deposition of thick greywacke conglomerate beds in the Matahorua Formation during this time (Fig. 7.9) indicates, however, that a substantial area of basement hinterland must have been present. The fluvial braidplain of the Matahorua Formation was at its greatest extent in the lowermost Nukumaruan, extending from Waiwhare in the southwest, to at least Willowflat Road in the northeast (Enclosure 6, Map 11). Coevally, along the eastern side of the basin, Scinde Island Formation, Mason Ridge Formation, and Pakipaki Limestone were deposited on and around structural highs inferred to be associated with the accretionary wedge. Around these structural highs the Taradale Mudstone continued to accumulate at shelf water depths.

During the Lower Nukumaruan, the Wakarara Range was shoaling to semi-emergent, and deposition of Mount Mary Pebbly Limestone occurred around its flanks. Rapid, tectonically-driven subsidence then occurred across the study area at about 2.36-2.3 Ma. The focus of subsidence appears to be around the Ohara Depression, where shallow marine Sentry Box Formation is abruptly overlain by upper bathyal (c. >200 m) mudstone of the Esk Mudstone (Fig. 7.8; Beu *et al* 1977). This event caused subsidence of the Wakarara Range, allowing Esk Mudstone to be deposited over both Mount Mary Pebbly Limestone and Torlesse basement. In the Esk River area, Grassy Knoll Conglomerate Member was overlain by Esk Mudstone and, further north, Esk Mudstone overlay Waipunga Formation (Fig. 7.9). Sedimentation rates during the deposition of the Esk Mudstone generally decreased away from the Ohara Depression, from c. 2.6 m/k.y. in the Ohara area to c. 0.5 m/k.y. in the Tangoio Block (Fig. 7.10). Immediately northeast of the study

area, Upper Mangapanian shallow-marine (inner shelf) sandstone beds in the lower reaches of the Mohaka River were overlain by Lower Nukumaruan flysch, illustrating that the subsidence event affected the basin at least this far outboard. It is uncertain what effect this event had on the eastern margin of the basin where shelfal Scinde Island Formation, Mason Ridge Formation, and Pakipaki Limestone were accumulating, as no overlying Mangaheia Group beds of this age are preserved. Certainly, Taradale Mudstone continued to accumulate around the Napier and Maraekakaho areas. It is possible that the structural highs at Scinde Island, Mason Ridge, and Pakipaki remained elevated during this period, and that no overlying beds were deposited.

Esk and Taradale Mudstones continued to accumulate across the study area through the Lower Nukumaruan until about 2.2 Ma. In the Ohara area the Wakarara Range began to rise again at this time, and by about 2.15 Ma it was partially emerged. However, the main uplift of the Wakarara Range probably didn't occur until after deposition of the Poutaki Formation (Erdman and Kelsey 1992), estimated to be about 1.7-1.6 Ma. Uplift of the Wakarara Range, centred on displacement on the Big Hill-Ohara Depression section of the Mohaka Fault, resulted in the deposition of Kereru Formation around and on the range (Fig. 7.8). It is likely that the Ruahine and Kaweka Ranges also began to rise, finally closing off the connection between Wanganui and East Coast Basins. Motion on the Wairarapa Fault at this time also uplifted the Mount Bruce basement block in the Wairarapa, closing off the interior seaway at its southern end. The area north of the Ohara Depression continued to accumulate Esk and Taradale Mudstones until c. 2.15 Ma when cyclothemic deposits again began to accumulate, recorded in the Petane and Okauawa Formations. Braidplain progradation was renewed at this time, but occurred from two regions, rather than the single system of the Matahorua Formation. During sea level lowstand, a braidplain extended from the Ohara Depression northeast to Flag Range and Mount Cameron, depositing conglomerate beds of the Kikowhero and Whakamarumaru Members (Okauawa Formation) (Enclosure 6, Map 12). At the same time, another system prograded over the Tangoio Block and as far southwest as Glengarry Road. Conglomerate beds in the Tutira and Darkys Spur Members were deposited by this fan (Fig. 7.9). It is inferred that the two systems then merged into one system, with two main areas of sediment source, with the Flag Range Conglomerate Member (Petane Formation; c. 1.84 Ma) a result of this. Although not preserved, it is inferred that fluvial systems also existed during deposition of upper members of the Petane Formation, based on the presence of common to abundant basement clasts in the Tangoio and Waipatiki Limestone Members (Petane Formation).

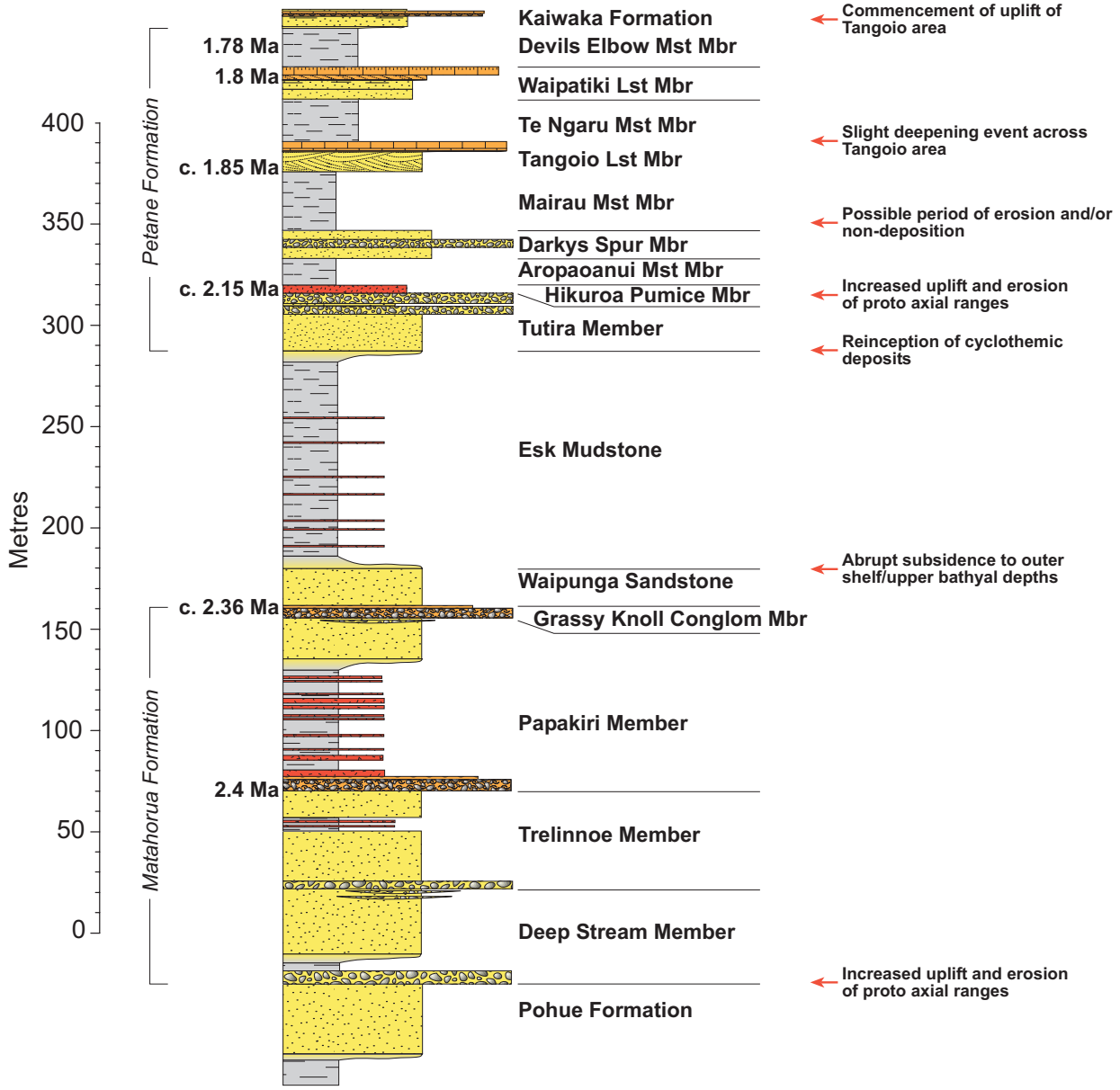


Fig. 7.9: Composite stratigraphic column of the Esk-Tangoio area, illustrating significant events in the geological history of this part of the basin (central forearc basin domain). The Esk-Tangoio area lies between the North Island Shear Belt and the accretionary wedge, and has not become involved in the deformation and growth of either area.

The Tutira Member is overlain by the Hikuroa Pumice Member, recording the influx of very large amounts of volcaniclastic sediments into the basin. It is possible that the Hikuroa Pumice Member may be the result of the eruption of the either the Waiteariki Ignimbrite from the Kaimai Volcanic Centre, or one of the Papamoa Ignimbrites from the Tauranga Volcanic Centre, both of which were described by Briggs *et al.* (2005).

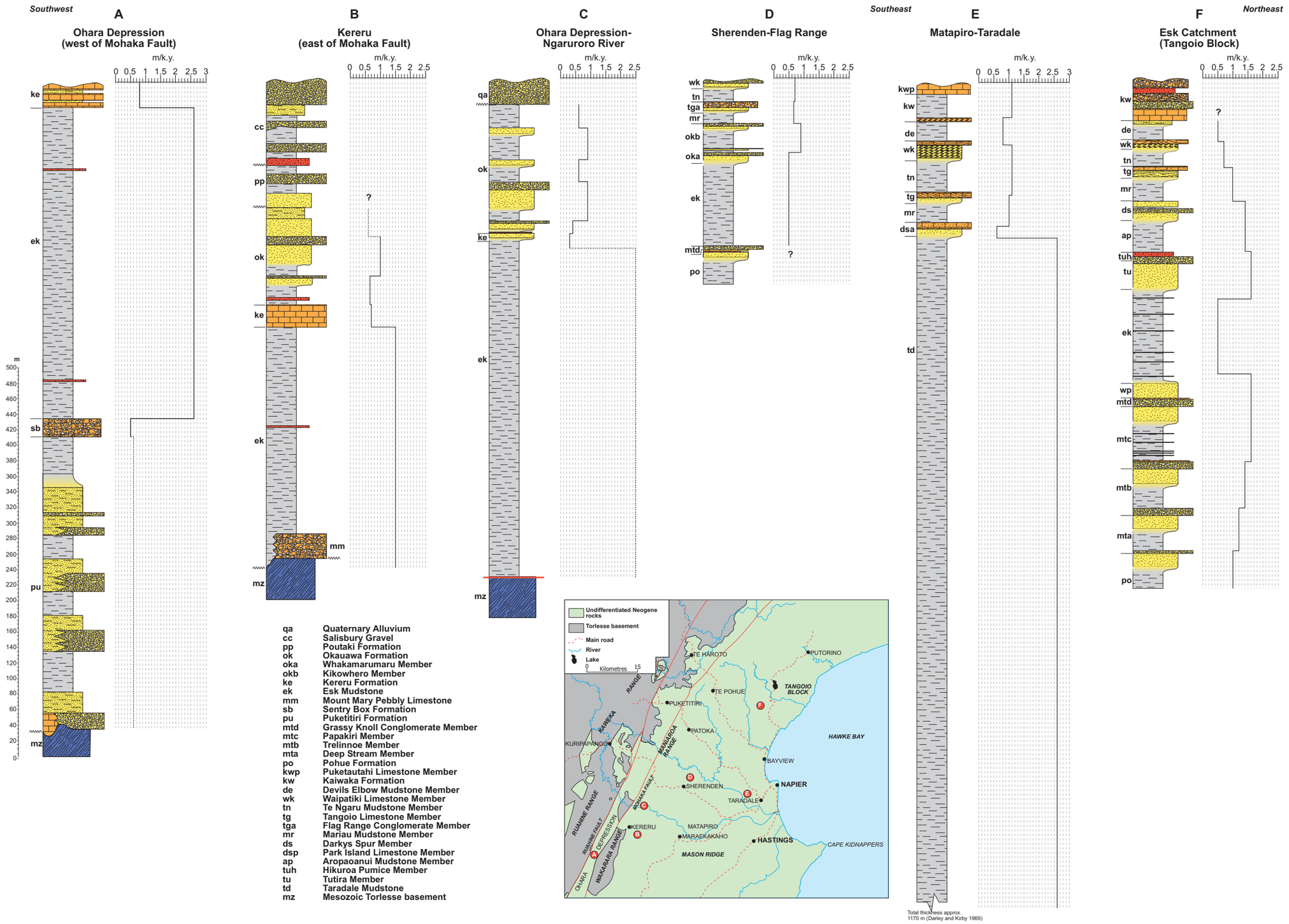


Fig. 7.10: Sedimentation rate plots (m/k.y.) for Nukumaruan Mangaheia Group rocks in central and western parts of Hawke's Bay. No allowance has been made for compaction so these are minimum rates. Cyclothemic intervals assume a 41 k.y. periodicity of sea-level change.

Along the most inboard parts of the accretionary wedge, structural highs at Taradale, Fern Hill, and Roys Hill began to rise. This occurred at about the same time as basement blocks in the North Island Shear Belt began to uplift again. By c. 2.1 Ma the Taradale, Fern Hill, and Roys Hill areas had reached a point where carbonate factories developed upon them, and the Park Island Limestone Member was deposited during regressive and transgressive parts of a sea-level oscillation (Enclosure 6, Map 12). It is inferred that the highs became subaerially exposed during sea level lowstand. Around the location of Whakatu-1, Taradale Mudstone continued to accumulate, although to the north and west shelfal beds of the Okauawa and Petane Formations accumulated.

By the Upper Nukumaruan (Enclosure 6, Map 13), the western shoreline was probably heavily indented, with numerous bays, estuaries, and harbours, particularly during periods of sea level lowstand when the braidplains were at maximum progradation. The eastern shoreline was much smoother, with the landmass being a long narrow island to peninsula.

Shoreline retrogradation occurred between deposition of the Darkys Spur Member and Devils Elbow Mudstone Member from the Tangoio to the Matapiro areas, indicating a short-lived period of subsidence at about 1.8 Ma. Marine sedimentation in much of the study area ceased in the Upper Nukumaruan, the emergence recorded by the varied lithofacies in the Kaiwaka and Poutaki Formations (about 1.7-1.6 Ma; Enclosure 6, Map 13). The Matapiro area probably remained more fully marine longer than the Tangoio Block and Napier-Puketapu areas, judging by the presence of the thick, Puketautahi Limestone Member in the Kaiwaka Formation.

MIDDLE TO LATE PLEISTOCENE

Castlecliffian (1.63-0.34 Ma)

Approximately 600 k.y. into the Castlecliffian, after deposition of the Mangaheia Group, the Kidnappers Group beds were deposited. The Castlecliffian was characterised by the deposition of thick, non- to marginal-marine beds, dominated by conglomerate and gravel beds.

The Big Hill Fault had developed in the Lower Castlecliffian, elevating the Big Hill block. At about 1 Ma the Ruahine Ranges began to rapidly rise. This coincides with the time Erdman and Kelsey (1992) suggested that the Big Hill Fault began to accommodate some strike-slip displacement. Many contractional structures formed in the Ohara Depression during this period, including the Herricks Syncline and Anticline, and the Matapuna Fault. The Balcony Syncline probably formed due to uplift of the Wakarara Range on the Big Hill-Ohara Depression section of the Mohaka Fault.

The Wakarara Fault continued to displace basement, with the Wakarara Range rising. Rocks along the eastern margin of the Wakarara Range continued to become involved in the Wakarara Monocline. To the north in the Kuripapango area, the Miroroa Thrust (described by Browne 1986) was probably active during this time. It was interpreted by Beanland (1995) as a cross-fault or relay structure between the Comet and Ruahine Faults.

Also at about 1 Ma, the rate of uplift of the axial ranges dramatically increased, especially those ranges south of Kuripapango. This resulted in a very large flux of greywacke detritus entering central Hawke's Bay during this time, and the widespread deposition of thick greywacke gravel and conglomerate beds as part of the Kidnappers Group. The uplift of the axial ranges was mirrored by subsidence at Cape Kidnappers. The Cape Kidnappers area had probably been emergent since the Nukumaruan, due to uplift of the accretionary wedge. This uplift resulted in the angular unconformity present between the Waipipian Black Reef Calcareous Sandstone (Mangaheia Group) and the Castlecliffian Maraetotara Sandstone (Kidnappers Group). The non-marine Salisbury Gravel was deposited about the Salisbury Terraces, and represents the deposits of significant river systems that were transporting sediment to a marginal-marine Cape Kidnappers.

Although the various s of the Mohaka Fault appear to have been active during the Neogene, inception of dextral-slip displacement on Mohaka Fault has probably occurred only since 0.5 Ma (e.g. Beanland 1995; Beanland *et al.* 1998). This is inferred to be due to continued differential rates of rifting in the TVZ, and rotation and contraction of eastern North Island. An inferred migration of some degree of strike-slip motion from the Ruahine to Mohaka Faults is suggested by the presently higher rates of dextral offset on the Mohaka Fault.

LATE QUATERNARY

Haweran (0.34 Ma-present)

The Hawke's Bay area was almost entirely non-marine by the Haweran, and by 300 k.y. virtually the entire inner forearc was uplifting. Beanland (1995) suggested that regional uplift of this area since the Late Quaternary has been driven by a deep-seated crustal process, probably related to crustal thickening by sediment underplating. Reyners *et al.* (2006) suggest that subduction of the buoyant Hikurangi Plateau is driving uplift of the forearc basin.

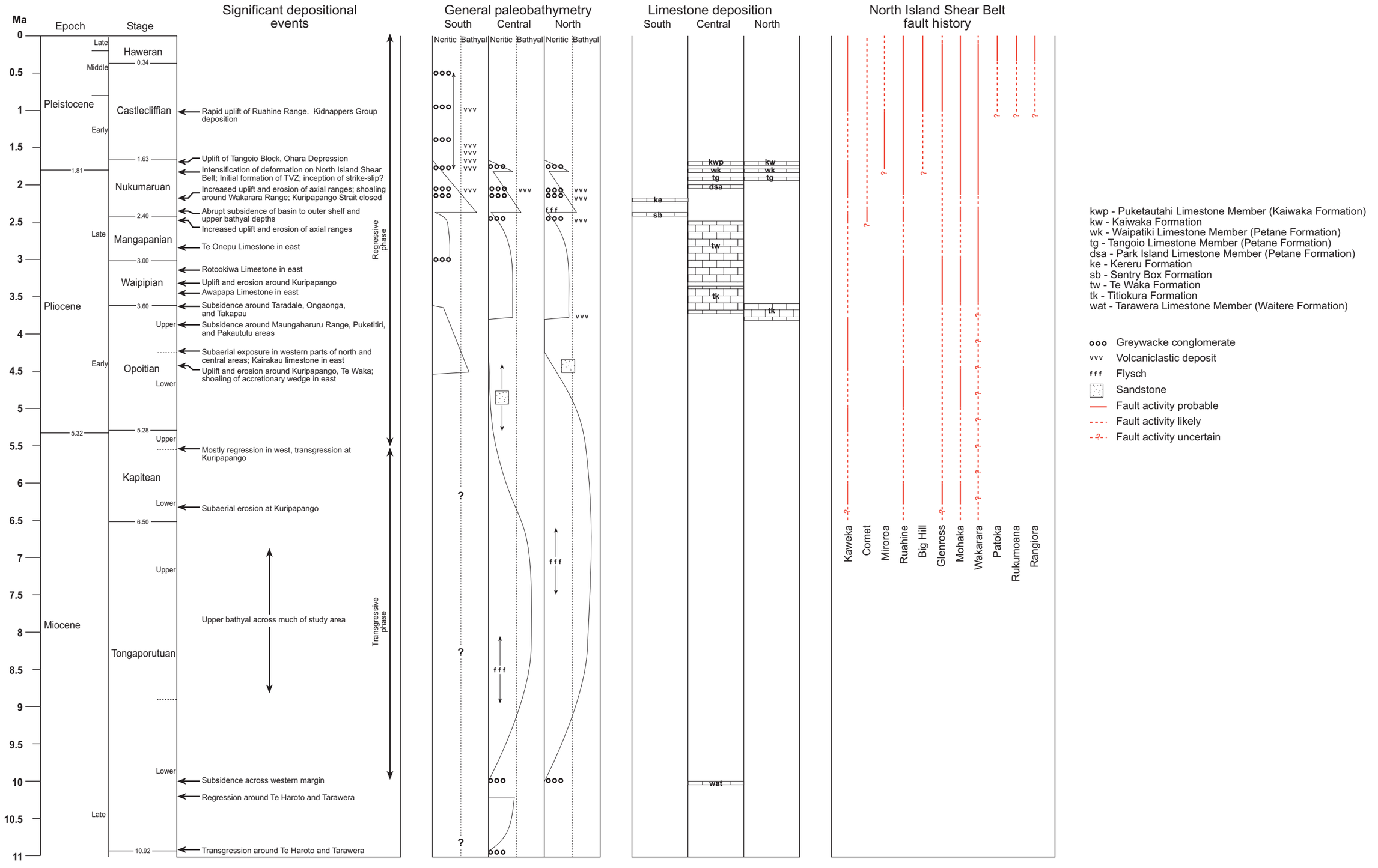


Fig. 7.11: Diagramatic summary of the generalised subsidence, uplift, and depositional history of the study area. "South" refers in general to the area around the Ohara Depression, "Central" to the area around Kuripapango, Patoka, and the Te Waka Range, and "North" the area north of the Napier-Taupo Road. Timescale is adapted from Cooper (2004).

In the Ohara Depression, the Ruahine Fault is presently moving at 1.0-2.0 mm/yr (Raub *et al.* 1987; Erdman and Kelsey 1992) and the Mohaka Fault is moving at 3.0-4.0 mm/yr. Dextral-slip continued to migrate outboard with on-going rotation of eastern North Island. The Mohaka Fault was almost certainly accommodating dextral-slip by the Haweran (Beanland *et al.* 1998), and the Patoka and Rangiora Faults began accommodating dextral-slip in the Holocene (Cutten *et al.* 1988; Halliday *et al.* 2003).

SUMMARY

Figure 7.11 presents a diagrammatic summary of the geological history of the study area over the past 11 m.y. It illustrates the significant depositional events documented for the Late Neogene succession. The basin fill has mostly been siltstone-dominated. Periods of notable flysch, limestone, conglomerate, and volcaniclastic deposition are indicated on Fig. 7.11, in association with generalised paleobathymetric curves. Of note is the significant period of bathyal deposition in the Late Miocene, and the neritic-dominated phase of deposition from the Early Pliocene to present. Limestone, conglomerate, and volcaniclastic deposition has also mostly occurred in this latter phase. The fault history of major structures within the North Island Shear Belt is summarised, indicating periods of activity on these faults.

CHAPTER EIGHT

SUMMARY

This chapter summarises the main results, interpretations, and conclusions presented in this thesis.

LITHOSTRATIGRAPHIC OVERVIEW AND ISSUES

A revised and comprehensive lithostratigraphy is provided in this thesis for the Neogene sedimentary succession cropping out in central parts of Hawke's Bay. Where possible, previously defined groups, formations, and members have been retained and their extent mapped and applied within the study area in an attempt to work towards a more unified regional lithostratigraphy. Neogene rocks of Early Miocene to Middle Pleistocene (Otaian to Castlecliffian) age, cropping out over an area of about 5 700 km^2, have been described and geologically mapped at 1:50 000 scale, as a basis for the 1:250 000 QMAP series (Enclosure 1, Sheets 1-6; Enclosure 2). Geological cross-sections are constructed from the 1:50 000 maps (Enclosure 3). Lithostratigraphic and lithofacies correlation panels are presented in Enclosures 4 and 5.

Basement rocks of the Torlesse composite terrane have been mapped, but not differentiated according to their structural divisions and domains. The overlying Neogene succession has been subdivided into three lithostratigraphic groups: Tolaga Group (Miocene-Early Pliocene, or Otaian-Lower Opoitian), Mangaheia Group (Late Miocene-Early Pleistocene, or Upper Kapitean-Upper Nukumaruan), and Kidnappers Group (Middle-Late Pleistocene, or Castlecliffian).

The Tolaga Group, which has been extended southwards from the QMAP Raukumara area (Mazengarb and Speden 2000), comprises the Whakamarino Formation, Poamoko Formation (Ngatapa Sandstone Member, Arapaepae Alternating Member, and Kingma Peak Mudstone Member), Te Haroto Formation (new), Waitere Formation (Tarawera Limestone Member (new), Te Ipuohape Sandstone Member, Auroa Alternating Member, and Rakaita Siltstone Member), and Mokonui Sandstone.

A significantly revised lithostratigraphy is proposed for the Late Miocene-Early Pleistocene succession in central parts of the forearc basin in Hawke's Bay, encompassed in the Mangaheia Group. The Mangaheia Group has also been extended from the QMAP Raukumara area into the current study area. Most changes to the lithostratigraphy in this group have been made in the

Nukumaruan part. It is proposed that the Hawke's Bay, Petane, Napier, and Poporangi Groups, as defined by Haywick *et al.* (1991) and Beu (1995), be abolished and become incorporated into the Mangaheia Group. Petane Group is demoted to Petane Formation. Most formations previously defined within the Petane Group are now defined as members of the Petane Formation. Due to their thickness and lateral extent, the Esk Mudstone and Kaiwaka Formation are maintained as separate formations. The lithostratigraphic units cropping out in the Ohara Depression-Kereru area, as mapped by Erdman and Kelsey (1992) and Beu (1995), have been correlated with units to the north and east in the field area. The Kaumatua Formation of Erdman and Kelsey (1992) is now included in the Puketitiri Formation and removed as a name. The Sentry Box Formation is defined to include the Whanawhana Limestone and Seconds Ridge Conglomerate units of Beu (1995). The Ohara Mudstone is now subsumed into the Esk Mudstone. Correlations of lithofacies and lithostratigraphic units within the Nukumaruan part of the Mangaheia Group are illustrated in Enclosure 5.

With the exception of the Salisbury Gravel, no other differentiation of units within the Kidnappers Group has been attempted in this thesis.

BIOSTRATIGRAPHY AND AGE

An integrated biostratigraphy and sequence stratigraphy (in parts of the succession) has been developed for the basin fill. This is based mostly on macrofossil biostratigraphy, particularly pectinid biostratigraphy, along with known positions of one paleomagnetic transition and some independently dated tephra beds. The lineage of pectinid species of the genera *Sectipecten, Mesopeplum, Phialopecten,* and *Towaipecten* has proven to be useful in the identification of New Zealand stages in shelfal parts the basin fill in Hawke's Bay. Some microfossil samples have yielded stage designations, particularly in the Tolaga Group.

The base of both the Titiokura and Te Waka Formations appears to become younger from northeast to southwest. Titiokura Formation in the northern Maungaharuru Range is of Upper Opoitian-lowermost Waipipian age, whereas it is mostly Waipipian in the Te Waka Range. Te Waka Formation is of uppermost Waipipian to Lower Mangapanian age at the northern end of the Te Waka Range, but is of Upper Mangapanian age in the Glenross Range. Likewise, the age of the overlying Pohue Formation decreases from Lower Waipipian-Mangapanian in the Maungaharuru Range to uppermost Mangapanian in the Waiwhare area.

Cyclothemic intervals within the Upper Mangapanian-Upper Nukumaruan part of the Mangaheia Group provide a framework for an integrated biostratigraphy, utilising molluscan biostratigraphy,

tephra correlation to ODP 1124, and the position of a paleomagnetic transition. The relatively complete lithostratigraphy cropping out in the Esk River catchment allows ages to be assigned that can then be applied to other parts of the basin through geological mapping and the correlation of horizons, including sequence boundaries. The Mangapanian-Nukumaruan boundary (2.4 Ma) is characterised by the L.O. of *Phialopecten triphooki* and less commonly by the L.O. of *Zygochlamys delicatula*. It is also marked by the H.O. of *Crassostrea ingens* and *Maoricardium spatiosum*, among several other extinctions. This boundary occurs at the base of the lower shellbed in the Papakiri Member, the base of the Sentry Box Formation, and at or near the base of the Scinde Island Formation. The Mason Ridge Formation is also of Lower Nukumaruan age, based on the occurrence of *P. triphooki* in all three limestone members. The Grassy Knoll Conglomerate Member has an inferred age of about 2.36 Ma, base on the occurrence of *P. triphooki*, and its stratigraphic position above the Papakiri Member. Geological mapping of this horizon into the Sherenden and Waiwhare districts has provided an approximate age marker for the base of the Esk Mudstone in these areas. Tephra correlation using the geochemistry of glass shards in the Hikuroa Pumice Member compared with the composition of tephra in the ODP 1124 core, provides an age of approximately 2.15 Ma for the Hikuroa Pumice Member. Geological mapping suggests a correlation between the Tutira and Hikuroa Pumice Members (Petane Formation) in the Esk River/Tangoio Block area, and the Kikowhero Member (Okauawa Formation) in the Ohara Depression and at Flag Range. The Darkys Spur Member (Esk-Tangoio Block) has been correlated with the Park Island Limestone Member (Taradale-Puketapu), and the upper parts of the Whakamarumaru Member (Ohara Depression-Flag Range). The Tangoio Limestone Member (c. 1.76 Ma) is equivalent to the Flag Range Conglomerate Member, and has been mapped into upper beds of the Okauawa Formation. The Plio-Pleistocene boundary (1.81 Ma) occurs within the Waipatiki Limestone Member (Beu and Edwards 1984; Haywick *et al.* 1991), and has tentatively been correlated into upper beds of the Okauawa Formation. The top of the Olduvai paleomagnetic subchron (1.78 Ma) is located in the Devils Elbow Mudstone Member. It probably also occurs within either the Okauawa Formation or Poutaki Formation. The Kaiwaka Formation is equivalent to uppermost beds of the Okauawa Formation, and the Poutaki Formation.

GEOLOGICAL STRUCTURE

Hawke's Bay has a pronounced NE-SW structural grain that trends parallel to the modern plate interface of the Hikurangi trough. The onshore structure of central parts of Hawke's Bay can be classified into four structural domains, each reflecting different styles and scales of deformation. The domains from west to east are: the axial range domain, the range front contractional domain, the central forearc basin domain, and the eastern contractional domain.

Some of the transcurrent component of the oblique movement of the Australia and Pacific plates on the subduction thrust is inferred to be partitioned across the four structural domains and in particular expressed as oblique (dextral)-slip displacement on faults bordering the axial ranges. The compressive component is expressed as shortening on reverse faults and folds in more eastern parts of the forearc region. The axial range domain involves the eastern parts of the North Island axial ranges, which includes the Ruahine and Mohaka Faults. Some dextral offset is accommodated in the range front contractional domain (e.g.on the Poporangi, Patoka, and Rangiora Faults), although dip-slip displacement is more significant (e.g. Wakarara Fault).

The central forearc basin domain is comparatively undeformed with only minor reverse faulting and force folding. By comparison, the adjacent eastern contractional domain, which comprises the accretionary wedge, is characterised by imbricate reverse and thrust faulting and associated folding. A small degree of dextral-slip is also accommodated in this domain. The highest elevation parts of the accretionary wedge, which occur on land, are currently undergoing gravitationally-driven collapse expressed as deep-seated landslides and normal faulting (Pettinga 2004).

Significant unconformities in the basin fill near the axial ranges may have developed as a result of movement on oblique-slip faults. The prominent and wide (>100 m) fault gouge along the Mohaka Fault at The Organs indicates a pre-Late Miocene period of substantial deformation, as it is overlain by relatively undeformed (Tongaporutuan) Te Ipuohape Sandstone Member (Waitere Formation). However, most deformation of the basin fill in central Hawke's Bay appears to be relatively young (post-Lower Nukumaruan (2.4 Ma)), and much of this has occurred since the early Pleistocene (1.8 Ma). The last phase of dextral-slip on the Ruahine Fault may have commenced c. 1.8 Ma, and on the Mohaka Fault after 0.5 Ma. On the Ruahine Fault this displacement is likely to be less than 10 km in total. Dextral-slip on the Mohaka Fault since the Early Pliocene may only total about 300-500 m. New dextral oblique-slip faults are developing in the basin fill to the east of the Mohaka Fault.

PALEOENVIRONMENTS AND SEQUENCE STRATIGRAPHY OF THE MANGAHEIA GROUP

The description and analysis of numerous outcrops have led to the identification of 41 lithofacies, which have been grouped into six lithofacies assemblages. These include sandstone, siltstone, conglomerate, volcaniclastic, bioclastic, and mixed bioclastic-siliciclastic assemblages. Each assemblage, with the exception of the volcaniclastic one, generally corresponds to a broad depositional environment. Conglomerate facies are mostly of non- to marginal-marine origin.

Sandstone facies accumulated in shoreface/nearshore to inner shelf settings, whereas siltstone facies are usually of middle to outer shelf origin. Bioclastic and mixed siliciclastic-bioclastic facies accumulated mostly in inner to middle shelf settings. The Hawke's Bay part of the forearc basin is a siliciclastic-dominated sedimentary system containing only a limited volume of bioclastic facies, which are nevertheless conspicuous in the landscape forming prominent ranges, strike ridges, and hilltops. Siltstone lithofacies dominate the succession, followed by sandstone, bioclastic, mixed siliciciclastic-bioclastic, and conglomerate facies in decreasing abundance. Volcaniclastic facies are least common, and are mostly restricted to the Late Pliocene part of the basin fill.

Thirty molluscan biofacies associations have been identified from a combination of over 300 field observations and Q-mode cluster analysis of 111 Nukumaruan bulk samples taken during this study, as well as using several dozen field observations from Bland (2001). Sixteen of these groupings have been defined from cluster analysis, the remainder having been defined from field observations. The faunal associations represent a combination of *in situ* (life position) and transported assemblages. Macrofauna from *in situ* associations tend to be well preserved, bivalves are often articulated, and shells are largely unbroken. Faunal diversity in such associations tends to be low to moderate. Reworked assemblages tend to have a higher degree of faunal diversity, but due to their reworked nature the taxa represent mixtures of natural faunal associations (e.g. Haywick 1990). Macrofauna in reworked associations have a high proportion of broken and disarticulated shells, and are usually preserved in cross-stratified beds. Abrasion is a common feature of fossils, particularly of estuarine faunas where they have been mixed with open-marine fauna.

Vail-type sequences are best developed in "middle" Pliocene to Early Pleistocene strata. These sequences are dominated by coarsening-upward packages of siliciclastic sediments, with bioclastic facies increasing in prominence in the younger Upper Nukumaruan cycles. The Plio-Pleistocene sequences are typically 20-80 m thick, and are stacked in a strongly aggradational pattern. The aggradational nature of the succession shows that basin subsidence mostly kept pace with sediment flux for significant periods of time. The inference therefore is that between 20-80 m of subsidence was occurring in the basin every 41 k.y during the Plio-Pleistocene. Times of accelerated subsidence are recorded in the stratigraphic record (e.g. the Esk Mudstone, which lacks obvious sequences), but in general, from the Mangapanian to the Upper Nukumaruan, subsidence and sediment flux were relatively balanced.

Transgressive systems tracts (TSTs) in the study area typically comprise a combination of bioclastic and siliciclastic lithofacies of pebbly sandstone and moderately fossiliferous pebbly

shellbeds (e.g. lithofacies Cg_5, Cg_6, BC_3, MX_3). Highstand systems tracts (HSTs) are dominated by fine-grained siliciclastic-dominated facies that accumulated in wave and storm-dominated environments on a continental shelf (e.g. lithofacies S_4, Z_1, Z_2, Z_3, Z_8, Z_9). They are normally 10-60 m thick. In rare cases, where the shoreward edge of a sequence has been preserved and the beds are very sandy, the vertical extent of HSTs has been inferred. Macrofauna are generally relatively sparse to moderately common throughout HSTs, and are dominated by soft-sediment-dwelling infaunal bivalves such as those in the *Pratulum, Neilo, Dosinia (Kereia),* and *Atrina* associations, and the epifaunal *Talochlamys* association, *Talochlamys-Stiracolpus,* and *Tegulorhynchia-Talochlamys* sub-associations. Regressive systems tracts (RSTs) in the study area can be either siliciclastic or bioclastic-dominated. Siliciclastic-dominated RSTs are most common (facies S_1, S_2, S_3, S_9). Regressive facies are typically well sorted sandstone, and in many cases contain a significantly higher bioclastic content. Although mostly massive, some RSTs may also display prominent cross-stratification. Lowstand systems tracts (LSTs) in the study area are inferred to mostly be characterised by non-marine greywacke conglomerate beds of 2-15 m thickness. These beds (e.g. facies Cg_1-Cg_3) sharply overlie shallow-marine rocks of dominantly sandstone lithology (facies S_1-S_3, S_9) and are produced when high-bedload river systems emerged from a proto-North Island axial range belt onto a low-gradient coastal plain and exposed continental shelf. This process led the river systems to debouch their sediment load producing a low-gradient fan-delta system, much in the manner that the modern braided river systems of the Canterbury Plains and central Hawke's Bay do today.

This study has defined eight basic architectural forms, or "motifs" of sequences for the shelfal sedimentary succession in western and central Hawke's Bay (Fig. 6.12). While these motifs share some similar characteristics, unique combinations of subsidence, sediment flux, and sediment provenance have combined to produce each distinctive motif. Lateral transitions do occur between several of these motifs, and by linking surfaces in them an idealised "shoreline to slope" sequence model has been produced for the Nukumaruan part of the basin succession.

The eight "sequence motifs" described are inferred to represent outcrop windows of different positions across a paleoshelf. Not all of a sequence is preserved in the rock record due to differential uplift and erosion. In these cases, to produce an idealised sequence model (Fig. 6.13), correlation between the outcrop windows helps to better understand the character of a sequence across the shelf. The model sequence developed is two-dimensional, and is intended to illustrate the distribution across a paleoshelf of the various lithofacies, macrofaunal associations, and sequence stratigraphic surfaces.

GEOLOGICAL HISTORY AND BASIN SYNTHESIS

The Neogene geological history of central parts of Hawke's Bay can be usefully subdivided into three major phases, each of which is represented by one of the three lithostratigraphic groups documented in Chapter Three. The first phase, of Early Miocene-Early Pliocene (Otaian-Lower Opoitian) age, is represented by the Tolaga Group. This group comprises four deepening-upward packages (each a separate formation), with shelfal beds at the base passing upsection into bathyal units. This succession is overlain by a thick sandstone (Mokonui Sandstone) which is unconformably overlain by the Mangaheia Group. The Mangaheia Group (Upper Kapitean-Upper Nukumaruan) represents the second major Neogene sedimentation phase, and is characterised by shelfal deposits with some cyclothemic intervals. Occasional upper bathyal beds do occur in the succession, although they appear to represent short-lived depositional phases. The uppermost Neogene sedimentation phase is represented by the Middle Pleistocene (Castlecliffian) Kidnappers Group, which is characterised by thick non- to marginal-marine greywacke conglomerates.

The basin has been substantially inverted along its western side, involving movement on faults of the North Island Shear Belt. New paleogeographic maps of the Hawke's Bay area for the Neogene illustrate the eastward migration of the western basin margin throughout time, and the progressive uplift and inboard encroachment of the accretionary wedge from the Late Miocene-Early Pliocene onwards. It appears that from the Late Pliocene-Late Quaternary new dextral-slip faults have been progressively developing in a basinward direction. The current phases of oblique-slip to dextral-slip displacement in the North Island Shear Belt has occurred since the Late Pliocene, and is inferred to be due to clockwise rotation of the eastern North Island (Fig. 7.2) (e.g. Beanland and Haines 1998; Wallace *et al.* 2004). This rotation has apparently been matched with the southeast translation of the active andesitic volcanic arc south of Coromandel at about 4 Ma to its present day location at the eastern margin of the Taupo Volcanic Zone (TVZ) (Stern and Davey 1987). It is inferred that rifting of the TVZ in the latest Pliocene-Pleistocene is possibly linked to the inception of dextral-slip on the North Island Shear Belt.

The stratigraphic record along the eastern margin of the forearc basin records the development of faulting and folding associated with the accretionary wedge, such that parts of the forearc basin succession have become involved in the accretionary wedge. Sedimentary deposits around the eastern side of the forearc basin were dominated by bathyal units until at least the Late Miocene (e.g. Pettinga 1982). In the Lower Opoitian it appears that the accretionary wedge had developed enough that its associated deformation began to encroach into the forearc basin margin. Initial shoaling of the wedge to shelf water depths by the Upper Opoitian is recorded by deposition of

the Kairakau Limestone (Beu 1995). It is uncertain whether the wedge by this time was emergent, but more probably it resembled a series of shallow-marine platforms extending from Te Mata Peak to at least as far south as Cape Turnagain (Beu 1995). Waipipian Taradale Mudstone overlies Eocene rocks in Taradale-1 (Darley and Kirby 1969), indicating subsidence in this area in the Waipipian. The outcrop pattern of westward-younging Pliocene limestones demonstrates that the inboard margin of the accretionary wedge has migrated toward the centre of the basin over time. Younger limestone beds (e.g. Mason Ridge Formation) presently crop out close to the forearc basin axis and at lower elevations compared with the older Pliocene limestone beds (e.g. Kairakau and Awapapa Limestones) located at the outer margins of the basin.

Uplift of the accretionary wedge, which was shoaling in the Upper Kapitean-Opoitian, and partially emergent by the Waipipian, resulted in the development of an interior seaway, which was most extensive during the Mangapanian. The seaway was characterised by the development of prominent limestone formations (Te Aute lithofacies) along both margins (Nelson *et al.* 2003). Although large volumes of siliciclastic sediment were entering the basin, tidal currents periodically swept the sea floor of siliciclastic sediment, and allowed extensive "continent-attached" carbonate banks to develop along the western side of the basin. Thick "continent-detached" limestone beds developed along the eastern side of the basin due to the elevated positions of accretionary ridges (Kamp and Nelson 1987, 1988; Caron *et al.* 2004a). Breaches in the seaway were present at times in the areas of Kuripapango and the Manawatu Gorge. By the Lower Nukumaruan, the interior seaway became permanently closed to the south with uplift of the Mount Bruce block in the Wairarapa.

While the Late Miocene-Pleistocene part of the basin fill (Mangaheia Group) accumulated during a period of known, regular sea-level oscillations, the important influence on the stratigraphic architecture of the Neogene succession has been the tectonic factor. In comparison to the well developed cyclothemic record in the adjacent Wanganui Basin, the cyclothemic record in the Hawke's Bay area is incomplete and poorly developed. In most parts of the succession, tectonic influences have overprinted glacio-eustatic sea-level fluctuations. Only a limited correlation can be achieved between rocks in the Mangaheia Group and the $\delta^{18}O$ record contained in ODP records, as the sequences are not well enough developed in general to allow for cycle-by-cycle correlations. The fact that obvious sequences can be identified in parts of the Mangaheia Group is often due to the presence of prominent bioclastic beds within siliciclastic-dominated intervals. Significant carbonate production usually occurred during regressive and transgressive periods of sea level. In units such as the Titiokura Formation at Te Pohue, winnowing of bioclastic deposits has effectively condensed the sedimentary succession into a relatively thin limestone interval, masking field-based identification of cyclothems. Such condensation and stacking of bioclastic

sediments also occurred along the accretionary wedge in formations such as the Awapapa and Te Onepu Limestones (Caron *et al.* 2004a, b).

RECOMMENDATIONS FOR FURTHER RESEARCH

Several suggestions and recommendations are presented here for further work. Many of these would help to improve the age model for the basin fill presented in this study. Refining the age model would have implications for better understanding the timing of deformation in the North Island Shear Belt, and for dating the lowest and highest occurrences of biostratigraphically important micro- and macrofossils.

This study has demonstrated that cyclothems, produced by glacio-eustatic sea-level cycles, can be observed in places in the Mangapanian part of the basin fill, particularly in the Pohue and Te Waka Formations. However, the correlation of cycles across interfluves has proven difficult. There is a possibility, with a more focused study, to better define and map cycles within the Mangapanian succession. For example, cycles within the Te Waka Formation from around Puketitiri southwest to Awapai Station could possibly be correlated. This would help to better understand the role that sea-level oscillations may have played in the development of the basin fill, and would improve understanding of the Mangapanian paleogeography of the area.

Several dozen Late Pliocene-Early Pleistocene tephra beds have been observed during the course of fieldwork. It is suggested that geochemical analysis be undertaken on these tephras, in association with the application of dating techniques. This may help to better understand the eruptive history of the Central Volcanic Region, especially the transition from the Coromandel-Tauranga to Taupo Volcanic Zones. Better correlations between tephras in the basin fill may help firm-up correlations between stratigraphic units made in this study, and would also provide an important link between the onland tephra record, and that contained in deep-sea drill-cores such as ODP 1123 and 1124.

The potential exists for developing a better paleomagnetic stratigraphy of the Late Pliocene part of the basin fill. The Matuyama/Olduvai transition is likely to lie within the Petane and Okauawa Formations, the Reunion at about the level of the Tutira Member, and the Gauss/Matuyama within the Pohue Formation. It is probable that enough suitable (mudstone) lithologies are present to allow drilling of samples to determine these paleomagnetic events. Locating such transitions would provide more accurate age markers in the sedimentary succession.

Understanding the development of the forearc basin and the accretionary wedge could be aided by correlation of outcropping strata into seismic lines and hydrocarbon exploration drillholes. This could be linked with further geological mapping. There is much potential in expanding the geological mapping in this study to the north and south of the study area. This would help provide a better link between the QMAP Raukumara and Wairarapa sheets, and would be a positive step towards a more unified regional, East Coast Basin lithostratigraphy. Expanded mapping would also provide an opportunity to evaluate the stratigraphic nomenclature along the eastern side of the basin (Cape Kidnappers south), and to see how it relates to the nomenclature elsewhere in the basin. Further potential for geological mapping and lithostratigraphic evaluation also exists within basement rocks of the Torlesse composite terrane, and beds in the Kidnappers Group.

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ANALYSIS OF THE CENTRAL HAWKE'S BAY SECTOR OF THE LATE NEOGENE FOREARC BASIN, HIKURANGI MARGIN, NEW ZEALAND

A thesis
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of the requirements for the Degree
of
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at
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by

Kyle James Bland



THE UNIVERSITY OF
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Te Whare Wānanga o Waikato

The University of Waikato

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VOLUME ONE, PART TWO

(APPENDICES)



“If we knew what it was we were doing, it would not be called research, would it?”
-Albert Einstein-

Omahaki Depression, the southern Glenross Range, Big Hill, and the Ohara Depression viewed looking southwest from The Lizard, Kuripapango. The Wakarara and Ruahine Ranges form the skyline. Mangapanian (Late Pliocene) Te Waka Formation forms the rocks in the foreground.

APPENDIX I

SYSTEMATIC LITHOSTRATIGRAPHY

SUMMARY

A sedimentary succession of Otaian-Castlecliffian age (Early Miocene-Early Pleistocene), cropping out in central parts of Hawke's Bay, has been documented as part of this basin analysis. The Tongaporutuan-Castlecliffian part of this succession, which is the main focus of this study, comprises the uppermost 2-3 km of a total 5-7 km-thick basin fill that has accumulated since the Late Cretaceous.

The last major stratigraphic investigation in the study area was undertaken by Beu (1995). The Nukumaruan (Late Pliocene) stratigraphic framework established by Beu (1995) has been significantly revised during the course of this study. Geological mapping has demonstrated lateral continuity between formations previously regarded as distinct. It is proposed that the Hawke's Bay, Napier, and Poporangi Groups established by Beu (1995) be abolished.

Early to Middle Miocene beds are encompassed in the **Tolaga Group**. Constituting the Tolaga Group are the **Whakamarino**, **Poamoko, Te Haroto**, **Waitere**, and **Mokonui Sandstone Formations**. The Poamoko Formation includes the **Ngatapa Sandstone, Arapaepae Alternating** and **Kingma Peak Mudstone Members.** The Waitere Formation includes the **Tarawera Limestone, Te Ipuohape Sandstone, Auroa Alternating and Rakaita Siltstone Members.** Uppermost Miocene to Late Pliocene beds are largely encompassed in the **Mangaheia Group**. Beds constituting the Mangaheia Group include the **Blowhard, Mangatoro Mudstone, Pakaututu (including Hukanui Limestone Member), Puketitiri, Omahaki, Titiokura (including Naumai, Te Rangi, Taraponui, Bellbird Bush**, and **Opouahi Members), Te Waka**, **Pohue, Matahorua (including Deep Stream, Trelinnoe, Papakiri and Grassy Knoll Conglomerate Members), Waipunga, Esk Mudstone, Petane (including Tutira, Aropaoanui Mudstone, Darkys Spur, Park Island Limestone, Mairau Mudstone, Tangoio Limestone, Flag Range Conglomerate, Te Ngaru Mudstone, Waipatiki Limestone, and Devils Elbow Mudstone Members), Kaiwaka (including Puketautahi Limestone Member), Taradale Mudstone, Scinde Island, Makaretu Mudstone, Mason Ridge (including Mahana Limestone, Maharakeke Mudstone, Torran Limestone, Whakapirau Mudstone, and Pakihirua Limestone Members), Sentry Box, Mount Mary Pebbly Limestone, Kereru, Okauawa (including Kikowhero and Whakamarumaru Members)**, and **Poutaki Formations.**

The stratigraphically highest (and youngest) group in the study area is the **Kidnappers Group** and comprises the **Salisbury Gravel** together with undifferentiated greywacke gravel with minor sandstone and pumiceous beds of Castlecliffian (Middle Pleistocene) age.

The distribution of stratigraphic units documented here is displayed in the form of six geological map sheets at 1:50 000 scale (Enclosure 1). Stratigraphic columns are referred to throughout this chapter, and are contained in Appendix IV.

INTRODUCTION

The objective of this Appendix is to systematically document the stratigraphy of the Late Miocene-Early Pliocene strata in central parts of the Hawke's Bay forearc basin. This study builds on the

earlier work of Kingma (1971), Beu *et al.* (1980), Haywick *et al.* (1991), Erdman and Kelsey (1992), Kelsey *et al.* (1993), Beu (1995), Bland (2001), Graafhuis (2001), Baggs (2004), Bland *et al.* (2004) and Browne (2004a), and is intended as a contribution towards a definitive classification and stratigraphic subdivision of the Late Miocene to early Pleistocene sedimentary succession of Hawke's Bay Basin.

APPROACH TO GEOLOGICAL MAPPING

The distribution of stratigraphic units is displayed on a series of geological maps as part of Enclosure 1 (Sheets 1-6), the locations of which are illustrated in Fig. 1. Stratigraphic correlations of sections logged through the course of this study are presented in Enclosure 4. Detailed stratigraphic columns that form the basis of the stratigraphic correlations are contained in Appendix IV.

Geological units have been mapped on the basis of broad lithological properties. Essentially this means that limestone-dominated facies have been mapped as being different to sandstone-dominated facies and so on. While this may be viewed as the traditional approach to geological mapping, the emergence of sequence stratigraphy as a means of differentiating a sedimentary succession has lead to some studies using this as a tool for correlation of sedimentary successions. The cyclothemic nature of the Late Pliocene-Early Pleistocene strata in the study area allows for concurrent lithostratigraphic and sequence stratigraphic subdivision. This combined lithostratigraphic-sequence stratigraphic approach has recently been applied by McIntyre (2002) in his study of the cyclothemic Mangapanian succession exposed in Wanganui Basin, and by Vonk *et al.* (2002) for Late Miocene-Early Pliocene rocks in eastern Taranaki.

While siliciclastic units ranging in age from the Jurassic to Cenozoic are present in the study area, it is the Late Miocene to Early Pleistocene succession (Kapitean to Nukumaruan) that is of particular interest in this study. Consequently the greatest emphasis in fieldwork and analysis has been placed on them. Rocks of the Mangaheia Group are the focus of this study with descriptions provided for the underlying Tolaga and overlying Kidnappers Groups.

APPROACH TO NAMING UNITS

Geological units have been defined firstly from the broad lithological character of the units. Where possible a lithostratigraphic qualifier is used in the names of lithostratigraphic mapping units.

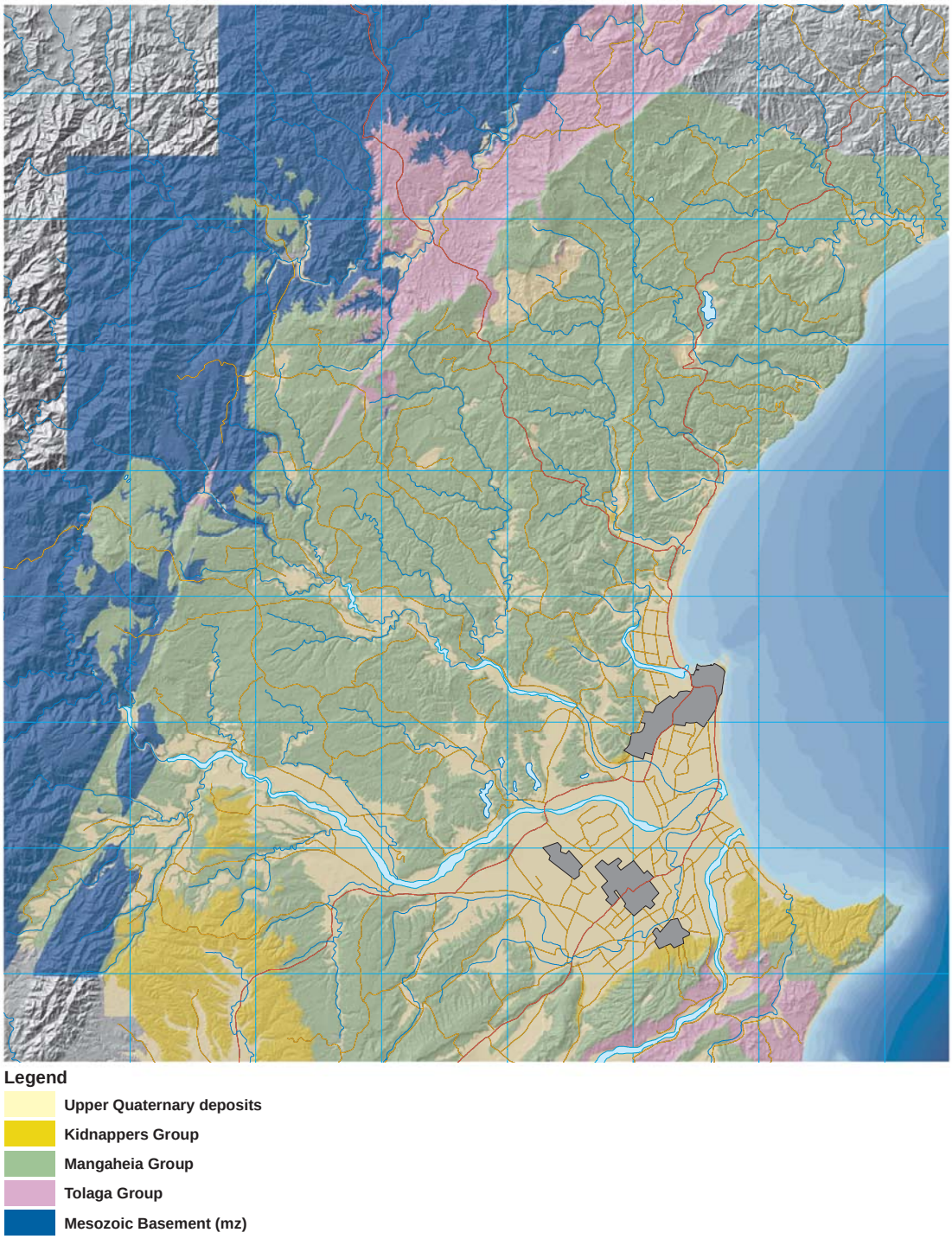


Fig. 1: Distribution of major rock units (groups) mapped in central Hawke's Bay superimposed on a hillshade relief model. Blue lines are 10 km NZMS 260 series gridlines. State highways (red lines), main roads (orange lines), significant water bodies (blue lines and light-blue polygons) are shown. Grey polygons are (from north to south) the major residential areas of Napier-Taradale, Flaxmere, Hastings and Havelock North. Topographic data are derived from the LINZ NZMS 260 dataset, supplied to The University of Waikato by Eagle Technology.

In the course of this study it has proven necessary to amalgamate some previously existing formations, and in the process this has simplified and strengthened the understanding of the lithostratigraphic development of the region. In many parts of the basin different names have been

applied to the same stratigraphic horizon or unit. This has led to the masking of relationships between beds across the study area, as well as generating a confusing number of names for often very similar facies in a small geographic area.

Full descriptions and definitions of stratigraphic units are given in this Appendix. Discussion of lithostratigraphic issues is contained in Chapter Three (main thesis).

MESOZOIC BASEMENT ROCKS

UNDIFFERENTIATED TORLESSE COMPOSITE TERRANE (mz)

Name and definition

Mesozoic basement rocks are widespread in the study area though mostly restricted to western parts where they form the main axial ranges (Fig. 1). The surface distribution of basement rocks in the study area was mapped by Grindley (1960) who subdivided these rocks into two major stratigraphic units, the Kaweka Greywacke and Urewera Greywacke. Kaweka Greywacke was mapped to the west of the Kaweka Fault and the Urewera Greywacke to the east of the Kaweka Fault. Urewera Greywacke was inferred by Grindley (1960) to be of Jurassic age, and the Kaweka Greywacke of Jurassic-Triassic age. Subsequent new analysis of basement rock stratigraphy means that basement rocks underlying the East Coast region are assigned to the Torlesse composite terrane (e.g. Lee and Begg 2002). This is one of several Late Paleozoic to Early Cretaceous fault-bounded tectonostratigraphic units of low grade metasedimentary rocks that constitute the Eastern Province of New Zealand (Mazengarb and Speden 2000). Basement rocks of the East Coast region consist mainly of Triassic to Early Cretaceous indurated sandstone and mudstone (greywacke and argillite).

Mortimer (1995) subdivided the Torlesse rocks of eastern North Island on the basis of differences in sandstone petrographic modes, age, bulk chemical composition and the known and inferred extent of mélange belts. He defined two major basement units east of the Taupo Volcanic Zone, namely the Pahau subterrane and a previously unrecognised Waioeka subterrane. Both are of Late Jurassic to Early Cretaceous age. The boundary between the two was placed at a major mélange that was inferred to extend from the modern Bay of Plenty coast to a point WSW of Lake Waikaremoana. This subdivision was accepted by Field *et al.* (1997). On the basis of presumed geological origins, Begg and Johnston (2000) elevated units formally known as subterranes (such as the Pahau subterrane) to full terrane status, and applied the name “Torlesse composite terrane” for Torlesse rocks in general. Basement rocks of the East Coast region, North Island, are

therefore assigned to the Rakaia, Pahau and Waioeka terranes as part of the Torlesse composite terrane, in association with two mélange zones (the Esk Head and Whakatane mélanges).

Other than brief field descriptions, no attempt has been made in this study to differentiate the various facies within the basement rocks. They are collectively and informally referred to as "basement", and no inferences as to composition or depositional environments are intended.

Upper contact

Basement exposed in the Pakaututu area comprises alternating greywacke-argillite beds of up to 0.3 m thick. These units are well indurated and moderately to strongly weathered. No fossils have been found in outcrops of this unit. Where the upper surface is exposed, metre-scale relief is typically visible. Stacks up to 2 m in height may protrude into overlying units, and small caves and overhangs in the basement units are commonly infilled with overlying Cenozoic siliciclastic sediments and less commonly bioclastic deposits. Exposures through basement rocks are often several hundred metres in height, especially in areas close to the Kaweka Range (such as along Mangatutu Hot Springs Road).

Distribution

Mesozoic basement rocks are widespread is western parts of the study area, forming the Ruahine, Wakarara, Kaweka, and Ahimanawa Ranges among others. With the exception of an outlier near Patoka, and the Wakarara Range at Kereru, these beds do not crop out west of the Mohaka Fault. Their distribution is illustrated in Fig. 1.

Description

Basement rocks are greywacke-dominated although argillite, chipwacke, flysch, conglomerate and minor chert facies are also present.

Flysch facies are common in the Pakaututu and Puketitiri areas where they are moderately to highly deformed. In close proximity to major faults these beds may be highly sheared and fractured, with varying degrees of folding.

Environment of deposition

The generally monotonous sequence of indurated, interbedded greywacke and argillite typical of the Torlesse composite terrane is inferred to have accumulated mainly in deep marine environments within an accretionary prism (Mortimer 2004).

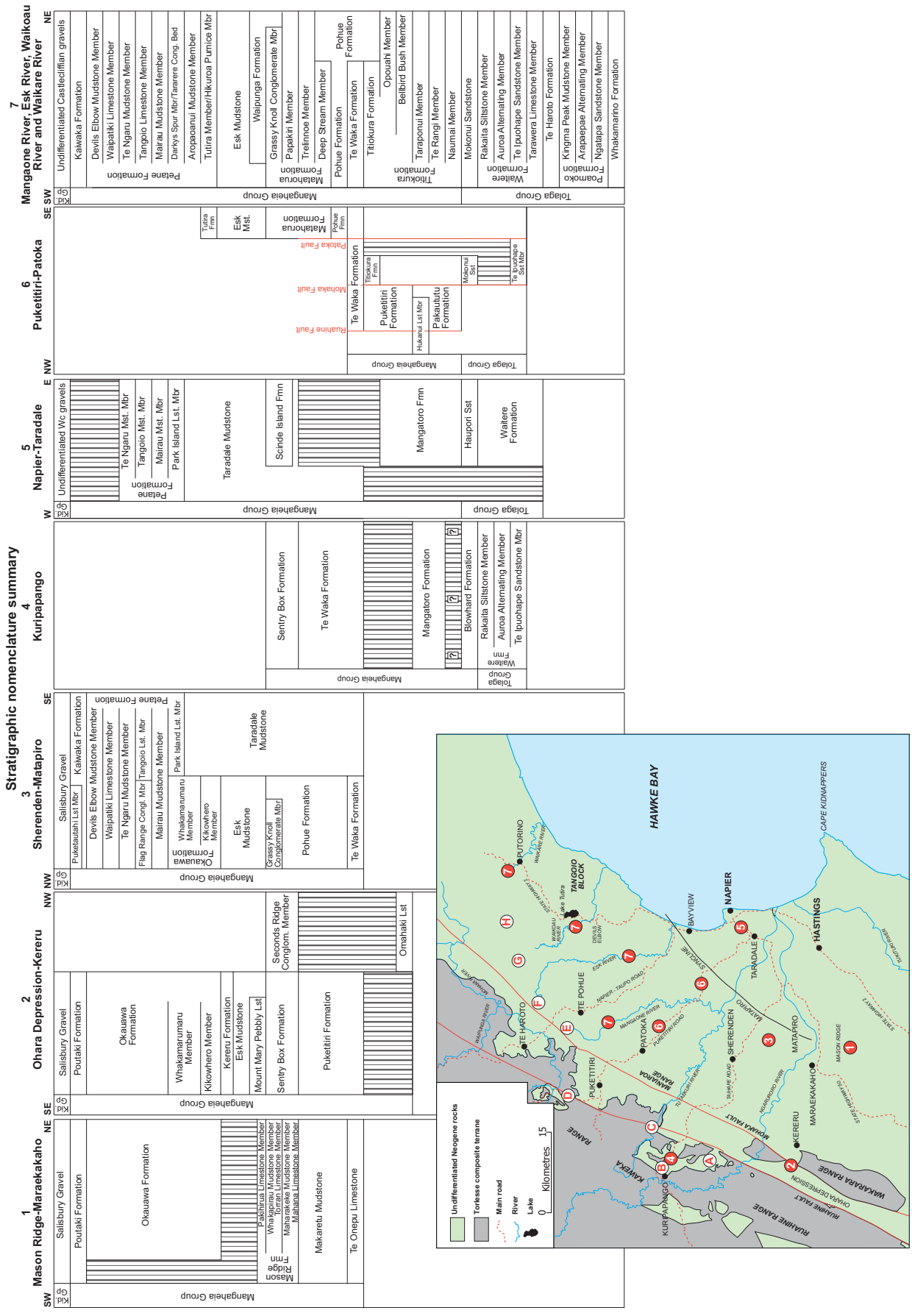


Fig. 2: Diagrammatic summary of the stratigraphic nomenclature proposed in this study for central Hawke's Bay. Letters relate to locations of sections in areas Fig. 3.7 and 3.8 (Chapter Three).

NEOGENE STRATIGRAPHY

The Neogene sedimentary succession in Hawke's Bay Basin can be usefully classified into three lithostratigraphic groups: the Tolaga Group; the Mangaheia Group; and the Kidnappers Group (Fig. 2). While the stratigraphic focus of this study is on the Late Miocene-Early Pleistocene (Kapitean to Nukumaruan) deposits, in northwestern parts of the study area Early to Late Miocene sedimentary beds crop out. These older rocks, assigned to the Tolaga Group, are mostly restricted to the region of Waitere Station and the Mohaka-Te Hoe River confluence. Their distribution was documented in a series of maps produced to identify either potential hydro electric dam sites (e.g. Cutten 1988), hydrocarbon exploration wells (e.g. Moore 1987, 1991; Francis *et al.* 1990) or as summary geological reports (e.g. Grindley 1960; Scott *et al*. 1990a; Cutten 1994). The Tolaga Group is overlain by the Mangaheia Group, the interval of prime focus in this study. The Mangaheia Group is in turn overlain by the Kidnappers Group.

The following sections describe in detail the nature of the Neogene sedimentary succession in the study area. They define stratigraphic units presented on the geological map series (Enclosure 1), and document their distribution, thickness, character, age and inferred depositional environments. Discussion of lithostratigraphic issues related to these beds is contained in thesis Chapter 3: Lithostratigraphic Overview and Issues.

TOLAGA GROUP

(Mazengarb *et al.* 1991)

Name and definition

Tolaga Group was introduced and defined by Mazengarb *et al.* (1991) for sedimentary rocks of Waitakian to Upper Tongaporutuan age in the Tauwhareparae area inland from Tolaga Bay, from where the name is derived. In the original definition of the Tolaga Group, a mainly offshore, moderate to deep-water (outer shelf to ?upper slope) environment of deposition was inferred (Mazengarb *et al.* 1991, p. 33). Only a limited extent and volume of shallow-water beds are present in the Tauwhareparae area and this suggests that shallow conditions only existed in localised areas for temporary periods.

Mazengarb and Speden (2000) extended the definition of the Tolaga Group to include all rocks of Early to Late Miocene age cropping out in the area of the Raukumara QMAP sheet. Beds of similar age, lithology and inferred depositional environments crop out widely through northern parts of the present study area and have previously not been included in any stratigraphic group.

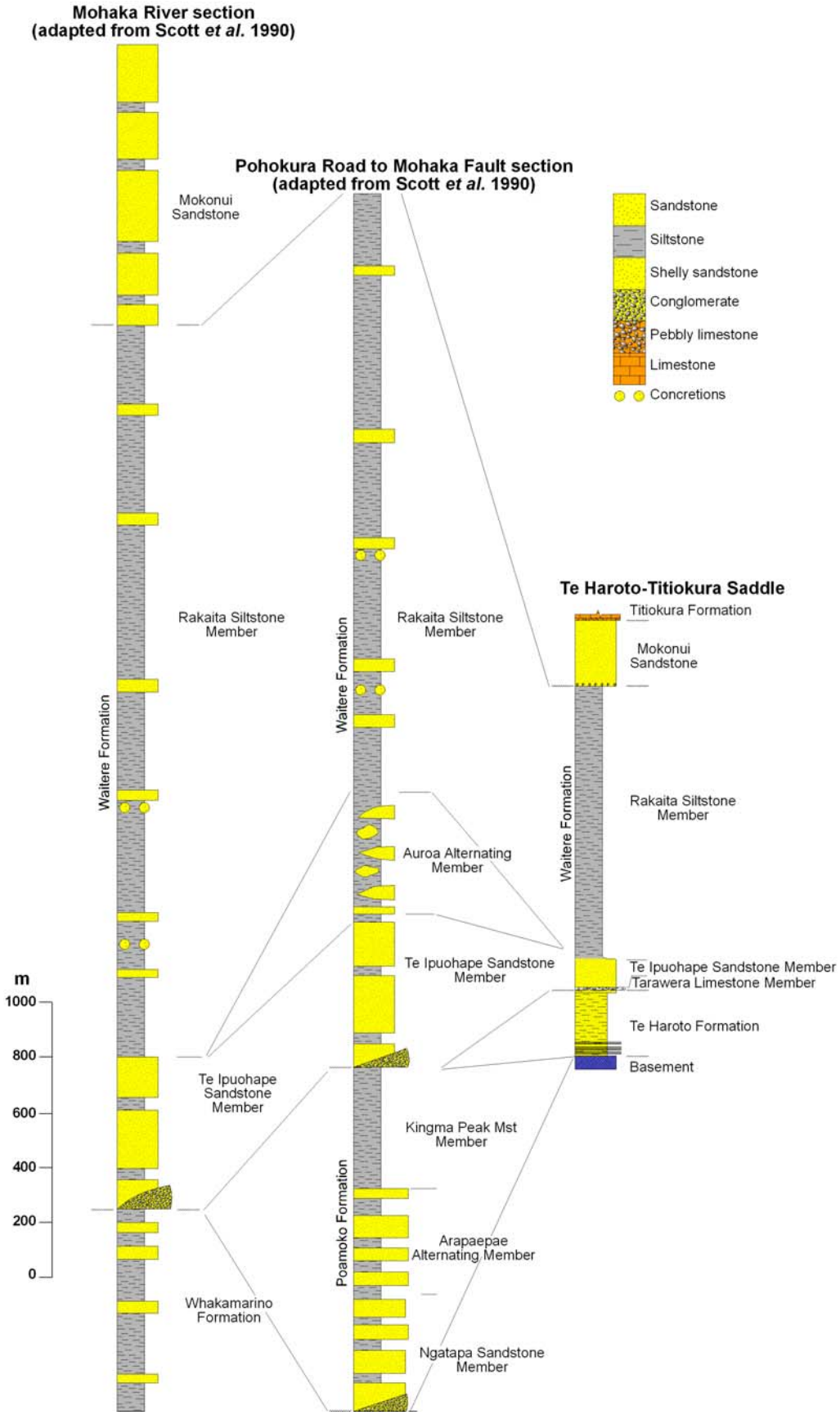


Fig. 3: Schematic stratigraphic columns of the Tolaga Group succession cropping out in the study area from the Mohaka River at Waitere Station to the Napier-Taupo Road. Evident is the dominance of siltstone and mudstone facies in the group, and the limited volume of shallower water facies such as shelfal sandstones and limestones. Also evident is how not all formations occur in all areas.

As in the Tolaga Group of Mazengarb *et al.* (1991), shallow-water beds of Early to Late Miocene age are limited in extent in the study area, and the succession is dominated by massive deep-water mudstones and redeposited sandstones. The Late Miocene-Pliocene aged Mangaheia Group of Mazengarb *et al.* (1991) was extended into the Wairoa region by Mazengarb and Speden (2000), and from there into the current study area where it is defined to unconformably overlie the Early to Late Miocene succession prominent from the Napier-Taupo Road to Waitere Station. The Mangaheia Group *sensu stricto* by definition overlies the Tolaga Group. It is viewed as appropriate that the Tolaga Group therefore be extended into the study area (Fig. 1). Formations included here in the Tolaga Group are the Whakamarino, Poamoko, Te Haroto and Waitere Formations.

WHAKAMARINO FORMATION

(Cutten 1988; formally defined by Cutten 1994)

Name and definition

Whakamarino Formation is the oldest Cenozoic unit in the study area and is the basal unit of the Tolaga Group (Fig. 3). The name Whakamarino siltstone lithofacies was introduced by Cutten (1988). The unit was formally defined and named Whakamarino Siltstone Formation by Cutten (1994). As the formation contains a significant thickness of sandstone the unit is renamed Whakamarino Formation in this study, though the general definition of Cutten (1994) is retained. The name is derived from Whakamarino Stream, a tributary of the Te Hoe River.

Type locality and reference sections

The type section established by Cutten (1994) is retained in this study. This section crops out in the banks of the Te Hoe River from the confluence with the Mohaka River upstream to the contact with the Poamoko Formation (V19/406350 to 406386). The basal part of the formation is not exposed in this section but occurs in a small tributary of the Mangahouanga Stream (Moore 1987) at V19/440483 to the north of the study area (Cutten 1994).

Distribution and thickness

Whakamarino Formation forms the core of the Pohokura Anticline exposed around the Mohaka-Te Hoe River confluence. The formation is also present west of Te Kootis Lookout, north to the Hautapu River, and along Ngatapa Road east of the upper Te Hoe River (Cutten 1994).

In the study area, exposure of the Whakamarino Formation is restricted to the area around the Mohaka-Te Hoe River confluence. Excellent exposures are present in the banks of the Mohaka River, especially near the new forest road bridge at Waitere Station (V19/400356; Fig. 4A). Whakamarino Formation is up to 350 m thick in the study area, and reported to be up to 750 m thick north of the Mohaka River (Cutten 1994).

Lower and upper contacts

The lower contact of the Whakamarino Formation is not exposed in the study area. North of the study area the unit is reported to unconformably overlie Wanstead Formation (Moore 1987).

The Whakamarino Formation is conformably overlain by the Ngatapa Member of the Poamoko Formation (Cutten 1994).

Description

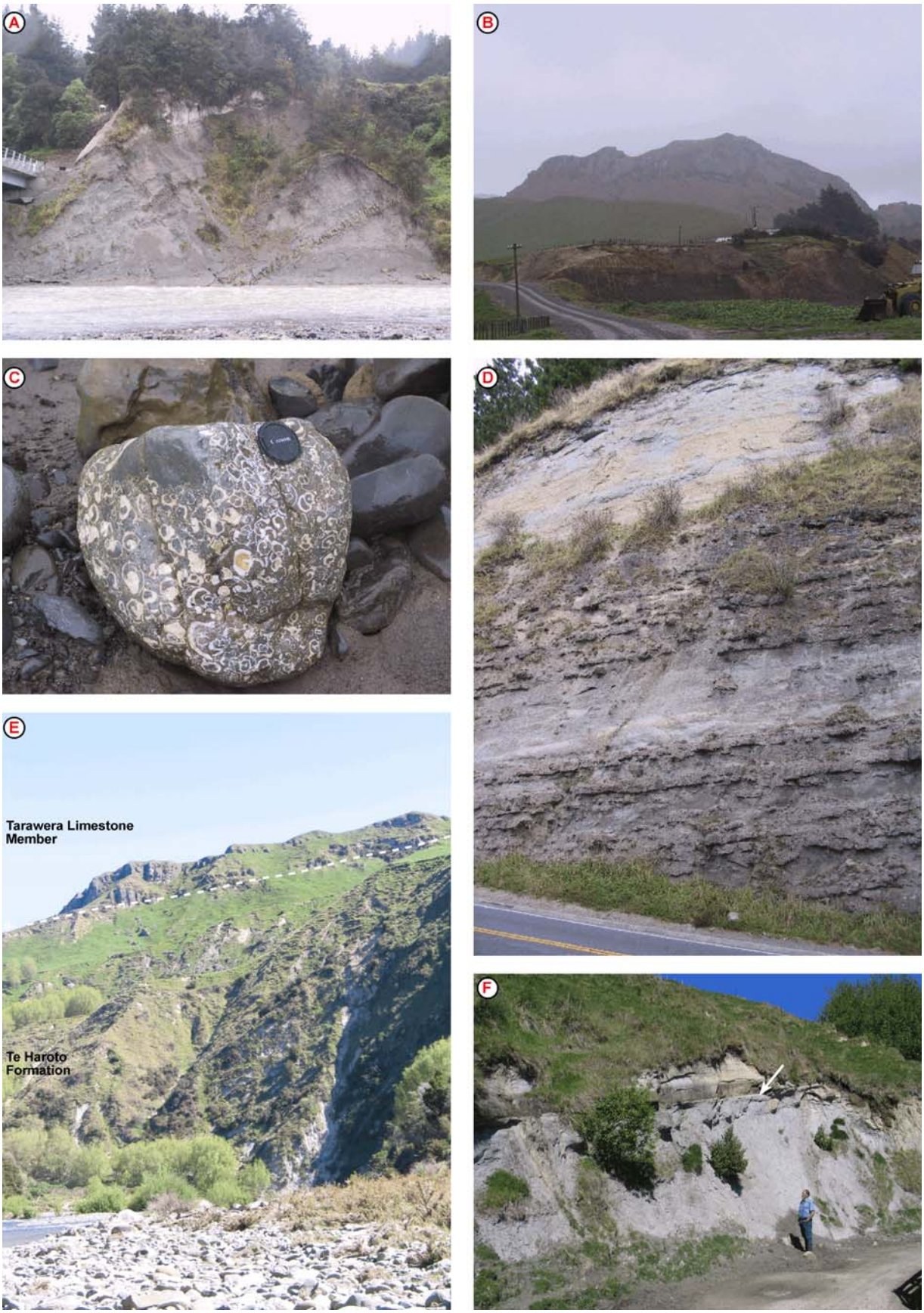
Whakamarino Formation comprises blue-grey frittery very fine siltstone with sandstone interbeds up to 0.5 m thick (Fig. 4A). Beds are commonly offset by small-scale (<1 m throw) reverse and normal faults. The Whakamarino Formation can be distinguished from the overlying Kingma Peak Mudstone Member of the Poamoko Formation by the absence of sandstone beds in the Kingma Peak Mudstone Member (Cutten 1994).

Paleontology and age

Foraminifera from the Whakamarino Formation include *Globoconella incognita, Haeuslerella hectori* (Upper Otaian) and *Globoconella zelandica* (Middle Altonian). Scott *et al.* (1990a) suggest that deposition of the Whakamarino Formation may have continued into the Upper Altonian, although there is no conclusive evidence for this (Cutten 1994).

Based on foraminifera an Upper Otaian to Altonian age is assigned to the Whakamarino Formation (Scott *et al.* 1990a; Cutten 1994).

Fig. 4 (facing page): Early to Late Miocene Tolaga Group rocks cropping out in the study area (Whakamarino, Poamoko and Te Haroto Formations). **A)** Alternating siliciclastic siltstone-sandstone beds of the Whakamarino Formation in the Mohaka River at Waitere Station. A series of small reverse and normal faults offset several beds in this photograph. Photo location: Mohaka River at new forest bridge, Waitere Station (V19/400356). **B)** Typical high bluffs and hills of Ngatapa Sandstone Member (Poamoko Formation) on Waitere Station. Photograph is taken from Pohokura Road looking south (V19/404350). **C)** Highly fossiliferous boulder of Ngatapa Sandstone Member from the Mohaka River, Waitere Station (V19/400355). This boulder contains abundant *Struthiolaria (Callusaria) spinifera* with *Cucullaea* cf. *ponderosa* and *Tropicolpus milleri*. **D)** Slightly to highly fossiliferous concretionary beds of the basal Te Haroto Formation beside the Napier-Taupo Road near Te Haroto (V19/196265). These beds mark the first Neogene sedimentary rocks encountered on the Napier-Taupo Road above Mesozoic basement. **E)** High bluff in Te Haroto Formation to the overlying Tarawera Limestone Member in the Mohaka River section downstream of Glenfalls Reserve. Immediately upstream of the photo location (V19/274243) Te Haroto Formation unconformably overlies Torlesse basement. **F)**



Sharp contact between siltstone and an overlying sandstone bed in the Te Haroto Formation (contact arrowed). This sandstone is in turn unconformably overlain several metres above by the Tarawera Limestone Member (Waitere Formation). Photo location: Tarawera Station (V19/246221).

Environment of deposition

Microfauna from near the base of the formation (*Robulus* spp. dominant and rare *Karreriella cushmani*) indicate deposition at upper bathyal water depths. Deepening may have occurred upsection though some Lower Altonian assemblages include outer shelf to upper bathyal taxa (Cutten 1994). Sandstone beds are probably of turbiditic origin.

POAMOKO FORMATION (pa)

(Cutten 1994)

Name and definition

Poamoko Formation (Fig. 3) is named after Poamoko Stream, a tributary of the Mohaka River whose confluence is at V19/327331. Poamoko Formation was originally named Narrows Formation in Cutten (1988a, 1988b) and Scott *et al.* (1990a). Poamoko Formation comprises three members: Ngatapa Sandstone Member, Arapaepae Alternating Member, and Kingma Peak Mudstone Member.

The three members of the Poamoko Formation thin and pinch out towards the east on the western limb of the Pohokura Anticline. Each successive member wedges out further to the east than the previous member (Cutten 1994).

Ngatapa Sandstone Member (pan)

(Cutten 1994)

Name and definition

Ngatapa Sandstone Member (Fig. 3) is named after Ngatapa Station, and was formally defined by Cutten (1994). The member was referred to as Narrows sandstone lithofacies in Cutten (1988a, 1988b), Latimer (1990) and Scott *et al.* (1990a). The definition of Cutten (1994) is retained in this study. Ngatapa Sandstone Member comprises the basal fossiliferous sandstone-dominated portion of the Poamoko Formation that conformably overlies the Whakamarino Formation.

Type locality and reference sections

The type section nominated by Cutten (1994) has been retained. The section is located from the base of the bluff at V19/385358 south of the Mohaka River to the top of the bluff at V19/384357.

Lower and upper contacts

The Ngatapa Sandstone Member conformably overlies the Whakamarino Formation (Cutten 1994). The base is well exposed at V19/398349.

Ngatapa Sandstone Member is overlain by two different stratigraphic units. In the Waitere Station area the member is conformably overlain by the Arapaepae Alternating Member. South of Waitere Station the Ngatapa Sandstone Member is unconformably overlain by the Te Ipuohape Sandstone Member (Waitere Formation). The upper contact is well exposed at the type section at V19/384357 (Cutten 1994). In places the Ngatapa Sandstone Member is in fault contact with basement across the Mohaka Fault.

Distribution and thickness

Ngatapa Sandstone Member crops out in a restricted area in the immediate area of Waitere Station and the Mohaka-Te Hoe River confluence area. On Waitere Station the Ngatapa Sandstone Member forms prominent bluffs (Fig. 4B). The member is up to 150 m thick (Cutten 1994).

Description

The Ngatapa Sandstone Member comprises moderately to well indurated very fine to fine sandstone with occasional medium and rare coarse sandstone. Grain size coarsens towards the top of the member. Minor siltstone and mudstone interbeds are present (Francis 1994). The member is typically a pale yellowish-brown colour, though is blue-grey when fresh. A distinguishing feature of the Ngatapa Sandstone Member is the richly fossiliferous limestone beds present throughout that may comprise up to 95% shell material (Cutten 1994) (Fig. 4C). These shellbeds are well cemented. Scattered greywacke pebbles may be present, where they directly overlie basement (Francis 1994a, b).

Paleontology and age

Molluscs are common in hard, well cemented beds of the Ngatapa Sandstone Member. These include the gastropods *Polinices huttoni*, *Tropicolpus milleri* and *Struthiolaria* (*Callusaria*) *spinifera,* and the bivalve *Cucullaea* cf. *ponderosa* (Fig. 4C). Flabellid corals are also common components of the macrofauna. A Clifdenian (lower-Middle Miocene) age is assigned to the Ngatapa Sandstone Member based chiefly on the occurrence of the foraminifera *Textularia gladizea* and *Praeorbulina glomerosa* (Cutten 1994).

Environment of deposition

Ngatapa Sandstone Member was deposited in a deepening-upward environment from outer shelf to uppermost bathyal depths (supported by the presence of *Notorotalia waiauensis*) in a neritic water mass (Cutten 1994).

Arapaepae Alternating Member (paa)

(Cutten 1994)

Name and definition

Arapaepae Alternating Member (Fig. 3) was introduced and formally defined by Cutten (1994). The name replaced the informal Narrows alternating lithofacies introduced by Cutten (1988), and used in Scott *et al*. (1990a) and Latimer (1990). The definition of Cutten (1994) is retained here. Arapaepae Alternating Member represents a transitional lithological unit between the Ngatapa Sandstone Member and the overlying Kingma Peak Mudstone Member.

Type locality and reference sections

The type section nominated by Cutten (1994) is retained. This section is located on the south side of the Mohaka River from V19/360347 to 358346.

Distribution and thickness

The Arapaepae Alternating Member is confined to an area within 2-3 km of the Mohaka River between its confluence with the Te Hoe River and the Mohaka Fault. North of the study area and the Mohaka River, where the member forms the core of the Ngatapa Syncline, the Arapaepae Alternating Member is 240 m thick (Cutten 1994). The member wedges out towards the south and east and is truncated by the Waitere Unconformity (Cutten 1994).

Description

The Arapaepae Alternating Member is distinguished from the younger Auroa Alternating Member (of the Waitere Formation), and parts of the older Whakamarino Formation, by the presence of abundant shells in the sandstone beds of the unit. The alternating mudstone and sandstone beds that comprise the member are individually 0.5-5 m thick. Beds are blue-grey in colour when fresh, weathering to pale yellowish-brown (Cutten 1994).

Paleontology and age

A Lillburnian age was assigned to the Arapaepae Alternating Member by Cutten (1994) on the basis of microfossil assemblages as reported in Scott *et al.* (1990a).

Environment of deposition

Sandstone beds contain the same macrofossils as the underlying Ngatapa Sandstone Member. Higher strata contain middle bathyal taxa and indicate a period of significant deepening (Cutten 1994). These beds also contain an increased abundance of planktonic foraminiferal assemblages from underlying beds, and indicate improved paleo-oceanographic access to oceanic water toward the Lillburnian-Waiauan boundary.

Kingma Peak Mudstone Member (pak)

(Cutten 1994)

Name and definition

Kingma Peak Mudstone Member (Fig. 3) of Cutten (1994) was named Narrows mudstone lithofacies in Cutten (1988) and Scott *et al.* (1990a). The name is derived from Kingma Peak, a hill located at V19/388344. Kingma Peak Mudstone Member was formally defined by Cutten (1994). His definition is retained in this study.

Type locality and reference sections

The type section designated by Cutten (1994) has been retained. It is located on the south bank of the Mohaka River from V19/370341 to 372341.

Lower and upper contacts

Kingma Peak Mudstone Member conformably overlies, and is considered to be a partial lateral equivalent of, the Arapaepae Alternating Member (Cutten 1994).

The Kingma Peak Mudstone Member is unconformably overlain by the Waitere Formation (Fig. 5).

Distribution and thickness

Kingma Peak Mudstone Member has only limited exposure in the study area, almost entirely restricted to the south bank of the Mohaka River below the ridge west of Kingma Peak. The Member is up to 120 m thick, and wedges out against the Pohokura Anticline (Cutten 1994). To the west the member is truncated by the Mohaka Fault.

Description

Kingma Peak Mudstone Member consists entirely of dark to medium blue-grey poorly indurated mudstone (Cutten 1994).

Paleontology and age

An Upper Lillburnian age is assigned to the Kingma Peak Mudstone Member on the basis of microfauna. Scott *et al.* (1990a) and Cutten (1994) suggest that the member was deposited concurrently with the upper beds of the Arapaepae Alternating Member.

Environment of deposition

Kingma Peak Mudstone Member was inferred by Cutten (1994) to have been deposited in an environment similar to that of the upper beds of the Arapaepae Alternating Member. Foraminiferal assemblages including *Sigmoilopsis schlumbergi, Tritaxia instar* and *Triaxilina zelandica* are similar to those contained in the Arapaepae Alternating Member (Scott *et al.* 1990a; Cutten 1994). The occurrence of the foraminifera *Haeuslerella pukeuriensis* and *Vaginulinopsis recta* suggest upper bathyal rather than middle bathyal depositional water depths (Scott *et al.* 1990a).

TE HAROTO FORMATION (th)

(Francis 1994b)

Name and definition

Te Haroto Formation (Fig. 3) is named after the small village of Te Haroto, located at the summit of the Napier-Taupo Road. The formation name was introduced by Francis (1994b) to encompass a basal highly fossiliferous concretionary sandstone and overlying silty sandstone to sandy siltstone that unconformably overlies basement, and underlies the Tarawera Limestone Member (Waitere Formation).

Type locality and reference sections

No type locality was nominated by Francis (1994b). The type locality for the Te Haroto Formation is designated as the part of the cliff along the Mohaka River from the unconformable contact with greywacke (V19/274243) upstream to section on the true left bank near Glenfalls Reserve (V19/276223), where it is overlain by the Waitere Formation. A reference section is designated along the Napier-Taupo Road in a road cutting from V19/196265 to 213219 (Fig. 4D). Although discontinuously exposed, most of the formation is visible along this section. Another reference section on Tarawera Station displays the uppermost 20 m of the formation, incorporating very

good exposures of the upper contact (V19/246221 to 247220) (Fig. 4E). Several good exposures of the formation occur along the northeastern end of the Tarawera Station farm track above the Mohaka River from V19/273243 to 275234 (Fig. 4F).

Lower and upper contacts

The lower contact is everywhere unconformable on basement. The contact is well exposed in the eastern bank of the Mohaka River downstream of Glenfalls Reserve (V19/274243). On the Napier-Taupo Road the lower contact is mostly obscured, though can be located in places in overgrown road cuts (e.g. V19/193264).

The Te Haroto Formation is unconformably overlain by the Tarawera Limestone Member (Waitere Formation) on Tarawera Station. The contact is erosional with decimetre-scale relief. This contact is exposed in a cutting along a farm track on Tarawera Station at V19/247220, in a nearby hill section at V19/249227, in the Mohaka River where the main Tarawera Station track first meets the Mohaka River bank (V19/251221) and at Glenfalls Reserve above the Mohaka River (V19/276223) (Fig. 4E).

Distribution and thickness

The Te Haroto Formation is restricted in outcrop to the Te Haroto and Tarawera areas near the Napier-Taupo Road (Fig. 4D) to Mohaka River cliffs near Glenfalls Reserve (Fig. 4E). The formation thins out rapidly to the south of the Napier-Taupo Road and is not present in Mohaka River cliffs near the State Highway 5 road bridge. The formation crops out extensively along the Mohaka River from Glenfalls Reserve to Tarawera Station, and along the Napier-Taupo Road in the Te Haroto area.

Te Haroto Formation is about 200 m thick.

Description

Te Haroto Formation comprises a lower highly concretionary zone of fossiliferous sandstone (Fig. 4D), passing upsection into weakly bedded fine sandstone to sandy siltstone. Occasional redeposited sandstone beds are present, although they tend to be minor components of the unit.

Paleontology and age

Basal parts of the Te Haroto Formation contain an abundant macrofauna, as displayed in cuttings on the Napier-Taupo Road (V19/196265; Fig. 4D). Macrofauna identified at this locality include *Zeacolpus* sp., *Zenatia* sp., *Struthiolaria* sp., *Dosinia* sp. and *Glycymeris modesta.*

Microfossil samples from lower parts of the Te Haroto Formation reported in the fossil record file for sites along the Napier-Taupo Road are reported as having a Waiauan-Lower Tongaporutuan age (V19/f258; V19/f259). Samples V19/f8644, V19/f8521, V19/f8644 and V19/f6491, from middle and upper parts of the formation, have been assigned a Tongaporutuan age. On the basis of stratigraphic position, microfossil content, and the abundance of *Struthiolaria (Callusaria)* the Te Haroto Formation is assigned a Lower Tongaporutuan age.

Environment of deposition

Te Haroto Formation accumulated in a progressively deepening-upward environment. Macrofauna in the basal concretionary interval indicate an inner shelf depositional setting.

WAITERE FORMATION (wa)

(Cutten 1988 (informal); formally defined by Cutten 1994)

Name and definition

Waitere Formation (Fig. 3) was informally introduced by Cutten (1988), the name being derived from Waitere Station (V19/388334) at the end of Pohokura Road on the south bank of the Mohaka River. The formation was formally defined by Cutten (1994). The Waitere Formation is the stratigraphically highest formation of the Tolaga Group. Waitere Formation comprises four members: Tarawera Limestone Member (new); Te Ipuohape Sandstone Member; Auroa Alternating Member; and Rakaita Siltstone Member. Waitere Formation has been mapped as its constituent members in the maps produced in this thesis, and by Cutten (1994).

Lower and upper contacts

Waitere Formation overlies several stratigraphic units. On Tarawera Station the formation unconformably overlies the Te Haroto Formation (Fig. 4E). At Waitere Station region Waitere Formation unconformably overlies the Whakamarino Formation, Ngatapa Sandstone Member, Arapaepae Alternating Member and Kingma Peak Mudstone Member of the Poamoko Formation.

Throughout much of the outcrop area Waitere Formation appears to be conformably overlain by the Mokonui Sandstone The contact is exposed at Titiokura Saddle on the Napier-Taupo Road, where it is a condensed contact. In Opau Stream the formation is unconformably overlain by the Te Waka Formation. In the Tutaekuri River section the Waitere Formation is inferred to be unconformably overlain by the Waikarokaro Sandstone Member of the Blowhard Formation.

In Hukarere-1 exploration well the Waitere Formation unconformably overlies the Oligocene-aged Weber Formation (Westech Energy Ltd 2001).

Distribution and thickness

Waitere Formation is widespread, although discontinuously exposed, through western portions of the map area from Te Hoe Station in the north to the Tutaekuri River in Kaweka Forest Park to the south. The most widespread occurrence of the formation is from the McVicars Road bridge over the Mohaka River north to the Te Hoe-Mohaka River confluence. South of Crohane Forest outcrops become restricted to small localised areas.

A 380 m-thick interval named Waitere Formation was identified in Hukarere-1 exploration well at the Napier Breakwater. This may suggest that Waitere Formation underlies much of the study area at depth (Westech Energy NZ Ltd 2001).

Description

The Waitere Formation effectively represents a Late Miocene deepening-upward succession.

Tarawera Limestone Member (wat) (new)

Name and definition

Tarawera Limestone Member is named after Tarawera Station on and around which the member crops out. The member represents the stratigraphically lowest member of the Waitere Formation.

Type locality and reference sections

The type locality for the Tarawera Limestone Member is located on Tarawera Station where both lower and upper contacts are well exposed (V19/247220) (Fig. 5A). An easily accessible reference section is nominated beside Waitara Road near Glenfalls Reserve, where most of the member is visible. The base of the member is well exposed in a reference section on Tarawera Station on the true left bank of the Mohaka River (V19/276223: Fig. 4E), and at V19/249227 (Fig. 5B). The member is also well exposed in a reference section in Crohane Forest beside Church Bush Road (V20/209133; Fig. 5C). At this site the member has a more concretionary appearance than in the Tarawera Station area (Fig. 5A).

Lower and upper contacts

The Tarawera Limestone Member unconformably overlies two stratigraphic units. In the region of Tarawera Station the member overlies the Te Haroto Formation with a sharp erosion surface. In

the Mohaka River section above the Napier-Taupo Road bridge, and at Crohane Forest and Tutaekuri River (Kaweka Forest Park), the member overlies basement by way of an angular unconformity. In Hukarere-1 well an inferred lateral equivalent of the Tarawera Limestone Member unconformably overlies the (Oligocene-aged) Weber Formation.

The member is conformably and gradationally overlain by sandstone facies of the Te Ipuohape Sandstone Member.

Distribution and thickness

The Tarawera Limestone Member is restricted to the Te Haroto and Tarawera Station areas. The member becomes less well developed towards the southwest of Tarawera Station and Crohane Forest and cannot be differentiated in the Tutaekuri River section where the Te Ipuohape Sandstone Member directly overlies basement. The Tarawera Limestone Member is also absent in many localities in Crohane Forest although it is widespread and well developed on and around Tarawera Station. The member is also sporadically present through the map area of Cutten (1994), although he did not differentiate it from basal beds of the Te Ipuohape Sandstone Member. It is not present on Waitere Station.

A 35 m-thick limestone interval was reported at the base of Waitere Formation in Hukarere-1 well (Westech Energy NZ Ltd 2001). On the basis of stratigraphic position this interval is included in the Tarawera Limestone Member.

Description

The Tarawera Limestone Member comprises either a pebbly, moderately to highly fossiliferous limestone (Fig. 5A, B), or a series of well cemented, non to highly fossiliferous concretionary beds (Fig. 5C, D).

Greywacke clasts are a common component throughout the Tarawera Limestone Member in the Tarawera Station area. Large mudstone and sandstone clasts of pebble to boulder size are common in basal parts of the member in this area (Fig. 5B).

South of the Napier-Taupo Road, greywacke clasts generally become less conspicuous components of the member, although where the member directly overlies basement they are present in basal greywacke conglomerate beds.

Limestone at the base of the Waitere Formation in Hukarere-1 well comprises light greenish-grey very sandy limestone with abundant well sorted angular to subrounded quartz, rare lithics, and rare glauconite, cemented by calcite spar. Subordinate beds of grainstone are present and are dominated by bryozoans with sparse siliciclastic sandstone (Westech Energy NZ Ltd 2001).

Paleontology and age

In the Tarawera Station and Waitara Road areas the Tarawera Limestone Member contains a sparse intact macrofauna, with a high shellhash content. Fossiliferous beds cropping out through southern parts of Crohane Forest and in Opau Stream contain a macrofauna rich in *Struthiolaria* (*Callusaria*) *?calcar* (Fig. 5D) and *Zenatia acinaces.* Macrofossils are more commonly intact here than in the Tarawera Station area.

The presence of *Struthiolaria* (*Callusaria*) *?calcar* strongly suggests an age not older than Tongaporutuan, and not younger than Opoitian. On the basis of macrofossil content and stratigraphic position the Tarawera Limestone Member is assigned a “middle” Tongaporutuan (Late Miocene) age.

Environment of deposition

The Tarawera Limestone Member was deposited as the basal unit in a broadly deepening-upward shelf setting from shoreface to outer shelf depths.

Te Ipuohape Sandstone Member (wai)

(Cutten 1994)

Name and definition

Te Ipuohape Sandstone Member (Fig. 3) was introduced by Cutten (1994). The name is derived from Te Ipuohape peak located at V19/422371. The unit was informally referred to as the Waitere sandstone lithofacies in Cutten (1988a, 1988b), Scott *et al.* (1990a) and Latimer (1990). The formal definition of Cutten (1994) is emended in this study, with removal from it of the basal concretionary, fossiliferous portions of the member and their assignment to the Tarawera Limestone Member (new; see above).


A
Tarawera Limestone Member
Te Haroto Formation


B


C


D


E
TOYOTA


F


G

Type locality and reference sections

The type section nominated by Cutten (1994) is retained. It is located in a gorge of the Mohaka River just downstream of the confluence with the Te Hoe River. This section is through the nearly vertically-dipping eastern limb of the Pohokura Anticline and extends downstream from V19/407350 where Te Ipuohape Sandstone Member rests unconformably on the Whakamarino Formation to V19/408348 at the conformable upper contact with the Rakaita Siltstone Member (Fig. 3). Excellent reference sections are located in the Mohaka River banks in several localities around the Napier-Taupo Road and on Tarawera Station.

Lower and upper contacts

Throughout most of its outcrop area the Te Ipuohape Sandstone Member conformably and gradationally overlies the Tarawera Limestone Member. In localities in the Crohane Forest area where the Tarawera Limestone Member is absent, Te Ipuohape Sandstone Member directly overlies Torlesse basement, such as at V19/251217 and V19/276233, on Tarawera Station at V19/247220 and V20/192127 (Fig. 5E), in Crohane Forest, and U20/055982 in the Tutaekuri River.

Fig. 5 (facing page): Field examples of the Tarawera Limestone and Te Ipuohape Sandstone Members of the Waitere Formation, Tolaga Group. **A)** Tarawera Limestone Member unconformably overlying uppermost sandstone beds of the Te Haroto Formation (contact arrowed). Photo location Tarawera Station (V19/247220). **B)** Basal beds of the Tarawera Limestone Member. Large sandstone (arrowed) and greywacke clasts are present in this unit. The member unconformably overlies the Te Haroto Formation across a contact that displays decimetre-scale relief. Photo location Tarawera Station (V19/249227). **C)** Non to highly fossiliferous concretionary sandstone beds of the Tarawera Limestone Member in close proximity to an unconformable contact with basement. Photo location Church Bush Road, Crohane Forest near Inangatahi Stream (V20/209133). **D)** Highly fossiliferous concretionary beds, lowermost parts of the Te Ipuohape Sandstone Member (Waitere Formation). At this locality the Tarawera Limestone Member is not developed and the Te Ipuohape Sandstone Member directly overlies Torlesse basement. Macrofauna in the concretionary beds here are virtually exclusively *Struthiolaria (Callusaria) callosa.* Photo location Crohane Forest (V20/205140). **E)** Te Ipuohape Sandstone Member (Waitere Formation) unconformably overlying Torlesse basement in Crohane Forest (contact arrowed). The Tarawera Limestone Member is not developed at this locality. Greywacke conglomerate interbeds and lenses are common in the lower few metres of the Te Ipuohape Sandstone Member around this area (V20/198138). **F)** Bluffs of Te Ipuohape Sandstone Member (Waitere Formation) cropping out beside Pohokura Road (V19/385336). **G)** Te Ipuohape Sandstone Member (Waitere Formation) cropping out in the Tutaekuri River above the Lawrence Road swingbridge (U20/057982). The small sets of rapids in the middle right of the photograph mark the confluence of the Tutaekuri and Donald Rivers. The sandstone bluffs display prominent concretionary sandstone beds rich in macrofauna including *Crepidula radiata, Struthiolaria (Callusaria) calcar, Crassostrea ingens* and *Sectipecten grangei.* The Ruahine Fault cuts across the river approximately 250 m upstream of this locality.

North of Auroa Road (V19/305267) the Te Ipuohape Sandstone Member is conformably and gradationally overlain by the Auroa Alternating Member. South of Auroa Road the Te Ipuohape Sandstone Member is conformably and rapidly overlain by the Rakaita Siltstone Member. The basal contact is well exposed on the Napier-Taupo Road immediately south of the Mohaka River bridge where the Te Ipuohape Sandstone Member is gradationally although rapidly overlain (over 0.5 m) by siltstone of the Rakaita Siltstone Member (V20/241185). In Opau Stream (V20/207049) and Waipunga Streams the Te Ipuohape Sandstone Member is overlain by the Te Waka Formation across a spectacular angular unconformity

Distribution and thickness

Te Ipuohape Sandstone Member crops out widely through northern and western parts of the study area, in particular as a series of high bluffs along Pohokura Road on the descent to Waitere Station (Fig. 5F). Steeply-dipping Tongaporutuan sandstone exposed in Opau and Waipunga Streams (V20/208048) is referred to the Te Ipuohape Sandstone Member. The member crops out in the Mohaka River from Glenfalls Reserve downstream to the McVicars Road bridge.

Highly fossiliferous concretionary sandstone in Crohane Forest is referred to the Te Ipuohape Sandstone Member on the basis of lithology and stratigraphic position. The member also crops out in Gorge Stream at the entrance to Te Kowhai Forest (V20/118011).

A fault-bounded Tongaporutuan aged fine sandstone unit exposed in the upper reaches of the Tutaekuri River (Fig. 5G) contains common, highly fossiliferous concretionary and shell horizons with common *Sectipecten grangei*. This suggests that either Waitere Formation was much more widespread than its present distribution would indicate, or that there was a complicated paleogeography during the Tongaporutuan. With the exception of the fault-bounded Tutaekuri River block, the Te Ipuohape Sandstone Member is not present west of the Mohaka Fault, and it is likely that erosion associated with or following post-Pliocene movement along this fault has truncated the unit.

The Te Ipuohape Sandstone Member thins through its outcrop extent. Downstream of the confluence between the Mohaka and Te Hoe Rivers the Te Ipuohape Sandstone Member is 300 m thick. To the north it reaches a thickness of 600 m. South of Waitere Station the thickness decreases to approximately 100 m at the Napier-Taupo Road, to at least 60 m in Opau Stream, and 30-50 m in the Tutaekuri River section.

Description

Prominent sandstone bluffs of Te Ipuohape Sandstone Member up to 50 m high crop out along Pohokura Road (Fig. 5F). The member in this region comprises discrete sandstone and siltstone bodies. At V19/385336 grey-green sparsely fossiliferous siltstone to sandy siltstone is abruptly overlain by yellowish-brown, clean, non cemented non fossiliferous fine sandstone. At V19/385335 firm yellow-brown moderately well sorted sandstone is abruptly overlain by sparsely fossiliferous siltstone. Fauna in the siltstone consists of gastropods and large flabellid corals. The 3 m-thick siltstone grades up-section into a fine sandstone.

Where Te Ipuohape Sandstone Member crops out along Auroa Road in Mohaka Forest (e.g. V19/305267) the member comprises blue-grey to yellowish-brown, thickly-bedded, firm, non calcareous massive fine sandstone with no obvious macrofossils.

The uppermost parts of the Te Ipuohape Sandstone Member crop out on the Napier-Taupo Road immediately on the south side of the Mohaka River bridge (V20/241185). Medium sandstone with scattered shellhash grades over 50 cm into blue-grey siltstone (Rakaita Siltstone Member). The Auroa Alternating Member is absent from this locality. This contact represents the uppermost part of a section well exposed in the Mohaka River from near the McVicars Road bridge (V20/216167) to Glenfalls Reserve (V20/276233). Immediately upstream of the McVicars Road bridge Te Ipuohape Sandstone Member is in fault contact with basement (V20/219171). Several hundred metres above the McVicars Road bridge the Te Ipuohape Sandstone Member rapidly overlies concretionary macrofossil-rich (largely *Struthiolaria*) beds of the Tarawera Limestone Member (V20/216167). The Te Ipuohape Sandstone Member in this section is quite concretionary and poorly to moderately well bedded. Macrofossils are very sparse throughout.

The most macrofossil-rich expression of the member crops out in the Tutaekuri River, Kaweka State Forest Park, above the Lawrence Road swingbridge (Fig. 5G). The Tarawera Limestone Member appears to be absent at this site, with the Te Ipuohape Sandstone Member directly overlying, or in fault contact with basement. The member here comprises blue-grey, non cemented massive fine sandstone to silty sandstone with common concretionary bands up to 0.3 m thick every few metres (U20/057982). Macrofauna are abundant in concretionary layers, and relatively sparse in the non cemented intervals. The member is abruptly overlain by strongly bedded channelised deposits assigned to the Auroa Alternating Member. These channelised deposits have eroded up to 20 m into the underlying Te Ipuohape Sandstone Member (Fig. 6B, C).

At Opau Stream near Patoka (V20/208048) steeply dipping Te Ipuohape Sandstone Member is overlain by Te Waka Formation across a spectacular angular unconformity. The Te Ipuohape

Sandstone Member dips at 45° and unconformably overlies basement, and wedges out to the south of the section.

The Te Ipuohape Sandstone Member is generally coarser-grained than the Ngatapa Sandstone Member (Poamoko Formation). Macrofossils are generally absent, except at the base of the formation in the vicinity of the gradational contact with the underlying Tarawera Limestone Member.

Paleontology and age

Macrofossils are dominated by *Struthiolaria* spp.*, Zeacolpus,* and *Zenatia,* although they are almost entirely restricted to basal parts of the member. Only in the Tutaekuri River section are macrofauna abundant. Fauna at that section are dominated by *Crassostrea ingens, Struthiolaria* (*Callusaria*) *callosa* and *Crepidula radiata.* The Tongaporutuan pectinid *Sectipecten grangei* is common, together with *Alcithoe, Dosinia, Anomia, Patro* and *Glycymerita.* Other fauna present include *Talochlamys gemmulata, Zeacolpus*, *Eumarcia ?benhami, Maoricardium spatiosum* and *Panopea worthingtoni*. *Crepidula* are typically present in the form of "fornicating stacks"; one such stack observed to comprise 24 individuals.

Foraminiferal assemblages are poorly preserved and diversity is low. Diagnostic taxa are rare and biostratigraphic resolution is usually poor (Scott *et al.* 1990a). The limited microfossil data available for the Te Ipuohape Sandstone Member indicate that deposition of the member commenced during the Lower Tongaporutuan and continued into the Upper Tongaporutuan. There is no definite evidence of Waiauan deposition (Scott *et al.* 1990a). The occurrence of *Struthiolaria* (*Callusaria*) *callosa* strongly suggests an age not younger than Tongaporutuan. The presence of common *Sectipecten grangei* in the Tutaekuri River section also indicates a Tongaporutuan age.

In samples from the Napier-Taupo Road section (V19/f228, V20/f384 and V20/f386) the presence of *Globoconella miotumida* and absence of *G. dehiscens* suggests an Upper Tongaporutuan age.

On the basis of stratigraphic position, macrofossil and microfossil content an Upper Tongaporutuan age is assigned to the Te Ipuohape Sandstone Member.

Environment of deposition

The Te Ipuohape Sandstone Member is inferred to have been deposited in a variety of progressively deepening environments, from shallow-water settings with a rocky coastline (Fig.

5E), to possible outer shelf water depths. Shallower water environments are more prominent south of the Napier-Taupo Road. Highly fossiliferous concretionary beds in Crohane Forest are rich in *Struthiolaria (Callusaria)* and *Zenatia acinaces*, suggesting a relatively nearshore depositional setting with a sandy bottom substrate. These beds occur in very close proximity to basement. The rarity of planktonic taxa suggests that deposition of much of the unit occurred in a neritic water mass (Cutten 1994).

Auroa Alternating Member (waa)

(Cutten 1994)

Name and definition

Auroa Alternating Member (Fig. 3) is named after Auroa Road near The Organs, Mohaka Forest. The unit was informally referred to as the Waitere alternating lithofacies in Cutten (1988a, b) and Scott *et al*. (1990a). Cutten (1994) formally defined the unit as the Auroa Alternating Member. The member represents a transitional zone between the Te Ipuohape Sandstone and the Rakaita Siltstone Members.

Type locality and reference sections

The type section designated by Cutten (1994) has been retained. It is located in Anticline Creek from V19/401313 to V19/396311. A reference section is designated in the Tutaekuri River from the Lawrence Road swing bridge upstream to the confluence with the Donald River (U20/062980 to U20/060980; Fig. 6B-D).

Lower and upper contacts

In almost all localities Auroa Alternating Member conformably and gradationally overlies the Te Ipuohape Sandstone Member, and is conformably overlain by the Rakaita Siltstone Member. An exception to this is in the Tutaekuri River where channelised facies of the Auroa Alternating Member unconformably and erosionally overlie sandstone of the Te Ipuohape Sandstone Member (Fig. 6B-D).

The Auroa Alternating Member passes conformably upsection into the Rakaita Siltstone Member.

Distribution and thickness

The Auroa Member is up to 240 m thick in the type section and is reported to wedge out against the eastern limb of the Pohokura Anticline (Cutten 1994). Auroa Alternating Member is mostly restricted in outcrop to the map area of Cutten (1994) (NZMS260 V19 Te Haroto). Strongly bedded fine-scale alternating siltstone-sandstone couplets cropping out in the Tutaekuri River (Kaweka Forest Park) have been assigned to the Auroa Alternating Member, and represent the only known occurrence of the unit south of the Napier-Taupo Road. In this section the member is estimated to be 30-50 m thick.

Description

Auroa Alternating Member comprises an alternating sequence of an approximately equal number of 5 cm to 5 m-thick sandstone and siltstone beds. Sandstone units are similar to the underlying Te Ipuohape Sandstone Member, whereas siltstone beds are similar to the overlying Rakaita Siltstone Member. Sandstones are well indurated, fine to medium-grained, yellow-brown in colour and generally massive. Siltstones are massive to finely laminated, poorly indurated and blue-grey in colour (Cutten 1994).

The Auroa Alternating Member sporadically crops out along parts of Coppermine Road in Mohaka Forest. At V19/339298, in the boundary zone with the underlying Te Ipuohape Sandstone Member, Auroa Alternating Member comprises grey to yellowish-brown, non cemented, firm, very fine siltstone with a prominent blocky conchoidal fracture weathering pattern. Some well cemented sandstone beds up to 0.2 m thick are present at this site. No obvious macrofossils are present.

Auroa Alternating Member cropping out in the Tutaekuri River differs from outcrops in the Mohaka-Te Hoe River area in its fine-scale bedding.

Paleontology and age

Macrofossils are very rare in the Auroa Alternating Member. One fragmented valve of *Sectipecten grangei* and scattered shell fragments have been observed in the Tutaekuri River section.

Based on foraminifera a Tongaporutuan age was assigned to the Auroa Alternating Member by Scott *et al.* (1990a). The absence of *Globoquadrina dehiscens* suggests deposition after the Lower Tongaporutuan, but whether this foraminifer is restricted to the Upper Tongaporutuan, or extended into the Lower Kapitean, has not been resolved (Cutten 1994). Changes in the morphology of *Bolivinita* spp. suggest close proximity to the Tongaporutuan-Kapitean boundary.



Fig. 6: Waitere Formation cropping out in Tutaekuri River cliffs, above Lawrence Road end, Kaweka Forest Park. These units represent the southernmost outcrops of Waitere Formation and Tongaporutuan beds in the study area. **A)** Highly fossiliferous concretionary sandstone of the lower Te Ipuohape Sandstone Member (U20/061980). The pectinid valves visible are *Sectipecten grangei* which confirms a Tongaporutuan age for this unit. The sample is dominated by the gastropod *Crepidula radiata.* **B)** Strongly channelised alternating sandstone-siltstone couplets of the Auroa Alternating Member unconformably overlying Te Ipuohape Sandstone Member (U20/060980). Incision of channelised beds into the Te Ipuohape Sandstone Member is as much as 30 m. **C)** Close-up view of channelised beds in B (U20/060980). **D)** Finely laminated sandstone-siltstone couplets of the Auroa Alternating Member. This interval conformably overlies similar channelised facies, and is inferred to pass conformably upsection into massive to weakly laminated Rakaita Siltstone Member. A microfossil sample (U20/f150) collected from near the hammer (circled) yielded a confident Tongaporutuan age, and an outer shelf to upper bathyal depositional environment (U20/061980).

Microfossil sample U20/f150 (Appendix V) contained a sparse, moderately well preserved predominantly calcareous assemblage. A Tongaporutuan age was assigned on the basis of planktic and benthic content (*Globoconella miotumida, Neogloboquadrina pachyderma* and *Bolivinita* cf. *plioliqua*). Glauconite is common in this sample.

Based on foraminifera (Scott *et al.* 1990a; Cutten 1994) an Upper Tongaporutuan age is assigned to Auroa Alternating Member.

Environment of deposition

Throughout its outcrop extent microfossil evidence suggests that the Auroa Alternating Member was deposited at upper to middle bathyal water depths (Scott *et al*. 1990a; Cutten 1994). Greater abundances of planktic foraminifera in the Auroa Alternating Member than the underlying Te Ipuohape Sandstone Member suggest a higher degree of exposure to oceanic water and that the focus of deposition may have been located further offshore.

The composition of microfossil sample U20/f150 from the Tutaekuri River section indicates deposition at middle shelf water depths (50-100 m) under normal marine conditions for beds in the Kuripapango region. The presence of 9% planktics in this sample (U20/f150) suggests an inner neritic water mass (Appendix V).

Rakaita Siltstone Member (war)

(Cutten 1994)

Name and definition

Rakaita Siltstone Member (Fig. 3) is named after Rakaita peak, located at V19/437345. Cutten (1988) introduced the informal name Waitere siltstone lithofacies for this member, with Cutten (1994) formally defining the unit as the Rakaita Siltstone Member of the Waitere Formation. The definition of Cutten (1994) is extended to include the thick siltstone unit exposed in road cuttings along State Highway 5, immediately below Titiokura Saddle on the southern side of the Mohaka River bridge at the base of the Maungaharuru Range.

Type locality and reference sections

The type section nominated by Cutten (1994) has been retained in this study. Rakaita Siltstone Member is best exposed in road cuttings on the western side of the Te Waka Range as the Napier-Taupo Road climbs from the Mohaka River bridge to Titiokura Saddle. Waitara Road between Glenfalls Reserve and Pohokura Road provides numerous outcrop windows into the member.

Distribution and thickness

The unit is exposed in many slips along the western face of the Maungaharuru Range. A fault-bounded Tongaporutuan aged fine-grained thinly-bedded unit (Fig. 6D) exposed in the upper reaches of the Tutaekuri River is included in the Waitere Formation based on age and lithological similarities. This section marks the southernmost outcrop known in the study area of the Waitere Formation.

A foraminiferal sample (V20/f442) collected from sandy siltstone in Gorge Stream near Te Kowhai forest yielded a Tongaporutuan age. On the basis of age and lithological similarities this unit is assigned to the Rakaita Siltstone Member.

The occurrence of the member south of the Napier-Taupo Road is strongly controlled by vertical displacement on faults of the North Island Shear Belt and associated erosion. The member erosionally wedges out rapidly south of the Napier-Taupo Road, a reflection of post-depositional oblique-slip on the Mohaka Fault.

In the section below Taraponui Trig the Rakaita Siltstone Member is approximately 850 m thick, increasing to 3000 m in the Willowflat area to the north (Cutten 1994). Over 1100 m of section is exposed on State Highway 5 from the Mohaka River bridge to Titiokura Saddle (V20/241185-V20/278152). The Mohaka Fault passes through this section (V20/245176) making an accurate estimate of thickness difficult.

Lower and upper contacts

The Rakaita Siltstone Member overlies three stratigraphic units. Where the Auroa Alternating Member is present the Rakaita Siltstone Member gradationally overlies it. This transition is poorly exposed in the study area, but crops out on Auroa Road, Mohaka Forest. Where the Auroa Alternating Member wedges out against the Pohokura Anticline the Rakaita Siltstone Member overlies the Te Ipuohape Sandstone Member (Cutten 1994). A cutting immediately south of the Mohaka River bridge on the Napier-Taupo Road shows a fine sandstone rapidly grading over 0.5 m into siltstone. This is inferred to represent the lower contact of the Rakaita Siltstone Member.

The upper contact is only confidently identified in one locality, that being in a cutting on the Napier-Taupo Road immediately on the Taupo side of Titiokura Saddle (V20/278152). At this location the Rakaita Siltstone Member is sharply overlain by a strongly cemented concretionary layer up to 50 cm thick, capped by a 10-15 cm-thick interval rich in phosphate nodules, glauconite and shark teeth.

It was suggested by Cutten (1994) that the upper contact was exposed on Pohokura Road near the Woodstock Road intersection. Exposure is poor in this area and the location of the contact has not been confidently resolved.

Description

In the vicinity of State Highway 5 the Rakaita Siltstone Member comprises blue-grey, massive, non to slightly cemented, non to slightly fossiliferous sandy siltstone that is relatively consistent in grainsize through its thickness. Scattered concretions of variable size are present through the member.

Paleontology and age

Only very sparse macrofossils have been observed in the Rakaita Siltstone Member. An Upper Tongaporutuan to Lower Kapitean age has been inferred for this member in the north of the study area (Scott *et al.* 1990a). The assemblage in sample V19/f100, taken from a site along the Mohaka River, includes *Bolivinita pohana* and *Globoquadrina dehiscens* (Scott *et al.* 1990a). The appearance of *Bolivinita pliozea* in sample V19/f4 (V19/414329) suggests proximity to the Tongaporutuan-Kapitean boundary (Cutten 1994).

A suite of samples reported in the fossil record file from sites along the Napier-Taupo Road from the Mohaka River bridge to Titiokura Saddle are consistently dated as Upper Tongaporutuan to Lower Kapitean. The microfossil content in the stratigraphically highest of these samples (V20/ f399), while dated as Upper Tongaporutuan-Kapitean is more suggestive of a Kapitean age.

A Tongaporutuan age for foraminiferal sample V20/f442 (Appendix V) in Gorge Stream is constrained by both planktic and benthic taxa, including *Globoconella miotumida, Neogloboquadrina pachyderma* and *Bolivinita pohana.* The relative abundance of *Globigerinoides* and the apparent lack of *Globoquadrina dehiscens* suggest an age of 8.8-8.0 Ma (Upper Tongaporutuan) (M. Crundwell IGNS pers. comm. 2004).

The overlying Mokonui Sandstone is assigned a “lower to middle” Kapitean to Opoitian age, helping to constrain the age of the Rakaita Siltstone Member. On the basis of microfossil content and stratigraphic position, the Rakaita Siltstone Member is assigned an Upper Tongaporutuan to Lower Kapitean age.

Environment of deposition

Foraminiferal collections V19/f163-f53 from the Mohaka River include some bathyal taxa such as *Karreriella cylindrica* and *Sigmoilopsis schlumbergeri* which also occur in the underlying Auroa Alternating Member. Other depth diagnostic species such as *Vulvulina pennatula,* however, are absent. As in the Auroa Alternating Member, *Cibicides molestus* and *Haeuslerella morgani* are well represented in the Rakaita Siltstone Member. A continuation of depositional conditions initiated during the latest phase of Te Ipuohape Sandstone Member deposition is inferred (Scott *et al.* 1990a). Deposition in the Waitere region at upper to middle bathyal water depths is inferred for the Rakaita Member, an environment similar to that inferred for the Auroa Alternating Member (Cutten 1994). 20% planktics were present in sample V19/f53 from the Mohaka River site indicating a neritic water mass (Scott *et al.* 1990a), but taxa could have been reworked into deeper water.

Foraminiferal sample V20/f442 from Gorge stream contained approximately 6% planktics that were largely crust-free specimens, and indicates an inner neritic water mass. An upper slope (300-400 m) depositional setting under normal marine conditions is inferred for this area based on the presence of *Cibicides molestus* (M. Crundwell GNS pers. comm. 2004).

MOKONUI SANDSTONE (mk)

(Cutten 1988; formally defined by Cutten 1994)

Name and definition

Cutten (1988) introduced the informal name Mokonui sandstone lithofacies, in reference to a massive sandstone unit prominent on the northern face of the Maungaharuru Range. McKay (1886a) had earlier referred to this unit as the Maungaharuru Range sandstone. (informal) The name is taken from a peak located at V21/432330. This peak was named Mokonui on NZMS 1 Tutira N114 (1975 3rd edition), but the name was dropped on NZMS 260 V19 Te Haroto (Edition 1, 1988). Cutten (1994) retained Mokonui as a name for consistency with earlier reports published on the area. The unit is named here Mokonui Sandstone in reference to the dominant lithology of the formation. The formation is defined as a sandstone unit that conformably to unconformably underlies the Titiokura Formation in a region from the northern parts of the Maungaharuru Range to the Maniaroa Range in the south. The formation is the uppermost unit of the Tolaga Group for much of the study area east of the Mohaka Fault, north of Puketitiri Road.

Type locality and reference sections

The type section nominated by Cutten (1994) along Pohokura Road on the western face of the Maungaharuru Range has been retained (Fig. 7A), although the base of the formation here remains poorly resolved. The basal and upper contacts of the formation are exposed in a reference section along the Napier-Taupo Road from V20/278152 to V20/287144. Much of the formation is visible in scrappy outcrops along this section, which is one of the very few localities where the basal contact has been confidently identified. The unit is well exposed in the upper parts of Jeph Everett Road north of Pohokura Saddle.

Lower and upper contacts

The lower contact is highly variable through the study area and is very poorly exposed. The contact has only been confidently identified at Titiokura Saddle on the Napier-Taupo Road (V20/278152) where a pronounced glauconite layer up to 50 cm thick is present immediately above a very sharp contact with the underlying Waitere Formation. This layer contains abundant phosphate nodules, as well as very high numbers of shark teeth and less common phosphatised gastropods, solitary corals, and bivalves.

The upper contact of the Mokonui Sandstone is marked throughout the field area by the presence of a conglomerate bed at the base of the overlying Titiokura Formation. The upper contact is exposed on Pohokura Road near the intersection with Jeph Everett Road, on the Napier-Taupo Road at V20/287144, in Titiokura Quarry at the northern end of the Maungaharuru Range, at two locations on Oakmere Station near the boundary with Rock Station, Te Pohue, and in numerous localities on the north face of the Te Waka Range (e.g. V20/270115; V20/239128).

Although partially obscured by vegetation, the upper contact can also be located on the Napier-Taupo Road near Titiokura Saddle (V20/287144). A prominent feature of the upper contact is the increasing level of erosion on the upper contact southward along the Maungaharuru and Te Waka Ranges, especially south of the Napier-Taupo Road. At Pohokura Saddle relief on the upper contact is up to 6 m (Fig. 7D). Approximately 21 km to the southwest erosional relief on the upper surface of the Mokonui Sandstone is in the order of 30 m on the western face of the Te Waka Range (V20/235127) (Fig. 7F).

Distribution and thickness

Mokonui Sandstone is widespread through the high hill country in northern parts of the study area, and is particularly well exposed in the Maungaharuru and Te Waka Ranges. The unit steadily decreases in thickness from 300 m at Pohokura Road to 240 m at Titiokura Saddle on the Napier-

Taupo Road (V20/280152). South of the highway, the unit thins slightly to 180 m in the Hells Hole area (V20/233126) southwest of Te Waka Trig. North of the study area, Mokonui Sandstone increases in thickness to over 1000 m (Cutten 1994).

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Mokonui Sandstone has been mapped as far south as the southern Maniaroa Range. As the outcrop strike of the Mokonui Sandstone is oblique to that of the North Island Shear Belt (in particular the Mohaka Fault), it is truncated by the Mohaka Fault near Hawkston Station and does not crop out south of this point.

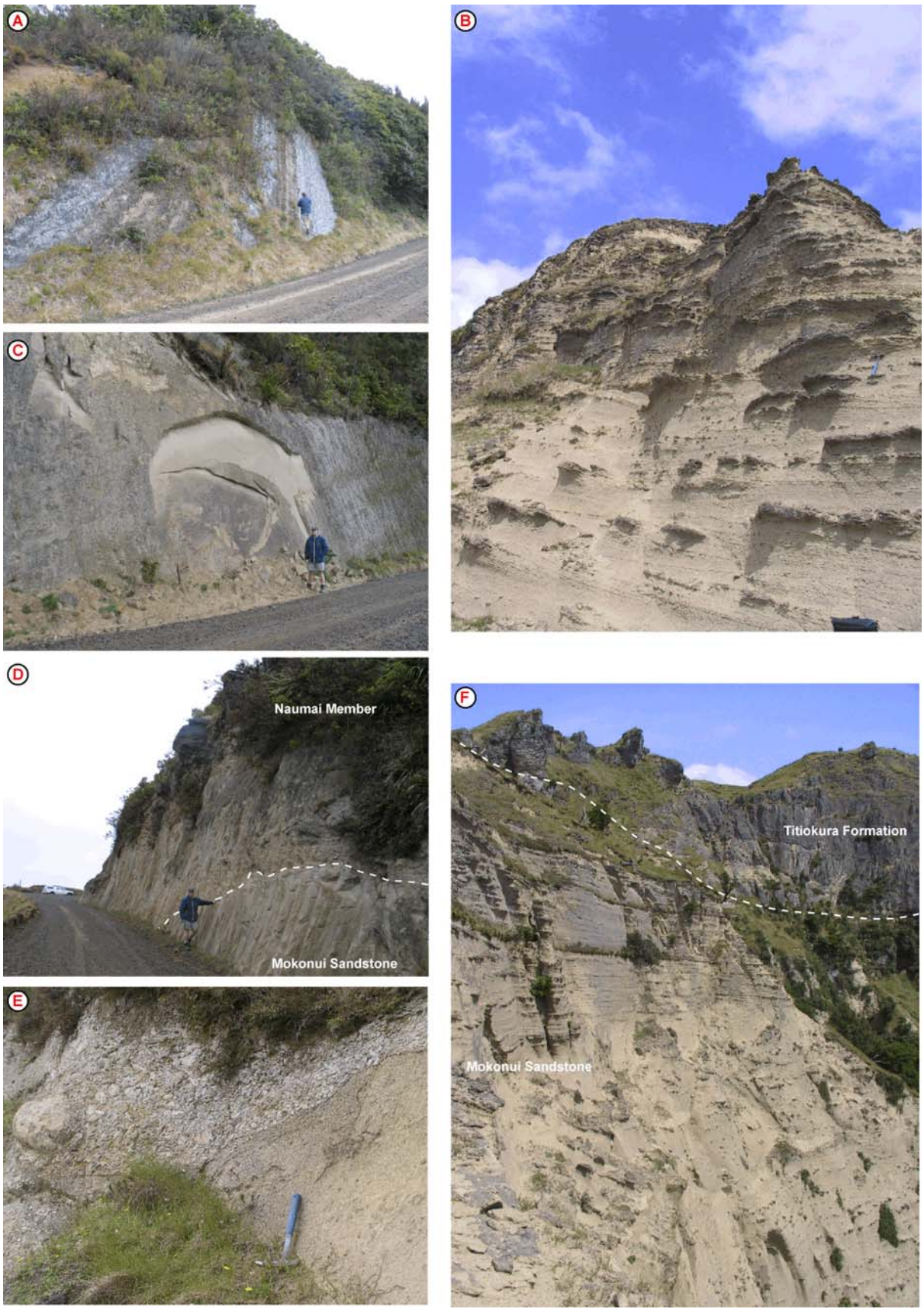
A siliciclastic sandstone unit 180 m thick was intercepted in Hukarere-1 and dated as Upper Opoitian to possibly uppermost Kapitean age. Although named Haupori Sandstone it was acknowledged that it may be possible that this 180 m-thick sandstone is correlative with the Mokonui Sandstone (Westech Energy NZ Ltd 2001).

Description

The Mokonui Sandstone comprises blue-grey weathering to light brown, non to slightly cemented, slightly concretionary, non to sparsely fossiliferous, very well sorted fine to medium sandstone as observed at the type section (Fig. 7A). Weathering of exposures has tended to obscure primary sedimentary structures. Scattered brachiopods are the only macrofossils observed at this locality. Faint channelised beds, large-scale and low-angle tabular cross-beds are evident in sections along Pohokura Road (Fig. 7C). At the type section the Mokonui Sandstone is unconformably and erosionally overlain by basal conglomerate facies of the Naumai Member, Titiokura Formation (Fig. 7D).

At Titiokura Quarry in southern parts of the Maungaharuru Range (V20/293159) the Mokonui Sandstone comprises slightly cemented, moderately weathered medium sandstone that displays faint laminar bedding and small-scale tabular cross-stratification. Concretions up to 6 cm thick are present and frequently contain common *Talochlamys gemmulata*. At this locality the Mokonui Sandstone is sharply overlain by basal conglomeratic facies of the Titiokura Formation.

The Mokonui Sandstone is exposed in road cuttings near Titiokura Saddle on State Highway 5 from the disconformable lower contact with the Rakaita Siltstone Member (Waitere Formation) described above, to the upper sharp contact with the Titiokura Formation. In this section the formation comprises blue-grey weathering yellow-brown, non cemented, massive to planar laminated, fine sandstone.


A
B
C
D
Naumai Member
Mokonui Sandstone
E
F
Titiokura Formation
Mokonui Sandstone

Macrofossil content increases upsection at this locality, from slightly to moderately fossiliferous, and largely consists of the bivalves *Tawera, Mactra* and *Talochlamys,* with some shellhash and occasional burrows.

Mokonui Sandstone often becomes relatively concretionary in upper parts south of Titiokura Saddle. Bedding in the form of planar laminations and cross-stratification is prominent (Fig. 7B, F). Near Hells Hole, central Te Waka Range (V20/235127) (Fig. 7B, E), the unit contains channels filled with siltstone rip-up clasts up to 0.1 m in size. The channels are typically 2-5 m below the upper surface of the unit, and are continuous over several metres (Fig. 7E).

At Hells Hole well sorted, fine to medium sandstone crops out in a steep cliff-face exposure over 200 m high (Fig. 7F). Concretionary beds (Fig. 7B) become more common upsection, as do well-developed small to moderate-scale, low- to moderate-angle tabular and trough cross-beds. A spectacular paleo-relief of up to 30 m has been carved into the top of the Mokonui Sandstone, which is overlain by Titiokura Formation (Fig. 7F).

Paleontology and age

Very few macrofossils have been observed in the Mokonui Sandstone. Most fauna collected have come from Titiokura Saddle (V20/278152), and are dominated by shark teeth. Scattered, unidentified, brachiopod fossils have been observed at the base of the type section along Pohokura Road near the Woodstock Road intersection. Common *Talochlamys gemmulata* have been observed in thin concretions in upper beds of the formation at Titiokura Quarry. Based on foraminifera, Cutten (1994) assigned a Lower Kapitean to Opoitian age to this formation. A collection taken 100 m above the base of the unit near Pohokura Road by Cutten (1994) (sample V19/f160) included *Truncorotalia crassaformis, Globoconella pliozea,* and *Globoconella. puncticulata*, indicating a Lower to “Middle” Opoitian age. Collections near the base of the unit (also by Cutten) in the Mohaka River (sample V19/f46) contain *Globoconella miotumida* (with *conomiozea* morphotypes) and are dated Lower Kapitean, possibly near Upper Kapitean boundary. Mokonui Sandstone is assigned a Kapitean to Upper Opoitian (Late Miocene to Early Pliocene) age.

Fig. 7 (facing page): Mokonui Sandstone. **A)** Basal moderately steeply-dipping and possibly slumped beds of the Mokonui Sandstone cropping out at the base of the type section (V19/375276) on Pohokura Road, near the Woodstock Road intersection **B)** Highly concretionary sandstone of the upper Mokonui Sandstone at Hells Hole on the north face of the Te Waka Range (V20/235127). **C)** Mokonui Sandstone cropping out beside Pohokura Road at the top of the type section on Pohokura Road near the Jeph Everett Road intersection (V19/389273). **D)** Mokonui Sandstone unconformably overlain by basal conglomerate beds of the Naumai Member (Titiokura Formation) on Pohokura Road (V19/ 390273). Metre-scale relief is present on this erosional contact. **E)** Mokonui Sandstone overlain by Titiokura Formation at Hells Hole (V20/235127), central Te Waka Range. Up to 30 m of relief is present on the contact between the two formations at this site. **F)** Siltstone clast-filled conglomerate bed in the Mokonui Formation immediately below the sharp erosional upper contact with the Titiokura Formation, north face Te Waka Range (V20/239128).

Mokonui Sandstone is in part a chronostratigraphic equivalent of the Blowhard, Omahaki, Mangatoro, and (possibly) the lower Pakaututu Formations cropping out west of the Mohaka Fault.

Environment of deposition

Mokonui Sandstone was deposited in a progressively shallowing environment from upper bathyal to inner shelf water depths. A broadly shore-perpendicular shelf to upper bathyal depositional gradient is evident from the Te Waka Range to the northern Maungaharuru Range. Upper bathyal deposition is suggested in lower parts of the unit near Pohokura Road (V19/f160) based on the presence of *Cibicides deliquatus, C. neoperforatus, Haeuslerella pliocenica, Karreriella cylindrical, Notorotalia* sp. and common *Robuslus* spp. (Cutten, 1994). Cutten (1994) also suggests that exposure to oceanic water is indicated by the presence of c. 40-50% planktic specimens in foraminiferal assemblages. Mokonui Sandstone cropping out in the Te Waka Range was deposited at much shallower water depths than equivalent horizons in the Maungaharuru Range. This is supported by the abundance of shallow-water bedforms (Fig. 7B, E) and the spectacular paleo-relief carved into the formation at Hells Hole.

MANGAHEIA GROUP

(Steineke 1934; formally defined by Mazengarb *et al.* 1991)

Name and definition

Mazengarb *et al.* (1991) introduced Mangaheia Group in a geological map of the Tauwhareparae area located north of Gisborne and inland from Tolaga Bay. The name of the group was redefined from the Mangaheia Formation of Steineke (1934), the name derived from the Mangaheia River, which occurs immediately south of the Tauwhareparae area. The original definition of the Mangaheia Group (Mazengarb *et al.* 1991, p. 33) comprised shallow-water sandstone and limestone facies, with some deeper water (upper bathyal) mudstones of Kapitean to at least Opoitian age. For the Raukumara QMAP Sheet, Mazengarb and Speden (2000) extended the definition and occurrence of the Mangaheia Group south from the Tauwhareparae area to encompass rocks of similar age and facies in the Wairoa and Mahia regions. In this definition the group was defined to incorporate rocks of Kapitean-Waipipian age. The top of the Mangaheia Group as defined by both Mazengarb *et al.* (1991) and Mazengarb and Speden (2000) was marked by the youngest Cenozoic marine rocks present in their map areas.

Pallentin and Nelson (2001) and Pallentin (in prep.) recognised similarities between rocks of the Mangaheia Group in the Wairoa-Mahia area, and strata in the Maungaharuru-Willowflat-Putere Lakes area further south. Bland (2001) and Graafhuis (2001) had included rocks of this area in a

new group they named the Maungaharuru Group (a redefinition of the Maungaharuru Formation of Cutten (1994)). Given Mangaheia Group is an accepted and established stratigraphic name, and there are lithological and paleoenvironmental similarities between rocks in these two areas, it seems appropriate to extend the use of Mangaheia Group south into the present study area. Mangaheia Group includes rocks of Kapitean (Late Miocene) to Upper Nukumaruan (Early Pleistocene) age cropping out widely through western and northern parts of the study area. It unconformably overlies deep-water-dominated beds of the Tolaga Group and is overlain by non- to marginal-marine-dominated beds of the Kidnappers Group.

The Mangaheia Group includes rocks assigned to the Maungaharuru Subgroup of Bland *et al.* (2004) and the Petane Group by Haywick *et al*. (1991), Beu (1995), Bland (2001), Graafhuis (2001), Baggs (2004) and Dyer (2005). Mangaheia is preferred over Petane as a group name as it has a more widespread and accepted usage, and the base of the group can be confidently defined (see "Petane Formation" this appendix, and Chapter Three, p. 77). There are no broad lithological differences between rocks of the Mangaheia Group and Petane Group, and there seems little sense in maintaining beds in two separate groups.

Type locality

Mazengarb *et al.* (1991) nominated the type locality of Steineke's (1934) Mangaheia Formation, and the section on the Tolaga Bay-Tauwhareparae Road as the type locality for the Mangaheia Group. This section has its base at Y17/597076, with its top near the headwaters of Ramanui Stream at Y16/559108. This locality is retained in this study. Reference sections are nominated in the study area. An easily accessible reference section is nominated across the Maungaharuru Range to the Tangoio Block along Pohokura Road and State Highway 2 to the Tangoio Block. It has its base at Pohokura Saddle (V19/389273), and its top at Ridgemount Road (W20/537133). Another reference section extends from the Mohaka River near Riverlands (V20/236180), along the Napier-Taupo Road to Petane Corner (V20/437937).

Distribution

Rocks of the Mangaheia Group crop out widely through western and central parts of the study area (Fig. 1), and appear to be part of an almost continuous outcrop belt extending from the Ohara Depression northeast through the Maungaharuru Range, towards Willowflat, the Putere Lakes (inland from Raupunga), Tiniroto Lakes (inland from Gisborne), and toward Tolaga Bay and Tauwhareparae.

Lower and upper contacts

The base of the Mangaheia Group is unconformable through all of the study area. At Titiokura Saddle and along the western face of the Maungaharuru Range the group unconformably overlies Mokonui Sandstone (Tolaga Group). In southwestern parts of the study area Mangaheia Group unconformably overlies basement, such as at Kuripapango, Pakaututu and in the Ohara Depression.

The group is unconformably overlain by Kidnappers Group (Middle to Upper Castlecliffian, Late Pleistocene).

Age

Mangaheia Group is of Lower Kapitean to Upper Nukumaruan age (Late Miocene to Early Pleistocene).

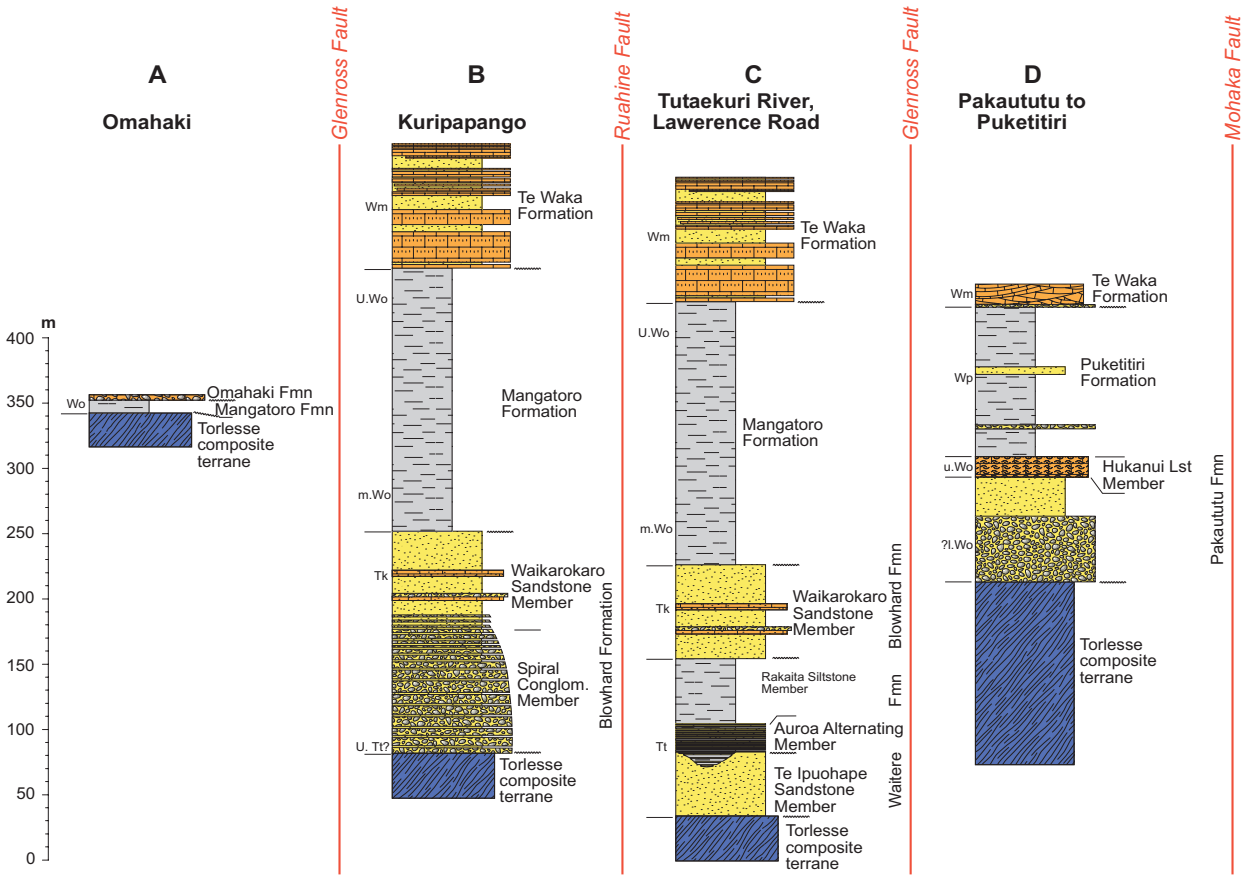


Fig. 8: Schematic stratigraphic columns illustrating the relationships between lower formations in the Mangaheia Group along the western side of the study area in the North Island Shear Belt. Omahaki is in the southwest, Pakaututu-Puketitiri is to the northeast. Note how the Te Waka Formation is common across several fault blocks, indicating its importance in determining displacement histories of faults in the North Island Shear Belt.

Environment of deposition

Rocks of the Mangaheia Group accumulated in a variety of shelfal depositional paleoenvironments. Limited incursions into upper bathyal water depths are recorded in some Lower Nukumaruan (Late Pliocene) rocks. Non-marine beds, although volumetrically uncommon, are geographically widespread in upper beds of the group.

BLOWHARD FORMATION (bh)

(Browne 1981; formally defined by Browne 2004a)

Name and definition

In his geological map of the Kuripapango region, Browne (1981) introduced the Blowhard Formation in reference to beds unconformably overlying basement on the Blowhard and Castle Rock Plateaus. Included were two members, namely the Spiral Conglomerate Member and the Waikarokaro Sandstone Member. The Blowhard Formation and its constituent members were formally defined by Browne (2004a).

Beu (1995) introduced the informal name Owhaoko limestone (informal) for beds of the Blowhard Formation. In reality, "limestone" beds are uncommon, thin and discontinuous in this unit. Beu's definition of the Owhaoko limestone excluded the prominent thick greywacke conglomerate beds that comprise lower parts of the Blowhard Formation in many parts of the Kuripapango region. For these reasons Browne's (2004) formal definition of the Blowhard Formation is used in this study. The name is derived from Blowhard Plateau on the foothills of the Kaweka Range, east of Kuripapango. Although Blowhard Formation comprises two distinctive members, the unit has been mapped as undifferentiated Blowhard Formation. These members are the Spiral Conglomerate and Waikarokaro Sandstone Members.

Blowhard Formation represents the stratigraphically lowest unit of the Mangaheia Group west of the Mohaka Fault (Fig. 8B, C).

Type locality and reference sections

This study nominates type sections for each of the two members of the Blowhard Formation (see below) as at no one locality is the entire formation exposed in a clear manner.

Distribution and thickness

Blowhard Formation is restricted in distribution to the Kuripapango area. In this study area Blowhard Formation is not known west of the Kaweka Fault or east of the Glenross Fault. Neither

has it been identified north of the Tutaekuri River. Browne (2004a, b) describes similar lithologies west of Kuripapango on Ngamatea and Timahanga Stations which are probable equivalents of the Blowhard Formation. Further correlatives are probably present in other regions of isolated Tongaporutuan-Kapitean rocks in the Mangaohane Plateau-southern Kaimanawa Range area. Blowhard Formation has a maximum exposed thickness of up to 170 m.

Spiral Conglomerate Member (bas)

(Browne 1981; formally defined by Browne 2004a)

Name and definition

Spiral Conglomerate Member (Fig. 8B) is named after "The Spiral", a local name for a now realigned part of Taihape Road near Kuripapango.

Type locality and reference sections

The type section nominated by Browne (2004a) is retained in this study and occurs along "The Spiral" (now part of the Kaweka Forest road system) near the modern path of Taihape Road and the hillsides immediately above (U20/996958-U20/001956: Fig. 9A).

Lower and upper contacts

The Spiral Conglomerate Member always unconformably overlies greywacke basement.

The member is conformably and gradationally overlain by the Waikarokaro Sandstone Member.

Distribution and thickness

Spiral Conglomerate Member crops out in a very small part of the Kuripapango area and is best development adjacent to the Napier-Taihape Road and in the Waikarokaro Stream catchment (Fig. 9A) (Browne 2004a). The member is thickest adjacent to faults, which may indicate contemporaneous fault displacement.

Spiral Conglomerate Member is present infilling localised (?fault) depressions in basement rocks in the Waikarokaro Stream catchment, and is not known away from this region. In this area the member is over 100 m thick (Browne 2003).

Description

The Spiral Conglomerate Member consists of poorly sorted, clast-supported greywacke conglomerate comprising angular to well rounded clasts of greywacke with thin interbeds of pale-grey, non calcareous, moderately well sorted, fine to medium sandstone and minor siltstone.

The basal portion of the member comprises poorly sorted, poorly stratified greywacke conglomerate to breccia (Fig. 9A). Clasts in this basal zone are coarser-grained than further up-section. Clasts in this interval are angular, and beds have scoured bases. Sandstone interbeds are rare, although typically very thin (Browne 2004a).

Paleontology and age

No macrofossils have been collected from Spiral Conglomerate Member. Browne (1981, 2004) reports a palynological sample (U20/f129) collected from the member that contains species indicating a Tongaporutuan or younger age, although these could not be refined any further. The overlying Waikarokaro Sandstone Member contains the pectinid *Sectipecten wollastoni*, which places a Kapitean age on the Spiral Conglomerate Member.

Environment of deposition

Pollen from the uncommon mudstone intervals within the member indicates a kauri swamp forest with podocarps, broadleaf trees, and a cool climate (Browne 2003). These areas were likely part of alluvial fans that were probably not very extensive and largely restricted to the outcrop area.

Waikarokaro Sandstone Member (baw)

(Browne 1981; formally defined by Browne 2004a)

Name and definition

Waikarokaro Sandstone Member (Fig. 8) was introduced by Browne (1981) and formally defined by Browne (2004a). It is the stratigraphically highest member of the Blowhard Formation. The unit is named after Waikarokaro Stream, a small waterway in the Kuripapango region near Taihape Road. The spelling of the name is taken from NZMS 1 map series, rather than the "Waikarekare" spelling that occurs on the NZMS 260 map series (Browne 2004a).

Type locality and reference sections

Browne (2004a) nominated a quarry exposure at U20/99498 (Fig. 9B) as the type section. This section is retained in this study and shows well-developed greywacke stacks unconformably

overlain by a slightly concretionary, well sorted sandstone. A reference section is nominated below Mount Miroroa (U20/008927) above an old forest road past the abandoned Miroroa Road greywacke quarry.

Lower and upper contacts

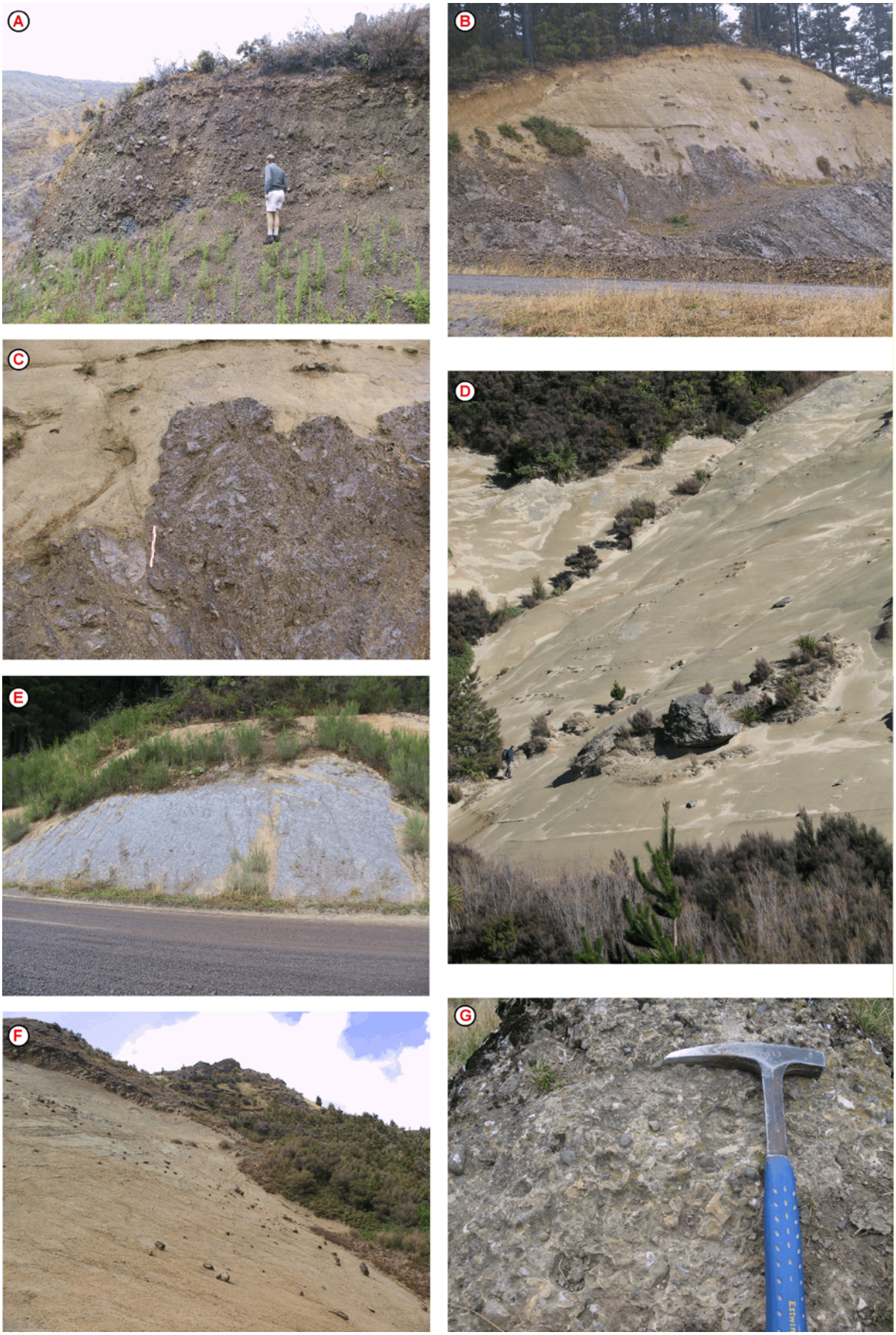
The Waikarokaro Sandstone Member conformably overlies the Spiral Conglomerate Member. Where the Spiral Conglomerate Member is not present Waikarokaro Sandstone Member rests directly on basement (Fig. 9B, C). The member is inferred to unconformably underlie the Mangatoro Mudstone, although this contact is not exposed in the study area. In almost all localities the Waikarokaro Sandstone Member is in fault contact with the Mangatoro Mudstone.

Throughout much of the Kuripapango region the top of the Waikarokaro Sandstone Member is marked by the modern eroded land surface. In isolated areas it is probable that the member is overlain by the Mangatoro Mudstone. At Mount Miroroa (Fig. 9D) the member is inferred to be overlain by limestone facies of the Lower Nukumaruan Sentry Box Formation, the Mangatoro Mudstone having been eroded during the Late Pliocene.

Distribution and thickness

Waikarokaro Sandstone Member is widely distributed across the Blowhard and Castle Rocks Plateaus in the Kaweka Forest area, although it forms mainly isolated, thin outcrops. The member does not crop out north of the Tutaekuri River, west of the Kaweka Fault or east of the Glenross Fault. Browne (1981, 1986, 2003, 2004) displayed on geological maps Blowhard Formation capping the MacIntosh Plateau. Although the MacIntosh Plateau (located north of the Tutaekuri River) has a geomorphology indicative of being capped by the Waikarokaro Sandstone Member, recent field investigations have failed to locate any Cenozoic sediments overlying basement (Greg Browne, GNS Science pers. comm. 2004). The Waikarokaro Sandstone Member is a maximum of 70 m thick in the Kuripapango region.

Fig. 9 (facing page): Blowhard Formation, Mangatoro Formation and Omahaki Formation cropping out in western parts of the study area. These beds represent some of the basal units of the Mangaheia Group in the Kuripapango and Omahaki areas. **A)** Very poorly sorted basal beds of the Spiral Conglomerate Member (Blowhard Formation) cropping out beside "The Spiral", Kaweka Forest. **B)** Basal beds of the Waikarokaro Sandstone Member (Blowhard Formation) overlying highly shattered basement. Metre-scale relief is clearly visible on this basal contact. The sporadic concretions and concretionary lenses visible in the sandstone are non to moderately fossiliferous. Rare valves of *Sectipecten wollastoni* have been observed at this locality. Uncommon *Crassostrea ingens* valves are present immediately above the basal contact. Quarry beside Kuripapango Road, Kaweka Forest (U20/994981). **C)** Close-up of the basal contact of the Waikarokaro Sandstone Member at Kuripapango Road quarry (U20/994981). **D)** Bluffs of Waikarokaro Sandstone Member cropping out below Mount Miroroa, Kaweka Forest (U20/008927). **E)** Mangatoro Formation beside Taihape Road, Kaweka Forest. **F)** Mangatoro Formation on the north face of Mount Kohinga (U20/980938). The formation is unconformably overlain by limestone beds of the Te Waka Formation at this locality. **G)** Well cemented pebbly limestone to shelly conglomerate of the upper part of the Omahaki Formation at Omahaki Station (U21/013867).


A
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Description

The Waikarokaro Sandstone Member comprises sandstone, conglomerate, pebbly limestone and calcareous sandstone, of which massive to trough cross-bedded, slightly concretionary and fossiliferous, very well sorted medium sandstone is the dominant lithology (e.g. Fig. 9B). Sandstones are generally fine to medium-grained and moderately to well sorted. The two best exposed sections through the member are at the type section (U20/994981) and below Mount Miroroa (U20/008927). At the type section it unconformably overlies strongly fractured greywacke through a surface displaying decimetre to metre-scale relief (Fig. 9B, C). The sandstone is massive to weakly laminated with scattered 10-20 cm thick oval-shaped concretions that are typically concentrated into bands up to 3 m long. Macrofossils are sparse through the sandstone, though slightly more common in the concretions. Scattered valves of *Crassostrea ingens* may be present encrusting hollows in the basal contact. Uncommon *Sectipecten wollastoni* are present in this section.

Blowhard Formation cropping out across the Castle Rocks Plateau is dominated by sandstone facies with lenses and stringers of greywacke pebbles typical near the basal contact with basement. At U20/023974 fine-grained massive sandstone crops out in a road cutting with greywacke pebble stringers up to 0.1-0.15 m thick. Pebbles are well rounded. A prominent block of Waikarokaro Sandstone Member crops out beside Castle Rocks Road at U20/029994. This block consists of grey weathering to cream, hard, very well cemented, fine to medium sandstone.

A section below Mount Miroroa (U20/008927) (Fig. 9D) displays at least 30 m of sandstone very similar to that in the type section. The Waikarokaro Sandstone Member consists of brown, non cemented, slightly micaceous fine to medium sandstone. Scattered concretions and concretionary horizons are present. The concretionary bodies are largely composed of cemented sandstone though some consist of coarse sand to gravel-sized shellhash. The main sandstone body is massive although occasional sigmoidal and tabular cross-beds are present. Thin pebble stringers of sandstone and mudstone clasts are also occasionally present. The base of the member is not exposed at this locality.

Paleontology and age

The Waikarokaro Sandstone Member contains a sparse to moderate macrofauna. *Crassostrea ingens* occurs just above the basement contact. Occasional barnacle plates and fragments have been observed in the type section in Kaweka Forest. Waikarokaro Sandstone Member contains the pectinid *Sectipecten wollastoni* (Kapitean index fossil). Based on the presence of *Sectipecten wollastoni* a Kapitean age is assigned to the Waikarokaro Sandstone Member.

Environment of deposition

The Waikarokaro Sandstone Member was deposited in a nearshore setting on and adjacent to exposed basement.

MANGATORO FORMATION (ma)

(Lillie 1953)

Name and definition

Mangatoro Formation (Fig. 8) was introduced by Lillie (1953) in reference to Early Pliocene mudstones in the Dannevirke Subdivision. The name is derived from the Mangatoro River. Lillie (1953) did not define a type section for the Mangatoro Formation, and the formation was emended by Harmsen (1985).

Browne (1981, 1986, 2004) applied the name Mangatoro Formation to Early Pliocene (Opoitian) siltstone cropping out in the Kuripapango area. This extension is retained in this study.

Type locality and reference sections

The type section designated by Harmsen (1985) is retained in this study. This section is located along part of Mangahei Road from V23/926057 to 920062. As the type section is well south of the study area, reference sections are nominated along Taihape Road (U20/993982; Fig. 9E) and on Mount Kohinga (U20/979937; Fig. 9F).

Lower and upper contacts

Except for in the Omahaki Depression, the lower contact of the Mangatoro Formation in the study area is not exposed and is almost always in fault contact with older units. In the Omahaki Depression Mangatoro Formation unconformably overlies Torlesse basement. The contact has been observed beside a farm track near the end of Glenross Road (U21/011866). Although not positively identified elsewhere, the lower contact with basement can be located to within a few metres to tens of centimetres at other locations in the Omahaki Depression. In the Kuripapango area it is inferred that Mangatoro Formation unconformably overlies the Blowhard Formation (Browne 2004a). In the Cape Kidnappers and Maraetotara areas Mangatoro Formation unconformably overlies undifferentiated Miocene rocks.

Mangatoro Formation unconformably underlies Mangapanian (Late Pliocene) limestone of the Te Waka Formation, although this contact is not exposed. A Waipipian unconformity is inferred in the Kuripapango area from the Opoitian age of the Mangatoro Formation (see below) and the

Mangapanian age of the Te Waka Formation in this area. In the Omahaki Depression, Mangatoro Formation is inferred to be unconformably overlain by coarse-grained shelly conglomerate and pebbly limestone of the Omahaki Formation. In the Kidnappers Section Mangatoro Formation grades conformably into the Black Reef Calcareous Sandstone (Kingma 1971; Francis 1993).

Distribution and thickness

Mangatoro Formation is widespread through the wider East Coast Basin, from at least as far north as Kuripapango, south to the Dannevirke region. The formation crops out more commonly away from the study area than in it.

In no place in the study area is the entire thickness of the Mangatoro Formation exposed. Most outcrops of Mangatoro Formation are contained in the Kuripapango region. The formation crops out in several cuttings beside Taihape Road and around Mount Kohinga, and is well exposed on the northern slopes (U20/994981;3 Fig. 9F). It is also well exposed in the Kidnappers Section from Cape Kidnappers to Black Reef.

A Mangatoro Formation equivalent unit 990 m thick was reported in the hydrocarbon exploration hole Hukarere-1 by Westech Energy NZ Ltd. This well was sited on a wharf in the Port of Napier (Westech Energy NZ Ltd 2001). The formation is likely to be thicker here than in outcrop as all Te Aute lithofacies are absent at this site.

In the Dannevirke Subdivision (Lillie 1953) Mangatoro Formation averages 300 m thick and is best developed in western parts of that area (Harmsen 1985). In the Te Aute subdivision (Kingma 1971) Mangatoro Formation is 530 m thick and only occurs between Cape Kidnappers and the Maraetotara River. This marks the region of greatest outcrop thickness for the formation.

Browne (1981) undertook a gravity profile across part of the Kuripapango area to determine the thickness of the Mangatoro Formation. From his modelling he estimated the depth to basement at 1 km. On the basis of geological mapping, Browne (1981) estimates the Mangatoro Formation in the study area may be as much as 1500 m thick (Browne 2003, 2004a). This thickness estimate is vastly greater than any other Opoitian succession present in the study area and Hawke's Bay Basin. It is very probable that Browne (2004a) has significantly overestimated the thickness of this unit. Geological cross sections (Enclosure 3) suggest that Mangatoro Formation in the Kuripapango area is more likely to be 200-500 m thick.

Description

Mangatoro Formation comprises muddy very fine to fine sandstone and sandy mudstone (Fig. 9E, F). The sediments in the formation are massive, but laminated silty sandstone beds up to 0.4 m-thick are present (Browne 2003). Macrofossils are rare although foraminifera are abundant (Browne 2004a).

Paleontology and age

No macrofossils have been collected from the Mangatoro Formation, although Browne (2004a) records abundant well-preserved foraminifera, with ostracods, molluscs, echinoid spines, bone fragments and fish teeth.

Foraminiferal sample (FRF U21/f87) from Omahaki Stream taken from near the base of the Mangatoro Formation yielded an Opoitian age. The age of this sample was constrained by planktics (*Globoconella puncticulata, Globoconella pliozea* and *Truncorotalia juanai*). On the basis of foraminifera, Mangatoro Formation in the study area is assigned a late Lower to Upper Opoitian age (Kingma 1957; Browne 2003). Mangatoro Formation is possibly age equivalent to upper beds of the Mokonui Sandstone, lower and middle beds of the Titiokura Formation and the Pakaututu Formation.

Environment of deposition

Mangatoro Formation appears to record a marked period of subsidence in the Kuripapango region (Browne 2004a). Foraminifera collected from the Mangatoro Formation in the Kuripapango area indicate a middle shelf environment of deposition (Browne 2004a). Foraminifera from near the base of the formation in the Omahaki Depression (U21/f87, Appendix V) indicate deposition at upper bathyal (300-400 m) water depths.

OMAHAKI FORMATION (om)

(Beu 1995)

Name and definition

Omahaki Formation (Fig. 8) was introduced by Beu (1995) for a very pebbly limestone to shelly conglomerate occurring in close proximity to basement in the Omahaki Depression (Omahaki Station), from which the name is derived. Beu (1995) suggested that the pebbly limestone of his original definition directly overlay basement rocks. In reality the limestone is separated from basement by several metres of siliciclastic siltstone and sandstone, assigned to the Mangatoro Formation.

Type locality and reference sections

The type locality designated by Beu (1995) is retained, although access is now somewhat difficult and exposure poor due to recent planting of *Pinus radiata*. A reference section in Omahaki Stream provides an easily accessible section through the basal siltstone-sandstone elements of the formation (U21/008858).

Lower and upper contacts

Throughout the Omahaki Depression the Omahaki Formation is inferred to unconformably overlie Mangatoro Mudstone.

The upper contact has not been observed in outcrop. On the northern end of the Ruahine Range at Seconds Ridge (informal local name) the formation is inferred to unconformably overlie greywacke and underlie Sentry Box Formation (U21/973802) (Beu 1995).

Distribution and thickness

The Omahaki Formation is not known east of the Glenross Fault. Outcrop is mostly restricted to the Omahaki Depression although one small outlier occurs on the northern end of the Ruahine Range at Seconds Ridge (U21/973802) (Beu 1995). The Omahaki Formation was mapped as Blowhard Formation in Browne (1986, 2003, 2004), and therefore by implication assigned a Kapitean (Late Miocene) age. This extended the distribution of the Blowhard Formation significantly south of Kuripapango. However, microfossil analysis of a sample from the Omahaki Formation gives an Opoitian (Early Pliocene) age. This, and the different lithology of the unit, separates it as a distinct unit from the Blowhard Formation.

Description

Basal beds of the Omahaki Formation comprise thin-bedded sandstone and siltstone units. Coarse-grained upper facies of the formation vary from a pebbly limestone to a shelly greywacke conglomerate to non fossiliferous greywacke conglomerate (Fig. 9G).

The Pakaututu Formation, which includes a limestone unit also stratigraphically near basement, can easily be differentiated from the Omahaki Formation by its much more diverse faunal content, and the abundant *Tucetona laticostata* valves it contains. Valves of *Phialopecten marwicki* are also common in the Pakaututu Formation, with none being identified in the Omahaki Formation.

Paleontology and age

The sole age diagnostic fossil identified in the Omahaki Formation is *Struthiolaria* (*Callusaria*) *obesa* which has an age range of Tongaporutuan to Opoitian (Beu 1995). The formation overlies Mangatoro Formation which has yielded an Opoitian foraminiferal age (U21/f87, Appendix V). On the basis of macrofaunal and stratigraphic position the Omahaki Formation is assigned an Opoitian (Early Pliocene) age. The Omahaki Formation is age equivalent to the Pakaututu Formation cropping out widely in the Puketitiri and Pakaututu areas, and the upper parts of the Mokonui Sandstone. It may also be equivalent to parts of the Titiokura Formation in the Maungaharuru Range.

Environment of deposition

The lithology of the coarse-grained beds of the Omahaki Formation suggests deposition in a high-energy nearshore setting, proximal to an emergent basement hinterland. The presence of *Struthiolaria (Callusaria) obesa, Crassostrea ingens* and *Ostrea chilensis* further suggest that the upper facies of the formation were deposited in a relatively high-energy shelf setting. The presence of Opoitian Omahaki Formation above upper bathyal Opoitian Mangatoro Formation infers a rapid shallowing to allow deposition of the upper pebbly limestone facies.

PAKAUTUTU FORMATION (pk) (new)

(Including Hukanui Limestone Member (pkh) (new))

Name and definition

The name Pakaututu Formation (Fig. 8) is derived from Pakaututu Road in western Hawke's Bay northwest of Puketitiri. It is applied to previously undescribed Neogene rocks that unconformably overlie basement above the Ripia River/Mohaka River confluence at the end of Pakaututu Road (V20/136160), Hot Springs Road (V20/119126), and the Balls Clearing Scenic Reserve area (V20/120090).

The name Hukanui Limestone Member is introduced to encompass the distinctive shelly limestone interval that characterises the Pakaututu Formation. In many areas the Hukanui Limestone Member represents the entire formation. The name is derived from Hukanui Station (V20/153109) where the member is widespread (Fig. 10A).

Type locality and reference sections

The type locality for the Pakaututu Formation is designated at Ripia Station above the Ripia River, on what is locally referred to as the "Ripia Face" (V20/128207). The type section for the formation is also designated as the type section for the Hukanui Limestone Member (Fig. 10A). Reference sections, where the base of the formation is exposed, are located above Pakaututu Road (V20/127123) and in the Mohaka River downstream of the Makahu River confluence (V20/123000-165000). These sections are all located west of the Ruahine Fault. A reference section is nominated east of the Ruahine Fault (V20/127123). This section is located on Hukanui Station and displays a thick basal greywacke conglomerate, overlain by concretionary sandstone and the Hukanui Limestone Member.

The lower contact in the Ripia area is an angular unconformity between the Hukanui Limestone Member and greywacke (Fig. 10C, D). No encrusting faunas were observed on the upper surface of the greywacke, although the facies immediately above the greywacke are highly variable, with sandstone, shellbed and conglomerate all present. This contact displays metre-scale relief, with common greywacke stacks protruding into the overlying limestone. Small caves in the greywacke have been infilled with calcareous sediments, as have many fissures. Valves of the large oyster *Crassostrea ingens* are often present near the basement onlap.

The upper contact is poorly exposed through the study area and has been observed only on Hukanui Station (Fig. 10A).

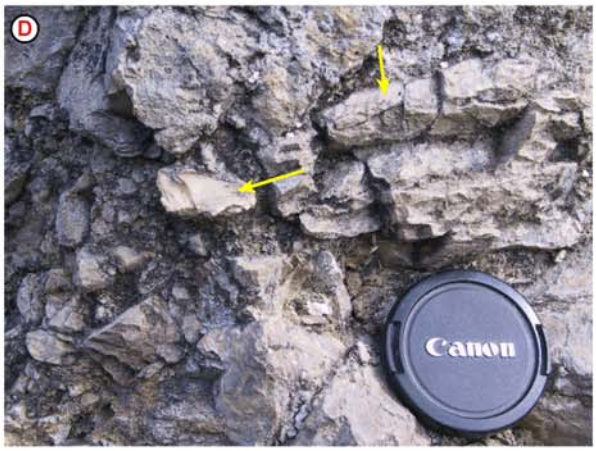
Above Hot Springs Road near the Ruahine Fault the Hukanui Limestone Member is separated from the underlying basement rocks by at least 50 m of mainly thick greywacke conglomerate beds (Fig. 10A). The contact between the conglomerate facies and basement has not been observed, though it has been located within a few metres of WP128 (V20/120117) and WP476 (V20/136129).

Fig. 10 (facing page): Pakaututu Formation and Puketitiri Formation. These two units comprise the basal beds of the Maungaharuru Subgroup (Mangaheia Group) in the Puketitiri and Pakaututu areas. **A)** Panorama of part of Hukanui Station illustrating the stratigraphic relationship between basement, the Pakaututu Formation, Puketitiri Formation and Te Waka Formation. Photo taken from V20/132128 looking southeast. **B)** Hukanui Limestone Member (Pakaututu Formation) unconformably overlies basement at the type section, Ripia Station (V20/134198). **C)** Unconformable contact between basement and the Hukanui Limestone Member (V20134198). Decimetre- to metre-scale relief is present on this contact. **D)** Fragmented valves of *Crassostrea ingens* (arrowed) overlying basement at the base of the Hukanui Limestone Member, Ripia Station (V20/128207). **E)** Abundant large intact valves of *Tucetona laticostata* in the Hukanui Limestone Member in a section above Pakaututu Road (V20/122117). **F)** Interbedded siltstone and sandstone beds of the Puketitiri Formation cropping out beside Puketitiri Road at the type section (V20/170067).


A
Te Waka Formation
Puketitiri Siltstone
Hukanui Limestone Member
Pakaututu Formation
Torlesse basement


B


C


D
Canon


E


F

Distribution and thickness

Pakaututu Formation is widespread on farms above the Ripia and Mohaka Rivers at the end of Pakaututu Road, and on farms above Hot Springs Road near "the switchback" (V20/119126). Small outcrops are also present beside Puketitiri Road near Rocky Hill and Anawhenua Stations (V20/133074, V20/118075), and on the northern side of Hukanui Station above Hot Springs Road (e.g. V20/122117). Units mapped by Grindley (1960) in Awahohonu Forest inland from State Highway 5 are also likely to be Pakaututu Formation. These areas display the same flat hilltop geomorphology known to be associated with Pakaututu Formation outcrops (e.g. at V19/139216 and V19/128234). A conglomeratic sandstone bed present near Makahu Road (U20/096134) is inferred to be a correlative of the Pakaututu Formation. Pakaututu Formation does not crop out east of the Mohaka Fault.

Lower and upper contacts

Pakaututu Formation overlies Torlesse basement (Fig. 10A-D). Significant decimetre-scale relief is common on this contact (Fig. 10C). The top of the unit has not been observed, and it is inferred that Pakaututu Formation conformably underlies Puketitiri Formation (Fig. 10A). West of the Ruahine Fault, where only the Hukanui Limestone Member crops out, the Pakaututu Formation is up to 15 m thick, and averages 8-10 m thick. East of the Ruahine Fault the Pakaututu Formation is up to 90 m thick. The increase in thickness reflects the increased prominence of basal siliciclastic beds. The basal conglomerate facies are 0 m to over 50 m thick, concretionary sandstone up to 20 m thick and the Hukanui Member 8-15 m thick. The increased thickness between sections east and west of the Ruahine Fault reflects the occurrence of prominent greywacke conglomerate and concretionary sandstone facies that underlie the limestone unit in this area.

Description

The Pakaututu Formation is one of the most distinctive units in the study area, containing a shelly limestone bed (defined here as the Hukanui Limestone Member) dominated by the large semi-infaunal bivalve *Tucetona laticostata* (Fig. 10E), many valves of which are commonly articulated. West of the Ruahine Fault only the Hukanui Limestone Member is present and it unconformably overlies basement; east of the fault the member is underlain by greywacke conglomerate and sandstone facies that vary in thickness with proximity to the Ruahine Fault trace.

The Hukanui Limestone Member is moderately to highly fossiliferous, moderately to well cemented with a matrix of medium siliciclastic sandstone and granule-sized greywacke grains,

and in places is whole shell dominated (Fig. 10E). While valves are typically disarticulated they are otherwise intact.

Beds of very well sorted coarse sandstone to granule sized greywacke grains are common, especially at the base of the limestone. Greywacke detritus comprises a larger part of the Hukanui Limestone Member west of the Ruahine Fault, reflecting the proximity of the unit here to basement. In many places west of the Ruahine Fault (e.g. V20/128207 and V20/123195) the Hukanui Limestone Member comprises two shelly limestone beds separated by up to 5 m of non cemented, very well sorted greywacke granules, shellhash and coarse sand.

Thick non fossiliferous greywacke conglomerate facies in the Pakaututu Formation have been identified only east of the Ruahine Fault. The conglomeratic interval comprises metre-scale alternating intervals of poorly to very poorly sorted massive to imbricated conglomerate interbedded with massive to trough cross-stratified gritty coarse sandstone containing scattered greywacke pebbles and thin pebble stringers. The gritty sandstone is composed entirely of coarse sandstone to granule greywacke clasts. Clasts in the poorly sorted greywacke conglomerate beds range from 0.5-20 cm across, although average about 2.5 cm across. All beds are clast supported. Conglomerate facies are well exposed in a high cutting at the head of a stream above Hot Springs Road at V20/127123 (face shown in Fig. 10A). Above the conglomeratic interval at this site is an 8 m-thick interval of non-exposure, above which is a 10 m thick interval of clean, well sorted non cemented sandstone with common concretionary lenses and horizons up to 60 cm thick and averaging 30 cm thick. These concretions contain any of, or a combination of, well rounded greywacke pebbles up to 3 cm across, bivalve, and gastropod fossils. *Stiracolpus, Zeacolpus* and *Struthiolaria (Callusaria) obesa/dolorosea* are common in these concretions. A further 1.5 m is not exposed, followed by 8 m of moderately cemented fossiliferous Hukanui Limestone Member rich in *Tucetona laticostata* with a few scattered greywacke grains.

An outcrop near Makahu Road of pebbly sandstone to greywacke conglomerate is thought to be a lateral equivalent of the limestone facies of Pakaututu Formation (U20/096154). This outcrop is characterised by the occurrence of distinctive, angular pebble and cobble-sized clasts set in a matrix often filled with shellhash. Fauna are typically sparse and highly fragmented, and only the thick shelled oyster *Crassostrea ingens* is commonly present intact.

Paleontology and age

A moderate range of fauna have been collected from this formation, although mostly from the Hukanui Limestone Member. *Tucetona laticostata* conspicuously dominates the taxa present

(Fig. 10E), with *Phialopecten marwicki, Dosinia* sp., *Purpurocardia purpurata, Glycymeris* sp., and *Eucrassatella* sp., also common. Other fauna observed include *Crassostrea ingens* (Fig. 10D), *Oxyperis ?komakoensis*, *Eumarcia benhami., Talochlamys gemmulata, Zeacolpus* sp., *Stiracolpus* sp., *Panopea* sp., *Mesopeplum* sp., and sparse *Tawera* sp.

Pakaututu Formation is inferred to be of Opoitian age based on the occurrence of *Phialopecten marwicki* (Wo form). *Phialopecten* has not previously been known from Lower Opoitian rocks in eastern North Island (Beu 1995, p. 59). The accurate identification of specimens of the gastropod genus *Struthiolaria* fossils in the formation has been problematic. Specimens collected resemble Opoitian *S. dolorosea,* a species not known away from the Awatere River valley in Marlborough. If these specimens are indeed *S. dolorosea* then it dramatically extends the known range of this form, and helps to support a confident Opoitian age for the Pakaututu Formation. It is possible that the *Struthiolaria* fossils collected are of the more common and widespread species *Struthiolaria (Callusaria) obesa* (Tt-Wo). The upper age limit of this species (Opoitian), when coupled with the presence of *Phialopecten marwicki,* further supports an Opoitian age for the Pakaututu Formation. Lowermost beds of the Pakaututu Formation may be of Kapitean age, although this is very poorly resolved.

The Pakaututu Formation is likely to be age equivalent of parts of the Titiokura Formation cropping out east of the Mohaka Fault, and the Omahaki Formation and Mangatoro Mudstone cropping out west of the Glenross Fault.

Environment of deposition

The fauna in the Pakaututu Formation are consistent with the *Tucetona-Ostrea* assemblage described by Hendy and Kamp (2004) for Opoitian rocks of the Matemateaonga Formation in Wanganui and Taranaki basins. *Tucetona* prefers clean water of relatively high-energy, and presently occupies environments such as channels in many Northland harbours. A similar depositional environment is envisaged for the limestone and sandstone facies of the Pakaututu Formation. The presence of strong relief on the lower greywacke surface west of the Ruahine Fault indicates a rugged sea-bottom with sea stacks.

The basal thick conglomerate facies adjacent to the Ruahine Fault probably accumulated as alluvial fans infilling fault depressions.

PUKETITIRI FORMATION (pu) *(new)*

Name and definition

Puketitiri Formation (Fig. 8) is named after the small farming community of Puketitiri (V20/150074) near the northern end of the Kaweka Range, western Hawke's Bay. The name has been applied to "middle" Pliocene siltstone and sandstone with thin locally prominent coarse-grained conglomerate beds overlying either Torlesse basement, Rakaita Siltstone Member (Waitere Formation) or the Hukanui Limestone Member (Pakaututu Formation). The Puketitiri Formation underlies Te Waka Formation limestone facies in the area west of the Mohaka Fault from Puketitiri to Awapai Station, and Sentry Box Formation in the Ohara Depression.

Puketitiri Formation is defined to incorporate the Kaumatua Formation of Erdman and Kelsey (1992). Kaumatua Formation was introduced as a name by Erdman and Kelsey (1992) for Pliocene (Mangapanian) rocks overlying Torlesse basement, and underlying Sentry Box Formation in the Ohara Depression. Beu (1995) included the Kaumatua Formation in the Poporangi Group. This study suggests it is more appropriate to include the formation in the Puketitiri Formation, as it underlies the Te Waka Formation on Awapai Station, and is similar to the Puketitiri Formation in terms of age, lithology and general character. This helps to simplify the stratigraphic nomenclature.

Type locality and reference sections

The type section is designated as the series of road cuttings on Puketitiri Road (V20/170067) near Misty Valley and Potter Road (Fig. 10F).

The type locality established by Erdman and Kelsey (1992) for the Kaumatua Formation is nominated here as a reference section for Puketitiri Formation in the Ohara Depression. This section is located in Kaumatua Stream extending from the unconformable contact with Torlesse basement above Mangleton Road, downstream to the contact with the overlying Sentry Box Formation. Reference sections are nominated in Jumped Up Stream above the Mangleton Road bridge and on Awapai Station.

Distribution and thickness

Puketitiri Formation crops out sparsely through the Puketitiri area, on Hukanui Hill (V20/137121, and below V20/155114), Rocky Hill Station (V20/139060), Puketitiri Road (V20/170067; V20/148074), Te Kowhai Forest (V20/119013) and on Anawhenua Station above Lucknow Road, Kaweka Forest Park (U20/099053). It is absent from Kuripapango to the Omahaki Depression,

and occurs again from the Glenross Range southwest into the Ohara Depression. Puketitiri Formation is not seen east of the Mohaka Fault.

The formation thins from northern to southern outcrops. At least 40 m of Puketitiri Formation is partially exposed near Hukanui Trig (V20/155114, Column Pu-2). Near Little Bush Road (V20/156061) at least 50 m of Puketitiri Formation is present. The Puketitiri Formation is a minimum of 100 m thick in the Ohara Depression (Erdman and Kelsey 1992). In the Awapai Station area Puketitiri Formation is absent at The Lizard, and thickens southwest along the Glenross Range toward Awapai Station to a minimum thickness of 140 m. The thickness for the formation in the Ohara Depression is a minimum as all along its western edge, except for near the Kaumatua Stream reference section, its outcrop extent is truncated by the Ruahine Fault or the Glenross Fault.

In the Ohara Depression Puketitiri Formation is restricted in outcrop to the Ohara Depression and Awapai Station areas. It is inferred to also underlie areas east of the Mohaka Fault based on rocks intercepted in drill holes (e.g. Kereru-1; Johnston and Francis 1996). Puketitiri Formation is a lateral equivalent, at least in part to the Te Waka and Pohue Formations.

Lower and upper contacts

The lower contact is poorly exposed in the study area. Through the Puketitiri and Pakaututu areas the Puketitiri Formation is inferred to conformably overlie the *Tucetona*-rich Hukanui Limestone Member (Pakaututu Formation) (Fig. 10A). In the Ohara Depression Puketitiri Formation unconformably overlies or is in fault contact with basement. The lower contact is exposed in Kaumatua Stream above Mangleton Road (Kelsey *et al.* 1993), although flood debris and vegetation have now mostly obscured this outcrop (U21/920643). On Awapai Station the Puketitiri Formation interdigitates with the massive lower member of the Te Waka Formation (U21/016841). Along the Glenross Range the formation underlies the Te Waka Formation.

The upper contact is exposed in several locations across Hukanui and Rocky Hill Stations. At V20/145117 near Hukanui Trig, 5 m of upper Puketitiri Formation is exposed and coarsens upwards into a 0.7 m-thick unit comprising moderately cemented sandstone beds each up to 1 m long and 0.25 m thick. Above this interval is a 2 m-thick unit of Te Waka Formation comprising bioclastic lenses up to 0.4 m-thick consisting of moderately cemented partially recrystallised sandy limestone. The Puketitiri Formation is unconformably overlain by the Te Waka Formation near the northwestern end of Hukanui Hill (Fig. 130). At this locality (V20/141117) a coarse-grained poorly sorted conglomerate containing common *Crassostrea ingens* of the Te Waka

Formation sharply overlies the Puketitiri Formation across an erosional surface. The upper 1.5 m of Puketitiri Formation exposed here comprises non cemented siltstone, the lower half of which is strongly bioturbated, and the upper half weakly to moderately laminated (Column Pu-7). At the southeastern end of Hukanui Hill (V20/155114, Column Pu-2) laminated fine sandstone of the Puketitiri Formation is sharply overlain by concretionary sandstone beds of the Te Waka Formation. On Rocky Hill Station (V20/139059) the Puketitiri Formation coarsens upwards over 20 m from silty sandstone into fine sandstone. This sandstone becomes more concretionary over several metres and is overlain by shellhash sandy limestone of the Te Waka Formation (Column Pu-4). A similar transition is present near Little Bush Road (V20/156061) where at least 50 m of silty sandstone passes up-section through a series of concretionary beds into calcareous sandstone of Te Waka Formation.

The upper contact is well exposed in Jumped Up Stream immediately above the Mangleton Road bridge where it has a gradational contact with the Sentry Box Formation (U21/933665). Pebbly mudstone and mudstone beds of the Puketitiri Formation pass conformably into pebbly limestone to pebbly muddy limestone of the Sentry Box Formation. In northern parts of the Ohara Depression, such as at Rocky Outcrop beside Gull Flat Road the Puketitiri Formation is unconformably overlain by the Sentry Box Formation.

Description

Puketitiri Formation comprises blue-grey to light-brown non to slightly cemented, massive, non to slightly fossiliferous sandy siltstone that coarsens up-section into fine to medium sandstone (Fig. 10F). The formation is typically massive to planar laminated. Localised beds of poorly sorted greywacke conglomerate up to 2 m thick occur on Hukanui Hill (V210/136124; V20/138123) and in the Whittle Road area on Anawhenua Station (V20/110159). Concretions may occur in the upper few metres of the formation, and are scattered elsewhere.

At V20/137121 on Hukanui Station, white, massive, hard fractured and frittered very fine siltstone is sharply overlain by grey, weathering to tan-brown, non cemented, very well sorted, strongly bioturbated massive to weakly laminated sandstone (Column Pu-7). The upper 5-10 cm of the lower siltstone interval is riddled with burrows, suggestive of a period of condensed sedimentation. The upper sandstone interval is at least 2 m thick and passes up-section into laminated fine siltstone to silty sandstone, as exposed at V20/141117.

Macrofossils are rare and have only been observed in fresh road cuttings on Puketitiri Road near Misty Valley (Fig. 13F; V20/170067, Column Pu-9). The lower 3 m of this section comprises non

cemented non fossiliferous blue-grey sandy siltstone. This interval is sharply overlain by a highly fossiliferous 0.45 m-thick shellbed with a fine sandstone matrix. The shellbed notably contains common large *Crassostrea ingens* and *Maoricardium spatiosum*, many of which are articulated. Other components of the shellbed include *Trachycardium rossi, Phialopecten* sp., and *Panopea* sp. The shellbed is in turn overlain by over 2.5 m of non cemented slightly to moderately fossiliferous sandstone with a diverse bivalve and gastropod fauna. *Maoricolpus roseus, Atrina pectinata zelandica, Amalda (Baryspira) mucronata, Ostrea chilensis, Talochlamys gemmulata* and *Dosinia greyi* are the most common faunal elements of this interval, although many other species are present. Overlying this shellbed is approximately 9 m of centimetre to metre-scale interbedded silty sandstone/fine sandstone beds. Fauna in the silty sandstone beds are similar to those for the underlying bed, though sandstones are non fossiliferous. The section is capped by nearly 4 m of non cemented, non fossiliferous, well sorted, fine to medium sandstone. Pebbly limestone of the Te Waka Formation crops out in low bluffs 40-50 m above this section. Although there is no exposure between the two intervals it is probable that the contact between the two formations is unconformable. An unconformable contact between the Te Waka Formation and Puketitiri Formation is seen in natural exposures in a farm paddock near Puketitiri Road (V20/ 173068; V20/174068). At these two sites moderately well cemented greywacke gravel-rich calcareous sandstone of the Te Waka Formation very sharply overlies olive-brown, non cemented well sorted fine to medium sandstone of upper parts of the Puketitiri Formation. This sandstone is massive, although faint low-angle, small- to moderate-scale sigmoidal cross beds are present. The contact is erosional with centimetre-scale relief. Greywacke clasts up to 70 mm across are concentrated immediately above the contact as part of a shellbed rich in large chalky aragonitic bivalves such as *?Maoricardium spatiosum*, with *Zethalia coronata,* oyster and other bivalves and gastropods. A prominent feature of this contact is the abundant well-developed burrows that occur for up to 60 cm below the contact in the Puketitiri Formation. These (?*Ophiomorpha*) burrows are up to 20 cm long and 4 cm wide, and are infilled by greywacke granules, pebbles and shellhash (Columns Pu-4, Pu-6).

Uncommon plant fossils (leaf impressions) have been observed in a concretion on Rocky Hill Station (V20/139060, Column Pu-4).

Coarse-grained intervals rich in greywacke clasts occur periodically through the Puketitiri Formation. At V20/136124 the Pakaututu Formation is abruptly overlain by siltstone facies of the Puketitiri Formation. Approximately 10 m above the Pakaututu Formation occurs a moderately cemented greywacke conglomerate to breccia containing clasts of granule to boulder size. This unit is poorly to moderately cemented, massive and contains a sandy matrix. Approximately 12 m above the Pakaututu Formation at V20/138123 on Hukanui Station this interval is represented

by a 2.5 m-thick well cemented sandstone containing greywacke clasts of granule to coarse pebble size with occasional cobble-sized clasts. Biomoulds, shellhash and oyster valves are scattered through this chaotically-bedded unit. Approximately 1 m of section is not exposed, followed by a 0.7 m-thick well cemented conglomerate with a 0.2 m-thick basal massive sandstone unit. Small abundant biomoulds are present through the conglomerate, with occasional oyster valves. Greywacke clasts are well sorted, well rounded, of granule to coarse pebble size and average 2 cm across. At V20/110059 on Anawhenua Station a pebbly limestone bed 2.5 m thick crops out sharply overlying well sorted fine to medium sandstone. The sandstone is massive, moderately weathered and passes up into 0.25 m of sandstone similar to below, but containing scattered shellhash and occasional pectinid valves. Above this is a dark-grey, massive to broadly laminated, weathered flaggy pebbly limestone containing abundant greywacke granules and cobbles, although pebble-sized clasts dominate. Shellhash and intact disarticulated bivalves are present, including *Tucetona laticostata* and unidentified pectinids. Biomoulds are abundant in this unit.

In the Ohara Depression Puketitiri Formation comprises sandy mudstone, sandstone, pebbly grainstone lenses, and shelly conglomerate beds that unconformably overlie basement. In Kaumatua Stream, where the basal contact is exposed, basal beds of the formation comprise a slightly cemented granule to pebble-sized grainstone approximately 3 m thick. This grainstone passes up-section into siltstone to sandy siltstone.

Fine sandstone beds are slightly muddy, locally calcareous and blue-grey to olive-green in colour, weathering to tan colour. Mudstone beds are blue-grey and sandy (Erdman and Kelsey 1992). In Jumped Up Stream approximately 100 m above the Mangleton Road bridge (U21/933665) Puketitiri Formation comprises non cemented massive to weakly laminated, slightly fossiliferous siltstone. Macrofossils are largely dissolved and only biomoulds remain. *Neilo* is the main macrofaunal element, with *Notocallista, Calliostoma, Talochlamys, Pleuromeris* and *Nuculanid.* This interval passes up-section into a series of interbedded shelly pebbly mudstone and mudstone beds that are overlain by pebbly limestone to pebbly muddy limestone beds of the Sentry Box Formation. These beds significantly contain the last occurrence of *Crassostrea ingens* and *Phialopecten thomsoni*, and the first occurrence of *Zygochlamys patagonica delicatula* and *Phialopecten triphooki.*

Northeast from Awapai Station the Puketitiri Formation wedges out along the Glenross Range toward The Lizard. At the greywacke quarry beside Lizard Road (U20/038909, northern end of the Glenross Range) Puketitiri Formation is absent and limestone of the Te Waka Formation directly overlies basement. Southwest along the Glenross Range the Puketitiri Formation

thickens and at Awapai Station separates Te Waka Formation from basement by at least 140 m. Puketitiri Formation in this area is dominated by massive, slightly to moderately weathered non to slightly fossiliferous siltstone to sandy siltstone. At U21/023831 macrofauna are dominated by the gastropods *?Cominella, Taniella* and especially the bivalve *Dosinia greyi*.

Paleontology and age

The age of the Puketitiri Formation is poorly constrained, with few macrofossils observed. A foraminiferal sample from V20/141005 on the Little Bush-Hawkston Station paper road (V20/f445, Appendix V) contains a Waipipian assemblage constrained by planktics (*Truncorotalia crassaformis, Globoconella inflata, G. inflata triangula, G. puncticulata, G. subconomiozea* and *G. pliozea*). Foraminiferal sample V20/f444 collected from below the shellbed on Puketitiri Road (V20/170067, Column Pu-9) contained no foraminifera, but common radiolarians, sponge spicules and rare fish teeth.

Many fauna in the shellbed on Puketitiri Road display affinities with Nukumaruan species, although the presence of *Crassostrea ingens* and *Maoricardium spatiosum* (with no *Phialopecten triphooki* and/or *Zygochlamys delicatula*) strongly indicates an age no younger than uppermost Mangapanian. At least in this area, middle to upper parts of the Puketitiri Formation appear to be of Upper Mangapanian age. The underlying Pakaututu Formation is assigned a confident Opoitian age, and the overlying Te Waka Formation a confident Mangapanian age.

In the Ohara Depression Puketitiri Formation contains the Mangapanian index scallops *Phialopecten thomsoni* and *Towaipecten katieae* (Beu 1995), and underlies limestone and sandstone containing a basal Nukumaruan fauna including *Phialopecten triphooki* and *Zygochlamys delicatula* in association with *Crassostrea ingens* and *Phialopecten thomsoni.* In this area the Puketitiri Formation is of Mangapanian age, and older ages are known.

On the basis of stratigraphic position and macrofauna, the Puketitiri Formation is assigned a Waipipian to Upper Mangapanian age.

Environment of deposition

Foraminifera from V20/f445 near Hawkston Road (Appendix V) indicate an upper bathyal environment of deposition at this location. Significant reworking of the sample, including the presence of many taxa consistent an inner shelf (0-50 m water depth) environment of deposition, suggests an upper bathyal environment with normal marine conditions. The presence of 50% planktics indicates an intermediate water mass (M. Crundwell, GNS Science pers. comm. 2004).

The shellbed and overlying silty sandstone on Puketitiri Road (V20/170067) indicate deposition at shelf water depths on a hard-ground setting, supported by the presence of *Crassostrea ingens* and *Maoricardium spatiosum*. In the Ohara Depression Puketitiri Formation was deposited in a variety of shelfal environments adjacent to a slowly rising basement hinterland. Macrofauna in Jumped Up Stream indicate a progressively-shallowing marine environment from outer shelf to inner shelf water depths.

Common devitrified volcanic glass was recognised in sample V20/f444, suggesting contemporaneous volcanic activity.

TITIOKURA FORMATION (tk)

(Beu *et al.* 1980; formally defined by Beu 1995)

Name and definition

The stratigraphy of the Titiokura Formation (Fig. 11) has recently been documented by Bland *et al*. (2004). The history of naming and correlating limestone beds in the Te Waka and Maungaharuru Ranges has been complicated. Limestone beds forming the Te Waka Range (V20/257130) above Te Pohue (V20/277105) were included in the Pohui limestone of Hector (1877) and McKay (1886a) during early geological surveys through western Hawke's Bay. Subsequent geological study has revealed that the Te Waka Range is actually underlain by two discrete limestone packages, the lowermost of which is now referred to as the Titiokura Formation (the upper package is assigned to the Te Waka Formation).

The Titiokura limestone was first introduced as an informal name by Beu *et. al.* (1980) to describe a Waipipian limestone sheet exposed near the summit of the Napier-Taupo Road at the northern end of the Te Waka Range. In the original application of the name by Beu *et al.* (1980) a limestone of probable Waipipian age cropping out above Lake Opouahi (V19/152214) was also included in the Titiokura Formation. Limestone beds underlying the Titiokura limestone at Lake Opouahi were assigned by Beu *et al.* (1980) to the informal Maungaharuru limestone. Beu (1995) formally defined the Titiokura Limestone and restricted the name to the limestone sheet of Waipipian age cropping out in the Te Waka Range (south of the Napier-Taupo Road) above Te Pohue. Limestone beds immediately north of the Napier-Taupo Road were assigned by Cutten (1994) to the Maungaharuru Formation. Beu (1995) adopted the definition of Cutten (1994). This definition included the limestone cropping out above Lake Opouahi that was originally included in the Titiokura Limestone of Beu *et al.* (1980). The Maungaharuru Formation included over 1500 m of

rocks extending from Opoitian to Nukumaruan. The formation inadequately described the varied lithologies and stratigraphic units through the Maungaharuru Range area.

Detailed geological mapping by Bland (2001) and Graafhuis (2001) significantly subdivided the Maungaharuru Formation into a more manageable form, and effectively disbanded it. These two studies revealed that the Titiokura Limestone of Beu (1995) and Maungaharuru limestone (informal) of Beu *et al.* (1980) were in fact part of the same stratigraphic unit, and were best included in the same stratigraphic formation. Bland *et al.* (2004) formally defined and documented the correlations of Bland (2001) and Graafhuis (2001), including these beds in a highly redefined Titiokura Formation. The name Maungaharuru was elevated to subgroup status to incorporate much of the stratigraphy cropping out in western and northern districts of the study area. The Titiokura Formation is defined in this study (as in Bland *et al.* 2004) to include all Upper Opoitian to Waipipian calcareous sediments above a conglomeratic basal bed (overlying the Mokonui Sandstone), and below the Te Waka Formation occurring on the western side of the forearc basin in Hawke's Bay.

The "Limestone" portion of the name was dropped in favour of the term "Formation" by Bland *et al.* (2004) to reflect the varied facies present in the formation. The Titiokura Formation is defined as a succession unconformably overlying the Mokonui Sandstone that contains prominent limestone beds.

The character of the Titiokura Formation (Fig. 11) can usefully be subdivided into two broad packages. South of Ahuateatua Peak (V19/328216) the Titiokura Formation consists largely of a single limestone package 30-50 m thick (Fig. 12A-F). North of Ahuateatua Peak the formation has been mapped and described as five members. This reflects the greater amounts of subsidence, sediment thickness and diversification of lithofacies within the formation through this area. Each of these five members are described separately. Characteristics of the Titiokura Formation presented below deal dominantly with the southern (Te Waka Range-Ahuateatua Peak) outcrops of the formation where the formation consists essentially of a single limestone unconformably overlying Mokonui Sandstone (Fig. 12B).

Type locality and reference sections

Beu (1995) formally defined the Titiokura [Formation] and established a type section (V20/ 278148) at the northern end of the Te Waka Range. Neither the base nor the top of the formation is well exposed at this locality and a new type section was designated by Bland *et al.* (2004) 3 km

southwest along the range crest at V20/248133 (Fig. 12B; Column Tw-2). At this locality there is complete exposure of the formation from bottom to top.

A good, easily accessible reference section at the northern end of the Te Waka Range occurs along State Highway 5 (V20/289142, Column Ti-2). A useful reference section characterising stratigraphy through central parts of the Maungaharuru Range occurs on the western side of Taraponui Trig (V19/331228). A reference section in the northern part of the Maungaharuru Range is located along Pohokura Road, east of the intersection with Jeph Everett Road to Lake Opouahi (V19/387273-408218).

Distribution and thickness

Titiokura Formation is widespread throughout the high country inland of Lake Tutira and Te Pohue, and crops out in a broadly southwest-northeast belt from Te Pohue to at least as far north as Willowflat (W19/524371) and the Putere Lakes (W19/591433).

In the study area the formation crops out from Pohokura Saddle to Lake Opouahi on the Maungaharuru Range, and underlies the prominent dipslope below Te Waka Trig at the northern end of the Te Waka Range. Caron (2002) suggested that the lowermost limestone bed exposed in the headwaters of Wai-iti Stream (The Gorges Station) near Patoka (V20/186011) was a further southern occurrence of Titiokura Formation, thereby extending its distribution significantly to the south. Titiokura Formation is not known west of the Mohaka Fault, while the immediately overlying Te Waka Formation occurs west of the Mohaka and Ruahine Faults. This situation has implications for timing of movement on faults in the North Island Shear Belt.

The Titiokura Formation varies from as little as two metres thick to composited thicknesses of about 730 m. Graafhuis (2001) estimated a maximum thickness of the Titiokura Formation in the Waikare River catchment of over 800 m.

Lower and upper contacts

The lower contact of the Titiokura Formation is easily recognisable in the form of a conglomeratic bed that sharply and unconformably overlies sandstone facies of the Mokonui Formation (Fig. 12B, C). The internal composition of this bed is variable, but its stratigraphic position and continuity is a distinguishing feature of the Titiokura Formation throughout the study area. Below Taraponui Trig on the Maungaharuru Range (V19/332233) the conglomerate comprises a basal greywacke pebble conglomerate which in turn is overlain by a 1 m thick cross-bedded unit of well rounded pumice and carbonised wood set in a shelly matrix (Cutten 1994; Graafhuis, 2001).

Closer to Wakaateo Trig (V20/295169) the conglomerate is composed of sandstone and mudstone pebbles and boulders up to 1.5 m across with common large pebbles and cobbles of greywacke (Fig. 12C). In Titiokura Quarry near State Highway 5 (V20/292159) the bed comprises sandstone and mudstone pebbles set in a sandstone matrix. On Oakmere Station above Te Pohue (V20/270115), the basal conglomerate consists of sandstone and mudstone pebbles interbedded with shell fragments.

The upper contact appears to be conformable through the study area in the form of a gradational contact into sandstone facies of the Te Waka Formation. Beu (1995) suggests that an unconformity is present at this contact, but this is not conformed in this study.

Titiokura Formation overlies Mokonui Sandstone in the north face of the Te Waka Range where there is spectacular paleorelief of 30 m cut into Mokonui Sandstone.

Distribution and thickness

The Titiokura Formation is up to 800 m thick in the Waikare River catchment (Graafhuis, 2001), and thins dramatically to only 2 m thick in the southern parts of the Te Waka Range near Hells Hole (V20/239128). The change in thickness is due to increased subsidence and siliciclastic sediment deposition towards the north. Where the formation is represented by one carbonate unit (such as in the Te Waka and southern Maungaharuru Range), the unit is typically 35-50 m thick.

Description

The Titiokura Formation is a complex mixed bioclastic-siliciclastic sedimentary succession that displays dramatic facies and thickness changes along its outcrop extent (Fig. 11). The stratigraphy of the formation was detailed in Bland *et al.* (2004). The stratigraphy of southern portions of the unit was described by Bland (2001), while northern regions were studied by Graafhuis (2001). In its southern extent (Te Waka Range-southern Maungaharuru Range) Titiokura Formation is limestone dominated with some sandstone and minor conglomerate and rare siltstone facies. In northern sections (north of Ahuateatua Peak, Fig. 12A) the formation becomes more siliciclastic, and by the Waikare River catchment carbonate constitutes only a minor portion of the formation. This trend continues northwards towards Willowflat and the Putere Lakes.

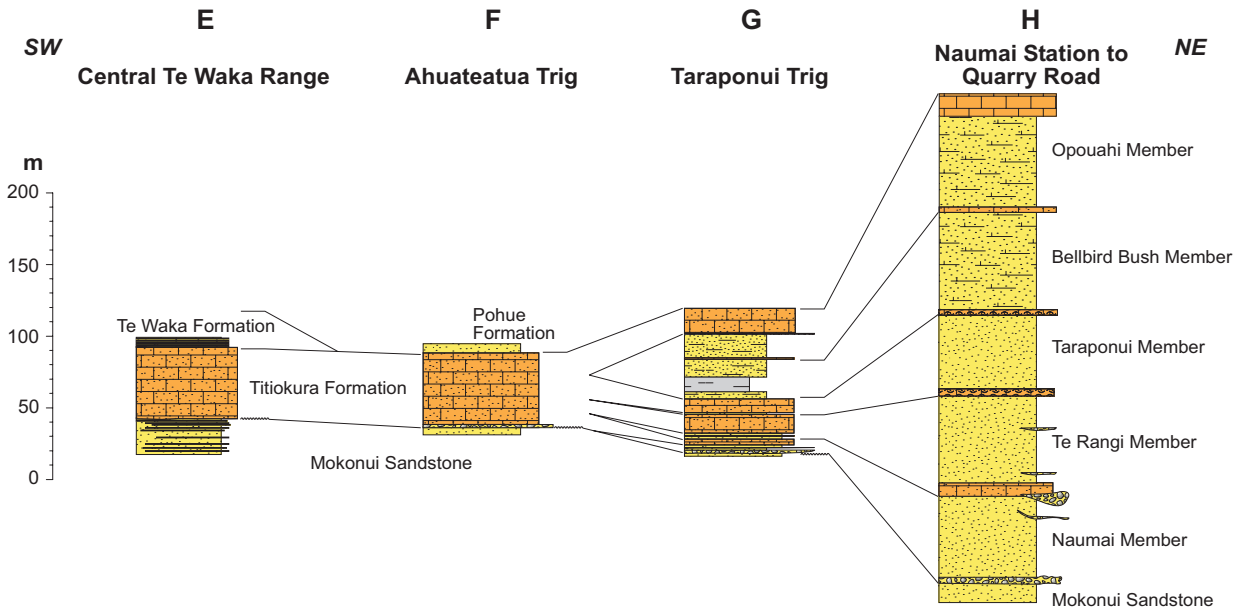


Fig. 11: Schematic stratigraphic columns of the Titiokura Formation from the type section on the Te Waka Range to the northern end of the Maungaharuru Range.

In southern regions Titiokura Formation typically comprises pale-grey to yellow-grey, parallel to cross-bedded, slightly to moderately cemented fine limestone dominated by small molluscan bivalve, barnacle plate and bryozoan fragments. Lower parts of the formation comprise a non to slightly fossiliferous conglomerate bed 0.5-1.5 m thick dominated by clasts of Miocene sandstone and siltstone, with rare greywacke grains (Fig. 12C). Erosional relief on the base of this conglomerate is generally 0.1-0.5 m. The Titiokura Formation comprises discrete stacked bodies of carbonate, sandstone and conglomerate that vary in thickness through the field area. The composition of these lenses is predominantly of mixed bioclastic-siliciclastic composition, though the bioclastic content dominates.

Outcrops of the Titiokura Formation are frequently flaggy, especially in exposures along the Te Waka Range crest, on Oakmere and Rock Stations, and at Ahuateatua Trig (Fig. 12A). The bioclastic beds are typically 0.03-0.2 m thick and continuous over tens of metres. The siliciclastic-beds average less than 0.4 m in thickness. Bioturbation trails and blebs are visible in this part of the formation.

Fragmented barnacle plates and shellhash dominate the composition of the limestone in the area above Te Pohue village. Rare intact bivalves are present, both articulated and disarticulated, and usually these are concentrated into fossiliferous beds. *Ostrea chilensis* valves are common in these beds, as are bryozoans, pectinids and some gastropods. The fossiliferous lenses have a matrix of bioclastic-dominated coarse siltstone to sandstone. These lenses display erosional

lower bases with centimetre-scale relief between them and underlying siliciclastic beds. This suggests that the bioclastic layers may have been storm emplaced. Well rounded lensoidal greywacke pebbles up to 15 mm across are scattered through the formation.

Titiokura Formation exposed in the southern Maungaharuru Range (Ahuateatua Trig-Titiokura Quarry) is much coarser-grained than those parts in the dipslope above Te Pohue. The Titiokura Formation becomes coarser-grained from the Te Waka Range to southern Maungaharuru Range. Around Wakaateo Trig the limestone consists of coarse sand to gravel sized barnacle plates. Barnacle plates and fragments are abundant and up to 5 cm across, although few intact barnacles occur. Secondary calcite is common, as are manganese coatings. Small greywacke grains are often present in the lower 8 m of the Titiokura Formation exposed in Titiokura Quarry. These grains make up less than 5% of the matrix of the limestone, and are less than 6 mm across in size, well sorted and well rounded. In some fall blocks, siltstone and sandstone clasts up to 0.6 m across occur. Sandstone clasts in the basal parts of the coquina are frequently bored, with the borings infilled with shellhash sandstone. Some blocks show abundant *Talochlamys gemmulata* valves. A sandy matrix is common, comprising shellhash, with faint primary bedding structures. Bivalve and oyster fragments also occasionally occur. Exposures around Wakaateo Trig contain abundant biomoulds. The limestone at this locality also appears to be relatively uncompacted. Overall grain size in the sediments of the formation decreases further northward toward Ahuateatua Trig, where its clast size is similar to that observed in the Te Waka Range.

Fig. 12 (facing page): Titiokura Formation south of Ahuateatua Trig. **A)** Moderately dipping (c. 22°) flaggy well cemented alternating packstone and grainstone beds of the Titiokura Formation cropping out on the summit ridge of the Maungaharuru Range at Ahuateatua Trig. North of this locality the formation diverges into multiple members. Location: V19/327216, looking south. **B)** Contact between the Titiokura Formation and Mokonui Sandstone. The 0.5 m-thick bed above the contact comprises a conglomerate consisting of Cenozoic sandstone and mudstone clasts. Relief on the contact is up to 0.3 m. Location: V20/239128. **C)** Coarse-grained mixed bioclastic-siliciclastic basal conglomerate of the Titiokura Formation displayed in fall blocks at the end of the Maungaharuru Range track, Waitara Station. Location: V20/219191. **D)** Sandy limestone facies of the Titiokura Formation unconformably overlying concretionary, non fossiliferous sandstone of the Mokonui Sandstone at Hells Hole, Te Waka Range. The limestone "sheet" is c. 50 m thick. Location: V20/235127 looking south. **E)** Slightly flaggy 20 m high bluffs of Titiokura Formation cropping out near Hells Hole. Arrows denote surfaces defining broad "packages" within an otherwise single limestone sheet. Western face of the Te Waka Range, V20/241129 looking southwest. **F)** Titiokura Formation unconformably overlying Mokonui Sandstone across a spectacular angular unconformity with at least 30 m of relief. The dark grey limestone on the left side of the photograph is c. 15 m thick, thins to < 1 m over the Mokonui Sandstone high in the centre, and then thickens to the right to > 50 m thick. The overlying grey limestone is part of the Te Waka Formation. Location: western face of the Te Waka Range, V20/242130 looking south. mk, Mokonui Sandstone; tk, Titiokura Formation; tw, Te Waka Formation.




tk
mk




tk
mk


tk
mk


tw
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mk

The basal conglomerate in the southern Maungaharuru Range near Wakaateo Trig comprises mudstone clasts with lesser sandstone clasts (Fig. 15C). These clasts are well rounded, of oblate shape, and up to 100 mm long. In places the lower parts of the formation above the basal conglomerate are composed of at least 40% well sorted mudstone clasts that average 20 mm in size.

Some very small-scale but finely-developed cross-bedding can be observed in some parts of the formation (e.g. V20/277149). Well developed cross-bedding is frequently visible in single flags in outcrops. Sediments in these zones are of medium to coarse sand size, with a concentration of heavy minerals at the top of a layer that highlight the bedforms. Above this is a thin layer of well rounded conglomeratic mudstone clasts (<6 mm across). Sediments above are frequently sandier and rich in shell fragments.

Throughout the Te Waka Range, and the dipslope running down to the Napier-Taupo Road and Te Pohue, the top of the Titiokura Formation is marked by a prominent brachiopod bed. A sandstone unit in the dipslope above Te Pohue Village overlies this brachiopod bed. At Te Waka Trig the brachiopod bed forms the top of the Titiokura Formation, and is overlain by the Te Waka Formation. In several locations highly fossiliferous beds dominated by brachiopods are present within the main body of the formation. The capping brachiopod bed is typically 0.3-0.5 m thick and dominated by *Neothyris* aff. *obtusa,* with occasional *Phialopecten marwicki, Mesopeplum convexum* and rare echinoids and echinoid spines. It appears that the brachiopod bed is lensoidal throughout the outcrop area and although widespread, does not crop out continuously.

In bluffs above Te Pohue on Translator Road coarse-grained limestone facies of the Te Waka Formation sharply overlie siltstone facies of the Titiokura Formation (V20/271106). This siltstone contains occasional concretions, many of which have been incorporated into the basal conglomerate facies of the overlying Te Waka Formation at this site. This suggests that concretionary beds in this siltstone probably formed at or very close to the sea floor. Bedding is faint in the siltstone, although "lam-scram" bedding is evident, perhaps suggesting muddy turbidite events (C. Nelson, University of Waikato pers. comm. 2004).

Near Hells Hole (Fig. 12D, E) the formation thins rapidly from 50 to 2 m where it unconformably overlies spectacular paleo-relief carved into the underlying Mokonui Formation (Fig. 7F). Southward, the formation thickens to over 50 m (Fig. 7F). In this region the Titiokura Formation comprises a 1 m-thick basal conglomerate that passes conformably up into shellhash limestone. The conglomerate comprises clasts of well cemented shellhash unit with well rounded greywacke pebbles up to 5 cm across, as well as sandstone and siltstone pebble clasts. Fauna are

dominated by brachiopods, with some oysters (*?Ostrea*). The overlying limestone interval comprises stacked beds of medium-grained shellhash. The limestone is conformably overlain by concretionary fossiliferous sandstone (Te Waka Formation) containing large *Phialopecten marwicki* (Wp) (Fig. 12F; Column Tw-3).

Paleontology and age

Beu (1995) described the Titiokura Formation as one of the least satisfactorily dated limestone units in the eastern North Island, despite at least four pectinid collections at GNS Science (Lower Hutt). *Phialopecten marwicki* occurs sporadically through the Titiokura Formation, with *Mesopeplum crawfordi* relatively rare. *Phialopecten* is not known in Lower Opoitian rocks of eastern North Island (Beu 1995, p.59). The Titiokura Formation is assigned an Upper Opoitian to Waipipian age based on the presence of *Phialopecten marwicki* (Opoitian form), co-occurrence of *Phialopecten marwicki* (Waipipian form) and *Mesopeplum crawfordi*, and stratigraphic position. Evidence strongly suggests that the Titiokura Formation is diachronous across the study area. More southern outcrops, such as those in the Te Waka Range and Patoka area, are likely to be of Waipipian age only.

Environment of deposition

The Titiokura Formation is inferred to represent a shoreline to shelfal mixed carbonate-siliciclastic depositional system (Bland *et al.* 2004). Beds cropping out in the Te Waka Range area were deposited at inner to middle shelf water depths in a current-swept seaway (Beu *et al.* 1980; Beu 1995; Bland *et al.* 2004). It is envisaged that carbonate production occurred on parts of the middle shelf or around rocky shorelines, with remobilisation of shell debris by strong tidal sea-floor currents. Fauna are dominated by barnacles, largely as plates and fragments, though rare intact specimens occur. A unique combination of marine conditions must have occurred to allow for this "blooming" of barnacles (Beu *et al.* 1980). *Mesopeplum (Borehamia) crawfordi*, present in the Titiokura Formation, is one of a group of pectinids that lives on current-swept "hard-grounds" where sediment will not clog their gills, as they lack a mantle cleaning mechanism (Beu *et al.* 1990). The presence of reasonably common *M. crawfordi* indicates that such an environment must have occurred during deposition of the Titiokura Formation. Other common fauna in the Titiokura Formation (e.g. *Neothyris*, *Phialopecten* and *Ostrea*) also require similar environments relatively free of siliciclastic sediment. Modern *Ostrea* presently live in areas such as Foveaux Strait. A similar depositional setting is envisaged for the Titiokura Formation. It is probable that there were contemporaneously high inputs of siliciclastic sediment occurring into the basin at this

time. It is considered that much of this sediment effectively by-passed the inner and middle shelf and was focused into deeper parts of the basin in the north, such as the Waikare River catchment.

Naumai Member (tka)

(Graafhuis, 2001; formally defined by Bland *et al.* 2004)

Name and definition

Naumai Member (Fig. 11H) was introduced by Graafhuis (2001) and formally defined by Bland *et al.* (2004). The name is derived from Naumai Station at the crest of the Maungaharuru Range on Pohokura Road (V19/388268). The name is applied to the stratigraphically lowest member of the Titiokura Formation immediately overlying the Mokonui Sandstone and underlying the Te Rangi Member.

Type section

The type locality is designated on Pohokura Road at the crest of the Maungaharuru Range and within adjacent parts of Naumai Station (Fig. 7D, 13A, B). The basal conglomeratic and limestone facies of the member are very well exposed on the southern side of the intersection of Pohokura and Jeph Everett Roads (V19/389273) (Fig. 16B). The majority of the type section is displayed in natural outcrops in the paddock on Naumai Station on the north side of Pohokura Road (Fig. 13A). The top of the section is located at V19/386265. Reference sections are nominated for the section below Taraponui Trig (V19/331228) (Fig. 13C) and on Te Rangi Station (V19/412306-416301).

Lower and upper contacts

The base of the member coincides with the base of the Titiokura Formation in the area north of Ahuateatua Trig. Throughout the study area the lower contact is an unconformity, perhaps slightly angular, and almost always overlain by a conglomerate bed of varying lithologies. The contact varies from being sharp to displaying metre-scale relief. At the type section relief on the lower contact is up to 6 m over a 10 m length of outcrop (Bland *et al.* 2004) (Fig. 13B, D, E). Northwards and basinwards from the type section, towards Te Rangi Station, the lower contact appears to become more conformable.

The upper contact of the Naumai Member is considered to be a disconformity, and is a sharp surface displaying minor localised relief (Bland *et al.* 2004).



Fig. 13: Naumai Member, the basal member of the Titiokura Formation north of Ahuateatua Trig. **A)** Dip slope of the Naumai Member on Naumai Station at the Pohokura-Jeph Everett Road intersection (V19392272). This site is the type section for both the Naumai and overlying Te Rangi Members of the Titiokura Formation. Dashed white line defines the contact between the Naumai and Te Rangi Members. **B)** Base of the Naumai Member at the Pohokura-Jeph Everett Road intersection (V19/390273). Up to 6 m of relief is present on this basal contact (highlighted by dashed line). **C)** View of part of the Maungaharuru Range from near Naumai Station south to Taraponui Trig (T). It is along this section of the range that the Titiokura Formation diverges from a single limestone unit into multiple members. Near V19/372281 on Waitara Road looking southeast. **D)** Close-up view of the conglomeratic beds that characterise basal parts of the Naumai Member at the type section (V19/390273). **E)** Limestone bed (above white dashed line) developed in basal parts of the Naumai Member at the type section (V19/390273). The base of the member where it unconformably overlies the Mokonui Sandstone is highlighted.

Distribution and thickness

Naumai Member crops out along the western face of the Maungaharuru Range (Fig. 13C) from below Ahuateatua Trig to Te Rangi Station. Lateral equivalents extend northeast towards the Mohaka River in the Willowflat area, and the Putere Lakes.

At Taraponui Trig the member is 15 m thick, which increases northeast to about 60 m in the Te Rangi Station area (Graafhuis 2001). The increase in thickness results mostly from the thickening of sandstone facies in middle to upper parts of the member (Bland *et al.* 2004).

Description

Naumai Member comprises a succession of conglomerate, calcareous sandstone/limestone, silty sandstone and sandy limestone facies. While the internal composition varies through the outcrop area, basal beds of the Naumai Member consistently comprise a variety of conglomerate and breccia facies. At the type section (V19389273-386265) the basal beds consist of a channelised conglomerate with well rounded and angular pebble to boulder-sized clasts of mudstone (90%) and sandstone (10%) lithologies in a shelly sandstone matrix (Fig. 13B, D, E). This conglomerate passes upsection into differentially cemented, bipolar cross-stratified sandy limestone and calcareous sandstone with rare mudstone clasts. This succession is repeated two or three times in the lower 6 m of this section. Greywacke pebbles are not prominent in the type section, but occur at localities above the contact to the south at Taraponui Trig, where pumice clasts and charcoal fragments are conspicuous components of the conglomerate facies (Cutten 1994; Bland *et al.* 2004). The conglomerate bed is thickest in southwestern areas (6 m), reducing to 4 m in northeastern areas. However, the basal conglomerate may be lacking at any point along the outcrop extent, depending on the degree of channelisation.

Sandstone beds comprise the bulk of the member at the type section and localities to the northeast. Lower parts comprise variably silty fine sandstone with thin beds of sandy siltstone. Upper parts are variably cemented, comprising moderately cemented, concretionary fine sandstone with a few thin discontinuous pebbly beds. Sandstone facies grade southward into limestone facies of the undifferentiated Titiokura Formation. The upper limestone facies of the member is thickest in the southwest, being 9 m thick at Taraponui Trig (Bland *et al.* 2004).

Paleontology and age

Several valves of *Phialopecten marwicki* have been collected from the Naumai Member at Naumai Station. The small size of these specimens is indicative of an Opoitian age for the member. The underlying Mokonui Sandstone has a Lower Kapitean to Opoitian age in the Mohaka River

section, and a Lower Opoitian age at Pohokura Road (Cutten 1994). As *Phialopecten* is not known in rocks of Lower Opoitian age in eastern North Island (Beu 1995, p.59) an Upper Opoitian age is assigned to the Naumai Member. Stratigraphic position above Lower Opoitian Mokonui Sandstone supports this interpretation.

Environment of deposition

The Naumai Member is inferred to have accumulated in shoreface to middle shelf water depths on the basis of sedimentary structures and macrofauna.

Te Rangi Member (tkb)

(Graafhuis 2001; formally defined by Bland *et al.* 2004)

Name and definition

The name Te Rangi Member is derived from Te Rangi Station at the end of Heays Access Road. Te Rangi Member was introduced by Graafhuis (2001) and formally defined by Bland *et al.* (2004). The Te Rangi Member comprises the succession immediately overlying the Naumai Member (Fig. 11H). It underlies the Taraponui Member.

Type locality and reference sections

The type section is on Naumai Station at V19/387273-386262 (Fig. 14A-G), and immediately overlies the type section of Naumai Member. Reference sections are designated at Taraponui Trig (V19/331228) (Fig. 13C), on Naumai Station (V19/392274; V19/407287) and on Te Rangi Station (V19/430297; V19/407287) where they were logged by Graafhuis (2001).

Lower and upper contacts

The lower boundary of the Te Rangi Member is disconformable. Towards the north at Te Rangi Station the contact is sharp, but possibly conformable. The upper boundary has a similar character to that of the lower contact, and locally displays relief of up to 0.6 m (Bland *et al.* 2004) (Fig. 14E).

Distribution and thickness

The Te Rangi Member immediately overlies the Naumai Member and is distributed in a broadly northeast-southwest trending belt immediately east of it, where it forms prominent dipslopes on the flanks of the Maungaharuru Range above deeply incised stream valleys (Bland *et al.* 2004).

At Taraponui Trig the member is 18 m thick, increasing to about 70 m thick in the region of Naumai and Te Rangi Stations (Graafhuis 2001). The increase in thickness is due almost entirely to substantial increases in the amount of siliciclastic sandstone within the member (Bland *et al.* 2004).

Description

The Te Rangi Member has a very similar content and facies succession to the Naumai Member (described above). At Naumai Station (type section) the base of the member (Fig. 14A) comprises a 0.5 m-thick fossiliferous pebble to cobble-sized greywacke conglomerate containing disarticulated and fragmented bivalves including *Crassostrea ingens*. This basal bed is overlain by 1-2 m of cross-stratified well sorted calcareous sandstone. This in turn is overlain by about 1 m of moderately to well cemented medium to coarse skeletal grainstone and packstone (Bland *et al.* 2004). Above this limestone is a 10 m-thick interval of massive, non cemented, well sorted fine sandstone with occasional thin interbeds of cemented skeletal grainstone. Overlying this is a 30 m-thick section comprising thin to medium bedded, non cemented fine sandstone, sometimes with internal ripple bedding, convolute bedding, thin skeletal grainstone beds and concretionary horizons. Bioturbation is a prominent element of this interval. The upper 30 m of the member comprises differentially cemented, medium to coarse calcareous sandstone with convolute bedding and disrupted mud drapes. Sandstone beds and sets become more thickly bedded (Fig. 14E) and cross-bedded towards the top of the member (Fig. 14B, C). Pumice and heavy minerals are conspicuous components of some cross-beds (Fig. 14D, F, G).

South of the type section at Taraponui Trig the Te Rangi Member comprises a basal 2 m-thick grey, calcareous fine sandstone, overlain by 16 m of cross-bedded, fossiliferous grainstone with greywacke pebbles and scattered large sandstone rip-up clasts throughout.

North of the type section in the region of Rangiora Stud and Te Rangi Station the member consists mostly of massive, bioturbated fine sandstone with mudstone drapes

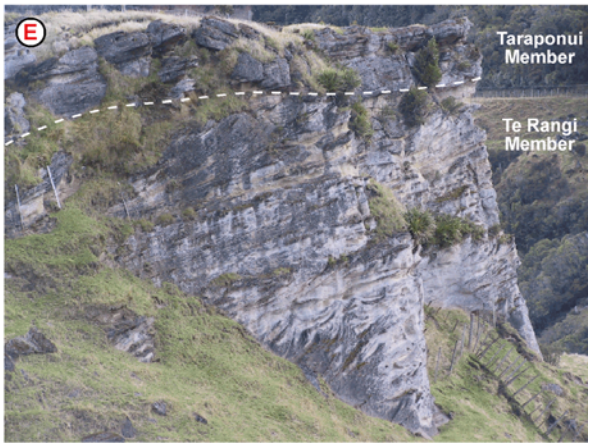
Fig. 14 (facing page): Te Rangi Member (Titiokura Formation). **A)** View of differentially cemented limestone and calcareous sandstone bluffs of the Te Rangi Member (Titiokura Formation) at the type section, Naumai Station (V19/392271). **B)** Trough cross-bedded limestone and calcareous sandstone of the upper Te Rangi Member, Naumai Station (V19390268). **C)** Differentially cemented cross-bedded mixed bioclastic and siliciclastic sandstone bodies of the upper Te Rangi Member, Naumai Station (V19/390271). **D)** Cross-bedded, ripple-laminated, convolute-bedded pumiceous calcareous sandstone in upper parts of the Te Rangi Member, Naumai Station. Photo location: V19/392272. **E)** Cross-bedded sandstone of the Te Rangi Member, overlain by limestone of the Taraponui Member on Naumai Station. The Te Rangi Member comprises wavy-bedded and trough cross-bedded sandstone. Pohokura Road is visible across the gully in the background. Photo location: V19/393272. **F)** Strongly laminated, cross-bedded, ripple- and wavy-bedded calcareous sandstone of the Te Rangi Member, Naumai Station (V19/390271). **G)** Truncated convolute-bedding in the Te Rangi Member, Naumai Station. Bedforms in this interval are highlighted by fine-scale alternating layers of heavy mineral and pumiceous-dominated sediments. Naumai Station (V19/390271).


A


B


C


D


E
Taraponui Member
Te Rangi Member


F


G

Paleontology and age

Small fragmented pectinid valves tentatively identified as *Phialopecten marwicki* (Opoitian form) occur in the type section on Naumai Station. No other age diagnostic fauna have been observed. The Te Rangi Member is assigned an Upper Opoitian age on the basis of stratigraphic position, and the presence of *Phialopecten marwicki*.

Environment of deposition

Te Rangi Member is inferred to have accumulated at middle shelf to nearshore water depths on the basis of sedimentary structures and macrofauna.

Taraponui Member (tkc)

(Graafhuis 2001; formally defined by Bland *et al.* 2004)

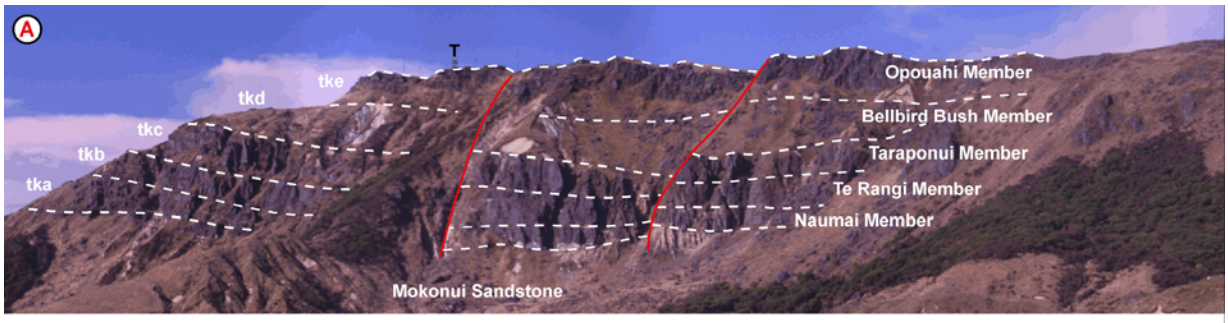
Name and definition

The name Taraponui Member is derived from Taraponui Trig (Fig. 15A) on the crest of the Maungaharuru Range. Taraponui Member was introduced by Graafhuis (2001) and formally defined by Bland *et al.* (2004). The Taraponui Member overlies the Te Rangi Member and underlies the Bellbird Bush Member (Fig. 11H, 15B).

Type locality and reference sections

The type section is designated at V19/430297 on Te Rangi Station. This is the most accessible section where the whole member is exposed and includes the lower contact. Reference sections established by Graafhuis (2001) are at Taraponui Trig (V19/331228-332231; Fig. 15A), Naumai Station (V19/408284; Fig. 14E), Boundary Stream Walkway (V19/440281-435271; Fig. 15D) and Rangiora Stud (V19/422270-423270).

Fig. 15 (facing page): Taraponui Member, Titiokura Formation. **A)** Panorama of Taraponui Trig from Waitara Road. This part of the Maungaharuru Range marks where the Titiokura Formation begins to diverge into its five constituent members. Photograph by Arne Pallentin. **B)** Relationship between the Te Rangi, Taraponui and Bellbird Bush Members on the western face of the Maungaharuru Range, south of Naumai Station. Photo location: V19/370265. **C)** Burrowed fine sandy packstone of the Taraponui Member, Boundary Stream Reserve (V19/446270). Photo by Arne Pallentin. **D)** Burrowed sandstone bluffs (over 40 m high) of the Taraponui Member at the northeastern end of the Boundary Stream walkway (V19445269). **E)** Close-up of a burrowed laminated siltstone lens in a mixed bioclastic-siliciclastic sandstone bed in the Taraponui Member at the northeastern end of the Boundary Stream walkway (V19/445269). **F)** Taraponui Member overlying the Te Rangi and Naumai Members on Te Rangi Station (V19/433288). Photograph by Rhys Graafhuis.


A
T
tke
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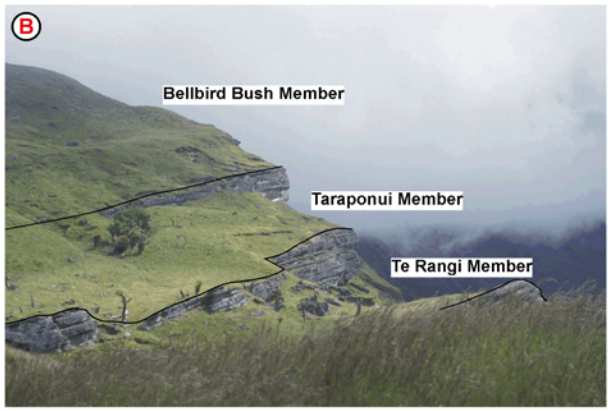
Opouahi Member
Bellbird Bush Member
Taraponui Member
Te Rangi Member
Naumai Member
Mokonui Sandstone


B
Bellbird Bush Member
Taraponui Member
Te Rangi Member


C


D


E


F
Taraponui Member
Naumai Member
Te Rangi Member

Lower and upper contacts

The lower boundary of the Taraponui Member is sharp and disconformable at localities between Taraponui Trig and Te Rangi Station (Fig. 14E). The upper boundary also has the form of a disconformity, showing relief of up to several decimetres, but tends to be poorly exposed (Bland *et al.* 2004).

Distribution and thickness

Taraponui Member is restricted in the study area to the eastern flanks of the Maungaharuru Range north of Ahuateatua Trig in a broadly northeast-southwest trending belt. The Taraponui Member overlies the Te Rangi Member and has a similar distribution pattern to it (Fig. 15B). The top of the member forms a prominent dipslope that runs out to bluffs above deeply incised streams (Graafhuis 2001; Bland *et al.* 2004).

The member is 10 m thick at Taraponui Trig, thickening to 75 m in the vicinity of Te Rangi Station and Rangiora Stud. The substantial increase in thickness reflects the increased amount of siliciclastic sandstone within the bulk of the member. South of Taraponui Trig the Taraponui Member amalgamates with other members of the Titiokura Formation, and by Ahuateatua peak cannot be easily differentiated.

Description

The Taraponui Member comprises two main lithologies - a lower limestone or shellbed facies and an overlying sandstone interval (Fig. 15C-E). The lowermost limestone portion of the Taraponui Member north of Taraponui Trig thickens southwards towards Taraponui Trig where it represents the bulk of the member (Fig. 15A). Sandstone facies overlying the basal limestone form the bulk of the member in the Naumai/Te Rangi Station and Rangiora Stud areas. At Taraponui Trig the base of the member comprises a 0.5 m-thick silty sandstone that is overlain by a 10 m-thick moderately cemented, cross-bedded glauconitic grainstone with mudstone rip-up clasts, rare pumice and greywacke pebbles. Bioclasts chiefly comprise barnacle and echinoderm plates with bryozoan and pectinid fragments.

At Naumai Station the same limestone is only 3 m thick, less calcareous, has a lesser shell content and is finer-grained than at Taraponui Trig. From Naumai Station toward Rangiora Stud the limestone grades into a sparsely fossiliferous cross-bedded amalgamated sandstone (Graafhuis 2001). This sandstone can be accessed from the Boundary Stream walkway (V19/440281-435271) (Fig. 15D, E).

On Naumai Station (V19/408284) the base of the member comprises a fossiliferous well cemented conglomerate containing sandstone and mudstone rip-up clasts and greywacke pebbles. Above is 1-2 m of cross-bedded sandstone, followed by a 0.5 m-thick shellbed with rip-up clasts and flame structures at its base. At V19/386262, also on Naumai Station, the basal unit is a cross-bedded sandy limestone (grainstone) with mudstone and pumice clasts at its base.

A very similar single shellbed at the base of the member crops out on Te Rangi Station at V19/430297, but lacks the pumice and greywacke clasts present on Naumai Station. Towards the northeast the lowermost beds appear to become amalgamated into a single shellbed, corresponding to a direction further out into the basin (Bland *et al.* 2004).

Sandstone facies in the Taraponui Member are 70-80 m thick, comprising most of the member away from Taraponui Trig. Lowermost parts of the sandstone interval are typically clean, fine-grained with low-angle megaripple cross-beds, passing up-section into massive and ripple-bedded bioturbated fine sandstone with mud drapes, reactivation surfaces and differentially cemented concretionary horizons. Further up-section the sandstone interval passes into amalgamated, well sorted, cross-bedded, fossiliferous fine sandstone (Graafhuis 2001).

Paleontology and age

No age diagnostic taxa have been observed in the Taraponui Member. An Upper Opoitian age is assigned on the basis of stratigraphic position.

Environment of deposition

On the basis of sedimentary structures and lithofacies a middle shelf to nearshore environment of deposition is envisaged for the Taraponui Member.

Bellbird Bush Member (tkd)

(Graafhuis 2001; formally defined by Bland *et al.* 2004)

Name and definition

Bellbird Bush Member (Fig. 11H) is named after Bellbird Bush, a DoC nature reserve near Boundary Stream Mainland Island in the Maungaharuru Range. Bellbird Bush Member was introduced by Graafhuis (2001) and formally defined by Bland *et al.* (2004). Bellbird Bush Member overlies the Taraponui Member and underlies the Opouahi Member (Fig. 15A).

Type section

The type section was designated on Te Rangi Station by Bland *et al.* (2004) (V19/430297). At this locality the Bellbird Bush Member directly overlies the Taraponui Member, and the middle and lower parts of the Bellbird Bush Member, and its lower contact, are exposed (Graafhuis 2001).

A reference section is located at V19/440281-435271 on Boundary Stream Walkway where about 110 m of section is well exposed.

Lower and upper contacts

The lower contact of the Bellbird Bush Member tends to be poorly exposed, but is unconformable, displaying relief up to several decimetres (Bland *et al.* 2004). The upper boundary is disconformable at Taraponui Trig, but conformable in other sections located to the northeast (Bland *et al*. 2004).

Distribution and thickness

Bellbird Bush Member is extensively distributed along the eastern flanks of the Maungaharuru Range from Ahuateatua Trig north. At Taraponui Trig, Bellbird Bush Member is 25 m thick, 70 m thick in the Waikoau River, thickening dramatically towards the northeast to 240 m thick in the Waikare River catchment (Rangiora Stud) (Graafhuis 2001; Bland *et al.* 2004). The dramatic increase in thickness into the paleobasin is associated with the accumulation of sandstone facies (Bland *et al.* 2004) and a high rate of basin subsidence.

Description

Bellbird Bush Member is characterised by very thick accumulations of sandstone facies. At the type section, basal beds of the Bellbird Bush Member comprise a conglomerate containing subangular pebbles and numerous gastropods. This unit rests on a surface cut across the underlying Taraponui Member with 0.6 m of local relief. The basal conglomerate is overlain by clean, fine sandstone with low-angle cross-beds. The lower 20 m of this sandstone displays numerous zones of intricately convoluted and deformed beds, perhaps indicative of synsedimentary dewatering. Above this is 20 m of fine sandstone with megaripples and mud drapes (about 2 cm thick) that are internally cross-laminated. Both the mud drapes and sandstone beds are heavily burrowed. This section passes into a 50 m-thick succession of cross-stratified fine sandstone with differentially cemented calcareous sandstone horizons.

The reference section located above the Boundary Stream Walkway is characteristic of other sections on Rangiora Stud. It appears to show a conformable base without basal conglomerate

or shellbed facies, and comprises sandstone facies throughout. The lower 25 m of the sandstone is planar-laminated to cross-bedded and heavily burrowed. Above is 40 m of cross-stratified sandstone with mud drapes and concretionary horizons. The uppermost 45 m comprises massive to planar-laminated sandstone with rare mudstone stringers and concretionary horizons. In general, the upper third of the member has common cemented horizons reflecting cleaner sandstone and higher carbonate content originating from finely comminuted shellhash.

At Taraponui Trig the Bellbird Bush Member comprises 23 m of thin-bedded fossiliferous sandy siltstone. At this locality the member may incorporate part of the underlying limestone, included above in the Taraponui Member as the position of the lower boundary here is uncertain. At Ahuateatua Trig the Taraponui Member can no longer be differentiated from other parts of the Titiokura Formation.

Paleontology and age

Macrofauna are uncommon in the Bellbird Bush Member (Graafhuis 2001) and are mainly gastropods. No age diagnostic macrofauna have been collected from the member, which is probably of uppermost Opoitian-Lower Waipipian age on the basis of stratigraphic position.

Environment of deposition

Bellbird Bush Member is inferred to have accumulated at middle shelf to nearshore water depths on the basis of sedimentary structures and lithofacies.

Opouahi Member (tke)

(Graafhuis 2001; formally defined by Bland *et al.* 2004)

Name and definition

Opouahi Member (Fig. 11H) is named after Lake Opouahi (V19/415215) near Pohokura Road on the eastern flank of the Maungaharuru Range. The member was introduced by Graafhuis (2001) and formally defined by Bland *et al.* (2004). Opouahi Member is the stratigraphically highest member of the Titiokura Formation (Fig. 11, 15A). It overlies the Bellbird Bush Member and underlies the Pohue Formation.

Type section

The type section is designated on Quarry Road from V19/403227 to 402225 (Bland *et al.* 2004). The base of the member is well exposed in this section, overlying the upper 14 m of the Bellbird

Bush Member. A reference section is designated at V19/439235 to 449235 north of Matahorua Road where the member forms the topographically highest beds of a steep-sided ridge named "Sharkies" by local residents.

Lower and upper contacts

Opouahi Member disconformably overlies the Taraponui Member at Taraponui Trig, but conformably overlies Taraponui Member in sections to the northeast (Bland *et al*. 2004). The upper contact, while not observed, is likely to be conformable and gradational over a short distance into non fossiliferous siltstone facies of the Pohue Formation.

Distribution and thickness

Opouahi Member crops out on the eastern flank of the Maungaharuru Range to the south and east of the Bellbird Bush Member where it forms the uppermost member of the Titiokura Formation.

At the type section the member is 45 m thick although the top is eroded. The reference section displays a 75 m thick profile through the member, although the top is also eroded here.

Description

Opouahi Member is characterised by varied lithologies, including silty sandstone, sandstone, and limestone (Fig. 16A, B). At the type section the Opouahi Member comprises two 0.5 m-thick beds of cross-bedded bioclastic grainstone which are separated by ripple- to planar-bedded siltstone. The limestone beds contain about 5% greywacke granules, and sandstone and mudstone rip-up clasts (Graafhuis 2001). Above is 1 m of cross-bedded fossiliferous sandstone that passes up-section into 43 m of weathered calcareous sandstone with abundant concretionary horizons. This sandstone is in turn sharply, and probably disconformably, overlain by 12 m of cross-bedded fossiliferous limestone containing greywacke granules.

The thick limestone bed cropping out beside Pohokura Road above Lake Opouahi (Fig. 16) is assigned to the Opouahi Member (Graafhuis 2001). This limestone displays prominent master weathering surfaces (Fig. 16B), a feature common to most exposures of Opouahi Member limestone facies. It is inferred that these surfaces may be sequence stratigraphic surfaces defining "sequences" in the member, similar to those described by Caron (2002). However, the limestone is typically case-hardened which makes the determination of fine-scale composition, sedimentary structures and lithofacies difficult.

At the reference section two coarsening-upward packages are evident that are inferred to represent two cyclothems. In these packages approximately 20 m of massive, bioturbated silty sandstone passes gradationally up into bipolar cross-bedded fossiliferous concretionary sandstone containing greywacke granules. Two potential sedimentary sequences are also represented in the Opouahi Member at Taraponui Trig. The lower sequence comprises a 1-2 m-thick basal cross-bedded shelly limestone lens with a disconformable base that grades rapidly into a thin-bedded fossiliferous sandy siltstone. The upper sequence comprises a 9 m-thick cross-bedded fossiliferous limestone with greywacke granules. Like the lower sequence, it also has an unconformable base.



Fig. 16: Opouahi Member, Titiokura Formation. **A)** Alternating grainstone and packstone beds of the Opouahi Member cropping out beside Pohokura Road, Maungaharuru Range near Lake Opouahi. The base of the member is arrowed, person (circled) for scale. Photo location: Pohokura Road, V19/ 408218. **B)** Alternating packstone-grainstone beds passing up-section into more siliciclastic-rich beds in the Opouahi Member cropping out beside Pohokura Road, Maungaharuru Range. The locations of master weathering surfaces are arrowed. Photo location: V19/403222.

Cross-bedded calcareous sandstone facies capping the member in the Rangiora Stud region were viewed by Graafhuis (2001) as lateral equivalents of limestone beds cropping out above Lake Opouahi.

Paleontology and age

Dating the Opouahi Member has been somewhat problematic in the past, due to the case-hardened nature of the limestone in the member, and by the lack of obvious macrofossils. Limestone of the Opouahi Member cropping out above Lake Opouahi was assigned a Waipipian age by Beu *et al.* (1980) when included in their informal Titiokura limestone. This was based mostly on the presence of *Mesopeplum (Borehamia) crawfordi* which at that time was viewed as a pectinid restricted soley to the Waipipian stage. More recent work by Beu (1995) has identified

definite occurrences of *M. crawfordi* in rocks of Opoitian age, therefore meaning a solely Waipipian age cannot be confirmed. Three fossil collections are reported in the fossil record file from beds of the Opouahi Member from Pohokura Road near Lake Opouahi. Sample V19/f8616 was assigned a Waitotoran age (therefore by implication either of Waipipian or Mangapanian age) on the basis of microfossils. Sample V19/f8529 was assigned an Opoitian-Waipipian age based on the presence of *M. crawfordi.* A comment in this record suggests that a Waipipian age is more probable, which is also the opinion of Beu (1995, p. 88) and Graafhuis (2001). Sample V19/f8615 reports a Waipipian age on the basis of microfossils.

On the basis of stratigraphic position and faunal content, the Opouahi Member is assigned a Lower Waipipian age.

Environment of deposition

A middle shelf to nearshore environment of deposition is inferred for the Opouahi Member on the basis of sedimentary structures, lithofacies and macrofauna. This is consistent with other members of the Titiokura Formation.

TE WAKA FORMATION (tw)

(McKay 1886a; formally defined by Beu 1995)

Name and definition

Limestone prominently capping the northern end of the Te Waka Range above Te Pohue was initially named either the Te Whaka limestone beds (informal) or Pohui limestone by Hector (1877) and McKay (1886a), the application of the names being unclear (Beu 1995). Beu *et al.* (1980) adopted Te Waka limestone as an informal limestone "sheet" name and applied it to limestone beds of Mangapanian age cropping out near the North Island axial ranges and faults on the western margin of the forearc basin in Hawke's Bay. Beu (1995) formally defined the Te Waka Limestone as the upper (Mangapanian) of two main limestone units on the Te Waka Range, those beds cropping out along the eastern slopes of the ranges around the Blowhard, Mount Kohinga and The Lizard near Kuripapango. Bland (2001) emended the name Te Waka Limestone to Te Waka Formation on the basis of the occurrence of prominent siliciclastic sandstone intervals in many parts of the formation. Bland (2001) also identified Waipipian-aged faunas in the lower and middle parts of the Te Waka Formation on the Te Waka Range. This meant a definition based entirely on age (i.e. Mangapanian only) was no longer sustainable. Caron (2002) also recognised Waipipian macrofauna in parts of the formation. Te Waka Formation is defined as a succession of interbedded sandstone and limestone beds cropping out along and near the eastern slopes of

the Kaweka Range, the Maniaroa Range and Te Waka Range, of uppermost Waipipian to Mangapanian age. Te Waka Formation contains one separately named member, a non to highly fossiliferous greywacke conglomerate bed restricted in outcrop to the Puketitiri-Patoka region named the Hassal Conglomerate Member.

Type and reference sections

Beu (1995) defined the section exposed below Te Waka Trig at the northern end of the Te Waka Range as the type section for this unit (Column Tp-3). This section represents the northernmost outcrop of Te Waka Formation and is retained in this study. A reference section is nominated along Kurowski Road, a track through Te Waka Forest at the southern end of the Te Waka Range (Column Tw-4). The Gorges section below Puketitiri Road provides a detailed section through cyclothemic mixed bioclastic-greywacke pebble beds of the Te Waka Formation (Column Pt-8). Cuttings on Lizard Road provide a very well exposed section through the cyclothemic part of the Te Waka Formation (Column Gr-1). The section below the wind meter on Sandy Ridge provides detailed insight into the nature of the unconformable contact between the Te Waka Formation and the underlying basement (Column Gr-2). A section in Opau Stream shows the nature in which the Te Waka Formation may overstep older stratigraphic units (Column Pt-2). In this section the Te Waka Formation helps define a spectacular angular unconformity between itself and either the Te Ipuohape Sandstone Member (Waitere Formation) or Torlesse basement over only a few hundred metres.

Lower and upper contacts

The nature of the lower contact of the Te Waka Formation is different east and west of the Mohaka Fault. The Te Waka Formation overlies many stratigraphic units and because of this its lower contact has important implications for unravelling the history of deformation of the North Island Shear Belt. West of the Mohaka Fault the Te Waka Formation may unconformably overlie basement, the Blowhard Formation (Waikarokaro Sandstone Member), Mangatoro Mudstone, or Puketitiri Formation. The Te Waka Formation underlies and interdigitates with the Puketitiri Formation. The formation rests unconformably on basement along Sandy Ridge and the northern end of the Glenross Range in the Kuripapango area. A possible contact with basement is also present on Hawkston Station immediately west of the Mohaka Fault. The Te Waka Formation is inferred to overlie basement at The Lizard and on the northern end of the Glenross Range south of the Napier-Taihape Road. On Hukanui Hill above Puketitiri village Te Waka Formation sharply and unconformably overlies silty fine sandstone of the Puketitiri Formation. The basal 1 m of Te Waka Formation at this locality comprises a poorly sorted coarse-grained greywacke conglomerate to breccia bed with common *Crassostrea ingens*, particularly near the base of the

unit. Te Waka Formation also unconformably overlies the Puketitiri Formation in sections near Puketitiri Road. Te Waka Formation conformably overlies Puketitiri Formation on Rocky Hill Station.

East of the Mohaka Fault the Te Waka Formation may unconformably overlie basement, Te Ipuohape Sandstone Member (Waitere Formation), Mokonui Sandstone, or Titiokura Formation (Fig. 17B). The lower contact of the Te Waka Formation is well exposed in Opau Stream near Patoka (Fig. 17D; Kingma 1958b; Katz 1973). Over a distance of c. 200 m the formation progressively overlies steeply dipping (45ºENE) Tongaporutuan sandstone (Te Ipuohape Sandstone Member, Waitere Formation) and basement. Where the Titiokura Formation is present it conformably underlies the Te Waka Formation through a series of concretionary mixed siliciclastic-bioclastic sandstone beds (assigned to the Titiokura Formation) (Fig. 20B). One exception to this is at Oakmere Station at Te Pohue where a thick channelised limestone bed (Caron 2002) rests on siltstone above the Titiokura Formation with a slight (c. 2-4º) angular discordance (Brash 1982; Bland 2001).

Te Waka Formation is conformably overlain in areas north of the Omahaki Depression by the Pohue Formation. South of the Omahaki Depression Te Waka Formation interdigitates with the Puketitiri Formation. Along strike to the north of Te Waka Trig the Te Waka Formation passes laterally into siliciclastic beds of the Pohue Formation. The upper contact of the Te Waka Formation is observable in few places. Concretionary sandstone of the Pohue Formation conformably overlies Te Waka Formation in cuttings on Puketitiri Road above "The Gorges" section and just west of Patoka. A similar conformable contact is evident above Te Pohue village in cuttings on some forest roads.

Distribution and thickness

Te Waka Formation is widespread along nearly 50 km of the western margin of the mapping area from the northern end of the Te Waka Range to Whanawhana at the southern end of the Glenross Range. The Formation forms prominent ridges along the Te Waka and Maniaroa Ranges, particularly between Hawkston and Puketitiri Roads. Te Waka Formation is not present north of Te Waka Trig, and it is likely that lower parts of the Pohue Formation in the eastern side of the Maungaharuru Range area are lateral equivalents. Field *et al.* (1997) suggested that Te Waka Formation is confined to the downthrown block between the Ruahine and Kaweka Ranges. The eastern extent of the Te Waka Formation is marked by the Patoka Fault at Patoka, and the Rukumoana Fault at Te Pohue. The only occurrence west of the Ruahine Fault is at Mount Kohinga. The presence of the unit there is suggestive that it once extended across the present

location of the Kaweka Range. Browne (2004a) included upper thin-bedded limestone and sandstone beds on The Lizard and Mount Kohinga at Kuripapango in the Kaumatua Formation. Examination of the Kaumatua Formation (now included in Puketitiri Formation) in the Ohara Depression shows it to be a sandy, relatively fine-grained formation quite distinct from "typical" Te Waka Formation. The upper beds on Mount Kohinga and The Lizard are very similar in lithology and of the same age to known Te Waka Formation beds exposed in adjacent and northern localities, and are therefore included here in the Te Waka Formation. Geological mapping has also demonstrated continuity between these areas. Beu (1995) also included these beds in the Te Waka Formation rather than the Kaumatua Formation.

Well cemented strongly fluted limestone near the intersection of Lawrence and Taihape Roads, and Blowhard Bush, Kaweka Forest are included in Te Waka Formation. Prominent limestone beds interbedded with differentially cemented sandstone forming the eastern dipslope of the Glenross Range is also included within the Te Waka Formation.

Te Waka Formation has not been identified south of the Ngaruroro River, although on the basis of age and some lithological similarities it is probable that Puketitiri Formation sediments exposed in the Ohara Depression are lateral, southern equivalents of the Te Waka Formation. However, it is desirable at present to keep these two units as separate formations due to lithological variations.

The Te Waka Formation thickens slightly southwards away from the type section toward Kuripapango, reflecting an increase in contemporary rates of subsidence and siliciclastic sediment flux. South of Kuripapango the formation thins into the Awapai Station area. At the type section the Te Waka Formation is approximately 100 m thick. At Kuripapango, Te Waka Formation is a maximum of 120 m thick.

Description

Lithologically the Te Waka Formation is a highly variable unit. Sandstone is usually the dominant lithology, but limestone is the distinctive lithology in the formation. Sandy to pebbly limestone facies are common and locally dominate outcrops. Conglomerate facies are minor and are usually restricted to lower parts of the formation, especially in close vicinity to greywacke basement. Te Waka Formation is characterised by varying amounts of soft to well cemented barnacle, bivalve and bryozoan sandy limestone beds separated by more siliciclastic-dominated beds. The lithology of Te Waka Formation in "The Gorges" at Patoka has been well documented by Caron (2002).

For much of its outcrop area, Te Waka Formation consists of a thick lower limestone unit overlain by packages of alternating limestone-siliciclastic sandstone beds each several metres thick. Siliciclastic lithologies become more common away from the type section, particularly towards the Kuripapango area. In northern outcrops (e.g. the type section on the Te Waka Range, Column Tp-3) Te Waka Formation consists of large lenses and pods of limestone in a siliciclastic sandstone unit. Towards the south the formation displays a more cyclothemic character, particularly in upper parts. This cyclothemic expression is perhaps best displayed in the Patoka and Kuripapango areas (The Gorges, The Lizard and Glenross Range sections). Cyclothems are also evident in the Glenross Range from Taihape Road through the Omahaki and Awapai Station areas (Fig. 18A-C).

At the type section (Fig. 17 A, C) the Te Waka Formation comprises a lower 80 m-thick silty fine sandstone that becomes coarser-grained and increasingly calcareous up-section. Two main limestone beds are present below Te Waka Trig, with the telecommunications tower constructed upon the uppermost of these beds. The upper limestone bed is 8 m thick, displays a coarsening-upward trend and comprises alternating bioclastic/siliciclastic-rich beds. The lower limestone is up to 2 m thick and is compositionally very similar to the upper limestone bed. Both limestone beds thin and become more siliciclastic towards the north and west. The 50 m-high bluff section exposed above Te Pohue on Oakmere Station is inferred to represent a broadly channelised unit that grades into the lower sandstone-dominated interval cropping out at Te Waka Trig (Fig. 18K-L). Bland (2001) included the channelised beds above Te Pohue in the Oakmere Member, although this unit cannot be traced away from the immediate Te Pohue region. The section sharply overlies fine-grained siltstone of the upper Titiokura Formation. A coarse-grained conglomerate bed that contains concretionary clasts from the underlying siltstone represents the basal beds of the Te Waka Formation there. Clasts in the conglomerate are of coarse pebble to boulder size and dominantly of sandstone and mudstone. The formation there consists of two main limestone packages separated by a siliciclastic sandstone interval. The lower part of the section comprises approximately 30 m of yellowish-brown, moderately to well cemented grainstone rich in barnacle plates and fragments with oysters, gastropod and bivalve grains.

In the section above Te Pohue Village (Fig. 18L; Column Tp-1) the lower half of the Te Waka Formation comprises alternating bioclastic/siliciclastic beds 0.2-0.25 cm thick. The brachiopod *Neothyris* aff. *obtusa* is common in this interval. Low-angle trough cross-stratification is evident throughout the section. Bioclastic beds tend to be coarser-grained (coarse sand texture) than their siliciclastic counterparts (fine sand). This interval coarsens up-section where, with macrofossils more common in the upper parts of the section. Case hardening over much of this section obscures large portions of the unit, although enough “windows” are visible to be able to

document the interval. The lower limestone interval is overlain by a thin (1 m thick) moderately fossiliferous strongly bioturbated siltstone with thin layer of coarse sand-sized shellhash. This siltstone is in turn overlain by approximately 2 m of moderately fossiliferous alternating bodies of fine to medium sandstone containing significant amounts of shellhash.

Above this is approximately 10 m of olive-brown, non to moderately cemented, moderately fossiliferous strongly bioturbated sandstone with moderately fossiliferous concretionary lenses and horizons. Planar to low-angle cross-stratification is evident. Thin mudstone stringers (up to 8 cm thick) and drapes are present, with well-developed ripple and planar laminations evident (Bland 2001). This concretionary interval passes gradationally and conformably into the Pohue Formation.

Very pebbly limestone crops out prominently in the Hawkston-Seaview Station area and represents the lower bed of the formation (Fig. 17E, 18F). Large areas of slumped deposits are prominent in this area with failure occurring along the contact between Te Waka Formation limestone and the underlying Puketitiri Formation. In Te Kowhai Forest above Gorge Stream a large circular-shaped failure is currently growing with subsidence in the order of centimetres/ month. At V20/128995 the limestone comprises a very pebbly highly fossiliferous shellhash limestone. *Patro undatus* is abundant together with barnacles, common *Crassostrea ingens* and *Phialopecten thomsoni*. Barnacles are commonly attached to bivalves and more rarely pebbles. The limestone comprises a lower 3 m-thick zone of stacked shellhash beds each 2-5 cm thick. These beds are arranged in planar form, or as broad, low-angle trough cross-stratification. Upper parts of the unit (up to 10 m thick) are more massive and weakly laminated, though pebbles and whole shells are abundant throughout. Nearby at V20/130003 the same pebbly limestone bed is sharply overlain by concretionary fine to medium sandstone. The basal 0.5 m of this sandstone has a noticeable bioclastic content that rapidly diminishes up-section. Concretions are scattered through the sandstone and are up to 0.2 m wide and 0.4 m long.

The same pebbly limestone interval crops out on nearby Seaview Station (V20/141003 and V20/ 143007; Fig. 18F). Prominent bluffs crop out nearby east across the Mohaka Fault (e.g. V20/ 145999). Beu (1995) inferred that beds immediately east and west of the fault were the same horizon. The prominent lithological differences between these beds clearly demonstrate that they are unlikely to be the same horizon, and that calculating vertical displacement on the Mohaka Fault is more difficult than appears at first.

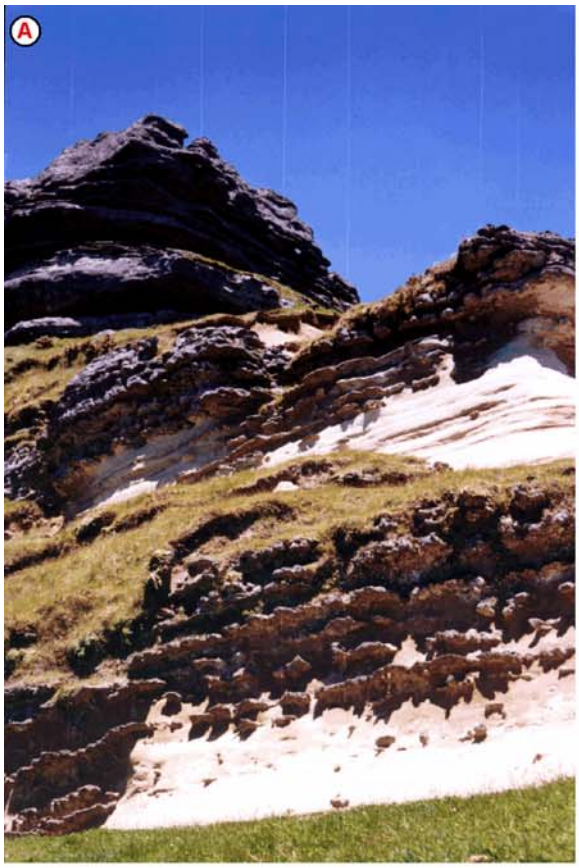
Caron (2002) studied a section of Te Waka Formation in the headwaters of Wai-iti Stream near Patoka which he referred to as “The Gorges” section, after the farm on which the section is located

(Fig. 18I; Column Pt-8). This section provides an important window into the cyclothemic expression of the Te Waka Formation through the Patoka region. The lowermost limestone exposed here is lithologically similar to Titiokura Formation present on the Te Waka Range. Caron (2002) tentatively included this bed in the Titiokura Formation, a view supported in this study. All strata above this lower bed to the modern land surface are assigned to the Te Waka Formation. The formation here comprises alternating coarsening-upward packages of sandstone and limestone.

Cycles at The Gorges differ from those at Kuripapango and the Glenross Range in that there is a more distinct differentiation between sandstone and limestone intervals than to the south. Pebbly and conglomeratic limestones are also more typical in The Gorges than in sequences further south. This probably reflects the presence of a greywacke outlier in Opau Stream (V20/208048).

In Opau Stream near Patoka (Fig. 18H; Column Pt-2) the Te Waka Formation successively overlies Tongaporutuan strata of the Te Ipuohape Member of the Waitere Formation and greywacke. The lowermost portion of the Te Waka Formation here is marked by a highly fossiliferous greywacke breccia 2.5 m thick (Fig. 17D). This unit contains abundant valves of *Crassostrea ingens* and Flabellum corals, with common *Phialopecten marwicki* and encrusting bryozoans. Angular, very poorly sorted clasts of greywacke are abundant, and are of granule to boulder size. Many of the more rounded clasts in the basal breccia are pholad bored. This bed passes up-section into about 10 m of barnacle-rich flaggy, well cemented sandy limestone with prominent alternating units of mixed bioclastic-siliciclastic sediments.

Fig. 17 (facing page): Te Waka Formation. **A)** Upper limestone beds of the Te Waka Formation at the type section. These beds mark the northernmost point of outcrop of the Te Waka Formation. The Te Waka Range microwave tower (Fig. 17C) rests on the limestone bed at the top of the photograph, approximately 50 m away. Photo location: Te Waka Trig, V20/257130. **B)** Alternating thin-bedded limestone and sandstone facies of the Te Waka Formation conformably overlying mixed skeletal-terrigenous limestone of the Titiokura Formation near Hells Hole on the northern face of the Te Waka Range. Photo location: V20/235126. **C)** Uppermost limestone bed of the Te Waka Formation, Te Waka Trig. The microwave tower is visible on this unit. The location of the Te Waka Range Splinter Fault is indicated (dashed red line), and downthrows the upper limestone bed 30 m to the northwest. The location of Photo Fig. 17A is indicated. Photo taken at V20/252129 looking southeast. **D)** Strongly developed angular unconformity (highlighted) between Tongaporutuan (Late Miocene) Te Ipuohape Sandstone Member (Waitere Formation, Tolaga Group) and Mangapanian (Late Pliocene) Te Waka Formation (Mangaheia Group). A very coarse-grained breccia dominated by greywacke clasts and Flabellum corals forms the lowermost 2 m of Te Waka Formation at this site, and infills a spectacular paleorelief. Te Ipuohape Sandstone Member dips at approximately 45°ENE, Te Waka Formation dips at 18-13°NE-SE. Photo location Opau Stream, V20/207049. Photo by Cam Nelson. **E)** Stacked grainstone and packstone beds of Te Waka Formation on Hawkston Station beside Hawkston Lake. These beds contain abundant macrofossils including barnacles, *Patro undatus, Crassostrea ingens* and *Phialopecten thomsoni*. Photo location V20/128995. **F)** Steeply dipping (c. 58°) beds of the Te Waka Formation forming the summit of The Lizard, Kuripapango area. The Lizard is truncated by The Lizard Fault to the left of the photograph, and the Glenross Fault behind the photographer. Photo location: The Lizard looking northwest towards the Kaweka Range (U20/035912). **G)** Steeply-dipping alternating grainstone and packstone beds of the uppermost Te Waka Formation forming the summit of Mount Kohinga above Kuripapango. Photo location: Mount Kohinga looking south (U20/981937).


A


B
Te Waka Formation
Titiokura Formation
(Mangahela Group)
Mokonui Sandstone
(Tolaga Group)


C
A
u
d
u
d


D
Te Waka Formation (Wm)
Te Ipuohape Sandstone Member (Tt)


E


F


G

Te Waka Formation overlies greywacke across an angular unconformity that displays decimetre-scale relief along the crest of Sandy Ridge (Fig. 18D; Column Gr-2). Greywacke clasts of granule to cobble size are common in the 1.5 m-thick basal beds of the Te Waka Formation in this area, and consist of a highly fossiliferous greywacke breccia to conglomerate with fauna dominated by the large robust oyster *Crassostrea ingens.* This coarse-grained lower bed passes conformably up-section into a moderately to well cemented flaggy shellhash limestone containing a variety of generally robust bivalve taxa including *Tucetona laticostata, Phialopecten thomsoni, Panopea* sp. and abundant barnacles.

At the northern end of Sandy Ridge Road an interval of siliciclastic sandstone crops out and overlies the bioclastic-dominated lower portion of the Te Waka Formation in this area. The Lizard section (Fig. 17F) displays steeply dipping Te Waka Formation in a spectacular outcrop south of Taihape Road (U20/035912, Column Ku-2). The steep dip (56-60° NW) of this section is a result of deformation associated with the Glenross and Lizard Faults, both of which are less than 100 m from the section. Immediately southeast of the Glenross Fault the same horizons dip 8-12° SE. This section clearly displays the cyclothemic character of middle and upper parts of the Te Waka Formation through the Mangatutu-Kuripapango-Glenross areas.

Beu (1995) regarded The Lizard section (Fig. 17F, 18C) as an overturned fault-bounded block. The order of stratigraphy observed at The Lizard is the same as present in the adjacent Glenross Range, and there is no reason to suggest that the succession has been overturned. The succession is merely dipping NW (albeit very steeply) instead of the more typical SE direction. The lowermost parts of The Lizard section are very poorly exposed in scrub and light forest below the ridge of The Lizard. Small glimpses of the lower beds are visible from the Glenross Range immediately southeast of The Lizard and appear to show a lower thick case-hardened limestone bed that probably overlies greywacke, as on nearby Sandy Ridge (U20/047927, Column Gr-2). The lower interval is inferred to be several tens of metres thick. Overlying this is the nearly 50-m thick series of beds that form The Lizard and provide continuous outcrop throughout. The base of the exposed section comprises a moderately cemented shellhash-rich sandy limestone containing common *Crassostrea ingens*, many of which are attached to each other in a reef-like fashion. *Crassostrea* become more common toward the base of this bed. The basal limestone package is conformably overlain by 11 m of non cemented fine sandstone with common moderately cemented concretionary horizons up to 0.3 m thick. This is in turn overlain by nearly 15 m of yellow-brown, non cemented, non to slightly fossiliferous fine sandstone with thick, discontinuous to continuous sandy limestone beds 0.6-2 m thick. These limestone beds have a mixed bioclastic-siliciclastic composition. They are in turn overlain by a 3 m-thick moderately cemented limestone bed consisting of alternating bioclastic and siliciclastic beds 0.3-0.6 m thick.

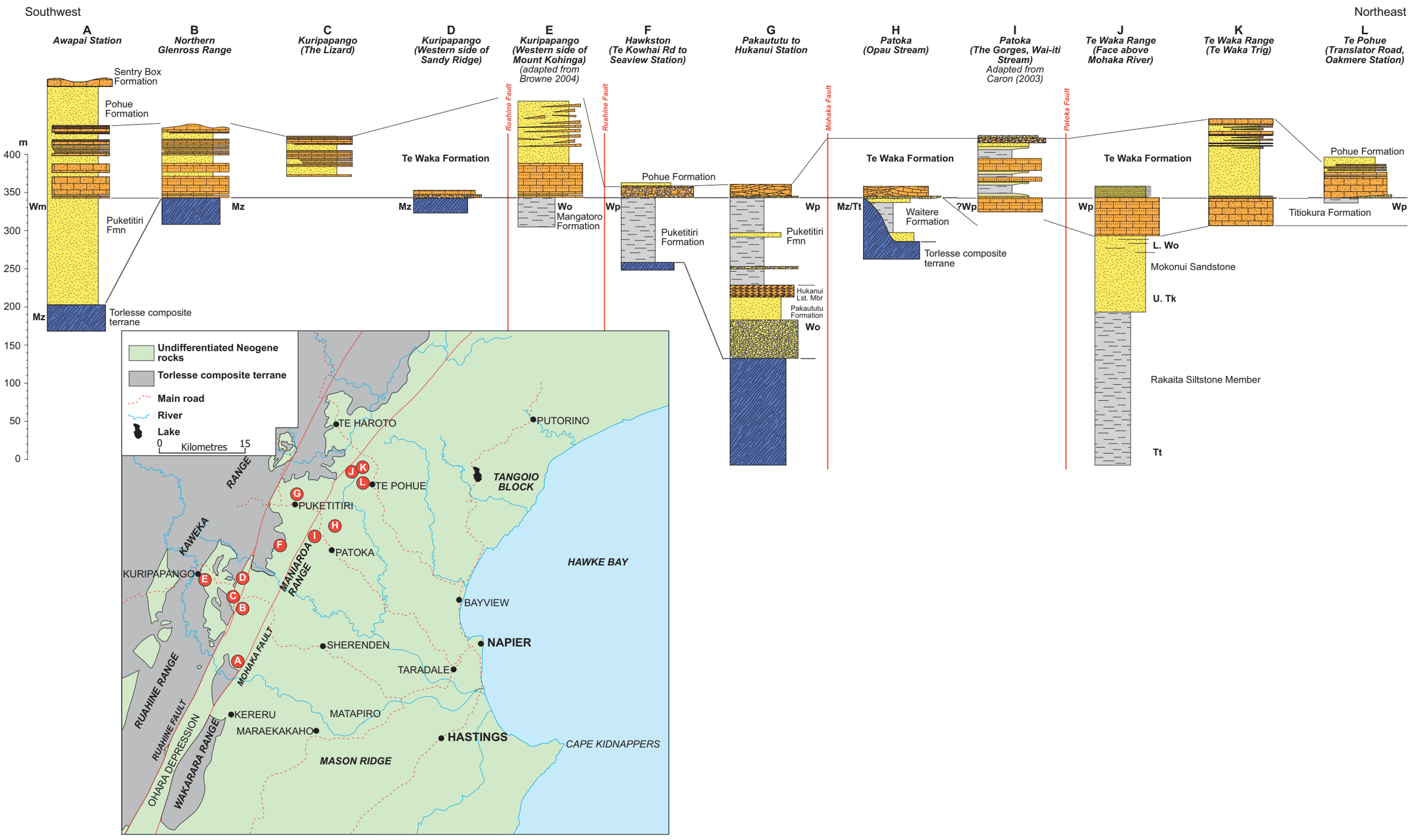


Fig. 18: Schematic column illustrating the distribution of the Te Waka Formation from the type section on the Te Waka Range (northeast) to Awapai Station (southwest). Of note is how the Te Waka Formation overlies a number of stratigraphic levels from Mesozoic basement to middle Pliocene limestone.

The bioclastic component is rich in barnacle and bryozoan fragments. Rare *Phialopecten thomsoni* valves and fragments are present. A thin (0.6 m thick) sandstone interval overlies this limestone, followed by another thin (0.5 m thick) sandy shellhash-dominated limestone containing common bryozoan fragments. The following interval comprises the core of The Lizard and consists of yellow-brown, moderately to strongly bioturbated, non to slightly cemented muddy fine sandstone. Occasional concretionary bodies and horizons are present up to 30 cm thick, as are common thin mudstone stringers up to 10 cm thick. These mudstone stringers are commonly ripple- and flaser-bedded and are very continuous along section. Concretionary bodies are largely non fossiliferous, although many contain abundant biomoulds resembling *Tawera* sp. (dominant) and various mussel genera (e.g. *Perna, Modiolus*). This interval is approximately 12 m thick. Concretionary bodies increase in number and size up-section, before passing into the uppermost limestone package. This 3 m-thick interval consists of moderately cemented, medium to coarse sand-sized shellhash limestone interbedded with mixed bioclastic-siliciclastic packages. Individual packages are generally about 0.5 m thick.

Hard, well cemented and fluted limestone cropping out near Blowhard Bush and Lawrence Road are included in the Te Waka Formation. At U20/036937 this interval comprises a moderately to well cemented massive, case-hardened limestone with scattered oyster valves and bivalve fragments. At U20/03892 the fluted outcrops comprise moderately well cemented creamy-brown coarse-grained bioclastic sandy limestone dominated by moderately well sorted shell fragments. Beu (1995) reported common *Phialopecten thomsoni* in fluted beds near the intersection of Lawrence and Taihape Roads.

On Mount Kohinga above Kuripapango (Fig. 18E) the formation comprises an approximately 30 m-thick massive lower member separated by several metres of fine sandstone from numerous interbedded thin bioclastic grainstone and laminated sandstone beds (Fig. 17G). The upper thin-bedded interval is at least 50 m thick and was regarded by Browne (2003) as Kaumatua Formation, although Beu (1995) included these beds in the Te Waka Formation. The succession exposed on Mount Kohinga very closely resembles that present on The Lizard and Glenross Range, both known to be Te Waka Formation outcrops. This study confirms Beu's interpretation and regards all sandstone and limestone beds capping Mount Kohinga above the Mangatoro Formation as Te Waka Formation. The summit of Mount Kohinga involves a syncline, with many cross-cutting faults displacing the stratigraphic units present.

In the vicinity of greywacke outcrops Te Waka Formation contains abundant basement-derived clasts. Limestone beds in the Kuripapango region are particularly rich in basement clasts,

although very pebbly limestone beds are present around Patoka and Puketitiri, among other areas.

The Glenross Range in the Omahaki-Awapai Station area (Fig. 18A, B) marks the southernmost extent of the Te Waka Formation (Column Gr-3). The cyclothemic character of the formation is well displayed there, particularly on Kohurau Station south of Omahaki Road, and up to three distinct sandstone-dominated cyclothemic packages can be identified.

Paleontology and age

Te Waka Formation contains a relatively diverse range of faunas that have been sampled throughout the outcrop belt. Barnacles, both as fragments and plates, dominate the faunal content of the formation. Bivalves are commonly present intact, although are mostly disarticulated. *Ostrea chilensis* is common in sections, as are specimens of the brachiopod *Neothyris* aff. *discors.* Large specimens of *Maoricardium spatiosum* have been collected from outcrops at Te Waka Trig and near Puketitiri Road north of the Maniaroa Range. *Crassostrea ingens* is common throughout the formation, particularly in the vicinity of basement rocks. This is presumably because the basement rocks provided substrate upon which these oysters could attach. In many localities around the Hawkston area the false oyster *Patro undatus* is locally abundant.

The age of Te Waka Formation appears to be mildly diachronous through the outcrop area. A small number of pectinids resembling *Phialopecten marwicki* in terms of their size and rib count have been collected from the base and middle of Te Waka Formation at the type section on the Te Waka Range, suggesting a Waipipian age for at least part of the formation in this area (Bland 2001). A scaphopod collected immediately below Te Waka Trig was tentatively identified as *Antalis pareorensis* (A. McIntyre pers. comm. 2000) and also suggests a Waipipian age for these beds (age range Tk-Wp, Beu and Maxwell 1990). Specimens of pectinids that exhibit characteristics of both *P. marwicki* and *P. thomsoni* have been collected immediately below Te Waka Trig, possibly representing the Waipipian-Mangapanian boundary (Bland 2001). The presence of *Maoricardium spatiosum* confirms an age no younger than Mangapanian for rocks at the northern end of the Te Waka Range, supported by the presence of uncommon *Phialopecten thomsoni*. *Phialopecten thomsoni* has been collected from numerous outcrops to the south of the Te Waka Range and in the upper beds at Te Waka Trig itself (Beu 1995). At its southernmost outcrop, Te Waka Formation is conformably overlain by lowermost Nukumaruan Sentry Box Formation (Beu, 1995) that contains both *P. triphooki* and *Zygochlamys patagonica delicatula.* This suggests that the Te Waka Formation in this area is of Upper Mangapanian age. *P.*

thomsoni has also been collected from several localities in the Patoka, Hawkston and Kuripapango areas, demonstrating that the formation in these areas is of Mangapanian age.

Environment of deposition

Deposition of the Te Waka Formation represents one end-member of a depositional system outlined by Caron *et al.* (2004a). The formation accumulated along the continent-attached margin of a paleo-seaway (the Ruataniwha Strait of Beu 1995) that developed during the Pliocene throughout Wairarapa and central Hawke's Bay. The mixed bioclastic-siliciclastic composition of the formation is entirely consistent with a continent-attached depositional setting, and contrasts with inferred continental-detached bioclastic-dominated limestones, such as the coeval Te Onepu Limestone, cropping out along the eastern margins of the forearc basin.

The continental shelf on which the Te Waka Formation accumulated is inferred to have been narrow, and bounded on it's landward side by elevated areas of Torlesse basement and areas of uplifted Neogene sediments. It is inferred that the coastline was irregular with areas of rocky coastline and sandy/gravelly beaches.

Macrofauna and sedimentary structures throughout the formation are consistent with nearshore to middle shelf environments of deposition. Te Waka Formation cropping out at Kuripapango and in the Hawkston Station areas are inferred to have accumulated in a more shoreward position than Te Waka Formation at Te Pohue. The onlap of Te Waka Formation onto Torlesse basement at Sandy Ridge, Kuripapango, demonstrates that some parts of the seaway had a rocky coastline during the Mangapanian. The formation contains a significant amount of siliciclastic material in places and illustrates that the continental shelf on which Te Waka Formation was accumulating was periodically supplied with terrigenous sediments.

Hassal Conglomerate Member (twh)

(Caron 2002)

Name and definition

Caron (2002) identified a greywacke conglomerate bed at the top of The Gorges section (Column Pt-8) at the headwaters of Wai-iti stream near Patoka that had not been observed in outcrops to the north by Bland (2001) or Pallentin (in prep.), and informally referred to the unit as the Hassal conglomerate. The name is derived from Mount Hassal Farm, immediately west of The Gorges section. For consistency the unit is renamed here Hassal Conglomerate Member

Type locality and reference sections

The type section is designated as the southern face of Romulus hill on Mount Hassal Farm, Patoka (V20/168027, Column Hw-2). Reference sections are nominated along Little Bush Road (V20/157059, V20/155056).

Lower and upper contacts

Both lower and upper contacts are poorly exposed in the study area, though are visible at the type section. The member unconformably overlies undifferentiated sandstone of the Te Waka Formation across an erosional surface, exposed on Romulus hill. The upper contact is also sharp and inferred to be unconformable, with non fossiliferous gravels of possible Castlecliffian age overlying the Hassal Conglomerate Member. This contact is also exposed on Romulus hill.

Distribution and thickness

Caron (2002) described one section through the Te Waka Formation in detail (The Gorges section), and identified the Hassal Conglomerate Member as occurring at the top of Mount Romulus on Mount Hassal Farm. The upper units on The Gorges section of Caron (2002) represent the type section of the Hassal Conglomerate Member. Non fossiliferous greywacke conglomerate commonly crops out along Little Bush Road, and in gravel pits near the airstrip above Te Wairere. These sections are west of the type section and are inferred to represent a more shoreward expression of the member. The maximum observed thickness of this unit is about 7 m.

Description

On Mount Romulus Caron (2002) described a conspicuous ravinement surface that placed a 5 m thick fossiliferous conglomerate (lower part of the Hassal Conglomerate Member) in direct contact with a 20-25 m thick siltstone to sandstone interval. This conglomerate bed contains mudstone and greywacke pebbles (up to 0.2 m across), interbedded with valves of oysters and various unidentified bivalves. The upper contact of this fossiliferous conglomerate is sharp and marked by a shell concentration that includes scattered large oyster valves. Overlying this zone is a package of fluvial gravel beds consisting of non fossiliferous, planar laminated pebbly sandstones with thin muddy horizons that contain lignite debris.

Further to the north in the vicinity of Little Bush Road near Puketitiri, the Hassal Conglomerate Member comprises well sorted, well rounded, laminated greywacke granule to cobble-sized clasts with no shelly sediments present that overlie clean, non cemented, slightly micaceous, well sorted medium sandstone. The greywacke clasts in the unit are dominated by spheroid-shaped grains,

and are set in a matrix of non cemented silty fine sandstone. A finer-grained matrix tends to be present in coarser-grained portions of the conglomerate. A fining-upward pattern is visible in many of the outcrops in the Little Bush area, and imbrication in grains towards the southeast is also evident. It appears that the Hassal Conglomerate Member is overlain by a slightly micaceous, non cemented fine sandstone that contains thin (<0.1 m thick) greywacke conglomerate pebble stringers.

The lack of fossiliferous deposits in the Hassal Conglomerate Member towards the north suggests that the shelly deposits observed by Caron become more terrestrial to the west, and that in a basinward direction (towards the east) the Hassal Conglomerate Member becomes fossiliferous and grades into a limestone.

Non-marine greywacke gravels unconformably overlying the Hassal Conglomerate Member on Romulus are likely to be Castlecliffian deposits and are not included in the Hassal Conglomerate Member.

Paleontology and age

The Hassal Conglomerate Member is unsatisfactorily dated. On Mount Romulus the unit contains abundant specimens of the shallow-water gastropod *Zethalia* sp. However, these shells are highly abraded and the characteristic shell nodules, used to differentiate *Zethalia* species, are largely missing. Based on test size and broad shape these *Zethalia* most closely resemble the Nukumaruan to Recent species *Zethalia zelandica*, although this identification is very tenuous. It is inferred, based on stratigraphic position, that the Hassal Conglomerate Member is more probably of Mangapanian age.

Environment of deposition

Hassal Conglomerate Member cropping out around Little Bush Road was deposited in a non-marine fluvial and marginal-marine shoreface setting. Fauna in Hassal Conglomerate Member cropping out on Mount Hassal Farm indicate a shoreface to nearshore environment of deposition, probably as part of a gravel beach setting. *Zethalia zelandica,* common in the Hassal Conglomerate Member at the type section, currently inhabits very shallow-water (3-5 m) environments off slightly protected sandy beaches (Beu and Maxwell 1990).

POHUE FORMATION (po)

(Smith 1877 (informal))

Name and definition

Pohue papa was introduced by Smith (1877) as a name for a series of interbedded sandstone-siltstone beds cropping out in the Te Pohue area of western Hawke's Bay. The name is derived from Te Pohue village, located approximately 40 km northeast of Napier along State Highway 5. Brash (1982) emended Smith's name and defined Pohue Formation as a series of alternating sandstone and siltstone beds with occasional shellbeds conformably overlying the uppermost limestone beds of the Te Waka Formation. This definition was adopted by McLennan (1990). Bland (2001) redefined the formation to exclude the siltstone and sandstone beds immediately below the first conglomerate bed of the Matahorua Formation. Similar units cropping out in the Waikoau and Waikare River catchments were defined by Graafhuis (2001) as the Rangiora Formation. The definition of the Pohue Formation is enlarged in this study to incorporate the Rangiora Formation of Graafhuis (2001) as there is little lithological difference between the two units, except for a gradual overall change to more siltstone-dominated facies towards the northeast. Pohue Formation is defined as alternating sandstone and siltstone beds with occasional shelly horizons conformably overlying the Te Waka Formation, and conformably underlying the first greywacke conglomerate bed of the Matahorua Formation. On the eastern side of the Maungaharuru Range, Pohue Formation is inferred to conformably overlie the Opouahi Member (Titiokura Formation) (Graafhuis 2001).

Type locality and reference sections

Brash (1982) defined the small sandstone exposure at the intersection of Ohurakura Road and State Highway 5 as the type section of the Pohue Formation (V20/291085). Bland (2001) proposed a new type section as Brash's section only displayed a 2 m-thick portion of one sandstone bed in a formation that is at least 350 m thick. Bland (2001) proposed a section along the Esk River upstream of a point near the confluence of the Esk River and Ohurakura Stream as the type section (V20/374114-378143). This section has been retained in this study as almost the entire formation is visible along this portion of the river.

A reference section is designated in the Mangaone River from V20/251065-V20/272019.

Upper and lower boundaries

In a regional sense Pohue Formation interdigitates with and overlies the Te Waka Formation, and conformably overlies the Titiokura Formation (Fig. 18). In the Maungaharuru Range Te Waka

Formation is absent, having passed laterally into Pohue Formation. Locally, such as in the Te Pohue area Te Waka Formation is conformably overlain by the Pohue Formation. At Te Pohue, Te Waka Formation gradually becomes more sandy and concretionary upwards, which marks the transition to the Pohue Formation (Column Tp-1). Mostly however, the base of the Pohue Formation is not exposed. In the Patoka are the base of Pohue Formation is truncated by the Patoka Fault, and the formation does not crop out west of the Mohaka Fault. Similarly, the Pohue Formation is juxtaposed against Te Waka Formation by the Rukumoana Fault at Te Pohue area.

The upper boundary is well-defined through central parts of the study area from the Waikare River southwest to the Tutaekuri River. In this area the top of the formation is marked by a sharp to erosional contact between sandstone of the Pohue Formation and the first greywacke conglomerate bed of the Matahorua Formation (e.g. Column Pt-9).

Pohue Formation conformably grades down-dip into the Taradale Mudstone.

Distribution and thickness

Pohue Formation is widespread through much of the central portions of the study area cropping out in an almost continuous, though southwestward-narrowing belt. Pohue Formation is highly variable in thickness throughout its outcrop extent. In northern areas (such as on the eastern flank of the Maungaharuru Range) lower parts are equivalent to the Te Waka Formation.

The Pohue Formation is at least 350 m thick in the Mangaone and Esk River catchments. The thickness is difficult to accurately determine as the western edge of the formation has been truncated by the Patoka and Rukumoana Faults. In the Waikoau River catchment Pohue Formation is 350 m thick. The formation thickens dramatically into the Waikare River catchment where it is 800 m thick (Graafhuis 2001).

Description

Pohue Formation comprises siliciclastic siltstone and sandstone beds with minor reworked shell lenses. In northern areas (such as the Waikare River section) Pohue Formation is dominated by siltstone (Graafhuis 2001). In the Esk and Mangaone River sections, the formation is characterised by alternating siltstone and sandstone beds, each many tens of metres thick (Bland 2001). The formation records the development of cyclothemic strata in the study area during the “middle to late” Pliocene.

Sandstone beds are blue-grey, weathering to tan, non cemented, massive to faintly laminated and cross-bedded, weathering to tan, non to sparsely fossiliferous, and well sorted. Occasional highly fossiliferous thin shellbeds may occur in upper parts of sandstone beds though these are largely restricted to an area between the Mangaone and Esk Rivers. These shellbeds are usually dominated by inner shelf to shoreface taxa such as *Zethalia coronata, Myadora stephaniae, Eumarcia plana* and *Fellaster zelandiae.* A fossiliferous sandstone interval in the Mangaone River contained *Limatula maoria, Divaricella huttoniana* and *Trachycardium rossi* interbedded with a shellhash matrix. Siltstone beds are typically blue-grey in colour, non cemented, slightly to moderately fossiliferous and well sorted. In outcrop these beds commonly have a frittered appearance. Occasional tephra beds may be present within the siltstone units as discrete layers up to 0.6 m thick (Bland 2001). More commonly tephric sediments have been incorporated into the surrounding siltstone. Fauna are dominated by genera typical of soft-bottom middle to outer shelf settings such as *Pratulum pulchellum,* with *Atrina pectinata zelandica, Maoricolpus roseus, Polinices waipipiensis, Ostrea chilensis* and *Talochlamys gemmulata.*

Upstream of the Berry Road ford in the Esk River (V20/377125), the Pohue Formation is comprised of sandstone facies with a variable concretion content. This concretionary interval may be a lateral equivalent of the Te Waka Formation cropping out to the southwest in the Te Waka Range, though lateral continuity cannot be demonstrated due to extensive coverage of landslide debris in the southern Maungaharuru Range.

The Pohue Formation becomes consistently finer-grained towards the northeast of the study area (Graafhuis 2001), and the base of the formation progressively becomes older in the same direction. The formation becomes finer-grained in a down-dip direction.

In the Mangaone and Esk River sections the uppermost sandstone bed of the Pohue Formation is well sorted, fine to medium-grained, blue-grey weathering to brown coloured and non cemented. In the Mangaone River the upper 8 m are laminated to trough cross-bedded. The sandstone may contain common thin shell and fine-grained conglomerate lenses up to 0.3 m thick in the upper 4 m (Column Pt-9). Occasional large spheroidal concretions up to 0.5 m across also occur in the upper beds. The sandstone interval is a minimum of 13 m thick in this section. The sandstone package is conformably underlain by blue-grey, non to highly fossiliferous massive siltstone. Fall blocks contain abundant *Atrina pectinata zelandica* and very abundant *Maoricolpus roseus* that are particularly large. The siltstone is approximately 50 m thick and conformably passes up-section into the overlying sandstone bed (Column Pt-10).

Paleontology and age

Pohue Formation is sparsely to moderately fossiliferous with only occasional, relatively thin, highly fossiliferous shellbeds present. No age-diagnostic pectinid fossils have been observed in the Pohue Formation south of the Waikare River catchment where Graafhuis (2001) reported the presence of *Mesopeplum (Borehamia) crawfordi* (age range of Upper Opoitian-Waipipian). *Atrina pectinata zelandica* is common throughout much of the formation, with *Talochlamys gemmulata* and *Maoricolpus roseus* also widespread. In some sandstone units highly fossiliferous shell horizons and lenses dominated by the shallow-water gastropod *Zethalia coronata* occur, frequently as part of moderate-scale trough cross-beds. *Polinices waipipiensis* is common in association with *Pratulum pulchellum*, *Maoricolpus* and *Atrina* fossils in siltstone facies.

The age of the Pohue Formation is diachronous through the study area. The presence of *P. waipipiensis* indicates an age not younger than Mangapanian or older than Waipipian for the Pohue Formation in the Esk and Mangaone catchments. In the Esk and Mangaone Rivers the Pohue Formation contains common highly fossiliferous beds of the Mangapanian-restricted gastropod *Zethalia coronata*. The presence of *Mesopeplum crawfordi* (Wo-Wp) in the Waikare River catchment (Graafhuis 2001, p.33) confirms that at least part of the formation is of Waipipian age, as the formation here overlies Waipipian-aged Titiokura Formation. The Pohue Formation is assigned a Lower Waipipian-Upper Mangapanian age in northern parts of the study area (the Waikare and Waikoau River catchments) (Graafhuis 2001). In the Te Pohue region Pohue Formation is middle to upper Mangapanian in age. In southernmost outcrop areas Pohue Formation is Upper Mangapanian in age.

Environment of deposition

The type of facies within the Pohue Formation suggest shelf water depths of accumulation. Macrofauna in sandstone facies lived on a shoreface, perhaps off slightly protected beaches, but are transported fauna when observed. Siltstone facies probably accumulated on a shelf at inner to outer shelf water depths. The character of the formation strongly indicates that the basin increased in subsidence toward the northeast of the study area (Waikare River catchment).

MATAHORUA FORMATION (mt)

(Cutten 1994; redefined by Bland 2001 and Graafhuis 2001)

Name and definition

Cutten (1994) introduced the name Matahorua Gravel Member (as part of the Maungaharuru Formation) in reference to a continuous greywacke conglomerate bed present near the Napier-

Wairoa road northwest of Lake Tutira. The name was derived from Matahorua Road, along which there are excellent exposures through one of the conglomerate beds. Both Bland (2001) and Graafhuis (2001) redefined Matahorua Formation to include a series of up to four greywacke conglomerate beds and associated sandstone and siltstone beds that crop out through central Hawke's Bay from Putorino to the Mangaone River. The definitions of Bland and Graafhuis are retained in this study though the distribution of the formation has been extended greatly south of the Esk River catchment and the geological map of Bland (2001). The Matahorua Formation is defined as the series of greywacke conglomerate beds, interspersed with sandstone and siltstone beds above the Pohue Formation, and below the first sandstone beds of the Waipunga Formation.

Type locality and reference sections

The type section designated by Bland (2001) in the Esk River has been retained in this study. This section is located in the Esk River from a point downstream of the confluence of Ohurakura Stream to the confluence with Deep Stream (V20/373097-380068). Excellent reference sections are present in the Mangaone River (V20/273018-289937) and Waikoau River (V20/417145-434142), although access can be difficult due to the incised nature of these water bodies. The conglomerates crop out in hills along the Napier-Taupo Road from near Te Whanau homestead (V20/299069) to Eland Station (V20/320231).

Lower and upper contacts

The base of the formation was defined by Bland (2001) and Graafhuis (2001) as the base of the siltstone bed forming the first conglomerate-capped "sequence" in the Esk-Waikoau and Waikare River catchments. This definition was a combination of lithostratigraphy and allostratigraphy. In practice this definition is very difficult to map in the field and the base of the Matahorua Formation is now redefined as the base of the first greywacke conglomerate bed overlying the Pohue Formation.

The Matahorua Formation Interdigitates with the Pohue Formation south of the Tutaekuri River. Interdigitation also occurs with the Pohue Formation and the Esk Formation northeast of the Waikoau and Waikare Rivers.

The Matahorua Formation interdigitates with the Waipunga Formation north of Kaiwaka Stream. South of Kaiwaka Stream (Esk River catchment) the Matahorua Formation is overlain conformably by the Esk Mudstone (Fig. 19D, F).

Distribution and thickness

Rocks of the Matahorua Formation are widespread through the study area and crop out from Willowflat Road in the north to the Tutaekuri River at Flag Range in the south. The distribution pattern of the formation reflects the shape of the depositional braidplain system of the formation. The Matahorua Formation is thickest in the Esk-Mangaone River catchments and thins along strike from this area.

Description

Matahorua Formation is one of the most distinctive units cropping out in the study area and forms marked dipslopes. While the Matahorua Formation is volumetrically made up mainly of sandstone and siltstone facies, it is the prominent greywacke conglomerate beds that distinguish this formation from other formations. Indeed, it is in this unit that the first major influx of greywacke gravels into the basin is recorded, presumably reflecting accelerated uplift along the axial ranges. The formation is characterised by the presence of four members, all of which are present in the Esk and Mangaone Rivers, although the extent of some members decrease to the north and south of this section Bland 2001; Graafhuis 2001).

Paleontology and age

While general sparsely to moderately fossiliferous, a wide range of faunas have been sampled from the Matahorua Formation. The pectinid *Phialopecten triphooki* has been sampled from several outcrops, as well as many specimens of *Mesopeplum convexum*. Many valves of these species exhibit growth ridges that may indicate that they grew in a stressful, high-energy environment. Based on the presence of *P. triphooki,* and rare *Towaipecten mariae* in the upper half of the Matahorua Formation, an uppermost Mangapanian to lowermost Nukumaruan age (Late Pliocene) is inferred for this formation. The presence of *Struthiolaria* n. sp. aff. *frazeri* in lower parts of the formation firmly suggests a Mangapanian age for these beds, while the occurrence of *Phialopecten triphooki* and *Towaipecten mariae* indicates a Lower Nukumaruan age for upper beds.

Environment of deposition

The conglomerate beds reflect the progradation of a fluvial braidplain into the basin during the lowstands of four sea-level cycles. The lowstand shorelines are not readily apparent in outcrop, and probably occur downdip in the subcrop.

Deep Stream Member (mta)

(Bland 2001; Graafhuis 2001)

Name and definition

Deep Stream Member (Fig. 19F) was introduced by Bland (2001) and Graafhuis (2001) in reference to the lowest conglomerate "cycle" of the Matahorua Formation in the Esk-Waikoau region. Deep Stream Member is named after Deep Stream, a small but deeply incised tributary of the Esk River immediately north of Trelinnoe Station, Te Pohue.

Type locality and reference sections

The type section is located in banks of the Esk River from V20/373097 to V20/372089. A reference section is nominated in the Mangaone River from V20/273018 to V20/286991.

Lower and upper contacts

In the Waikoau, Esk and Mangaone River catchments the Deep Stream Member sharply overlies the Pohue Formation (Fig. 19F). Northeast towards the Waikare River section Deep Stream Member interdigitates with the upper Pohue Formation. Southwest of the Mangaone River toward the Tutaekuri River, Deep Stream Member also interdigitates with the Pohue Formation. The sequence representing the Deep Stream Member can be identified in the Tutaekuri River section although the overlying greywacke conglomerate bed is not present.

For much of the outcrop area the Deep Stream Member is conformably overlain by the Trelinnoe Member (Fig. 20A). The member is in fault contact with the Pohue Formation in the Patoka area.

Distribution and thickness

Deep Stream Member is the most poorly exposed member of the Matahorua Formation. Most outcrops occur in a northeast-southwest trending belt between the Waikoau River and Patoka where its western extent is truncated by the Patoka Fault. Deep Stream Member has not been observed in, or south of, the Tutaekuri River.

Deep Stream Member is poorly developed in the Tutaekuri River section where the basal conglomerate bed is not present. The member is absent in the Ngaruroro River. In the Mangaone River the Deep Stream Member is a minimum of 72 m thick. Throughout the Esk River catchment Deep Stream Member is a maximum of 50 m thick (Bland 2001). In the Waikoau River the member is 45 m thick (Graafhuis 2001). Adjacent to Matahorua Road (V20/436168) the member is 50 m thick. The basal conglomerate bed of the Deep Stream Member does not crop out north

of this point. In the Waikare River the member is 45 m thick although the basal greywacke conglomerate bed is no longer present (Graafhuis 2001).

Description

The basal coarse-grained conglomerate facies of the Deep Stream Member mark the first major influx of greywacke gravels into the basin. Typically the member comprises a coarsening-upwards package of siltstone-sandstone facies overlying the basal greywacke conglomerate overlying the basal greywacke conglomerate that reflects continually falling sea level during sedimentation. In westernmost parts of the outcrop area the siltstone facies are much reduced and at times may be non-existent, this interval instead being represented by non cemented fine to medium sandstone. Lower parts of the member comprise siltstone to fine to medium sandstone depending on the position of the outcrop.

Deep Stream Member is most clearly exposed in the Mangaone, Esk and Waikoau River sections. Exposures in the Mangaone River section occur upstream of the confluence with Patoka Stream. The 7 m-thick conglomerate bed in this section overlies non cemented sandstone through a sharp, erosional contact with decimetre-scale relief (Column Pt-9). Basal parts of the conglomerate contain prominent mudstone and sandstone rip-up clasts. Clasts are sub to well rounded, up to 8 cm across and average 3 cm across. The unit as a whole is poorly- to moderately well sorted with common sandstone lenses. The conglomerate is sharply overlain by non cemented siltstone of the Trelinnoe Member. The member is poorly exposed through the Te Pohue region. Only the uppermost 3 m of the sandstone interval and the 4 m-thick capping conglomerate are exposed on State Highway 5 (V20/298068). Exposures in the Esk River are located downstream of the confluence with the Ohurakura Stream.Siltstone and sandstone facies vary little in the member through the study area. Siltstone facies are approximately 3.5 m thick on State Highway 5. In proximity to the basal greywacke conglomerate bed of the overlying Trelinnoe Member, the sandstone bed at the top of the Deep Stream Member may contain common greywacke conglomerate lenses and pebble beds, with common, scattered pebbles.

Paleontology and age

The Deep Stream Member contains a sparse to moderately diverse macrofauna. Highly fossiliferous shell lenses are exposed in cuttings beside State Highway 5 and are dominated by shallow-water open-ocean bivalves such as *Eumarcia* and *Paphies subtriangulata*. These lenses are interpreted as event-concentrated shellbeds. The member contains the Mangapanian-restricted gastropod *Struthiolaria* n. sp. aff. *frazeri* ancestral to *S. frazeri* (A. Beu GNS Science

pers. comm. 2003). Based on stratigraphic position the Deep Stream Member is confidently assigned an Upper Mangapanian age (Late Pliocene, c. 2.48 Ma).

Environment of deposition

The Deep Stream Member was deposited in a variety of shelfal to marginal-marine and non-marine settings. Conglomerate facies were deposited as part of fluvial braidplains and shingle beaches. Siltstone and sandy siltstone facies are consistent with inner to outer shelf depositional environments. Sandstone facies are inferred to represent beach and nearshore environments.

Trelinnoe Member (mtb)

(Bland 2001; Graafhuis 2001)

Name and definition

Cutten (1994) established the Matahorua Gravel Member as part of the Maungaharuru Formation. Bland (2001) and Graafhuis (2001) redefined this member as one of four conglomerate beds cropping out widely through the Esk and Waikoau areas. The name Matahorua Gravel Member was elevated to formation status to encompass these gravel beds, and a new name introduced to encompass Cutten's original definition. Trelinnoe Member (Fig. 19F) was established by Bland (2001) and Graafhuis (2001) to account for the second oldest greywacke conglomerate bed and overlying siltstone and sandstone facies in the Matahorua Formation. The conglomerate bed at the base of the Trelinnoe Member is equivalent to the Matahorua Gravel Member of Cutten (1994). The Trelinnoe Member is sharply overlain by the basal conglomerate of the Papakiri Member. The unit is named after Trelinnoe Station and arboretum near Te Pohue where the member forms conspicuous bluffs and hilltops.

Type locality and reference sections

The type locality is located in the Esk River from V20/372089 to V20/371084.

A reference section is nominated beside Matahorua Road where Cutten (1994) had his type section for the Matahorua Conglomerate Member (V19/490216).

Lower and upper contacts

The Trelinnoe Member sharply overlies the Deep Stream Member. This contact is exposed in the Esk River (V20/372089), beside Matahorua Road (V19/490216; Fig. 20A), and beside the Napier-Taupo Road (V20/299066).

The Trelinnoe Member is sharply overlain by the Papakiri Member. This contact is exposed in the Esk River (V20/371084), near Huiarangi Road (Fig. 20F; V20/256004, Column Pt-5) and beside the Napier-Taupo Road at Glengarry Hill (V20/371084, Column Gg-1).

Distribution and thickness

Trelinnoe Member crops out in a nearly continuous northeast-southwest trending belt from Putorino to Patoka. In southern regions the western extent of the member is truncated by the Patoka Fault. Trelinnoe Member is best exposed between the Esk and Mangaone Rivers catchments, especially in the Glengarry Forest region. The basal greywacke conglomerate bed of the Trelinnoe Member is not developed in the Tutaekuri River and the member is not present in the Ngaruroro River. Near Patoka and Waihau Road the member is a minimum of 50 m thick, 60 m thick in the Mangaone River, 20-40 m thick around Te Pohue, 50-60 m thick in the Esk River, 70 m thick in the Waikoau River and 45 m thick in the Waikare River.

Description

Trelinnoe Member comprises a package of greywacke conglomerate, siliciclastic siltstone and sandstone of variable thickness. The member is usually dominated by sandstone lithologies, although siltstone units are thick and prominent (>60 m) in many, particularly in southern and eastern, outcrops. The general character of siltstone and sandstone facies of the member change little through the study area. Siltstone units comprise non cemented, non to slightly fossiliferous blue-grey weathering to brown-grey fine-grained facies that coarsen up-section through silty sandstone beds into overlying sandstone. The lower siltstone interval is thinnest in more westerly (shoreward) exposures. The basal 0.5 m of the siltstone interval is commonly marked by a pebbly siltstone comprising abundant to common well sorted and well rounded greywacke clasts of granule to fine pebble size that rapidly decrease in volume up section. This pebbly zone is interpreted to represent reworking of the underlying Trelinnoe Member conglomerate bed during sea level transgression. The siltstone interval is approximately 45 m thick in Glengarry Forest, over 50 m thick near Huiarangi Road, and over 20 m thick on Cascade Farm (V20/204966).

The transition from siltstone to sandstone-dominated intervals is typically marked by a zone of alternating siltstone-sandstone beds. Sandstone facies consist of well sorted, non cemented clean, non to moderately fossiliferous fine to medium sandstone. Colour is blue-grey when fresh, but more typically light brown. The sandstone interval is a maximum of 5 m thick on State Highway 5, and 25 m thick on Trelinnoe Station (Bland 2001). In in both Deep Stream and the Esk River the lower siltstone interval is not present and is instead represented by fine to medium sandstone. In Deep Stream the sandstone interval is nearly 40 m thick, and in the Esk River is approximately

30 m thick (Bland 2001). This is interpreted to represent a more shoreward depositional setting than sections containing this lower siltstone (e.g. Glengarry Forest).

Greywacke conglomerate lenses, pebble stringers and scattered pebbles are all common in upper parts of the sandstone interval near the contact with the overlying conglomerate bed. Conglomerate and pebble lenses are typically up to 0.5 m thick, well sorted and dominated by greywacke clasts. Such lenses and bodies are normally contained within 4 m of the base of the main conglomerate bed of the member. The Trelinnoe Member is similar in character to other members of the Matahorua Formation typically comprising a lower siltstone interval which is conformably and gradationally overlain by a sandstone unit.

Sandstone facies of the Trelinnoe Member become less fossiliferous from the Esk River towards the Waikoau and Waikare catchments (Graafhuis 2001).

Paleontology and age

Fauna in siltstone facies are typical of soft-bottom Pliocene rocks through Hawke's Bay. Siltstone facies commonly contain *Pratulum pulchellum, Talochlamys gemmulata, Atrina pectinata zelandica* and *Maoricolpus roseus.* The first occurrence of the Lower Nukumaruan index scallop *Phialopecten triphooki* in the overlying Papakiri Member helps confirm an uppermost Mangapanian age for the Trelinnoe Member (Late Pliocene, approx. 2.44 Ma).

Environment of deposition

Fauna in siltstone facies are consistent with deposition in middle to outer shelf water depths. Sandstone facies were typically deposited in inner shelf to shoreface water depths. Conglomerate facies are inferred to largely be products of deposition at the shoreward-end of a braided river system. Conglomerate lenses and stringers in upper parts of the member are inferred to reflect sea level fall and the migration of gravel deposits further basinward during storm events.

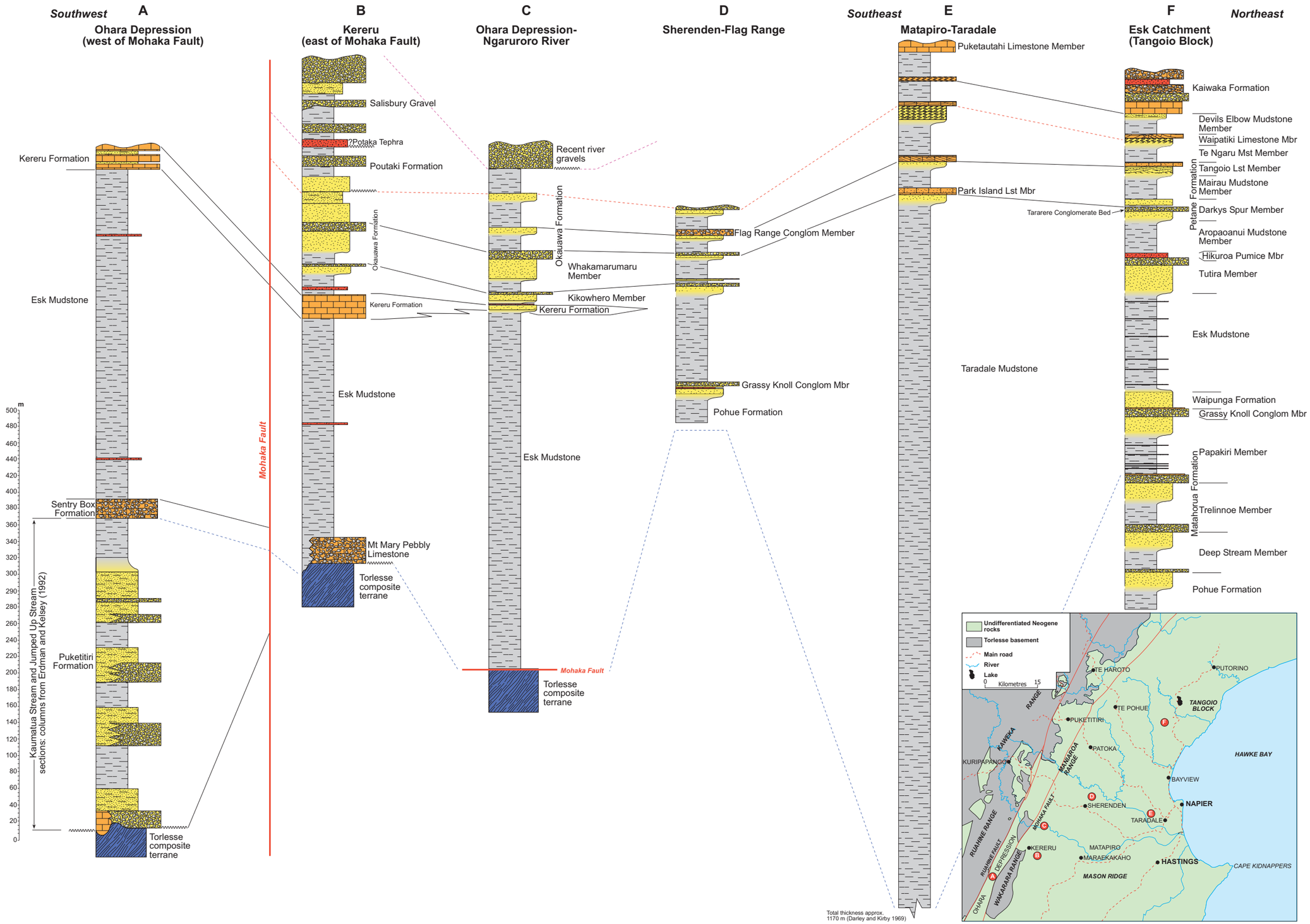


Fig. 19: Schematic stratigraphic columns illustrating the Nukumaruan stratigraphy from the Esk River catchment in the northeast to the Ohara Depression in the southwest..

Papakiri Member (mtc)

(Bland 2001; Graafhuis 2001)

Name and definition

Papakiri Member (Fig. 19F) is named after Papakiri Stream, a small stream that flows into the northern end of Lake Tutira. It sharply overlies the Trelinnoe Member, and is sharply overlain by the Grassy Knoll Conglomerate Member

Type locality and reference sections

The type section designated by Bland (2001) is retained. This section is located in the Esk River between V20/371084 (Column Tp-4) and V20/378067 (Column Tp-7). A reference section is designated at Glengarry Hill beside the Napier-Taupo Road (V20312037-V20/309036) (Column Gg-1).

Lower and upper contacts

The base of the Papakiri Member almost always corresponds to the base of a greywacke conglomerate, except in places (such as the Tutaekuri River) where a basal conglomerate is not developed. The lower contact of the Papakiri Member is exposed in several localities. At Glengarry Hill (V20/309036) coarse-grained greywacke conglomerate of the Papakiri Member sharply overlies interbedded sandstone and conglomerate of the Trelinnoe Member (Fig. 20F). At Huiarangi Road (V20/260002) near Patoka, marginal-marine sandy siltstone, rich in plant fossils, of the Trelinnoe Member is sharply overlain by conglomerate of the Papakiri Member (Column Pt-4).

The upper contact has been observed in numerous outcrops through the study area with pebbly and fossiliferous sandstone of the Papakiri Member sharply overlain by greywacke conglomerate of the Grassy Knoll Conglomerate Member. The contact is exposed in the Esk River (V20/ 378067, Column Tp-7), Kaiwaka Stream (V20/364052), the Mangaone River (V20/292951), and on the northeastern face of The Dome at Patoka (V20/265000).

Distribution and thickness

Papakiri Member crops out prominently in a northeast-southwest trending belt from the Waikare River in the north, through the Waikoau, Te Pohue and Patoka districts to the Waihau and Tutaekuri River area. Papakiri Member is well exposed in the Waikoau, Esk and Mangaone Rivers. The Papakiri Member cannot be differentiated in the Tutaekuri River from other parts of the Matahorua Formation.

At Matahorua Road the basal conglomerate bed is approximately 8 m thick (Graafhuis 2001), 3.5 m thick in the Waikoau River, 4 m thick in the Esk River, at least 4 m thick in Deep Stream (Column Tp-5), a maximum of 10 m thick on Trelinnoe Station, thickening dramatically to over 20 m in the Mangaone River (Fig. 20C; V20/30096, Column Gg-5), and 6 m at Huiarangi Road (Fig. 20E; Column Pt-4).

In the Tutaekuri River section the Papakiri Member is about 40-50 m thick. In the Patoka area the member is a minimum of 50 m thick. In the region of State Highway 5 the Papakiri Member is approximately 15 m thick, and at Glengarry Hill up to 60 m thick. The member thickens into the Esk River (80 m), thins to 25 m thick in the Waikoau River, and thins further northeast into the Waikare River where it is 12 m thick (Bland 2001; Graafhuis 2001). It is only a few metres thick where last observed in outcrop around the Willowflat Road area.

Description

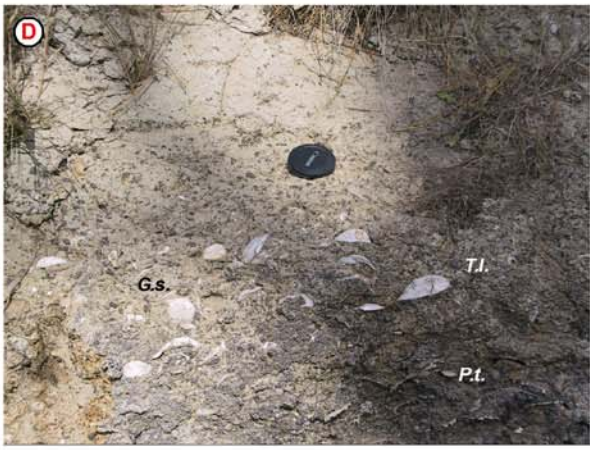
Papakiri Member typically comprises a basal conglomerate overlain by siltstone and sandstone. The greywacke conglomerate is dominated by non fossiliferous units, although moderately to highly fossiliferous beds are common (although typically thin (<1 m thick)). Clasts in the conglomerate are almost exclusively greywacke, with rare to minor contributions from Late Neogene sandstone and siltstone. Clasts in the conglomerate are poorly to very well sorted and average 3 cm across, although sizes vary between coarse sand and cobble. Clast shapes are sub to well rounded and include all of spheroidal, lensoidal and oblate types with spheroidal and oblate pebbles dominating. Sandstone lenses are common in lower parts of the conglomerate bed and are inferred to reflect dune migration in river channels. These beds are generally up to 0.3 m thick and may be continuous for up to several metres. Internal planar lamination and trough cross-stratification is common in sandstone bodies. Siltstone lenses and stringers, while present, are generally less common and thinner than sandstone beds. In the Waikoau River (V20/429144) a 10 cm thick lignite bed caps the conglomerate and is in turn overlain by marine mudstone (Graafhuis 2001).

Fig. 20 (facing page): Deep Stream, Trelinnoe, and Papakiri Members. **A)** Reference section of the Trelinnoe Member in an old quarry beside Matahorua Road (V19/490216). Location of the contact between the Trelinnoe Member and underlying Trelinnoe Deep Stream Member is highlighted. **B)** Tephra beds (dark bands) in middle to outer shelf siltstone facies of the Papakiri Member. Kaiwaka Stream, Trelinnoe Station (V20/347058). **C)** Thick (over 15 m) conglomerate bed at the base of the Papakiri Member, Mangaone River (V20/300963). **D)** Shellbed overlying non-marine conglomerate facies, Papakiri Member. This shellbed contains the first occurrence of *Phialopecten triphooki* and is therefore assigned a basal Nukumaruan age. *G.s.* is *Glycymeris shrimptoni, T.l.* is *Tucetona laticostata*. Huiarangi Road, Patoka (V20/260000). **E)** Conglomerate facies at the base of the Papakiri Member forming a prominent high bluff above Huiarangi Road, Patoka (V20/256004). **F)** Close-up view of the basal contact of the Papakiri Member where it sharply overlies shallow-water sandstone facies of the Trelinnoe Member. Note how the coarser clasts are concentrated into the bottom of a hollow in the underlying sandstone (V20/256004).


A
Trelinnoe Member
Deep Stream Member


B


C


D
G.s.
T.l.
P.t.


E


F
Papakiri Member
Trelinnoe Member

Fossiliferous zones in upper parts of the conglomerate bed mark a return to marine sedimentation under a regime of rising sea level (Fig. 20D). The thickest pebbly shellbed development occurs in southern and eastern exposures of the Papakiri Member, such as at Glengarry Hill and Huiarangi Road (Fig. 20D). Fauna are typically dominated by robust, thick-shelled semi-infaunal bivalves such as *Glycymeris shrimptoni* and *Tucetona laticostata,* with common epifauna such as *Ostrea chilensis* and *Phialopecten triphooki.*

Gastropods tend to be minor in number. The upper conglomerate bed is moderately to highly fossiliferous in Deep Stream and the Esk River. Upper parts of the conglomerate are moderately to highly fossiliferous at Glengarry Hill, Glengarry Forest and in Kaiwaka Stream. Sandstone facies are typically non fossiliferous and massive to weakly laminated and cross-bedded (tabular and trough bed forms dominate).

The Papakiri Member contains the first interval of prominent airfall tephra beds observed in the study area (Fig. 20B). These beds are well exposed in the Esk River and Deep Stream. While tephric detritus is present in underlying formations, it is generally present as reworked sediments and not the intact sharp-based bodies 5-50 cm thick with common burrows that are abundant in the Grassy Knoll Conglomerate Member. The tephra beds occur in the lower siltstone bed of the member which itself tends to be thicker than those in the underlying members. Excellent exposures of the siltstone interval with tephra beds occur in the Esk River upstream of the Deep Stream confluence and in Kaiwaka Stream on Trelinnoe Station below the farm bridge (Fig. 20B). The siltstone interval passes conformably up-section into the sandstone interval.

Sandstone facies are generally massive and consist of well sorted, clean, non cemented, non fossiliferous, fine to medium facies. The sandstone interval gradationally overlies the siltstone interval, usually through a series of alternating siltstone-sandstone beds. Upper parts of the sandstone interval are commonly pebbly with scattered grains and pebble lenses. The pebbly sandstone interval is largely non fossiliferous although tightly packed shellbeds are common in the Esk River. The sharp transition from pebbly sandstone to the overlying Grassy Knoll Conglomerate Member is well exposed in the Esk River, Kaiwaka Stream, and several locations on the north side of The Dome, Patoka (e.g. V20/265000).

Paleontology and age

Although it is mostly sparsely fossiliferous, the Papakiri Member often contains a diverse molluscan fauna with excellent fossil-rich beds present in Deep Stream, the Esk River, Glengarry Hill, and in Glengarry Forest.

The observation of the first occurrence of *Phialopecten triphooki* (Lower Nukumaruan-restricted) in lowermost beds of the Papakiri Member in the Esk River catchment (Bland 2001) provides a correlation tool for use away from this area (V20/371084, Column Tp-4). Specimens of *P. triphooki* have been collected in many localities in the study area, with excellent well preserved valves being observed in Deep Stream (V20/361073, Column Tp-5), Glengarry Forest (V20/ 293023), Glengarry Hill (V20/309038, Column Gg-1), and at the Huiarangi Road gravel pit near Patoka (Fig. 20D; V20/259002, Column Pt-4). The member is coeval with parts of the Scinde Island Formation at Napier, the lower limestone bed at Mason Ridge southwest of Hastings (Dyer, 2004), Pakipaki Limestone south of Hastings and Sentry Box Formation in the Ohara depression/ Whanawhana/Kuripapango regions. *Phialopecten* valves typically occur with other robust, thick-shelled and often semi-infaunal bivalves such as *Glycymeris shrimptoni, Tucetona laticostata, Purpurocardia purpurata* and *Ostrea chilensis. Mesopeplum convexum* has also been collected from a few sites such as the Huiarangi Road gravel pit (see Appendix V for locality fossil lists). Such faunal assemblages indicate deposition in high-energy, current swept environments such as tidal channels, entrances to harbours and current-swept embayments.

Upper parts of the conglomerate bed frequently contain estuarine-restricted taxa such as *Austrovenus stutchburyi*, reflecting more shoreward, estuarine, depositional settings. Siltstone facies commonly contain clusters of the thin-shelled bivalves *Pratulum pulchellum*, generally an indicator of middle to outer shelf water depths in the study area.

The underlying Trelinnoe Member was assigned a Mangapanian age by Cutten (1994) and Beu (1995; pers. comm. 2003) on the basis of the occurrence of the Mangapanian-restricted gastropod as *Struthiolaria* n. sp. aff. *frazeri*. The first occurrence of *Phialopecten triphooki* in the study area occurs in the pebbly shellbed near the base of the Papakiri Member. On this basis this shellbed is likely to be of basal Nukumaruan age (2.4 Ma; Beu *et al.* 2004) and is perhaps coeval with the Hautawa Shellbed in Wanganui Basin (McIntyre 2002).

Environment of deposition

Conglomerate facies accumulated in non-marine to shoreface environments as part of a fluvial braid-plain system that developed in response to sea level fall and the consequent drop in base level. Fossiliferous conglomerate beds reflect drowning of a non-marine fan-delta system caused by a glacio-eustatically-driven rise in sea level. Sandstone facies were generally deposited in inner shelf to shoreface environments, typically during periods of falling sea level. They are inferred to represent the regressive systems tract and mark a period of falling sea level and basinward progradation of the sedimentary system. Pebbly sandstone in upper parts of the

member marks the influence of falling sea level and the progradation of a fan-delta system. Siltstone facies accumulated in shelfal environments, probably at inner to middle shelf depths.

Grassy Knoll Conglomerate Member (mtd)

(Bland 2001; Graafhuis 2001)

Name and definition

Grassy Knoll Conglomerate Member derives its name from the prominent greywacke conglomerate-capped hill on Trelinnoe Station (V20/339052) locally known as the Grassy Knoll (Fig. 21A). The unit was established by Bland (2001) and Graafhuis (2001) to account for the youngest of the four major greywacke conglomerate beds of the Matahorua Formation (Fig. 19F). The definition of Bland (2001) and Graafhuis (2001) is emended in this study. The name Grassy Knoll Conglomerate Member is restricted to the stratigraphically highest greywacke conglomerate bed of the Matahorua Formation.

Grassy Knoll Conglomerate Member sharply overlies the Papakiri Member and underlies either the Waipunga Formation or Esk Mudstone (Fig. 21D). Siltstone and sandstone beds underlying this conglomerate were included in the Grassy Knoll Member by Bland (2001) and Graafhuis (2001). These beds are now included in the Papakiri Member.

Type locality and reference sections

The type section designated by Bland (2001) in the Esk River downstream of the Deep Stream confluence is retained in this study (V20/378067, Column Tp-7). An excellent reference section is present exposing the entire member in the Tutaekuri River from the confluence of the Waikonini Stream (V21/220885, Column Sh-5) to a point several hundred metres upstream (V21/203877, Column Sh-4). Both lower and upper contacts are exposed in a reference section in the Mangaone River (V20/297956-289937) (Fig. 21B).

Distribution and thickness

Grassy Knoll Conglomerate Member is one of the most widespread members of the Matahorua Formation through northern and central parts of the study area. Grassy Knoll Conglomerate Member crops out prominently from the Waikoau to Tutaekuri River catchments in a broadly northeast-southwest belt. To the north of the Waikoau River the unit thins and becomes less prominent, and by the Waikare River the member cannot be differentiated from finer-grained sediments of the Waipunga Formation. To the southwest, the member passes into fine-grained

siltstone facies of the Taradale Formation. The extent of the member is truncated by the Mohaka Fault Zone southwest of the Tutaekuri River and the Napier-Taihape Road.

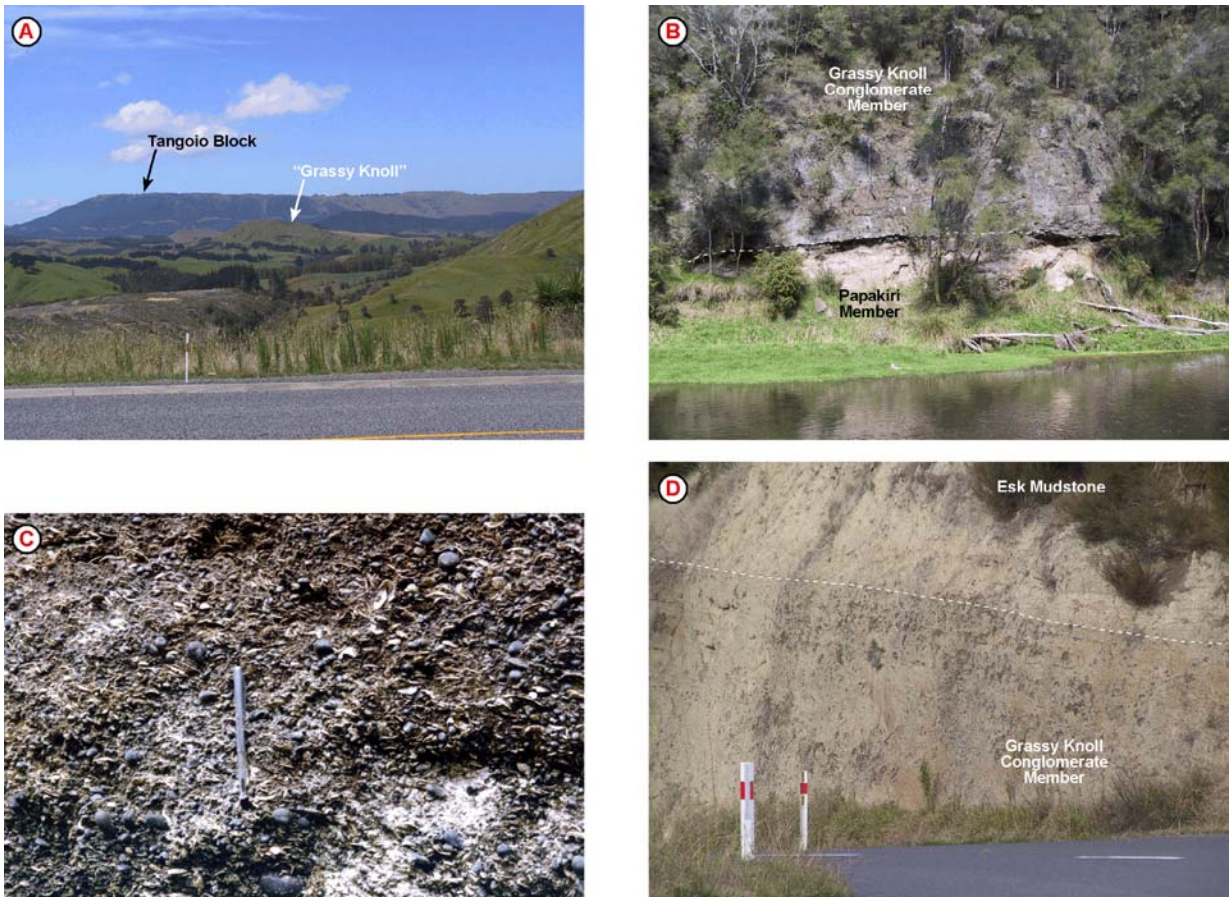


Fig. 21: Grassy Knoll Conglomerate Member. **A)** Landscape photograph of "Grassy Knoll**"** hill from State Highway 5 at Glengarry Hill (V20/309038). **B)** Grassy Knoll Conglomerate Member sharply overlying shallow-water sandstone facies of the Papakiri Member in the Mangaone River. The contact is highlighted by the white dashed line. V20/292951. **C)** Highly fossiliferous Grassy Knoll Conglomerate Member cropping out in the lower reaches of Kaiwaka Stream, Trelinnoe Station (V20/365052). Several small specimens of *Phialopecten triphooki* have been collected from this outcrop, helping to confirm a Lower Nukumaruan age for the member. **D)** Grassy Knoll Conglomerate Member conformably overlain by Esk Mudstone beside Puketitiri Road near Trigham Farm (V20/258955).

Grassy Knoll Conglomerate Member is the thinnest member of the Matahorua Formation as it comprises only a greywacke conglomerate interval. The member is 9 m thick in the Waikoau River (Graafhuis 2001), at least 4.5 m thick in the Esk River (V20/378068, Column Tp-7), 5 m thick in the Mangaone River (V20/292951; Fig. 21B), at least 2.5 m thick at The Dome, Patoka (V20/ 265000), over 10 m thick along Waihau Road (V20/193905), and 11 m thick in the Tutaekuri River and Flag Range region (V21/220885, Columns Sh-4, Sh-5).

Description

Grassy Knoll Conglomerate Member comprises greywacke conglomerate beds that vary in thickness across the study area.

The Grassy Knoll Conglomerate Member is highly fossiliferous in outcrops through the Esk River and Deep Stream areas, and largely non fossiliferous through the rest of the study area. Upper parts of the conglomerate in these other areas may be capped by thin slightly to moderately fossiliferous shellbeds rich in estuarine fauna such as *Austrovenus*. Lower parts of the conglomerate are generally coarser-grained and less sorted than upper parts. Bedding also tends to be cruder and more massive in lower parts relative to upper parts. In some places sandstone and mudstone clasts, assumed to be sourced from the underlying Papakiri Member, are incorporated into basal parts of the Grassy Knoll Conglomerate Member. Upper intervals of the conglomerate are characterised by alternating very well sorted beds of granule/fine pebble greywacke clasts.

Prominent fossiliferous conglomerate to pebbly shellbeds crop out on Waihau Road and are assigned to the Grassy Knoll Conglomerate Member. Fauna are dominated by *Ostrea* with *Purpurocardia purpurata, Lutraria solida* and glycymerid bivalves.

Paleontology and age

Grassy Knoll Conglomerate Member contains a rich molluscan fauna. The fauna of the member are dominated by species that are inferred to have lived in shallow-water, high-energy environments, and had to be robust enough to survive among greywacke pebbles and cobbles. Thick-shelled bivalves such as *Glycymeris shrimptoni* and *Ostrea chilensis* are common constituents of many conglomerate beds. The presence of *Paphies australis, Paphies subtriangulata* and *Fellaster zelandiae* indicate a shallow-water environment perhaps open to oceanic waters.

The member is almost always capped by a thin (<0.5 m thick) very pebbly shellbed rich in estuarine to shallow-marine bivalves such as *Austrovenus* (cockle)*, Tawera, Glycymeris* and *Ostrea.* In the Esk River and Deep Stream the conglomerate conspicuously contains common to abundant pectinids of which *Phialopecten triphooki* and *Mesopeplum convexum* are the dominant species. The conglomerate in the Esk River sharply overlies highly fossiliferous, very well sorted sandstone (Papakiri Member) rich in very shallow-water taxa such as *Paphies, Fellaster* and *Zethalia zelandica.* Pectinids are much rarer in Kaiwaka Stream, although the conglomerate here is still highly fossiliferous and sharply overlies well sorted, non fossiliferous sandstone to slightly pebbly sandstone. Fauna here are typical of shallow-water, high-energy environments and include *Paphies australis* ("Pipi") (Fig. 21C)*, Glycymeris shrimptoni* and uncommon *Phialopecten triphooki.* A 0.7 m-thick pebbly shellbed capping the conglomerate on Trigham Farm (V20/ 251941) comprises two distinct beds. The lower bed is dominated by characteristic estuarine taxa

such as *Xenostrobus huttoni* and *Barytellina crassidens.* The upper bed comprises fauna more typical of open-marine conditions such as *Tawera subsulcata* and *Ostrea chilensis.* This suggests flooding of a non-marine river system by sea level rise and the progression through marginal-marine to open-marine environments through time.

In many outcrops, particularly through the Esk-Glengarry regions (e.g. V20/251941, V20/301992), the upper portion of the conglomerate bed contains a fauna rich in the estuarine bivalve *Austrovenus stutchburyi*. At V20/289927 this same upper shellbed contains common *Paphies australis* and *Purpurocardia purpurata*.

The pectinid *Phialopecten triphooki* has been collected from numerous outcrops of the Grassy Knoll Conglomerate Member through the study area. Small juvenile pectinid specimens from Kaiwaka Stream (V20/364052), a tributary of the Esk River, exhibit characteristics of both *P. triphooki* and its immediate ancestor *P. thomsoni.* Mature specimens of *P. triphooki* have been collected from Eland Station (V20/324033), from fall blocks in Deep Stream near the Esk River confluence (V20/373070), as well as from highly fossiliferous conglomerate exposures in the Esk River itself (V20/378067, Column Tp-7). A single valve of *Towaipecten mariae* was also collected from Deep Stream. Like the underlying Papakiri Member, *Phialopecten* valves in this member are always found with other robust, thick-shelled bivalves such as *Tucetona laticostata* and *Glycymeris shrimptoni*. Other shallow-water bivalves such as *Paphies australis* are common in the capping shellbed. Many of the *P. triphooki* specimens from the Esk River exposures display prominent growth ridges, as do the majority of *Mesopeplum convexum* valves collected from the same outcrops. The appearance of such features is indicative of a high-energy stressful environment, where the scallops have regrown old shell injuries (A. Hendy Univ. Cincinnati pers. comm. 2001; cf. Beu 1995, p. 142).

Based on the presence of *Phialopecten triphooki* and *Towaipecten mariae,* a Lower Nukumaruan age is assigned to the Grassy Knoll Conglomerate Member. The occurrence of *Phialopecten triphooki* and *Zygochlamys patagonica delicatula* in limestones of the Pakipaki and Sentry Box Formations mean that these units are likely to be lateral equivalents. The Grassy Knoll Conglomerate Member is probably also a lateral equivalent of the Torran Limestone Member (Mason Ridge Formation), and middle parts of the Scinde Island Formation (perhaps Member C; see below).

Environment of deposition

Grassy Knoll Conglomerate Member was mostly deposited in a non-marine environment as part of a fluvial braid-plain system. Down-dip exposures of the member record marginal-marine to shoreface environments. Estuaries and embayments in the coastline during deposition were common, and best developed in the Te Pohue-Patoka area where the member is at its greatest extent. The well sorted and laminated conglomerate beds in the Grassy Knoll Member are interpreted as representing shingle beach deposits. The depositional environment for the Grassy Knoll Member may have resembled the current Napier coast in the vicinity of Ahuriri Lagoon, with nearby braided rivers occurring in association with estuaries and gravel beaches.

SCINDE ISLAND FORMATION (si)

(Hector 1877; McKay 1877a)

Name and definition

The name Napier Limestone was originally used by early geologists such as Buchanan (1870) and McKay (in reports before 1877) in relation to the limestone forming the hill on which the original city of Napier was built (Beu 1995). Hector and McKay adopted the name Scinde Island Limestone in 1877, and it is this name that has been subsequently used by geologists (e.g. Hill 1887; Kingma 1971; Beu *et al.* 1980; Boyle 1987; Kamp *et al.* 1988). Now known as Bluff Hill and Hospital Hill, Scinde Island ceased being an island after the 1931 Napier earthquake. Boyle (1987) introduced the term Scinde Island Formation, although it was emended by Beu (1995) to Scinde Island Limestone.

Boyle (1987) referred to all beds at Scinde Island, except for a thin capping layer of Pleistocene siltstone, as the Scinde Island Formation. Kingma (1971) had previously subdivided the strata at Scinde Island into three informal "formations" and mapped them through the Te Aute subdivision. Geological mapping in this study has demonstrated that beds cropping out at Scinde Island are restricted to that area and a small surrounding region in the subsurface only. This study has also demonstrated that beds Kingma (1971) correlated with rocks at Scinde Island are significantly younger. For these reasons Kingma's lithostratigraphic nomenclature for this part of the succession is not continued. Boyle argued that although beds at Scinde Island could be subdivided into mappable intervals their limited geographic distribution meant that having them as individual formations was inappropriate. She therefore established one formation and named five individual members within that formation. The definition of Boyle (1987) is retained in this study. Beu (1995) restricted the name Scinde Island Limestone to only the lowest limestone-dominated package exposed at Scinde Island (and it's assumed lateral correlatives elsewhere in the study

area). This corresponded to Kingma's "lower Scinde Island limestone" and Boyle's "Member A". The remainder of the beds exposed at Scinde Island remained unnamed and undescribed in the descriptions of Beu (1995). Geological mapping in this study has demonstrated that beds cropping out at Scinde Island are restricted to the immediate Scinde Island and Onekawa region at Napier and rapidly pass laterally into mudstone facies of the Taradale Formation. As with Kingma's (1971) stratigraphy for the Scinde Island Formation, that proposed by Beu (1995) is also discontinued. The term "Formation" is maintained over "Limestone" in the name of the Scinde Island Formation to reflect the diverse lithologies present in the unit.

Type locality and reference sections

The type section designated by Beu (1995) is retained in this study. This section was described by Boyle (1987) and Kamp *et al.* (1988). Caron (2002) described in detail a section above a car yard at Scinde Island which is nominated as a reference section.

Lower and upper contacts

Scinde Island Formation is sporadically overlain by Pleistocene silts and clays on Scinde Island (Boyle 1987). The lower contact of the Scinde Island Formation is not exposed.

Distribution and thickness

Scinde Island Formation is restricted in outcrop to Scinde Island itself at Napier city (Hospital and Bluff Hills). This locality corresponds with a structural high associated with the sub-surface Napier Fault. The presence of this fault (and the associated anticline) led to the drilling of hydrocarbon exploration hole Hukarere-1 by Westech Energy New Zealand Ltd in 2000 (Westech Energy New Zealand Ltd 2001, PR 2656).

Scinde Island Formation was intercepted in a drillhole sited at Onekawa and extends its distribution slightly to the west from Scinde Island. Scinde Island Formation is inferred to rapidly pass into mudstone facies of the Taradale Mudstone in all directions away from Scinde Island and Onekawa. Scinde Island Formation was not intercepted in the Taradale-1 drillhole where, Rather than limestone, mudstone with an outer shelf environment of deposition was intercepted (Darley and Kirby 1969). Scinde Island Formation was not intercepted in Hukarere-1 drillhole, probably because Kelly Bushing was below the base of the formation.

Correlations have been made in the past between Scinde Island Formation and limestone cropping out at Park Island (e.g. Kingma 1971). Geological mapping in this study has clearly

demonstrated that these units are not correlatives, and that Park Island Limestone Member (Petane Formation) is significantly younger than beds at Scinde Island.

Description

The subdivision of the Scinde Island Formation into five members by Boyle (1987) has been retained in this study. The character of each member is presented below based on Boyle (1987).

Paleontology and age

The type locality for the Lower Nukumaruan pectinid *Phialopecten triphooki* (Zittel) is located low in Scinde Island Formation at Napier (Beu 1995). Near the base, the formation has yielded reliable planktic foraminiferal ages at two localities. The diagnostic Lower Nukumaruan zonal species *Truncorotalia crassula* and dextral *Truncorotalia crassiformis* have been identified from both of these sample sites (Hornibrook 1981, p. 282; Beu 1995). Together with the presence of *Pelicaria convexa*, Beu (1995) suggests that this biostratigraphy provides a highly reliable Lower Nukumaruan age independent of *Phialopecten*, and allows for the occurrence of *P. triphooki* in a Lower Nukumaruan, post-Mangapanian zone to be relied on as a correlation tool away from Napier.

Samples from Scinde Island Formation intercepted by a New Zealand Geological Survey drillhole at Onekawa (V21/436815) contained *Truncorotalia truncatulinoides, T. crassiformis* (dextral), *T. crassula* (dextral), and *Globoconella punticulionoides* (Hornibrook 1981, p. 282; A. Beu GNS Science, pers. comm. 1986, cited in Boyle 1987 p.45). This assemblage is similar to that reported from Scinde Island itself by Beu (1995).

Scinde Island Formation is in part a lateral equivalent of the upper Matahorua Formation (top of Papakiri Member and Grassy Knoll Conglomerate Member) based on the first occurrence of *Phialopecten triphooki* in the Papakiri Member. Scinde Island Formation is also a lateral equivalent (at least in part) of the Mason Ridge Formation, and Sentry Box Formation.

Environment of deposition

Scinde Island Formation possibly developed on a growing anticlinal high during the Lower Nukumaruan. This was during a time when large braided river systems were actively supplying significant quantities of sediment to a proto-Hawke Bay (Bland 2001). The effect of the structural high was to keep carbonate factories above and away from the major supplies of siliciclastic sediment in the basin. Fauna in the Scinde Island Formation indicate deposition at shelf water depths. Strong tidal currents swept the sea floor as evidenced by the giant-scale cross-beds

exposed at the type section (Kamp *et al.* 1988). Boyle (1987) suggested that variations in the degree of cementation, siliciclastic content, crude bedding and the amount of micrite present in Member A may mean that deposition of at least lower parts of the formation occurred episodically

The correlation of Scinde Island Formation with Matahorua Formation, Mason Ridge Formation and Sentry Box Formation has interesting implications in terms of paleogeography as it suggests that limestone was accumulating in a proto-Hawke Bay at the same time that large volumes of siliciclastic sandstone and greywacke gravels were being deposited by major river systems to the west.

Member A

Definition, distribution and thickness

Member A is the basal and thickest member defined for the Scinde Island Formation. Beu (1995) restricted his definition of Scinde Island Limestone to only this member, leaving the remainder of the rocks at Scinde Island undifferentiated. The distribution of Member A at Scinde Island mostly corresponds to that shown by Kingma (1971) for his “lower Scinde Island limestone”. Member A is the most widespread of the five Scinde Island Formation members and forms the base of the block of Scinde Island. The member reaches its maximum thickness of 90 m at the end of Bluff Hill overlooking the Port of Napier. Towards the southwest Member A dips beneath the overlying sandy siltstone of Member B at Battery Point (Boyle 1987).

Contacts

The lower contact of Member A is not exposed. Logs from adjacent drillholes suggest that the Member overlies blue-grey siltstone of the Taradale Mudstone. It is not known if this contact is conformable, however, similar contacts in other parts of the study area are typically conformable and gradational.

In southwest parts of Scinde Island, Member A is unconformably overlain by Member B. In the north and east of Scinde Island, Member A is overlain by loess.

Description

Member A is characterised by very large-scale cross-beds that are well-exposed at the northern end of Scinde Island adjacent to the Port of Napier. The member consists of strongly cross-bedded, differentially cemented, calcareous sandstone interbedded with lenses of sandy coquina limestone (Boyle 1987). shellhash occurs scattered through the less well cemented sandstone

beds. Mud-lined *Ophiomorpha* burrows averaging 6 cm long and 0.5 cm wide occur frequently on the underside of preferentially cemented sandstone beds towards the base of the section at Scinde Island (Boyle 1987).

Around Centennial Gardens (V21/457840) the member comprises large-scale trough cross-bedded calcareous sandstone in sets up to 1 m thick.

Member B

Definition, distribution and thickness

Member B is restricted to northern and western parts of Scinde Island. It is thickest in southwestern parts of Scinde Island (16 m) and thins towards the northeast to 1 m thick (Boyle 1987).

Contacts

Member B unconformably overlies Member A, and is disconformably overlain by Member C in the southwest of Scinde Island. Member B is overlain by loess in the northeast of Scinde Island (Kingma 1971; Boyle 1987).

Description

Member B comprises light brown, massive, calcareous sandstone with occasional scattered fragments of *Talochlamys gemmulata*. Well cemented concretions 2-3 cm in diameter occur in the upper few metres of the member. The member is extensively burrowed and reworked resulting in obliteration of any sedimentary structures (Boyle 1987).

Member C

Definition, distribution and thickness

Member C was mapped by Hutton (1886) and Kingma (1971) as part of the upper Scinde Island limestone and correlated with the Waipatiki Limestone Member (Petane Formation) by Kingma. Geological mapping in this study has clearly illustrated no correlation between these two limestone intervals, which are separated by over 500 k.y. and many tens of metres of stratigraphic section. Boyle (1987) subdivided the upper Scinde Island limestone (of Kingma 1971) into three members, all of which are retained in this study. Member C is applied to the lowest of these three members.

Member C is mostly restricted in outcrop to the southwestern (Hospital Hill) end of Scinde Island. It is thickest at Scandinavian Point (30 m) and gradually thins northward towards Battery Point (18 m). The distribution of Member C has been strongly controlled by erosion such that the member is absent in the south and east of Scinde Island, and that only the more erosion-resistant limestone part of the member is present in the northeast (Boyle 1987).

Contacts

Member C disconformably overlies Member B toward the southwest end of Scinde Island. The contact is exposed at Scandinavian Point and Pandora Point (Boyle 1987). The upper gradational contact between Member C and Member D is poorly exposed. It has been recorded half-way between Battery Point and Pandora Point (Boyle 1987). Occasionally the contact may be marked by a thin, poorly sorted pebbly conglomerate.

Description

Member C is characterised by alternating thin (6 cm-thick) beds of shellhash and mudstone, and small-scale shallow trough cross-bedded limestone. Minor sandy units, conglomerates and shellbeds are also present (Boyle 1987).

Member D

Definition, distribution and thickness

Member D is restricted in outcrop to the southwestern end of Scinde Island near Pandora Point. The member is thickest south of Battery Point (V21/447833) and thins to 13 m at Pandora Point (Boyle 1987).

Contacts

Member D gradationally overlies Member C. In rare cases the contact may be marked by a thin poorly sorted pebbly conglomerate. Member D is overlain either by Member E or by a thin covering of Pleistocene loess (Boyle 1987). Although the contact between Members D and E was difficult to determine, (Boyle 1987) inferred it to be well defined and disconformable.

Description

Member D consists of up to 11 m of extensively bioturbated flaser to wavy and lenticular-bedded sandstone and mudstone which are overlain by up to 13 m of pumiceous muddy sandstone. The pumiceous muddy sandstone is finely laminated, and contains mudstone clasts and poorly sorted greywacke pebbles (Boyle 1987).

Member E

Definition, distribution and thickness

Member E is the stratigraphically highest member of the Scinde Island Formation as defined by Boyle (1987). Member E is restricted in outcrop to one small poorly exposed section at the southwestern end of Scinde Island toward the top of Pandora Point. The member is approximately 10 m thick (Boyle 1987).

Contacts

At Battery Point, muddy sandstone of Member D grades conformably into Member E (Boyle 1987).

Description

Member E comprises a whitish brown barnacle-rich limestone. The unit displays crude horizontal bedding. Around Pandora Point, Member E is unconformably overlain by Pleistocene loess (Boyle 1987).

WAIPUNGA FORMATION (wp)

(Haywick 1990; formally defined by Haywick *et al.* 1991)

Name and definition

Waipunga Formation (Fig. 19F) was formally defined by Haywick *et al.* (1991), and applied to soft to friable Nukumaruan sandstone exposed at the base of northwestern parts of the Tangoio Block. This definition replaced the informal Waikoau sandstone of Beu and Edwards (1984) as this name was pre-occupied elsewhere. Bland (2001) emended this definition and applied it to sandstone facies of Nukumaruan age lying stratigraphically above the last conglomerate bed of the Matahorua Formation, and below siltstone of the Esk Mudstone in the Esk River catchment. Graafhuis (2001) also extended the definition of the Waipunga Formation of Haywick *et al.* (1991) to include a series of sandstone and siltstone beds above the uppermost conglomerate bed of the Matahorua Formation, and below the siltstone of the Esk Mudstone in the Waikoau and Waikare River catchments.

Distribution and thickness

Waipunga Formation is one of the least widespread formations in the upper parts of the Mangaheia Group and is geographically restricted to northern parts of the Tangoio Block between the Esk and Waikare River catchments. In southeast and southwest directions Waipunga

Formation passes laterally into mudstone and siltstone facies of the Esk and Taradale Mudstones. Towards the northeast the formation passes into upper members (Grassy Knoll Conglomerate and Papakiri Members) of the Matahorua Formation and the Esk Mudstone.

Lower and upper contacts

Although generally poorly exposed, both the lower and upper contacts of this unit are conformable through outcrop extent. The lower contact is exposed in Kaiwaka Stream (V20/368064) and in the Esk River downstream of the Deep Stream confluence (V20/378067, Column Tp-7).

Description

The Waipunga Formation is a siliciclastic-dominated unit that varies between a single non cemented fine sandstone bed in the south, and fine-grained siltstone to sandy siltstone units in the north.

Paleontology and age

Waipunga Formation is sparsely fossiliferous and few age-diagnostic species have been recognised. Occasional valves of *Atrina pectinata zelandica* were collected in Kaiwaka Stream. On the basis of stratigraphic position between the H.O. of *P. triphooki* and the L.O. *Pelicaria convexa* a Lower Nukumaruan age is assigned to the Waipunga Formation.

Environment of deposition

Waipunga Formation was deposited in a number of shelf-dominated environments from nearshore to middle shelf water depths. Waipunga Formation probably accumulated in a region of slightly shallower water than surrounding areas.

ESK MUDSTONE (ek)

(Smith 1877; formally defined by Haywick *et al.* 1991)

Name and definition

Smith (1877) used the name Esk Papa for siltstone exposed along the Esk River to the west of the Tangoio Block. Beu and Edwards (1984) applied the name Taradale mudstone (informal) to this succession after the interval intercepted in the Taradale-1 drillhole (Darley and Kirby 1969). Esk Formation was introduced by Haywick (1990) and formally defined by Haywick *et al.* (1991). They preferred the name “Esk” over “Taradale” as they felt the sequence in Taradale-1 was not clearly correlated with the sequence exposed in the Tangoio Block. Haywick *et al.* (1991) argued

that Esk Formation had priority over, and was preferred to, Taradale Mudstone. Esk Formation was also adopted by Bland (2001) and Graafhuis (2001). Beu (1995) emended Esk Formation to Esk Mudstone to highlight the dominant lithofacies of the formation. The name of Beu (1995) is retained in this study although the definition has been emended to include beds previously omitted.

Erdman and Kelsey (1992) formally defined the Ohara Mudstone in reference to a Lower Nukumaruan mudstone-dominated interval cropping out widely in the Ohara Depression and Kereru region. Geological mapping in this study has demonstrated that a continuous northeast-southwest trending belt of Lower Nukumaruan mudstone and siltstone crops out from Putorino in the north of the study area to Kereru in the south. This belt includes mudstone assigned by Haywick *et al.* (1991) and Beu (1995) to the Esk Mudstone, and beds assigned by Erdman and Kelsey (1992) to the Ohara Mudstone. As Esk Mudstone is a well established stratigraphic unit in the study area, and outcrop is relatively continuous, the Ohara Mudstone of Erdman and Kelsey (1992) is now incorporated into Esk Mudstone and use of the name Ohara Mudstone is discontinued.

Type locality and reference sections

The type section designated by Haywick *et al.* (1991) on Dunvegan Farm has been retained (V20/386042). A reference section was designated by Bland (2001) in the Esk River from Island Farm up-stream to a point near the confluence with Deep Stream (V20/386042-383063).

Well exposed reference sections through southern outcrops of the Esk Mudstone are designated in the Ngaruroro River and Jumped Up Stream. The Jumped Up Stream section is the type section for the Ohara Mudstone of Erdman and Kelsey (1992). It extends from the top of the Sentry Box Formation (U21935665, Column Ke-3) 1 km downstream to a cliff face at the confluence of Jumped Up and Ohara Streams (Fig. 19A). This section is continuous up to the base of the Kereru Formation in a high bluff on the east bank of Ohara Stream (about U21/946653). The Ngaruroro River section occurs from the faulted lower contact between greywacke and the Esk Mudstone (Mohaka Fault; U21/022770) to the conformable lower contact with the Kereru and Okauawa Formations (Fig. 19C; U21/092760, Column Mt-1).

Lower and upper contacts

Esk Mudstone everywhere sharply overlies shallow-water formations throughout its outcrop extent, although in places on the Wakarara Range the formation unconformably overlies Torlesse basement. The formation coarsens upwards and is conformably overlain by a variety of

formations. In the Tangoio Block and Eskdale areas it passes into the lower sandstone facies of the Tutira Formation (Fig. 22D). Southwestwards through the Rissington (Fig. 22A) and Crownthorpe/Sherenden areas (Fig. 22B) the formation is conformably and successively overlain by the Tangoio Formation (Flag Range Member) and the Okauawa Formation. In the Ohara Depression, Esk Mudstone is overlain by the Kereru Formation. Esk Mudstone laterally interdigitates with the Tutira Formation, Aropaoanui Mudstone, Taradale Mudstone and Kereru Formation (Enclosure 5).

Where Mount Mary Pebbly Limestone is absent, Esk Mudstone rests directly and unconformably on greywacke comprising the Wakarara Range. In the Ngaruroro River section several hundred metres below the Whana Valley Cable, Esk Mudstone lies in fault contact with greywacke due to vertical displacement on the Mohaka Fault (Fig. 22E).

Distribution and thickness

Esk Mudstone is perhaps the most widespread formation in the upper Mangaheia Group, cropping out through central to western parts of the study area from Putorino (Fig. 22F, G) in the northeast to the Ohara Depression in the southwest (Fig. 22C). Lateral equivalents are likely to occur at the mouth of the Mohaka River where Lower Nukumaruan mudstone crops out.

Esk Mudstone is approximately 120 m thick through the Esk and Tangoio area (Fig. 19F) and thickens significantly north of the Tangoio Block into the Waikare River. In the Ohara Depression the formation is c. 410 m thick (Erdman and Kelsey 1992) (Fig. 19C).

Description

Esk Mudstone comprises blue-grey, non cemented, non to slightly fossiliferous sandy siltstone that becomes sandier up-section. It typically grades into the Tutira Formation, except in Rautoitoi Stream (Fig. 22D). The Esk Mudstone is characterised by many well sorted, frequently bioturbated tephra beds that punctuate the unit. Tephra beds are particularly well exposed in the Waikare (Fig. 22F, G), Esk, and Mangaone Rivers (Fig. 22A), although tephra beds are present in the Tutaekuri and Ngaruroro River and Ohara Stream sections. Tephra beds vary from fine ash to medium-lapilli-sized pumiceous materials, are 0.1-0.6 m thick (Fig. 22G), and are more common in lower to middle portions of the formation. Tephra beds appear to be less common in southern areas.

In the Jumped Up Stream section the lower 80 m of the Esk Mudstone consists of massive, slightly fossiliferous siltstone. This grades into interbedded sandstone and mudstone over 2-3 m.

Sandstone beds are 2-30 cm thick and alternate with 0.5-3 cm thick finely laminated fine-grained siltstone beds. Sandstone beds are blue-grey and locally fossiliferous and bioturbated. Siltstone layers are more calcareous and locally disrupted by burrows (Erdman and Kelsey 1992).

Paleontology and age

Scattered macrofossils occur throughout the Esk Mudstone, and are typical of shelfal soft-bottom assemblages in Hawke's Bay. In the lower parts of Otakowai Stream clusters of the large foraminifera *Purgo anomola* are visible (V20/372041). *Pratulum pulchellum, Talochlamys gemmulata* and *Maoricolpus roseus* are the dominant fauna, with *Atrina pectinata zelandica* and *Pelicaria acuminata* also common. Rare valves of *Ostrea chilensis* are occasionally present.

In Jumped Up Stream diagnostic bathyal faunas have been collected from near the base of the Esk Mudstone where it abruptly but gradationally overlies upper muddy limestone beds of the Sentry Box Formation (Beu 1995). Fauna in this lower part of the Esk Mudstone include *Aeneator orbita, Comitas onokeana*, and the very diagnostic bathyal taxon *Sassia kampyla jobbernsi* (Beu *et al.* 1977; Beu 1995).

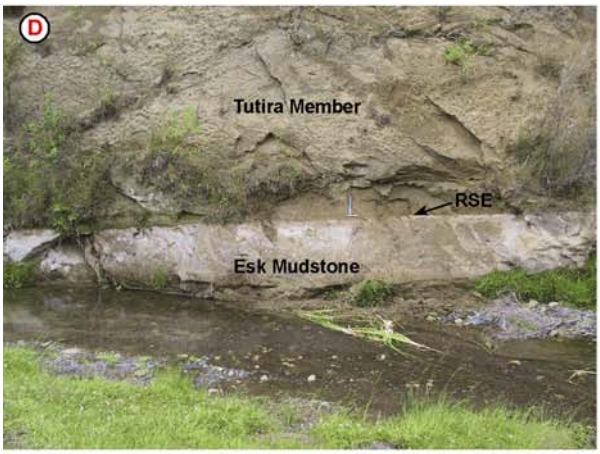
Based on the age of underlying units, the presence of *Pelicaria acuminata* and stratigraphic position, the Esk Mudstone is of Lower Nukumaruan (Late Pliocene) age. Foraminiferal samples from Mangatutu and Willowford (V20/f443 and U20/f149) confirm a Nukumaruan age, constrained by both planktic and benthic taxa. The Mangatutu sample includes *Truncorotalia crassula, Globoconella inflata triangula* and *Notorotalia zelandica,* while the Willowford sample is constrained by *Truncorotalia crassula* and *Notorotalia zelandica.*

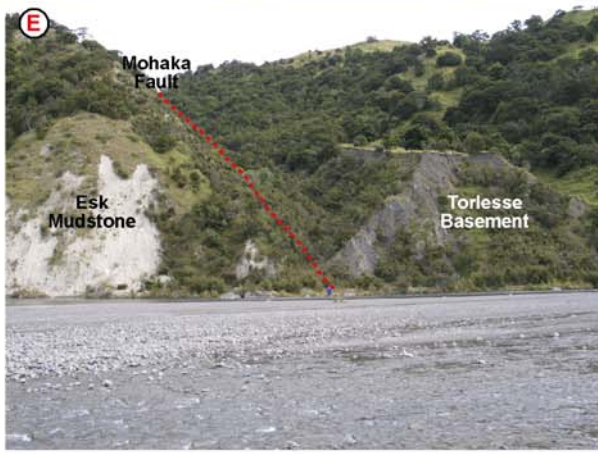
Fig. 22 (facing page): Esk Mudstone throughout the study area. **A)** High cliff face exposure of Esk Mudstone in the lower reaches of the Mangaone River upstream of Rissington (V21/303896). Two prominent tephra beds (arrowed) occur in this exposure, the lower one of which has been sampled for major element glass geochemical analysis (sample WP 1011). **B)** Esk Mudstone cropping out in the Tutaekuri River below Flag Range (V21/248857). The prominent dark-coloured horizon dipping through the outcrop is a tephra layer. **C)** Esk Mudstone in Ohara Stream below Mangleton Road sharply overlain by thick poorly sorted Holocene fluvial terrace deposits (U21/009721). **D)** Esk Mudstone sharply underlying Tutira Member (Petane Formation) in Rautoitoi Stream (V20/375000). This sharp contact is inferred to represent a regressive surface of erosion (arrowed) in terms of sequence stratigraphy. **E)** Esk Mudstone in fault contact with Torlesse basement rocks in the Ngaruroro River at Whana Valley (U21/022770). The trace of the Mohaka Fault is marked on the photo by a red line. It is a vertical trace, with over 100 m of fractured and strongly deformed rocks cropping out both upstream and downstream of the fault. **F)** Exposure of Esk Mudstone in the lower reaches of the Waikare River downstream of Putorino (W19/569221). Tephra beds (arrowed) are visible as thin prominent horizons near the top of the exposure. **G)** Close-up view of a tephra bed in Esk Mudstone, Glenbrook Road, near Putorino (W19/579211). Note the well-developed burrows in the tephra bed.


A


B


C


D
Tutira Member
RSE
Esk Mudstone


E
Mohaka Fault
Esk Mudstone
Torlesse Basement


F


G

Environment of deposition

Foraminiferal sample U20/f149 from Willowford (U20/096904) contains an assemblage that indicates an inner to middle shelf (0-100 m) depositional environment with a slight brackish influence. The sample contained 1% planktics which suggests a sheltered inner neritic water mass. Foraminiferal sample V20/f443 from V20/157915 suggests deposition in an outer shelf (100-200 m) environment under normal marine conditions (Appendix V).

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Macrofossil collections from the upper Esk Mudstone at V20/397107 along Darkys Spur Road contain *Jupiteria, Talochlamys gemmulata* (dominant)*, Atrina pectinata, Ostrea chilensis, Stiracolpus* and *Notocallista.* A collection from V20/403107, also on Darkys Spur Road, contained *Jupiteria, Pratulum pulchellum, Talochlamys, Ostrea, Nucula, Pelicaria ?acuminata, Dosinia greyi, Myadora, Pleuromeris* and *Stiracolpus*. This fauna suggests a deep-water assemblage towards the edge of the continental shelf (A. Hendy, University of Cincinnati, pers. comm. 2004). Bathyal deposition is indicated in basal parts of the formation in the Ohara Depression where Esk Mudstone gradationally overlies Sentry Box Formation (Beu 1995).

PETANE FORMATION (pe)

(McKay 1886a)

Name and definition

Bioclastic beds of the Tangoio Block were termed the "Petane Limestone" by McKay (1886a), and were subsequently incorporated into the more regional Petane Series defined by McKay (1887). This series included all rocks between the Pohui Series (Pliocene) and Patangata Series (?Pleistocene). McKay (1886a) derived the name Petane from a Maori Pa located on the north side of the Esk River, just up-stream of where modern State Highway 2 crosses the river. The Petane Series was subdivided into the Mahia, Waipatiki and Kaiwaka Beds. Beu and Edwards (1984) introduced the first detailed lithostratigraphic scheme for central Hawke's Bay, forming the basis for the lithostratigraphy established by Haywick (1990). The Petane Group was introduced by Haywick (1990) and formally defined by Haywick *et al.* (1991), emending the "Petane Limestone" of McKay (1886a). Haywick *et al.* (1991) could not accurately define the base of the group, and tentatively placed it at the base of the Waipunga Formation.

The top of the group was placed at the top of the Kaiwaka Formation, which coincided with either the modern land surface or an unconformable contact with Castlecliffian (Middle Pleistocene) Kidnappers Group gravels. Bland (2001) and Graafhuis (2001) placed the base of the Petane Group at the base of the Matahorua Formation, extending the group into rocks of Upper

Mangapanian age. The age of the basal surface of the Petane Group, as defined by Bland (2001) and Graafhuis (2001), is inferred to be approximately 2.48 Ma (see Chapter 4). This definition was supportable in the Esk and Waikoau River sections of which the Tangoio Block is a part.

Fieldwork during this study demonstrated that the base of the group could not be consistently or accurately defined away from the Tangoio Block. Formations within the Petane Group (such as the Tangoio and Waipatiki Formations) have been confidently mapped from the Tangoio Block southwest to Taradale and Puketapu near Napier. The succession here comprises Taradale Mudstone, overlain by the Park Island Limestone Member, Mairau Formation and higher formations above this (refer Enclosure 1, Sheet 4: Esk). The Matahorua Formation is not present here, having passed laterally into the Taradale Mudstone, as have the Esk Mudstone, Tutira and Aropaoanui Formations. Beu (1995, p. 126) placed the base of the Petane Group in the Napier area at the inferred position of the base of the Nukumaruan stage determined in Taradale-1. However, this level occurs *within* a lithologically identical massive mudstone facies which continues downwards for a further 550 m where the beds have a Waipipian age. It is accepted that biostratigraphy and chronostratigraphy cannot be employed for defining the boundaries of lithological groups. Further to this, the position of the base of the Nukumaruan Stage in Taradale-1 could not be accurately determined. Similar problems with identifying and defining the base of the Petane Group occur through the Sherenden, Otamauri and Matapiro areas.

An important conclusion of this study is that the maintenance of Petane as a group name is unsustainable in a regional context, and it is proposed that the Petane Group, as defined by Haywick *et al.* (1991) and Beu (1995), be incorporated into the Mangaheia Group. It is proposed that the group be demoted to a formation, and the name Petane retained in this context. Petane Formation is applied to a similar although more restricted interval of the Nukumaruan succession than in its previous usage. Mangaheia Group, as defined by Mazengarb *et al.* (1991) and Mazengarb and Speden (2000), is a well-defined interval of Kapitean to Waipipian shelfal rocks extending from the Tauwhareparae area north of Gisborne to the Wairoa District. The top of the group was defined as the top of the youngest marine beds in their study areas. This study has extended Mangaheia Group into the current study area to encompass rocks very similar in character to those for which the original definition was applied. In the current study area shelfal beds continue above “typical” Mangaheia Group beds into the Early Pleistocene succession with no major unconformities or breaks. It is logical, therefore, to incorporate all these units within the Mangaheia Group.

Abolishing the Petane Group has several benefits including: 1) it simplifies the stratigraphy of the Hawke’s Bay part of the forearc basin in that only three groups are now defined, each reflecting

key phases in the development of the area; 2) it better links stratigraphy north of the study area to the study area itself, and is an important step towards a more regional stratigraphy. This is important as the QMAP programme continues south through the eastern North Island; and 3) it means that the base of each of the groups is easily defined and identifiable in the field. It removes any ambiguity as to where a group boundary should be placed.

Petane is retained as a formation name for much of the succession in the Tangoio Block and its lateral equivalents because of historical usage, and because the interval can still be usefully subdivided and geologically mapped. The new definition of Petane Formation assembles together an interval comprising all or part of five shelfal sequences containing sandstone, siltstone, limestone and conglomerate lithofacies. This is consistent with other formations in the Mangaheia Group that also represent intervals of multiple sequences and similar lithologies such as the Titiokura, Matahorua, Mason Ridge, Kereru, and Okauawa Formations. The stratigraphic thickness (over 100 m) and diversity of lithofacies in the Kaiwaka Formation of Haywick *et al.* (1991), the stratigraphically highest unit of the old Petane Group, means that it is defined in this study to remain as a separate distinct formation. The internal composition of the Kaiwaka Formation, and lateral continuity of constituent beds also remains poorly resolved at this point, and it is desirable to maintain it as a separate formation until a higher degree of differentiation can be achieved. Likewise, the Esk Mudstone, part of the Petane Group of Haywick *et al*. (1991), is retained as a formation due to its significant stratigraphic thickness and lateral persistence across the entire study area from Putorino to the Ohara Depression. The Esk Mudstone gradationally underlies the Petane Formation.

The Petane Formation (Fig. 19F) is therefore defined as an interval comprising shallow-marine cyclothems that conformably overlie the Esk Mudstone and its lateral equivalent the Taradale Mudstone, and sharply underlie the Kaiwaka Formation. A consequence of demoting the name Petane from group to formation level is that all formations defined by Haywick *et al.* (1991) and Beu (1995) in the Petane Group between the Esk Mudstone and Kaiwaka Formation must also be demoted in rank. Consequently they are now incorporated as members in the Petane Formation, although they have been maintained as separate geological mapping units in this study. These members are the **Tutira Member, Hikuroa Pumice Member, Aropaoanui Mudstone Member, Darkys Spur Member, Tararere Conglomerate Bed, Mairau Mudstone Member, Tangoio Limestone Member, Te Ngaru Mudstone Member, Waipatiki Limestone Member,** and **Devils Elbow Mudstone Member.** In addition to these members, the Petane Formation is defined to incorporate beds that geological mapping has demonstrated are lateral equivalents to units in the Tangoio Block These include the **Park Island Limestone Member** (Darkys Spur Member equivalent) and **Flag Range Conglomerate Member** (Tangoio Limestone Member equivalent).

Type locality and reference sections

The type locality of the Petane Formation is defined as the section exposed in the valley of the Waikoau/Aropaoanui River near State Highway 2 and the Devils Elbow Road Section (V20448109-458070, Column Tg-4). Reference sections for parts of the formation are nominated along the Darkys Spur Road section (V20/390109-411096, Column Tg-3), and in coastal seacliffs from the mouth of the Aropaoanui River (W20/555067, Column Ap-1) to Tangoio Settlement (V20/469985, Column Tg-5).

Lower and upper contacts

Petane Formation typically overlies sandy mudstone of the Esk Mudstone and Taradale Mudstone across a conformable gradational contact. In the Tangoio Block this gradational interval is marked by the transition from the Esk Mudstone to sandstone of the Tutira Member. In the region around Taradale and Roys Hill the interval is marked by the transition from Taradale Mudstone to calcareous sandstone of the Park Island Limestone Member. Rautoitoi Stream is the only exposure known where Esk Mudstone is sharply overlain by sandstone of the Tutira Member (Fig. 24D). In the Matapiro area Mairau Mudstone Member (Petane Formation) abruptly overlies the uppermost conglomerate bed of the Okauawa Formation (Whakamarumaru Member). Lower members of the formation such as the Tutira, Aropaoanui, Mudstone Darkys Spur and Mairau Mudstone Members pass laterally into mudstone facies of the Esk Mudstone and Taradale Mudstone.

The Kaiwaka Formation sharply overlies the Devils Elbow Mudstone Member (Petane Formation) across a transgressive surface of erosion at the top of the Devils Elbow section on State Highway 2 (Column Tg-4). Decimetre-scale relief is common on this contact. The contact is well exposed in two localities on Ohiti Road (V21/298733 and V21/233722).

Distribution and thickness

Petane Formation is widespread across the study area in a northeast-southwest trending belt from the Tangoio Block to the Roys Hill area. The formation is thickest and best developed in the Tangoio Block (Fig. 19F) where it is up to 340 m thick. Away from the Tangoio Block Petane Formation is typically less than 150 m thick, reflecting the transition of lower members (e.g. Tutira) into mudstone lithofacies of the Esk Mudstone and Taradale Mudstone (Fig. 19D-F; Enclosure 5).

Tutira Member (tu)

(Haywick, 1990; formally defined by Haywick *et al.* 1991)

Name and definition

The Tutira Formation was referred to as an un-named "conglomerate member" of the Taradale mudstone by Beu and Edwards (1984). The name Tutira Formation was introduced by Haywick (1990) and formally defined by Haywick *et al.* (1991) for a prominent greywacke conglomerate bed and associated sandstone and volcaniclastic units immediately overlying Esk Mudstone. This definition was adopted by Bland (2001). Beu (1995) emended the name of Haywick *et al.* (1991) to the Tutira Conglomerate. Tutira Member is re-defined in this study as the basal member of the Petane Formation. It is a package of siliciciclastic sandstone and greywacke conglomerate that conformably overlies the Esk Mudstone and conformably underlies either the Hikuroa Pumice Member or the Aropaoanui Mudstone Member.

Type locality and reference sections

The type section nominated by Haywick *et al.* (1991) on Tutira Station is retained in this study (V20/441126). Reference sections are nominated in bluffs below Darkys Spur Road (V20/402108; Fig. 23B), in bluffs around Beattie Road (V20/355964; Fig. 23E, F), and in the lower reaches of Rautoitoi Stream (V20/379992; Fig. 22D).

Lower and upper contacts

In almost all cases Tutira Member gradationally overlies Esk Mudstone through a coarsening-upward interval of up to several metres. The only exception observed to this is in Rautoitoi Stream where Tutira Member sharply overlies Esk Mudstone (Fig. 22D).

Tutira Member is usually sharply overlain by the Hikuroa Pumice Member. In situations when the Hikuroa Pumice Member is absent, Tutira Formation is abruptly overlain by the Aropaoanui Mudstone (Fig. 23A) across an inferred downlap surface. Laterally Tutira Formation interdigitates with the Esk Mudstone and Taradale Mudstone (State Highway 2).

Distribution and thickness

Tutira Member is restricted in outcrop to the Tangoio Block, and a small area between the lower Esk and Mangaone Rivers. Tutira Member does not crop out west and south of an area near Glengarry and Beattie Roads (Eskdale). Geological mapping demonstrates that the member is coeval with lower parts (Kikowhero Member) of Okauawa Formation exposed in the Ohara-Whana Valley regions.

Description

Tutira Member comprises a coarsening-upwards package of sandstone to greywacke conglomerate facies with a combined thickness of up to 60 m. The lower sandstone interval comprises non cemented, massive, well sorted fine to medium sandstone that gradationally overlies Esk Mudstone. This sandstone is sharply overlain by a prominent greywacke conglomerate bed. The conglomerate bed is massive to strongly cross-bedded, with prominent trough cross-beds well exposed around Tiokapu and Parakowhai Stations. A distinctive element of the Tutira Member is the thick volcanic ash bed (Hikuroa Pumice Member) that consistently overlies the greywacke conglomerate beds (see below) in its upper parts. The member is typically non fossiliferous throughout, although around Eland Station (V20/346033), and in the Waikoau River (V20/449106) a capping shellbed rich in estuarine macrofauna, such as *Austrovenus stutchburyi,* occurs (Fig. 23D).

Paleontology and age

Tutira Member is generally unfossiliferous and no age diagnostic faunas have been sampled. Geochemical determination of glass shard composition with tephra in ODP 181 cores suggest that the overlying Hikuroa Pumice Member has an approximate age of about 2.15 Ma. On the basis of stratigraphic position, Tutira Formation is "middle" Nukumaruan (Late Pliocene) in age (approx 2.15 Ma).

Environment of deposition

Tutira Member was deposited in a combination of depositional paleoenvironments. Sandstone facies represent shallowing-upward nearshore to shoreface environments. Greywacke conglomerate facies are inferred to have been deposited in non-marine braid-plain settings and as part of shingle beaches.

Hikuroa Pumice Member (tuh)

(Haywick 1990; formally defined by Haywick *et al.* 1991)

Name and definition

Hikuroa Pumice Member was formally defined by Haywick *et al.* (1991) for a significant pumiceous unit present in upper parts of the Tutira Member overlying the main greywacke conglomerate bed and underlying the Aropaoanui Mudstone. It is now defined as a member of the Petane Formation. The name is derived from Hikuroa Farm on the Tangoio Block (V20/393109).

Type locality and reference sections

The type section designated by Haywick *et al.* (1991) on Hikuroa Farm is retained (V20/400105). Reference sections are designated along Darkys Spur Road and near Beattie Road (Fig. 23E, F) where the member is well exposed.

Lower and upper contacts

Hikuroa Pumice Member sharply overlies Tutira Member. In the Eskdale region the Hikuroa Pumice Member is abruptly overlain by the Aropaoanui Mudstone.

Distribution and thickness

Hikuroa Pumice Member is an easily recognisable member of the Petane Formation and provides an important marker bed that aids confident geological mapping through the Tangoio and Esk regions. Hikuroa Pumice Member is well exposed on Darkys Spur Road, on Eland Station, in low hills around Belmont Station and Beattie Road, and in cliffs along Rautoitoi Stream. Throughout the Tangoio Block the member is 8-15 m thick (Haywick *et al.* 1991).

Description

The Hikuroa Pumice Member comprises a basal primary ignimbrite overlain by reworked pumiceous ash and lapilli. Siliciclastic sand, silt and greywacke pebble lenses and interbeds are common. Carbonaceous fragments and plant imprints are common, with rare *in situ* rootlets (Haywick *et al.* 1991). The member is white to pale-cream in colour, and massive to strongly cross-stratified. Very well-developed trough cross-bedding is preserved in the Beattie Road area (Fig. 23F).

Fig. 23 (facing page): Tutira and Hikuroa Pumice Members, Petane Formation. **A)** Landscape view of the Tutira Member cropping out in the Tiokapu and Parakowhai Station area, near Glengarry Hill. The contact between the Tutira Member and the overlying Aropaoanui Mudstone Member is highlighted (V20/304994). **B)** View of part of the Darkys Spur section from Darkys Spur Road highlighting the relationship between the Tutira Member and overlying members in the Tangoio Block (V20/402107). **C)** Close-up view of the prominent conglomerate facies of the Tutira Member, Tiokapu Station (V20/301991). Note the well developed trough cross-beds illustrating the inferred fluvial deposition environment of much of this facies. **D)** Highly fossiliferous shellbed dominated by the estuarine-restricted bivalve *Austrovenus stutchburyi* (V20/299988). This shellbed commonly overlies conglomerate facies of the Tutira Member in the Glengarry-Parakowhai area and is assigned to a TST in terms of sequence stratigraphy. **E)** Hikuroa Pumice Member sharply overlying Tutira Member near Beattie Road (V20/362967, Column Ek-3). The hammer lies over the contact between the Hikuroa Pumice and Tutira Members. **F)** Close-up view of sedimentary structures within the Hikuroa Pumice Member. Note the well-developed trough cross-beds (V20/360968). **G)** Sandstone of the Tutira Member underlying the prominent conglomerate facies. Clearly visible are mudstone clasts (V20/360968).


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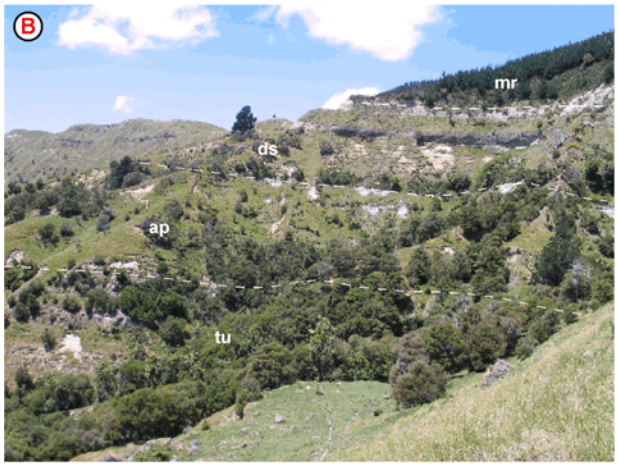
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Major element geochemical electron microprobe analyses has been undertaken on glass shards in samples from the Hikuroa Pumice Member collected from several localities by K. Bland (this study), B. Alloway and T. Naish (GNS Science), and by A. Palmer (Massey University). Results have helped to confirm correlations made in the field between inferred outcrops of Hikuroa Pumice Member. Average silica content is 77.42%, with 12.25% Al_2O_3, 0.94% CaO and 3.72% K_2O.

Paleontology and age

No age-diagnostic macrofossils have been collected from the Hikuroa Member. Volcanic glass from the Hikuroa Pumice Member has been correlated on the basis of major element geochemistry to tephras 1124C 7H 3W 71-71 and 1124C 7H 3W 117-119 in ODP 1124 (B. Alloway GNS Science pers. comm. 2004). These tephras have been assigned ages of approximately 2.14 Ma.

Hikuroa Pumice Member is assigned a "Middle" Nukumaruan age of approximately 2.15 Ma based on stratigraphic position and geochemical matching of glass shards with the ODP 1124C tephra record. This datum is an important absolute age marker for the Petane Formation and helps in correlating cyclothems in the Nukumaruan succession in the study area with other records.

Environment of deposition

Hikuroa Pumice Member was deposited in a combination of non-marine and marginal-marine to estuarine environments (Haywick *et al.* 1991).

Aropaoanui Mudstone Member (ap)

(Haywick 1990; formally defined by Haywick *et al.* 1991)

Name and definition

Aropaoanui Formation, introduced by Haywick (1990) and formally defined by Haywick *et al.* (1991), was applied to sandy siltstone facies overlying the Tutira [Member], and underlying the Darkys Spur [Member]. The name is derived from the Aropaoanui River which dissects the Tangoio Block, and along which the formation is exposed. This interval was included as part of the informal Taradale mudstone of Beu and Maxwell (1984). The definition of Haywick *et al.* (1991) was emended by Beu (1995) to Aropaoanui Mudstone. The definition of Beu (1995) is emended in this study to Aropaoanui Mudstone Member of the Petane Formation. The unit is not regarded as a distinct formation.

Type locality and reference sections

The type section in the Aropaoanui River nominated by Haywick *et al.* (1991) has been retained (V20/456086). A reference section is designated by Haywick *et al.* (1991) and Beu (1995) on Tutira Reserve (V20/456086).

Lower and upper contacts

Aropaoanui Mudstone Member is gradationally overlain by Darkys Spur Member (Fig. 24B, C). This contact is well exposed on Darkys Spur Road (Fig. 23B; Column Tg-3) and in sea-cliffs north of the mouth of the Aropaoanui River (Column Ap-1). Landslide deposits appear to have mostly obscured the contact at the base of the Devils Elbow Section, although it is exposed on the west side of the farm bridge across the Waikoau River at the base of the Devils Elbow on State Highway 2.

The Aropaoanui Mudstone Member abruptly overlies the Hikuroa Pumice Member. In the Tangoio Block the lower contact is poorly exposed on Darkys Spur Road (V20/402107). Away from the Tangoio Block it is well exposed in the region of Beattie Road, in Rautoitoi Stream (V20/375994), and in rare outcrops on Belmont Station.

Distribution and thickness

Aropaoanui Mudstone Member is locally widespread, though restricted to the Tangoio Block and an area south of the Esk River in the Glengarry and Eskdale areas. Beu (1995) suggested that Aropaoanui Mudstone Member is a lateral equivalent of upper parts of the Taradale Mudstone, a correlation that geological mapping in this study has confirmed. Geological mapping has demonstrated that the Aropaoanui Mudstone Member is a lateral equivalent of lower parts of the Okauawa Formation cropping out in the Kereru-Ohara-Sherenden areas (Enclosure 5).

The Aropaoanui Mudstone Member is 35-60 m thick through the Tangoio Block (Haywick *et al.* 1991).

Description

Aropaoanui Mudstone Member comprises non cemented slightly to moderately fossiliferous siltstone that coarsens up-section through silty sandstone into fine sandstone (Fig. 24E).

Paleontology and age

The Aropaoanui Mudstone Member is non to moderately fossiliferous. In the Tangoio Block the formation contains an open marine fauna (Haywick 1990). Based on stratigraphic position Aropaoanui Mudstone Member is of "middle" Nukumaruan age.

Environment of deposition

Macrofauna indicate a middle to outer shelf environment of deposition in the Tangoio Block (Haywick 1990) that shallows up-section to an inner shelf setting. The member is gradationally overlain by inner shelf sandstone of the Darkys Spur Member.

Darkys Spur Member (ds)

(Haywick 1990; formally defined by Haywick *et al.* 1991)

Name and definition

Darkys Spur Formation was introduced by Haywick (1990) and formally defined by Haywick *et al.* (1991) to describe a sandstone-dominated unit cropping out in western and northern portions of the Tangoio Block overlying the Aropaoanui Mudstone Member and underlying the Mairau Mudstone Member. The name is derived from Darkys Spur, a steep cliff above the community of Waikoau (Fig. 24A). Beu and Edwards (1984) included this formation in the Park Island Limestone, a correlation supported by Beu (1995). Haywick *et al.* (1991) viewed this correlation as inappropriate as Park Island is many tens of kilometres from the Tangoio Block, and that any correlation between the two areas was far from certain. Also, Park Island Limestone and Darkys Spur Formation are very different in lithology, reflected by separate names. Geological mapping in this study has demonstrated that these two units are most probably correlatives. The definition of the Darkys Spur Formation is emended in this study with the formation now regarded as a member of the Petane Formation, and renamed Darkys Spur Member. The Tararere Conglomerate Member, defined in the Darkys Spur Formation by Haywick *et al.* (1991), is now defined as a discrete bed within the Darkys Spur Member.

Type locality and reference sections

Road cuts midway up Darkys Spur Road, a now renamed part of Kaiwaka Road, are designated as the type section (V20/404104-407105, Column Tg-3). This is the type section established by Haywick *et al.* (1991). Reference sections are designated along the Napier-Wairoa Road at Devils Elbow (V20/447080, Column Tg-4) and immediately north of the mouth of the Aropaoanui River (W20/552065, Column Ap-1).

Lower and upper contacts

On Darkys Spur Road the Darkys Spur Member gradationally overlies the Aropaoanui Mudstone Member through a series of alternating sandstone-siltstone lenses 0.2-1.5 m thick (Fig. 24B, C). It is abruptly overlain by the Mairau Mudstone Member.

Distribution and thickness

Darkys Spur Member is widespread across the Tangoio Block. It is best exposed in road cuts along Darkys Spur Road, in the Devils Elbow section on the Napier-Wairoa Road and at the mouth of the Aropaoanui River. Darkys Spur Formation is age equivalent to middle parts of the Okauawa Formation cropping out in the Ohara Depression, although lateral continuity cannot be demonstrated. The member is a lateral equivalent of the Park Island Limestone Member cropping out in the hills above Taradale, at Fernhill and at Roys Hill.

Conglomerate beds interbedded in the member (Tararere Conglomerate Bed) are restricted to western outcrop areas and are best exposed in the road cutting along Darkys Spur Road (Fig. 26B). Conglomerate facies are also exposed on Eland and Belmont Stations near the Napier-Taupo Road and near Glengarry Road.

Throughout the Tangoio Block the Darkys Spur Member averages 68-90 m thick (Haywick *et al.* 1991). The member thins towards the south. Darkys Spur Member is at least 27 m thick on Darkys Spur Road (Column Tg-3), 16 m thick on the Napier-Wairoa Road (State Highway 2) (Column Tg-4), and 20 m thick at the Aropaoanui River mouth (Column Ap-1).

Description

Darkys Spur Member comprises a wide variety of generally coarse-grained facies that indicate relatively shallow-water to marginal-marine environments of deposition. In the Tangoio Block Darkys Spur Member comprises soft blue-grey to brown-weathering non to highly fossiliferous sandstone with lenses of greywacke conglomerate and minor calcareous sandstone and minor limestone.

The entire member is well exposed from bottom to top at the type section on Darkys Spur Road (Column Tg-3). In this section a variety of facies are present recording several depositional settings. Basal parts of the formation comprise alternating sandstone-siltstone beds (Fig. 24C). Siltstone beds get less common over about 4 m and are eventually overlain by 2 m of clean, well sorted, non to slightly cemented, non fossiliferous, slightly micaceous sandstone. This passes into a 0.5 m-thick bed of sandstone as below, but with abundant siltstone stringers up to 0.1 m

thick. The following 6 m of section comprises non cemented very well sorted slightly micaceous fine to medium sandstone. This interval is weakly laminated throughout, though planar laminations are more prominent in the lower 1.5 m. Scattered concretions up to 0.2 m-thick are present in this layer, with one large, very well cemented concretionary body up to 0.6 m thick prominent in the outcrop. The upper half of this interval is broadly trough cross-bedded with prominent moderately- to tightly-packed shell lenses dominated by disarticulated concave-down shallow-water bivalves such as *Dosinia anus, Rexithaerus spenceri, Tellinota edgari, Peronaea gaimardi,* and the barnacle *Austromegabalanus decorus.* Shell lenses become less prominent up-section. The fossiliferous trough cross-bedded sandstone interval passes gradually into approximately 2 m of non cemented, broadly trough cross-bedded to swaley-bedded, fine to medium sandstone with a 0.15 m-thick greywacke pebble lens. This in turn is capped by a ripple and flaser-bedded siltstone interval 0.2 m thick, and then sharply overlain by an 8 m-thick interval dominated by greywacke conglomerate (Tararere Conglomerate Bed). The lower 2 m of the conglomerate contains lenses and interbeds of non cemented, fine to medium sandstone. The 2 m of greywacke conglomerate itself comprises a crudely trough cross-bedded moderately sorted interval with coarse pebble-sized well rounded lensoidal to spheroidal-shaped clasts. This passes abruptly into 2.5 m of very well sorted strongly laminated greywacke conglomerate. This interval is characterised by alternating packages of granule and fine pebble-dominated beds up to 0.5 m thick. The conglomerate is overlain by a massive non fossiliferous siltstone that itself is truncated by a massive, moderately well sorted medium pebble-dominated greywacke conglomerate.

A variety of facies occur in the succession that overlies the conglomerate interval. This 4 m-thick interval comprises a basal massive, non fossiliferous very fine-grained siltstone that passes into massive, highly carbonaceous very fine-grained siltstone with occasional plant fragments and no marine macrofossils. Overlying this is a non fossiliferous fine-grained siltstone with pumiceous lapilli and fine ash, a greywacke conglomerate lens with angular pebble-sized clasts, and a ripple- and flaser-bedded non fossiliferous pumiceous siltstone. This is capped by a non fossiliferous fine-grained siltstone with scattered fine lapilli-sized pumice clasts. The siltstone is sharply overlain by a 0.2 m-thick blue-grey, moderately fossiliferous silty fine sandstone. Macrofauna are dominated by *Maorimactra ordinaria,* with *Panopea zelandica* and *Nucula nitidula.* This sandstone coarsens rapidly into the overlying 4 m-thick moderately to highly fossiliferous sandstone interval that characterises the Darkys Spur Member in this area. Lowermost parts of this sandstone comprises moderately fossiliferous fine to medium sandstone faunally dominated by *Maorimactra ordinaria.* The remainder of this section comprises well sorted fine to medium sandstone (Fig. 26D) dominated by shallow-water taxa representative of nearshore environments, such as *Fellaster, Struthiolaria frazeri, Dosinia anus,* and *Panopea.*



Fig. 24: Darkys Spur Member (Petane Formation) and adjacent units. **A)** Landscape photograph from Darkys Spur, western Tangoio Block. Major stratigraphic units (named) can be identified from geomorphology. Photograph taken from V20/402108, looking north. **B)** Cliff-face below Darkys Spur Road illustrating the stratigraphic relationship between members of the Petane Formation in this area (V20/403107). This is the type section of the Darkys Spur Member and Tararere Conglomerate Bed. Units conformably overlie each other, although the Tararere Conglomerate Bed has a scoured base. The location of Photo D is marked. **C)** Gradational transition from Aropaoanui Mudstone Member into sandstone of the Darkys Spur Member. Darkys Spur Road (V20/404104). **D)** Highly fossiliferous sandstone of the Darkys Spur Member on Darkys Spur Road (V20/407105). This sandstone overlies non- to marginal-marine conglomerate and siltstone facies. Macrofauna in the sandstone are dominated by shallow-water taxa such as *Fellaster* and *Zethalia*, and are characterised by the large Nukumaruan gastropod *Struthiolaria frazeri*. **E)** Moderately fossiliferous sandstone of the Darkys Spur Member cropping out beside Ridgemount Road, northern Tangoio Block (V20/498145). Shallow-water macrofauna are less common here, and the Tararere Conglomerate Bed is absent suggesting that the member here accumulated in a deeper water setting to that at Darkys Spur, and basinward of the lowstand shoreline.

Darkys Spur Member cropping out on the Napier-Wairoa Road at the Devils Elbow (V20/447080, Column Tg-4) represents a transitional unit between outcrops in the west and east of the Tangoio Block. Greywacke conglomerate beds prominent on Darkys Spur Road are absent at this site, as is the high component of calcareous sediment evident at the Aropaoanui River mouth (V20/552065, Column Ap-1). Darkys Spur Member at Devils Elbow comprises at least 2.5 m of orange-brown, non cemented, massive sandstone with macrofossils both scattered through the unit and concentrated with shellhash into small clusters. The base of the formation at this site has not been accurately located due to the large landslides that have occurred into the Waikoau/Aropaoanui River valley in this area. Fauna are *Fellaster* dominated, with *Gonimyrtea, Calliostoma, Sigapatella, Tanea, Gari lineolata, Maorimactra,* and *Stiracolpus,* and barnacles are also present. This interval is overlain by 1.8 m of sandstone as below with 0.1-0.15 m-thick concretionary beds that are continuous through the section. These more cemented intervals are present every 0.3-0.4 m. This section is overlain by 12 m of differentially cemented medium sandstone with a variable shellhash content. This interval is generally slightly fossiliferous throughout although some moderately fossiliferous areas occur. Fauna are dominated by *Fellaster zelandiae* at the base and changes up-section to be dominated by *Sigapatella novaezelandiae.* In one bed, *Oxyperis komakoensis* was observed. Crudely and broadly laminated slightly cemented bioclastic sandstone intervals up to 1.5 m-thick occur through this 12 m interval which is capped by 2 m of non to slightly cemented concretionary sandstone. Similar sandstone crops out beside Ridgemount Road in the northern Tangoio Block (Fig. 24E). The transition from the concretionary sandstone of the Darkys Spur Member to siltstone of the overlying Mairau Mudstone Member is not exposed in either this section or at Devils Elbow due to vegetation cover, although the change seems to occur quite abruptly at V20/449080.

Darkys Spur Member crops out in high sea-cliffs north of the mouth of the Aropaoanui River (V20/552065, Column Ap-1). Here the formation broadly comprises concretionary sandstone gradationally overlying fossiliferous fine-grained siltstone to sandy siltstone, and in turn is overlain by siltstone. Lower parts of the sandstone unit (at least 10 m thick) comprise several metres of intensely bioturbated non cemented clean, very well sorted, fine to medium sandstone with abundant concretionary lenses and horizons 0.1-0.3 m thick. The sandstone is ripple-laminated to small-scale cross-bedded. Common shell lenses are present and are characterised by shallow-water taxa such as *Dosinia* sp., many of which are articulated, and *Amalda, Zegalerus* and *Zethalia zelandica.* Abundant 1.5-2 cm-thick siltstone stringers are present in the non cemented sandstone layers. Scattered shellhash is present throughout this unit, as are flakes of mica. Up-section the sandstone appears to become slightly more calcareous and passes into concretionary shellhash fine to medium sandstone before passing into a siltstone (Mairau Mudstone Member).

Paleontology and age

Darkys Spur Member contains one of the most diverse shallow-water macrofossil assemblages present in Nukumaruan strata in the study area. Fauna at Darkys Spur are dominated by shallow-water species such as *Fellaster zelandiae, Struthiolaria frazeri, Dosinia* spp., and *Zethalia zelandica*.

Environment of deposition

Fauna observed in the Darkys Spur Member in the Tangoio Block show a deepening pattern from west to east. Fauna at V20/407105 beside Darkys Spur Road (Column Tg-3) are characteristic of shallow-water high-energy settings (e.g. *Fellaster zelandiae*). *Fellaster* are also common on Belmont Station (V20/374987). Fauna at V20/447080 (Column Tg-4) on State Highway 2 (at Devils Elbow) suggest an environment of deposition slightly on the shelf than at Darkys Spur. At Aropaoanui Beach (W20/552065, Column Ap-1) fauna indicate an environment slightly deeper on the shelf than either Devils Elbow or Darkys Spur. Subaerial exposure occurred in the western portion of the Tangoio Block and the Glengarry-Eland-Belmont Station region during deposition of the Darkys Spur Member, as evidenced by the distribution of the Tararere Conglomerate Bed.

Tararere Conglomerate Bed (dst)

(Haywick 1990; formally defined by Haywick *et al*. 1991)

Name and definition

In the western portion of the Tangoio Block the Darkys Spur Member is interbedded with a prominent greywacke conglomerate bed for which Haywick (1990) introduced the name Tararere Member. The name is derived from Tararere Stream (V20 405105). The member was formally defined by Haywick *et al.* (1991). The name has been emended to Tararere Conglomerate Bed, and the unit is now defined as a bed within the Darkys Spur Member.

Type locality and reference sections

The type section designated by Haywick *et al.* (1991) on Darkys Spur Road (Column Tg-3) is retained in this study (V20/405105).

Lower and upper contacts

In the Tangoio Block Tararere Conglomerate Bed is interbedded with the Darkys Spur Member. The lower contact of the Tararere Conglomerate Bed is well exposed on Darkys Spur Road where it sharply overlies a cross-bedded fossiliferous sandstone of the Darkys Spur Member (V20/

405105). The lower contact is well exposed on Belmont Station (V20/372985) where cross-bedded fine to medium sandstone of the Darkys Spur Member is sharply overlain by the Tararere Conglomerate Bed.

In the Tangoio Block Tararere Conglomerate Bed is overlain by a discontinuous oyster and greywacke cobble layer and carbonaceous siltstone of the Darkys Spur Member (Haywick *et al.* 1991). On Eland Station (V20/347020) the conglomerate is overlain by a highly fossiliferous shellbed. At Belmont Station the Tararere Conglomerate Bed is overlain by highly fossiliferous sandstone of the Darkys Spur Member, rich in reworked shallow-water taxa. Although the upper contact is not exposed at on Lucky Hill (V20/337980), fossiliferous float blocks nearby suggest the Tararere Conglomerate Bed is capped by a pebbly shellbed.

Distribution and thickness

The Tararere Conglomerate Bed is restricted to western parts of the Tangoio Block (Haywick 1990), Lucky Hill near Glengarry Road (V20/337980), "Cellphone Tower Hill" on Eland Station, and Belmont Station. In central and eastern parts of the Tangoio Block, Tararere Conglomerate Bed has probably graded into shallow marine sandstone facies. Geological mapping demonstrates that the Tararere Conglomerate Bed is likely to be a lateral equivalent of the conglomerate bed capping the Whakamarumaru Member of the Okauawa Formation, although lateral continuity cannot be demonstrated.

Tararere Conglomerate Bed is 8-15 m thick in the Tangoio Block (Haywick 1990). In the Belmont and Eland Station the member is about 5-6 m thick.

Description

The lower parts of the Tararere Conglomerate Bed at Darkys Spur Road dominantly comprises a non cemented massive, poorly to moderately sorted, fine to medium pebble greywacke conglomerate with clasts 1-2 cm across. Small to moderate-scale trough cross-stratification may be present. Upper parts of the member are better sorted, and display well-developed fine-scale laminations. The average clast size in this upper part is smaller, although larger pebble-sized clasts and layers are still common. Macrofossils are absent to rare, and tend to be concentrated in uppermost capping parts of the member.

In the Glengarry and Belmont Station areas the Tararere Conglomerate Bed comprises laminated to massive greywacke conglomerate. It is often capped by a pebbly shellbed, or fossiliferous sandstone.

Paleontology and age

On Belmont Station (V20/372985) upper parts of the Tararere Conglomerate Bed are moderately fossiliferous. Estuarine and nearshore fauna occur, such as abundant *Austrovenus stutchburyi, Paphies australis* and *Patro undatus.* On "Cellphone Tower Hill", Eland Station (V20/347020), the conglomerate is capped by a 0.15 m-thick highly fossiliferous shellbed containing broken, disarticulated bivalves dominated by *Tawera*.

No age diagnostic macrofossils have been identified in the Tararere Conglomerate Bed. On the basis of stratigraphic position the Tararere Conglomerate Bed is designated a confident "middle" Nukumaruan (Late Pliocene) age.

Environment of deposition

Outcrops on Darkys Spur Road indicate deposition in a combination of shoreface and non-marine settings, with shoreface deposits dominating. Haywick *et al.* (1991) interpreted the lower parts of the bed as representative of a shingle beach. This study interprets lower parts of the bed at the type section as representing non-marine river deposits and upper parts of the bed as shingle beach deposits. Occasional lenticular beds of gravels and rootlet-bearing silts were interpreted by Haywick *et al.* (1991) as non-marine braided stream deposits.

Park Island Limestone Member (dsa)

(Beu and Edwards 1984 (informal); formally defined by Beu 1995)

Name and definition

Kingma (1971) mapped outcrops of limestone cropping out in low hills behind Taradale, near Park Island, as the lower Scinde Island limestone. This unit was named informally Park Island limestone by Beu and Edwards (1984) and formally defined by Beu (1995). Geological mapping has demonstrated that Park Island Limestone Member is equivalent to Darkys Spur Member (Fig. 19E, F), a correlation initially proposed by Beu and Edwards (1984) and supported by Beu (1995). On the basis of stratigraphic position the name Park Island Limestone of Beu (1995) is emended to Park Island Limestone Member, and is incorporated into the Petane Formation. It is defined as a limestone-dominated interval overlying Taradale Mudstone. It is overlain by Mairau Mudstone.

Park Island Limestone Member is named after Park Island, which itself is named after Robert Park, Chief Surveyor of Hawke's Bay (1851-1860). It ceased to be an island after the 1931 Napier earthquake (Beu 1995).

Type locality and reference sections

The type section established by Beu (1995) is retained in this study (V21/417817). This locality comprises long, although incomplete, exposures around the southeastern face of Park Island (Column Td-1).

Lower and upper contacts

In no known location north of the Ngaruroro River is the lower contact of the Park Island Member exposed. The lower contact is exposed at Fernhill immediately south of the Ngaruroro River where the underlying Taradale Mudstone passes gradationally through friable, well sorted fine sandstone into the coarse-grained lower facies of the Park Island Limestone Member (Dyer 2005). The upper contact is exposed in a long section on the southeastern side of Park Island near Taradale (Column Td-1). At this locality siltstone of the Mairau Formation abruptly overlies an *Ostrea-Patro*-rich shellbed that caps the Park Island Limestone Member.

Distribution and thickness

Park Island Limestone Member is restricted in outcrop to southeastern parts of the study area and is present in hills behind Taradale and Puketapu, at Park Island, and the isolated erosional features of Fern Hill and Roys Hill (V. Caron, pers. comm. 2003; Dyer 2005) (Fig. 25A-D). The member is the first coarse-grained, shallow-water unit present in the Taradale area, overlying the Taradale Mudstone.

The outcrop pattern of the Park Island Limestone Member near Napier defines the form of the Taradale Anticline, with low to moderate dips towards the west in the Puketapu area, and low to moderate easterly dips around Taradale and Greenmeadows. The topographic features of Roys Hill and Fern Hill are inferred to represent isolated, fault-bounded blocks. Typically, exposures of Park Island Limestone Member are about 5 m thick, with some up to 8 m thick. A high exposure in an old quarry near Oak Road was described by Moore and Hatton (1985), who estimated a thickness of 18 m. Park Island Limestone Member capping Roys Hill and Fern Hill was estimated by Dyer (2005) to be a maximum of 20 m thick.

Description

Park Island Limestone Member is lithologically quite different to other limestone facies of the upper Mangaheia Group, lacking the greywacke pebbles and relatively intact macrofauna present in other beds (e.g. Waipatiki Limestone Member and limestone facies of the Kaiwaka Formation). Also the colour tends to be grey rather than cream which is typical of other upper Mangaheia Group limestones. Park Island Limestone Member is a lateral, although perhaps slightly more

offshore, equivalent of sandstone facies of the Darkys Spur Member cropping out in the central and eastern Tangoio Block (Fig. 19E, F).

Although not present in one single outcrop, composite sections appear to show that Park Island Limestone Member comprises non to slightly cemented medium- to coarse-grained strongly calcareous bioclastic sandstone that passes up-section into the biomouldic limestone exposed at Park Island. In cuttings on Puketitiri Road (e.g. V21/386824) the lower bioclastic sandstone displays moderate to large-scale foresets up to 3 m high by 15 m long. Thin (< 4 cm thick) highly calcareous siltstone stringers are also present at this locality.



Fig. 25: Park Island Limestone Member (Petane Formation) A) Stacked biomouldic grainstone beds of basal Park Island Limestone Member. Note the prominent tabular cross-beds. (V21/285701) B) Typical outcrops of Park Island Limestone Member, Roys Hill (V21/285701) C) Limestone bluffs around the summit of Roys Hill. D) *Atrina pectinata zelandica* in moderately fossiliferous silty sandstone underlying limestone facies of the Park Island Limestone Member. This silty sandstone gradationally overlies Taradale Mudstone (V21/294701).

In the Puketapu-Penrith Road area (Column Pk-2) the Park Island Limestone Member comprises a grey, slightly to well cemented, shellhash sandy medium-grained limestone with abundant biomoulds and uncommon intact macrofauna. Biomoulds in outcrops near Penrith Road (e.g. V21/379829) contain common calcite needles. Near Penrith Road (V21/379829) dissolution of

macrofauna makes identification of taxa very difficult. However, valves of Anomidae bivalves (*Patro/Anomia*) and *Zethalia* were observed, with occasional polychaete tubes.

At Roys Hill (Fig. 25A-D) and Fern Hill lower parts of the Park Island Limestone Member comprise creamy, strongly bioturbated, cross-bedded skeletal coarse-grained sandy limestone with a high bryozoan content (Fig. 27A-C). Upper parts of the unit consist of grey, coarse-grained well-bedded and strongly cemented recrystallised limestone (Dyer 2005). The unit contains abundant, biomoulds of aragonitic gastropod and bivalves.

Paleontology and age

Fauna is dominated by aragonitic infaunal bivalves that are largely dissolved and partially recrystallised, giving Park Island Limestone Member a prominent biomouldic texture. From fall blocks at the southern end of Park Island, Beu (1995) identified a shallow-water nearshore soft-bottom infaunal assemblage containing *Ostrea chilensis, Tucetona laticostata, Dosinia* sp., *Eumarcia plana, Dosina zelandica,* abundant *Tawera subsulcata, Purpurocardia purpurata, Lutraria solida, Zethalia zelandica* and *Trochus tiaratus. Atrina pectinata zelandica* is present in silty sandstone facies below the main limestone interval (Fig. 25D). Most biomoulds have polychaete tubes and encrusting bryozoans on their interiors indicating empty, single valves (Beu 1995).

Zethalia zelandica (Nukumaruan-Recent) is the only age diagnostic macrofossil observed in the Park Island Limestone Member. Based on stratigraphic position Park Island Limestone Member is of "middle" Nukumaruan (Late Pliocene) age.

Environment of deposition

Sedimentary structures and faunal composition indicate a nearshore to inner shelf, high-energy environment of deposition for the Park Island Limestone Member. It is possible that the lower, bioclastic sandstone facies represents a regressive deposit that accumulated during a period of falling sea level, and the upper limestone bed a transgressive unit that developed during the subsequent sea level rise. The abrupt contact between the Park Island Limestone Member and overlying Mairau Mudstone Member may represent a downlap surface. The nature of the capping *Ostrea* and *Patro*-rich shellbed supports this interpretation.

Development of the Park Island Limestone Member probably reflects synsedimentary uplift of the Taradale Anticline.

Mairau Mudstone Member (mr)

(Haywick 1990; formally defined by Haywick *et al.* 1991)

Name and definition

Beu and Edwards (1984) informally named the siltstone unit between the Darkys Spur Member and the Tangoio Limestone Member the Petane mudstone, a name that has had a long informal usage (Beu 1995). Haywick (1990) introduced Mairau Formation to avoid confusion with the (now redefined) Petane Group, the name formally being defined by Haywick *et al.* (1991). The name is derived from Mairau Stream (V20/460078). Beu (1995) emended the name to Mairau Mudstone to reflect the dominant lithology. The definition of Beu (1995) is emended in this study to Mairau Mudstone Member as the unit is now incorporated into the Petane Formation. Mairau Mudstone Member is mostly equivalent to the undefined "Waitio pumiceous siltstone" mapped by Kingma (1971). Mairau Mudstone Member is defined as a siltstone to sandy siltstone interval that conformably overlies the Darkys Spur Member and is overlain by the Tangoio Limestone Member (Fig. 19D-F).

Type locality and reference sections

The type section established by Haywick *et al.* (1991) on Te Taihoa Farm is retained (V20/ 467087).

Distribution and thickness

Mairau Mudstone Member is widespread throughout central and eastern parts of the study area, cropping out widely through the Tangoio and Eskdale regions. Towards the southwest it is probable that Mairau Mudstone Member interdigitates with middle to upper parts of the Okauawa Formation. In the lower reaches of the Mangaone River, near Rissington, the Mairau Mudstone Member cannot be differentiated from the Esk Mudstone (Enclosure 5).

Away from the Tangoio Block and Bayview areas the Mairau Mudstone Member is poorly exposed, although the unit is almost certainly present in the subsurface. The member is not exposed through the central parts of the Matapiro Syncline in the Okawa-Matapiro area where it is in the subsurface. Very limited exposures are present around Puketapu.

The Mairau Mudstone Member thickens westward across the Tangoio Block from 10 to 60 m thick (Haywick *et al.* 1991). The member thins southwest into the Matapiro district where it is between 20 and 30 m thick (Baggs 2004).

Lower and upper contacts

Mairau Mudstone Member gradationally overlies fossiliferous sandstone beds of the Darkys Spur Member, or the Tararere Conglomerate Bed. It is inferred to gradationally overlie the Whakamarumaru Member of the Okauawa Formation in an northeast-southwest-trending outcrop belt from Mount Cameron, through Flag Range to Crownthorpe Road.

Mairau Mudstone Member coarsens up-section and grades over 5-10 m into sandstone of the Tangoio Limestone Member throughout the outcrop area.

Description

Mairau Mudstone Member mostly comprises non cemented, slightly to moderately fossiliferous siltstone passing up-section into silty fine sandstone. In the Ahuriri/Bayview area, Mairau Mudstone Member may be represented by moderately fossiliferous fine sandstone facies.

The Mairau Mudstone Member has a similar character through the Sherenden and Crownthorpe regions where it comprises bioturbated massive sandy siltstone to silty sandstone with scattered macrofossils (Baggs 2004).

Paleontology and age

Mairau Mudstone Member contains a moderately diverse macrofossil assemblage through the area of outcrop. Fauna present are indicative of open marine circulation (Haywick 1990).

Mairau Mudstone Member contains a well constrained biostratigraphic molluscan content. The member contains the last occurrence of *Pelicaria acuminata* (Beu and Edwards 1984) and first occurrence of *Pelicaria convexa* (Beu 1995). Stratigraphic position and the co-occurrence of *P. acuminata* and *P. convexa* confirm an Upper Nukumaruan age for Mairau Mudstone Member (Late Pliocene).

Environment of deposition

Macrofauna from the Mairau Mudstone Member in the Tangoio Block are consistent with a middle shelf (50-100 m) environment of deposition with open marine circulation (Beu 1967; Haywick 1990). To the southwest in the Okawa-Matapiro area, macrofauna are similar to those in the Tangoio Block (Baggs 2004), and a middle shelf depositional environment is also inferred.

Tangoio Limestone Member (tg)

(Beu and Edwards 1984; formally defined by Haywick *et al.* 1991)

Name and definition

Tangoio limestone was introduced as an informal name by Beu and Edwards (1984), and applied to a carbonate-dominated unit conformably overlying the Mairau Mudstone in the Tangoio Block. The unit was given formation status by Haywick *et al.* (1991). The name is derived from Tangoio Settlement in the southeastern part of the Tangoio Block (V20/474101). The definition of Tangoio Formation has here been emended from that of Haywick *et al.* (1991) and Beu (1995) to Tangoio Limestone Member, incorporated into the Petane Formation.

Type locality and reference sections

The type section established by Haywick *et al*. (1991) has been retained in this study. It is located on Hikuroa Farm (V20/393098).

Distribution and thickness

Tangoio Limestone Member is widely distributed throughout the Tangoio Block and Matapiro Syncline areas. The member is well exposed in sea cliffs north and south of Waipatiki Beach (Fig. 26A, B, D, F). The member prominently crops out on the eastern limb of the Matapiro Syncline around Puketapu (Fig. 26E, G). Outcrops on Swamp Road (Fig. 26C), identified as Matapiro (Waipatiki) Limestone by Beu (1995), have been demonstrated by Baggs (2004) to be Tangoio Limestone Member, extending the occurrence of the member south into low hills around Omahu. The member dips into the subsurface in these areas, and re-emerges on the western limb of the Matapiro Syncline as the Flag Range Conglomerate Member.

A faulted limestone outlier at the northern end of Waipatiki Beach where State Highway 2 turns inland is included in Tangoio Limestone Member on the basis of lithological similarity with nearby known Tangoio Limestone Member exposures (D. Haywick, University of South Alabama, pers. comm. 2003) and stratigraphic position.

Outcrops of Tangoio Limestone Member through the Taradale and Omahu areas were mapped in part as Lower Scinde Island limestone by Kingma (1971), a correlation that this study has demonstrated from geological mapping is not possible.

Tangoio Limestone Member is 10-50 m thick (Haywick *et al.* 1991) in the Tangoio Block, 10 to 20 m thick in the Puketapu, Taradale, and Okawa-Matapiro areas (Baggs 2004).

Lower and upper contacts

In the Devils Elbow section (Column Tg-4) calcareous sandstone of the Tangoio Limestone Member gradationally overlies siliciclastic silty sandstone of the Mairau Mudstone Member. The Te Ngaru Mudstone Member abruptly overlies the upper limestone facies of the Tangoio Formation in this section, as it does in exposures along the Pacific coast between Tangoio Beach and Waipatiki Beach. This contact is marked by a concentration of large articulated bivalves such as *Glycymeris* and *Ostrea* (Haywick *et al*. 1991). The upper contact is not exposed through the Puketapu (Column Pk-3) and Omahu (Column Ou-1) areas, but it seems probable that limestone in these regions is also abruptly overlain by siltstone of the Te Ngaru Mudstone Member. Limestone beds in these regions are also capped by a shellbed rich in *Ostrea*.

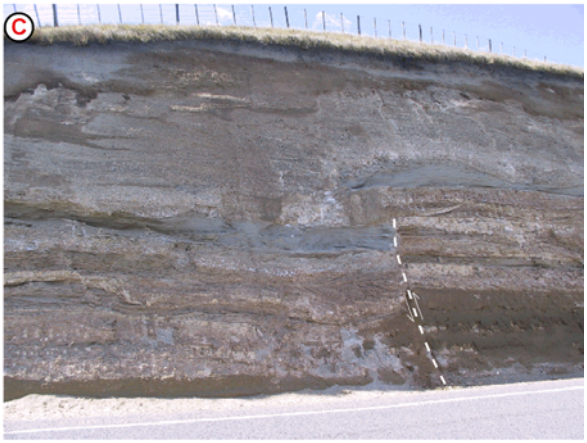
Description

Tangoio Limestone Member varies in content through its outcrop extent, ranging from sandstone overlain by sandy limestone, to calcareous sandstone to pebbly oyster-rich limestone. The member passes laterally and up-dip into non to highly fossiliferous conglomerates of the Flag Range Conglomerate Member. The change in lithological character of the member reflects differing paleogeography on the margins of the basin during sedimentation. As a rule, coarser-grained and more siliciclastic facies in the member occur in more westerly positions than bioclastic facies. Throughout the study area, Tangoio Limestone Member contains a diverse range of sedimentary structures. Such structures include small to moderate-scale cross-stratification, planar lamination, flaser-bedding and soft-sediment deformation structures. Well developed bedforms are particularly well exposed along the Devils Elbow Section and on Swamp Road near Puketapu (Fig. 26C).

Fig. 26 (facing page): Tangoio Limestone Member, Petane Formation. **A)** Sea-cliff exposure of Tangoio Limestone Member south of Waipatiki Beach (W20/523032). The Tangoio Limestone Member is gradationally overlain by the Te Ngaru Mudstone Member (tn) which then grades into the Waipatiki Limestone Member (wk). **B)** Tangoio Limestone Member cropping out in sea-cliffs south of Waipatiki Beach (W20/521029). The member here comprises stacked grainstone bodies. Case-hardening is common. **C)** Tangoio Limestone Member exposed in a road cutting beside Swamp Road between Puketapu and Omahu. A small fault (dashed white line) highlights offset of the member, indicating syn-depositional deformation in the basin. **D)** Bed of the shallow-water echinoid *Fellaster zelandiae* in Tangoio Limestone Member south of Waipatiki Beach (W20/521029). Thin shellbeds containing this and other shallow-water molluscs are common in this area. **E)** Tangoio Limestone Member cropping out beside the Tutaekuri River near Puketapu (V21/358804). This outcrop contains abundant soft-sedimentary deformation structures, including inferred water escape structures, that indicate syn-depositional deformation of the basin during the Upper Nukumaruan. **F)** Burrowed sandy interbed in lower parts of the Tangoio Limestone Member, south of Waipatiki Beach (W20/521029). **G)** Close-up of Tangoio Limestone Member near Puketapu showing prominent deformation structures (V21/358804).


A
wk
tn
tg


B


C


D


E


F


G

In the Devils Elbow section (Column Tg-4) the Tangoio Limestone Member comprises strongly cross-bedded and laminated sandstone that passes conformably up into sandy mixed bioclastic-siliciclastic limestone. Tangoio Limestone Member cropping out around Puketapu comprises strongly cross-bedded, moderately to well cemented, medium to coarse-grained cream limestone. Foresets are of small to large-scale, and low to high-angle. In the main, large areas of most outcrops display case-hardening, and the internal stratification of the formation is not easily visible. Few intact fossils have been found in this area, although shellhash dominates the composition.

In the Puketapu area (Fig. 26D, G) this limestone bed contains a higher bioclastic content (though still with noticeable siliciclastic material) and overlies calcareous sandstone with mudstone stringers. The contact between these two layers is not exposed here, but a similar exposure is present in a cutting along nearby Swamp Road (Fig. 26C). At this locality the limestone sharply overlies calcareous sandstone with common cross-stratification and mudstone stringers via a wavy, broad-amplitude contact. This outcrop was miscorrelated by Beu (1995) to the Waipatiki [Limestone Member], as geological mapping in this study can demonstrate a confident correlation with Tangoio Limestone Member.

At the base of sea cliffs south of Waipatiki Beach (W20/521029) the Tangoio Limestone Member is exposed as a sandy limestone with abundant shelly layers, often dominated by the shallow-water echinoid *Fellaster* (Fig. 26D). The lower contact here is not exposed, although the limestone is sharply overlain by siltstone of the Te Ngaru Mudstone Member.

The most southerly outcrops recognised of Tangoio Limestone Member occur in low hills immediately east of the small village of Omahu where the formation comprises weathered sandy limestone a few metres thick with abundant biomoulds capped by a thin *Ostrea*-dominated shellbed. The distribution of the Tangoio Limestone Member in this area was geologically mapped by Baggs (2004). The formation here is commonly strongly cross-bedded and has the form of stacked mixed bioclastic-siliciclastic sheets, each 0.1-0.3 m thick. This area of outcrop occurs on the eastern limb of the Matapiro Syncline.

Throughout the outcrop extent of the Tangoio Limestone Member, case hardening of the limestone facies is common. Fauna are dominated by aragonitic infaunal bivalves and because of this dissolution and partially recrystallisation of these shells is widespread. Biomoulds are also abundant.

Paleontology and age

Fauna are dominated by aragonitic infaunal bivalves such as *Tawera,* identification of which is often difficult due to dissolution of valves. An *Ostrea*-rich shellbed is common capping the limestone, especially through the Puketapu-Omahu areas. A limited macrofossil assemblage has been collected from the Devils Elbow section. Fauna through the formation here are dominated by *Tawera subsulcata*, with *Maorimactra ordinaria, Oxyperis* and *Ostrea chilensis.* Intact macrofauna near Waipatiki Beach are dominated by beds of the shallow-water echinoid *Fellaster zelandiae* (Fig. 26D).

A confident Upper Nukumaruan (Late Pliocene) age is assigned to the Tangoio Formation based on the occurrence of several Nukumaruan molluscs, such as *Pelicaria convexa*, and stratigraphic position.

Environment of deposition

Fauna and sedimentary structures within the Tangoio Limestone Member are consistent with a shoreface to inner shelf environment of deposition. Tangoio Limestone Member in western parts of the outcrop area were deposited at more shallow marine depths than beds in eastern areas.

Flag Range Conglomerate Member (tga)

(Beu 1995)

Name and definition

Beu (1995) formally defined Flag Range Limestone and Sherenden Conglomerate Member to include a prominent variably fossiliferous conglomeratic interval cropping out widely in the Sherenden and Matapiro districts. The name is emended in this study to Flag Range Conglomerate Member. The name is derived from the prominent conglomerate-capped ridge named Flag Range near Sherenden. This interval has in the past been included in a wide variety of stratigraphic units. Rocks of the Flag Range Conglomerate Member were included in part in the informal Sherenden greywacke gravels of Kingma (1971). Baggs (2004) mapped this interval as the Sherenden Conglomerate Member of the Flag Range Formation. It is proposed that the Flag Range Limestone of Beu (1995) be redefined as a member of the Petane Formation for several reasons. Firstly, Beu considered his Flag Range Limestone to be a lateral equivalent of the Tangoio Limestone Member. Geological mapping in this study has demonstrated that both the Tangoio Limestone Member (as mapped by Haywick 1990) and the Flag Range Limestone (and Sherenden Conglomerate Member) of Beu (1995) are most probably the same stratigraphic unit. Secondly, there is *very little if any* true limestone in Beu's definition of Flag Range Limestone.

In reality the formation is greywacke gravel-dominated with a localised increase in macrofossil content along the crest of Flag Range. In all other areas the Flag Range Limestone consists of a significant thickness of non fossiliferous greywacke conglomerate that is capped by up to 2.5 m of fossiliferous conglomerate. Thirdly, by including the Flag Range Conglomerate Member in the Petane Formation the stratigraphy of the study area is simplified by reducing the number of stratigraphic units.

The name Flag Range (from Beu 1995) is retained over Sherenden (from Kingma 1971) as Flag Range was formally defined, whereas Kingma's name remained informal. The Sherenden Conglomerate Member of Beu (1995) is incorporated into the Flag Range Conglomerate Member of this study.

Flag Range Conglomerate Member sharply though conformably overlies either siltstone and sandstone beds of the Okauawa Formation, or silty sandstone of the Mairau Mudstone Member, and is abruptly though conformably overlain by siltstone of the Te Ngaru Mudstone Member (Fig. 19D).

Type locality and reference sections

The type locality established by Beu (1995) on the crest of Flag Range (Fig. 29A) is retained in this study (V21/193851). Caron (2002, column F1) logged this section and documented elements of the diagenetic history of this section.

Excellent reference sections are common through the study area. Very well preserved, highly fossiliferous horizons are well exposed in Kikowhero Stream immediately above and below the Matapiro Road bridge (V21/192726). A cutting on Puketitiri Road, near Apley Road, clearly displays a highly fossiliferous estuarine variant of the member (V21/315884). The transition from the lower non fossiliferous into upper fossiliferous parts of the member are well exposed in a gravel pit on Muritai Station near Crownthorpe Settlement Road (V21/156786). The transition from the upper fossiliferous part of the member to overlying Te Ngaru Mudstone Member is well exposed on Taihape Road south of the Flag Range Road intersection (V21/185827, Column Sh-1). Large parts of the member are exposed in a farm track leading up to the summit of Mount Cameron from Waihau Road (V21/251881, Column Da-1).

Distribution and thickness

Flag Range Conglomerate Member crops out in a northeast-southwest belt from Puketitiri Road to Matapiro Road, capping the prominent hilltops of McNeil, Mount Cameron (Column Da-1) and

Flag Range (Fig. 27A; Column Sh-2). The distribution of the unit through the Matapiro area was mapped by Baggs (2004) Cuttings through the Flag Range Conglomerate Member occur along Taihape Road, south of the Flag Range Road intersection, and along Crownthorpe Road. The member occurs as far south as Kikowhero Stream on Matapiro Station, where it dips beneath fluvial terrace gravels comprising the modern land surface, and re-emerges on the eastern side of the Matapiro Syncline near Swamp Road and Omahu as a limestone facies of the Tangoio Limestone Member. Towards the southwest into the Ohara Depression the Flag Range Conglomerate Member appears to pass into highly fossiliferous fine sandstone facies of the Okauawa Formation. Superposition indicates that Flag Range Conglomerate Member is a lateral equivalent of Tangoio Limestone Member limestone facies cropping out widely in the low hills around the Tangoio Block, Bayview, Puketapu, Taradale and Omahu, an interpretation supported by the geological mapping of Baggs (2004).

Fossiliferous gravel facies of the member are perhaps thickest in the lower reaches of Kikowhero Stream at the Matapiro Road bridge, and on the summits of Flag Range and Mount Cameron (Fig. 29D). The non fossiliferous gravel facies are thickest in the Crownthorpe and Sherenden regions.

The Flag Range Conglomerate Member is a maximum of 20 m thick.

Lower and upper contacts

Flag Range Conglomerate Member sharply overlies fine sandstone of the Okauawa Formation. This lower contact is only exposed at Mount Cameron (V21/251880, Column Da-1).

The upper contact is exposed in three locations. In the lower reaches of Kikowhero Stream below the Matapiro Road bridge the member is gradationally overlain by siltstone of the Te Ngaru Mudstone Member (V21/251880). This gradational contact is also exposed in cuttings on Taihape Road immediately south of the Flag Range Road intersection (V21/185827). On Flag Range oyster-dominated pebbly limestone is gradationally overlain by siltstone (V21/196844).

Description

Flag Range Conglomerate Member represents a more westerly and shoreward expression of the Tangoio Limestone Member and appears to have developed in close proximity to a major source of greywacke detritus adjacent to a fan-delta fluvial system. Flag Range Member comprises two distinctive units: a lower non fossiliferous greywacke conglomerate similar to those present in the Matahorua Formation; and a pebbly limestone to shelly conglomerate rich in valves of robust, shallow-water dwelling bivalves (Fig. 27B-E). The pebbly limestone expression of the upper beds

is restricted to the top of Flag Range and parts of adjacent Mount Cameron. Fossiliferous gravels are more widespread cropping, out from the lower reaches of Kikowhero Stream northeast to Puketitiri Road.

The upper shelly conglomerate typically comprises moderately to highly fossiliferous clast-supported greywacke conglomerate rich in fauna characteristic of shallow-water, relatively high-energy settings. In the lower reaches of Kikowhero Stream (Fig. 27B, C), the Flag Range Conglomerate Member comprises alternating gravelly-sandy bodies. *In situ*, articulated *Tawera subsulcata* valves are abundant in the finer-grained sandy layers which interfinger with, and are erosionally overlain by, shelly gravel beds. Fauna in gravelly layers are rich in *Zethalia zelandica* and *Dosinia,* with common *Lutraria* and *Alcithoe*. Below the Matapiro Road bridge the member gradationally passes into fine-grained fossiliferous siltstone of the Te Ngaru Formation through a pebbly fossiliferous basal zone.

The thickness of both main facies of the Flag Range Member varies through the study area. The lower non fossiliferous conglomerate interval is thickest in the region of Crownthorpe Settlement Road. The upper shelly conglomerate interval is thickest along the crest of Flag Range. A higher bioclastic content in the area of Flag Range, Mount Cameron and McNeil has led to increased cementation of the Flag Range Conglomerate Member relative to other areas, and hence more resistance to erosion (and the resulting higher topography than surrounding areas).

Fig. 27 (facing page): Flag Range Conglomerate Member. **A)** Panorama of the crest of Flag Range around the type section of the Flag Range Conglomerate Member (V21/191842). ok, Okauawa Formation; tga, Flag Range Conglomerate Member. **B)** Highly fossiliferous *Tawera subsulcata*-dominated (arrowed "t") shellbeds in the Flag Range Conglomerate Member, Kikowhero Stream, Matapiro Station (V21/192726). Other arrowed macrofossils common at this site are "p"-*Patro undatus*, "a"-*Atrina pectinata zelandica*, and "pp"-*Panopea zelandica*. **C)** Slightly to highly fossiliferous conglomerate in cliff-face exposure, Kikowhero Stream, Matapiro Station (V21/192726). **D)** Fossiliferous conglomerate to pebbly limestone facies of Flag Range Conglomerate Member at the summit of Mount Cameron (V21/251880). This locality is directly along strike and northeast and across the Tutaekuri River from the type section at Flag Range. **E)** *Ostrea chilensis*-dominated pebbly limestone facies of the Flag Range Conglomerate Member on Flag Range (V21/200838).


A
tga
ok


B
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C


D


E

Paleontology and age

Macrofauna in the Flag Range Conglomerate Member are dominated by thick-shelled, robust, epifaunal to semi-infaunal taxa such as *Ostrea, Tucetona, Glycymeris.* Locally *Zethalia zelandica* is very abundant. *Patro undatus, Ostrea chilensis* and *Purpurocardia purpurata* are common in outcrops along the summit ridge of Flag Range Road. Abundant estuarine bivalves such as *Austrovenus stutchburyi* and *Xenostrobus huttoni* are present in a cutting on Puketitiri Road immediately north of Apley Road. A similar *Xenostrobus*-rich shelly conglomerate occurs on Hedgeley Station near the series of lakes (V20/353266). Assemblages rich in *Tawera, Purpurocardia* and *Tucetona* are common in exposures in Kikowhero Stream, above Crownthorpe Road and in cuttings along Taihape Road (Between Flag Range Road and Black Bridge).

A confident Upper Nukumaruan age can be assigned to the Flag Range Conglomerate Member based on faunal content and stratigraphic position. The co-occurrence of *Lutraria solida* (Wp-Wn) and *Zethalia zelandica* (Wn-Wq) confirms a Nukumaruan age for this unit.

Environment of deposition

Flag Range Conglomerate Member accumulated in a variety of contemporaneous non-marine, marginal-marine and shallow-water nearshore settings in proximity to a large source of greywacke detritus. The dominant lithology of the member is the basal non fossiliferous massive to laminated and cross-bedded greywacke conglomerate. This basal interval is inferred to have been deposited in a non-marine to shoreface setting as part of a prograding fan-delta system. Progradation probably occurred during a sea level lowstand. The overlying highly fossiliferous conglomerate beds of the member are inferred to have been deposited during the subsequent sea level transgression over the fan-delta.

The common to abundant presence of *Zethalia zelandica* is a clear indicator of high-energy very shallow nearshore environments. Assemblages rich in *Tawera, Purpurocardia* and *Tucetona* are common in modern environments such as tidal channels near the heads of harbours such as Whangarei. Such assemblages are common at Crownthorpe Road, and in cuttings along Taihape Road (Between Flag Range Road and Black Bridge).

Based on the diverse macrofaunal association observed in Kikowhero Stream (Fig. 27B, C), a harbour-type sheltered embayment very close to a high-bedload river system supplying abundant greywacke detritus is envisaged for this site. The fauna present at this locality are consistent with modern day faunal assemblages in many harbours and semi-enclosed water bodies, such as Whangarei Harbour and the Hauraki Gulf. Sandstone lenses exposed in Kikowhero Stream are

inferred to represent normal background sedimentation and were quickly colonised by large numbers of *Tawera subsulcata,* abundant specimens of which are preserved articulated and in life position. In the Hauraki Gulf, modern beds of *Tawera* can reach densities of up to 25,000 individuals/m^2 (Hendy and Kamp 2004). Periodically shifting substrate buried and scoured into these sandy layers, which themselves were buried and scoured in time by more sandy horizons. Overlying coarser-grained pebbly substrates were colonised by robust semi-infaunal bivalves such as *Tucetona laticostata, Purpurocardia purpurata* and *Glycymeris shrimptoni*. The shallow-water-restricted (3-5 m water depth; Beu and Maxwell 1990, p. 347) gastropod *Zethalia zelandica* is very abundant in these gravelly beds and its presence with *Tucetona, Purpurocardia and Glycymeris* strongly suggests remobilisation of nearshore beds out into deeper water. These coarser-grained intervals may therefore represent storm or flood-emplaced deposits. Uncommon highly-abraded fragments and valves of *Austrovenus stutchburyi* were observed and further suggest remobilisation of nearshore deposits. *Xymene plebeius* is a further indicator species for a nearshore, shallow-water environment (Beu and Maxwell 1990, p. 360).

Contemporaneous estuarine settings are evident in the Puketitiri Road and Hedgeley Station areas, supported by the common to abundant presence of diagnostic estuarine taxa such as *Austrovenus stutchburyi* and *Xenostrobus huttoni*. The occurrence of common flaser bedding, mud drapes and ripple lamination also support an estuarine setting in these areas. By contrast, a nearby slightly deeper water setting is envisaged for areas around the summit ridge of Flag Range (Fig. 27A), and to a lesser degree Mount Cameron and McNeil. The *Ostrea*-rich assemblage in these areas is suggestive of a high-energy current-swept tidal channel, with common *Purpurocardia purpurata*.

The more fossiliferous, bioclastic-rich nature of beds capping Flag Range may represent a slightly deeper water broad channel more favourable to *Ostrea* than surrounding areas.

In essence the Flag Range Conglomerate Member represents the more shoreward, marginal-marine part of the Tangoio Formation. In the Tangoio Block equivalent depositional facies of the member are not present and have probably been removed through erosion of the western margin of the block by the modern Esk and Waikoau River systems.

Te Ngaru Mudstone Member (tn)

(Beu and Edwards 1984; formally defined by Haywick *et al.* 1991)

Name and definition

The mudstone overlying the Tangoio Limestone Member and underlying the Waipatiki Limestone Member was informally referred to as Te Ngaru mudstone by Beu and Edwards (1984), and was formally defined by Haywick *et al.* (1991). The name is derived from Te Ngaru Stream (V20/431029). The definitions of Haywick *et al.* (1991) and Beu (1995) are emended in this study to Te Ngaru Mudstone Member, with the interval included in the Petane Formation. Geological mapping has demonstrated that Te Ngaru Mudstone Member in the Tangoio Block and the Waitio Mudstone of Beu (1995) are likely the same stratigraphic unit. Because Te Ngaru Mudstone has precedence over Waitio Mudstone, Waitio Mudstone is now included within the Te Ngaru Mudstone and the name Waitio disestablished.

Type locality and reference sections

The type section nominated by Haywick *et al.* (1991) in Te Ngaru Stream (V20/431029) has been retained in this study.

A good section through the southern part of the member occurs on the true left bank of the lower reaches of Kikowhero Stream, 300-400 m north of the Omapere Road bridge (V21/213703) (Baggs 2004). This section, known as "Shrimptons", incorporates the type section of the old Waitio Mudstone (now part of the Te Ngaru Mudstone Member). Shrimptons has been an important fossil collection site for nearly 100 years, the name derived from the original owner of Matapiro Station, Walter Shrimpton (Beu 1995).

Distribution and thickness

Geological mapping in this project has extended the occurrence of Te Ngaru Mudstone Member south of the Tangoio Block into the Puketapu and Matapiro areas. Good exposures through the Te Ngaru Mudstone Member occur on State Highway 2 near White Pine Bush reserve. The member is also well exposed in sea-cliffs from Tangoio settlement north to Waipatiki Beach. Te Ngaru Mudstone Member, while present, does not crop out widely through the Matapiro-Okawa area. Exposures are largely limited to the lower reaches of Kikowhero Stream below the Matapiro Road bridge, and occasional, weathered outcrops along Taihape Road between Black Bridge and Flag Range Road.

In the Tangoio Block, Te Ngaru Mudstone Member is 10-40 m thick. Baggs (2004) estimated Te Ngaru Mudstone Member in the Matapiro-Okawa area to be 30-50 m thick.

Lower and upper contacts

In the Tangoio Block, Te Ngaru Mudstone Member abruptly overlies the *Ostrea*-rich capping shellbed of the Tangoio Limestone Member. The upper contact varies through the Tangoio Block, with Te Ngaru Mudstone Member either grading into, or sharply overlain by, the Waipatiki Limestone Member. The gradational contact is well exposed in the Devils Elbow section (Column Tg-4), in sea cliffs around Waipatiki Beach, and on Puketitiri Road (Column Gg-2). The sharp contact is visible in the Darkys Spur area.

In the Glengarry-Puketitiri Road area (e.g. Columns Gg-2, Rs-1) Te Ngaru Mudstone Member coarsens up-section and is gradationally overlain by interbedded sandy and muddy horizons of the Waipatiki Limestone Member. In the Matapiro-Okawa districts the upper contact is not exposed and it is inferred that shellbeds of the Waipatiki Limestone Member gradationally overlie Te Ngaru Mudstone Member.

Description

Te Ngaru Mudstone Member typically comprises non cemented blue-grey to pale-brown, massive siltstone and silty sandstone with scattered to common macrofossils. Around Puketapu, Te Ngaru Mudstone Member comprises blue-grey to light-grey, non cemented, slightly micaceous siltstone that coarsens upsection into fine sandstone.

The Te Ngaru Mudstone Member tends to be less fossiliferous south of the Tangoio Block, although macrofossils are still common. A particularly fossiliferous section occurs at “Shrimptons” in the lower reaches of Kikowhero Stream, near Matapiro Station (V21/212702) (Beu 1995).

Paleontology and age

Abundant valves of juvenile and adult *Talochlamys gemmulata* occur, together with juvenile *Ostrea chilensis, Maoricolpus roseus* and brachiopods. Other partially dissolved and unidentified bivalves and gastropods also occur. Exposures in Kikowhero Stream at “Shrimptons” comprise moderately fossiliferous siltstone with a diverse macrofossil assemblage.

The Te Ngaru Mudstone Member contains common *Pelicaria convexa* form *“fossa”,* indicating a depositional environment slightly deeper than that for the underlying Aropaoanui and Mairau Mudstones. The occurrence of *Pelicaria convexa* form *“fossa”* and *Austrofusus taitae*, together

with stratigraphic position, constrain the Te Ngaru Mudstone Member to an Upper Nukumaruan (Late Pliocene) age.

Environment of deposition

The molluscan fauna, rich in *Pelicaria convexa* form *"fossa"* through the Tangoio Block, indicate an open marine, middle to outer shelf environment of deposition (Beu 1995). *P. convexa* form. *"fossa"* further suggests that water depths over the Tangoio Block during deposition of the Te Ngaru Mudstone Member were greater than during deposition of the underlying Mairau Mudstone Member (Beu 1995).

Pelicaria convexa form *"fossa"* is also common in Te Ngaru Mudstone Member cropping out through the Matapiro district (Baggs 2004), confirming an open marine, middle to outer shelf depositional setting in this area.

Waipatiki Limestone Member (wk)

(McKay 1887; formally defined by Haywick *et al.* 1991)

Name and definition

McKay (1887) referred to the upper beds at Petane as the Waipatiki Beds. Beu and Edwards informally named these units the Waipatiki limestone, with Haywick *et al.* (1991) formally defining the unit. The name is derived from the settlement of Waipatiki Beach, midway along the eastern coastal margin of the Tangoio Block. These definitions are emended in this study, and the interval is now named the Waipatiki Limestone Member, part of the Petane Formation. Waipatiki Limestone Member is defined as a limestone-dominated succession conformably overlying the Te Ngaru Mudstone Member and overlain by the Devils Elbow Mudstone Member.

Kingma (1971) mapped limestone beds in the Matapiro-Crownthorpe region as upper Scinde Island limestone (informal), and by implication assigned a Lower Nukumaruan age to them. As these limestone beds are actually significantly younger (i.e. they are of Upper Nukumaruan age) than any limestone at Scinde Island, Beu (1995) introduced Matapiro Limestone as a formal name for these Upper Nukumaruan beds. Geological mapping in this study has demonstrated lateral continuity between the Matapiro limestone of Beu (1995) and the Waipatiki Limestone Member. This correlation was first proposed by Beu (1995). Given the long historical usage of the name Waipatiki, the Matapiro Limestone is now incorporated into the Waipatiki Limestone Member and the name Matapiro discontinued.

Type locality and reference sections

The type locality designated by Haywick *et al.* (1991) on Hikuroa Farm is retained in this study (V20/393097).

Complete exposure of the member occurs on Puketitiri Road, near the Glengarry Road intersection from the gradational lower contact with the Te Ngaru Mudstone Member to the abruptly gradational upper contact with the Devils Elbow Mudstone Member (V21/333882, Column Gg-2). This section provides an excellent window into the character of the formation through its central outcrop area. The Devils Elbow section on State Highway 2 provides an excellent section through the central part of the member in the Tangoio Block with complete exposure of the formation, including lower and upper contacts (V20/458079, Column Tg-4).

Other useful reference sections are widespread through the study area. Excellent well exposed sections through the lower shellbed member and upper limestone member occur on Waipunga Road, at Lambs Corners (local name) on Taihape Road (V21/293749), and Kawera Road, Ngamahanga Station (V21/273811, Column Ok-1). Coastal cliffs south of Waipatiki Beach display the transition from the Te Ngaru Mudstone Member to Waipatiki Limestone Member (Fig. 28A), although access is difficult. A strongly cross-stratified expression of the limestone part of the formation is well exposed on Ohiti Road near Taihape Road, (V21/300732).

Lower and upper contacts

Where exposed the lower contact is always observed to be gradational. This transition is well exposed at the Devils Elbow Section (Column Tg-4), in coastal cliffs south of Waipatiki Beach (Fig. 28A), and at Puketitiri Road (Fig. 28D, E; Column Gg-8). The upper contact is abruptly gradational at Puketitiri Road, and abrupt at the Devils Elbow section.

Distribution and thickness

Waipatiki Limestone Member is one of the most widespread of the Mangaheia Group limestone units, and correlation of this formation has been a key in determining the Nukumaruan stratigraphy throughout the study area. The member is expressed mostly as a limestone unit (with common sandstone facies) in a northeast-southwest trending belt that extends from Ridgemount Road in the northern Tangoio Block to Matapiro Station just north of the Ngaruroro River. The well cemented nature of the upper limestone beds of the member means that outcrops are common, and the unit, compared to others in the study area, can be mapped relatively easily across the basin. Outcrop is relatively continuous, except for a small area in the Hedgley Road-Eskdale area,

and correlation between outcrops in the Tangoio Block and the Matapiro-Okawa area is confident. This correlation was suggested, but not confirmed by Beu (1995) and Baggs (2004).

Two prominent limestone bodies, separated by a 20 m-thick siliciclastic interval (Caron 2002) crop out on Ohiti Road, near Omahu, and were both incorporated into the Matapiro Limestone of Beu (1995), Caron (2002) and Baggs (2004). As discussed above, geological mapping has demonstrated that the Matapiro Limestone is an equivalent of the Waipatiki Formation, and as such has been incorporated into the Waipatiki Limestone Member. At no known locality are two separate "cycles" present in the Waipatiki Formation. Indeed, in no other locality of "Matapiro Limestone" did any of Beu (1995), Caron (2002) or Baggs (2004) identify a second, upper limestone unit or cycle. The upper limestone unit present at Ohiti Road has been correlated with a prominent, sharp-based shellbed well exposed further along Ohiti Road towards the Matapiro Road intersection. A more logical interpretation of the Ohiti Road section is that siltstone overlying the lower limestone body at Ohiti Road is equivalent to the Devils Elbow Mudstone Member cropping out north of this area, and that the upper limestone unit and correlative shellbed are basal units of the Kaiwaka Formation. The lower limestone at Ohiti Road is lithologically and topographically equivalent to beds of known Waipatiki Limestone Member cropping out nearby along Taihape Road and on Ngamahanga Station. Therefore, assignment of this lower bed to the Waipatiki Limestone Member is confident, as is assignment of the upper shellbed unit on Ohiti Road to the Kaiwaka Formation.

Prominent exposures occur in high sea cliffs between the Aropaoanui River mouth and Tangoio Beach (Fig. 28A). Geological mapping has extended the occurrence of the member south through the Glengarry and Brooklands area to the Tutaekuri River at Puketapu and Dartmoor. An almost continuous line of limestone outcrops occurs from Glengarry Road (Columns Gg-3, Gg-4) to Ruawai Station at Dartmoor (Column Da-2), where they are truncated by the Tutaekuri River. Exposure continues across the river however through Ngamahanga Station (Column Ok-1) to Matapiro Station. Small blocks of limestone assigned to the Waipatiki Limestone Member crop out beside Ohiti Road and on the north bank of the Ngaruroro River in this same area. These blocks are likely to represent erosional remnants of a wider outcrop belt.

Throughout the Tangoio Block the Waipatiki Limestone Member is 10-40 m thick (Haywick *et al.* 1991). The member is at least 15 m thick near Puketitiri Road and gradually thins towards the Ngaruroro River. In the Matapiro area Waipatiki Limestone Member is 10-15 m thick (Baggs 2004).

Description

Variations in lithology occur through the formation from northern to southern outcrops, with three dominant "motifs" identified. A general trend from northeast to southwest shows an increase in greywacke pebble content. Central outcrops are characterised by partially to largely recrystallised, pale-grey to dirty-cream, medium to coarse-grained shellhash limestone with common biomoulds of infaunal bivalves. Waipatiki Limestone Member typically comprises a lower, fossiliferous sandstone interval sharply overlain by a package often containing two distinct limestone units.

Throughout much of the outcrop area, particularly in western parts, the Waipatiki Limestone Member is characterised by a lower highly fossiliferous packed shellbed rich in *Tawera, Sigapatella* and *Crepidula,* fossils among many others. This shellbed is especially well exposed along Waipunga Road, Puketitiri Road, Taihape Road at Lambs Corners, and along Kawera Road on Ngamahanga Station. The highly fossiliferous lower part of the Waipatiki Limestone Member (e.g. Fig. 28E) is an easily recognisable attribute of the member in western and central parts of the outcrop extent and aids geological mapping. The faunal composition of this shellbed appears to indicate shallower depositional environments than more eastern exposures of Waipatiki Limestone Member, such as those present at Puketapu, the Devils Elbow section, Waipatiki Beach and Tangoio Quarry. Greywacke clasts also appear to be more common in western parts of the formation, probably reflecting closer proximity to paleo-river mouths.

In most areas (e.g. Matapiro-Glengarry) the Waipatiki Limestone Member can be subdivided into three packages. The best and clearest example of this is at V21/333882 (Column Gg-2) on Puketitiri Road (Fig. 28D). The lower zone comprises alternating bioclastic-siliciclastic-dominated beds up to 0.5 m thick. In sequence stratigraphy this interval is assigned to the regressive systems tract (RST) and records falling sea level. This interval is sharply overlain by two beds of bioclastic-dominated limestone assigned to the transgressive systems tract (TST), recording a period of rising sea level. The sharp contact between the two zones is inferred to be a transgressive surface of erosion (TSE) and a sequence boundary is superimposed on this surface. No deposits representing sea level lowstand have been identified. The lower limestone bed is a 1.5 m-thick coarsening-upward well cemented shellhash-dominated limestone with a coarse sand to granule-sized matrix of shellhash. Scattered greywacke clasts are present in this limestone. Fauna are dominated by *Eumarcia plana, Tawera subsulcata, Ostrea chilensis, Lutraria solida* and *Purpurocardia purpurata.* This limestone is sharply overlain by a 10 cm-thick non fossiliferous siltstone that may represent a small part of a shore-connected wedge. The siltstone is itself sharply overlain by a 1.5 m-thick well cemented bioclastic limestone with virtually no siliciciclastic content.

Macrofauna comprise *Eumarcia, Talochlamys gemmulata, Tawera subsulcata* and *Amalda novaezelandiae.* The two 1.5 m-thick limestone beds probably represent onlap and backlap shellbeds following the nomenclature of Kidwell (1991). The upper limestone grades over 40 cm into fine-grained sandy siltstone of the Devils Elbow Mudstone Member. In some localities, such as the Ohiti area, the transition from Waipatiki Limestone Member to Devils Elbow Mudstone Member is abrupt and may be marked by a concentration of oysters (*Ostrea chilensis*). This contact records is a downlap surface and the oyster-concentration a downlap shellbed. The positions of such shellbeds have been noted elsewhere in the Hawke's Bay area by Caron *et al.* 2004b).

Above Puketapu and Brooklands Station, upper parts of Waipatiki Limestone Member outcrop typically consist of a weathered biomould-rich grey limestone package. Lower parts consist of stacked alternating packages of bioclastic-siliciclastic-rich sediments that are overlain by weathered massive to laminated and trough to planar cross-stratified slightly pebbly limestone. Fauna are dominated by infaunal bivalves such as *Tawera* that are largely dissolved and partially recrystallised. Biomoulds are common to abundant. The prominent tightly-packed *Tawera-Crepidula-Sigapatella* shellbeds, common in nearby areas (such as Ngamahanga Station), do not occur in this region.

Fig. 28 (facing page): Waipatiki Limestone Member (Petane Formation). **A)** Waipatiki Limestone Member cropping out in sea cliffs south of Waipatiki Beach (W20/524032). Here Waipatiki Limestone Member conformably overlies Te Ngaru Mudstone Member. The basal unit exposed in these sea cliffs is the Tangoio Limestone Member. **B)** Deformed mixed siliciclastic-bioclastic sandstone and limestone beds unconformably underlying massive to laminated limestone. Note the abrupt change between deformed and undeformed units in this exposure, Okawa Stream near Pukehaumoamoa School (V21/250781). **C)** Herringbone, trough and sigmoidal cross-stratification in the lower highly fossiliferous shellbed facies of the Waipatiki Limestone Member, Okawa Stream (V21/250781). Fauna in this interval are characterised by abundant *Tawera, Sigapatella* and *Crepidula.* This outcrop is directly opposite that shown in the above photograph (Fig. 30B), and is in the deformed interval. **D)** Road cutting on Puketitiri Road near the Glengarry Road intersection where the entire Waipatiki Limestone Member is exposed (V21/333882). Below the level of the vehicle the lower gradational contact with the Te Ngaru Mudstone Member is exposed. The Waipatiki Limestone Member then passes through interbedded shellbed and silty sandstone beds (Fig 30E), before passing into two well cemented limestone beds. The base of the lower limestone here is sharp and mildly erosional. The member is conformably overlain by the Devils Elbow Mudstone Member. **E)** Close-up view of the interbedded shellbed-silty sandstone facies exposed beside Puketitiri Road, typical of lower parts of the Waipatiki Limestone Member (V21/333882). **F)** *Eumarcia*-rich, biomouldic and partially recrystallised limestone of the Waipatiki Limestone Member exposed in Tangoio Quarry at the southern end on the Tangoio Block near Tangoio Settlement (V20/490006). Limestone facies of the member here are thicker than any other observed area of outcrop. The quarry also shows good separation of RST and TST parts of the limestone.


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TOYOTA


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A non fossiliferous greywacke conglomerate bed cropping out above the Flag Range Conglomerate Member on Flag Range is inferred to be a more shoreward non-marine equivalent of the Waipatiki Limestone Member, and was probably deposited during sea level lowstand. The interval representing this deposit is inferred to be tied-up in the TSE surface recognised in the Tangoio and Puketitiri Road areas, and not lithologically expressed there. The Flag Range area is the only place where the non-marine to marginal-marine edge of the Waipatiki Limestone Member has been identified.

Sandstone facies, prominent in lower parts of the formation through the Tangoio Block, are much less significant southwest through the Taradale-Matapiro regions. The thinning of lower sandstone facies is reflected in the thinner nature of the formation in the Matapiro-Okawa region compared with the Tangoio Block.

Paleontology and age

Waipatiki Limestone Member contains a diverse fauna throughout the outcrop area, dominated by shallow-water taxa. A large number of bulk samples have been collected and analysed from the Waipatiki Limestone Member, and many field observations have been documented. Identifiable fauna are dominated by the Venerid bivalve *Tawera subsulcata,* with common to abundant *Crepidula radiata* and *Sigapatella novaezelandiae*. The member is often capped by a shellbed dominated by *Ostrea chilensis*, with valves dispersed in a muddy siliciclastic-rich matrix.

Uncommon *Pelicaria convexa* indicate an Upper Nukumaruan age for the formation. The Plio-Pleistocene boundary was identified in the Waipatiki Limestone Member by Beu and Edwards (1984). The top of the Olduvai paleomagnetic subchron has been recognised in the overlying Devils Elbow mudstone (P. Kamp, U.O.W, unpublished data). On the basis of stratigraphic position and micro/macrofaunal content, the Waipatiki Formation is assigned an Upper Nukumaruan age. The formation lies across the Plio-Pleistocene boundary.

Environment of deposition

The Waipatiki Limestone Member was deposited during a period of falling sea level and the subsequent rise, with facies recording regressive, transgressive and very rarely lowstand sea level states. Bioclastic-dominated beds in the form of limestones are typically representative of shoreface to inner shelf environments of deposition. This is supported by the rich macrofauna collected from the formation. A non-marine expression of the Waipatiki Limestone Member is present on Flag Range and indicates that river systems with a high greywacke gravel bed load

were present and active during the period of deposition. In all other areas the shoreward edge of the unit has been removed through erosion.

Devils Elbow Mudstone Member (de)

(Beu and Edwards 1984; formally defined by Haywick *et al.* 1991)

Name and definition

Beu and Edwards (1984) informally referred to the siltstone sharply overlying their Waipatiki limestone as the Devils Elbow mudstone. This interval was formally defined by Haywick *et al.* (1991). The name is derived from Devils Elbow corner on State Highway 2 south of Tutira. The name is emended in this study to Devils Elbow Mudstone Member (Petane Formation). Mudstone overlying the Matapiro Limestone (name now abolished, see Waipatiki Limestone Member below) of Beu (1995) was included in the Moteo Mudstone, a formation established by Beu (1995). Kingma (1971) had previously mapped this unit as the Puketautahi pumiceous siltstone (informal). Baggs (2004) following Beu (1995), geologically mapped this same interval as the Moteo Mudstone, and both appreciated that the Moteo Mudstone and Devils Elbow Mudstone Member were possible lateral equivalents. Geological mapping in this study has demonstrated that the Moteo Mudstone is most probably a correlative of the Devils Elbow Mudstone Member. As the name Devils Elbow has precedence over Moteo, the Moteo Mudstone of Beu (1995) and Baggs (2004) is disestablished in favour of the name Devils Elbow Mudstone Member.

Type and reference sections

The type section established at the top of Devils Elbow on State Highway 2 by Haywick *et al.* (1991) is retained in this study (V20/460079-461078, Column Tg-4). Reference sections are relatively limited through the study area.

Distribution and thickness

The Devils Elbow Mudstone Member is widespread across the Tangoio Block, particularly south of the Aropaoanui River (Haywick *et al.* 1991). Haywick *et al.* (1991) suggested that no equivalent was known outside of the Tangoio Block. However, correlation of the underlying Waipatiki Limestone Member southwest towards the Ngaruroro River has provided a known surface on which to “hang” stratigraphy away from the Tangoio area. Siltstone overlying the Waipatiki Formation through the Matapiro and Okawa areas are therefore included in the Devils Elbow Mudstone Member. Devils Elbow Mudstone Member is therefore widespread through central portions of the study area, in a northeast-southwest trending outcrop belt from Ridgemount Road in the Tangoio Block to the Ngaruroro River near Matapiro Station. Devils Elbow Mudstone

Member does not occur south of the Ngaruroro River, where it is truncated by the Ngaruroro River Fault.

Devils Elbow Mudstone Member is 10 to 40 m thick in the Tangoio Block (Haywick *et al.* (1991), and up to 30 m thick in the Matapiro and Okawa areas, although usually less than 20 m here (Baggs 2004).

Lower and upper contacts

On Puketitiri Road (V21/333882), Devils Elbow Mudstone Member abruptly but gradationally though overlies coarse-grained limestone facies of the Waipatiki Limestone Member (Column Gg-2).

Devils Elbow Mudstone Member is sharply overlain by limestone of the Kaiwaka Formation at the top of Devils Elbow (V20/461078, Column Tg-4). Similarly, Devils Elbow Mudstone Member is sharply overlain by a highly fossiliferous shellbed of the Kaiwaka Formation on Ohiti Road (V21/ 233722; Fig. 29C, D).

Description

Devils Elbow Mudstone Member dominantly comprises slightly to moderately fossiliferous siltstone that coarsens up into silty sandstone. Through the Tangoio Block the Devils Elbow Mudstone Member contains a diverse molluscan fauna that lessens in abundance away from the Tangoio region. Through the Matapiro and Okawa areas macrofossils are sparse. This is inferred to represent the movement into positions higher on the paleoshelf from the Tangoio region into the Matapiro region and a corresponding loss of macrofaunal diversity.

In the Devils Elbow section fauna reflect a coarsening and shallowing-upwards trend.

Paleontology and age

Devils Elbow Mudstone Member contains one of the most diverse offshore Pliocene fossil assemblages in the Hawke's Bay region (Beu 1995). Fauna are mostly gastropod dominated, although bivalves are common. The assemblage is characteristic of Upper Nukumaruan rocks in the study area, involving *Pelicaria convexa, Austrofusus taitae, Austrofusus glans,* and *Cominella excoriata,* among many other gastropod-dominated species (Beu 1995). The occurrence of common *Pelicaria convexa* form "*fossa"* in the Tangoio Block in the Devils Elbow Mudstone Member is consistent with a period of deepening over this area during the Upper Nukumaruan, as highlighted also in the underlying Te Ngaru Mudstone Member.

The top of the Olduvai paleomagnetic subchron (1.784 Ma; Cooper 2004) has been identified in the Devils Elbow Mudstone Member (P. Kamp U.O.W. unpublished data). The Plio-Pleistocene boundary (1.8 Ma) was identified in the underlying Waipatiki Formation by Beu and Edwards (1984). On the basis of stratigraphic position and faunal content the Devils Elbow Mudstone Member is assigned a confident Upper Nukumaruan age (Early Pleistocene).

Environment of deposition

Devils Elbow Mudstone Member is inferred to have accumulated on an open marine shelf at middle to outer shelf water depths (60-150 m). Water depths were likely greater over the Tangoio area than the Matapiro district as reflected in the macrofaunal content and thickness of the member.

KAIWAKA FORMATION (kw)

(McKay 1887; formally defined by Haywick *et al.* 1991)

Name and definition

The term Kaiwaka Beds was introduced by McKay (1887) for limestone beds exposed near the top of the Tangoio Block, north of Napier. Beu and Edwards (1984) used the informal name Kaiwaka limestone, and the unit was formally defined as the Kaiwaka Formation by Haywick *et al.* (1991). Beu (1995) reverted the name back to Kaiwaka Limestone. This study, however, has for reasons of consistency, retained the original formal definition of Haywick *et al.* (1991) to reflect the varied lithofacies that comprise this formation. The definition is emended to include the Puketautahi Limestone of Beu (1995) as a member of the Kaiwaka Formation as geological mapping has demonstrated that it, and beds of the Kaiwaka Formation in the Tangoio region, are lateral equivalents.

Baggs (2004) included a prominent shellbed cropping out in isolated exposures in the Matapiro region within the Moteo Mudstone (now incorporated in the Devils Elbow Mudstone Member). The base of this shellbed marks a prominent, possible ravinement surface (Fig. 29C, D). For consistency with other Mangaheia Group formations, the base of the Kaiwaka Formation through the Matapiro region is therefore placed at the base of this shellbed.

The two limestone packages present in cuttings beside Ohiti Road have previously been mapped and described as Matapiro Limestone (now incorporated in the Waipatiki Limestone Member (see above; e.g. Hood 1993; Caron 2002; Baggs 2004). At no other locality in the study area does the Waipatiki Formation comprise two such limestone packages. The lower limestone bed at Ohiti

Road has confidently been mapped and correlated with known Waipatiki Limestone Member outcrops on Taihape Road and at Ngamahanga Station. The upper limestone bed is now assigned to the Kaiwaka Formation, and correlated with a shellbed cropping out further along Ohiti Road near the Tauhara Road intersection.

Three members are defined in the Kaiwaka Formation in this study (Puketautahi Limestone Member, Ruataha Conglomerate Member, and Taihoa Pumice Member). However, only the Puketautahi Limestone Member has been mapped as a separate unit during the course of this study due to its thickness and lateral continuity.

Type locality and reference sections

The type section established by Haywick *et al.* (1991) is retained on Te Taihoa Farm (V20/461101). A well exposed reference section is nominated along the southern end of Waipunga Road where it ascends the western face of the Tangoio Block (V20/398983; Fig. 29E).

Distribution and thickness

Kaiwaka Formation discontinuously crops out in a northeast-southwest belt from the northern Tangoio Block to the north bank of the Ngaruroro River in the Matapiro district. The single largest area of outcrop occurs in the Tangoio Block. Kaiwaka Formation is up to 100 m thick. The member is well exposed along Waipunga Road (Fig. 29E), and can be seen from Waipatiki and Ridgemount Roads (Fig. 29A, B).

Lower and upper contacts

Near the top of Devils Elbow on the Napier-Wairoa Road the Kaiwaka Formation sharply overlies fossiliferous fine sandstone of the Devils Elbow Mudstone Member (Petane Formation). The base of the Kaiwaka Formation in the Matapiro district is exposed on Ohiti Road near the intersection with Tauhara Road (V21/233722; Fig. 29C, D). The base is also well exposed on Ohiti Road near the Taihape Road intersection (V21/298733). This section was logged by Caron (2002) who also documented elements of the diagenesis of limestones at this locality. This section was previously studied by Hood (1993).

The top of the Kaiwaka Formation is usually marked by the modern land surface. In some places the formation may be overlain by a thin veneer of Castlecliffian gravels.

Description

Kaiwaka Formation contains a diverse range of facies reflecting a wide variety of depositional environments. The formation predominantly comprises cross-stratified, coarse-grained carbonate sand/sandstone with massive to cross-stratified limestone (Fig. 29F, G). Lateral interdigitation of all lithologies is common in the Kaiwaka Formation (Haywick *et al.* 1991).

Greywacke clasts are common components throughout the outcrop area (Fig. 29G). Although limestone facies are perhaps most common, conglomerate, sandstone and even (locally) pumiceous beds are all common. Kaiwaka Formation is much thicker than other formations within the upper Mangaheia Group (up to 100 m thick) and probably accumulated during several 41 k.y. sea-level cycles while this part of the basin was emerging from the ocean due to net uplift.

Kaiwaka Formation becomes coarser-grained from northern to southern outcrops. In the Puketapu area the unit comprises very coarse-grained, non to highly fossiliferous conglomerate to pebbly limestone. In the Glengarry and Matapiro areas Kaiwaka Formation appears to be represented by a number of differentiated cyclothems that can be traced (albeit poorly) through the region. It appears that these sequences are condensed in the Tangoio region.

Paleontology and age

Below “The Gums” (V21/340898) near Glengarry Road, Kaiwaka Formation comprises a highly fossiliferous very pebbly limestone bed with virtually all shells being of *Paphies australis*. Rare valves of *Ostrea chilensis* and *Lutraria solida* also occur in this unit. A similar *Paphies*-dominated unit occurs above Hendley Road, though the shell-pebble ratio is lower in this area.

Environment of deposition

The *Paphies*-dominated beds prominent in the Glengarry-Hedgley areas were deposited in a nearshore, semi-enclosed, possibly estuarine setting.

Ruataha Conglomerate Member (kwr)

(Haywick 1990; formally defined by Haywick *et al.* 1991)

Name and definition

Ruataha Conglomerate Member was introduced by Haywick (1990) and formally defined by Haywick *et al*. (1991). The name is derived from Ruataha Farm in the western part of the Tangoio

Block near Kaiwaka Road. Brown siltstone facies in the Ruataha Member are equivalent to the (informal) Tareha laminated siltstone of Beu and Edwards (1984) (Haywick *et al.* 1991).

Type locality and reference sections

Ruataha Conglomerate Member is poorly exposed in the Tangoio Block. Isolated exposures occur on Ruataha Farm (V20/412088; 423073), on Waipunga Road (V20/413066) and sporadically along Kaiwaka and Aropaoanui Roads (Haywick *et al.* 1991). Outcrop is constrained to a small area around the top central parts of the Tangoio Block. This area is between the junction of Waipunga and Kaiwaka Roads (V20/415091), Glenview homestead (V20/475065) and Koraki Homestead (V20/416057) (Haywick *et al*. 1991).

Conglomeratic units exposed above Puketapu village and Glengarry Road are probably lateral equivalents of the Ruataha Member, although confident lateral continuity cannot be demonstrated. The Ruataha Conglomerate Member is up to 20 m thick.

Description

The Ruataha Conglomerate Member consists of uncemented poorly sorted siliciclastic sandstone interbedded with lenses and continuous bodies of greywacke gravel and laminated brown siltstone. Silt beds contain scattered carbonaceous material, rare *in situ* rootlets and rare shell moulds. In a few localities, sand and gravel beds contain shellhash (Haywick *et al.* 1991).

Environment of deposition

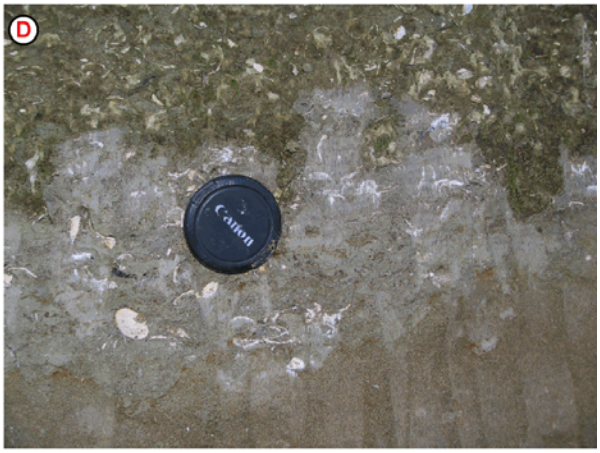
The Ruataha Conglomerate Member was mostly deposited in a non-marine fluvial environment with rare estuarine incursions (Haywick *et al.* 1991).

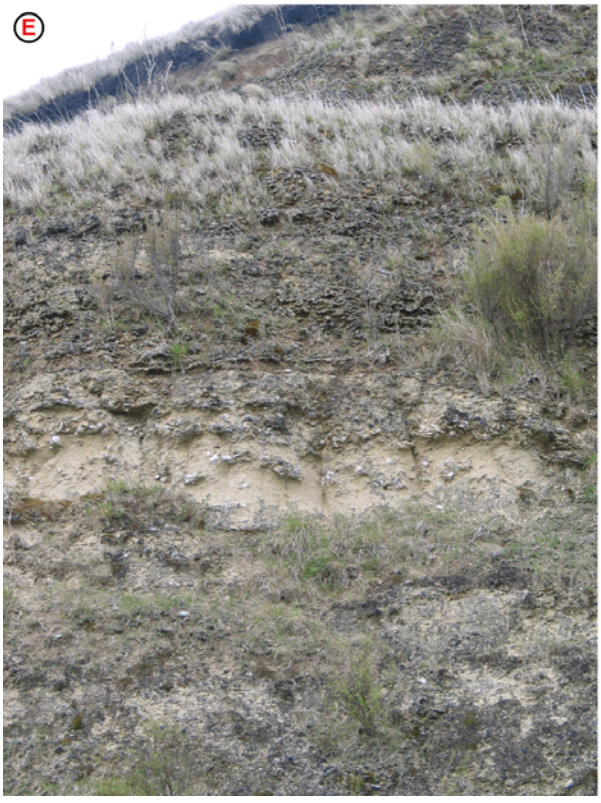
Fig 29 (facing page): Kaiwaka Formation. **A)** Landscape view of the Kaiwaka Formation forming the bluffs capping dip slopes on the Tangoio Block around Ridgemount Road (W20/537133 looking west). **B)** Bluff-forming pebbly limestone facies of the Kaiwaka Formation near Ridgemount Road (W20/535130). **C)** Basal *Tawera subsulcata*-dominated shellbed of the Kaiwaka Formation unconformably overlying Devils Elbow Mudstone Member (Petane Formation), Ohiti Road, Matapiro district (V21/233722). **D)** Close-up of base of shellbed in above photograph (Fig. 31C; V21/233722). **E)** Kaiwaka Formation cropping out beside Waipunga Road, southwestern Tangoio Block (V20/398983). **F)** Strongly cross-bedded Kaiwaka Formation near "The Gums", above Glengarry Road (V20/340898). Macrofauna in the limestone shown here are dominated almost entirely by valves of the estuarine to brackish water-dwelling bivalve *Paphies australis.* **G)** Very pebbly fossiliferous shellbed of the upper Kaiwaka Formation below The Gums (V20/340898).


A


B


C


D


E


F


G

Taihoa Pumice Member (kwt)

(Haywick 1990; formally defined by Haywick *et al.* 1991)

Name and definition

Taihoa Pumice Member was introduced by Haywick (1990) and formally defined by Haywick *et al.* (1991). The name is derived from Te Taihoa Farm and homestead in the Tangoio Block (V20/ 452108). It is defined as a fossiliferous interval of pumiceous sediments within the Kaiwaka Formation.

Type locality and reference sections

The type section established by Haywick *et al.* (1991) on Te Taihoa Farm (V20/461101) is retained.

Distribution and thickness

The Taihoa Pumice Member only occurs in the Tangoio Block in the vicinity of the type section, and around V20/399983 on Waipunga Road. It is a maximum of 10 m thick (Haywick *et al.* 1991).

Description

Taihoa Conglomerate Member comprises massive, bioturbated silty volcanic ash interbedded with a fine to very coarse pumice sand (Haywick *et al.* 1991). It is fossiliferous with an estuarine-restricted macrofauna, and contains carbonaceous rootlets.

Paleontology

At the type section Taihoa Conglomerate Member contains an estuarine-restricted faunal assemblage comprising *Austrovenus stutchburyi, Macomona liliana* and *Zeacumantus perplexus.* In other localities the member contains a significant amount of shellhash (broken and abraded shell material) and common interbeds of carbonate sand/bioclastic limestone (Haywick *et al.* 1991).

Environment of deposition

Taihoa Conglomerate Member was deposited in a marginal-marine setting adjacent to a supply of greywacke gravels. It probably represents the deposits of an estuary that developed near the mouth of a river system actively supplying greywacke sediments.

Puketautahi Limestone Member (kwp)

(Kingma 1971; formally defined by Beu 1995)

Name and definition

Puketautahi limestone was introduced by Kingma (1971) as an informal name for small patches of the stratigraphically highest limestone in the Matapiro-Crownthorpe area in his Te Aute subdivision map. The name is derived from Puketautahi (Trig 61), on Ngamahanga Station. Because Kingma (1971) had also applied the name "Puketautahi" to his informal Puketautahi pumiceous siltstone, Beu (1995) formally defined the Puketautahi Limestone, and renamed the siltstone the Moteo Siltstone. Geological mapping in this study demonstrates that Puketautahi is most likely a lateral equivalent of Kaiwaka Formation in the Tangoio Block and is hence included in Kaiwaka Formation. However, the Puketautahi Limestone Member is a thick, prominent limestone bed that can be mapped as a distinct stratigraphic unit through the Matapiro area, as demonstrated by Baggs (2004). Because of this, the name Puketautahi is retained, but now the unit is referred to member status of the Kaiwaka Formation.

Type locality and reference sections

The type section established by Beu (1995) for the Puketautahi Limestone is retained in this study. This section occurs along the summit ridge capping Puketautahi hill (Trig 61, 353 m; V21/253829).

Lower and upper contacts

In no known location is the lower contact between Puketautahi Limestone Member and underlying parts of the Kaiwaka Formation exposed. It is inferred to sharply overlie sandstone and siltstone facies of the Kaiwaka Formation.

The upper surface of the Puketautahi Limestone Member represents the modern land surface, although there may be a thin veneer of Castlecliffian and/or Haweran gravels present.

Distribution and thickness

It appears probable that the distribution of Puketautahi Limestone Member, as described by Beu (1995) and mapped by Baggs (2004), contains a mixture of stratigraphically separate limestone beds that overlie Waipatiki Formation and Devils Elbow Formation rocks in the Matapiro-Okawa area. Puketautahi Member occurs for nearly 800 m along the summit ridge of Puketautahi hill on Ngamahanga Station where it comprises a series of large jumbled blocks, none of which are *in situ*, up to about 15 m high. It also sporadically crops out in hills around the Matapiro Station area.

Puketautahi Limestone Member is not known north of the Tutaekuri River or south of the Ngaruroro River.

Description

At the type section Puketautahi Limestone Member typically comprises several metres of dirty cream to grey, well cemented, hard, recrystallised coarse-grained shellhash limestone. Outcrop on Puketautahi hill is restricted to large blocks of intact limestone capping the summit ridge. In some places greywacke granules and pebbles are common. Blocks are massive to flaggy, with common case hardening. Where relatively clean surfaces are visible, well-developed tabular cross-bedding and laminations are visible. Foresets are of moderate to large-scale. Some valves of *Ostrea chilensis* are present, with biomoulds of inferred aragonitic bivalves common.

Paleontology and age

Few relatively intact identifiable macrofossils have been observed in the Puketautahi Limestone Member. Those identified are typically shallow-water dwelling infaunal bivalves. *Tawera subsulcata* is most common with *Glycymeris shrimptoni, Ostrea chilensis* and *Patro undatus* also present (Beu 1995).

Few age diagnostic macrofossils were identified in this unit. The presence of *Glycymeris shrimptoni* and *Patro undatus* demonstrate that Puketautahi Limestone Member is no younger than Nukumaruan (Beu 1995). Stratigraphic position strongly suggests that the Puketautahi Limestone Member is Upper Nukumaruan (Early Pleistocene) in age.

Environment of deposition

Fauna and sedimentary structures in the Puketautahi Limestone Member support deposition at inner shelf water depths in a current-swept environment, probably on a sandy to gravelly seafloor.

TARADALE MUDSTONE (td)

(Beu and Edwards 1984; formally defined by Beu 1995)

Name and definition

Taradale Mudstone derives its name from Taradale, a township southwest of Napier around which the formation crops out. Taradale Mudstone is equivalent in part to Roys Hill siltstone of Kingma (1971), a unit that is regarded as a synonym of Makaretu Formation (Beu 1995; Dyer 2005).

Taradale Mudstone was introduced by Beu and Edwards (1984) for the succession recovered from the Taradale-1 drillhole. It was correlated to Esk Mudstone strata cropping out in the Tangoio Block. Haywick *et al.* (1991) formally defined the Esk Mudstone for this unit as this name had priority over Taradale Mudstone (Esk papa of Smith 1877). Beu (1995) redefined and formally introduced Taradale Mudstone in reference to Nukumaruan mudstone present in the Taradale-1 drillhole and the immediately surrounding hill country between Taradale and Puketapu. The Waipipian and Mangapanian mudstone interval present in Taradale-1 was unnamed by Beu (1995), despite being the same lithology and not separated by any obvious stratigraphic break. For these reasons all of the Waipipian to Nukumaruan mudstone intercepted in Taradale-1 is here assigned to the Taradale Mudstone. It is defined as a Waipipian to Nukumaruan mudstone-dominated unit underlying the Park Island Limestone Member of the Darkys Spur Formation. Due to lack of exposure a definite lower contact is not defined, although it is taken as any deviation from mudstone-dominated lithology.

Lower and upper contacts

The lower contact of the Taradale Mudstone has not been observed in outcrop. In Taradale-1 the Taradale Mudstone overlies Mangaorapan (Early Eocene) glauconitic calcareous mudstone across an angular unconformity (Darley and Kirby 1969).

Taradale Mudstone is conformably overlain by the Park Island Limestone Member in hills behind Taradale (Fig. 19E), at the Taradale Sugarloaf, Roys Hill and Fern Hill. It is inferred that Taradale Mudstone conformably underlies and interdigitates with the Scinde Island Formation beneath Napier city. It also interdigitates with many other Mangaheia Group formations, including the Matahorua Formation, Esk Mudstone, Tutira Member, Aropaoanui Mudstone Member and Mason Ridge Formation (Enclosure 5).

Type locality and reference sections

Beu (1995) designated the first large road cut on the north side of Springfield Road west of Taradale as the type section for the Taradale Formation (V21/386766). This section has been retained. The type section represents the stratigraphically lowest exposure of the formation, and is located only 700 m east of the location of the Taradale-1 drillhole.

Distribution and thickness

In outcrop Taradale Mudstone is restricted to the southern end of the Taradale Anticline (see Chapter 5, p. 177) between State Highway 50 and the northern end of Springfield Road, at Fern

Hill and Roys Hill. The formation is inferred to be widespread in the subsurface through much of the central and eastern parts of the study area.

Much of what is known of the Taradale Mudstone is derived from information acquired by the Taradale-1 drillhole. Geological mapping in this study demonstrates that at least 60 m of Taradale Mudstone crops out around the Taradale Anticline. Taradale-1 intercepted a further 1170 m of Taradale Mudstone (Darley and Kirby 1969; Beu 1995). The formation therefore has a minimum thickness of 1230 m in Taradale-1. Beu (1995) suggested that at least 300 m of Taradale Mudstone cropped out behind the hills of Taradale. This appears to be a significant over-estimation of outcrop thickness, the reason for which is unclear.

Taradale Mudstone was mapped in isolated areas in the Maraekakaho and Fern Hill areas by Dyer (2005), where it conformably underlies the Park Island Limestone Member (Darkys Spur Formation). In this area Taradale Mudstone is separated from younger Upper Nukumaruan beds to the north of the Ngaruroro River by a large fault. The Taradale Mudstone is also separated from beds of equivalent age in the nearby Mason Ridge Formation by a fault or series of faults.

Lower Nukumaruan mudstone intercepted in Hukarere-1 (Westech Energy Ltd 2001, PR 2656) is also assigned to the Taradale Mudstone. At this site the formation is inferred to conformably underlie the Scinde Island Formation.

Description

The upper 60 m of the Taradale Mudstone comprises blue-grey to light-grey, massive, non cemented, non to slightly fossiliferous sandy siltstone. Macrofossils are sparse, although the formation contains a diverse microfossil assemblage (Beu 1995).

The lower 800 m of the Taradale Mudstone comprises soft grey mudstone with thin sandy intervals in the upper 160 m (Darley and Kirby 1969). Shell material is typically more common in the upper 370 m of the formation. Apart from the slightly fossiliferous, sandy and more massive "intervals", the Taradale Mudstone intercepted in Taradale-1 cannot be subdivided further.

Paleontology and age

Scattered macrofossils are present in outcrop. Beu (1995) has identified specimens of *Pelicaria acuminata* and only one fragmented *Pelicaria convexa.* The presence of both *P. acuminata* and *P. convexa* in upper parts of the Taradale Formation indicates that this part of the formation is at

least age equivalent to Mairau Formation exposed north and west of Taradale (Beu 1995). Valves of *Atrina pectinata zelandica* were observed in upper beds of the formation on Roys Hill.

Beu (1995) has recognised a diverse foraminiferal fauna. The Lower Nukumaruan planktic assemblage of *Truncorotalia crassula* and dextral *Truncorotalia crassiformis* has been identified in Taradale-1 (Beu and Edwards, 1984).

Taradale Formation is of Late Pliocene age. Microfossil dating of strata in the Taradale-1 drillhole indicates continuous sedimentation from possibly the Waipipian through to the Upper Nukumaruan (Darley and Kirby 1969; Beu 1995).

Environment of deposition

Taradale Formation represents a very broadly shallowing-upwards succession. Microfauna from Taradale-1 indicate an inner shelf depositional environment. Throughout the Pliocene the region around Taradale-1 remained at relatively deep water depths, and only at the time of deposition of the Darkys Spur Formation (Park Island Limestone Member) in this region did water depths reduce to innermost shelf and subaerial levels. This may reflect the start of growth of the Taradale Anticline.

Approximately 800 m of Lower Nukumaruan section was intercepted in Taradale-1, indicating rapid sedimentation during this period (about 2.6 m/k.y.). The remaining 370 m was deposited during the Mangapanian and Waipipian (sedimentation rate of about 0.3 m/k.y.). It is probable that the Taradale Formation represents the main depocentre during the sedimentation history of central parts of the study area.

MAKARETU MUDSTONE (me)

(Thomson 1926; formally defined by Kelsey *et al.* 1993)

Name and definition

The Makaretu clays were introduced by Thomson (1926) for beds overlying the “Te Aute limestone” (Te Onepu Limestone) and underlying the “Pukeora oyster-beds” (equivalent to the lower limestone of the Mason Ridge Formation (Kelsey *et al.* 1993)). The name appears to be derived from the Makaretu River where the formation was first described by Thomson (1926). The Makaretu clays were formally renamed and defined as the Makaretu Mudstone by Kelsey *et al.* (1993), a definition retained by Dyer (2005) and this study. Makaretu Mudstone is defined as the fine-grained interval overlying the Te Onepu Limestone and underlying the Mahana Limestone

Member of the Mason Ridge Formation. It was included as part of the undefined Roys Hill Siltstone of Kingma (1971).

Type locality and reference sections

The type section established by Thomson (1926) is retained for the Makaretu Mudstone (U22/ 085308). This section occurs along a short section of road now abandoned by the realignment of State Highway 2 around the northern end of Pukeora Hill.

Distribution and thickness

The Makaretu Mudstone is a minimum of 20 m thick (Kelsey *et al.* 1993) in the region of the Makaretu River where described by Thomson (1926). The unit is at least 40 m thick at the southern end of the Raukawa Range, increasing to several hundred metres at the northern end of the range (Kelsey *et al.* 1993). Dyer (2005) reported thicknesses of 50-60 m for the Makaretu Mudstone in the study area.

The Makaretu Mudstone passes laterally into the Taradale Mudstone.

Lower and upper contacts

Makaretu Mudstone conformably overlies the Te Onepu Formation, and is gradationally overlain by the Mahana Limestone Member (Mason Ridge Formation) (Dyer 2005). Over approximately 0.3 m the top of the Makaretu Mudstone coarsens into a 0.7-1.2 m-thick fine sandstone before passing into a limestone. This transition is best exposed at V22/165584 above the Maraekakaho River on Mason Ridge Station.

Description

The Makaretu Mudstone comprises a massive, blue-grey, slightly to moderately fossiliferous siltstone. Occasional bioturbated intervals are evident. The unit becomes firmer with increased proximity to limestone of the overlying Mason Ridge Formation, and near the contact with this formation comprises a very firm biomouldic unit with common moulds of *Talochlamys* and *Tawera.*

Paleontology and age

Ostrea, Zeacolpus, Talochlamys and *Tawera* are common in the Makaretu Mudstone. Dyer (2005) reported rare *Pelicaria convexa* although given the likely Upper Mangapanian to Lower Nukumaruan age of the Makaretu Mudstone, *Pelicaria* specimens present are more likely to be *P. acuminata* than *P. convexa.*

Environment of deposition

The Makaretu Mudstone was probably deposited at inner to middle shelf water depths based on macrofauna.

MASON RIDGE FORMATION (ms)

(Kelsey *et al.* 1993)

Name and definition

The name Mason Ridge Limestone was introduced by Kelsey *et al.* (1993) for Nukumaruan rocks cropping out in the Mason Ridge-Maraekakaho area, which were earlier part of the informal, stratigraphically complex Petane limestone of Beu *et al.* (1980). As this stratigraphic interval contains significant thicknesses of sandstone and mudstone it is here renamed the Mason Ridge Formation. Unravelling the stratigraphy of this area has been important in determining the evolution of Nukumaruan rocks south of the Ngaruroro River, and has recently been reported by Dyer (2005). The cyclothemic disposition of the Mason Ridge Formation, as documented by Dyer (2005), is remarkably similar to that of the Petane Formation in the upper parts of the Mangaheia Group within the Tangoio Block. On the basis of age, lithology, stratigraphic position, and its cyclothemic character, the Mason Ridge Formation is included here in the Mangaheia Group.

Mason Ridge Formation was mapped as the (informal) lower Scinde Island limestone and (informal) upper Scinde Island pebbly limestone by Kingma (1971). Beu (1995) referred to the lower limestone bed of the Mason Ridge Formation as the Scinde Island Limestone, but didn't describe, define, or name the two other stratigraphically higher limestone beds at Mason Ridge. Beu (1995) included the basal limestone at Mason Ridge in the Napier Group, which he established in the same study. This work strongly suggests that the Napier Group is not sustainable as its base and top were not defined, Beu provided no type section, reference section or stratigraphic columns, and it could not be differentiated from rocks of his Petane Group. As Petane Group has now been redefined as Petane Formation and incorporated into the Mangaheia Group, it is proposed that the Napier Group be disestablished.

Although hypothetically containing at least part of the Scinde Island Formation at its base (Beu 1995), the name Mason Ridge Formation, as defined by Kelsey *et al.* (1993), was retained by Caron (2002, p. 30) for several reasons including:

- The geographical extent of the formation is well delineated
- The limestone units (of which there are three) are vertically and laterally well-developed and can easily be mapped south of the Ngaruroro River (Fig. 32A).

Although several authors have attempted to correlate the lower limestone bed of the Mason Ridge Formation with other limestone units in the basin (Kingma 1971; Kelsey *et al* 1993; Beu 1995), correlation of the upper sheets with more geographically restricted outcrops of limestone remains doubtful. It was therefore viewed appropriate to retain rocks in the Mason Ridge region as a separate formation. Any direct correlation between the Scinde Island Formation at Napier and the lower limestone bed at Mason Ridge (such as Beu 1995) is far from certain. No Lower Nukumaruan limestone units were intercepted in the Taradale-1 drillhole, suggesting lateral continuity is not present. Neither were any intercepted in Whakatu-1. The thickness of limestone at Scinde Island, coupled with the stratigraphic form of this interval, strongly indicates sedimentation during several glacio-eustatic sea-level cycles. It is viewed as inappropriate to use the name Scinde Island Limestone Member for only one cycle at Mason Ridge when clearly at least three such cycles are present.

Five members were defined and geologically mapped in the Mason Ridge Formation by Dyer (2005) and are all retained in this study. These members are the Mahana Limestone, Maharakeke Mudstone, Torran Limestone, Whakapirau Mudstone and Pakihirua Limestone Members. The Maharakeke Mudstone and Whakapirau Mudstone Members were included as part of the undefined Roys Hill Siltstone of Kingma (1971), and the undefined "interbedded sandstones and siltstones of the Mason Ridge Formation" by Kelsey *et al.* (1993). Kingma (1971) mapped two distinct limestone intervals in the Mason Ridge area as the lower Scinde Island limestone and the upper Scinde Island pebbly limestone, separated by the Waitio pumiceous siltstone. In his accompanying report (Kingma 1971) he acknowledged that three limestone beds occurred in this area, but offered no formal explanation or reason as to why only two limestone beds were mapped.

Type locality and reference sections

Although defined by Kelsey *et al.* (1993), no type section was designated. No type section was nominated by Dyer (2005), who studied the Mason Ridge Formation at Mason Ridge. This study nominates the section exposed in road cuttings along Raukawa Road as the type section (V22/ 204586-V22/201581). At this locality the entire formation is exposed, including the lower contact with the Makaretu Mudstone (Dyer 2005, Column 7, Appendix 1).

Lower and upper contacts

The lower contact of the Mason Ridge Formation is poorly exposed, and has only been clearly observed on Mason Ridge Station (V22/165584), and at the type section (V22/204586). The formation gradationally overlies the Makaretu Mudstone through a coarsening upward interval.

The upper contact of the Mason Ridge Formation is usually marked by the modern land surface, although in places a thin veneer of Kidnappers Group Castlecliffian gravels is present. In western parts of Mason Ridge the formation is inferred to be unconformably overlain by both the Okauawa and Poutaki Formations. Although the contacts with both the Okauawa and Poutaki Formations are concealed, geological mapping strongly suggests that the contacts are unconformable, recording a period of uplift, erosion, and subsidence between deposition of the Mason Ridge Formation and the Okauawa-Poutaki Formations of at least 500 k.y.

Distribution and thickness

Mason Ridge Formation is widespread in the area south of the Ngaruroro River and Heretaunga Plains. Outcrop is mostly around Mason Ridge itself from near Maraekakaho south to Argyll East. The distribution has been mapped by Dyer (2005). In essence the extent of the unit appears to be restricted to an area of elevated hill country with a strong structural control. The formation does not crop out north of the Ngaruroro River. A large inferred fault in the region of Maraekakaho and Roys Hill (Kingma 1971) has juxtaposed Upper Nukumaruan limestone beds north of the river against Lower Nukumaruan Mason Ridge Formation limestone beds south of the river. The Mason Ridge Formation may underlie the Matapiro and Okawa regions at depth, and interdigitate with conglomerate facies of the Matahorua Formation, although a lack of subsurface data means this relationship cannot be confirmed. More likely is that the Mason Ridge Formation occupies, and is restricted to a, paleohigh occupying the area of the modern Mason Ridge, while north of the current outcrop area the formation rapidly passes into mudstone of the Taradale Mudstone.

The Mason Ridge Formation is chronostratigraphically equivalent, at least in part, to upper beds of the Matahorua Formation, Scinde Island Formation, Sentry Box Formation and Pakipaki Limestone.

On the basis of the presence of *Phialopecten triphooki*, Kelsey *et al.* (1993) suggested that the lower limestone of the Mason Ridge Formation is a lateral equivalent of the Pakipaki and Scinde Island Formations. Any direct correlations with these two formations are far from certain due to structural complexity, and it is probable that each formation has developed in isolation. Certainly, it appears that limestone exposed at Pakipaki has been brought into its present topographic position through strike-slip faulting on the Waipukurau-Poutaki fault system (Beu 1995).

Description

The Mason Ridge Formation comprises a succession of at least three siltstone-sandstone-limestone packages that are inferred to represent individual 41 ka cyclothems. Members defined

for the formation by Dyer (2005) reflect siliciciclastic-dominated and limestone-dominated packages. Other cyclothemic intervals have been identified in the study area in rocks of similar age, such as the Matahorua Formation.

Paleontology and age

The lowest limestone bed of the Mason Ridge contains the Lower Nukumaruan index pectinids *Phialopecten triphooki* and *Towaipecten mariae. P. triphooki* has also been identified in the uppermost limestone bed (Dyer 2005). The formation is inferred to be of Lower Nukumaruan age. Kelsey *et al.* (1993) proposed that the middle and upper limestone beds of the Mason Ridge Formation were Upper Nukumaruan in age. Caron (2002) collected a single specimen of *Phialopecten triphooki* from the uppermost limestone bed (Pakihirua Limestone Member) at his Mangatai section (V22/163494). Dyer (2005) has also identified fragmented *Phialopecten triphooki* in the Pakihirua Limestone Member at both the Mangatai section (V22/163494) and other localities in the Mason Ridge area. The presence of *Phialopecten triphooki* in both the lowest and highest limestone beds of the Mason Ridge Formation strongly suggests an age no older than Lower Nukumaruan (Late Pliocene).

It is possible that the lower limestone bed of the Mason Ridge Formation (Mahana Limestone Member) may contain the basal Nukumaruan index pectinid *Zygochlamys patagonica delicatula*, although no specimens have yet been observed. Specimens of *Zygochlamys* have been collected from the adjacent Pakipaki Limestone (Beu 1995) as well as the Sentry Box Formation (Erdman and Kelsey 1992; Beu 1995), although none have been reported from the Lower Nukumaruan Scinde Island Formation. It is possible that poor exposure of the Mahana Limestone Member means that simply not enough sections have been sampled to locate any *Zygochlamys* valves.

Environment of deposition

The Mason Ridge Formation was deposited in a combination of inner to middle shelf environments. It is probable that the unit accumulated in a region of slightly higher elevation than surrounding areas, perhaps developing above a thrust zone. No trace of the formation is evident in the Taradale-1 drillhole (Darley and Kirby 1969), suggesting that water depths there were too great, or the siliciclastic sediment flux was too high.

Mahana Limestone Member

(Dyer 2005)

Name and definition

Mahana Limestone Member was introduced by Dyer (2005). The name is applied to the stratigraphically lowest of three limestone intervals cropping out in the Mason Ridge area. Mahana Limestone Member is defined as the lowermost, limestone-dominated member of the Mason Ridge Formation, which overlies Makaretu Mudstone, and underlies Maharakeke Mudstone Member.

The name Mahana Limestone Member replaces lower Scinde Island limestone (informal, Kingma 1971) and Scinde Island Limestone (Beu 1995) as Mahana Limestone Member and Scinde Island Formation (as defined and geologically mapped in this study) are not depositionally linked. Kingma (1971) and Beu (1995) both correlated the Mahana Limestone Member with Scinde Island Limestone on the basis of them both containing the Lower Nukumaruan index pectinid *Phialopecten triphooki.* Abandoning the name "Scinde Island" in reference to the Mahana Limestone Member removes any inference that only the Mahana Limestone Member is equivalent to Scinde Island Formation at Scinde Island, Napier, as *P. triphooki* has been collected, albeit rarely, in all limestone members of the Mason Ridge Formation (Dyer 2005). This means that all of the Mason Ridge Formation may be equivalent to Scinde Island Formation in a stratigraphic sense, however no lateral continuity is believed to exist and because of this it is desirable to maintain the Lower Nukumaruan stratigraphy in a separate formation.

Type locality and reference sections

The type locality designated by Dyer (2005) is retained. The section is on Mahana Station at V22/174509.

Lower and upper contacts

The lower contact of the Mahana Limestone Member is poorly exposed, though can be clearly observed on Mason Ridge Station above the Maraekakaho River (V22/166582; Fig. 32E). The Makaretu Mudstone grades over 0.2-0.4 m into sandstone at the base of the Mahana Limestone Member.

The upper contact is poorly exposed, but can be observed on Torran Station at V22/208588 and along Pakihirua Stream at V22/192551. In these sections the Mahana Limestone Member is abruptly overlain by Maharakeke Mudstone Member.

Distribution and thickness

Mahana Limestone Member is widespread across the Mason Ridge area occurring from Mahana Station (Anaroa Road) to Glencoe Station (State Highway 50) (Dyer 2005). The Mahana Limestone has a relatively uniform thickness of approximately 15 m across the outcrop area (Dyer 2005).

Description

The Mahana Limestone Member mostly comprises a differentially cemented, cream to almost white, barnacle-dominated unit similar in lithology to the underlying Te Onepu Limestone, but slightly coarser in texture (Dyer 2005). It further differs from the Te Onepu Limestone in lacking common *Phialopecten thomsoni* and *Crassostrea ingens.* The member comprises three main intervals. The lower interval comprises differentially cemented skeletal coarse sandstone (Fig. 30G). Cementation increases up-section and coincides with a general decrease in grain-size to medium skeletal sand in the middle parts of the member. Weak to strongly-developed, low to moderate angle, moderate scale sigmoidal, tabular and trough cross-stratification is common in these middle parts (Fig. 30B, C). The Mahana Limestone Member is capped by a 1-1.5 m-thick *Ostrea*-dominated shellbed. In terms of sequence stratigraphy this is inferred to represent a backlap shellbed following the nomenclature of Kidwell (1991). The *Ostrea* bed is best exposed at V21/227659, above the Ngaruroro River. This interval tends to be better cemented than the lower two intervals.

Paleontology and age

The Mahana Limestone Member contains abundant *Mesopeplum convexum* and *Ostrea chilensis.* The member also contains *Glycymeris shrimptoni* and the Lower Nukumaruan index pectinid *Phialopecten triphooki* (Beu 1995; Dyer 2005). Based on the presence of *Phialopecten triphooki* an Lower Nukumaruan age is confidently assigned to this member (Late Pliocene).

Environment of deposition

The Mahana Limestone Member accumulated during regressive and transgressive phases of a sea-level cycle. Middle cross-stratified elements of the member are inferred to represent the early phase of sea level rise during marine transgression. Macrofauna and sedimentary structures are consistent with a high-energy inner shelf environment of deposition. The upper oyster bed, corresponding to a backlap shellbed of Kidwell (1991), is inferred to have accumulated at middle to outer shelf water depths under a regime of very low siliciclastic sediment input during the middle to late stages of sea level rise.

Maharakeke Mudstone Member

(Dyer 2005)

Name and definition

Maharakeke Mudstone Member was introduced by Dyer (2005) for the fine-grained siliciclastic interval separating the Mahana and Torran Limestone Members of the Mason Ridge Formation. Maharakeke Mudstone Member replaced in part the term “interbedded sandstone and mudstone” used by Kelsey *et al.* (1993).

Type locality and reference sections

A road cutting on Raukawa Road at V22/205587 is designated as the type section for the Maharakeke Mudstone Member.

Lower and upper contacts

The lower contact is poorly exposed, although can be observed on Torran Station (V22/208588) and in Pakihirua Stream (V22/192551) where it abruptly overlies the capping oyster bed of the Mahana Limestone Member. The member is sharply overlain by skeletal grainstone of the Torran Limestone Member.

Distribution and thickness

The Maharakeke Mudstone Member is poorly exposed, and only crops out through central parts of the Mason Ridge area (Dyer 2005; Enclosure 1, Sheet 5). The member is a maximum of 5 m thick.

Description

Maharakeke Mudstone Member comprises blue-grey, massive, sparsely fossiliferous, poorly cemented, calcareous mudstone. Superficially the member resembles the Makaretu Mudstone but can be distinguished on the basis of stratigraphic position above *Phialopecten triphooki*-bearing limestone of the Mahana Limestone member. Maharakeke Mudstone Member becomes increasingly sandy up-section before passing abruptly into the Torran Limestone Member (Dyer 2005).

Paleontology and age

The poorly exposed nature of Maharakeke Mudstone Member means that macrofossils are not commonly observed. *Tawera subsulcata* and *Zeacolpus ?vittatus* were reported as common by

Dyer (2005), with occasional *Pelicaria ?convexa* also present. Clark (1976) noted the occurrence of *Patro undatus, Tugali pliocenica* and *Sigapatella novaezelandiae*.

Stratigraphic position demonstrates a Lower Nukumaruan age for the Maharakeke Mudstone Member (Late Pliocene).

Environment of deposition

Macrofauna support an inner to middle shelf environment of deposition for the Maharakeke Mudstone Member.

Torran Limestone Member

(Dyer 2005)

Name and definition

Torran Limestone Member was introduced by Dyer (2005) for the second of three limestone units cropping out in the Mason Ridge area. The name is derived from Torran Station where the type section is located. Torran Member is defined as the interval from the base of the siliciclastic bed forming upper parts of the Maharakeke Mudstone Member, to the base of the lower siliciclastic beds of the Pakihirua Limestone Member.

Type locality and reference sections

The type section nominated by Dyer (2005) on Torran Station is retained (V22/207589).

Lower and upper contacts

The Torran Limestone Member sharply overlies the Maharakeke Mudstone Member. It is abruptly overlain by the Whakapirau Mudstone Member, and can be observed on Ibstone Station at V22/174539 (Dyer 2005).

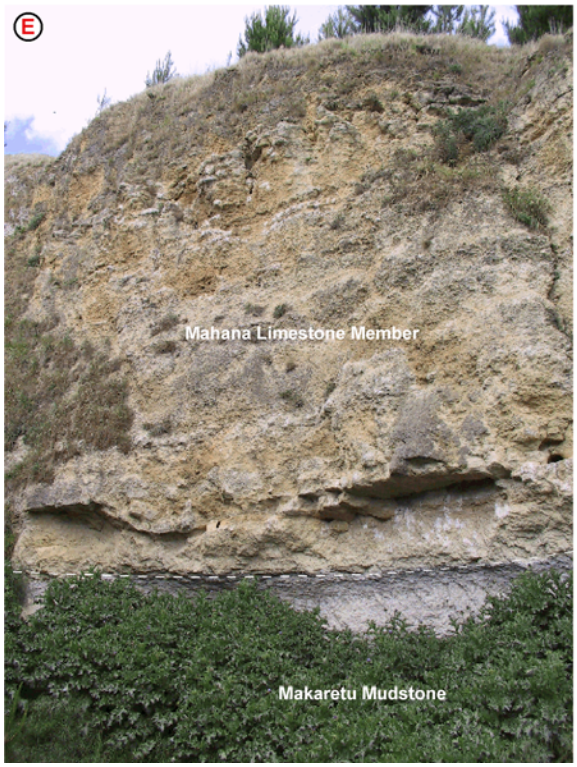
Fig. 30 (facing page): Mason Ridge Formation. **A)** Typical outcrop and geomorphology of the Mason Ridge area. White dotted line marks the base of the Mahana Limestone Member. Photo taken on Glen Coe Station. **B)** Outcrop of Mahana Limestone Member (V22/107615). Note the cross-bedding in upper parts of the exposure. **C)** Mahana Limestone Member cropping out around V22/154596. Note person for scale. **D)** Torran Limestone Member exposed in a quarry on Marae Downs Station (V22/201622). The upper rubbly-looking skeletal grainstone sharply overlies shelly packstone across a sharp wavy contact. Upper parts of the exposure comprise the capping *Ostrea*-dominated shellbed (Dyer 2005). **E)** Mahana Limestone Member, the basal unit of the Mason Ridge Formation, gradationally overlying Makaretu Mudstone on Mason Ridge Station (V22/166582). **F)** Torran Limestone Member in a quarry on Marae Downs Station (V22/201622). Person is examining the lower shelly packstone part of the member. **G)** Orange-coloured sandy skeletal packstone overlying poorly cemented skeletal grainstone, Mahana Limestone Member. Photo location Glen Coe Station (V22/154596).


A


B


C


D


E
Mahana Limestone Member
Makaretu Mudstone


F


G

Distribution and thickness

The Torran Limestone Member thins from 15 m in eastern parts of the Mason Ridge area to 8 m in the west (Dyer 2005).

Description

Torran Limestone Member comprises a basal skeletal packstone and grainstone unit that becomes increasingly biomouldic and more cemented up-section (Dyer 2005). Cross-stratification also becomes more common up-section. The transition from the skeletal grainstone to oyster beds of the member are well exposed in an old quarry on Marae Downs Station (V22/ 202224; Fig. 30D, F). These two intervals are separated by a sharp wavy contact. Small greywacke clasts up to 3 mm across are scattered through the member. The member is capped by a 1.6 m-thick bed of *Ostrea chilensis* valves and brachiopods in a grey-tan coloured silty matrix.

Paleontology and age

Macrofauna reported in the Torran Limestone Member are typical of those present in Nukumaruan limestones in the study area and include *Purpurocardia purpurata, Mesopeplum convexum, Glycymeris shrimptoni, Ostrea chilensis, Zethalia zelandica* and *Tawera subsulcata.*

The presence of *Towaipecten mariae, Zethalia zelandica* and *Glycymeris shrimptoni* assigns the member to the Nukumaruan Stage. Its stratigraphic position between two limestone beds containing *Phialopecten triphooki* (Beu 1995; Caron 2002; Dyer 2005) suggests that the Torran Limestone Member is of Lower Nukumaruan age (Late Pliocene).

Environment of deposition

Macrofauna in the Torran Limestone Member are typical of those observed in coarse-grained shallow-water deposits in the study area, and are common in harbour channel and nearshore settings around the modern New Zealand coastline. The abundance of *Zethalia zelandica* indicates deposition in a shoreface to nearshore setting on sandy to gravelly substrates, perhaps in or near tidal channels.

Whakapirau Mudstone Member

(Dyer 2005)

Name and definition

Whakapirau Mudstone Member was introduced by Dyer (2005). The name is derived from Whakapirau Station and replaced in part the term "interbedded sandstone and mudstone" used by Kelsey *et al.* (1993). The unit is defined as a coarsening-upward interval of mudstone that overlies the Torran Limestone Member and underlies the Pakihirua Limestone Member.

Type locality and reference sections

The type section designated on Raukawa Road (V22/201583) by Dyer (2005) is retained. Reference sections are located on Whakapirau Station (V22/196597) and along Pakihirua Stream (V22/191551).

Lower and upper contacts

Whakapirau Mudstone Member abruptly overlies the oyster bed capping the Torran Limestone Member. The member is gradational over 0.5 m into the overlying Pakihirua Limestone Member.

Distribution and thickness

The Whakapirau Mudstone Member is restricted in outcrop to central parts of the Mason Ridge area. The member is 10 m thick at Whakapirau Station, and thins to 4 m in western parts of Mason Ridge (Dyer 2005).

Description

The Whakapirau Mudstone Member comprises a blue-grey, sparsely fossiliferous, massive, calcareous sandy mudstone that passes upsection into friable, shelly, fine sandstone. Macrofauna are commonly concentrated into thin layers.

Paleontology and age

The member comprises typical Nukumaruan macrofauna in the study area, such as *Tawera subsulcata, Atrina pectinata zelandica, Ostrea chilensis, Zethalia zelandica* and *Purpurocardia purpurata,* together with *Pelicaria convexa* and *Zeacolpus* sp. (Dyer 2005). Dyer (2005) reported *Towaipecten mariae* in the Whakapirau Mudstone Member. Based on the presence of *Towaipecten mariae, Zethalia zelandica* and *Pelicaria convexa* a Nukumaruan age is inferred for the member. The stratigraphic position of the Whakapirau Mudstone Member below the Pakihirua

Limestone Member (which contains *Phialopecten triphooki*) implies a Lower Nukumaruan age (Late Pliocene).

Environment of deposition

Macrofauna and sedimentary structures in lower parts of the member suggest an inner shelf environment of deposition for the Whakapirau Mudstone Member. Deposition is likely to have occurred adjacent to a shoreface-nearshore sandy wedge as indicated by the presence of *Zethalia zelandica. Atrina pectinata zelandica* is common around the modern New Zealand coastline in nearshore to inner shelf settings, such as in Coromandel Harbour and the inner Hauraki Gulf, consistent with the inferred paleoenvironment for the member.

Macrofauna in upper parts of the Whakapirau Mudstone Member are consistent with a shallow nearshore environment of deposition, reflecting shallowing induced by sea level fall. *Austrovenus* is an important indicator of estuarine environments, and typically *Maoricolpus* presently occupies coarse-grained substrates in harbour channels. *Zethalia zelandica* presently occurs in shallow-water (<3 m deep) (Beu and Maxwell 1990) off sandy beaches around New Zealand. It is probable that the upper parts of Whakapirau Mudstone Member accumulated slightly offshore of a sandy beach with nearby estuarine environments. The abraded and fragmented nature of *Austrovenus* valves are consistent with redeposition of them from estuarine settings.

Pakihirua Limestone Member

(Dyer 2005)

Name and definition

Pakihirua Limestone Member was introduced by Dyer (2005) for the stratigraphically highest of three limestone units in the Mason Ridge area. The name is derived from Pakihirua Stream above which the type section is located. The top of the Pakihirua Limestone Member is equivalent to the top of the Mason Ridge Formation.

Type locality and reference sections

The type section nominated by Dyer (2005) in Pakihirua Stream is retained (V22/190551).

Lower and upper contacts

Pakihirua Limestone Member grades up over about 0.5 m from the Whakapirau Mudstone Member. The contact is exposed on Whakapirau Station (V22/196595) (Dyer 2005).

The upper surface of the Pakihirua Limestone Member, which also marks the top of the Mason Ridge Formation, is usually marked by the modern land surface. Although not exposed, it is inferred through geological mapping that the overlying Okauawa and Poutaki Formations unconformably overlie the Pakihirua Limestone Member with > 500 k.y. "missing" in the unconformity. In places the member may be unconformably overlain by a thin veneer of non cemented gravels of undifferentiated Kidnappers Group.

Distribution and thickness

The Pakihirua Limestone Member underlies central parts of the Mason Ridge area (Dyer 2005; Enclosure 1, Sheet 5), typically cropping out in scrappy uncommon exposures. The clearest outcrops occur along Pakihirua Stream in the vicinity of the type section. The unit thins from 15 m thick along Pakihirua Stream and Torran Station to 8 m at the southern end of Glencoe Station (Dyer 2005).

Description

Although generally poorly exposed, a number of different lithologies were identified in the Pakihirua Limestone Member by Dyer (2005) including: 1) basal differentially cemented, calcareous fine to coarse sandstone beds. These beds increase in their degree of cementation up-section and laterally interdigitate with each other; 2) a middle part comprising creamy-grey coloured, well cemented tabular cross-bedded biomouldic limestone, and 3) a 1.5 m-thick skeletal packstone capping bed dominated by valves of *Ostrea chilensis* and biomoulds of aragonitic bivalves. Separating these three main units are intervals of moderately cemented skeletal grainstones dominated by fragments of bryozoans with discontinuous sandstone and siltstone interbeds. The layer separating the lower and middle intervals of the member is frequently highly bioturbated with *Ophiomorpha* burrows (V. Caron, pers. comm. 2002 *in* Dyer 2005, p. 38). Greywacke granules (<0.3 cm across, up to 5% abundance) are more common in the Pakihirua Limestone Member than the underlying Torran Limestone Member. The upper *Ostrea*-dominated shellbed contains rare well rounded spheroidal greywacke pebbles up to 5 cm across (Dyer 2005).

Paleontology and age

Dyer (2005) reported *Pelicaria convexa, Ostrea chilensis, Maoricolpus roseus, Zethalia zelandica* and fragmented and abraded *Austrovenus* sp. from the Pakihirua Limestone Member.

Kelsey *et al.* (1993) assigned an Upper Nukumaruan age to this limestone. Both Caron (2002) and Dyer (2005) identified *Phialopecten triphooki* in the Pakihirua Limestone Member. This

pectinid is not known in rocks younger than Lower Nukumaruan (Beu 1995), and so a Lower Nukumaruan age is adopted for the member (Late Pliocene).

Environment of deposition

Only a sparse macrofauna was noted in the Pakihirua Limestone Member by Dyer (2005). *Phialopecten triphooki* is typically collected from coarse-grained rocks such as limestones and conglomerates that are inferred to have a nearshore to innermost shelf environment of deposition. The presence of *P. triphooki* indicates a period of deepening following deposition of the Whakapirau Mudstone Member.

SENTRY BOX FORMATION (sb)

(Erdman and Kelsey 1992)

Name and definition

Sentry Box Limestone was introduced and formally defined by Erdman and Kelsey (1992) in reference to a fossiliferous pebbly grainstone cropping out on the western margin of the Ohara Depression at the foot of the Ruahine Range. The name is derived from the Sentry Box, a prominent hill and scenic reserve immediately southwest of the type section (U21/925664; Fig. 31A, C). Sentry Box Formation was included within the informal Kereru limestone by Beu *et al.* (1980), a stratigraphic unit that contained limestones of multiple ages. Detailed geological mapping by Erdman and Kelsey (1992) clearly demonstrated that the Kereru limestone could be subdivided into three distinct limestone intervals occupying different stratigraphic positions. Sentry Box Formation is applied to the oldest of these three intervals, the others being Mount Mary Pebbly Limestone and Kereru Formation (see below). Although mostly limestone dominated, the term "Formation" is preferred over "Limestone" in this study to reflect the varied lithologies in the unit.

Sentry Box Formation has been redefined to incorporate the Whanawhana Limestone, named by Beu (1995), for a geographically-restricted lowermost Nukumaruan limestone containing both *Phialopecten triphooki* and *Zygochlamys patagonica delicatula.* The co-occurrence of these two pectinids indicates Beu's Whanawhana Limestone is of the same age as the Sentry Box Formation. Given that Beu (1995) described Sentry Box Formation both north and south of the Whanawhana region, and that the Sentry Box Formation contains the same diagnostic basal Nukumaruan pectinids, it seems appropriate to include Whanawhana Formation in the Sentry Box Formation. This simplifies the stratigraphy through this region without masking any structural or depositional influences.

Sentry Box Formation also incorporates the Seconds Ridge Conglomerate, introduced by Beu (1995). Seconds Ridge Conglomerate comprises a very small area of fossiliferous conglomerate cropping out in one locality on the northern end of the Ruahine Range. As with the Sentry Box Formation, the Seconds Ridge Conglomerate contains a diagnostic, very basal Nukumaruan fauna (Beu 1995). Erdman and Kelsey (1992) had included this unit within the Sentry Box Formation, but it was excluded from the definition of Beu (1995) on the basis of lithology. This study views the Seconds Ridge Conglomerate merely as a very shallow-water, nearshore facies variation of Sentry Box Formation cropping out elsewhere in the study area, and not requiring a separate formation name. A further point is that the only known outcrop of the Seconds Ridge Conglomerate is a 200 m-long by 30 m-high exposure at Seconds Ridge. Given the units limited geographical extent it seems inappropriate to give it formation status. However, because of the distinctive lithology reported for the Seconds Ridge Conglomerate by Beu (1995), the name is retained as a member of the Sentry Box Formation. Sentry Box Formation is defined to incorporate all basal Nukumaruan limestone and minor sandstone, conglomerate and mudstone facies containing *Zygochlamys delicatula* cropping out along the western margin of the study area from Sentry Box Scenic Reserve in the south, northwards to Mount Miroroa and the Gentle Annie at Kuripapango.

Type locality and reference sections

The type section for the Sentry Box Formation was designated by Erdman and Kelsey (1992) and is located in Jumped Up Stream where crossed by Mangleton Road from a point approximately 50 m above the road bridge to a point 50 m downstream (U21/934666, Column Ke-3). The section near Awapai Station gate (U21/043805, Column Wh-3) is designated as an excellent, easily accessible reference section for the formation in this particular area.

Lower and upper contacts

Sentry Box Formation overlies several stratigraphic units. The formation conformably to unconformably overlies the Puketitiri Formation, unconformably overlies the Blowhard Formation and unconformably overlies basement. In Jumped Up Stream Sentry Box Formation conformably and gradationally overlies fine sandstone facies of the Puketitiri Formation. Sentry Box Formation conformably overlies At Rocky Outcrop beside Gull Flat Road (U21/971717, Column Ke-6) Sentry Box Formation unconformably overlies the Puketitiri Formation across an erosional contact. The base of the formation here comprises a poorly sorted greywacke conglomerate to breccia. On the Napier-Taihape Road at the Gentle Annie a fossiliferous conglomerate of the Sentry Box Formation overlies greywacke through an angular unconformity with a paleo-high or sea-stack relief (U20/956957) (Browne 2003). Although the contact is not exposed, on Mount Miroroa

("Cattle Hill") the Sentry Box Formation is inferred to unconformably overlie the Blowhard Formation (Browne 2003, 2004a). At Seconds Ridge on the northern end of the Ruahine Range, Sentry Box Formation unconformably overlies the Omahaki Formation of Opoitian age (Beu 1995).

At the type section (Columns Ke-2, Ke-3), Sentry Box Formation is conformably overlain by fine-grained sediments of the Esk Mudstone through a 1 m-thick muddy limestone with few macrofossils. A thin (10 cm thick) shellbed above this gradational zone was found by Beu (1995) to contain common faunas diagnostic of bathyal environments.

Distribution and thickness

Sentry Box Formation crops out along the western margins of the Ohara Depression (Fig. 31A-C), prominently in the Whanawhana/Awapai Station area (Fig. 31E, F) and on isolated hilltops as far north as Mount Miroroa (Fig. 31D) and the Gentle Annie in the Kuripapango area (Browne,1981, 2004a, b). Sentry Box Formation does not crop out east of the Mohaka Fault, though it is probably present in the subsurface. In the Whanawhana area the Mohaka Fault truncates the eastern margin of Sentry Box Formation.

In the Kuripapango region the Sentry Box Formation crops out in several largely fault-bounded areas. At Mount Miroroa the formation forms a steep cliff face on the northern side of the mountain that is clearly visible from Taihape Road (Fig. 31D). The formation also crops out below Mount Kohinga and on the Gentle Annie on Taihape Road. At both of these locations the distribution of the unit is controlled by fault-bounded blocks. Sentry Box Formation is not known in outcrop east of the Mohaka Fault, or north of Taihape Road. Limestone beds south of the Ohara Depression containing *Zygochlamys delicatula* reported by Beu (1995) may be lateral equivalents of the Sentry Box Formation. The Pakipaki Limestone, Scinde Island Formation, Papakiri/Grassy Knoll Members (Matahorua Formation) and lower parts of the Mason Ridge Formation are all chronostratigraphic equivalents of the Sentry Box Formation. Erdman and Kelsey (1992) considered the Mount Mary Pebbly Limestone to be a lateral equivalent of the Sentry Box Formation as it also is overlain by the Esk Mudstone. However, the Mount Mary Pebbly Limestone lacks all diagnostic Lower Nukumaruan taxa and is most probably slightly younger.

Johnston and Francis (1996) correlated Sentry Box Formation into the Kereru-1 drillhole to a sandstone interval they named the Homeward Sandstone.

Sentry Box Formation is typically 20-25 m thick through the Ohara Depression, although outcrop thickness is generally much less than this. The thickest exposures of the Sentry Box Formation occur in the region of Jumped Up Stream and Sentry Box Scenic Reserve, and the northern face of Mount Miroroa. At Mount Miroroa Sentry Box Formation is up to 30 m thick (Browne 2003).

Description

Around the type section at Sentry Box hill and Jumped Up Stream, Sentry Box Formation consists of slightly to moderately-well cemented barnacle-dominated grainstone (Fig. 31A, B) to packstone that conformably overlies shelly conglomerate beds of the Puketitiri Formation and Sentry Box Formation. Basal conglomerate beds are highly fossiliferous, with a muddy matrix. A very diverse macrofauna are recorded from this area (Column Ke-3). Interbeds of well sorted shelly conglomerate up to 1 m thick are common throughout the main package of the formation. Master weathering surfaces are prominent in the Sentry Box hill section, and may record syndepositional fluctuations in sea level (Fig. 31A). Up-section the formation becomes increasingly muddy before passing into the Esk Mudstone. The macrofauna within the formation are dominated by the barnacles *Austromegabalanus decorus* and *Fosterella dubulatus* with common *Phialopecten triphooki, Ostrea chilensis* and *Crassostrea ingens. Zygochlamys delicatula* is locally common.

While typically limestone-dominated, facies within the Sentry Box Formation vary throughout the Ohara Depression, reflecting proximity to a paleo-shoreline. Along Gull Flat Road at Rocky Outcrop (Column Ke-6) the formation comprises a steeply dipping package of sandstone containing scattered shellhash overlain by a 0.5 m-thick greywacke conglomerate and breccia, and capped by 5 m of massive to laminated and cross-bedded slightly pebbly limestone. In Kaumatua Stream limestone of the Sentry Box Formation grades laterally into fossiliferous sandstone containing *Zygochlamys patagonica delicatula* (Erdman and Kelsey 1992).

Sentry Box Formation through the Whanawhana and Corbin Road areas (Fig. 31E, F) comprises a lower package of stacked alternating bioclastic/siliciclastic-dominated sheets overlain by an upper shellbed dominated by large aragonitic bivalves with some to common *Phialopecten triphooki* and uncommon *Zygochlamys delicatula.*

Very shallow-water deposition of the Sentry Box Formation is expressed at Seconds Ridge on the northern Ruahine Range (Seconds Ridge Conglomerate Member). shallow-water, nearshore deposition is also recognised at Kuripapango along the Gentle Annie (Browne 2003). In the Kuripapango region the Sentry Box Formation crops out as a combination of sandstone, siltstone, conglomerate and shellhash facies (Browne 2003). Browne (2004a) recognised two lithofacies in

the Kuripapango region, a gravelly grainstone and fossiliferous sandstone and siltstone. The section exposed on Mount Miroroa comprises 30 m of dark-yellowish-coloured, very poorly sorted fine sandstone to gravelly grainstone. *Zygochlamys patagonica delicatula* and *Jacquinotia edwarssi* have been collected from siltstone overlying the main limestone bluff on Mount Miroroa (Beu *et al.* 1977; Beu 1995; Browne 2004a).

Paleontology and age

Both *Zygochlamys patagonica delicatula* and *Phialopecten triphooki* are present throughout the formation and allow for confident correlation of the unit from the Ohara Depression, through the Whanawhana region to Kuripapango. In Jumped Up Stream, Sentry Box Formation contains a very diverse faunal assemblage which contains some *Zygochlamys patagonica delicatula* and common *Phialopecten triphooki*.

The presence of *Crassostrea ingens* in association with *P. triphooki and Z. delicatula* at Jumped Up Stream and Seconds Ridge demonstrates a very basal Nukumaruan age for lower parts of this unit. Only at Seconds ridge is *Crassostrea ingens* at all common (Beu 1995). Beds here also contain specimens of Mangapanian pectinids *Phialopecten thomsoni* and *Towaipecten katieae,* together with the Nukumaruan pectinid *Towaipecten mariae,* further demonstrating a very basal Nukumaruan age for lowermost parts of the formation (Beu 1995).

Environment of deposition

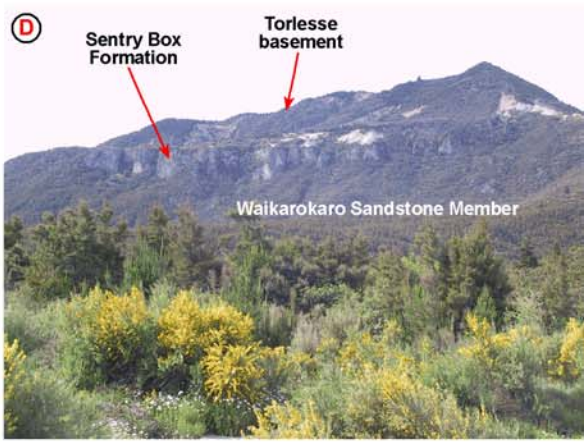
The presence of many subantarctic species in the Sentry Box Formation indicates a change to very cold waters from the underlying Puketitiri Formation. This flux of cold, subantarctic waters north into the study area (and many other parts of New Zealand such as Wanganui Basin) effectively marks the base of the Nukumaruan Stage.

Fig. 31 (facing page): Sentry Box Formation. **A)** Stacked grainstone and packstone beds of the Sentry Box Formation on the western side of Sentry Box hill (U21/925664). Person (circled) for scale. Master weathering horizons are arrowed. Sentry Box Formation here comprises packages of coarse-grained skeletal limestones with common pebbly interbeds up to 2 m thick. The formation is moderately to highly fossiliferous with a diverse ranges of bivalve and gastropod faunas. **B)** Close-up view of barnacle-dominated grainstone and packstone beds of the Sentry Box Formation at the outcrop in A (U21/925664). **C)** Sentry Box Formation in a ridge on the north side of Jumped Up Stream. Viewed looking northeast from the summit of Sentry Box Hill (U21/924664). **D)** View of Mount Miroroa from Taihape Road, Kuripapango area. Kapitean (Late Miocene) Waikarokaro Sandstone Member (Blowhard Formation) is unconformably overlain by Sentry Box Formation. The Miroroa Thrust has placed Torlesse greywacke over the Sentry Box Formation. Viewed from about U20/022935 looking south. **E)** Sentry Box Formation cropping out above the entrance to Awapai Station, Whana Valley (U21/041804). **F)** Dipslopes of Sentry Box Formation on Awapai Station. The Sentry Box Formation overlies Puketitiri Formation (arrowed). The bluffs of Te Waka Formation arrowed in this image mark the southernmost outcrop of the formation. Te Waka Formation here interdigitates with Puketitiri Formation. Viewed from U21/040806 looking northeast.

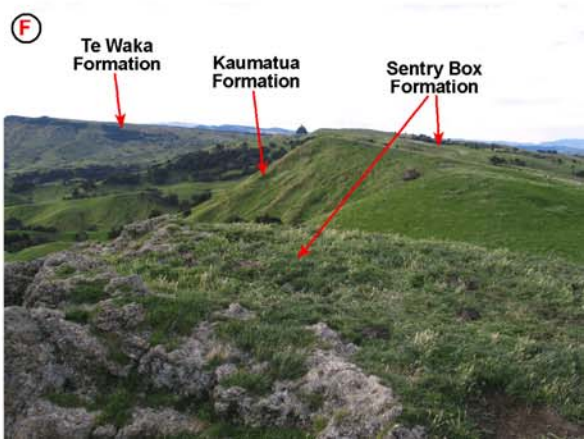

A


B


C


D
Sentry Box Formation
Torlesse basement
Waikarokaro Sandstone Member


E


F
Te Waka Formation
Kaumatua Formation
Sentry Box Formation

The rugged nature of the onlap surface exposed along the Gentle Annie (U20/956957) suggests deposition on a very rocky coastline. Throughout the Kuripapango region a shallow marine (<50 m) depositional setting is inferred. The wide variety of facies present (from siltstone to gravel) suggests varied localised depositional settings

Seconds Ridge Conglomerate Member (sba)

(Beu 1995)

Name and definition

Beu (1995) introduced the informal Seconds Ridge limestone for a fossiliferous conglomerate cropping out on the northern Ruahine Range which was included in the Sentry Box Limestone (renamed Sentry Box Formation in this study) by Erdman and Kelsey (1992). Seconds Ridge Conglomerate Member has a very localised distribution, and a basal Nukumaruan macrofauna very similar to that of the Sentry Box Formation. These factors suggest that maintaining Sentry Box Conglomerate Member as a distinct formation is inappropriate. However the unit is mappable and lithologically distinct enough to have member status. Seconds Ridge Conglomerate Member is defined as a coarse-grained interval of basal Nukumaruan age cropping out on the northern Ruahine Range that overlies Early Pliocene Omahaki Formation.

Type locality

The type section defined for the Seconds Ridge Conglomerate Member by Beu (1995) is retained (U21/972802).

Distribution and thickness

Seconds Ridge Conglomerate Member is not known away from the type locality on Seconds ridge where it crops out in a single 200 m-long by 30 m high exposure (Beu 1995).

Lower and upper contacts

Seconds Ridge Conglomerate Member unconformably overlies the Omahaki Formation of Opoitian age (Beu 1995). The upper contact is marked by the modern land surface.

Description

The only description of the Seconds Ridge Conglomerate Member is that by Beu (1995). It comprises flat-lying, parallel-bedded to low-angle cross-bedded calcareous-cemented conglomerate. Individual beds vary from 0.2-1 m thick and consist of pebble-supported very well

rounded Torlesse basement clasts with a minor fine calcareous matrix. The matrix varies from fine-grained calcarenite to coarse-grained barnacle plate grainstone. Beds 0.3-0.5 m thick are present that are less conglomeratic, and richer in the matrix sediments. *Crassostrea ingens* is scattered through all lithologies, although is more common in beds richer in calcareous sediments. Pectinids occur more rarely in the calcareous beds.

Paleontology and age

Crassostrea ingens is the only mollusc at all common in the Seconds Ridge Conglomerate Member (Beu 1995). Pectinids present in small numbers include *Phialopecten thomsoni, Towaipecten katieae* n.sp., *T. mariae, Mesopeplum convexum, Talochlamys gemmulata,* and *Zygochlamys delicatula.*

A very basal Nukumaruan age is assigned to the Seconds Ridge Conglomerate Member based on the co-occurrence of *C. ingens, P. thomsoni* and *Towaipecten katieae* (a Mangapanian assemblage) with *T. mariae* and *Z. delicatula* (Beu 1995). The fauna at Seconds Ridge (GS12421, U21/f5; Beu 1995, p. 141) is unique in the study area and comprises a very shallow-water, high-energy assemblage that can be correlated with the Sentry Box Formation based on the occurrence of *Z. delicatula* with *P. thomsoni* and *C. ingens.*

Environment of deposition

Seconds Ridge Conglomerate Member is viewed as being a nearshore, very shallow-water expression of deeper water Sentry Box Formation beds in Jumped Up Stream, at Rocky Outcrop, Whanawhana and Mount Miroroa. It was deposited immediately adjacent to an exposed basement hinterland, and probably records the final stages of the Kuripapango Strait before it was finally uplifted in the Upper Nukumaruan.

MOUNT MARY PEBBLY LIMESTONE (mm)

(Erdman and Kelsey 1992)

Name and definition

Erdman and Kelsey (1992) introduced the name Mount Mary Limestone in reference to a series of interbedded grainstone and conglomerate beds capping Mount Mary (from where the name is taken) in the Ohara Depression. This formation was originally included in the Kereru limestone (informal) of Beu *et al*. (1980). Mount Mary Pebbly Limestone is older than limestone of the Kereru Formation, and the separate formation name reflects this.

Type locality and reference sections

The type section designated by Erdman and Kelsey (1992) on Mount Mary (U21/969681) is retained in this study. Although the section is incomplete, the type locality contains the greatest thickness of the formation.

Distribution and thickness

Mount Mary Pebbly Limestone is restricted in outcrop to margins of the Wakarara Range in the Ohara Depression, and does not occur west of the Mohaka Fault. Mount Mary Pebbly Limestone is absent where mudstone of the Esk Mudstone rests directly on basement greywacke. Mount Mary Pebbly Limestone is a maximum of 30 m thick.

In the Ohara Depression the formation crops out on the northwestern summit of Mount Mary on Glendale Farm (e.g. U21/969681), and beside Mangleton Road (U21/279701).

Lower and upper contacts

The Mount Mary Pebbly Limestone everywhere unconformably overlies Torlesse basement with common metre-scale relief on the contact.

Mount Mary Pebbly Limestone is gradationally overlain by, and interdigitates with, the Esk Mudstone (Erdman and Kelsey 1992).

Description

Mount Mary Pebbly Limestone is typically a moderately to well cemented grainstone composed of shellhash and fragmented bryozoans with common greywacke pebbles averaging 3-15 mm across (Kelsey *et al*. 1993). At the type section the Mount Mary Pebbly Limestone comprises 30 m of calcareous-cemented matrix-supported greywacke conglomerate with a few interbeds of grey-brown coarse sandstone (Beu 1995). Greywacke clasts are supported in a matrix of mudstone to shellhash and display parallel to low-angle cross-stratification in stacked beds 0.2-0.5 m thick (Beu 1995). In a cutting on Mangleton Road, where the unit rests on greywacke basement, Mount Mary Pebbly Limestone consists of thin (<0.3 m thick) alternating grainstone, pebbly limestone and greywacke conglomerate beds. Rare pebbly beds up to 0.7 m thick are present. Clasts are well rounded and well sorted, typically 2-3 cm across, rarely up to 6 cm. Bryozoan fragments are common in the more carbonate-dominated interbeds, and presumably reflect organisms that encrusted an irregular greywacke seafloor. This locality is adjacent to where the Mohaka Fault crosses Mangleton Road.

A cyclothemic expression of the formation is evident in Matthews Stream, based on descriptions by Erdman and Kelsey (1992). In this section the formation comprises three distinct packages comprising a coarse-grained pebbly limestone gradationally overlain by 5-10 m of massive mudstone (Kelsey *et al.* 1993). it is probable that this section accumulated in a slightly more offshore setting than that exposed at the type section.

Paleontology and age

Samples of Mount Mary Pebbly Limestone from cuttings on Mangleton Road are rich in sheet and branching bryozoans, presumably derived from organisms attached to a nearby rocky substrate of basement. Kelsey *et al.* (1993) suggested that Mount Mary Pebbly Limestone was age equivalent to Sentry Box Formation (i.e. basal Nukumaruan). No specimens of typical Lower Nukumaruan fauna have been collected from Mount Mary Pebbly Limestone. Because Mount Mary Pebbly Limestone is overlain by Esk Mudstone (as is Sentry Box Formation), it must be of a similar age to the Sentry Box Formation. However, Mount Mary Pebbly Limestone lacks all diagnostic basal Nukumaruan index fossils, such as *Phialopecten triphooki* and *Zygochlamys delicatula,* and is therefore younger than the Sentry Box Formation. On the basis of stratigraphic position beneath the Esk Mudstone, the Mount Mary Pebbly Limestone is assigned a Lower Nukumaruan (Late Pliocene) age.

Environment of deposition

Mount Mary Pebbly Limestone probably developed adjacent to a greywacke “island” (the proto-Wakarara Range) on the margins of a region of otherwise relatively deep-water (outer shelf to perhaps uppermost bathyal). Mount Mary Pebbly Limestone is only present in the vicinity of the Wakarara Range. It is envisaged that the emerging Wakarara Range acted as a shoal area, with Mount Mary Pebbly Limestone accumulating on and around it. The cyclothemic expression of the formation indicates that strata in Matthews Stream were deposited in a slightly deeper water setting than those at the type section on Mount Mary (hence more accommodation space). The presence of metre-scale relief on the lower contact on Mount Mary (U21/969681) indicates a rocky coastline environment in areas proximal to the Wakarara Range.

KERERU FORMATION (ke)

(McKay 1887; formally defined by Erdman and Kelsey 1992)

Name and definition

Kereru Formation derives its name from Kereru Station, one of the earliest established stations in Hawke’s Bay. Limestone in this area was first described by McKay (1887) and originally all

limestone beds in the Ohara Depression, such as those at Sentry Box and Mount Mary, were included in the Kereru Limestone (e.g. Beu *et al.* 1980). Erdman and Kelsey (1992) recognised that there are in fact limestone units of multiple ages and depositional settings in the Kereru and Ohara Depression areas and redefined the Kereru Limestone. Erdman and Kelsey (1992) restricted the name Kereru Limestone to very pebbly limestone and sandy oyster beds cropping out in very steeply-dipping (c. 90º) ridges along most of the eastern edge of the Wakarara Range, and on several small platforms along the western edge of the range. Outcrops in the western areas are still relatively shallow-dipping. Elements of the diagenetic history of the Kereru Limestone were described by Caron (2002). As sandstone and siltstone beds are common in this unit, the Kereru Limestone of Erdman and Kelsey is here emended to Kereru Formation.

Type locality and reference sections

No type locality was nominated for the Kereru Formation by either Erdman and Kelsey (1992), Kelsey *et al.* (1993, or Beu (1995). The section on Glendale Farm off Mangleton Road, described in detail by Caron (2002), is nominated as the type section for the Kereru Formation (Fig. 32B-E; U21/967687, Column Ke-8). This section exposes the base of the formation.

Lower and upper contacts

On Glendale Farm (U21/967687) the Kereru Formation sharply overlies coarsening upwards siltstone to fine sandstone of the upper part of Esk Mudstone (Caron 2002) (Fig. 32B, C, E). The upper contact, where abruptly although gradationally overlain by the Kikowhero Member of the Okauawa Formation, is exposed in Ohara Stream in several locations (e.g. U21/050731, U21/041726). The Kereru Formation is in fault contact with basement southwest of Poporangi Road due to reverse displacement on the Wakarara Fault (U21/996654).

Distribution and thickness

Kereru Formation is restricted in outcrop to an area proximal to the North Island axial faults south of the Ngaruroro River, largely in the vicinity of elevated regions of greywacke basement. Kereru Formation underlies and interdigitates with Okauawa Formation, as exposed at the confluence of the Big Hill and Ohara Streams. To the east of the Wakarara Range, Kereru Formation crops out as a series of near-vertically dipping ridges truncated by the Wakarara Fault. Northwards from the Wakarara Range the Kereru Formation grades into massive to laminated muddy fine sandstone and highly fossiliferous pebbly shellbeds.

The Kereru Formation is clearly visible from Mangleton Road near the Sentry Box as a long ridge extending along the western side of the Wakarara Range. A steeply dipping ridge of Kereru

Formation is prominent southwest of Poporangi Road (U21/996654). At this locality the formation is truncated to the west by the Wakarara Fault and juxtaposed against basement.

Kereru Formation has been correlated into the Kereru-1 drillhole, where it is represented by a sandstone interval (Johnston and Francis 1996). The formation is not present in either the Mason Ridge-1 or Taradale-1, drillholes by which time it has likely graded into mudstone dominated facies of the Taradale Formation. An 8 m-thick sandstone body underlying the Kikowhero Member of the Okauawa Formation in the Ngaruroro River (U21/092883, Column Mt-1) is a potential, more offshore lateral equivalent of at least part of the Kereru Formation.

The formation crops out widely, in small areas, south of the study area, around the southern end of the Wakarara Range, and as far south as Ashley Clinton (Beu 1995). Raub (1985) reported Kereru Formation as far south as Waipawa River.

Kereru Formation is age equivalent to upper parts of the Esk Mudstone in the Tangoio-Esk areas which were at that time probably accumulating in deeper water environments. The presence of the Kereru Formation records concurrent early uplift on the Wakarara Range associated the Wakarara Fault movement.

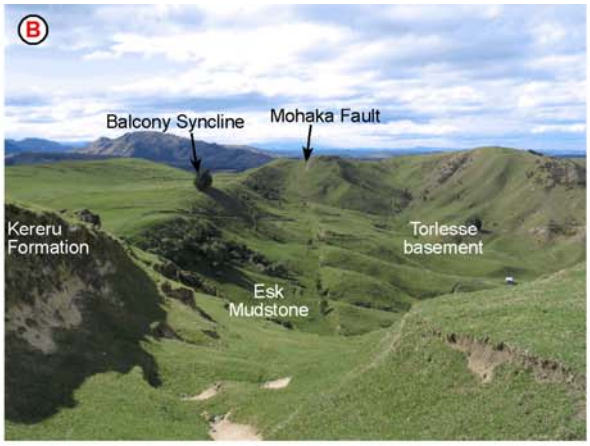
Description

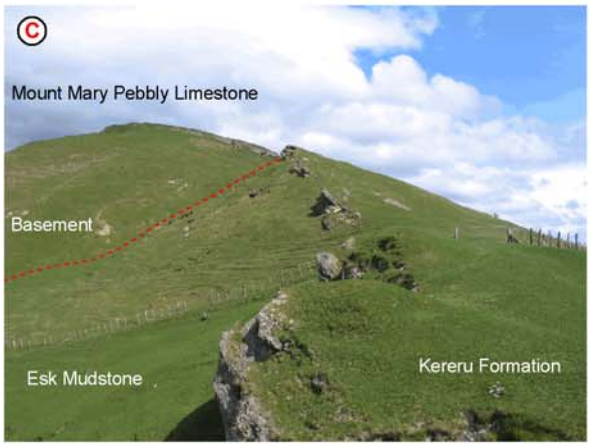
Details of the diagenetic history of the Kereru Formation were studied by Caron (2002). Kereru Formation comprises alternating pebble-rich siliciclastic-carbonate beds, each of several metres thickness. Bioclastic beds typically consist of distinctive tightly packed beds rich in *Ostrea chilensis* as well as calcarenites and hard, calcareous-cemented fine to medium litharenites (Erdman and Kelsey 1992). Greywacke pebbles comprise up to 25% of bioclastic beds along the western edge of the Wakarara Range. Clasts are well rounded, 3-20 mm across, with some larger grains up to 150 mm across.

In Ohara Stream near the Big Hill Stream confluence (Fig. 32F, G) Kereru Formation was observed to comprise highly fossiliferous shellbeds with a fine-grained muddy matrix (U21/ 026720, Column Ke-7). Fauna were dominated by the shallow-water bivalve *Tawera subsulcata*.

On Glendale Farm (U21/968684, Column Ke-8), Kereru Formation comprises three distinct carbonate units separated by 5-6 m thick siltstone-sandstone intervals comprising a succession of coarsening-upward packages, individually 0.15-0.2 m thick. Each package consists of a lower bioturbated siltstone to sandstone capped by poorly cemented shelly sandy beds (Caron 2002).


A


B
Balcony Syncline
Mohaka Fault
Kereru Formation
Torlesse basement
Esk Mudstone


C
Mount Mary Pebbly Limestone
Basement
Esk Mudstone
Kereru Formation


D


E
Kereru Formation
Esk Mudstone


F


G

The lower carbonate bed comprises a 3-4 m thick, massive moderately cemented shellbed packed with oyster and brachiopods with a muddy matrix. The unit is sharp-based and overlies fine sandstone of the uppermost parts of the Esk Mudstone. The upper 5-6 m thick carbonate bed erosionally overlies the siltstone-sandstone interval and consists of two broad units. The lower 2 m-thick part comprises a moderately cemented, tangential to trough cross-bedded packstone containing common mudstone clasts from the underlying interval. The upper package (4 m thick) consists of a coarsening-upward well cemented barnacle packstone/grainstone comprising stacked beds 0.2-0.3 m thick (Caron 2002). The upper surface of this layer is not exposed.

Paleontology and age

Kereru Formation cropping out along the western edge of the Wakarara Range contains a limited macrofauna, mostly restricted to valves of *Ostrea chilensis, Talochlamys gemmulata, Patro undatus* and little else (Beu 1995). At Glendale Farm, below Mount Mary (Fig. 32B-E; U21/ 968684, Column Ke-8), fauna are dominated by *Ostrea* with common *Neothyris, Patro, Talochlamys* and some *Mesopeplum convexum* and *Tucetona.* While still *Ostrea* dominated, Kereru Formation exposed in Ohara Stream below the Big Hill Road bridge also contains common *Purpurocardia purpurata* and some *Dosina* sp. Kereru Formation in these outcrops is much thinner and finer-grained than beds at the type section, and also is generally less pebbly. At the confluence of Big Hill and Ohara Streams, where an upper shelly limestone bed of Kereru Formation is conformably overlain by the Okauawa Formation (U21/026720; Fig. 32F, G), the Kereru Formation is dominated by valves of *Tawera subsulcata,* with common *Ostrea chilensis, Patro undatus, Purpurocardia purpurata* and some *Dosina* sp. *Purpurocardia* become more common as the limestone coarsens up-section.

Fig. 32 (facing page): Kereru Formation, Ohara Depression. **A)** Landscape photograph from U21/934665 on Mangleton Road near Sentry Box Reserve, looking east of a ridge of Kereru Formation cropping out adjacent to the Wakarara Range. **B)** Kereru Formation cropping out on Glendale Farm adjacent to the Mohaka Fault (arrowed). Kereru Formation overlies Esk Mudstone which is juxtaposed by the Mohaka Fault against Torlesse basement in the Wakarara Range. Vertical displacement on the Mohaka Fault has folded Kereru Formation and the underlying Esk Mudstone into the Balcony Syncline (arrowed). Photograph is taken from the slopes of Mount Mary looking north (U21/968682). **C)** Eastern limb of the balcony syncline showing steeply dipping Kereru Formation cropping out adjacent to the Mohaka Fault (Glendale Farm, U21/968684). **D)** Steeply dipping Kereru Formation cropping out at the type section on Glendale Farm (U21/968684). **E)** Western limb of the Balcony syncline on Glendale Farm beside Mount Mary looking south from U21/967686. **F)** Steeply dipping Kereru Formation cropping out at the Ohara Stream-Big Hill Stream confluence (viewed from U21/028720). Folding here is a result of subsurface reverse displacement on the Wakarara Fault and formation of the Wakarara Monocline. In this outcrop highly fossiliferous Kereru Formation is conformably overlain by the Kikowhero Member of the Okauawa Formation. **G)** Close-up view of Kereru Formation in F. Macrofauna in this outcrop are dominated by *Tawera subsulcata* with common *Ostrea chilensis, Patro undatus, Purpurocardia purpurata* and some *Dosina* sp. (U21/026720).

Kereru Formation underlies and interdigitates with lower parts of the Okauawa Formation, and is assigned an Upper Nukumaruan age. Kereru Formation is age equivalent to upper parts of the Esk Mudstone in the Tangoio region to the northeast.

Environment of deposition

Greywacke clasts in the Kereru Formation tend to be larger, and comprise more of the formation closer to the Wakarara Range. Throughout the study area fauna in the Kereru Formation are typically dominated by robust bivalves characteristic of reasonably high-energy environments with a coarse-bottom substrate. Faunal diversity increases away from the Wakarara Range, reflecting increased water depth away from what is inferred to have been a shoal area during depositional times.

OKAUAWA FORMATION (ok)

(Erdman and Kelsey 1992)

Name and definition

Okauawa Formation was introduced and formally defined by Erdman and Kelsey (1992). The name is derived from Okauawa Stream in the Kereru region. The Okauawa Formation incorporates the undefined Kikowhero and Crownthorpe Formations of McLennan (1990), and western parts of the Roys Hill siltstone (informal) of Kingma (1971). The formation was studied in part by Clarke (1976) who informally referred to it as the upper Petane clays.

The Okauawa Formation in the Wakarara, Kereru and Sherenden areas contains two members that have been newly defined in this study. These two units, the Kikowhero and Whakamarumaru Members, are defined to accommodate the distinctive coarse-grained lower parts of the formation and the greywacke conglomerate beds present. However, the two members have not been individually mapped, although descriptions of them are presented below. The discussion that follows for the Okauawa Formation relates mostly to the more uniform fossiliferous siltstone-sandstone succession present east of Kereru. Detailed mapping of the lower conglomerate facies of the Okauawa Formation has been crucial to determining the stratigraphy of this region, and establishing the relationship of beds in the Tangoio area with those in the Ohara Depression. This has led to more unified stratigraphic nomenclature for the Nukumaruan stratigraphy throughout central Hawke's Bay.

Type locality and reference sections

The type section designated by Erdman and Kelsey (1992) was first described by Clark (1976) and is retained in this study. A well exposed reference section is present in Ohara Stream downstream from the confluence with Big Hill Stream to the confluence of Poporangi Stream (U21/026720-U21/055737; Columns Ke-4, Ke-5, Ke-7). Along this section the coarse-grained conglomerate facies of the formation are well exposed in stream cliffs. Cliff faces in the Ngaruroro River downstream of Whana Valley are designated as clear, well exposed reference sections for the formation, although they are relatively difficult to access due to river levels and flow strength (U21/092760-V21/104750, Column Mt-1). The highly fossiliferous facies of the Okauawa Formation are easily accessible along Kereru Road near the entrance to Whanakino Station (U21/094689, Column Ke-1). This section displays the upper parts of one cyclothem and the lower parts of the subsequent cyclothem.

Distribution and thickness

Okauawa Formation is widely distributed in a northeast-southwest trending outcrop belt from Mount Cameron to the northern Ohara Depression. Distribution of the formation through the Ohara Depression and wider Kereru area was mapped by Erdman and Kelsey (1992) and Kelsey *et al.* (1993). The Okauawa Formation is not present west of the Mohaka Fault. The conglomerate facies are well exposed in Ohara Stream from the Big Hill Stream confluence, downstream to the Poporangi Stream confluence. Kelsey *et al.* (1993) indicate that the conglomerate facies are also well exposed in Waitangi Stream, stratigraphically above the last grainstone bed of the Kereru Formation. Mapping has demonstrated that conglomerate beds in the Ohara depression crop out nearly continuously through the Ngaruroro River, Whakamarumaru Station, the Crownthorpe and Sherenden districts to the Tutaekuri River near Flag Range. The lowermost conglomerate is probably equivalent to the Tutira Member, and the upper conglomerate to the Tararere Conglomerate Bed (Darkys Spur Member). It is important to note that conglomerate beds in the Okauawa Formation and the Tutira/Darkys Spur Formations do not pass into one another, and appear to be separated by an interval of the Esk Mudstone.

Along the eastern front of the Wakarara Range the formation is a minimum of 100 m thick, which increases away from this region. The formation is at least 150 m thick in Ngaruroro River cliffs below Whana Valley.

Lower and upper contacts

In Ohara and Waitangi Streams the Okauawa Formation conformably overlies and interdigitates with the Kereru Formation. Away from these streams the Kereru Formation passes laterally into

Esk Mudstone, so consequently east of the Ohara Depression it is over Esk Mudstone that the Okauawa Formation conformably lies (Enclosure 5).

Throughout the Waihau, Sherenden and Crownthorpe areas the Okauawa Formation is conformably overlain by the Mairau Mudstone and subsequently Flag Range Conglomerate Members of the Petane Formation. In the region of Kereru Road it is probable that the Flag Range Member has graded into the upper parts of the Okauawa Formation and may be equivalent to one of the highly fossiliferous sandy shellbeds present in this area (e.g. that exposed at Whanakino Station gate). In the Kereru region the Okauawa Formation is overlain by the Poutaki Formation (Erdman and Kelsey 1992).

Description

Okauawa Formation comprises fossiliferous sandstones, shelly conglomerates, and siltstones that are often highly fossiliferous. Conglomerate facies, where present, are restricted to basal parts of the formation. The conglomeratic interval has been differentiated into two members that have been mapped through a large part of the study area (see below).

In basal parts, Okauawa Formation contains prominent greywacke conglomerate beds, though these beds are lacking in Okauawa Stream (Kelsey *et al.* 1993). These beds probably reflect the start of acceleration of uplift of the north end of the Wakarara Range late in the Lower Nukumaruan. The conglomeratic lower part of the formation has been differentiated into two lithostratigraphic members that are discussed below. This section details the nature of the siltstone-sandstone dominated parts of the Okauawa Formation.

Cyclothemic deposits are present through the formation. In Ngaruroro River cliffs above the Whakamarumaru Member, siltstone-sandstone cycles are well exposed (Columns Mt-1, Mt-2). Cyclothemic deposits have been recognised at the Whanakino Station gate along Kereru Road (U21/094689, Column Ke-1). Previously this section was interpreted as a single fossiliferous silty sandstone bed (e.g. McLennan 1990). Faunal sampling from this site has revealed prominent variations in water depth. The lower 1 m of the section comprises non cemented silty sandstone dominated by *Tawera* with *Gonimyrtea, Zeacolpus, Maorimactra, Zethalia* and *Fellaster* among many other species. This in turn is overlain by a 3 m-thick interval of non cemented fine sandstone containing *Dosinia, Fellaster, Myadora* and *Bassina.* Both of these two intervals indicate shallow-water deposition in proximity to a sandy beach. Above is a 0.5 m-thick highly fossiliferous shellbed dominated by *Tawera* and notably containing common large *Struthiolaria frazeri,* with *Talochlamys, Ostrea, Dosina* and the brachiopod *Waltonia inconspicula.* The fauna in this

shellbed, and overlying units, strongly suggests an increase in water depth and is inferred to represent a transgressive deposit.

The 2 m of section above this shellbed comprises a highly fossiliferous shellbed with a fine sandstone matrix dominated by *Tawera* with *Ostrea, Patro, Purpurocardia, Zeacolpus* and *Maoricolpus.* This shellbed is capped by scattered *Waltonia inconspicula*. The section above this fines-upwards over 3 m through silty sandstone into at least 10 m of fine-grained non cemented siltstone and is inferred to record highstand sedimentation. The silty sandstone is less fossiliferous than lower beds and contains common *Tawera* and *Dosina.* The overlying siltstone is dominated by *Talochlamys* with common *Ostrea.* The gastropod *Pelicaria convexa* is also present in this interval. Very large valves of *Austrovenus crassitesta* (an estuarine bivalve) are present in fall blocks at the base of the section, and have presumably come from beds above the road section. These *Austrovenus* valves presumably record a subsequent fall in sea level and another cyclothem. Further along Kereru Road is a small series of road cuttings rich in *Austrovenus* valves and may be the equivalent bed responsible for the valves visible at Whanakino Station gate. In this section *Austrovenus* valve are abundant with common *Barytellina crassidens* in a muddy fine sandstone containing well-developed flaser bedding, mud drapes and ripple laminations, supportive of an estuarine setting.

The Ngaruroro River section (U21/092760-V21/104750) is similar to that exposed along Kereru Road and consists of coarsening-upward siltstone-sandstone packages generally 30-40 m thick. Although well exposed, sections are difficult to access due to the vertical nature of cliffs in the river valley. What this section does demonstrate, however, is the character of cyclothemic deposits in this part of the Okauawa Formation.

Paleontology and age

Okauawa Formation comprises non to highly fossiliferous beds containing a large variety of macrofauna typical of Nukumaruan rocks through the study area. Shellbeds crop out beside Kereru Road at Whanakino Station gate (U21/094689, Column Ke-1). Macrofauna in sandstone facies at this site are characterised by shallow-water taxa such as *Fellaster, Tawera, Struthiolaria frazeri* and *Zethalia*. Siltstone lithofacies contain *Talochlamys gemmulata, Ostrea chilensis* and *Pelicaria convexa*. Estuarine *Austrovenus stutchburyi/A. crassitesta* occur in fall blocks. A diverse shelfal macrofaunal assemblage was observed in a cutting on Salisbury Road (V21/ 138651). At this site a highly fossiliferous sandstone passes rapidly into a non fossiliferous siltstone. Fauna comprise *Sigapatella, Talochlamys, Ostrea, Purpurocardia, Pelicaria convexa, Penion, Struthiolaria frazeri, Tawera, Amalda mucronata, Patro, Maoricolpus, Zeacolpus,*

?*Waltonia inconspicula* and ?*Glycymeris modesta.* Conglomerate beds near the base of the formation interdigitate with beds of the Kereru Formation, a unit that has been demonstrated to have an Upper Nukumaruan (Late Pliocene) age. Beu (1995) described taxa in the Okauawa Formation that are consistent with the Upper Nukumaruan Devils Elbow Mudstone Member in the Tangoio Block (*Amalda mucronata* form *erica, Aeneator comptus, Glaphyrina plicata* and *Cominella excoriata*). This assemblage is also known only at "Shrimptons" in the lower reaches of Kikowhero Stream near Matapiro Station, and in Okauawa Formation in Okauawa Stream and Mangatahi River near Kereru Road. These fauna appear to be indicative of Upper Nukumaruan age in Hawke's Bay (Beu 1995). Several key Nukumaruan index macrofossils such as *Struthiolaria frazeri* and *Austrovenus crassitesta* have been collected from the Okauawa Formation and help confirm a Nukumaruan age. The presence of *Pelicaria convexa* throughout the formation constrains the age further to Upper Nukumaruan. Okauawa Formation is therefore of Upper Nukumaruan age based on superposition and macrofaunal content.

Environment of deposition

Facies in the Okauawa Formation indicate deposition at shelf water depths with occasional non- to marginal-marine influxes, demonstrating that the formation was deposited under a regime of eustatically-driven sea-level oscillations. The presence of coarse-grained conglomerate beds in the Okauawa Formation reflects an increase in the rate of deformation of the study area during the Upper Nukumaruan. Conglomerate facies represent deposition in non-marine to shoreface settings in conjunction with fluvial braid-plain progradation during periods of sea level lowstand (see below, Kikowhero Member and Whakamarumaru Member). Greywacke clasts transported as bedload in these rivers were derived from the Ruahine and Wakarara Ranges, which were actively rising at this time. Sandstone beds were deposited in shoreface to inner shelf environments, as indicated by macrofauna such as *Bassina, Struthiolaria frazeri* and *Zethalia zelandica*. Siltstone beds were deposited at inner to middle shelf water depths, an inference supported by macrofauna typical of such settings. Occasional periods of estuarine deposition are indicated by the presence of restricted taxa such as *Austrovenus stutchburyi* and *A. crassitesta*.

Kikowhero Member (oka)

(Kingma 1971 (informal))

Name and definition

Kikowhero Member is named after Kikowhero Stream in the Otamauri-Matapiro area, and is in part equivalent to the undefined Kikowhero gravels of Kingma (1971). Kikowhero Member is probably an age equivalent of the Tutira Member in the Tangoio Block, although the two units are

not continuous across the basin, and represent the development of different fan-delta systems during the early part of the Upper Nukumaruan. The member is defined to include all strata from the conformable lower contact with the Kereru Formation to the top of the greywacke conglomerate bed that caps the member.

As part of a large-scale geological map through the Esk-Kereru districts, McLennan (1990) mapped the Kikowhero Member as the Mistletoe Conglomerate Member of the Kikowhero Formation. The Kikowhero Member was wrongly correlated by McLennan (1990) to one of the Upper Mangapanian conglomerate beds (Matahorua Formation) cropping out through the Patoka-Esk-Waikoau districts. Geological mapping and macrofaunal analyses in this study has demonstrated that the conglomerates in the Okauawa Formation are significantly younger than those in the Matahorua Formation. This distinction is important as it highlights the development of two separate fan-delta systems in different parts of the basin at different times.

Type locality and reference sections

The type locality is designated as the section exposed in Ohara Stream from the confluence with Big Hill Stream (Fig. 33C; U21/026720, Column Ke-7) to a point just downstream of the Big Hill Road bridge over Ohara Stream (Fig. 35A; U21/046727, Column Ke-4). This section is the most accessible place where the entire member can be viewed.

An excellent reference section is present in the Ngaruroro River downstream of Whana Valley (U21/092760). Nearly the entire member is exposed in high cliff sections in this area, although access is difficult and only readily achievable through raft or jet boat, or by walking downstream when the Ngaruroro River is in very low-flow conditions.

Lower and upper contacts

In the Ohara/Poporangi Stream section, Kikowhero Member gradationally overlies the Kereru Formation (Fig. 33E) over less than 0.2 m. Where the Kereru Formation is absent the base of the member is defined as the conformable contact between a prominent sandstone bed and overlying siltstone, as exposed in the Ngaruroro River below the Whanawhana cable. The sandstone is likely to be a distal equivalent of pebbly limestone facies of the Kereru Formation cropping out in the Ohara Depression. The overlying siltstone is assigned to the Kikowhero Member. The lower contact of the Kikowhero Member is not exposed between the Ngaruroro River and Mount Cameron, although it is assumed that the member conformably overlies the Esk Mudstone.

Kikowhero Member is abruptly overlain by siltstone of the Whakamarumaru Member. In the Whana Valley region this contact occurs through a thin pebbly shellbed rich in *Tawera* valves with common, largely dissolved bivalves (U21/096771, Column Wh-1). The upper contact is also exposed in Kikowhero Stream on Whakamarumaru Station where the Whakamarumaru Member abruptly overlies fossiliferous conglomerate facies of upper parts of the Kikowhero Member (Fig. 33B; V21/124773, Column Wh-2).

Distribution and thickness

The Kikowhero Member is widespread through southwestern parts of the study area from the Ohara Stream (Fig. 33A, C, E), through the Ngaruroro River, Whakamarumaru Station (Fig. 33B) to Flag Range and Mount Cameron. The member has not been identified north of Waihau Road near Dartmoor. Away from the Ohara and Poporangi Streams and the Ngaruroro River only the upper greywacke conglomerate bed tends to crop out. The entire member is well exposed in cuttings along Ohara Stream below the Big Hill Stream confluence to the Poporangi Stream confluence. Complete exposure is also present in the Ngaruroro River at Whana Valley. The transition from the upper sandstone bed into greywacke conglomerate is well exposed at and near a gravel pit located at the western end of Matapiro Road (Fig. 33D). Partial exposures of the member are present west of Crownthorpe Settlement Road.

Towards the east, away from the Ohara Depression, the Kikowhero Member passes into a more fine-grained siltstone and sandstone-dominated expression of the Okauawa Formation. The most eastern exposures of the member occur on the prominent northerly ridge extending from the main block of Mount Cameron between the Tutaekuri River and Waihau Road. The member cannot be differentiated in the nearby Mangaone River from relatively massive mudstone facies of the Esk Mudstone.

In the Ohara Stream section the Kikowhero Member is 20 m thick. In the Ngaruroro River section the member is approximately 15 m thick. At Flag Range and Mount Cameron the member is at least 25-30 m thick.

Fig. 33 (facing page): Okauawa Formation. **A)** Okauawa Formation (Kikowhero Member) conformably overlying Kereru Formation in Ohara Stream below the Big Hill Road bridge (U21/046727). The grey-coloured conglomerate bed at the top of the Kikowhero Member is clearly visible in this image. **B)** Kikowhero and Whakamarumaru Members cropping out in the upper reaches of Kikowhero Stream, Whakamarumaru Station (V21/124773). **C)** Okauawa Formation cropping out at the Ohara Stream-Big Hill Stream confluence (U21/026720). The prominent large-scale folding evident in this section is the result of deformation of the sub-surface Wakarara Fault and the resulting Wakarara Monocline. **D)** Parallel bedded conglomerate bed of the Kikowhero Member cropping out beside Matapiro Road near Whana Valley (U21/094774). A non-marine depositional environment is inferred for this unit. **E)** *Tawera*-dominated shellbed at the top of the Kereru Formation overlain conformably by siltstone of the Okauawa Formation (Kikowhero Member) in Ohara Stream below the Big Hill Road bridge (U21/ 050731). **F)** Shellbed overlying the Kikowhero Member at the base of the Whakamarumaru Member near Matapiro Road, Whana Valley (U21/096771). The shellbed is dominated by the bivalve *Tawera subsulcata*.


A
Whakamarumaru Member
Kikowhero Member
Kereru Formation


B
Whakamarumaru Member
Kikowhero Member


C
Whakamarumaru Member
Kikowhero Member


D


E


F

Description

The Kikowhero Member is similar in character to members of the Matahorua Formation in that it comprises a coarsening-upwards succession comprising a lower siltstone unit that passes up into sandstone that is sharply overlain by a greywacke conglomerate bed. Each major facies package is inferred to represent systems tracts during a single sea-level cycle; siltstone reflects maximum water depth or highstand conditions, sandstone represents falling sea level or regressive conditions, and upper conglomerate facies reflect sea level lowstand and early rise conditions.

Most of the member is well exposed in the Ngaruroro River where the reference section has been designated (U21/092760). The lower parts of the member comprise 2 m of siltstone that passes rapidly up section into 8 m of sandstone. The lower siltstone abruptly overlies a sandstone bed inferred to represent a lateral equivalent of the Kereru Formation. The siltstone passes gradationally over < 1 m into sandstone, which is in turn sharply overlain by approximately 5 m of greywacke conglomerate.

The transition from the middle sandstone facies into the capping conglomerate facies is well exposed along Matapiro Road, near Whana Valley (U21/099771-093775). Approximately 5 m of non cemented, massive, well sorted fine to medium sandstone passes up section into 2.5 m of non cemented, cross-stratified, fine to medium sandstone with scattered (<5%) greywacke pebbles and conglomerate lenses up to 30 cm thick. These conglomerate lenses are typically cross-bedded to laminated. The greywacke clast content increases up-section with the next 1 m of section comprising coarse pebble to cobble greywacke conglomerate with abundant cross-stratified to laminated sandstone lenses (Fig. 33D). Cross-beds are of tabular and trough forms and typically low-angle. This interval is conformably overlain by 2.5 m of coarse-grained massive conglomerate, in turn passing up-section into 5 m of alternating granule-fine pebble/pebble-cobble beds 0.05-0.3 m thick. Packages are non cemented and internally massive to laminated. The interval displays a fining-upward pattern throughout. The transition to the overlying Whakamarumaru Member is obscured at this locality.

Uppermost parts of the Kikowhero Member are exposed in Kikowhero Stream on Whakamarumaru Station (V21/124773; Fig. 33B). A non cemented 1.5 m-thick slightly fossiliferous fine sandstone is exposed at stream level. Fauna are dominated by *Dosinia*, *Tawera* and *Austrofusus.* The sandstone is abruptly overlain by 2 m of highly fossiliferous greywacke conglomerate to pebbly sandstone. This interval is equivalent to the non fossiliferous upper greywacke conglomerate facies exposed in the Ngaruroro River and at Matapiro Road. Clasts are of coarse sand to fine pebble size and the bed as a whole is non to slightly cemented. Above this bed is a non fossiliferous 2 m-thick greywacke grit bed, followed by nearly 3 m of variably

fossiliferous greywacke grit and conglomerate beds. Fauna are typically robust shallow-water bivalves such as *Tawera, Purpurocardia* and *Tucetona.* The member is abruptly overlain by pebbly siltstone of the Whakamarumaru Member.

Paleontology and age

Fauna are typically sparse in the Kikowhero Member and are largely confined to the lower siltstone interval and the upper conglomerate bed. Fauna in the conglomerate are typically dominated by relatively shallow-water, robust, high-energy dwelling bivalves of which *Tawera* and *Purpurocardia* are most common (Fig. 33F). *Glycymeris shrimptoni, Tucetona, Panopea, Ostrea, Xenostrobus* and *Dosinia*, all common components of other fossiliferous conglomerate beds in the study area, are also present in this member.

On the basis of stratigraphic position the Kikowhero Member is assigned a confident Upper Nukumaruan age.

Environment of deposition

Siltstone and sandstone facies of the member were deposited at inner to middle shelf water depths. Greywacke conglomerate facies were deposited in a non-marine fluvial braid-plain setting. Capping intervals of fossiliferous conglomerate reflect a return to marine sedimentation following a rise in sea level and the submergence of the braid-plain environment. Alternating fine-grained/coarse-grained conglomerate facies are inferred to represent shingle beach deposits. Similar facies are evident in the Tararere Member of the Darkys Spur Member and throughout the Matahorua Formation.

Whakamarumaru Member (okb) (*new*)

Name and definition

Whakamarumaru Member is named after Whakamarumaru Station on and around which the member widely crops out. The Whakamarumaru Member incorporates all strata from the conformable contact with the greywacke conglomerate bed capping the Kikowhero Member to the upper surface of the greywacke conglomerate capping this member.

McLennan (1990) mapped the conglomerate facies of what is now considered Whakamarumaru Member as the Tiokapu Conglomerate Member of the Crownthorpe Formation. Tiokapu Member was named after a tributary of the Mangaone River near Te Pohue. McLennan (1990) wrongly correlated conglomerate beds in the Ohara Depression with conglomerate beds in the Te Pohue

region. Detailed geological mapping and macrofossil analysis during this study clearly demonstrate that conglomerate beds in the Ohara Depression are significantly younger than those present at Te Pohue. This mean that conglomerate beds exposed in Tiokapu Stream are not the same those in the Ohara Depression. Because of this the name Tiokapu is not appropriate for units in the Ohara Depression, because of the geographical separation of the two areas. The new name Whakamarumaru Member is therefore introduced here.

The Whakamarumaru Member incorporates upper parts of the informal Kikowhero gravels of Kingma (1971). Geological mapping demonstrates that the member is most probably an age equivalent of the Tararere Conglomerate Bed and Park Island Limestone Members of the Petane Formation. Conglomerate facies of the Whakamarumaru and Darkys Spur Formation (Tararere Member) were deposited by different fan-delta systems reflecting uplift and erosion of separate greywacke blocks.

Type locality and reference sections

A type section for the member is designated in the Ngaruroro River below Whana Valley. While access is difficult, the entire member is exposed in cliffs along the course of the river. Reference sections are nominated on Whakamarumaru Station where the member is widely exposed.

Lower and upper contacts

Whakamarumaru Member abruptly overlies the Kikowhero Member across a thin, pebbly shellbed. The lower contact is well exposed in Kikowhero Stream on Whakamarumaru Station (V21/124773) where highly fossiliferous conglomerate of the Kikowhero Member is abruptly overlain by siltstone of the Whakamarumaru Member (Fig. 33B).

The upper contact is generally poorly exposed through the study area. It is clearly exposed in the Ngaruroro River below Whana Valley and in cuttings along a driveway below the crest of Flag Range. Although the contact is not exposed on Mount Cameron it appears that the upper conglomerate bed of the Whakamarumaru Member is abruptly overlain by siltstone of the Mairau Formation. The member cannot be recognised in either the Tutaekuri or Mangaone Rivers where it appears to have passed conformably into mudstone facies of the upper Esk Mudstone. The member is overlain by undifferentiated siltstone facies of the Okauawa Formation in the Kereru and Whana Valley regions. Through the Crownthorpe, Sherenden and Waihau regions the Whakamarumaru Member is abruptly overlain by siltstone of the Mairau Mudstone Member and subsequently the Flag Range Conglomerate Member (Petane Formation).

Distribution and thickness

The Whakamarumaru Member is widespread across southwestern parts of the study area from the Ohara Stream (Fig. 33A, C), through the Ngaruroro River, Whakamarumaru Station to Flag Range and Mount Cameron. The member has not been observed north of Waihau Road near Dartmoor. Exposures are generally restricted to the upper greywacke conglomerate bed of the member. The member as a whole is well exposed In the Ngaruroro River below Whana Valley and in the middle reaches of Kikowhero Stream on Whakamarumaru Station (Fig. 33B). Prominent exposures of the upper conglomerate facies are present along Flag Range road where it descends from the range crest towards the Tutaekuri River. Numerous cuttings along the western end of Matapiro Road display the conglomerate facies of the member.

Many exposures of the Whakamarumaru Member are present west of Crownthorpe Settlement Road, and in occasional outcrops between Ringarua and Sherenden Stations. The northernmost outcrops of the member occur on the northern face of Mount Cameron above Waihau Road, although the unit is fairly poorly exposed.

The Whakamarumaru Member passes laterally northeast into the Esk Mudstone.

In the Ngaruroro River and Matapiro Road sections near Whana Valley the member is 53 m thick. In Kikowhero Stream the unit is 35 m thick. At Flag Range the member is 40 m thick and at Mount Cameron it is at least 41 m thick.

Description

Whakamarumaru Member is lithologically very similar to the Kikowhero Member, and can only be differentiated on the basis of stratigraphic position. The member is also very similar to the four members of the older Matahorua Formation.

The Whakamarumaru Member overlies the Kikowhero Member through a pebbly shellbed. The matrix in this 0.5 m-thick interval is dominated by fine-grained siliciclastic siltstone. The capping greywacke conglomerate bed is dominantly non fossiliferous, although it may be capped by a thin pebbly shellbed in a few locations.

In the Ngaruroro River below Whana Valley, the Whakamarumaru Member is well exposed in high clean cliff-face exposures. The lower siltstone facies of the member abruptly overlies the capping conglomerate bed of the Kikowhero Member. Fauna in the siltstone are dominated by *Maoricolpus* with *Ostrea* and *Atrina.* This siltstone is approximately 15 m thick and coarsens up-

section through silty sandstone into approximately 10 m of fine to medium sandstone. The sandstone is in turn sharply overlain by 8-10 m of greywacke conglomerate representing the upper beds of the member. The conglomerate is subsequently overlain by siltstone of the undifferentiated Okauawa Formation.

In outcrops on the northern face of Mount Cameron a 3 m-thick interval of blue-grey massive fine-grained siltstone to sandy siltstone crops out, corresponding with the lower part of the member. Approximately 22 m of section is not exposed, followed by a 6 m-thick interval of greywacke conglomerate. The lower 2 m of this conglomerate comprises moderately to poorly sorted, fine pebble to cobble-sized spheroidal to oblate-dominated clasts. A fluvial/marginal-marine environment is inferred for this lower conglomerate interval. It is in turn gradationally overlain by 4 m of fine to medium pebble-sized clasts dominated by oblate-shaped grains. This upper interval consists of alternating fine pebble/medium pebble beds each 0.05-0.3 m thick and is interpreted as a shingle beach deposit based on clast shape, sorting and stacking. The conglomerate is abruptly overlain by pale-grey slightly micaceous siltstone of the undifferentiated Okauawa Formation. This siltstone is equivalent to the Mairau Mudstone cropping out in the Matapiro-Glengarry-Tangoio areas.

Paleontology and age

The Whakamarumaru Member contains a sparse macrofauna. A confident Upper Nukumaruan age is assigned based on stratigraphic position.

Environment of deposition

Most interpretation of the depositional setting for the member is based on facies stacking and sedimentary structures. Few environmentally-indicative macrofossils have been observed. The basal siltstone bed is inferred to have been deposited in an inner to middle shelf environment. The overlying sandstone was most likely deposited in a shallowing-upward inner shelf to nearshore setting. The upper conglomerate facies represents the development and progradation of a fan-delta system during a sea level lowstand. The bedding and clast morphology in the lower half of the conglomerate bed indicates non-marine deposition. The pattern of alternating granule-fine pebble beds in the upper half of the conglomerate, the degree of sorting and clast morphology is consistent with deposition in a shoreface shingle beach environment. Greywacke detritus was derived from erosion of the emerging Wakarara, Kaweka and Ruahine Ranges (Erdman and Kelsey 1992).

POUTAKI FORMATION (pp)

(Erdman and Kelsey 1992)

Name and definition

Poutaki Formation was mapped and formally defined by Erdman and Kelsey (1992) and represents the uppermost unit of the Mangaheia Group in the Kereru region. Poutaki Formation is named after Poutaki Stream. The formation was included by Kingma (1971) as part of his undefined Roys Hill siltstone.

Type locality and reference sections

The type section designated by Erdman and Kelsey (1992) is retained. This section occurs in Poutaki Stream at U21/007653.

Lower and upper contacts

The Poutaki Formation unconformably overlies the Okauawa Formation across a 1-1.5 m thick pumiceous sandstone interval containing mudstone and sandstone rip-up clasts. A 0.3-1 m thick grainstone bed may be present at or within 0.3 m of the basal contact at some localities (Erdman and Kelsey 1992).

The Poutaki Formation coarsens up-section and passes into the Salisbury Gravel. This contact is marked by the first prominent ignimbrite in the Kereru region (Erdman and Kelsey 1992), inferred to be the Kidnappers A Ignimbrite (Wilson *et al.* 1995).

Distribution and thickness

Distribution of the Poutaki Formation in the Mason Ridge area was documented by Dyer (2005). In the Kereru region the Poutaki Formation is a minimum of 60 m thick, and up to 100 m thick further east (Erdman and Kelsey 1992; Beu 1995). The formation is well exposed in cuttings and banks beside Duff Road, near Kereru, near the Poporangi Stream. In the general Mason Ridge area the formation is 40 m thick (Dyer 2005). The member is well exposed in cuttings along Duff Road.

The Ngaruroro River section is similar to that exposed along Kereru Road and consists of coarsening-upward siltstone-sandstone packages generally 30-40 m thick. Although well exposed, sections are difficult to access due to the vertical nature of cliffs in the river valley. What this section does demonstrate however is the character of cyclothemic deposits in this part of the Okauawa Formation. Poutaki Formation does not occur north of the Ngaruroro River and is

restricted to the Kereru-western Mason Ridge area. The Poutaki Formation may be a lateral equivalent to beds of the Kaiwaka Formation in the Tangoio Block. However, lateral continuity cannot be demonstrated and it is desirable to use different names in these two widely separated areas.

Description

Beu (1995) described the Poutaki Formation as 60-100 m of coarse pumiceous sandstone, granule to cobble pumice conglomerate, dark-green medium sandstone, alternating thin-bedded sandstone and mudstone, and massive mudstone (Fig. 34A, B). In the Maraekakaho region the Poutaki Formation comprises medium- to coarse-grained pumiceous conglomerate beds and massive, non calcareous mudstones. Mudstone beds commonly contain rounded but highly weathered pumice clasts up to 15 cm across. The pumiceous conglomerate beds are typically planar laminated to low angle (<2°) trough cross-bedded (Erdman and Kelsey 1992). The formation is non to sparsely fossiliferous.

In cuttings on Duff Road (Fig. 34A, B), Kereru, the Poutaki Formation comprises several intervals of highly volcaniclastic sediments. Very well-developed sedimentary structures (Fig. 36B) such as trough cross-bedding and convolute bedding indicate significant reworking of the pumiceous sediments. Water escape structures are common. No macrofossils were observed in this area.

Paleontology and age

Few macrofossils have been collected from the Poutaki Formation, although Beu (1995) reported the presence of *Pelicaria convexa*. This confirms that at least part of the formation is still Nukumaruan in age. Poutaki Formation is probably uppermost Nukumaruan in age, most likely close to the Castlecliffian boundary.

Environment of deposition

The Poutaki Formation is inferred to have accumulated in a combination of marginal-marine to shallow-marine settings similar to that envisaged for the Kaiwaka Formation. Like the Kaiwaka Formation, the Poutaki Formation is inferred to represent the shoaling and emergence of much of the study area from a marine environment into a non-marine environment during the Upper Nukumaruan.



Fig. 34: Poutaki Formation (Mangaheia Group) and Kidnappers Group. **A)** Poutaki Formation, Duff Road, Kereru (U21/010644). **B)** Close-up of road cutting in Fig. 34A (U21/010644). Lens cap (58 mm) for scale. Note the well-developed sedimentary structures in this outcrop. **C)** Unconformable base of the Kidnappers Group at the type section, overlying Black Reef Calcareous Sandstone. Photo viewed from Black Reef looking southwest (W21/596661). **D)** Panorama along the Kidnappers section from Black Reef southwest towards Rabbit Gully (from W21/596661). Black Reef Calcareous Sandstone (Waipipian age) forms the dark-coloured rocks in the ocean. E) Shelly lenses within the Maraetotara Sandstone, the basal unit of the Kidnappers Group at the type section (W21/583655). **F)** Ignimbrite within thick non fossiliferous greywacke conglomerates. Photo location: Kidnappers Section (approx. W21/554651).

QUATERNARY DEPOSITS

KIDNAPPERS GROUP

(Hill 1877; formally defined by Kingma 1971)

Name and definition

Kidnappers Group is named after Cape Kidnappers, the landform that marks the southern end of Hawke Bay. Kingma (1971) formalised the long usage of the name "Kidnappers" in reference to the well exposed section between Clifton and Black Reef. The name itself was introduced by Hill (1877) who referred to the strata in this area as the Kidnapper Beds or Kidnappers Section, and in 1891 as the Kidnapper Conglomerates and the Kidnapper Pumice and Conglomerate Beds.

The definition of Kingma (1971) is retained, and extended to incorporate the prominent thick Castlecliffian gravel beds cropping out adjacent to the northern Ruahine and Wakarara Ranges. These more westerly beds are inferred to represent proximal non-marine equivalents of the marginal-marine strata exposed in the Clifton-Black Reef Section.

Type and reference section

The Kidnappers coastal section extending from the unconformable lower contact with the Black Reef Calcareous Sandstone west to Clifton is designated as the type section for the Kidnappers Group (Fig. 34C, D). This section was nominated as the Standard Section in the Te Aute subdivision for Castlecliffian strata by Kingma (1971).

Lower and upper contacts

The lower contact of the Kidnappers Group is well exposed at Black Reef in the Kidnappers section (W21/597662; Fig. 34C). Here the Maraetotara Sandstone, the basal unit of the Kidnappers Group in the section, overlies Waipipian Black Reef Calcareous Sandstone across an angular unconformity. Sediments and some macrofauna from the underlying Black Reef Calcareous Sandstone are reworked into the basal shellbed on the Kidnappers Group in this section. The basal contact is also exposed in several localities in the Kereru district where the Salisbury Gravel (Kidnappers Group) overlie the Poutaki Formation (Mangaheia Group).

The upper surface of the Kidnappers Group is typically marked by the modern land surface, although may be mantled by a thin veneer of Recent alluvium and/or tephras.

Distribution and thickness

Rocks of the Kidnappers Group crop out sporadically across the study area, although tend to be concentrated in two main regions (Fig. 1). Kidnappers Group beds *sensu stricto* crop out in only in the southeastern part of the study area, where they underlie northernmost parts of the Maraetotara Plateau. The second main outcrop region is in the Kereru district along the eastern flanks of the northern Ruahine and Wakarara Ranges, where rocks of the Salisbury Gravel form the prominent Salisbury terraces. Small outcrops occur at Waiohiki beside Springfield Road, at Petane Corner, and at Whirinaki Bluff. Veneers of Castlecliffian gravels are present on the highest hills of Mason Ridge, and above the Dartmoor-Puketapu area.

Kidnappers Group is thickest and best developed in the Kidnappers section where it is approximately 396 m thick (Kingma 1971).

Description

Description of the Salisbury Gravel in the southwest of the study area is given below. In the Kidnappers section thick conglomerates (Fig. 34D) are interbedded with thin blue-grey siltstones, brown sandstones, ignimbrites and pumiceous beds (Fig. 34F). Macrofossils are mostly uncommon and are restricted to finer-grained beds. Highly fossiliferous shell lenses are common in the uncemented Maraetotara Sandstone, the 33 m-thick basal formation of the Kidnappers Group at the type section (Fig. 34E). This formation contains a diverse assemblage of shallow-water taxa. The Maraetotara Sandstone has as its basal unit a coarse-grained shellbed named the “basal shellbed” by Kingma (1971). This shellbed overlies the Black Reef Calcareous Sandstone across a mild angular unconformity. Shellhash dominates the composition of the basal shellbed, including notably fragments of Waipipian *Phialopecten marwicki* that have been reworked from the underlying Black Reef Calcareous Sandstone. The Maraetotara Sandstone is overlain by a prominent tephric horizon (the Kidnappers Ignimbrite) and then by thick interbedded gravels, sandstones, siltstones, and minor peat beds that extend west along the Kidnappers Section to Clifton.

Paleontology and age

A diverse macrofauna have been collected from the Kidnappers Group in the coastal section, though most from the Maraetotara Sandstone and overlying siltstone beds. Shellbeds in the Maraetotara Sandstone are typical of “event concentrated shellbeds”, and are dominated by *Dosinia anus.* Estuarine-restricted bivalves such as *Austrovenus stutchburyi* and *Barytellina crassidens* have been collected from siltstones between Rabbit Gully and Clifton. The Kidnappers Ignimbrite has been assigned an age of 1.05 Ma by Wilson *et al.* (1995).

Environment of deposition

Kidnappers Group in the Maraetotara Plateau area was deposited in a marginal-marine environment following a period of uplift, erosion, and subsequent subsidence. Thick gravels in the section reflect rapid uplift and erosion of the North Island axial ranges. Siltstones and sandstones reflect shallow-marine incursions into the basin, supported by estuarine and shallow-water taxa in these beds (e.g. *Austrovenus, Barytellina*). Thick volcaniclastic deposits reflect contemporaneous volcanism from the Taupo Volcanic Zone. It is inferred that the Salisbury Gravel (see below) record the deposits of the river systems that fed the Cape Kidnappers area.

SALISBURY GRAVEL

(Kingma 1971)

Name and definition

Salisbury Gravel is named after the Salisbury terraces in the southern part of the study area. The name was first introduced by Kingma (1971). Beu (1995, p. 140) excluded the informal Salisbury gravel lithofacies of Erdman and Kelsey (1992) from his Poporangi Group (now Mangaheia Group) as he viewed these beds to paraconformably or unconformably overlie older marine-dominated units. He suggested that the Salisbury Gravel lithofacies should be included in the Kidnappers Group, a well-established stratigraphic unit conspicuously dominated by non-to marginal-marine gravel facies of Castlecliffian age. Kingma (1971) had initially included the Salisbury Gravel in the Kidnappers Group, as does this study. The Salisbury Gravel is defined as a thick interval of basement-derived gravels and conglomerates, with minor sandstones and volcaniclastic interbeds that overlie older marine to marginal-marine rocks. They are of Castlecliffian age.

Type locality and reference sections

As the Salisbury Gravel has only been mapped as an informal unit by both Kingma (1971) and Erdman and Kelsey (1992), no type section has been designated. No reference sections were nominated by Erdman and Kelsey (1992), the reason for this being that the formation is poorly exposed. Although no one section displays the entire formation, the type section designated by Dyer (2005) is retained. It is located in Poutaki Stream (U21/007653) where the lower contact with the Poutaki Formation is exposed.

Lower and upper contacts

Salisbury Gravel gradationally overlie the Poutaki Formation (Erdman and Kelsey 1992). The base of the formation is defined as the first prominent ignimbrite bed (6 m thick) and is exposed

in the Kereru region, inferred to be the Kidnappers A Ignimbrite (Wilson *et al.* 1995). This contact is exposed at the type section (U21/007653). The upper surface of the Salisbury Gravel represents the modern land surface.

Distribution and thickness

Salisbury Gravel is widely distributed in southwestern parts of the study area adjacent to the northern Ruahine and Wakarara Ranges although outcrop is generally poor. In this area they form prominent high flights of terraces well above the level of Recent deposits. The thickness of the Salisbury Gravel is uncertain due to their poor exposure. Dyer (2005) estimated a thickness of 40 m based on cross-sections, but this is likely to be an underestimate based on the topographic heights of terraces underlain by the formation.

Description

With the exception of the ignimbrite beds at the base of the Salisbury Gravel, the lower part of the formation is difficult to distinguish from the Poutaki Formation, as both formations contain massive mudstone interbedded with pumiceous sandstone and conglomerate beds (Erdman and Kelsey 1992). Conglomerate beds are frequently trough cross-bedded, and sorting is generally poor (Dyer 2005). The pebble-cobble conglomerates of the Salisbury Gravel become more prevalent up-section to the east of the Kereru district, and are interbedded with pumiceous sandstone and ignimbrites (Erdman and Kelsey 1992). Kingma (1971) identified that the Salisbury Terraces comprised the same components as beds exposed in the Kidnappers section, but differed in being less well sorted and non fossiliferous (a result of their more inboard topographic position). They can be differentiated from post-Castlecliffian terrace deposits due to the more advanced weathering of their greywacke components and by their distinct but irregular pumice interbeds (Kingma 1971).

Paleontology and age

No macrofossils have been observed or reported in the Salisbury Gravel. Erdman and Kelsey (1992) assigned a Lower Castlecliffian age to the formation. Beu (1995) suggested that the basal ignimbrite of the Salisbury Gravel is the Potaka Tephra (Shane 1994), although Wilson *et al.* (1995) regard this bed as the Kidnapper Ignimbrite. This ignimbrite is inferred to lie within the Jaramillo normal subchron (1.07-0.99 Ma) (Kamp 1990), and the formation is therefore of Castlecliffian age (Turner and Kamp 1990).

Environment of deposition

Salisbury Gravel was deposited in a non-marine environment proximal to rapidly rising and eroding Torlesse basement blocks bounded by the Ruahine, Mohaka and Wakarara Faults. The generation of large volumes of terrigenous material during this period indicates an acceleration in the rate of deformation of the study area. The presence of prominent tephra beds indicates contemporaneous volcanic eruptions from the Taupo Volcanic Zone, which was active by this time.

UNDIFFERENTIATED KIDNAPPERS GROUP

Distribution and thickness

A thin veneer of Castlecliffian gravels occurs throughout much of the study area, with noticeably thicker deposits occurring near Puketapu, Taradale, Petane Corner and Whirinaki Bluff. These units have been mapped as undifferentiated Castlecliffian deposits. The interval is thickest above Apley-Dartmoor Roads, at Taradale and Whirinaki Bluff.

Description

Undifferentiated Castlecliffian beds are dominated by poorly sorted, non cemented greywacke gravels. Interbedded sand and silt layers are common, as are rip-up clasts of similar lithologies. These gravels typically form thin veneer deposits throughout the study area.

LATE QUATERNARY DEPOSITS

Distribution and thickness

Late Quaternary deposits are very widespread throughout southeastern parts of the mapping area in proximity to the Tutaekuri and Ngaruroro Rivers. Late Quaternary deposits are 50 m thick in the vicinity of Taradale-1 (Darley and Kirby 1969), and 75 m thick at Whakatu-1 (Ozolins and Francis 2000).

Description

Late Quaternary deposits are dominated by coarse-grained, non cemented, poorly sorted greywacke gravels derived from erosion of the adjacent axial range belt.

High Level Terraces 1 and 2 (h1, h2)

(Kingma 1971)

Name and definition

High level terraces 1 and 2 are defined as the second and third major terraces above modern river level. They occur geomorphically above the Ripia Alluvium terrace (see below). The names are derived from alluvial terraces mapped by Kingma (1971).

Distribution

H1 alluvial terrace are moderately well distributed along the margins of major river systems in the study area. H1 terraces are typical about 60 m above modern river level. H2 terraces are less widespread, and are up to about 120 m above modern river level.

Ripia Alluvium (ra)

(Cutten 1994)

Name and definition

Cutten (1994) introduced and formally defined Ripia Alluvium, the name derived from the Ripia River, a major tributary of the Mohaka River near Pakaututu. Cutten (1994) mapped aggradational and degradational Ripia Alluvium terraces. These two units have not been differentiated in this study. Ripia Alluvium is defined as the first major terrace above modern river level.

Lower and upper contacts

The lower contact of Ripia Alluvium is everywhere erosional and unconformable. Metre-scale relief is common on its lower contact, reflecting the inferred depositional paleoenvironment of high-energy river systems.

Distribution and thickness

Ripia Alluvium is widely distributed in river terraces near the axial ranges, and in river valleys seaward from here. Thick gravel beds are well exposed in the Ngaruroro River downstream of Whana Valley, with large-scale channel incision prominent. Similar, well-developed channel incision is also exposed in Ohara Stream above the Mangleton Road bridge and below the Big Hill Road bridge.

Ripia Alluvium is typically 10-20 m thick in the Ngaruroro River-Ohara Stream area, with some strongly incised deposits up to 50 m thick.

Description

Ripia Alluvium comprises poorly sorted sandy greywacke gravel with interbedded sand and minor tephric materials forming post-glacial terraces of the last glaciation. Ripia Alluvium terraces are typically 20-40 m above modern river level. In the Mohaka River these terraces may be as high as 140 m above present river level (Cutten 1994).

Age

By definition, Cutten (1994) designated a last glaciation to post-glacial age for the Ripia Alluvium.

Undifferentiated Taupo Pumice (tp) (informal)

(Kear and Schofield 1968)

Name and definition

Taupo Pumice derives its name from Lake Taupo, the volcanic centre from which the stratigraphic unit was erupted. Kear and Schofield (1968) introduced the name Taupo Pumice Alluvium (TPA) to describe volcaniclastic deposits from the most recent eruption from Taupo Caldera. Undifferentiated Taupo Pumice is used in this study in an informal way in reference to both TPA and Taupo Ignimbrite deposits through western parts of the study area.

Distribution and thickness

Undifferentiated Taupo Pumice is widely distributed through western parts of the study area in the vicinity of the axial ranges. Occurrences of this unit in the study area are summarised in Segscheider *et al.* (2002). Bluffs of pumice and ash up to 70 m thick are prominent where the Ngaruroro, Ripia, Mohaka and Waipunga Rivers emerge from gorges through the Kaweka and Ahimanawa Ranges. Excellent exposures occur at the Mohaka-Ripia River confluence near Pakaututu Bridge, and in road cuttings on the Kaweka Range side of the bridge.

Description

Undifferentiated Taupo Pumice includes all primary and reworked products of pyroclastic deposits associated with the last Taupo eruption. The unit comprises non welded massive to strongly laminated and trough cross-stratified pumiceous ash and lapilli-sized clasts, with rare blocks and lithics. In many localities carbonised logs and branches are common.

Age

Undifferentiated Taupo Pumice has been dated at 1850 ± 10 years B.P. (Froggatt and Lowe 1990).

Recent Alluvium (qa)

This mapping unit includes all modern-day stream and river bed alluvium, Holocene alluvial plain deposits and Holocene lake deposits. The composition of this alluvium (and minor lacustrine sediment) is typically similar to that of the Ripia Alluvium. Greywacke clasts dominate the composition of much of the alluvium, although limestone pebbles and boulders, and pebbles of Cretaceous and Tertiary sandstone (Cutten 1994) may be locally important.

Reclaimed Land (qr)

A particular feature of the study area is the large extent of reclaimed land in the area around Napier, much of which has occurred since the 1931 Napier earthquake.

At least 25 m of reclaimation fill was intercepted in Hukarere-1 (Westech Energy New Zealand Ltd 2001).

APPENDIX II

PALEOENVIRONMENTAL ANALYSIS

INTRODUCTION

This appendix gives more detailed descriptions of the lithofacies and macrofaunal associations described in Chapter Six: Paleoenvironments and Sequence Stratigraphy of the Mangaheia Group.

LITHOFACIES ANALYSIS

Six main lithofacies groups have been defined in this study on the basis of their broad lithology. These groups are sandstone, siltstone, conglomerate, volcaniclastic, bioclastic, and mixed bioclastic-siliciclastic lithofacies.

SILICICLASTIC–DOMINATED LITHOFACIES

Sandstone lithofacies

Sandstone lithofacies are interpreted to be almost exclusively the products of deposition at shoreface to inner shelf water depths. A total of 12 sandstone lithofacies have been identified.

Massive sandstone (S_1)

This facies comprises massive, non cemented, non fossiliferous, slightly micaceous, very well sorted, fine to medium sandstone (Fig. 1A). This facies is widespread in regressive systems tract (RST) sandstone of the Pohue and Matahorua Formations in the Waikoau and Te Pohue areas.

Interpretation

A shoreface to inner neritic environment of deposition is inferred for this lithofacies on the basis of stratigraphic position and sediment texture.

Massive to cross-stratified sandstone (S_2)

Massive to cross-stratified, non cemented, non fossiliferous very well sorted fine to medium sandstone. Foresets are of medium to large scale, and bedding mainly comprises tabular and planar bedforms. This lithofacies passes laterally into a number of other similar facies including

sandstone S_1 (massive sandstone), S_3 (massive to cross-stratified fossiliferous sandstone) and S_9 (pebbly sandstone).

Interpretation

A shoreface to inner shelf environment of deposition is inferred for this lithofacies on the basis of grain sorting and sedimentary structures.

Massive to cross-stratified fossiliferous sandstone (S_3)

Massive to cross-stratified, non cemented, very well sorted, moderately to highly fossiliferous, fine to medium sandstone (Fig. 1B, C). Foresets are of medium to large scale, and bedding mainly comprises tabular and planar cross-beds. Macrofossils are commonly concentrated into highly fossiliferous lenses that are interpreted to represent event-concentrated shell lenses. Macrofauna are typically represented by the *Dosinia, Fellaster* and *Zethalia* associations.

Interpretation

A shoreface to inner shelf environment of deposition is inferred for this lithofacies. This is consistent with the macrofossil associations and sedimentary structures in the facies.

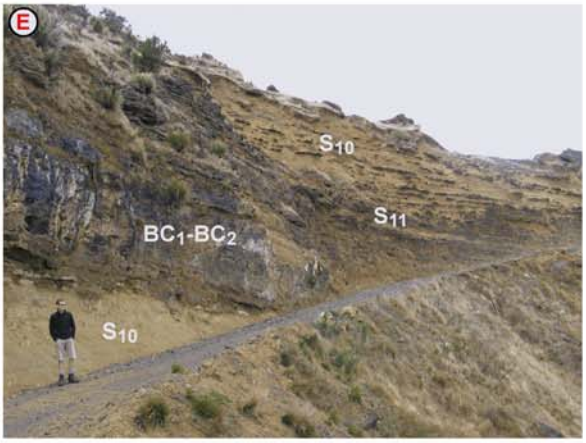
Fig. 1 (facing page): Examples of sandstone-dominated lithofacies in the study area. **A)** Gradational transition from siltstone-dominated facies (Mairau Mudstone Member) to sandstone-dominated facies (Darkys Spur Member). Massive non fossiliferous Z_1 siltstone passes through Z_4 siltstone and S_6 sandstone into massive non fossiliferous S_1 sandstone. Darkys Spur Road (V20/404104). **B)** Event-concentrated shellbeds in S_3 sandstone of the Deep Stream Member. Napier-Taupo Road near Transmission Road intersection (V20/299066). **C)** S_3 sandstone of the Darkys Spur Member. Darkys Spur Road (V20/407105). **D)** Flaser and ripple-bedded siltstone stringers within fine sandstone, lithofacies S_8, Okauawa Formation. Kereru Road (U21/068686). **E)** Te Waka Formation in the Glenross Range. Concretionary sandstone (facies S_{10}) overlain by limestone (facies BC_1 and BC_2). The limestone is in turn overlain by S_{10} sandstone. Contacts between all facies are gradational. Photo location: Lizard Road, Glenross Range, Kaweka Forest (U20/039907). **F)** Interbedded S_1, S_2 and S_{10} sandstone facies in the Waikarokaro Sandstone Member (Blowhard Formation). Mount Miroroa, Kaweka Forest Park (U20/000927). **G)** S_{12} sandstone of the Te Rangi Member, Titiokura Formation. Note how the presence of heavy minerals highlight the bedforms. Naumai Station (V19/390273).


A
S_1
S_6/Z_4
Z_1


B


C


D


E
S_{10}
S_{11}
BC_1-BC_2
S_{10}


F


G

Sandy siltstone (S_4)

This lithofacies comprises well sorted, non cemented, non to sparsely fossiliferous, massive to laminated fine sandstone to sandy siltstone. Macrofauna are sparse and typically represented by shelfal infaunal taxa such as *Atrina pectinata zelandica, Maorimactra ordinaria* and *Dosinia (Kereia) greyi*. This lithofacies passes laterally into and is usually underlain by facies Z_3 (fossiliferous sandy siltstone). It usually passes conformably up into coarser-grained sandstone facies through facies S_6 (interbedded sandstone-siltstone) or Z_9 (alternating siltstone-sandstone).

Interpretation

A lower inner to middle shelf environment of deposition is envisaged for this lithofacies. This is consistent with macrofaunal associations in the facies.

Calcareous sandstone (S_5)

Non to well cemented, massive to laminated, slightly to moderately calcareous non to slightly fossiliferous fine sandstone with prominent concretions and cemented horizons. The lithofacies often contains a noticeable bioclastic sand content. Macrofauna are mostly represented by the *Atrina* association.

Interpretation

An inner to middle shelf environment of deposition in envisaged for this facies. Bioclastic contributions to the facies are interpreted as redeposited materials from adjacent carbonate factories.

Interbedded sandstone-siltstone (S_6)

Non to well cemented, non to sparsely fossiliferous fine sandstone to sandy siltstone with common concretionary horizons and prominent sandstone and siltstone interbeds (Fig. 1A). In rare occasions channels may occur throughout the facies. Rip-up clasts are typically of sandstone and mudstone lithologies. Macrofauna are usually part of the *Dosinia (Kereia)* and *Atrina* associations.

Interpretation

An inner shelf environment of deposition is inferred for this lithofacies, consistent with macrofaunal associations.

Sandstone with siltstone stringers (S_7)

Non to well cemented, non to moderately fossiliferous fine sandstone to sandy siltstone with common mudstone stringers to 0.1 m thick that may extend laterally for several metres through an outcrop. Sandstones are typically weakly to strongly laminated, as are the siltstones stringers. Macrofauna are of low diversity, and are represented by the *Austrovenus* and *Patro* associations.

Interpretation

An estuarine to sheltered nearshore environment of deposition is assigned to this facies. This facies is often present in close association with non- to marginal-marine greywacke conglomerate facies.

Ripple and flaser-bedded sandstone (S_8)

Non to slightly fossiliferous ripple-bedded, flaser-bedded and cross-stratified fine to medium sandstone with common interbeds and detached lenses of massive siltstone (Fig. 1D). The lithofacies is restricted to rocks of Nukumaruan age and younger, particularly in those stratigraphic intervals containing greywacke conglomerate beds. Occasional channelised interbeds and calcareous lenses and horizons are present, together with sandstone and siltstone rip-up clasts of pebble to cobble size. Valves of estuarine-restricted bivalves such as *Austrovenus stutchburyi, Xenostrobus huttoniana* and *Barytellina crassidens* are commonly observed in this facies, although faunal diversity is very low.

Interpretation

The stratigraphic position, sedimentary structures and faunal content of this lithofacies are consistent with an estuarine to marginal-marine environment of accumulation.

Pebbly sandstone (S_9)

Non cemented, non to moderately fossiliferous massive to cross-bedded to laminated slightly micaceous sandstone with common to abundant pebbles. Clasts are dominantly of greywacke composition, with occasional Tertiary sandstone and mudstone clasts. Grains are generally well rounded and well sorted. Conglomerate lenses are common. The pebbly sandstone lithofacies is common in RST sandstone packages below greywacke conglomerate beds of the Matahorua, Tutira, Darkys Spur and Okauawa Formations. Fauna in the facies are dominated by shoreface to shallow-water dwelling taxa such as *Zethalia* spp.*, Fellaster zelandiae* and *Dosinia (Phacosama)/Dosinia (Austrodosinia).* These macrofauna are consistent with the *Dosinia* and *Zethalia* associations. Macrofauna are usually concentrated into lenses up to 0.2 m thick and less than 3 m long with bivalves disarticulated and generally concave-down. This lithofacies commonly

passes laterally into sandstone facies S_1, S_2 and S_3. It is most commonly unconformably overlain by conglomerate facies Cg_2 (conglomerate with sand and silt lenses), but also by facies Cg_1, Cg3, Cg_6 and MX_3 (Fig. 3A).

Interpretation

This lithofacies was deposited in a very shallow-water shoreface to nearshore environment of deposition, probably just offshore from a shingle beach or river mouth. This interpretation is consistent with the macrofauna and sedimentary structures observed in the facies. Accumulation occurred during periods of falling sea level with conglomerate lenses and greywacke pebbles deposited as a result of storm remobilisation.

Shell lenses are inferred to represent event-concentrated shellbeds that formed during periods of storm activity.

Concretionary sandstone (S_{10})

Non to slightly cemented non to sparsely fossiliferous fine to medium sandstone with common to abundant concretionary horizons that are usually less than 0.3 m thick (Fig. 1E, F). The facies is moderately to strongly laminated and displays tabular to trough and sigmoidal cross-stratification. In Kaweka Forest, this lithofacies (in the Waikarokaro Sandstone Member, Blowhard Formation) directly overlies greywacke basement with significant relief on the contact. Macrofauna at this site include *Crassostrea ingens* and *Sectipecten wollastoni.* Macrofauna are generally sparse and of low diversity. They are typically part of the *Atrina* association, although may less commonly be part of the *Crassostrea* association.

Interpretation

A nearshore to inner shelf environment of deposition is assigned to this lithofacies. This interpretation is consistent with sedimentary structures and the sparse macrofauna displayed in the facies.

Sandstone with fossiliferous concretions (S_{11})

Slightly to well cemented fine to medium sandstone with moderately to highly fossiliferous moderately to well cemented concretionary bodies up to 1 m thick. The facies is most widespread in shelfal rocks of Tongaporutuan (Late Miocene) age in western margins of the study area in close proximity to greywacke basement. Macrofauna are mainly represented by the *Struthiolaria (Callusaria)* and *Zeacolpus* associations with *Zenatia acinaces* and other shallow-water taxa such as *Crassostrea ingens, Sectipecten wollastoni* and *Maoricardium spatiosum* locally common.

Non fossiliferous sandstone concretionary bodies are present and common, as are well cemented greywacke conglomerate lenses. This lithofacies generally passes conformably up-section into facies Z_1, though in Kaweka Forest it is unconformably overlain by facies Z_6 and Z_7. In the Puketitiri area facies S_{11} is sharply overlain by facies BC_3 (shelly limestone). Facies S_{11} typically unconformably overlies greywacke basement, though may be separated from it by up to 50 m (in rare cases) of conglomerate (Cg_1, Cg_2, Cg_3, Cg_7) or sandstone (S_1) lithofacies.

Interpretation

This facies was deposited at inner shelf water depths, consistent with macrofauna and sedimentary structures. A rocky greywacke coastline lay near the site of deposition. The presence of common epifaunal and semi-infaunal molluscs indicates firm-ground to hard-ground substrates.

Laminated to convolute-bedded sandstone (S_{12})

This lithofacies comprises slightly to moderately sorted strongly laminated to cross-stratified to convolutedly-bedded, non fossiliferous fine to medium sandstone that are arranged in a series of individual, stacked bodies up to 0.5 m thick (Fig. 1G). The facies is best developed in the Titiokura Formation in the Maungaharuru Range. Low to moderate angle, small to moderate-scale tabular, trough, sigmoidal and hummocky cross-stratifications are widespread. Individual beds display evidence of redeposition with truncation of underlying horizons a typical feature. Heavy minerals and volcaniclastic detritus are common and highlight bedforms in the facies.

Interpretation

The lithofacies was deposited at inner shelf water depths during periods of contemporaneous volcanic activity. Soft-sediment deformation occurred frequently.

Siltstone lithofacies

Siltstone lithofacies represent inferred depositional environments from non-marine to upper bathyal settings, although were mostly inferred to have been deposited at middle to outer shelf depths. A total of 10 siltstone lithofacies have been defined in this study.

Massive siltstone (Z_1)

The massive siltstone lithofacies comprises non fossiliferous, massive to weakly laminated non to slightly cemented siltstone (Fig. 1A). Concretions up to 1 m thick are present to common in Late

Miocene expressions of the facies, and are sparse in younger beds. This lithofacies is common in the Rakaita Siltstone Member (Waitere Formation), Kingma Peak Mudstone Member (Poamoko Formation), the Pohue Formation and siltstone-dominated Nukumaruan formations of the upper Mangaheia Group.

Interpretation

Microfauna collected from this lithofacies are consistent with a marine depositional environment at outer shelf to bathyal water depths.

Fossiliferous siltstone (Z_2)

The fossiliferous siltstone lithofacies comprises slightly to moderately fossiliferous, massive to laminated non cemented firm bioturbated siltstone. Faunal diversity ranges from low to moderate. This lithofacies may pass laterally into a number of other siltstone-dominated facies including Z_1, Z_3 and Z_8. Macrofauna are commonly represented by the *Pratulum, Talochlamys, Neilo* and *Ostrea* associations.

Interpretation

A middle to outer shelf environment of deposition is assigned to this lithofacies on the basis of grainsize, stratigraphic position and faunal content.

Fossiliferous sandy siltstone (Z_3)

This lithofacies comprises slightly to moderately fossiliferous massive to laminated bioturbated sandy siltstone. Macrofauna are generally sparse and are usually represented by the *Atrina, Maorimactra, Patro, Dosinia (Kereia)* associations and *Stiracolpus-Talochlamys* sub-association.

Fig. 2 (facing page): Examples of siltstone and volcaniclastic lithofacies in the study area. **A)** Esk Mudstone cropping out in a cliff beside the Waikare River near Putorino. The prominent thin horizons (arrowed) in the outcrop are airfall tephra beds within the Z_8 mudstone (W19/574213). **B)** Burrowed airfall tephra bed in a Z_8 siltstone, Esk Mudstone near Putorino (W19/579211). **C)** Tephra bed within a Z_8 siltstone interval cropping out in the Matahorua Formation in the Waikare River near Putorino (W19/553229). **D)** Strongly laminated and channelised Z_7 siltstone lithofacies of the Auroa Alternating Member erosionally truncating S_{11} sandstone of the Te Ipuohape Sandstone Member. Tutaekuri River, Kaweka Forest Park (U20/060980). **E)** Lithofacies Z_7 of the Auroa Alternating Member (Waitere Formation) cropping out in the Tutaekuri River, Kaweka Forest Park (U20/061980). **F)** Strongly cross-stratified and laminated V_3 volcaniclastic beds of the Hikuroa Pumice Member (Petane Formation). Beattie Road (V20/362967).


A
Z_4
Z_1


B


C


D


E


F

Interpretation

A lower-inner to middle shelf environment of deposition is assigned to this lithofacies on the basis of stratigraphic position and faunal content.

Siltstone with sandstone interbeds (Z_4)

This lithofacies consists of non to moderately fossiliferous siltstone with sandstone interbeds and stringers (Fig. 1A). Ripple and flaser-bedded units are common and are frequently interbedded with massive siltstone. The facies commonly contains mudstone and sandstone clasts of large pebble- to cobble size. In Nukumaruan beds a restricted estuarine to marginal-marine macrofauna are common that may include *Austrovenus* spp., *Xenostrobus huttoni* and *Zeacumantus lutulentus.*

Interpretation

On the basis of faunal content and sedimentary structures an estuarine to marginal-marine environment of deposition is assigned to this facies.

Pebbly siltstone (Z_5)

This lithofacies comprises non cemented, slightly to moderately fossiliferous, slightly to moderately pebbly siltstone to sandy siltstone. This lithofacies only occurs in beds immediately overlying greywacke conglomerates (Fig. 3F). Clasts are dominantly of greywacke composition and are very well sorted and very well rounded. Maximum clast size is usually 10 mm across, and size and volume of clasts decreases rapidly up through the facies. Macrofauna are generally sparse but may be represented by fauna of the *Neilo, Pratulum* and *Stiracolpus* associations. The lithofacies is a maximum of 0.7 m thick and is most commonly 0.3-0.5 m thick.

The pebbly siltstone lithofacies conformably though abruptly overlies most conglomerate facies, though is probably most common above facies Cg_5 (slightly fossiliferous conglomerate) and Cg_6 (fossiliferous conglomerate). It generally passes conformably into siltstone facies Z_1 and Z_2.

Interpretation

The lithofacies developed on a sediment-poor continental shelf during rapid marine transgression over a fluvial braidplain.

Siltstone-sandstone couplets (Z_6)

This lithofacies has only been observed in rocks of Tongaporutuan age and older, and is best developed in the Tutaekuri River at the end of Lawrence Road, and in the Whakamarino

Formation near Waitere Station. It comprises strongly laminated planar-bedded non cemented fine-scale, siltstone-sandstone couplets. Couplets vary from 0.01-0.05 to 0.1-0.3 m thick. Scattered shellhash is common and intact macrofossils are rare. The facies may overlie facies Z_8, and passes conformably into Z_1.

Interpretation

This lithofacies is inferred to represent mass emplaced deposits. Sandstone beds represent the main body of the submarine flow, with the siltstones representing finer-grained sediments that settle out of the associated sediment cloud, and background sedimentation.

Channelised siltstone-sandstone couplets (Z_7)

This lithofacies has only observed in the Tutaekuri River in the Kuripapango area in rocks of Tongaporutuan age. It consists of strongly laminated, non cemented alternating siltstone-fine sandstone couplets contained in large packages with sharp, highly erosional and channelised bases (Fig. 2D, E). Channels are up to 15 m high by 30 m long. This lithofacies passes conformably into facies Z_6 (siltstone-sandstone couplets).

Interpretation

It is inferred to represent submarine slope (upper bathyal) channels. Microfauna from this facies are consistent with an upper bathyal environment of deposition.

Siltstone with tephra beds (Z_8)

Non to slightly fossiliferous, non cemented sandy siltstone to siltstone with prominent discrete tephra beds (Facies V_1 ;Fig. 2A-C). Tephra beds are usually intensely burrowed and 0.1-0.6 m thick.

Interpretation

This lithofacies is inferred to have accumulated at middle to outer shelf water depths below storm wave-base under a regime of relatively fast sedimentation.

Alternating siltstone-sandstone (Z_9)

This is a transitional lithofacies between siltstone and sandstone-dominated lithotypes that is inferred to have accumulated during a period of falling sea level. It comprises 0.1- 1 m-thick alternating beds of non to slightly fossiliferous, non cemented sandy siltstone interbedded with fine well sorted non fossiliferous sandstone. This lithofacies marks the transition between highstand

and regressive systems tracts where a regressive surface of erosion is absent. The alternating siltstone-sandstone lithofacies conformably overlies facies Z_3 (silty sandstone) and conformably underlies facies S_4 (silty sandstone).

Interpretation

This lithofacies marks the transition between the siltstone-dominated highstand systems tract and the sandstone-dominated regressive systems tracts of Upper Mangapanian-Nukumaruan rocks through the study area. This lithofacies accumulated at inner shelf water depths below fair-weather wave-base and above storm wave-base, during periods of falling sea level.

Siltstone with plant remains (Z_{10})

Non cemented, slightly to strongly laminated grey-brown siltstone with some to abundant plant and leaf remains and impressions. The facies is restricted in occurrence to an association with conglomerate facies in the Matahorua Formation. This lithofacies overlies S_1 (massive sandstone) and is usually interbedded with facies Cg_2 (conglomerate with sand and silt lenses). It is occasionally overlain by conglomerate facies Cg_1 (massive conglomerate) and Cg_3 (cross-stratified conglomerate).

Interpretation

Non-marine flood-plain to swamp environment. Deposition of silt probably occurred from overbank flood sedimentation, or in abandoned alluvial channels.

Muddy shellbed (Z_{11})

This lithofacies comprises non cemented, massive to weakly laminated siltstone to silty sandstone with a concentration of molluscan macrofauna. The facies is matrix supported, may be moderately pebbly in places and macrofauna are usually typical of the *Ostrea* association. Macrofauna may occasionally be representative of the *Ostrea*-glycymerid association. Macrofauna are mostly intact and articulated. This facies is normally restricted to position above inferred downlap surfaces in Pliocene cyclothems, and usually passes conformably into other siltstone lithofacies such as Z_1-Z_3 types.

Interpretation

A middle to outer shelf environment of deposition is inferred for this facies. Background sedimentation was generally low, allowing for the development of firm-grounds on top of coarse-grained transgressive deposits.

Conglomerate lithofacies

Conglomerate lithofacies are present through the succession studied in this project, though they are by far more common in the Late Pliocene-Pleistocene strata in the basin. Differentiation into individual facies types in this association has been undertaken chiefly on the basis of fossil content, sedimentary structures and to a lesser degree sorting of clasts in the units. All but one facies in this association is dominated by greywacke conglomerate clasts thought to be derived from the erosion of a basement hinterland. The work of Browne and Naish (2003) on fluvial deposits of the Canterbury Plains has been an additional basis for developing conglomerate lithofacies. A total of seven conglomerate lithofacies types have been characterised.

Massive conglomerate (Cg_1)

The massive conglomerate lithofacies comprises non to moderately cemented, non fossiliferous, clast-supported massive greywacke conglomerate (Fig. 3A, B). Greywacke clasts are of coarse-sand to boulder size, although typically pebble to cobble-size. Sorting is highly variable, and clasts are generally sub to well rounded. The massive conglomerate lithofacies is the most common conglomerate facies in the study area. The base of this facies is typically erosional, and scours up to several tens of centimetres into underlying facies of which S_9 pebbly sandstones are most common (Fig. 3A, B). The massive conglomerate lithofacies may also conformably overlie lithofacies S_2 (massive to cross-stratified sandstone) or S_3 (massive to cross-stratified fossiliferous sandstone). The massive conglomerate lithofacies passes laterally into either the conglomerate with sand and silt lenses (Cg_2) or cross-stratified conglomerate lithofacies (Cg_3). The facies is overlain by a variety of other facies types, including conglomerates Cg_4, Cg_5, Cg_6 or less commonly siltstone facies Z_5 (pebbly siltstone).

Interpretation

This facies is interpreted to represent a high-energy, high-bedload braided river system, with clasts derived from erosion of an actively uplifting greywacke basement hinterland. Browne and Naish (2003) suggested that massive greywacke conglomerate facies in the Canterbury Plains represented a variety of channel fill and bar forms. It is probable that this facies represents similar depositional features. Browne and Naish (2003) further suggest that much of this facies, particularly portions which exhibit faint stratification, likely represent central portions of bars, or gravel deposited rapidly in channels.

Conglomerate with sand and silt lenses (Cg_2)

This lithofacies comprises non to slightly cemented, massive to laminated and cross-stratified, clast-supported greywacke conglomerate with interbeds of sandstone and siltstone up to 0.5 m

thick and several metres long (Fig. 3C). The base of the facies is typically scoured and channelised, with decimetre-scale relief. In rare cases thin seams of lignite are present interbedded in this facies. Clasts of sandstone and siltstone are common. It is equivalent to facies A1 of Haywick (1990).

Interpretation

This lithofacies resembles deposits associated with the modern Tutaekuri, Ngaruroro, and Tukituki Rivers in Hawke's Bay. Therefore, a non-marine braid-plain system is inferred as the depositional setting. Conglomerates were deposited in high-energy fluvial channels. Sandstone and siltstone interbeds reflect a combination of overbank flood deposits and lower-energy channels in the fluvial system. Channel migration is reflected in the incorporation of sandstone and siltstone clasts into the conglomerate.

Cross-stratified conglomerate (Cg_3)

The cross-stratified conglomerate lithofacies consists of non to slightly cemented, poorly to well sorted tabular to trough cross-stratified, clast-supported greywacke conglomerate. It is equivalent to facies A2 of Haywick (1990). The degree of sorting varies from poor to high and clast sizes range from granule (uncommon) to large cobble. A medium pebble grainsize is typical, and clasts are moderately to well rounded, and of spheroidal to lensoidal shapes. Cross-stratification varies from small to moderate scale, and low to moderate angle. Imbrication of gravel clasts varies from rare to well developed. This lithofacies passes laterally into facies Cg_1 and Cg_2, and is overlain conformably by any of facies Cg_4, Cg_5, Cg_6 and MX_3. It is usually underlain by facies Cg_2 and S_9, although may be by facies Cg_1, S_1, S_2 or S_3 in occasional situations.

Fig. 3 (facing page): A) Contact between Cg_1 conglomerate of the Deep Stream Member (Matahorua Formation) and S_9 sandstone of the Pohue Formation. Mangaone River near Patoka Stream confluence (V20/272019). **B)** Contact between Cg_1 conglomerate of the Trelinnoe Member and S_9 sandstone of the Papakiri Member (Matahorua Formation). Prominent bluffs in hillside near the switchback on Huiarangi Road (V20/254002). **C)** Contact between S_1 sandstone of the Papakiri Member and Cg_2 conglomerate Grassy Knoll Conglomerate Member. The Dome (V20/265000). **D)** Highly fossiliferous Cg_6 conglomerate of the Flag Range Conglomerate Member. Macrofauna are dominated by *Zethalia zelandica* (*Zethalia* association). Kikowhero Stream at the Matapiro Road bridge (V21/192726). **E)** Highly fossiliferous Cg_6 conglomerate of the Flag Range Conglomerate Member. Macrofauna are dominated by *Ostrea chilensis* (*Ostrea* association). Flag Range (V21/191842). **F)** Gradational contact between Cg_6 conglomerate and Z_5 siltstone, Papakiri Member (Matahorua Formation). Macrofauna in the Cg_6 conglomerate comprise *Glycymeris shrimptoni, Ostrea chilensis, Phialopecten triphooki* (L.O.), and *Maoricolpus roseus* (*Ostrea*-glycymerid association). Macrofauna in the Z_5 siltstone are sparse, but comprise *Neilo* as part of the *Neilo* association. Huiarangi Road gravel pit (V20/259002).



Interpretation

This lithofacies is interpreted as a deposit of high-energy fluvial channels as part of a braid-plain system. Similar deposits are observed in the modern braided river systems of Hawke's Bay (e.g. Ngaruroro and Tutaekuri Rivers) and Canterbury (e.g. Waimakariri and Rakaia Rivers). Cross-stratification in this facies is inferred to reflect migration of gravel channel bars.

Laminated conglomerate (Cg_4)

This lithofacies comprises strongly laminated, very well sorted, alternating coarse sand and fine pebble to fine cobble, clast-supported greywacke conglomerate beds. This lithofacies is the second-most common conglomerate lithofacies. Clasts are well sorted and well rounded. Sorting is better in finer-grained beds which themselves are usually thicker than coarser-grained beds. Clast shape is dominated by lensoidal and oblate forms. The laminated conglomerate lithofacies conformably overlies facies Cg_1 (massive conglomerate), Cg_2 (conglomerate with sand and silt lenses) and Cg_3 (cross-stratified conglomerate). It is often overlain by a thin pebbly shellbed of facies Cg_3 (slightly fossiliferous conglomerate) or facies Z_5 (pebbly siltstone).

Interpretation

This facies is interpreted as a shingle beach deposit, equivalent to facies D1 of Haywick (1990). It is used in this study as a proxy for the approximate position of the lowstand shoreline in conglomeratic units in the Petane Group. It overlies non-marine fluvial conglomerates (facies Cg_1-Cg_3) which represent non-marine deposition. This facies records the return to marine deposition at the start of a transgression. Similar deposits occur along the modern Napier coastline, and outer parts of the Firth of Thames. The centimetre to decimetre-scale interbedding of greywacke sand and gravel in this facies is ubiquitous within and diagnostic of the breaker zone (Haywick 1990). The excellent sorting of this facies is consistent with such a depositional setting. Overlying shellbeds (e.g. facies Cg_5, Cg_6, Z_5) record submergence of the depositional system due to marine transgression.

Slightly fossiliferous conglomerate (Cg_5)

Non to moderately cemented, clast-supported, slightly fossiliferous greywacke conglomerate. Fauna are usually representative of brackish and nearshore environments, and include *Austrovenus stutchburyi, Patro undatus,* and *Barytellina crassidens* (*Austrovenus* association). This lithofacies may pass laterally into facies Z_5 (pebbly siltstone), Cg_6 (fossiliferous conglomerate), BC_3 (shelly limestone), BC_7 (cross-stratified limestone) or facies MX_3 (conglomeratic limestone). This lithofacies is conformably overlain by either facies Z_5 or Cg_6, and is underlain conformably by conglomerate facies Cg_1, Cg_2, Cg_3 and Cg_4.

Interpretation

This facies is inferred to have accumulated in a marginal-marine environment adjacent to a discharge source of greywacke gravels such as in an estuary or upper reaches of a harbour. *Austrovenus stutchburyi* is an estuarine-restricted bivalve very abundant around the modern New

Zealand coast and as such deposition of this facies must have occurred within close proximity to cockle banks.

Fossiliferous conglomerate (C_6)

Non to moderately cemented, moderately to well sorted moderately to highly fossiliferous greywacke conglomerate (Fig. 3D-F). Clasts are typically of pebble to cobble size, with medium pebble grains dominating. Robust, thick-shelled bivalves and subordinate gastropods common in nearshore environments are common throughout the facies. Typical bivalve fauna include *Glycymeris shrimptoni, Tucetona laticostata, Patro* undatus, and *Phialopecten triphooki* (Fig. 3F), with *Alcithoe* and *Zethalia* spp (Fig. 3D). being common gastropod genera. Valves of estuarine-restricted taxa such as *Paphies australis* and *Austrovenus stutchburyi* are often common, although are usually abraded and display evidence of current reworking and redeposition. This lithofacies overlies either S_1, S_2, S_3 and S_9 sandstones across a sharp unconformable contact, or conglomerate facies Cg_1, Cg2, Cg_3, Cg_4 and Cg_5 through gradational, conformable contacts. It is abruptly overlain by facies Z_5 (pebbly siltstone). The fossiliferous conglomerate lithofacies passes laterally into several other transgressive facies including BC_3 (shelly limestone), BC_7 (cross-stratified sandy limestone) and MX_3 (conglomeratic limestone).

Interpretation

This facies accumulated in a relatively high-energy marine setting such as a harbour channel, or tidal channels on the inner shelf. The faunal associations present in this facies is common in modern settings such as the entrance to many Northland harbours e.g. Whangarei and Whangaroa Harbours

Fossiliferous breccia (Cg_7)

Non to moderately cemented, poorly to slightly cemented, slightly to highly fossiliferous coarse-grained greywacke breccia. The unit is clast-supported in a sandy to gravelly matrix. Fauna are dominated by the *Crassostrea* association, though flabellid corals are locally abundant. This lithofacies may pass laterally into facies BC_3 (shelly limestone), and is overlain by facies S_9 (pebbly sandstone), and bioclastic facies BC_1, BC_2, BC_3, BC_5, and BC_6. This lithofacies usually unconformably overlies greywacke basement, though may be present unconformably overlying facies Z_1 (massive siltstone).

Interpretation

A shoreface to nearshore depositional environment is inferred that was adjacent to a rocky basement coastline. Sea-stacks and a rugged sea floor were present and remains of these can often be seen in outcrop.

Volcaniclastic lithofacies

Volcaniclastic lithofacies are the least common of the four lithofacies groups identified in this study, and is mainly restricted in outcrop to uppermost Mangapanian strata and younger. Three volcaniclastic lithofacies types are defined within this association, and likely reflect varying degrees of depositional depth, and distance from a source volcano.

Airfall tephra (V_1)

Non cemented, non-welded fine ash to lapilli-sized tephra in beds up to 0.6 m thick (Fig. 2A-C). This facies occurs exclusively in siltstone facies Z_8 in strata of uppermost Mangapanian age and younger.

Interpretation

This lithofacies represents airfall tephra, mostly from rhyolitic eruptions, that accumulated on a continental shelf below storm wave-base. At least 5 cm of ash needs to accumulate for a deposit to be preserved in the marine environment (Haywick 1990).

Ignimbrite (V_2)

Non to slightly welded, massive to laminated to cross-stratified fine ash with occasional medium lapilli-sized clasts. This facies is associated with non-marine greywacke conglomerate beds in Nukumaruan strata.

Interpretation

This facies is inferred to represent the primary portion of an ignimbrite flow. It is restricted to the upper parts of the Tutira Formation (Hikuroa Pumice Member) and is overlain conformably by facies V_3. It was probably deposited in non-marine to marginal-marine environments such as fluvial braidplains and estuaries. The thickness of some ignimbrite deposits in the study area (e.g. the 8-10 m thickness of the Hikuroa Pumice Member) suggests that the depositional setting was of relatively low-energy.

Laminated to cross-stratified volcaniclastics (V_3)

This lithofacies comprises non welded, massive to strongly laminated and cross-stratified fine ash to medium lapilli-sized sediments that display evidence of current reworking (Fig. 2F, 4A). This facies overlies primary ignimbrites and represents reworked ignimbrite, or sediments from the surrounding landscape that have been transported and redeposited.

Interpretation

A variety of depositional environments for this lithofacies are inferred, from non-marine to inner shelf settings. Lithofacies V_3 probably represents remobilised volcaniclastic sediments from facies V_1 and V_2.

BIOCLASTIC-DOMINATED LITHOFACIES

Hawke's Bay Basin is a siliciclastic-dominated sedimentary system that contains only a small volume of bioclastic facies. Although accounting for only about 5% of the total volume of the Late Miocene-Pliocene basin fill, due to their cementation and resistance to erosion, bioclastic facies, and the rocks they form, are prominent throughout Hawke's Bay. It is the presence of limestone beds in the Te Waka and Maungaharuru ranges, as well as in Te Mata Peak that gives these topographical features their elevation and prominence in the landscape. Seven bioclastic lithofacies have been characterised in this study.

Stacked medium to coarse skeletal beds (BC_1)

This lithofacies consists of moderately to well cemented, sparsely fossiliferous pale-cream to grey, medium to coarse-grained stacked skeletal grainstone to packstone as sheets 0.1-0.3 m thick Fig. 4B, D). The association is dominated by epifauna, usually in the form of fragmented barnacles, bryozoans, with other macrofauna relatively sparse. This lithofacies may occasionally contain macrofauna consistent with the *Neothyris* association. The stacked packstone-grainstone lithofacies may pass laterally into facies BC_2 (fossiliferous stacked packstone-grainstone beds), BC_5 (giant cross-stratified limestone), BC_6 (pebbly limestone) or BC_7 (cross-stratified sandy limestone).

Interpretation

This lithofacies was deposited at inner to middle shelf water depths under a regime of moderate to strong bottom-floor currents. Individual beds probably represent sediments remobilised from carbonate factories during periods of storms. The sea floor during deposition of the facies is likely to have been a firm-ground comprising coarse-grained sandy to gravelly sediments.

Fossiliferous stacked medium to coarse skeletal beds (BC_2)

Moderately to well cemented moderately to highly fossiliferous stacked packstone and grainstone bodies 0.1-0.3 m thick (Fig. 4C). Fauna are almost exclusively epifaunal to semi-infaunal bivalves with brachiopods (*Neothyris* aff. *obtusa*), pectinids (*Phialopecten* spp., *Mesopeplum crawfordi*), oysters (*Crassostrea ingens, Ostrea chilensis*), and false oysters (*Patro undatus*) common to abundant. In most cases the facies is dominated by barnacle plates and fragments with some to common intact specimens. These macrofauna are consistent with the *Neothyris* association and the *Crassostrea-Phialopecten* sub-association. Greywacke pebbles are common, and increase in volume with proximity to the axial ranges. The lithofacies is typically 5-30 m thick and widespread through the Patoka and Puketitiri areas.

Interpretation

This lithofacies accumulated on a coarse sand to shell-gravel firm-ground bioclastic-dominated substrate under a regime of strong tidal and storm currents. It is probable that this lithofacies accumulated very close to, or on top of, a carbonate factory. Sediments remobilised from these factories contributed sediments to facies BC1 and BC3. The influence of the strong currents was to keep the sea floor relatively free of fine-grained siliciclastic sediments. Fauna in the lithofacies are characteristic of the *Neothyris* faunal association and the *Crassostrea-Phialopecten* sub-association.

Fig. 4 (facing page): Examples of volcaniclastic and bioclastic-dominated lithofacies from the study area. **A)** Strongly bedded V_3 volcaniclastic deposits in the Papakiri Member (Matahorua Formation. Deep Stream above Alexandra Road ford (V20/364069). **B)** BC_1 limestone of the Opouahi Member, Titiokura Formation. Individual stacked bodies are 0.1-0.5 m thick. Pohokura Road, Maungaharuru Range (V19407215). **C)** BC_2 limestone of the Te Waka Formation. Stacked bodies are 0.1-0.3 m thick. Greywacke pebbles are common. Macrofauna are part of the *Crassostrea-Phialopecten* sub-association, and include common *Crassostrea ingens, Phialopecten thomsoni* and *Patro undatus.* Hawkston Lake, Hawkston Station (V20/128995). **D)** Barnacle-dominated interval of BC_1 grainstone to rudstone, Sentry Box Formation. Sentry Box Scenic Reserve, Ohara Depression (U21/925663). **E)** Highly fossiliferous interval of BC_3 limestone, Waipatiki Limestone Member. Macrofauna at this site are dominated by *Ostrea chilensis*, and are present in a fine sandstone matrix. Ruawai Station, Dartmoor (V21/301857). **F)** Well cemented BC_3 limestone of the Waipatiki Formation. Macrofauna are dominated by *Eumarcia* as part of the *Eumarcia* association. Partially recrystallised shells and biomoulds are common in this interval. Tangoio Quarry (V20/487007). **G)** Poorly cemented tabular, herringbone and sigmoidally cross-stratified interbedded BC_4 limestone and MX_1 sandstone of the Waipatiki Limestone Member. Macrofauna comprise the *Tawera-Crepidula* and *Crepidula-Sigapatella* associations. Okawa Stream (V21/250781).


A


B


C


D


E


F
Canon


G

Shelly limestone (BC_3)

Slightly to well cemented, medium to coarse-grained, moderately to highly fossiliferous limestone characterised by very abundant biomoulds of aragonitic bivalves. In some areas macrofossils are intact and valves are commonly articulated. Rare to common valves of ostreids and pectinids are present through the facies. Facies BC_3 is restricted in occurrence to 1) the western margin of the field area where it onlaps Torlesse basement and, 2) along the eastern margin of the study area where it forms parts of Upper Nukumaruan limestone beds in the Tangoio Block. Macrofauna are consistent with the *Tucetona, Eumarcia* and *Tawera* associations. The lithofacies is common to dominant in the Hukanui Limestone Member (Pakaututu Formation) cropping out in the Puketitiri-Pakaututu area, where it is characterised by very abundant intact and articulated valves of *Tucetona laticostata.* In rocks of Nukumaruan age this lithofacies is rich in valves and biomoulds of *Tawera subsulcata* and *Eumarcia benhami.* In places this facies may contain scattered greywacke granules and pebbles, reflecting the common occurrence of this facies immediately above greywacke basement in the Pakaututu area. The facies comprises stacked bioclastic-dominated bodies in planar and cross-stratified patterns reflecting continued influence from tidal and storm currents during deposition. In Opoitian rocks the shelly limestone lithofacies may pass laterally into the fossiliferous breccia (Cg_7) lithofacies. This lithofacies may overlie either greywacke basement directly or through up to 1.5 m of the fossiliferous breccia lithofacies, or may sharply overlie facies S_{11} (sandstone with fossiliferous concretions). In Upper Nukumaruan rocks this facies sharply overlies either facies BC_4 (fossiliferous shell-gravel), facies MX_1 (bioclastic-siliciclastic sandstone) or facies MX_4 (alternating bioclastic-siliciclastic bodies) through a transgressive surface of erosion. Geological mapping has demonstrated that the shelly limestone lithofacies may pass laterally into a number of lithofacies including facies BC_7 (cross-stratified limestone), facies Cg_5 (slightly fossiliferous conglomerate) facies Cg_6 (fossiliferous conglomerate) and facies MX_3 (conglomeratic limestone).

Interpretation

Sedimentary structures and macrofauna are consistent with deposition in high-energy nearshore to innermost shelf environments on a substrate of coarse sandstone to shell-gravel. In Opoitian rocks the lithofacies accumulated adjacent to a rocky basement coastline with sea-stacks and a rocky sea floor common. Much of the facies is consistent with deposition in tidal channels.

Fossiliferous shell-gravel (BC_4)

Slightly to moderately cemented highly fossiliferous cross-stratified coarse bioclastic sandstone to shell-gravel with abundant intact macrofossils (Fig. 4G). Low to moderate-scale tabular, trough and sigmoidal cross-stratification is common. This association is common in RST facies of the

upper Petane Group and is most common in the Waipatiki Formation. This facies often contains abundant soft-sediment deformation structures interpreted to reflect syn-depositional seismic activity. Faunal associations in this facies are typically dominated by epifaunal to semi-infaunal taxa such as *Crepidula radiata* and *Sigapatella novaezelandiae* (*Crepidula-Sigapatella* association and *Tawera-Crepidula* sub-association). The fossiliferous shell-gravel lithofacies is overlain by facies BC_3 (shelly limestone) and BC_7 (cross-stratified limestone) through a transgressive surface of erosion. Laterally this lithofacies passes into facies MX_1 (bioclastic-siliciclastic sandstone), MX_4 (alternating bioclastic-siliciclastic bodies) or several sandstone-dominated lithofacies including S_1, S_2 and S_3.

Interpretation

This lithofacies was deposited at nearshore to inner shelf water depths where it formed a firm-ground substrate of coarse shell gravel. This is consistent with macrofauna and sedimentary structures. Fine-grained siliciclastic sediments are uncommon and were probably removed by strong tidal currents.

Giant cross-stratified limestone (BC_5)

The giant cross-stratified limestone lithofacies is characterised by the presence of giant-scale cross-stratification and is restricted in outcrop to the Scinde Island Formation at Napier, and the Te Waka Formation on Hukanui Hill, Puketitiri. Macrofauna are absent to sparse, and are dominated by epifauna such as barnacles, bryozoans, brachiopods (*Neothyris* aff. *obtusa*), pectinids (*Phialopecten* spp.) and oysters (*Crassostrea ingens* and *Ostrea chilensis*). These macrofauna are typical of the *Neothyris* association and *Crassostrea-Phialopecten* sub-association.

The composition of the lithofacies is similar to that of facies BC_1, BC_2 and BC_7, but differs in the scale of cross-bedding. On Hukanui Hill this association passes laterally into facies BC_1 and BC_2. The nature of this lithofacies at Napier was documented in Kamp *et al*. (1988).

Interpretation

This lithofacies is inferred to represent remobilisation of carbonate sediments from a carbonate factory during periods strong current flow. The giant cross-beds are interpreted as the internal stratification of large carbonate sand bodies that migrated from carbonate factories across each other thereby forming a series of overlapping small submarine deltas or fans (Kamp *et al.* 1988). Currents may have been the result of either tidal or storm processes, but most probably a

combination of both. Shedding of sediments to produce this facies occurred from submarine highs, many of which were likely to have been cored by reverse faults.

Pebbly limestone (BC_6)

Slightly to well cemented, sparsely to moderately fossiliferous alternating skeletal grainstone and mixed bioclastic-siliciclastic packstone as sheets up to 0.3 m thick with common to abundant greywacke pebbles. Pebbles are well rounded and well sorted, and of lensoidal to spheroidal shapes. Macrofauna are sparse to common, and are dominated almost exclusively by epifaunal taxa such as oysters, pectinids, barnacles and bryozoans. These macrofauna are typical of the *Crassostrea-Phialopecten* sub-association. The pebbly limestone lithofacies passes laterally into facies BC_1 (stacked packstone-grainstone beds), BC_2 (fossiliferous stacked packstone-grainstone beds) or facies BC_7 (cross-stratified sandy limestone).

Interpretation

The environment of deposition for this facies is inferred to have been an inner shelf setting with moderate to strong sea-floor currents. The strong bottom-currents acted to periodically sweep the sea floor clean of fine-grained siliciclastic sediments. This produced a coarse-grained shell-gravel-dominated sea floor that was conducive to the accumulation of the *Crassostrea-Phialopecten* sub-association.

Cross-stratified sandy limestone (BC_7)

Moderately to well cemented tabular to sigmoidal cross-stratified sandy limestone (Fig. 5A, B). Contains a sparse to moderate macrofauna, usually present as biomoulds. This facies may contain scattered to common well sorted, well rounded spheroidal to lensoidal greywacke granules to pebbles. This lithofacies commonly passes laterally into the shelly limestone (BC_3) lithofacies. Macrofauna in this lithofacies are typical of the *Tawera* association.

Interpretation

This facies is interpreted to have been deposited at inner shelf water depths, with moderate to strong tidal currents. A sandy to sandy gravel substrate is probable.

MIXED SILICICLASTIC-BIOCLASTIC LITHOFACIES

Mixed siliciclastic-bioclastic facies are important contributors to the sedimentary succession in the field area. Siliciclastic and bioclastic facies represent sedimentary end-members in this region,

with the mixed assemblage being a transitional facies type between these end members. Four mixed siliciclastic-bioclastic lithofacies have been characterised.

Bioclastic-Siliciclastic sandstone (MX_1)

Non to slightly cemented, mixed siliciclastic-bioclastic medium sandstone, commonly cross-bedded with mudstone lenses and stringers up to 0.3 m thick (Fig. 4G). The lithofacies may display tabular, herringbone, sigmoidal and trough cross-stratification, as well as soft-sediment deformation structures. Macrofauna comprise the *Tawera, Tawera-Crepidula* and *Crepidula-Sigapatella* associations.

Interpretation

This facies was deposited at inner shelf water depths on a narrow continental shelf subjected to strong tidal and storm currents. This is consistent with macrofauna.

Coarse-grained mixed conglomerate (MX_2)

Pebble to cobble dominated, conglomerate with rare clasts up to boulder size, and sparse to common valves of robust epifaunal and infaunal bivalves in a coarse-grained bioturbated matrix of mixed siliciclastic-bioclastic sediments. The facies is poorly sorted and grains are frequently bored and infilled with sand. Greywacke clasts typically make up <5% of the volume of the unit. *Crassostrea ingens, Phialopecten marwicki*, and some flabellid corals occur in places. This lithofacies is typically 0.5-6 m thick and is most common in lower beds of the Titiokura Formation.

Interpretation

This lithofacies is inferred to represent a high-energy, nearshore to inner shelf depositional environment. Accumulation of the facies probably occurred in tidal channels.

Conglomeratic limestone (MX_3)

This lithofacies comprises moderately to well cemented, medium to coarse-grained bioclastic-dominated beds with common to abundant pebble to cobble-sized clasts of siliciclastic sandstone and mudstone and/or Torlesse greywacke comprising less than 50% of the volume of the facies (Fig. 5C). This facies is usually slightly to highly fossiliferous and may be rich in brachiopods (*Neothyris* aff. *obtusa*) and pectinids (*Phialopecten marwicki* and *Mesopeplum crawfordi*) in Early Pliocene rocks, and *Paphies australis, Austrovenus stutchburyi, Glycymeris shrimptoni, Tucetona laticostata, Purpurocardia purpurata, Patro undatus*, and *Phialopecten triphooki*, with *Alcithoe* and *Zethalia* spp. in younger beds.

Interpretation

A shoreface to nearshore environment of deposition is inferred for this lithofacies. Fauna often share characteristics with harbour and tidal channel associations on the modern New Zealand shelf.

Alternating bioclastic-siliciciclastic bodies (MX_4)

Slightly to well cemented, sparsely fossiliferous alternating skeletal grainstone and mixed bioclastic-siliciclastic packstone as sheets up to 0.3 m thick (Fig. 5D). Bioclastic beds are generally better cemented than their siliciclastic counterparts. Bioclastic beds are dominated by shellhash, with plates and fragments of barnacles common. Intact macrofauna are sparse to common, and comprise mainly shallow-water dwelling epifaunal to semi-infaunal taxa. *Tawera subsulcata* is common in this facies. This facies is typically 1-15 m thick.

Interpretation

This lithofacies was deposited at nearshore to inner shelf water depths. Bioclastic beds represent sediments remobilised from adjacent carbonate factories during periods of increased wave or storm currents. Siliciclastic beds are inferred to mark background sedimentation.

LITHOFACIES SUMMARY

The deposition of sandstone facies mostly occurred on the inner shelf and siltstone facies at middle to outer shelf depths. A tidal influence is inferred for the deposition of facies S_7 based on the abundance of flaser-bedding, ripple laminations, and cross-stratification. The accumulation of conglomerate facies represents high-energy deposition of clasts in beach to fan-delta settings. The presence of older Neogene sandstone and mudstone clasts in facies Cg_1, S_5, and Z_2 is suggestive of emergent areas of basin fill in northern hinterland regions. Facies Z_1 and Z_2 generally occur beneath sandstone facies, and gradationally pass into them.

Bioclastic facies accumulated on a carbonate-dominated shelf subjected to strong tidal currents at inner to middle shelf water depths. The presence of greywacke clasts implies an emergent basement hinterland and substrate to which bryozoans, bivalves, and brachiopods could attach. These bioclastic facies are inferred to have accumulated in water depths of 40-60 m. The composition and discontinuous nature of individual sheets of facies BC_3 indicate a wave-dominated environment on an open shelf. The skeletal grainstone and rudstone beds are inferred to represent storm-emplaced sheets mobilised from carbonate factories and dispersed across a shelf characterised by mixed bioclastic-siliciclastic sedimentation. Facies BC_1 is also thought to

represent sedimentation in a current-swept environment with individual skeletal grainstone and packstone sheets being products of sediment remobilisation off carbonate factories during storm events. The occurrence of burrows extending from overlying into underlying sheets, and sharp bases to beds in facies BC_1 and BC_2, indicate that deposition of the sheets occurred as discrete sedimentation events



Fig. 5: A) Sigmoidally to tabular cross-stratified sandy BC_7 limestone in the upper beds of the Te Rangi Member, Titiokura Formation at Naumai Station (V19/390273). **B)** Tabular to sigmoidally and trough cross-stratified sandy limestone (facies B_7) overlying concretionary sandstone (facies S_{10}), Te Waka Formation, Rocky Hill Station, Puketitiri (V20/139059). **C)** Interbeds of BC_2 and MX_3 pebbly limestone and conglomeratic limestone in the Mount Mary Pebbly Limestone. Mangleton Road, Ohara Depression (U21/976701). **D)** Interbedded siliciclastic and bioclastic sandstone of facies MX_4 in the Waipatiki Limestone Member. Puketitiri Road (V21/333882).

BIOFACIES ANALYSIS

INTRODUCTION

Biofacies are the relicts of paleocommunities. Analysis of macrofossil populations in the study area have been studied to delineate macrofossil associations. Macrofossil associations have proven to be useful aids in resolving the architecture of cyclothems (e.g. Abbot and Carter 1997, Hendy and Kamp 2004, Kondo *et al.* in review). Understanding the spectrum and environmental preferences of biofacies within the study area enables the rates and magnitudes of paleoenvironmental change to be quantitatively estimated. The classification of macrofaunal associations has proven to be a useful aid in making paleoenvironmental interpretations of the study area.

BIOFACIES OF THE STUDY AREA

Thirty faunal associations and six sub-associations have been identified, reflecting the large variety of lithofacies in the study area, and the wide age range of the Early Miocene-Early Pleistocene succession studied. Sixteen of these associations and sub-associations have been defined from cluster analysis, the remainder having been defined from field observations where bulk sampling was not possible. The faunal associations characterised represent a combination if *in situ* (life position) and transported assemblages. Macrofauna from *in situ* associations tend to well preserved, often articulated and valves largely unbroken. Faunal diversity in such associations tends to be low to moderate. Transported assemblages tend to have a higher degree of faunal diversity, but due to the reworked and redeposited nature of taxa within them there is often significant overlap between faunal associations (e.g. Haywick 1990). Macrofauna in transported associations have a high proportion of broken and disarticulated shells, and are usually preserved in cross-stratified patterns. Abrasion is common on taxa, particularly in estuarine faunas (such as *Austrovenus stutchburyi*) when they occur with open-marine fauna.

Interpretations as to the inferred environment of accumulation have been determined from a combination of macrofaunal content, sedimentary structures and lithofacies of the enveloping sedimentary rocks, and comparisons of the association with modern equivalents (where possible). Many macrofossils and associations in the study area have modern analogues to which direct comparisons can be made.

Austrovenus association (au)

The *Austrovenus* association (Fig. 6A, B) is dominated by the extant *Austrovenus stutchburyi* and the extinct (Wn-restricted) *A. crassitesta*. The *Austrovenus* association has a low faunal diversity reflecting the estuarine depositional setting for the association. In many places the association may be monospecific. Where present common secondary taxa include *Zeacumantus lutulentus, Xenostrobus huttoniana* and *Barytellina crassidens.* In terms of sequence stratigraphy the *Austrovenus* association only occurs in TST stratal positions and usually marks an initial period of marine submergence during transgression. The association is most common on top of non fossiliferous, non-marine LST conglomerate beds of the Matahorua Formation though has been observed in transgressive systems tracts overlying sandstone facies in the Okauawa Formation.

Interpretation

Austrovenus stutchburyi is extremely abundant in harbours and estuaries around the modern New Zealand coastline, and is restricted to areas of reduced salinity. The *Austrovenus* association was deposited in an estuarine environment on a substrate of silt to silty sand. Facies containing the association are often flaser-bedded with mud drapes and ripple laminations. The presence of several marginal-marine and estuarine-restricted taxa support this interpretation.

Fellaster association (fe)

Lithofacies containing the *Fellaster* association (Fig. 6C) are mainly sandy, although a minor shell-gravel component is present in some sites. The association is characterised by the dominance of the echinoid *Fellaster zelandiae* (about 70%), although at times a diverse macrofauna may occur. Modern *Fellaster* associations were identified by McKnight (1969) from sandy substrates in sheltered to partly sheltered environments from 0-31 m. The *Fellaster* association has been recognised by Hendy and Kamp (2004) in Late Miocene-Early Pliocene shelfal rocks in Wanganui and Taranaki Basins. Their *Fellaster* association is inferred to have occupied a similar stratal and paleoenvironmental position to that defined here. Haywick (1990, p. 5-6) identifies a *Struthiolaria-Fellaster* association in Upper Nukumaruan rocks in the Tangoio Block. This association is equivalent to the *Fellaster* association defined in this study.

The *Fellaster* association commonly occurs concentrated into scour-based shell lenses, indicating it is usually a transported association. It is therefore most common in uppermost parts of RST sandstone and limestone facies.

Interpretation

Both the *Fellaster* and *Zethalia* associations occupied nearshore to shoreface environments in keeping with modern distributions of these associations (McKnight 1969). It is inferred that the *Fellaster* association accumulated on finer-grained substrates in more sheltered settings than the *Zethalia* association. *Fellaster* is also usually restricted to regressive systems tract sandstone facies (and less commonly limestone facies), whereas the *Zethalia* association is common in both regressive and transgressive facies. Pebble-sized clasts are very uncommon in the *Fellaster* association, although are often common to abundant in the *Zethalia* association. The scour-base of shell lenses containing the *Fellaster* association is inferred to represent remobilisation of sediments during storm events.

Zethalia association (ze)

The *Zethalia* association (Fig. 6E, F) is most common in rocks of Nukumaruan age where the faunal content is dominated by *Zethalia zelandica* (average 75%). The association does occur sporadically in uppermost Mangapanian beds where it is dominated by *Zethalia coronata.* Lithofacies containing *Zethalia* association are typically sandy to pebbly (Fig. 3D). Such facies are interpreted to have accumulated in nearshore to harbour environments proximal to a fluvial river system that was actively supplying large volumes of greywacke pebbles.

The association contains a variety of shallow-water-dominated taxa. The bivalves *Lutraria solida* and *Dosinia* spp. are commonly found with *Zethalia zelandica* with occasional *Panopea* sp. Mangapanian beds of the *Zethalia* association contain common *Myadora stephaniae.*

While most common in TST conglomerate beds the *Zethalia* association is often found in RST sandstones where taxa are concentrated in reworked event-concentrated shell lenses.

Interpretation

The *Zethalia* association accumulated in a shoreface to nearshore setting. In modern environments *Z. zelandica* is abundant in sandy environments on open marine beaches at 3-5 m water depth (Beu and Maxwell 1990). The association comprises a combination of *in situ* and redeposited *Zethalia*.

Paphies association (ph)

The *Paphies* association (Fig. 6D) is a distinctive association restricted in outcrop to the Glengarry region. Facies containing the *Paphies* association are largely pebbly, although sandy facies are present in the Napier-Taupo Road area.

The association almost exclusively comprises *Paphies australis* with localised minor contributions from *Ostrea chilensis* and *Lutraria solida. Paphies australis* is today extremely common in very shallow-water intertidal environments such as the Ahuriri Lagoon at Napier, the Firth of Thames and Tauranga Harbour. The association may pass laterally into a number of other shallow-water faunal associations such as the *Eumarcia, Glycymeris* and *Zethalia* associations.

Interpretation

The *Paphies* association accumulated in marginal-marine to shoreface settings and represents a combination of *in situ* to redeposited valves. *In situ* valves accumulated in highly fossiliferous shell banks in estuarine and upper to middle harbour settings, consistent with the modern distribution of *Paphies australis.*

The *Paphies* association is dominantly restricted to TST conglomerate beds in both lowermost and uppermost beds of the Mangaheia Group. It is inferred to represent early submergence of a fluvial fan-delta system during early parts of a sea level rise.

***Crepidula-Sigapatella* association (cr-sg)**

The *Crepidula-Sigapatella* association is only observed in coarse-grained highly fossiliferous limestone and shellbeds of middle to upper Nukumaruan age. *Crepidula radiata* comprises on average 35.5% of the association, with *Sigapatella* comprising 24%. The association is particularly noticeable in the Matapiro and Okawa areas.

It is inferred that the *Crepidula-Sigapatella* association passes laterally into the *Tawera* association and its sub-associations, and accumulated on a sea floor with a coarser-grained substrate than the *Tawera* association. Low-angle, small to medium-scale planar, bi-directional and herringbone cross-stratification are common in facies containing the association.

The *Crepidula-Sigapatella* association is restricted to highly fossiliferous RST shellbed to fossiliferous sandstone facies of the uppermost Mangaheia Group, such as those in the Waipatiki Formation.

Interpretation

The *Crepidula-Sigapatella* association accumulated at nearshore to inner shelf environments on a firm-ground substrate of coarse-grained shellhash. The depositional setting was subjected to a strong tidal regime that is inferred to have kept the sea floor relatively free of fine-grained

siliciclastic sediment. This interpretation is consistent with bedforms of facies containing the association and stratigraphic position.

Tawera association (tw)

The *Tawera* association (Fig. 7A-C) is one of the most common faunal associations observed in the Hawke's Bay area, particularly in rocks of Nukumaruan age where the association is dominated by the extinct *Tawera subsulcata* (average 71%). In the field, this association is commonly observed to contain *Ostrea chilensis. Ostrea chilensis* becomes more common in progressively offshore sub-associations and in many cases the *Tawera* association probably grades into the *Ostrea* association. The *Tawera* association is inferred to represent a mainly life-position association, and passes laterally into the transported accumulations of the *Crepidula-Sigapatella* association among others. *Tawera subsulcata* is extremely abundant in the fossil record and is characteristic of very shallow-water soft bottom facies (Beu and Maxwell 1990, p. 317).

Tawera associations resembling those characterised in this study have been documented in several studies in both modern settings (e.g. Powell 1937, McKnight 1969) and Cenozoic rocks (e.g. Hendy and Kamp 2004). Modern *Tawera* associations (dominated by *Tawera spissa*) are widespread in open coastal settings in depths of 10-50 m on substrates of gravelly sand to sand though the modern *T*. spissa itself may occur to depths as great as 260 m and on substrates ranging from gravel to sandy mud (McKnight 1969).

The *Tawera* association as characterised in this study has dominantly been observed in sandy to coarse-grained moderately to highly fossiliferous shelly and sandy limestones (Fig. 7B) that correspond to the transgressive systems tract. The association is still common however in coarse-grained shelly conglomerates (Fig. 7A), fine sandstones (Fig. 7C), and sandy siltstones of regressive systems tracts.

Modern sea floor samples collected from the Hauraki Gulf may contain up to 25,000 *Tawera subsulcata* individuals per m^2 (Hendy 2002). It is inferred that the *Tawera* association accumulated in such a setting.

Interpretation

The *Tawera* association accumulated in nearshore to inner shelf environments on a sandy to shell-gravel substrate subject to a strong tidal influence. The sedimentary structures of facies

containing the association, such as low-angle, planar, bi-directional, and herringbone cross-stratification are consistent with such an environment.

***Tawera-Sigapatella* sub-association (tw-sg)**

The *Tawera-Sigapatella* sub-association is restricted to coarse-grained limestone beds of Upper Nukumaruan age, usually in association with the *Tawera-Crepidula* association. It is commonly observed in toplap shellbed facies in the Waipatiki Limestone Member in the Matapiro area, and near Waipunga Road in the Tangoio Block. It has a moderately high faunal diversity, and is dominated by *Tawera subsulcata* (about 25%) with common *Sigapatella novaezelandiae* (about 20%) and *Crepidula radiata* (about 15%). This sub-association is equivalent to the *Tawera-Sigapatella* association described by Haywick (1990).

Interpretation

A tide-dominated nearshore to innermost-shelf depositional environment is inferred for this sub-association. Seafloor substrate comprised coarse-grained shell gravel. Deposition occurred above storm wave-base, allowing siliciclastic sediments to be winnowed from bioclastic debris. Haywick (1990, p. 5-7) inferred a tidally-affected inner shelf environment of deposition for his *Tawera-Sigapatella* association, consistent with sedimentary structures he observed such as low angle, planar and bi-directional cross-stratification occurring in rocks containing the association.

Haywick (1990, p. 5-7) noted that there is no identical modern analogue in New Zealand for the *Tawera-Sigapatella* sub-association, and suggested that the *Tawera spissa-Venericardia* [*Purpurocardia*] *purpurata* association of Mcknight (1969) and *Tawera-Glycymeris* formation of Powell (1937) were comparable. These infaunal associations inhabited sandy and gravelly substrates similar to those inferred for the *Tawera-Sigapatella* sub-association at water depths of 10-50 m (occasionally up to 260 m) along open coastline settings (McKnight 1969).

***Tawera-Crepidula* sub-association (tw-cr)**

The *Tawera-Crepidula* association has only been observed in coarse-grained highly fossiliferous limestone beds of Upper Nukumaruan age. The sub-association is characterised by the dominance of *Tawera subsulcata* and the common presence of *Crepidula radiata. Sigapatella novaezelandiae* is also common and where dominant over *Crepidula* the association is classified as the *Tawera-Sigapatella* sub-association. A moderate faunal diversity is present, and probably reflects redeposition of taxa from several overlapping and adjacent environments. The *Taw*era-*Crepidula* sub-association occurs in facies comprising almost exclusively coarse shell-gravel with a limited contribution from siliciclastic sand and gravel. It is inferred that tidal currents played a

strong influence in the accumulation of the association keeping the sea floor relatively free of siliciclastic sediments.

The *Tawera-Crepidula* sub-association is very similar to the *Tawera-Sigapatella* association of Haywick (1990), with very similar faunal components, and almost identical inferred environments of accumulation. The *Tawera-Crepidula* sub-association passes laterally into the *Crepidula-Sigapatella, Tawera-Sigapatella*, *Tawera* and *Zethalia* associations.

Interpretation

The *Tawera-Crepidula* association is inferred to have accumulated in a tide-dominated nearshore to innermost shelf setting on a substrate of coarse shell-gravel.

***Tawera-Patro* sub-association (tw-pt)**

The *Tawera-Patro* sub-association is characterised by the co-dominance of *Tawera subsulcata* and extinct *Patro undatus.* The sub-association has been defined from cluster analysis of bulk samples. The *Tawera-Patro* sub-association occurs sporadically through the study area.

Interpretation

The *Tawera-Patro* sub-association is inferred to have accumulated at lower inner to upper-middle shelf water depths on a semi firm-ground sandy to silty substrate, in an environment slightly further offshore than other *Tawera* sub-associations

***Dosinia* association (do)**

The *Dosinia* association (Fig. 6G, H) is characterised by the occurrence of the extant bivalves *Dosinia (Phacosama) subrosea* and *Dosinia (Austrodosinia) anus*. *Dosinia (Phacosama) subrosea* lives commonly near the low tide mark off sand beaches in both enclosed embayments and on open coasts in a variety of soft-bottom facies. *Dosinia (Austrodosinia) anus* is an open-ocean sand beach species (Beu and Maxwell 1990). Other fauna common in the *Dosinia* association include *Rexithaerus spenceris, Tellinota edgari, Peronaea gaimardi* and the barnacle *Austromegabalanus decorus.*

Fig. 6 (facing page): Examples of shoreface and nearshore macrofossil associations in the Mangaheia Group. **A)** *Austrovenus* association, Okauawa Formation, Kereru Road (U21/068686). **B)** *Austrovenus* association, Matahorua Formation, Tiokapu Station (V20/301992). **C)** *Fellaster* association, Tangoio Limestone Member, Waipatiki Beach (W20/521029). **D)** *Paphies* association, Kaiwaka Formation near The Gums (V21/340898). **E)** *Zethalia* association, Flag Range Conglomerate Member, Kikowhero Stream (V21/192726). **F)** *Zethalia* association, Pohue Formation. Esk River near Berry Road Ford (V20/192726). **G)** *Dosinia* association, Deep Stream Member, Napier-Taupo Road (V20/299066). **H)** *Dosinia* association, Okauawa Formation. Kikowhero Stream, Whakamarumaru Station (V21/124773).


A
B
C
D
E
F
G
H

The *Dosinia* association is most common in well sorted clean sandstone facies of regressive systems tracts, although it has been recognised in sandy interbeds in conglomeratic transgressive systems tract facies in Kikowhero Stream. Valves in this association are typically arranged in a disarticulated, concave-down pattern in moderately to highly fossiliferous shell lenses

Interpretation

The *Dosinia* association is inferred to have accumulated on sandy substrates at nearshore to inner shelf (5-30 m) mostly below fair-weather wave-base but above storm wave-base. Concentration of valves probably occurred during storm events when sediments were winnowed from around in situ shells with a minimal degree of remobilisation of the valves themselves. Evidence of harbour deposition for some beds of the *Dosinia* association is present in Kikowhero Stream. In most other cases accumulation of this association occurred in open-marine settings. This association occurs in the form of event concentrated shell lenses following the nomenclature of Hendy and Kamp (in review).

***Maoricolpus* association (mc)**

The most abundant taxa in the *Maoricolpus* association is the extant gastropod *Maoricolpus roseus* (39% on average). *Maoricolpus roseus* is widespread on the modern New Zealand shelf in very shallow-water depths, such as intertidal environments in Manukau Harbour (Beu and Maxwell 1990).

The *Maoricolpus* association is likely to pass laterally into the *Glycymeris, Tawera* and *Crepidula-Sigapatella* associations. The *Maoricolpus* association of Powell (1937) passed laterally into a *Tawera-[Tucetona]* association.

McKnight (1969) noted that in the modern New Zealand environment the *Maoricolpus* association is only known in Manukau Harbour where it occurs on shelly to sandy substrates at water depths of 5-20 m. McKnight also remarked that the *Maoricolpus* association may be more widespread in the modern environment than indicated although tidal scour accumulations of *Maoricolpus* and other species may be confused with it.

Interpretation

A modern *Maoricolpus* association was described by Powell (1937) in the Waitemata and Manukau Harbours. The association in these harbours occurred on a hard bottom comprised of coarse shell debris redeposited from shallower environments by tidal currents (Powell 1937). Powell suggested that these same tidal currents kept the bottom moderately free from silts. Such

a depositional setting is inferred for the accumulation of the *Maoricolpus* association. It is inferred that the *Maoricolpus* association accumulated in a more shoreward setting than the *Tawera* association as described by Powell (1937) in association with strong tidal currents.

Ostrea-glycymerid association (os-gl)

This association (Fig. 7D-F) is present in rocks of Opoitian to Upper Nukumaruan age and is characterised by an abundance of the extant "Bluff Oyster" *Ostrea chilensis* in association with glycymerid bivalves such as *Glycymeris* spp. and *Tucetona laticostata.* The most common facies containing the association are coarse-grained pebbly to conglomeratic facies as parts of TST shellbeds and limestones. In lowermost beds of the Petane Group the *Ostrea*-glycymerid association contains the pectinids *Phialopecten triphooki* and *Mesopeplum convexum*. Faunal diversity is moderately high in this association.

The large dog cockle *Tucetona laticostata* is frequently associated with *O*. *chilensis* and *Purpurocardia purpurata* on the modern New Zealand shelf and has been recognised in many Cenozoic macrofossil associations such as Hendy and Kamp (2004).

The *Ostrea*-glycymerid association may passes laterally into several other shallow-water faunal associations such as the *Austrovenus*, *Maoricolpus, Ostrea-Purpurocardia, Eumarcia, Tucetona* and *Tawera* associations.

Interpretation

The *Ostrea*-glycymerid association accumulated at nearshore to innermost shelf water depths on a firm sandy to gravelly substrate, as indicated by modern distributions of similar assemblages. Strong tidal currents kept the sea floor relatively free of siliciciclastic sediment. Abraded valves of estuarine and marginal-marine-restricted bivalves such as *Austrovenus stutchburyi* and *Paphies australis* are often common in this association and suggest adjacent estuaries during the period of accumulation.

Eumarcia association (eu)

The *Eumarcia* association (Fig. 7G) is characterised by the abundance of the large extinct bivalve *Eumarcia plana.* The *Eumarcia* association is one of the most distinctive associations in the Nukumaruan stratigraphy of the basin and is chiefly restricted to TST limestone beds in upper formations of the Tangoio Block, although has been observed in the uppermost, Mangapanian limestone bed of the Te Waka Formation. The *Glycymeris-Eumarcia* association of Haywick (1990) is equivalent to the *Eumarcia* association.


A


B


C


D


E


F


G

As *Eumarcia plana* is an extinct taxon its habitat during the Plio-Pleistocene can only be inferred. The closest living relative of *E. plana* is *E. fumigata* (Sowerby), a species that lives amongst mangroves and in estuaries in eastern Australia. It was inferred by Haywick (1990) that *Eumarcia plana* may have inhabited a similar environment to *E. fumigata*. Facies containing the *Eumarcia* association are typically coarse bioclastic sands and shell gravels, suggesting the taxon preferred such substrates. Haywick (1990, p. 5-8) reasoned that *E. plana* probably inhabited shell bars, banks and tidal channels. The *Eumarcia* association contains a wide variety of extant shallow-water marginal-marine to nearshore taxa such as *Paphies australis, Fellaster zelandica, Mactra discors, Zethalia* spp., *Bassina* spp., *Dosinia (Asa) lambata, Glycymeris shrimptoni, Gari lineolata, Scalpomactra scalpellum, Divaricella huttoniana* and *Myadora stephaniae.* Other notable fauna include *Purpurocardia purpurata* and *Tawera subsulcata.* These taxa, together with sedimentary structures in the enclosing facies are consistent with Haywick's interpretation of the environment of accumulation. The *Eumarcia* association probably passes in to the *Austrovenus, Fellaster,* and *Zethalia* associations in a shoreward direction and the *Ostrea*-glycymerid*, Crepidula-Sigapatella* and *Tawera* associations in an offshore direction. The *Maoricolpus* association probably accumulated in a similar setting to the *Eumarcia* association, but tends to occur in facies with a coarser-grained conglomeratic nature.

Interpretation

The *Eumarcia* association accumulated in a shallow-water nearshore to innermost shelf environment under a regime of strong tidal currents, consistent with macrofauna and sedimentary structures.

***Ostrea-Purpurocardia* association (os-pu)**

The *Ostrea-Purpurocardia* sub-association is common and widespread in conglomerate facies of Upper Nukumaruan age in central and southern parts of the study area. In many cases *Purpurocardia purpurata* dominates the faunal composition. Faunal diversity is high in this sub-association with taxa typically comprising robust thick-shelled semi-infaunal and epifaunal species. Conspicuous taxa include *Lutraria solida* and *Alcithoe arabica* with some *Glycymeris shrimptoni* and *Tucetona laticostata.*

Fig. 7 (facing page): Examples of nearshore and inner shelf macrofossils associations in the Mangaheia Group. **A)** *Tawera* association, Flag Range Conglomerate Member, Kikowhero Stream (V21/192726). **B)** *Tawera* association in uppermost beds (onlap shellbed) of the Kikowhero Member, Okauawa Formation, Whana Valley near Matapiro Road (U21/096771). **C)** *Tawera* association in an onlap shellbed overlying a TSE, Kaiwaka Formation, Ohiti Road (V21/233722). **D)** *Ostrea*-glycymerid association, Flag Range Conglomerate Member, Flag Range (V21/191842). **E)** *Ostrea*-glycymerid association, Waipatiki Limestone Member, Ruawai Station, near Dartmoor (V21/301857). **F)** *Ostrea*-glycymerid association, Papakiri Member, Huiarangi Road (V20/259002). **G)** *Eumarcia* association, Waipatiki Limestone Member, Tangoio Quarry (V20/486007).

Facies containing the *Ostrea-Purpurocardia* sub-association are exclusively conglomeratic. The *Ostrea-Purpurocardia* sub-association has modern equivalents on the New Zealand shelf, such as the *Ostrea-Purpurocardia-Modiolarca* association of Estcourt (1967).

Interpretation

The *Ostrea-Purpurocardia* sub-association accumulated in nearshore to innermost shelf environments on gravelly substrates. Strong tidal currents kept the sea floor relatively free of fine siliciclastic sediment.

***Tucetona* association (tu)**

The *Tucetona* association (Fig. 8B, C) is most common in Early Pliocene rocks adjacent to the Kaweka Range and is characterised by the abundance of the extant dog cockle *Tucetona laticostata*. The association contains a moderately diverse range of robust epifaunal and semi-infaunal taxa including *Ostrea chilensis, Crassostrea ingens, Oxyperis komakoensis, Phialopecten* spp. and *Eucrassatella* sp. In the area surrounding Sandy Ridge in Kaweka Forest, the *Tucetona* association comprises very abundant barnacle plates and fragments with *T. laticostata,* rare *Phialopecten thomsoni* and *Panopea* sp.

The *Tucetona* association is widespread on the modern New Zealand shelf and has been documented by several authors including Morton and Miller (1968), and Gillespie and Nelson (1996). The *Tucetona* association shares characteristics with Assemblage C of Gillespie and Nelson (1996).

Interpretation

The *Tucetona* association accumulated in nearshore settings on very coarse sandy to gravelly substrates, probably in tidal channels. This setting was in very close proximity to a rocky greywacke coastline.

***Maorimactra* association (mm)**

The *Maorimactra* association is dominated by the small bivalve *Maorimactra ordinaria* and is usually contained in fine sandstone to silty sandstone facies. All bulk samples analysed of the *Maorimactra* association comprised over 50% *Maorimactra ordinaria*. *Maorimactra ordinaria* is an extant species that occupies in a broad bathymetric range (10-170 m) although it is most commonly present in water depths less than 80 m (Hendy and Kamp 2004). Beu and Maxwell (1990) regarded the genus *Maorimactra* as an indicator of shallow-water soft-bottom facies.

Modern communities resembling the *Maorimactra* association are common on the New Zealand shelf in water depths of 20-60 m (McKnight 1969).

Interpretation

The Maorimactra association is inferred to have accumulated on soft fine sandstone to silty sandstone substrates at inner to upper-middle shelf water depths (20-60 m). This environment is envisaged to have been more open-marine than that for the *Dosinia (Kereia)* association.

***Dosinia (Kereia)* association (dk)**

This association occupies a slightly more offshore position than the *Maorimactra* association. The association is dominated by *Dosinia (Kereia) greyi*. The *Dosinia (Kereia*) association is widespread though uncommon in silty sandstone to sandy siltstone facies assigned to the regressive systems tract. *Dosinia (Kereia) greyi* is an extant species that preferentially inhabits sheltered inner shelf settings (Hendy and Kamp 2004).

Valves of *Dosinia (Kereia) greyi* are usually *in situ* and articulated. *Atrina pectinata zelandica, Pratulum pulchellum, Ostrea chilensis, Talochlamys gemmulata, Stiracolpus* sp. are common components of the association with many other taxa locally present. Such taxa include *Alcithoe* spp., *Austrofusus* spp. and *Pelicaria* spp.

The *Dosinia (Kereia)* association was recognised in Late Miocene-Early Pliocene shelfal rocks by Hendy and Kamp (2004) in Wanganui and Taranaki Basins.

Interpretation

The *Dosinia (Kereia)* association is inferred to have accumulated on silty sand substrates at inner shelf (10-50 m) water depths, based on the modern distribution of Dosinia (Kereia) greyi. Substrates and water depths are similar to that of the *Maorimactra* association. The *Dosinia (Kereia)* association probably represents a more sheltered depositional setting than the *Maorimactra* association.

***Ostrea* association (os)**

The *Ostrea* association occurs in silty facies immediately above coarse-grained limestone beds of the Petane Group. In terms of sequence stratigraphy the *Ostrea* association is inferred to represent a downlap shellbed, and marks a period of sediment starvation and the approximate point of maximum sea level rise. In these cases the association is often monospecific though *Zeacolpus vittatus* and *Dosina* spp. may also be present.

Interpretation

The *Ostrea* association accumulated on silty firm-ground substrates at lower inner to outer shelf water depths. It is inferred that periods of accumulation of this facies marked periods of sediment starvation and minor biostrome and reef development.

Patro association (pt)

The *Patro* association (Fig. 8A) occurs in a limited number of sites and differs from the *Tawera-Patro* sub-association and *Talochlamys* association by the more common presence of the extinct false oyster *Patro undatus.* As *Patro undatus* is an extinct taxon its habitat during the Plio-Pleistocene can only be inferred from co-occurring taxa and enveloping sedimentary facies.

Interpretation

The *Patro* association accumulated at lower inner to middle shelf water depths on fine sandy silty firm-ground substrates. The association represents a transitional grouping from the shallow-water *Tawera*-dominated associations to the deeper water *Pratulum* and *Talochlamys* associations.

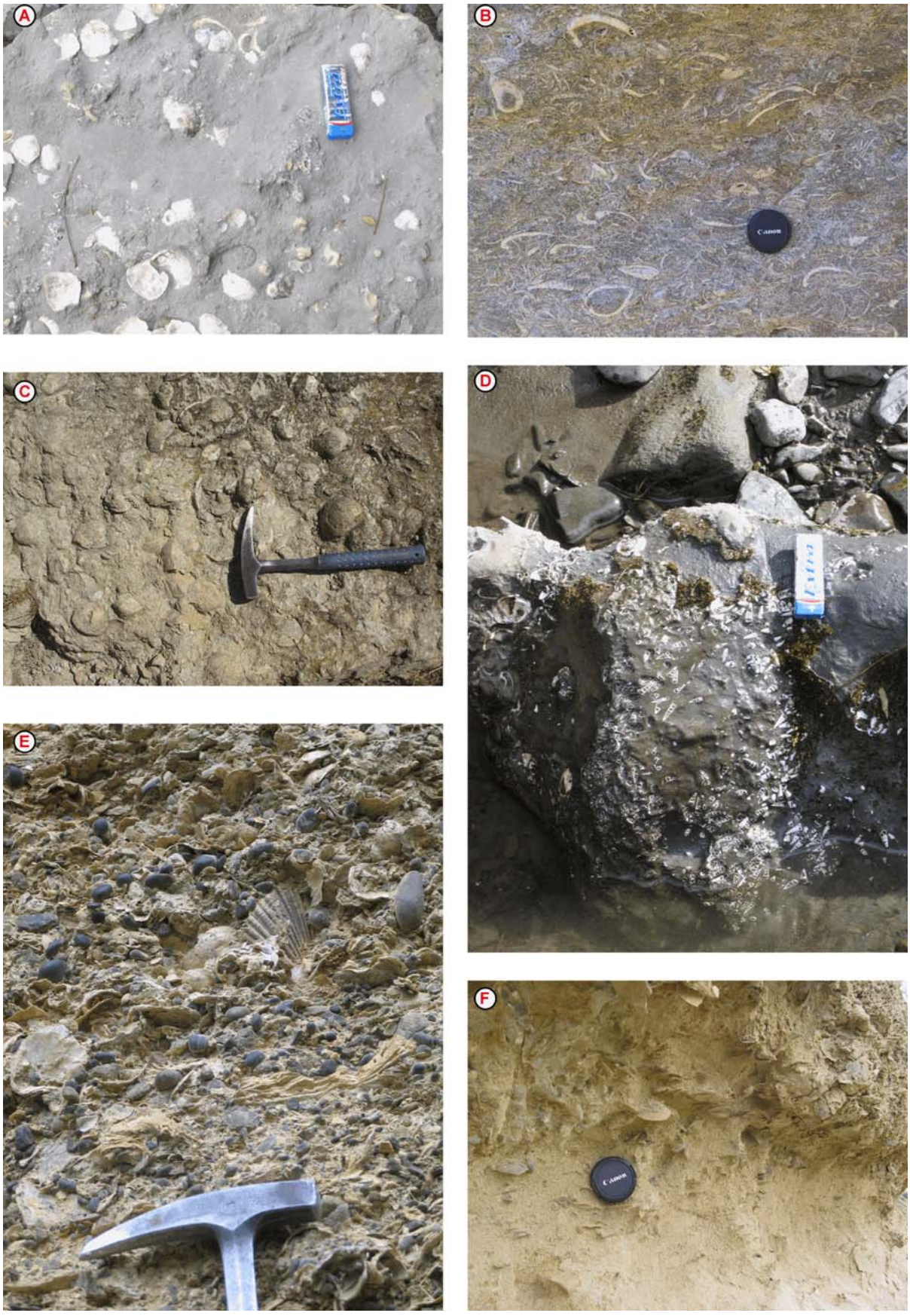
Zeacolpus association (zc)

The *Zeacolpus* association (Fig. 8D) is common in coarse-grained pebble-rich limestones of Late Miocene (Tongaporutuan) age in the study area. The association is commonly present in beds above pronounced unconformities. The association is usually almost monospecific and characterised by the turritelid gastropod *Zeacolpus* spp. The *Zeacolpus* association is commonly interbedded with, and passes laterally into, the *Struthiolaria (Callusaria)* association (see below).

Interpretation

The *Zeacolpus* association accumulated in shallow-water nearshore to inner shelf environments on a sandy to slightly gravelly substrate.

Fig. 8: Examples of inferred inner to middle shelf macrofossils associations in the Tolaga and Mangaheia Groups. **A)** *Patro* association, Te Ipuohape Sandstone Member, Tutaekuri River, Kaweka Forest Park (U20/057982). **B)** *Tucetona* association. Hukanui Limestone Member, Puketitiri (V20/114116). **C)** *Tucetona* association, Hukanui Limestone Member, Puketitiri (V20/112117). **D)** *Zeacolpus* association, Te Ipuohape Sandstone Member, Tutaekuri River, Kaweka Forest Park (U20/057982). **E)** *Crassostrea-Phialopecten* sub-association, Te Waka Formation, Seaview Station (V20/141019). **F)** *Talochlamys* association, Waipatiki Limestone Member, Rorookiwa Hill, Bayview (V21/418898).


A
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Struthiolaria (Callusaria) association (st)

The *Struthiolaria (Callusaria)* association is restricted to rocks of Tongaporutuan-Opoitian age in western parts of the study area. Facies containing the *Struthiolaria (Callusaria)* association are fine to medium strongly concretionary sandstones to less common pebbly limestones and shelly conglomerates. The association is most common in proximity to Mesozoic basement rocks. The association does not occur in rocks younger than Opoitian as *Struthiolaria (Callusaria)* became extinct at the end of this stage (Beu and Maxwell 1990; Beu 1995). The association is dominated by the gastropod *Struthiolaria (Callusaria)* spp. with common *Zenatia acinaces* and *Zeacolpus* sp. In Tongaporutuan expressions of the association *Sectipecten grangei* and *Crepidula radiata* are common secondary taxa.

The *Struthiolaria (Callusaria)* association is commonly interbedded with, and grades laterally into, the *Zeacolpus* association.

Interpretation

The *Struthiolaria (Callusaria)* association accumulated in nearshore to inner shelf environments on sandy to slightly gravelly substrates. The association is present in settings that were in close proximity to a rocky greywacke coastline.

Crassostrea association (cs)

The *Crassostrea* association is common in "early to middle" Pliocene rocks in western parts of the study area and is dominated by the large, thick-shelled oyster *Crassostrea ingens*. The *Crassostrea* association is typically restricted to settings in close proximity to basement rocks, although may occur on hardground surfaces representing unconformities. Fauna in the *Crassostrea* association are dominated by epifaunal or robust semi-infaunal taxa such as *Maoricardium spatiosum, Tucetona laticostata* and occasional *Phialopecten* spp. In some localities such as Opau Stream, the association contains abundant flabellid corals. Facies containing the *Crassostrea* association are usually very coarse conglomerates to breccias that directly overlie greywacke basement. Where the association is separated from greywacke basement by other Cenozoic beds, the facies containing the association still typically comprise conglomerates of varying lithologies.

Interpretation

The *Crassostrea* association accumulated in high-energy shoreface to nearshore settings on hard-ground substrates adjacent to a rocky greywacke coastline.

Crassostrea-Phialopecten sub-association (cs-pp)

In the study area the *Crassostrea-Phialopecten* association (Fig. 8E) is restricted to limestone facies of the Te Waka Formation in the Patoka and Puketitiri area, though is common in Te Aute limestone lithofacies in the eastern hill country of Hawke's Bay. The association is characterised by the abundance of the large oyster *Crassostrea ingens* and the scallop *Phialopecten thomsoni*, both of which are now extinct. *Patro undatus,* also extinct, is a very common component of the association. The association is dominated by barnacle plates and fragments.

Interpretation

The *Crassostrea-Phialopecten* sub-association accumulated at nearshore to inner shelf water depths on a gravelly mixed bioclastic-siliciclastic hardground substrate. The association probably represents the development of a carbonate factory.

Neothyris association (ne)

The *Neothyris* association is restricted to "early" and "middle" Pliocene limestone beds (Te Waka and Titiokura Formations) in the western margin of the study area. The *Neothyris* association is dominated by plates and fragments of barnacles, it is the abundance of intact *Neothyris* aff. *obtusa* that distinguished the association. The association commonly contains *Phialopecten marwicki or P. thomsoni* and almost always some *Ostrea chilensis*.

Hendy and Kamp (2004) recognised a *Neothyris* association in the Matemateaonga Formation in Wanganui and Taranaki Basins. While the *Neothyris* association in this study is inferred to have accumulated in a different depositional setting to that described by Hendy and Kamp (2004).

Interpretation

Accumulation of this association is inferred to have occurred on a firm shell-gravel to sandy substrate at lower-inner to middle shelf water depths. Abundant epifauna such as brachiopods, barnacles, oysters and pectinids are consistent with a firm-ground environment. Strong tidal currents kept the sea floor relatively free of fine siliciclastic sediment.

Talochlamys association (ta)

The *Talochlamys* association (Fig. 8F) is widespread throughout the study area and occurs in a wide variety of generally fine-grained facies. The association is characterised by common *Talochlamys gemmulata* (average 31%) though faunal diversity is high. *Talochlamys gemmulata*, an extant fan-shelled scallop is widespread on the modern New Zealand shelf from the low-tide

zone to bathyal water depths on a wide variety of substrates. This modern distribution is reflected in the widespread occurrence of *Talochlamys* in the fossil record.

Lithofacies containing the *Talochlamys* association are typically siltstone to sandy siltstones, and as such the association is usually reflective of a middle to outer shelf (50-150 m) depositional environment. The association resembles the *Talochlamys* association of Haywick (1990). The lack of dominance of any one taxa reflects the high diversity observed in the faunal content of such middle to outer shelf environments.

Atrina pectinata zelandica is commonly observed in this association. In upper formations of the Mangaheia Group, particularly in the Tangoio Block, *Pelicaria acuminata* and *P. convexa* are common in the association and may dominate taxa at some localities.

Interpretation

Although modern *Talochlamys gemmulata* may occupy environments from the low-tide zone to upper bathyal water depths (Beu and Maxwell 1990), the *Talochlamys* association is inferred to have accumulated on silty firm-ground substrates at middle to outer shelf water depths, supported by other macrofauna in the association. It is possible that these firm-grounds may record periods of sediment starvation.

***Stiracolpus-Talochlamys* sub-association (sc-ta)**

The *Stiracolpus-Talochlamys* sub-association is characterised by the co-dominance of the turritelid gastropod *Stiracolpus* spp. and the pectinid bivalve *Talochlamys gemmulata.* Faunal diversity in the association is relatively high. *Nucula* and *Neilo* are common secondary taxa. This association resembles the *Stiracolpus-Talochlamys* association of Haywick (1990). Faunal lists of the siltstone formations comprising the *Talochlamys-Stiracolpus* association are contained in Beu (1965).

Interpretation

The *Stiracolpus-Talochlamys* association accumulated at middle to outer shelf water depths (50-150 m) on silty substrates.

***Tegulorhynchia-Talochlamys* sub-association (tg-ta)**

The *Tegulorhynchia-Talochlamys* association occurs in only a limited number of sites and is restricted to upper formations of the Petane Group. The association is characterised by the dominance of the brachiopod *Tegulorhynchia niagricans.*

Interpretation

This association accumulated on a firm-ground substrate at lower inner to middle shelf water depths. The environment of accumulation is inferred to be similar to that of the *Neothyris* association, though this association developed under a regime with a lesser tidal and storm-current influence, and on a finer-grained sea floor. Accumulation of the association may mark periods of sediment starvation and firm-ground development.

Atrina association (at)

The *Atrina* association contains a sparse macrofauna almost exclusively dominated by the common extant horse mussel *Atrina pectinata zelandica.* Facies containing the *Atrina* association are typically silty sandstones to sandy siltstones.

Atrina pectinata zelandica is widespread on the modern New Zealand shelf in a variety of harbour and inner to middle shelf environments. An *Atrina* association was identified by Kondo *et al.* (in prep) in the Nukumaruan Rangitikei River section in Wanganui Basin. The *Atrina* association is inferred to have accumulated in a sheltered sandy inner shelf environment, similar to that inferred by Kondo *et al.* (in prep).

Interpretation

The *Atrina* association accumulated at inner shelf to upper-middle shelf water depths on and in silty sand substrates with a reasonably high sediment input. Modern *Atrina* associations are common on the modern New Zealand shelf.

Neilo association (ni)

The *Neilo* association is uncommon in the study area. Facies containing the *Neilo* association are fine massive sandy siltstones to siltstones, often with a fine pebble content. The association is usually present at the bottom of HST siltstone facies and records the deepest part of a sea-level cycle. Other fauna common in the association include *Notocallista multistriata, Calliostoma* sp.*, Talochlamys gemmulata, Pleuromeris* sp. and Nuculanid.

A *Neilo* association was recognised by Kondo *et al.* (in prep) in the Nukumaruan Rangitikei River section in Wanganui Basin.

Interpretation

A middle to outer shelf environment of accumulation is inferred for the *Neilo* association.

Pratulum association (pr)

The *Pratulum* association is widespread in shelf facies in the study area of Upper Mangapanian to Upper Nukumaruan age, and most common in lower parts of HST siltstone beds. The association is conspicuously dominated by the extant cariid bivalve *Pratulum pulchellum*. Lithofacies containing the *Pratulum* association are typically siltstone. The *Pratulum* association may be either monospecific or contain a moderately diverse fauna. *Talochlamys gemmulata, Ostrea chilensis, Dosinia (Kereia) greyi, Zenatia acinaces, Antalis nana, Pelicaria* spp., and *Austrofusus* spp. are fauna typical of the *Pratulum* association. Other common fauna include *Penion sulcatus, Atrina pectinata zelandica, Notocallista* sp.*, Taniella* sp., and *Alcithoe* spp.

The *Pratulum* association passes laterally into the *Talochlamys* and *Tegulorhynchia-Talochlamys* associations. Both of these associations probably accumulated on a firmer substrate, although at similar water depths to the *Pratulum* association. Modern *Pratulum pulchellum* occupies a broad bathymetric range from 17-400 m (Luckens 1974) though the majority of these occurrences are less than 200 m (Hendy and Kamp 2004). Modern associations dominated by *P. pulchellum* occur in depths <150 m (Dell 1951a, b; Estcourt 1967; Grace and Hayward 1980; Hayward *et al.* 1984). *Pratulum pulchellum* occurs in gregarious clumps with numerous specimens occupying a small space.

Hendy and Kamp (2004) identified a *Pratulum* association in Late Miocene-Early Pliocene shelfal rocks in Wanganui and Taranaki Basins, although this association was characterised by the extinct *P. finlayi*. The *P. finlayi* association of Hendy and Kamp (2004) differs from that characterised in this study as it posses a less-diverse faunal content and often contains typical inner shelf faunas such as *Tawera*, *Ostrea*, *Crassostrea,* and *Gari.* The *P. pulchellum* association of this study lacks characteristic inner shelf faunas and is inferred to have accumulated in a more offshore setting than the *P. finlayi* association. This is similar to modern *P. pulchellum* associations. A *P. pulchellum* association was described by Kondo *et al.* (in prep) in the Nukumaruan Rangitikei River section in Wanganui Basin. Fauna in the association of Kondo *et al.* are similar to that observed in this study including *Talochlamys gemmulata, Zenatia acinaces, Dosinia (Kereia) greyi* and *Antalis nana.*

Interpretation

On the basis of stratal position, faunal content and relationship to other faunal associations the *Pratulum* association accumulated in lower-inner to outer shelf water depths on a sea floor characterised by soft incoherent silty sediments. The most common distribution of this association is inferred to be in beds that were deposited at middle to outer shelf water depths.

APPENDIX III

GEOLOGICAL MAP PRODUCTION UTILISING A GEOGRAPHIC INFORMATION SYSTEM

INTRODUCTION

A large component of this research project has involved the use of Geographic Information System (GIS) technology for the cataloguing, storage, manipulation and analysis of spatially referenced data collected during the course of the study. A large volume of spatially referenced data was collected during fieldwork, which was undertaken over a period of more than 50 weeks from December 2001 to October 2004. Over 1070 outcrops were described during this time resulting in the construction of 117 stratigraphic columns distributed through the study area, and contained in Appendix IV. Geological units were established and mapped at a field scale of 1:25,000 where possible. The status of pre-existing geological units was evaluated during this period, resulting in a revised lithostratigraphy for the study area (Chapter Three; Appendix I). Macrofossil samples were collected where possible, in addition to the 300+ locations where macrofossil observations were made in the field (Appendix V). Data compiled in this study are in addition to geological mapping and section description undertaken by the author during 1999/ 2000 as part of an MSc project in the Esk River catchment around Te Pohue. The result of this is that a significant volume of geological data has been collected and compiled. The management and manipulation of spatially referenced data such as that compiled in this study is best achieved through the utilisation of a GIS. The software used to create and manage the GIS has been ESRI ArcGIS™ Desktop 9.x suite.

A major product of this thesis is a new geological map of central Hawke's Bay, which is presented as a series of six map sheets (Enclosure 1, Sheets 1-6). Data presented on the map are stored in geological and topographic computer-based spatial databases. While presented as six separate map sheets in the thesis, the GIS database contains a seamless coverage of the study area and geological maps can easily be produced of any geographical area contained within the database.

The purpose of this chapter is to outline the basis of GIS systems, to describe the methodology used to produce the geological database, and to describe the structure of this database (e.g. Fig. 1). The chapter concludes by describing the methods employed in producing the final hard copy maps contained in this thesis, and problems encountered during this process. The use of GIS

analysis in geological investigations is becoming common, and a discussion on the implementation of GIS in geological mapping at The University of Waikato was presented by Vonk *et al.* (2003). Other recent studies utilising GIS in published literature include landslide analysis (e.g. Van De Eeckhaut *et al*. 2005), fault analysis (e.g. Ganas *et al.* 2005) and bedrock recognition (e.g. Belt and Paxton 2005). GIS has also been a vital tool for the production of the 1:250 000 scale QMAP sheets published by GNS Science to date (e.g. Rattenbury and Heron 1997) (Fig. 3). While the use of GIS technology is becoming more common in geological investigations it is felt that a detailed description of methods used in this study is valuable and warranted. Few studies of this nature in New Zealand have utilised GIS in the manner employed here. Although similarities exist with the GNS Science QMAP programme, this study is working at a finer-scale. It is hoped that this appendix will assist further studies that intend to use GIS technology for geological investigations.

OVERVIEW OF A GEOGRAPHIC INFORMATION SYSTEM

In its most fundamental sense, a Geographic Information System (GIS) is a computer-based system that displays, stores, integrates and manipulates spatially referenced data. The system does this by using a set of computer-based procedures and tools.

A glossary of key terms relevant to this chapter is presented below. Definitions are from the series of ArcGIS™ helpbooks, and the online ESRI GIS Dictionary. Many of the terms defined below are used in the chapter, and are commonly encountered when working with GIS systems.

GLOSSARY OF KEY TERMS

Annotation: Text and graphics associated with a feature or an area on a map. Annotation in this study is stored in a geodatabase as an annotation feature class.

ArcCatalog™: A software application that is used to manage and store geographic data.

ArcGIS™: A package of GIS software that includes several applications including ArcMap™, ArcCatalog™, and ArcToolbox™.

ArcMap™: A software application used to create, display and query maps. The map sheets included in this thesis were created in ArcMap™.

ArcToolbox™: A software application that provides an environment for processing geoprocessing operations. Although originally a stand-alone component of ArcGIS™, ArcToolbox™ is now incorporated within ArcMap™, and ArcCatalog™.

Attribute: A characteristic of a map feature. Attributes of a geological unit might include its name, age, rock type or depositional environment, which is stored in a field within an attribute table.

Coverage: A file-based vector data storage format for storing the location, shape, and attributes of geographic features. A coverage usually represents a single theme such as soils, streams, or land-use. It is one of the primary vector data storage formats for ArcInfo. Associated feature attribute tables describe and store attributes of the geographic feature. Coverages are stored in an ArcInfo™ workspace. The coverage data model wasn't typically used in this study.

Digital Elevation Model (DEM): The representation of continuous elevation values over a topographic surface by a regular array of z-values, referenced to a common datum. DEMs are typically used to represent terrain relief.

Digitise: The process by which non-digital data is turned into digital data. For example, this may occur through tracing a scanned paper copy of a geological map on screen, or by entering X-Y-Z data into a digital database such as those created using Microsoft® Access™.

Domain: Also called *attribute domain*, it is a named constraint in the database. A domain can be assigned to a field of a feature class or object class to make an attribute rule. Types of domains include range and coded value domains.

Hillshade Relief Model: A raster dataset that represents the hypothetical illumination of a surface. It is created from a surface dataset such as a DEM.

Feature attribute table: Information formatted in rows and columns. Entries in a table are termed attributes.

Feature class: The conceptual representation of a geographic feature. When referring to geographic features, feature classes include point, line, area, and surface. In a geodatabase, feature classes are objects that are normally stored with related features in a feature dataset and have a field of type geometry. Annotation feature classes are also used.

Feature dataset: A collection of feature classes in a geodatabase that share the same spatial reference. Because the feature classes share the same spatial reference, they can participate in topological relationships with one another such as in a geometric network.

Field: A column in a table. Each field contains values for a single attribute.

GPS: Acronym for *Global Positioning System*. A system of geosynchronous, radio-emitting and receiving satellites used for determining positions on the earth. The orbiting satellites

transmit signals that allow a GPS receiver anywhere on earth to calculate its own location through triangulation. Developed and operated by the U.S. Department of Defense, the system is used in navigation, mapping, surveying, and other applications in which precise positioning is necessary.

Layer file: A file that represents similar geographic features-such as rivers, lakes, geological units or faults-of a particular area for display on a map. The layer file references geographic data stored in a data source (such as a geodatabase) and defines how to display it.

Personal geodatabase: The fundamental storage mechanism for spatially referenced data in this study. All geological data used in the production of the geological map is included in a personal geodatabase. It is a geographic database that is hosted inside a relational database management system (RDBMS) that provides services for managing geographic data. These services include validation rules, relationships and topological associations.

Point: A geometric element defined by a pair of x,y coordinates. Examples of point features include dips and strikes and waypoint locations.

Polygon: On a map, a polygon is a closed shape defined by a connected sequence of x,y coordinate pairs, where the first and last coordinate pair are the same, and all other pairs are unique. In ArcGIS™ software, a polygon is a shape defined by one or more rings, where a ring is a path that starts and ends at the same point. If a polygon has more than one ring, the rings may be separate from one another, or they may nest inside one another, but they may not overlap. Examples of polygon features include geological units and landslide extents.

Polyline: In ArcGIS™ software, a shape defined by one or more paths, in which a path is a series of connected s. If a polyline has more than one path (a multipart polyline) the paths may either branch or be discontinuous. Examples of polyline features include fault traces, lineaments, geological boundaries and geological horizons.

Schema: The structure or design of a database. The schema of the database developed in this study is based of that of the QMAP GIS, with additions made where required.

Shapefile: A vector data storage format for storing the location, shape and attributes of geographic features. A shapefile comprises a set of related files, is stored in a folder, and contains one feature class.

Surface: A set of continuous data such as elevation or air temperature over an area or the boundary between two distinct materials or processes. DEMs are examples of a surface.

Raster data: Rasters represent any data source that uses a grid structure to store information, and comprise grids and images. Grids are geographic representations of an area that comprise an array of equally sized square cells arranged in rows and columns. Each grid cell is reference by its geographic X-Y location. A DEM is an example of a grid. Images represent geographic features by dividing an area into discrete squares called cells. Examples of images include satellite and aerial photographs, and scanned documents.

Rectify: The process of applying a mathematical transformation to an image so that the result is a planimetric image (a georeferenced image).

Vector data: A coordinate-based data model that represents geographic features as points, lines, and polygons. Each point feature is represented as a single coordinate pair, while line and polygon features are represented as ordered lists of vertices. Attributes are associated with each vector feature, as opposed to a raster data model, which associates attributes with grid cells. Vector data is also any quantity that has both magnitude and direction.

Waypoint: A geographic location constrained by X-Y (Eastings-Northings) values. A waypoint may also record an associated Z (Elevation) value. Waypoints were recorded with a GPS receiver.

METHODOLOGY OF DATABASE PRODUCTION

Geological mapping has been a fundamental part of this project. The production of the geological map series in this thesis has involved four main steps: **database construction**; **data compilation**, which consisted of fieldwork and the use of existing information; **data entry**, which involved the loading of data into the GIS; and **geological map production**, the final stage of which resulted in the creation and printing of hard-copy geological maps (Enclosure One).

DATABASE CONSTRUCTION

Geological data collected during this study, either from existing work or new to this study, has been stored in a personal geodatabase created as part of this project. The first section of producing the geological map series involved the construction of a GIS database named “Master Geological Database” (Fig. 1). This section describes the structure of this database and the features that it contains.

Database structure

The structure (or "schema") of the GIS geological database (see Enclosure 7) at the core of this study was created using the data and attribute structure established by the GNS Science QMAP programme (Rattenbury and Heron 1997) by Adam Vonk (PhD student, Department of Earth and Ocean Sciences, The University of Waikato) and the author. The database is named the "Master Geological Database". This database contains a hierarchy of feature datasets with feature classes included within each dataset. While the QMAP GIS stores data using coverages, data in this study are stored using the Personal Geodatabase model created by ESRI® for ArcGIS™ 8, and was updated with every new software release. Final map production in this thesis was undertaken using ArcGIS™ 9.1.

Feature datasets

Data stored in the Master Geological Database are grouped into a series of feature datasets (Fig. 1). The feature dataset groups together data with similar themes, and all features within the feature dataset are assigned the same co-ordinate system. New Zealand Map Grid (NZMG) was used in this study. Within a feature dataset are feature classes. These store more specific features such as geological units, faults, roads, rivers and so on. Feature datasets and feature classes were created in ArcCatalog™. Feature classes were then added to a map environment in ArcMap™ and edited through the use of on-screen digitising.

The following sections describe the main feature datasets in the Master Geological Database, and the feature classes within these feature datasets.

Geological features

This feature dataset contains feature classes that are related to the stratigraphic units that comprise the study area. It comprises polygon and line feature types.

Geol_Units

Delineating geological map units is a fundamental part of the geological mapping process (Rattenbury and Heron 1997). The feature class **GEOL_UNITS** (Fig. 1) stores the distribution and attributes of geological units as polygons. Distinct stratigraphic units (e.g. Esk Mudstone, Sentry Box Formation) are assigned unique mapping unit codes (attribute field UNIT_CODE; e.g. ek (Esk Mudstone), sb (Sentry Box Formation)). Examples of derivative maps produced from attributes stored in the GEOL_UNITS feature class are shown in Fig. 4.

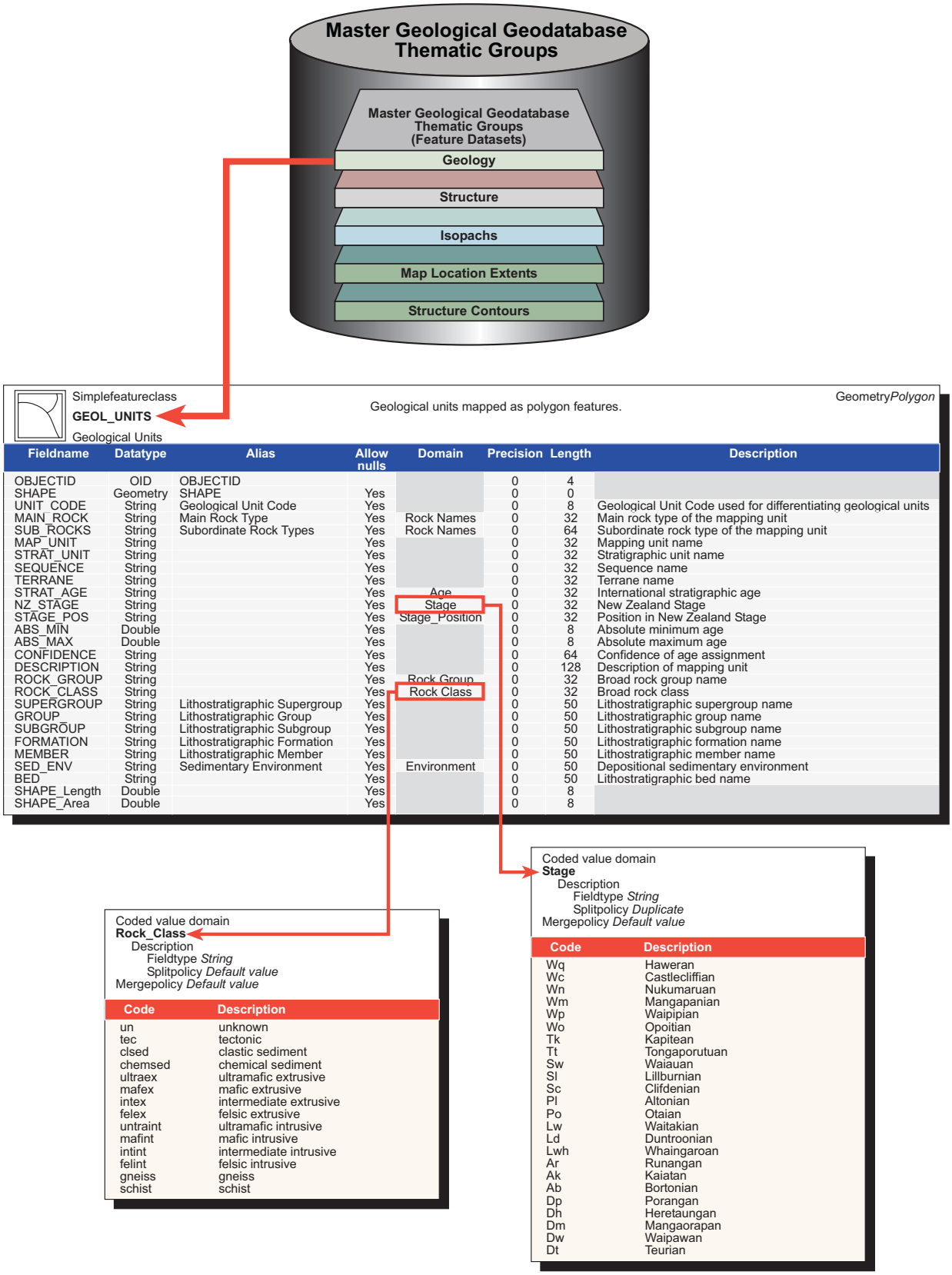


Fig. 1: Example of the relationship between the Master Geological Database, feature datasets, feature data classes and domains. The Geological Units dataset is used here as an example. The full structure of the Master Geological Database is displayed in Enclosure 7.

Important attributes in the GEOL_UNITS feature class include MAIN_ROCK and SUB_ROCKS. Values assigned to both the MAIN_ROCK and SUB_ROCKS attribute fields can only be selected from the list contained in the **Rock_names** domain in the Master Geological Database.

Following the approach of the QMAP GIS (Rattenbury and Heron 1997), geological units must be of a significant thickness (generally >10 m thick) to be mapped as a polygon feature. Geological units thinner than this, such as many limestone and conglomerate beds, are mapped and stored as geological horizons (GEOL_HORIZONS).

The QMAP GIS uses the ArcInfo coverage data model and topology to store and display geological data pertinent to their project. This enables the QMAP programme to store line (arc) and polygon information within a single coverage. For example the GEOL_UNITS coverage would have the geological unit defined by the arcs forming its outer boundary. User ID's are used to create a polygon attribute table (PAT). As this project has utilised the personal geodatabase concept, geological units and their associated boundaries are stored as two separate feature classes (GEOL_UNITS and GEOLOGICAL_BOUDARIES).

Horizons

The **Horizons** feature class stores the distribution and attributes of geological units as line feature types. Geological units stored in this feature class are those that are too thin in a stratigraphic sense to be displayed as polygons, and typically comprise limestone and conglomerate beds less than 10 m thick. Attributes assigned to this feature class are essentially the same as those assigned to the GEOL_UNITS feature class. An addition to this feature class is the ACCURACY and TYPE attribute fields and associated domains.

Boundaries

The **Boundaries** feature class stores the distribution and attributes of features that represent the contacts between geological units stored in the GEOL_UNITS feature class. It displays the accuracy of the mapped geological unit and its position with regard to neighbouring units. The feature class also stores information regarding the nature of the boundary, such as whether it is conformable or unconformable (and the type of unconformity if relevant). Boundaries shown on the geological maps are symbolised on the basis of their entries in the ACCURACY and TYPE attribute fields. These entries can only be chosen from restricted lists contained in the **Accuracy** and **Boundary_type** domains in the Master Geological Database. The entry chosen was determined from observations made during fieldwork.

Mass_Movement_Extent

The deposits of large-scale (>100 m^2) mass movement events are mapped and stored in the **Mass_Movement_Extent** feature class. The portrayal of these features can be problematic (Rattenbury and Heron 1997). In many cases mass movement features act to completely conceal the underlying geology. In other cases, the mass movement deposit may on form a thin veneer over the underlying bedrock. Where the mass movement deposit completely conceals the underlying geology it is represented on the geological map as a geological unit, stored in the GEOL_UNITS feature class. Where the mass movement deposit forms a surficial veneer it is stored in the Mass_Movement_Extent feature class, and depicted on geological maps with a transparent fill, allowing the underlying *in situ* geological units to remain visible.

Sources

This feature class stores the geographical position and attributes of previous investigations in the study area. The geographical extent of the previous investigation is delineated by a polygon. The feature class is differentiated on the basis of entries in the **author** attribute field.

Structural Features

This feature dataset contains features related to the geological structure of the study area and consists of line and point features.

Faults

The locations and attributes of faults in the mapping area are stored within the **FAULTS** feature class, a polyline geometry. Faults are differentiated on the final geological maps by entries in their type, activity and accuracy attribute fields. Attributes in the accuracy attribute field are selected from the **Accuracy** domain.

Folds

The **FOLDS** feature class stores line features that delineate the axes of anticlines, synclines and monoclines. Folds are symbolised on the geological map by their type, activity and accuracy.

Lineaments

The **Lineaments** feature class stores the distribution and attributes of line features that represent traces and lineaments identified from remotely sensed data such as aerial photographs and DEMs. Features stored in this feature class are those for which a structural origin cannot be determined. The method of determining the location of a lineament is described in the **type**

attribute field, and describes whether the features trace has been derived from aerial photographs, satellite images, digital elevation models or other sources.

Dips_and_Strikes

The **Dips_and_Strikes** feature class, a subset of "Structure" in the QMAP data model, stores point data that describes the geological strike, dip, azimuth and dip direction of beds cropping out at the surface. Most point data in this feature class represent measurements made on rocks in the field. Provision exists in the feature class for remotely-sensed data to be represented. Such data may include general dip-directions determined from aerial photographs or DEMs.

Structure_Contours

This feature dataset stores information relating to structure contours of geological units. It comprises a combination of line and point data. This dataset is used to infer geological boundaries in areas that have not been visited, or areas with little outcrop.

Domains

Domains are a series of lists included in the Master Geological Database that act to help ensure database integrity. Domains do this by ensuring that entries in to attribute fields are consistent and aim to remove the possibility of spelling mistakes and invalid entries. When a domain is assigned to an attribute field, values entered into that field can only be chosen from a restricted list contained within the associated domain. For example, the **MAIN_ROCK** attribute field (storing information on the main rock type of that feature) in the **GEOL_UNITS** feature class (storing the mapped extents of geological units) is assigned to the **rock_name** domain. Any rock type entered into the MAIN_ROCK attribute field can only be selected from a list of rock names contained in the rock_name domain. Values are assigned to an attribute class from a domain in ArcMap™ using "drop down windows" which display a list of available choices. The domains themselves are stored in the central geodatabase, independent of feature classes and feature datasets in the geodatabase.

A domain can be assigned to multiple feature classes. For example the **Accuracy** domain contains a list of attributes that describe a (typically linear) features mapped accuracy from choices such as "accurate", "inferred" or "approximate" among others. This domain can be assigned to "Accuracy" attribute fields in feature classes such as FAULTS, FOLDS, HORIZONS, LINEAMENTS and GEOL_BOUNDARIES. A domain can also be assigned to multiple attributes within a single feature class. For example the GEOL_UNITS feature class has the **rock_name** domain assigned to both the MAIN_ROCK and SUB_ROCKS attribute fields. This means that

entries for both of these attribute fields can only be selected from the list contained in the **rock_name** domain.

A list of domains contained in the Master Geological Database is shown in Enclosure Six. An example of the relationships between the Master Geological Database, a feature class, its attribute list structure, and a domain is illustrated in Fig. 1. The contents of domains were based on attribute lists presented in the procedures for the QMAP GIS (Rattenbury and Heron 1997). Where required, domain contents were emended to fit the unique requirements of this study. A small number of new domains not present in the QMAP GIS were created. For example, no provision is made in the QMAP GIS for assigning a New Zealand Stage to a geological unit. This attribute and domain has been added to the database structure.

DATA COMPILATION AND DATA ENTRY

The second and third stages of geological map production involved compiling and loading georeferenced data into the Master Geological Database. Data used consisted of two types; data already in digital format, and data on non-digital paper hard copies.

Topographic data

Topographic data formed the basemap upon which geological data, collected and compiled during this study, could be added. It was also used to produce fieldsheets for data capture in the field. Topographic data consisted of three main types. Firstly, was a shapefile vector dataset of the NZMS260 1:50 000 coverage of New Zealand (Fig. 2), from which data relevant to the study area was extracted. This dataset was created by Land Information New Zealand (LINZ), and supplied to the University of Waikato by Eagle Technology. The second topographic dataset involved scanned copies of the LINZ NZMS 260 series 1:50 000 scale topographic map sheets. The third dataset consisted of scanned LINZ NZMS 262 series 1:250 000 scale topographic map sheets.

Existing digital geological data

Where available, existing geological data was used to assist in the production of the Master Geological Database. Such data was derived from a variety of sources and comprised point, line and polygon datatypes.

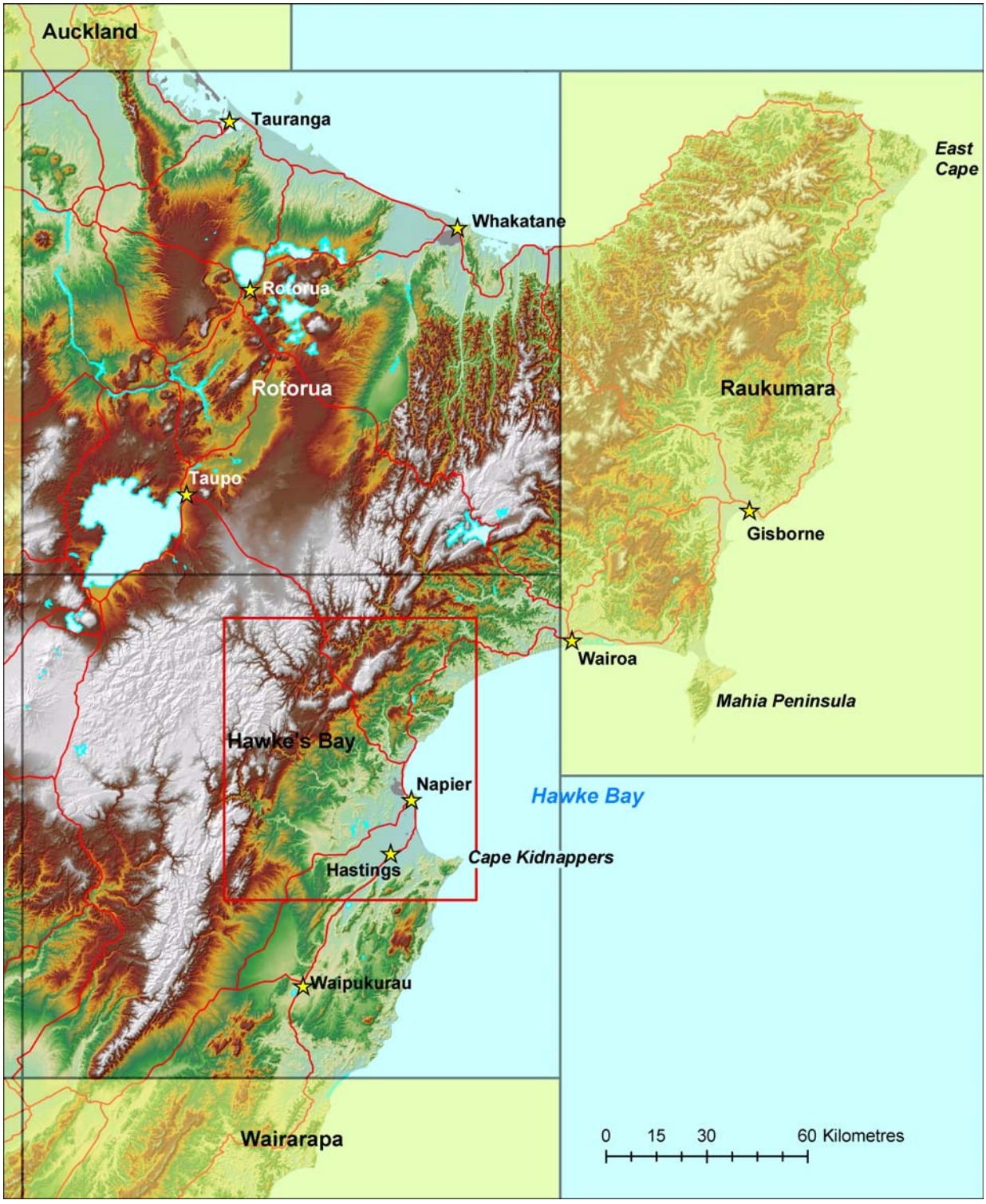


Fig. 2: Relationship between study area (extent of figure), the NZMS260 topographic map sheet coverage (black boxes), and the six map sheets in Enclosure One (white boxes). The light yellow polygon depicts the extent of geological mapping in this study. Names on this figure are the names of the NZMS260 topographic map sheets.

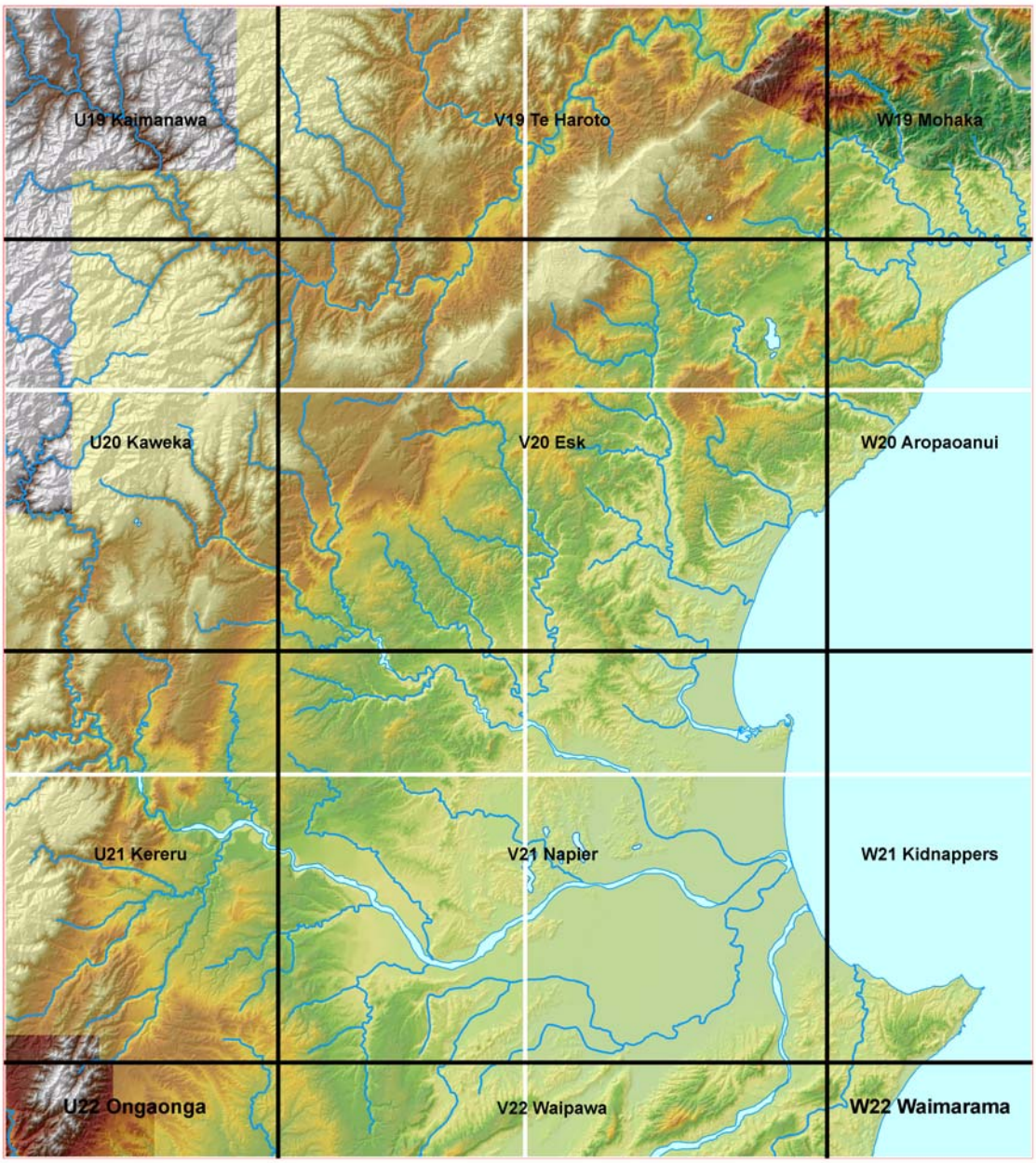
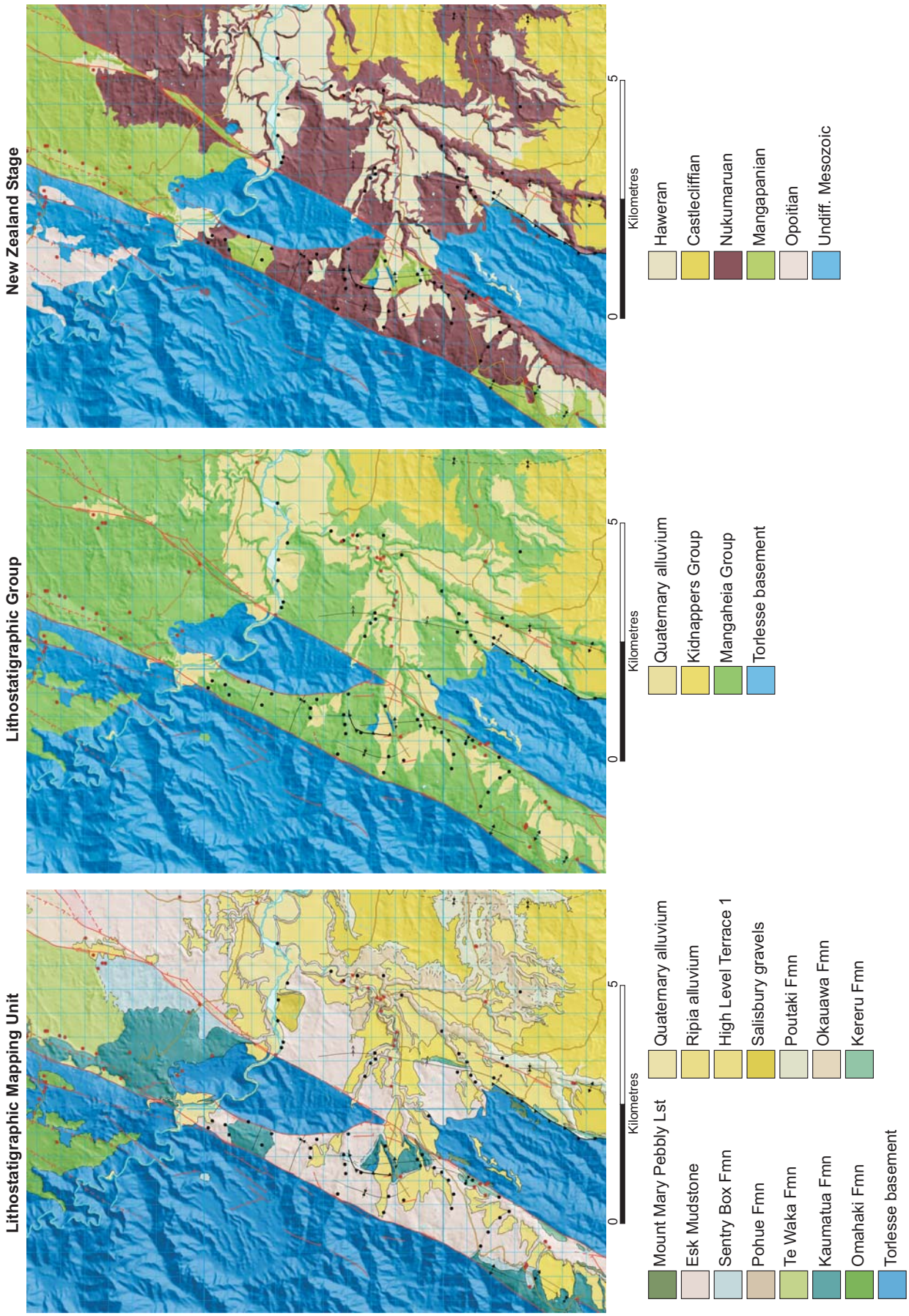


Fig. 3: Extent of 1:250 000 QMAP sheets of eastern North Island New Zealand, and their relationship to the current study area (red box). Boxes with a light yellow fill indicate completed QMAP sheets at the time of printing. QMAP sheets are shown by the larger font.


Lithostatigraphic Mapping Unit
Mount Mary Pebbly Lst
Esk Mudstone
Sentry Box Fmn
Pohue Fmn
Te Waka Fmn
Kaumatua Fmn
Omahaki Fmn
Torlesse basement
Quaternary alluvium
Ripia alluvium
High Level Terrace 1
Salisbury gravels
Poutaki Fmn
Okauawa Fmn
Kereru Fmn
0
5
Kilometres
Lithostatigraphic Group
Quaternary alluvium
Kidnappers Group
Mangaheia Group
Torlesse basement
0
5
Kilometres
New Zealand Stage
Haweran
Castlecliffian
Nukumaruan
Mangapanian
Opoitian
Undiff. Mesozoic
0
5
Kilometres

The extent of the study area and existing geological mapping is shown in Fig. 5. Of these maps five were in digital form, with three in formats suitable for GIS and two in unsuitable formats. This section documents the methods used to import digital geological maps into the Master Geological Database.

Geological maps in GIS formats

The geological maps of Baggs (2004) and Dyer (2005) (Fig. 5) were loaded directly into the Master Geological Database. These studies were undertaken in conjunction with this project, and databases developed for their work were based on that developed for this study.

Detailed mapping of mass movement deposits in the Esk River catchment was undertaken by Kerry Leith (University of Canterbury) as part of an investigation into the active deformation of this area (Leith 2003). The extent of these deposits was recorded in a shapefile which was imported into the Mass_Movement_Extent feature class in the Master Geological Database.

Freehand-based geological maps

Geological maps of the Esk and Waikoau-Waikare catchments were produced by Bland (2001) and Graafhuis (2001) respectively using Macromedia® Freehand 8™. While these maps were stored digitally, Freehand is a vector graphics software application and no spatial references are stored or associated with these maps. The Freehand maps were loaded into the Master Geological Database through a series of steps. Firstly, the eastings and northings in NZMG co-ordinates of corner points in the maps were noted. Next, the maps were imported into CorelDraw® 8™. From here they were exported as .dxf files. Dxf is an AutoCAD file format that can be spatially referenced and "read" by ArcGIS™. The next stage was to import the .dxf files into ArcMap™. At this stage the imported files were not in their correct spatial positions as they were not georeferenced. World files were created to enable the maps to be transformed to their appropriate locations. The world file is a text file that includes the objects imported X-Y location, and the correct eastings and northings. Once the maps were transformed to their locations they were loaded into the GEOL_UNITS feature class in the Master Geological Database.

Fig. 4 (facing page): A series of maps illustrating how several derivative maps can be produced from a single datasource within the GIS. All geological polygons within these maps are part of the GEOL_UNITS feature class, and the 3 outputs displayed here represent some of the many different attribute fields associated with it. From left to right the maps display lithostratigraphic mapping units (as depicted in Enclosure One), lithostratigraphic group, and New Zealand stage distribution. Such maps can be produced for any attribute associated with a feature class, coverage, or shapefile. This illustrates the power of the GIS in managing a wide variety of data.

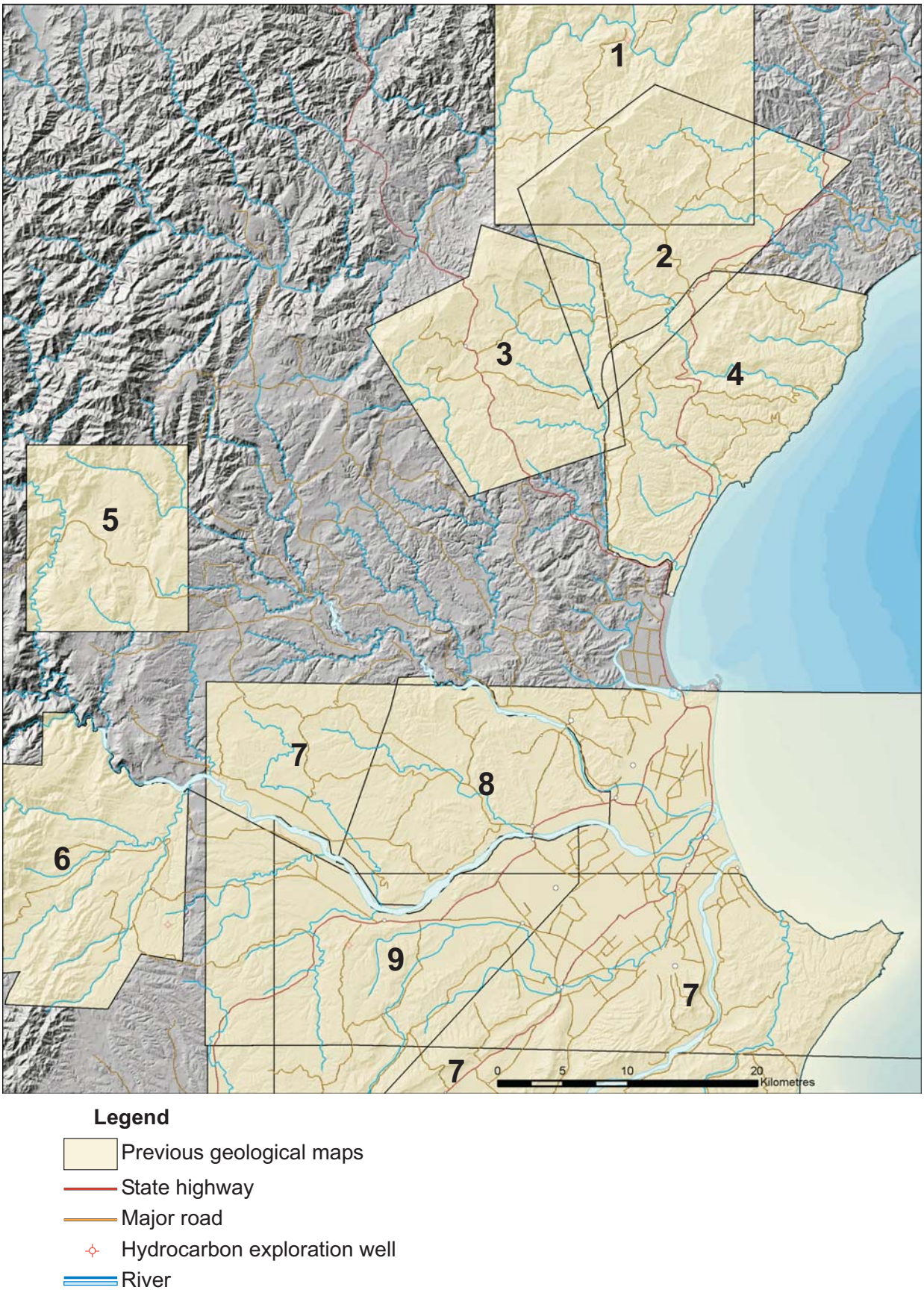


Fig. 5: Locations of previous geological mapping studies used in the compilation of the Master Geological Database. 1, Cutten (1994); 2, Graafhuis (2001); 3, Bland (2001); 4, Haywick (1990); 5, Browne (1981); 6, Erdman and Kelsey (1992); 7, Kingma (1970); 8, Baggs (2004); 9, Dyer (2005). Extent of the image is the extent of the study area.

IGNS 1:50 000 active faults database

Provision was made by the administrators of the GNS Science active faults database to allow access to their coverage of 1:50 000 scale active faults traces in Hawke's Bay for this study. Data was exported from their ArcInfo coverage-based system, and imported into the Master Geological Database. Data from the active faults database consists of traces that are well-defined, traces that are approximately located, and traces that are inferred. It was envisaged that fieldwork in this study may help to more precisely locate the positions of some of the fault traces contained in the database. More discussion on faults in the study area is contained in Chapter Five: Geological Structure.

Fossil record file

Data from the fossil record file (FRF), established by the Geological Society of New Zealand, and held and administered by GNS Science (Lower Hutt), was utilised in this study. The FRF is a database that aims to record the location of every site in New Zealand for which fossil data has been collected. The database is a useful tool for providing an initial assessment of the age of a rock unit, or its depositional environment. Data was obtained from the FRF in Microsoft® Excel™ format. It was cleaned and loaded into a Microsoft® Access™ database table which could then be loaded directly into ArcMap™. Once the dataset was added a shapefile was created in ArcMap™ of the FRF data. This shapefile was then added to the Master Geological Database.

New Zealand hydrocarbon exploration data

New Zealand well and seismic line location data coverages used in this study were downloaded as shapefiles from the Crown Minerals (Ministry of Economic Development) website (http:// www.crownminerals.govt.nz/petroleum/index.asp).

Existing non-digital geological data

Non-digital geological data used in this study was typically in the form of paper geological maps, although data tables, such as fossil collections and dip and strike lists, were also used. It was an important process to digitise as much of the useful data as possible. Paper maps were scanned using an A4 scanner. If the map sheet was larger than A4 it was scanned in sections, and then composited into one raster image using the Canon® PC programme Photostitch™. The scanned map was then georeferenced in ArcMap™ using the Georeference toolbar. Georeferencing involves assigning map co-ordinates to raster data. Georeferencing scanned images was achieved by layering scanned maps over the top of other data with a known geographic position such as digitial topographic data or aerial photographs. A minimum of four control points were assigned to the raster data that essentially shifts the scanned image to the required geographic

position. Once the image was aligned to its correct location it was rectified, a process that created a new raster dataset with the georeferenced position of the original scanned map. Once the rectified image was added to the drawing environment (ArcMap™), it was then a matter of digitising features from it into the Master Geological Database. Digitising was essentially achieved by tracing over the scanned map using various editing tools, and storing the data in the appropriate feature class. Maps loaded and digitised in this way include work by Kingma (1971), Browne (1981), Erdman and Kelsey (1992) and Kelsey *et al.* (1993) (Fig. 5).

Non-digital point datasets, such as lists of macrofossil locations, dip and strike locations, or rock outcrops were contained in tables in documents such as theses and petroleum reports. Data relevant to this table was entered into tables either in either Microsoft® Excel™ or Microsoft® Access™. Data entry in these cases was undertaken by simply typing relevant data into the appropriate table. Tables created in Microsoft® Excel™ were eventually loaded into Microsoft® Access™, or converted in DBF tables which ArcMap™ could "read". Coordinate fields were added to the tables so that they were able to be plotted in ArcMap™.

Aerial photographs

Two type of aerial photographs were used in this study, these being non-digital contact prints, and digital orthorectified aerial photographs.

Contact prints (non-digital)

Contact aerial photographs were accessed from the collection held at Hawke's Bay Regional Council. These photos are traditional oblique aerial photographs and were not georeferenced or rectified. Contact prints required were photocopied, scanned, and then georeferenced into position. These images were important for determining the positions of many fault traces along the western margin of the study area.

Orthorectified aerial photographs (digital)

Orthorectified aerial photographs (Fig. 6) are images which have been corrected for distortion, and are already in digital format. The scale of regular oblique aerial photos changes across the image, resulting in edge distortion effects. Orthorectified photos have been captured in such a way that the distortion across them is removed. Only part of the study area (around 40%) is covered by publicly available orthophotos in NZMG format, and those accessible were downloaded from Land Information New Zealand (LINZ) website (http://linz.govt.nz/core/topography/aerialandorthophotos/index.html). Four orthophotos from LINZ cover a single NZMS 260 topographic map sheet, and while they are not spatially referenced, they were easily

georeferenced into position, using the same methods employed for scanned geological maps. More recently LINZ has made available georeferenced orthorectified aerial photos in the new NZTM co-ordinate system. These have also been downloaded from the LINZ website and mostly fill in the gaps between the NZMG orthophoto coverage.

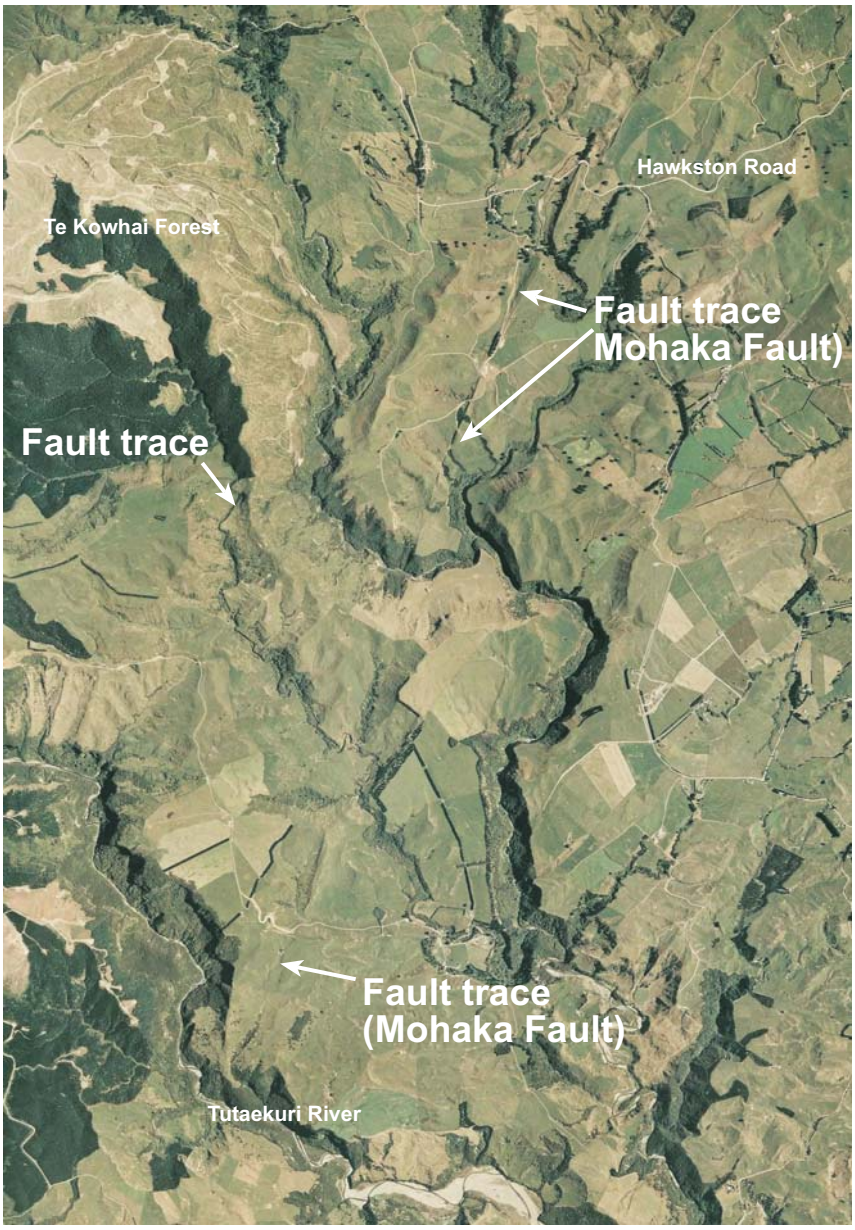


Fig. 6: Examples of fault traces mapped using orthorectified aerial photos downloaded from the LINZ website (http://linz.govt.nz/core/topography/aerialandorthophotos/index.html). The main trace evident in this image is of the Mohaka Fault in the Hawkston and Mangatutu Station areas. The aerial photo is part of NZTM BJ38b.

New geological data

A large amount of new geological data was collected during fieldwork. Such data includes the extent of geological units, rock and fossil samples, structural data and fault positions.

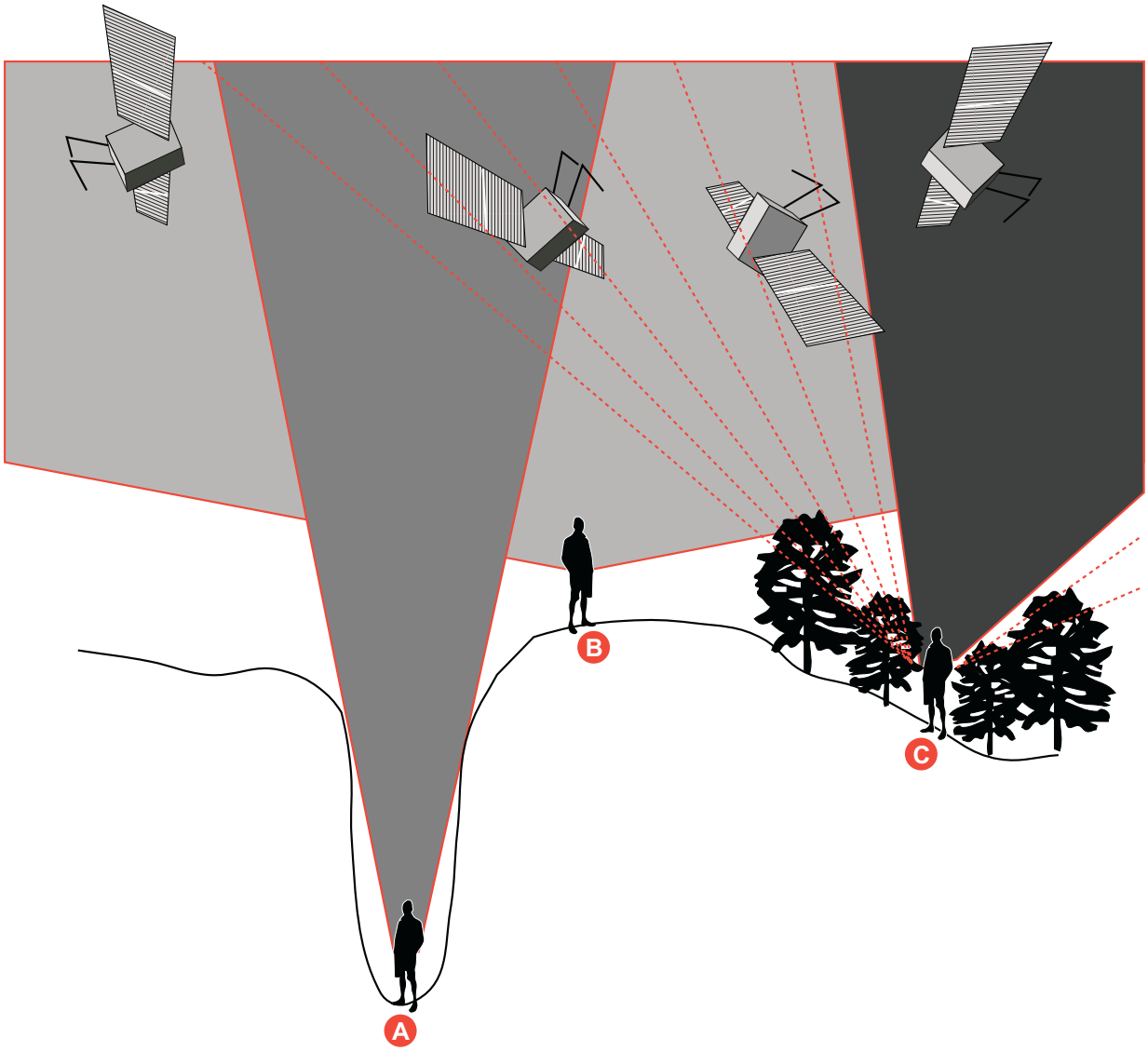


Fig. 7: Diagram illustrating the influence of topography and vegetation cover on the visibility of GPS satellites in the study area, and the ease of gaining a location fix with a GPS unit. Example "A" shows how the view of GPS satellites is limited by steep topography, such as that present in the Mangaone and Esk valleys. In these cases a fix can be difficult to obtain as few satellites are visible to the GPS unit. In example "B" many satellites are visible with a complete view of the sky. The most accurate readings are obtained in such a situation, within the smallest amount of time. The dashed red lines in example "C" illustrate how signal strength can be weakend by vegetation, such as in forested areas (e.g. Kaweka Forest).

Geological mapping

Geological mapping in the field was undertaken on field sheets derived from the NZMS 260 topographic maps sheets covering the study area. Field sheets were printed from the GIS at 1:25,000 scale. During a fieldtrip, geological data such as contacts, fault traces, outcrops and sample sites were marked on to the fieldsheets. Each evening data from the fieldsheets were transferred into the Master Geological Database by digitising on-screen in ArcMap™ (also known as "heads-up" digitising). Attributes were added to features during this process. Any data not

loaded during a fieldtrip was loaded into the database as soon as possible at returning from the study area.

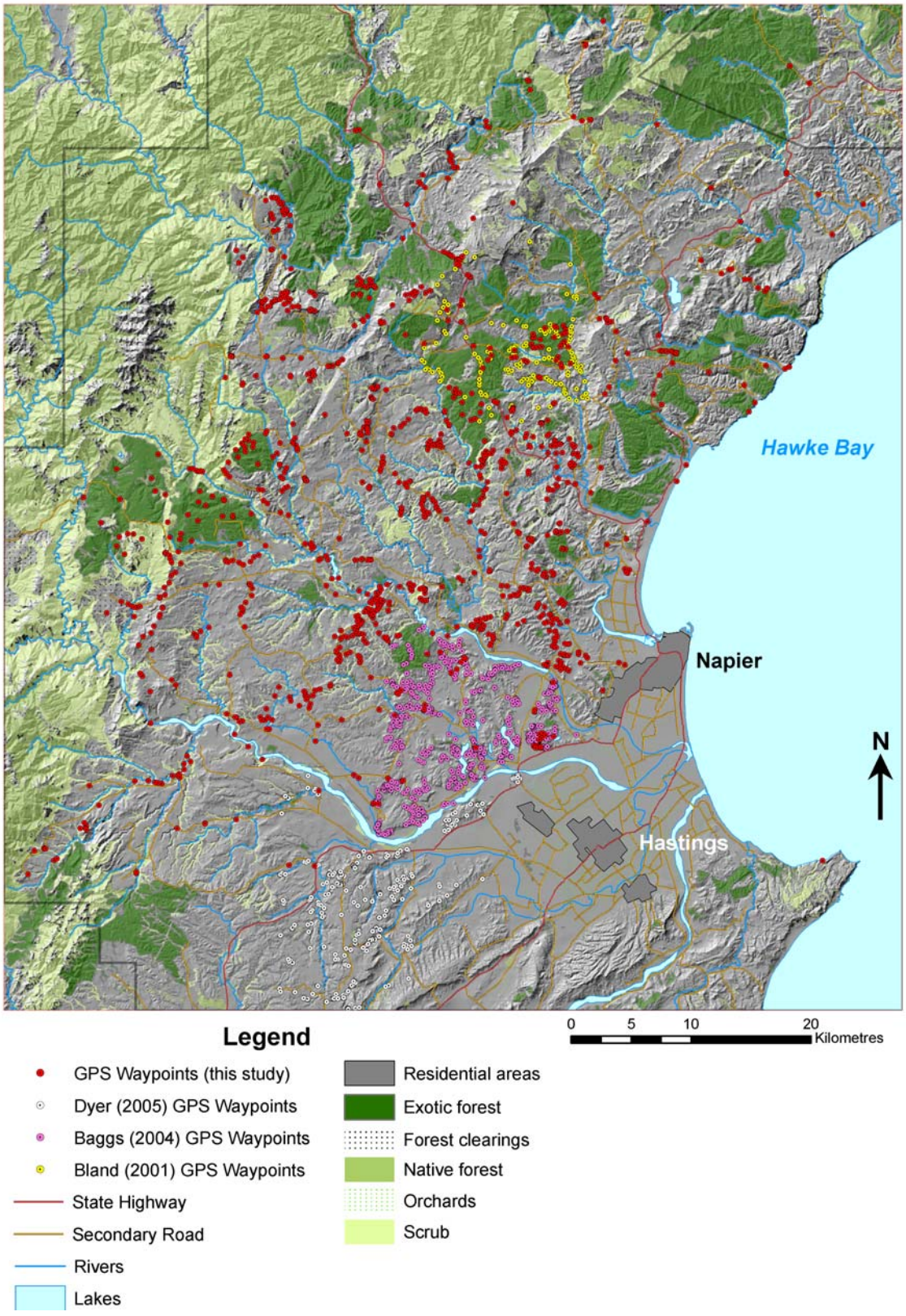


Fig. 8: Distribution of GPS waypoints and forest cover in the study area. The extent of geological mapping is indicated by the black polygon. Datapoints collected in several recent studies have been integrated into this current project.

GPS waypoints

Point data collected during fieldwork were positioned using a Garmin etrex handheld GPS unit. Points were spatially located with an error of 5-8 m in typical conditions with a good view of the sky (Fig. 7). Problems arose in obtaining an accurate position with the GPS unit when working in areas surrounded by forest or in narrow river and stream gorges. In these cases it may have taken up to 30 minutes for the GPS unit to obtain a position. Once a GPS co-ordinate was collected, its position was checked against the appropriate NZMS 260 topographic map sheet to ensure datapoints were as accurate as possible. GPS waypoints were collected in New Zealand Map Grid (NZMG) co-ordinates, and marked the locations of outcrops, geological contacts, sample sites, dips and strikes, fault traces, and other notable geological features (Fig. 8).

Digital Elevation Models

DEMs (Fig. 9) are three-dimensional representations of a surface produced in ArcInfo™ Workstation from coverage datasets. X, Y and Z co-ordinates are required inputs. X and Y co-ordinates represent New Zealand Map Grid eastings and northings, and Z values represent elevation. While DEMs were not stored in the Master Geological Database, they remain important tools for helping to understand the geomorphology of the study area and are valuable for determining the positions of dip-slopes, fault traces, folds and lineaments. Broad determinations of the underlying bed rock of an area can be made from the geomorphology shown on DEMs. DEMs were created from NZMS 260 contour and height point data, and an appropriate bounding box. The contour and height point datasets were clipped in ArcInfo™ to only include the areas needed for the DEM. As the original datasets are in shapefile format, they needed to be converted into coverages in order to create a DEM. This was achieved by using the SHAPE_ARC tool in ArcInfo™ Workstation. The bounding polygon of the DEM was also converted to a coverage. Production of the DEM was undertaken using the TOPOGRIDTOOL command in ArcInfo™ Workstation. Appropriate entries were made in the TOPOGRIDTOOL window to define line, point and bounding features, and the required cellsize of the DEM.

The DEM created for the entire study area was produced with a cellsize of 20 m, meaning that each pixel in the DEM represents an area of 20 m by 20 m. DEMs with finer resolution (smaller cellsizes) were created when needed. Once a DEM was created an appropriate colour ramp was selected to illustrate elevation.

DEMs were used to produce topographic profiles for use in cross-sections and long river profiles. Sources of error in using DEMs for these products are considerable. One of the main sources of error is that data to produce topographic DEMs was derived from 20 m contours and interpolated

to fit a rectilinear grid. This process produced a stepped surface at low gradients, because for widely spaced contours the region between contours is assigned elevation values only slightly below those of the upper bounding contour. Near the lower bounding contour, elevations sharply decrease (Leith 2003).

A very useful derivative of a DEM is a hillshade raster, an example of which underlies the geological maps produced in this study. Hillshades are essentially rasters that show patterns of light and dark that a surface would show when hypothetically illuminated from a particular angle. They are useful for increasing the perception of depth and relief in a 3D surface, such as a DEM. Hillshade models were produced using the ArcGIS™ 3D Analyst™ extension. To give the appearance of relief to a DEM, a hillshade raster is layered beneath the DEM in ArcMap™. A degree of transparency is then applied to the DEM (usually 30-40 % transparency) so that the hillshade raster beneath the DEM shows through, and gives the illusion of relief on the DEM.

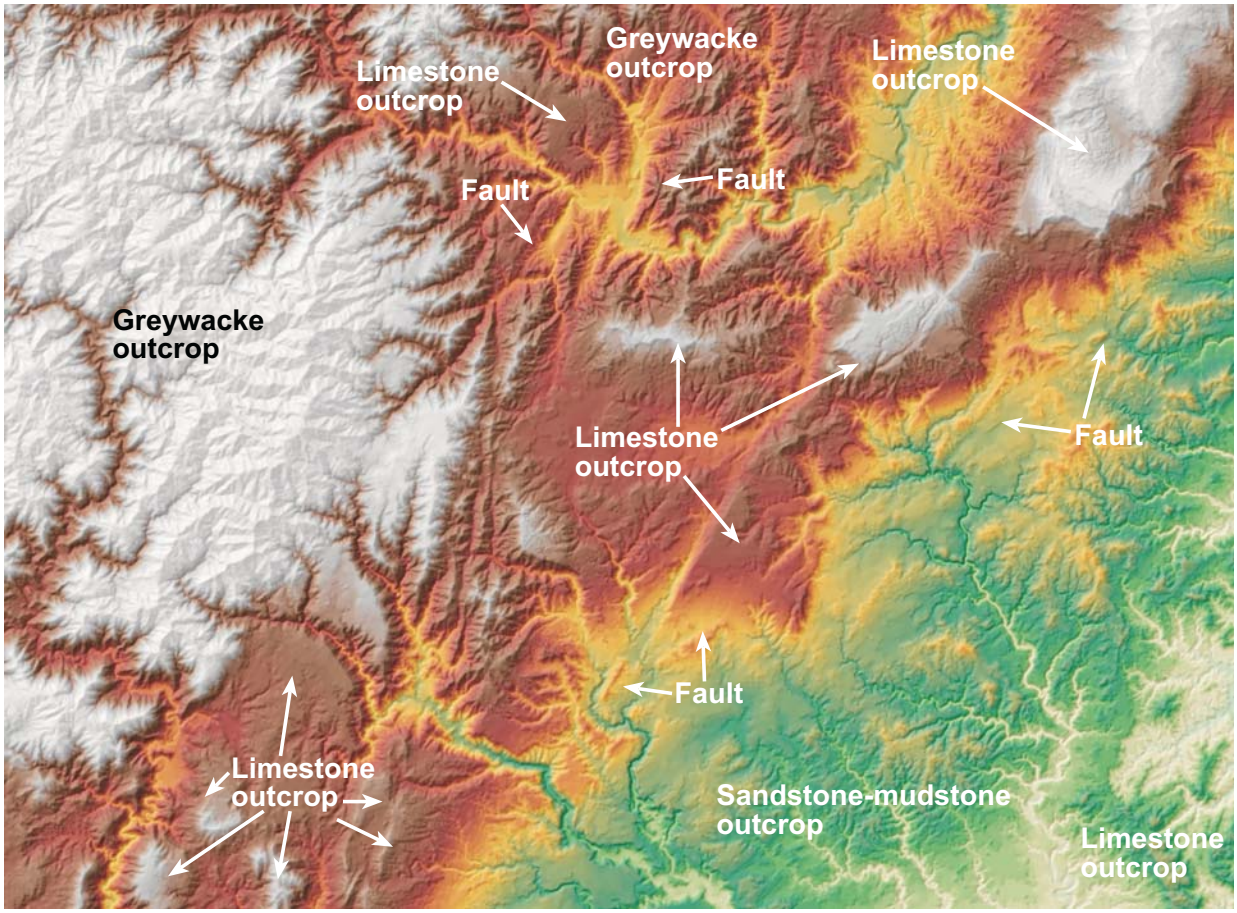


Fig. 9: Part of the DEM of the study area showing its use in displaying the geomorphology of the area. Features that are clearly identifiable, such as lineations, faults and ridges, which may be underlain by limestones, can be digitised into the Master Geological Database. The area of this DEM extends from Kuripapango in the south to Puketitiri in the northwest, and the Maungaharuru Range in the northeast.

DEMs have also been derived from structure contour data to produce "depth-to-surface" maps. Structure contour lines and elevation points on a surface replace the topographic contours and height points used to create a topographic DEM.

While DEMs have been very useful tools for identifying landslides, fault traces and lineaments (e.g. Fig. 9), they must be used with caution. Several recent studies highlight inconsistencies with using these models to identify landslides and other structural features (e.g. Van Den Eeckhaut *et al.* 2004).

Layer files

Features stored in the geological and topographical databases were differentiated on geological maps by variations in one, or a combination of, their attributes. For example, geological units were differentiated on the basis of their geological unit code, with a different colour assigned to each unit code. These are the colours that appear on the final geological maps sheets. In order to maintain the appearance of features presented on the maps a number of layer files were created. Layer files are stored in a folder separated from the Master Geological Database.

ACCESS DATABASES

Waypoint, fossil record file and dip and strike data were loaded into Microsoft® Access™ tables when collected. Access tables are in a database format that can be loaded directly into ArcMap™ via an open database connectivity (ODBC) connection in Microsoft® Windows™. Once fieldwork was completed, data in the access database were loaded into the Master Geological Database where it is stored as point feature classes.

TOPOGRAPHICAL DATA

In addition to the geological database, a database storing topographic data has also been created. Data covering the study area contained in the LINZ topo NZMS 260 dataset was extracted from the original dataset supplied to the University of Waikato by Eagle Technology, and loaded into a central database.

GEOLOGICAL MAP PRODUCTION

The final stages of the GIS component of this study were to produce the series of hard copy geological maps that are included in the back of the thesis. Careful attention was paid to cartographic principles to make the maps visually appealing while still maintaining the integrity of

the map. Elements of the design of the maps in this thesis were derived from published GNS Science QMAP sheets, and from LINZ NZMS 260 topographic map sheets.

Symbolisation of map layers

For reasons of consistency topographic data was stylised with symbology as close as could be achieved to that depicted on the NZMS 260 topographic map sheets. The QMAP font marker set was used to depict point and line datasets such as faults, folds and structural point features. Colours of geological units followed no defined pattern, with the exception of trying to maintain dark blue colours for basement rocks, yellow colours for Pleistocene to Recent beds, and pink colours for volcaniclastic deposits.

Graphic additions to the geological maps

Geological cross-sections, legends and associated text boxes presented on the final maps were created using Macromedia® Freehand™ 10, a graphics software package. Once created, these features were imported into the final map layouts.

Graphics added to the geological maps were prepared separately in Freehand™. When they were required to be placed on the final map sheet a Freehand™ window was open in ArcMap™ using the "File/import object/create new" option. Once the window was opened the required Freehand object was copied from its source and pasted into the newly opened window. It was important that File/Update/ArcMap was selected in the Freehand™ window, before returning to ArcMap™ and placing the graphic where required on the map layout. If the graphic required editing, it could be "double-clicked" on in ArcMap™, then a window in Freehand™ would open in which the graphic could be manipulated. It was important to once again update ArcMap™ to re-import any changes made.

It was found that the "File/Import Object/Import" option usually caused ArcMap™ to crash. While a valuable tool for managing geographic data, ArcMap™ is difficult to use for the creation of detailed graphics. It was for these reasons that Macromedia® Freehand™ 10 and Freehand MX™ were instead used for graphic production.

The positioning of NZMG labels at the corners of the geological map sheets was problematic. Individual elements within annotation in ArcMap™ cannot be selected and given different features. For example if it was decided that the third word of a sentence needed to be shown in bold font, it could not be selected and assigned a bold font as the entire sentence would become bolded, not just the required word. This problem became apparent when labelling corner gridlines of the

geological maps where various text sizes and boldness levels are required. As ArcMap™ uses VB code for labelling, the following code was used to produce the required label:

```
FNT name="Arial" size="7">61</FNT><FNT name="Arial" size="9"><BOL>81</
BOL></FNT><FNT name="Arial" size="7">000</FNT><FNT name="Arial"
size="9"><BOL>N</BOL></FNT
```

The code above will produce a label that appears as: 61**81**000N, with the entire label in Arial font.

Printing

Geological maps were printed using an AdobePS HP designjet 1055CM PS3 printer. Processing of the maps was undertaken using the "Windows printer engine" option in the ArcGIS™ printer dialogue box through Microsoft® Windows XP™. This meant that processing of the maps for printing was undertaken in the PC, rather than at the printer. This was found to be a way of minimising problems while printing. Using the Postscript and Arc printer engines within the ArcGIS™ environment usually resulted in unsatisfactory, or uncompleted print jobs.

Problems were encountered with sending print jobs through the local charge queue, a process that almost always resulted in objects being missing from the final map, or in printing errors on the maps sheets. Sending the print jobs to a print queue not connected to a charge queue, and processing the print job in the computer, were methods found to avoid most printing problems. PosterJet 7™ RIP software was also employed to assist printing the final map sheets, and further helped to reduce printing problems. This software also operated on a non-charged print queue.

STRATIGRAPHIC COLUMN LEGEND

LITHOLOGY

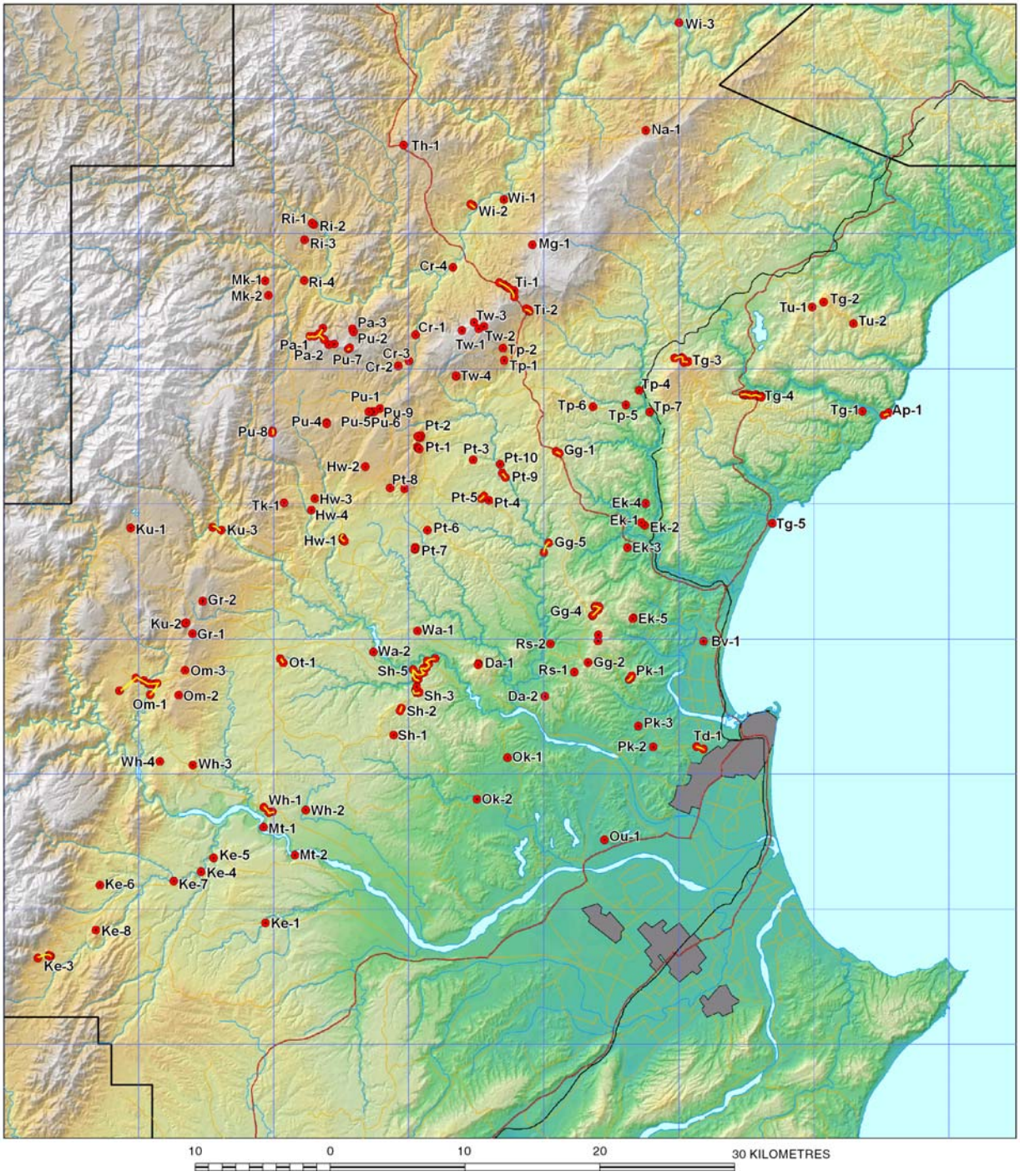
- Sandstone
- Limestone
- Sandy limestone
- Siltstone
- Silty sandstone
- Calcareous sandstone
- Pebbly limestone
- Volcaniclastic sediments
- Muddy limestone
- Greywacke conglomerate

OTHER INFORMATION

- Rip-up clasts
- Pebbles
- GPS Waypoint
- Sample
- Fossils
- Fossils in general
- Fossils in general
- Disarticulated concave down bivalves
- Photo label and location
- Cg_1 Lithofacies code

MACROFAUNAL ASSOCIATIONS

- *Atrina* association
- *Austrovenus* association
- *Crassostrea* association
- *Crassostrea-Phialopecten* sub-association
- *Crepidula-Sigapatella* association
- *Dosinia (Kereia)* association
- *Dosinia* association
- *Eumarcia* association
- *Fellaster* association
- *Maoricolpus* association
- *Maorimactra* association
- *Neilo* association
- *Neothyris* association
- *Ostrea* association
- *Ostrea*-glycymerid sub-association
- *Ostrea-Purpurocardia* sub-association
- *Paphies* association
- *Patro* association
- *Pratulum* association
- *Stiracolpus-Talochlamys* association
- *Struthiolaria (Callusaria)* association
- *Talochlmays* association
- *Tawera* association
- *Tawera-Crepidula* sub-association
- *Tawera-Patro* sub-association
- *Tawera-Sigapatella* sub-association
- *Tegulorhynchia-Talochlamys* sub-association
- *Tucetona* association
- *Zeacolpus* association
- *Zethalia* association



Stratigraphic column location map.

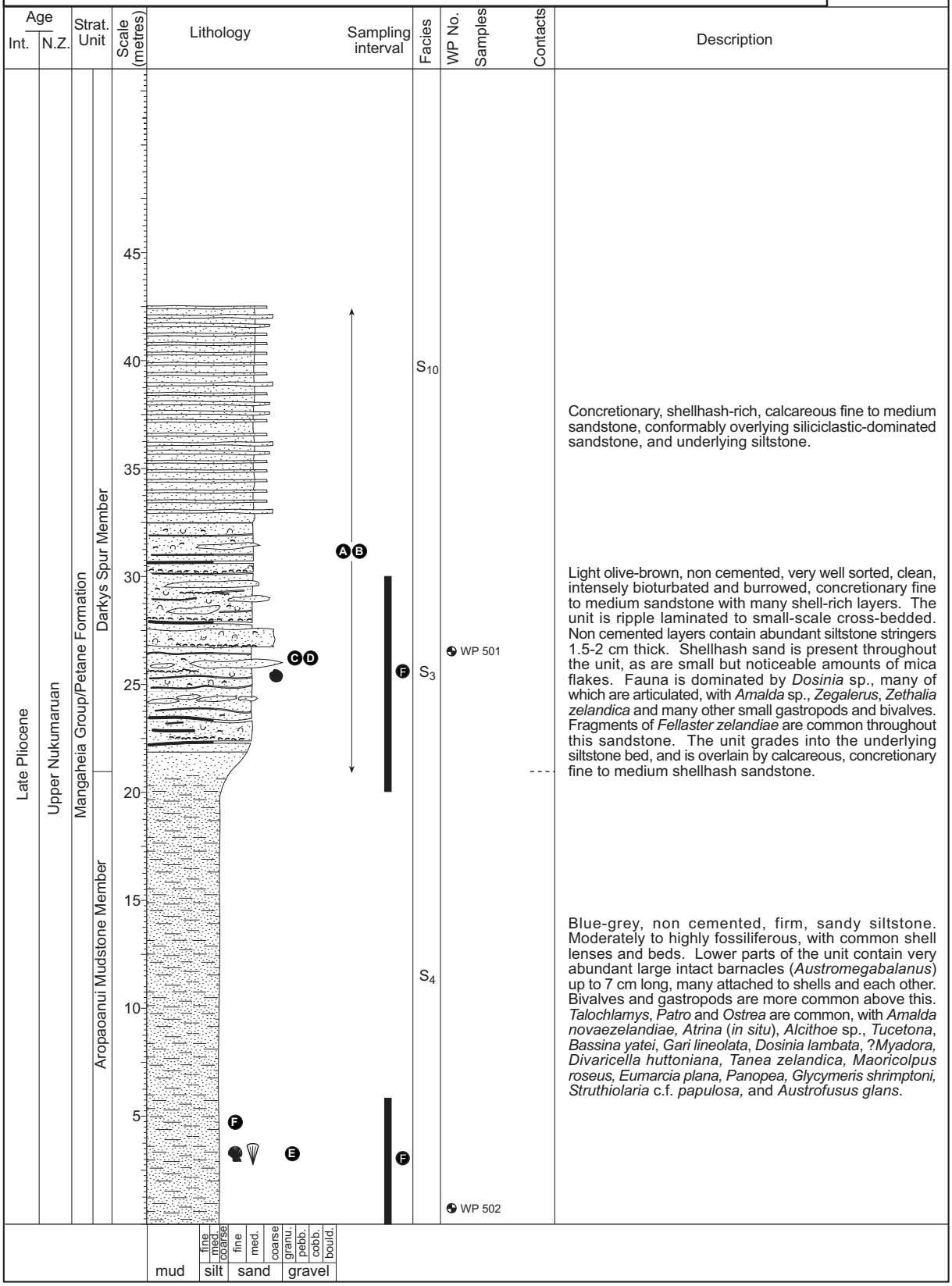
Stratigraphic Column No: *Ap-1* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 501-502 ***E:*** 2855217 2855556

Region: Aropaoanui ***N:*** 6206553 6206726

Location: Composite column at Aropaoanui Beach north of river mouth ***Altitude:*** 14 0

NZMS 260 Sheet: W20 Aropaoanui *Page* 1 *of* 1

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Stratigraphic Column No: *Bv-1* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 496 ***E:*** 2841846 -

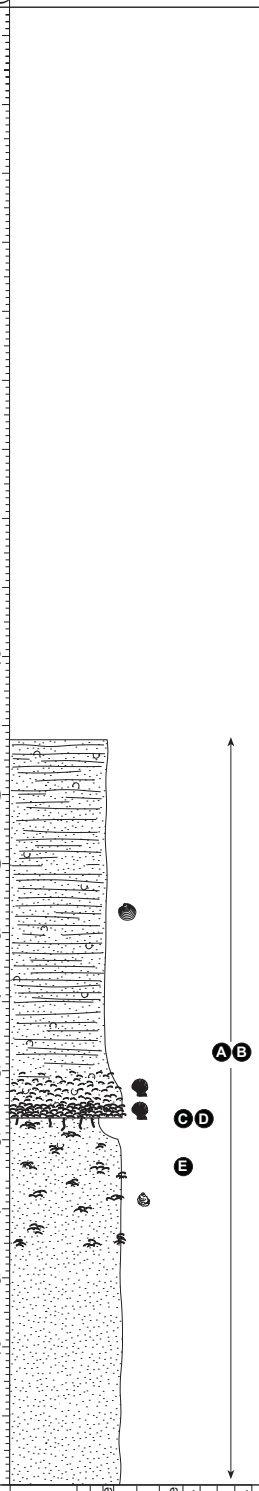
Region: Bayview ***N:*** 6189837 -

Location: Rorookiwa Hill off Onehunga Road Bayview ***Altitude:*** -4m -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1

Age: Int. / N.Z. | Strat. Unit | Scale (metres) | Lithology | Sampling interval | Facies | WP No. Samples | Contacts | Description

Pliocene / Nukumaruan / Mangaheia Group/Petane Formation / Mairau Mudstone Member



Highly fossiliferous shellbed. The lower 0.15 m contains packed beds of stacked *Talochlamys* of large size, with many large *Mesopeplum convexum* valves and scattered gastropods. A 0.25-0.30 m thick zone above this contains smaller although equally abundant *Talochlamys* with common *Ostrea*, some in situ *Atrina* and many gastropods. Barnacles are also common, many attached to bivalve shells. This bed is overlain by laminated sandy siltstone with scattered shells. This unit contains much less shellhash than the lower sandstone. The contact with the underlying shellbed is gradational.

Yellow-brown, non cemented non to slightly fossiliferous fine sandstone.Small clusters of shells are present, dominated by *Ostrea* and *Talochlamys* with some *Eumarcia* sp. and gastropods. Shell clusters are more common towards the top of the bed. This unit contains a prominent shellhash component and is intensely bioturbated and burrowed. Burrows underneath the overlying shellbed are commonly filled with shellhash.


A


B


C


D


E
Canon

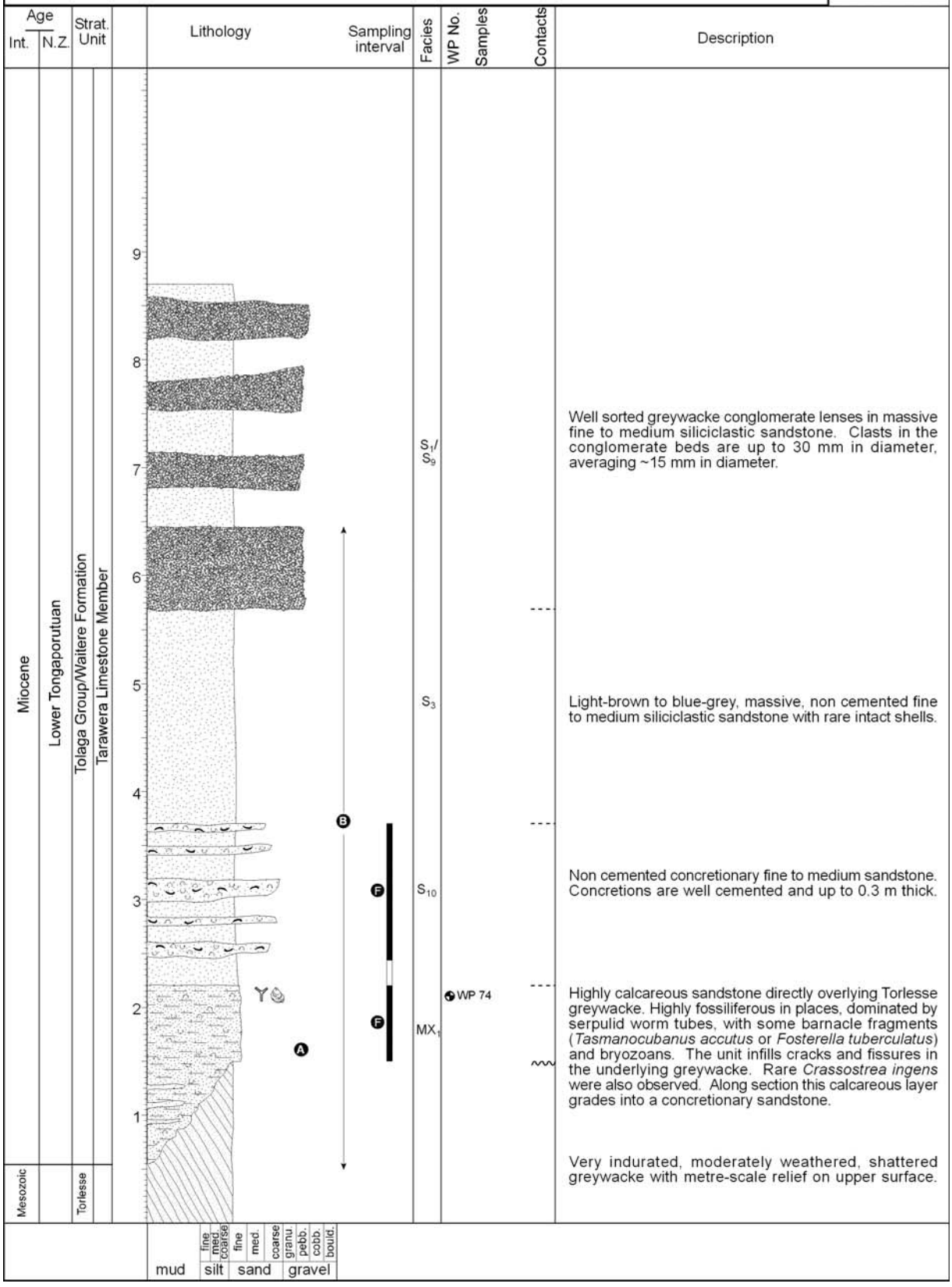
Stratigraphic Column No: Cr-1 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 74 ***E:*** 2820543

Region: Crohane ***N:*** 6212478

Location: Church Bush Road in Crohane Forest south of Inganatahi Stream. ***Altitude:*** 517m -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1





Angular unconformity between strongly fractured greywacke and bioclastic-dominated basal bed of the Te Ipuohape Sandstone Member. Metre-scale relief is present on this contact.



Overview of lower parts of the section logged. Conglomerate beds are well exposed in the middle-top of the photograph (arrowed).

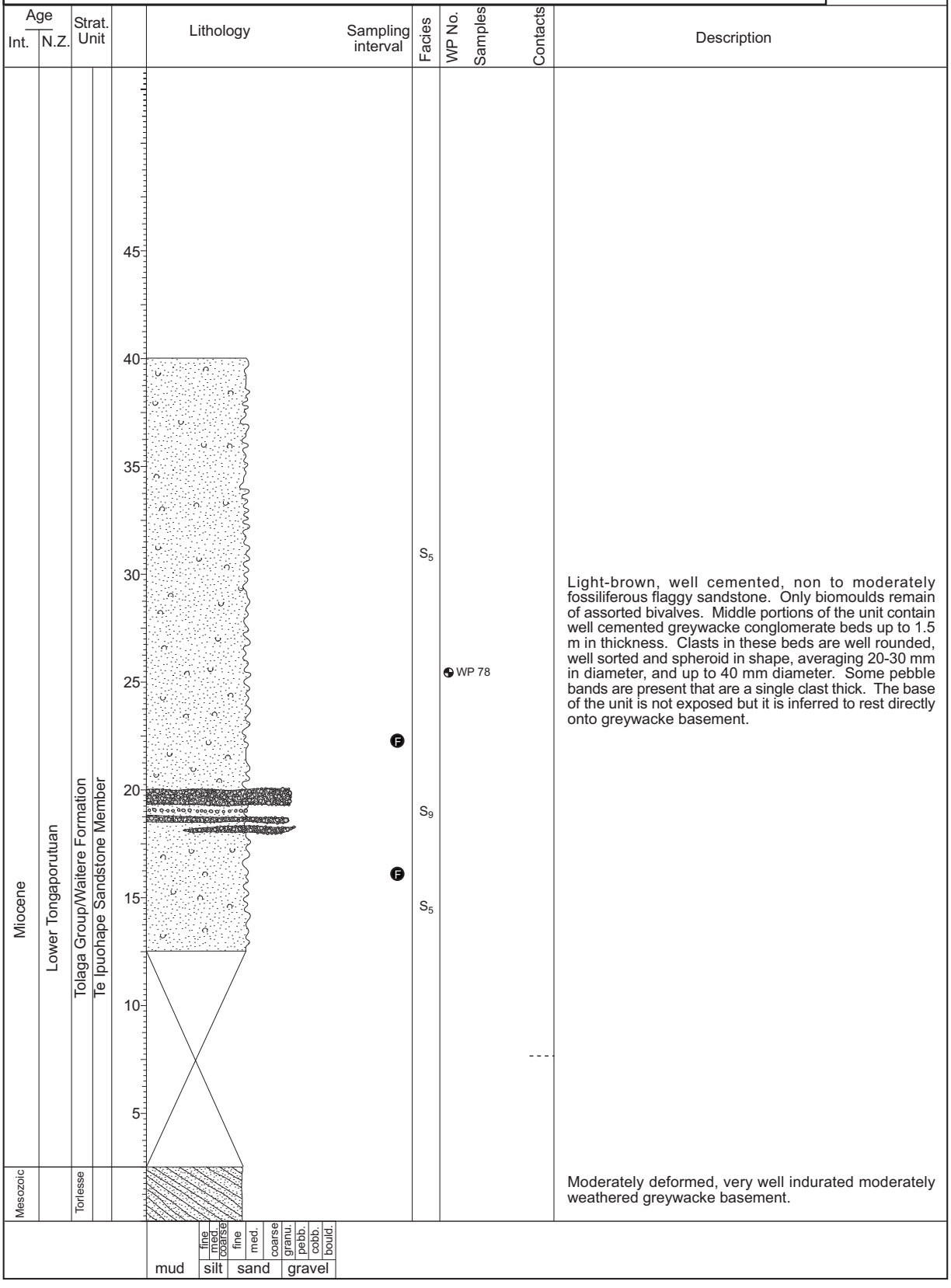
Stratigraphic Column No: *Cr-2* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 78 ***E:*** 2820039

Region: Crohane ***N:*** 6210545

Location: Cherry Block Station, up small stream from end of Potter Road. ***Altitude:*** 547m -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1



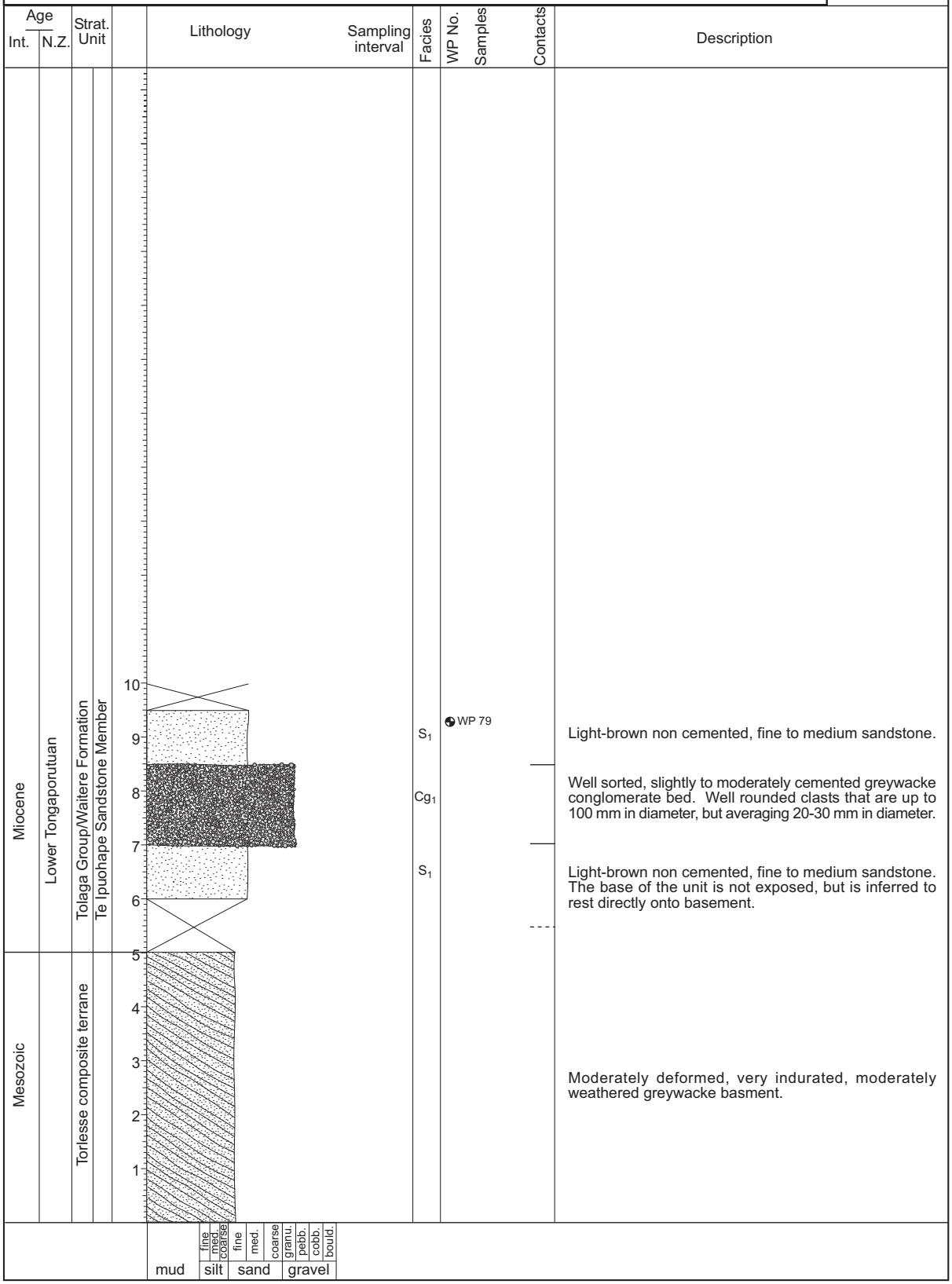
Stratigraphic Column No: Cr-3 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 79 ***E:*** 2819271

Region: Crohane ***N:*** 6210191

Location: Outcrop up small stream on Cherry Block Station at end of Potter Rd. ***Altitude:*** 525m -

NZMS 260 Sheet: V20 Esk



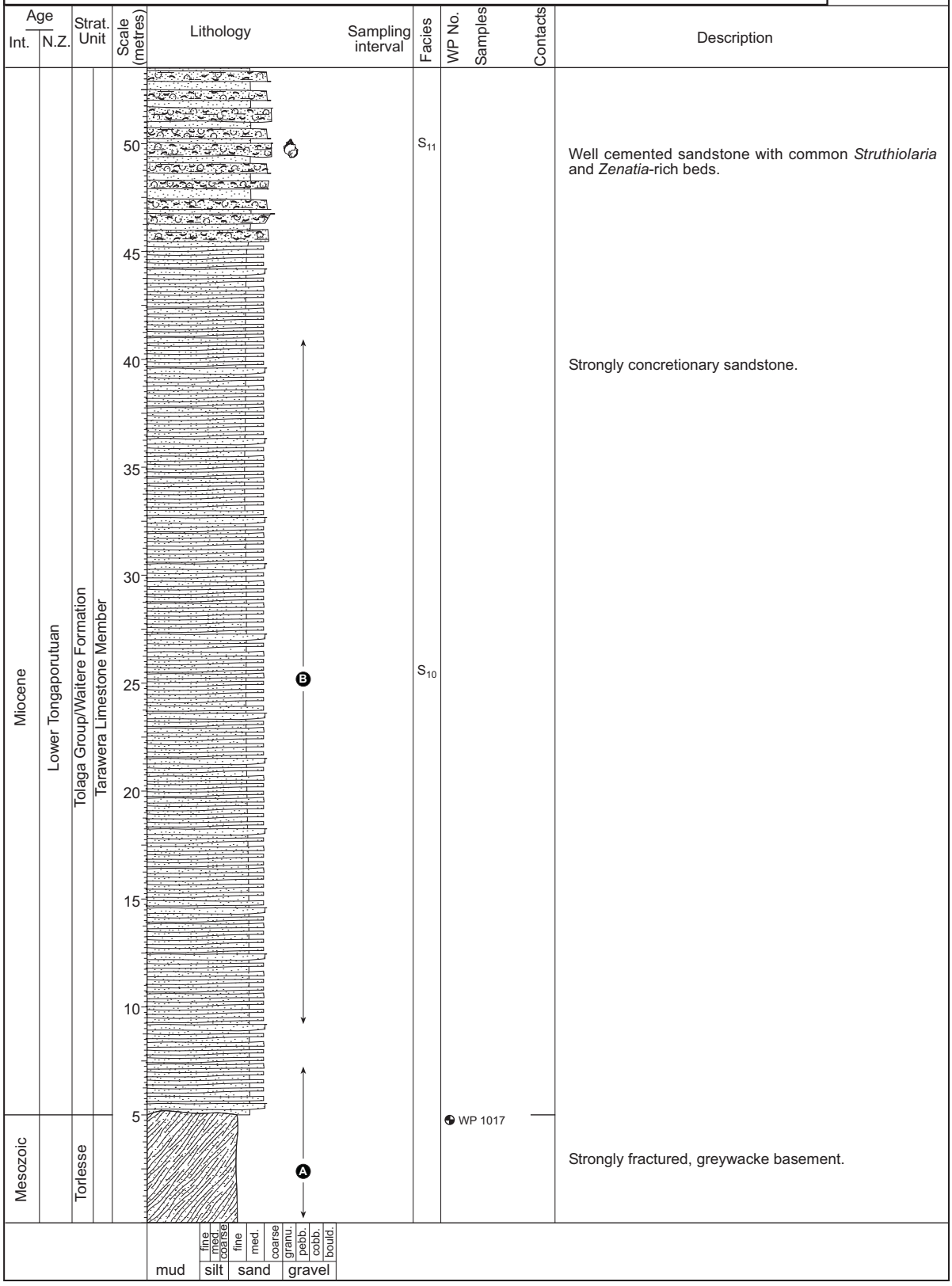
Stratigraphic Column No: *Cr-4* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 1017 ***E:*** 2823296 -

Region: Crohane ***N:*** 6217459 -

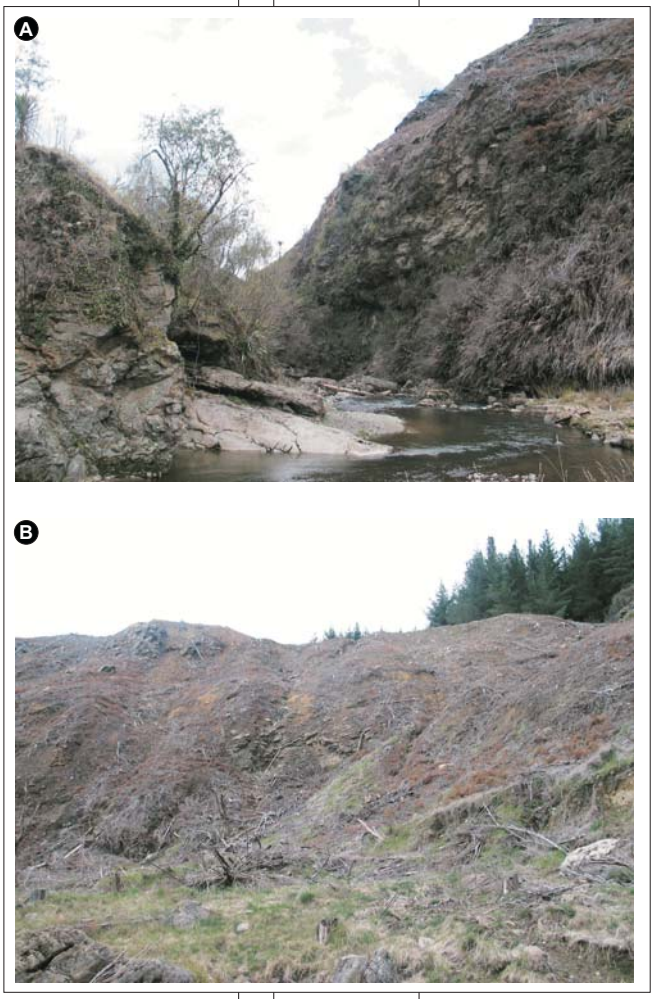
Location: Inganatahi Stream below Church Bush Road ***Altitude:*** 301 m -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 2



Stratigraphic Column No: *Cr-4*	***Grid Reference:***	***Top***	***Bottom***
GPS Waypoint No(s): Wp 1017	***E:***	2823296	-
Region: Crohane	***N:***	6217459	-
Location: Inganatahi Stream below Church Bush Road	***Altitude:***	301 m	-
NZMS 260 Sheet: V20 Esk	*Page 2 of 2*		

Age: Int. / N.Z. | Strat. Unit | Scale (metres) | Lithology | Sampling interval | Facies | WP No. Samples | Contacts | Description



Miocene — Lower Tongaporutuan — Tolaga Group/Waitere Formation — Tarawera Limestone Member

70
65
60
55
50

S_{11}

Well cemented sandstone with common *Struthiolaria* and *Zenatia*-rich beds.

mud | silt: fine, med., coarse | sand: fine, med., coarse | gravel: granu., pebb., cobb., bould.

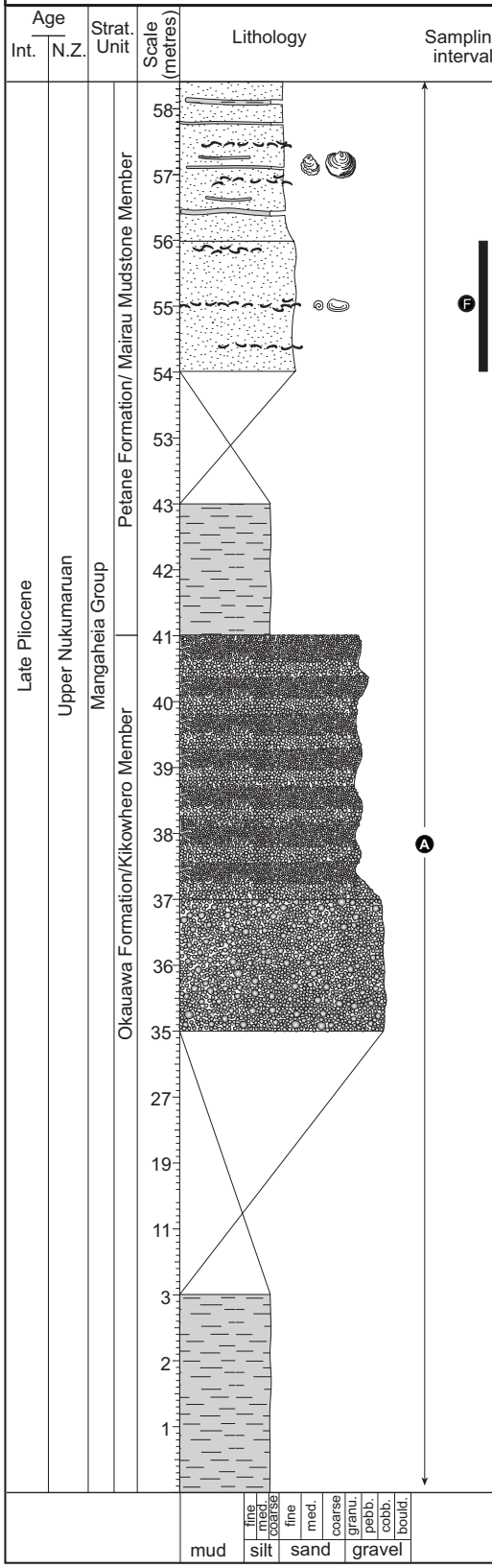
Stratigraphic Column No: Da-1 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 644-646 ***E:*** 2825187 2825159

Region: Dartmoor ***N:*** 6188178 6188088

Location: Section up farm track on Waihau Road face of Mount Cameron ***Altitude:*** 289 m 338 m

NZMS 260 Sheet: V21 Napier



Pale yellow-brown, non cemented, bioturbated fine sandstone. Common siltstone stringers are present. The unit contains relatively common scattered *Ostrea* and *Patro* valves, typically concave-down. Lenses <30 cm thick of biomoulds resembling *Tawera* are common, interbedded with *Ostrea* valves.

Orange-brown, non cemented fine sandstone with common shell-rich layers and scattered macrofossils. Common *Zethalia zelandica* (typically in discrete monospecific beds), and some *Paphies australis*. Many other unidentified bivalves occur in this unit.

Pale-grey slightly micaceous siltstone.

Fine to medium pebble-dominated greywacke conglomerate. The bed comprises of alternating granule - pebble beds 5-30 cm thick. Oblate shaped grains dominate.

Moderate to poorly sorted, greywacke conglomerate. The unit contains fine pebble to cobble-sized clasts, dominated by spheroidal to oblate-shaped clasts.

Blue-grey to brownish-grey, massive, fine-grained slightly micaceous siltstone to sandy siltstone.

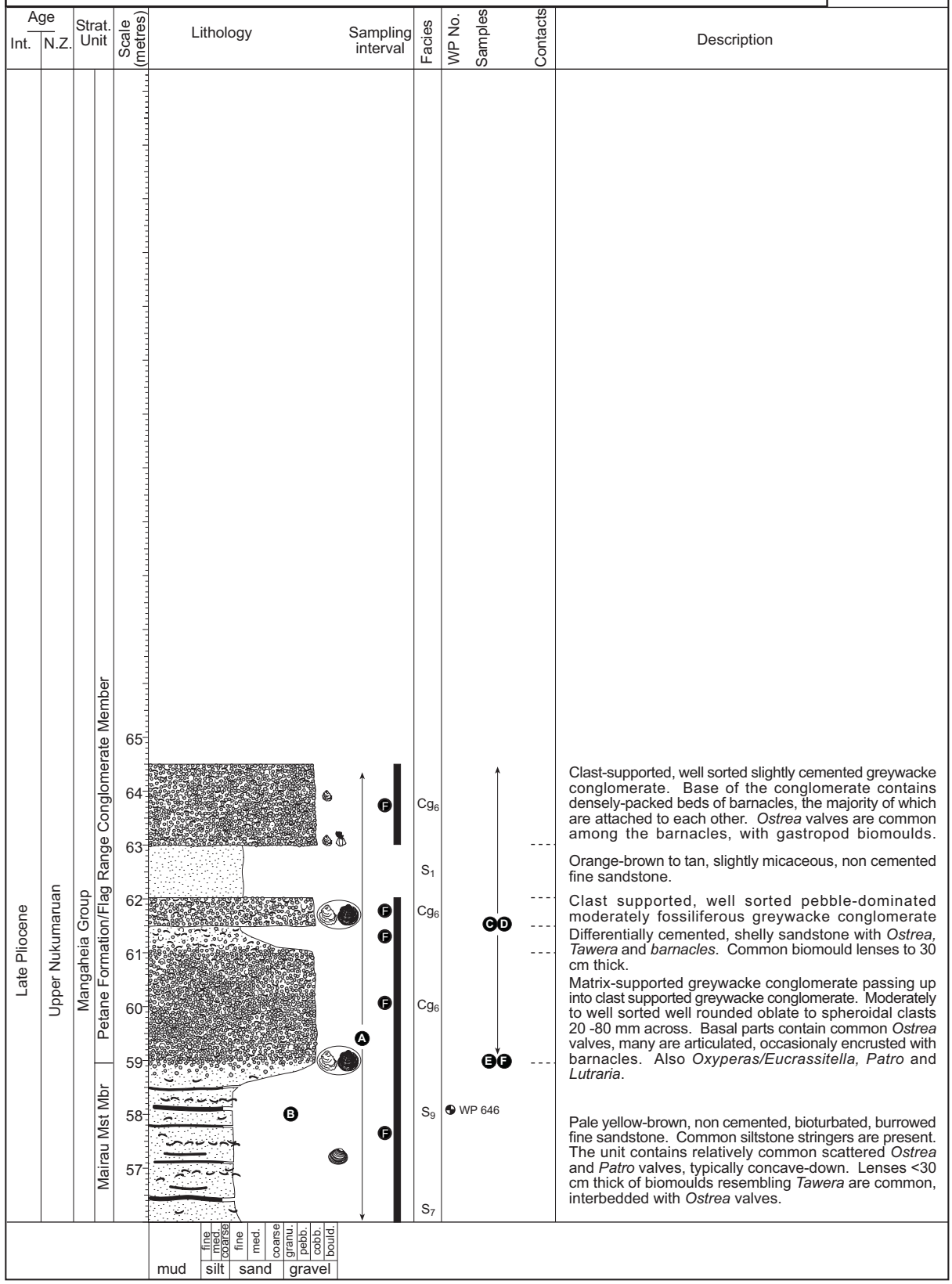
Stratigraphic Column No: Da-1 ***Grid Reference:*** ***Top*** ***Bottom***

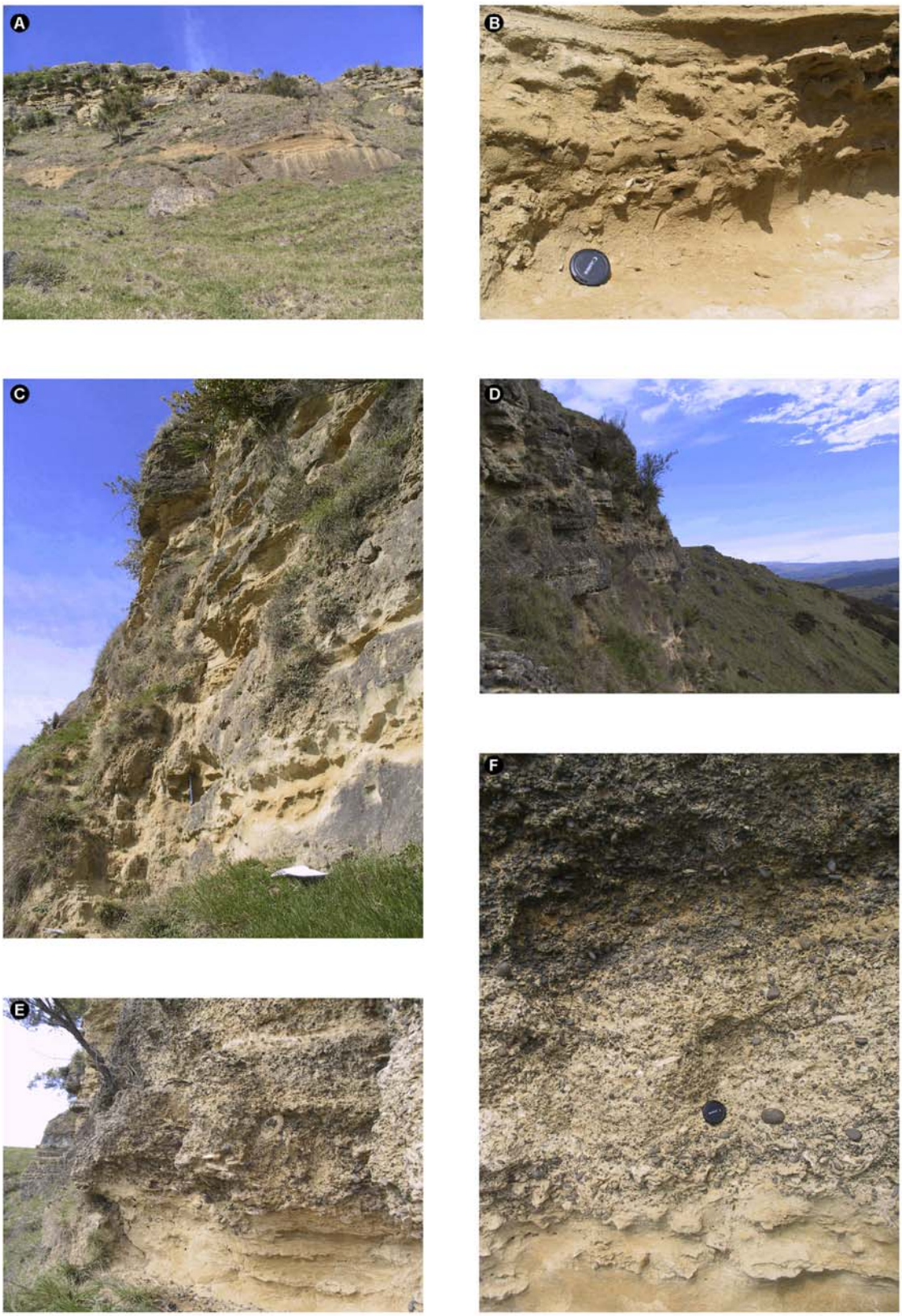
GPS Waypoint No(s): Wp 644-646 ***E:*** 2825187 2825159

Region: Dartmoor ***N:*** 6188178 6188088

Location: Section up farm track on Waihau Road face of Mount Cameron ***Altitude:*** 289 m 338 m

NZMS 260 Sheet: V21 Napier

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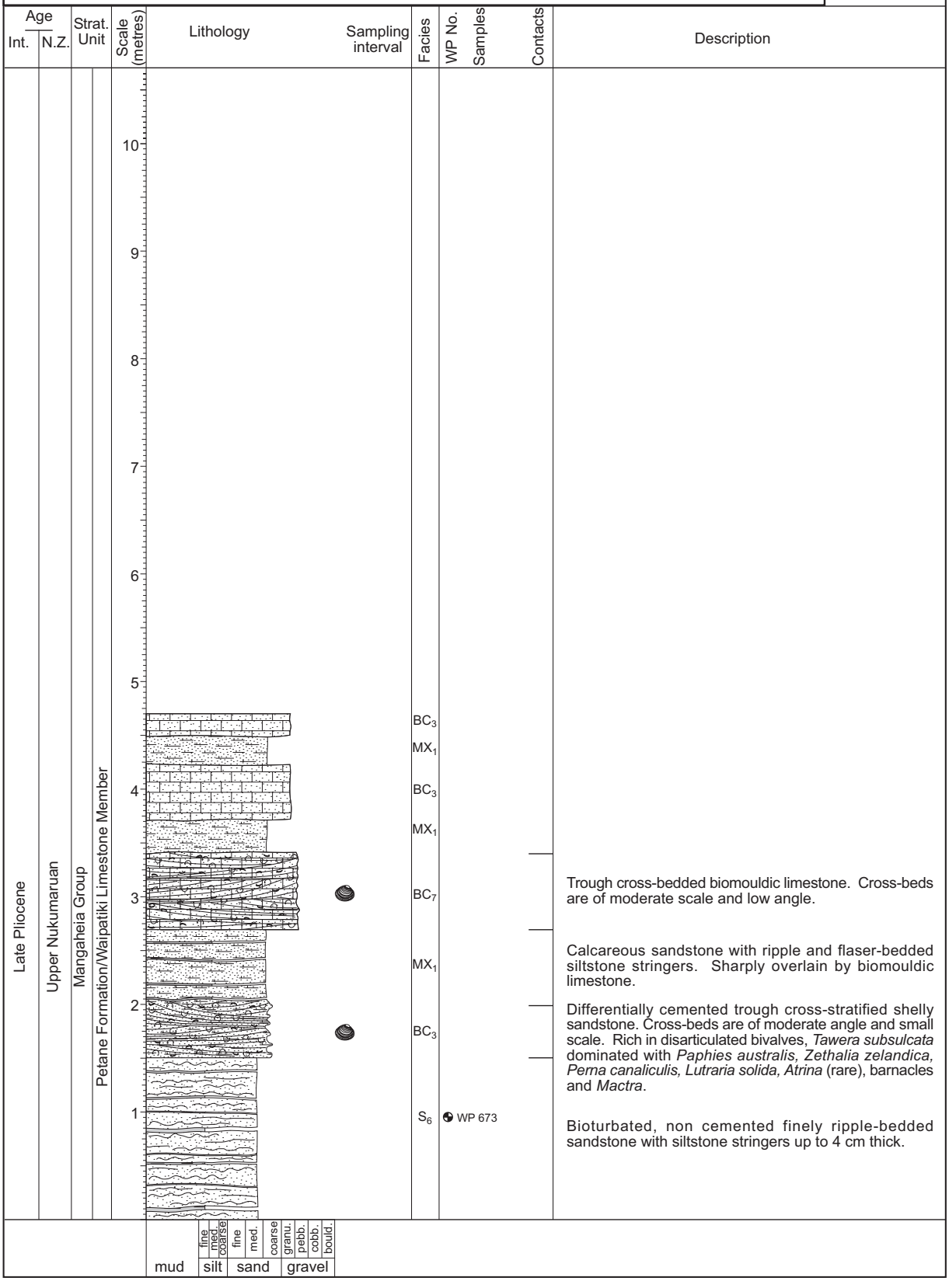
Stratigraphic Column No: Da-2 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 673 ***E:*** 2830120 -

Region: Dartmoor ***N:*** 6185737 -

Location: Ruawai Station overlooking Rissington ***Altitude:*** 205 m -

NZMS 260 Sheet: V21 Napier



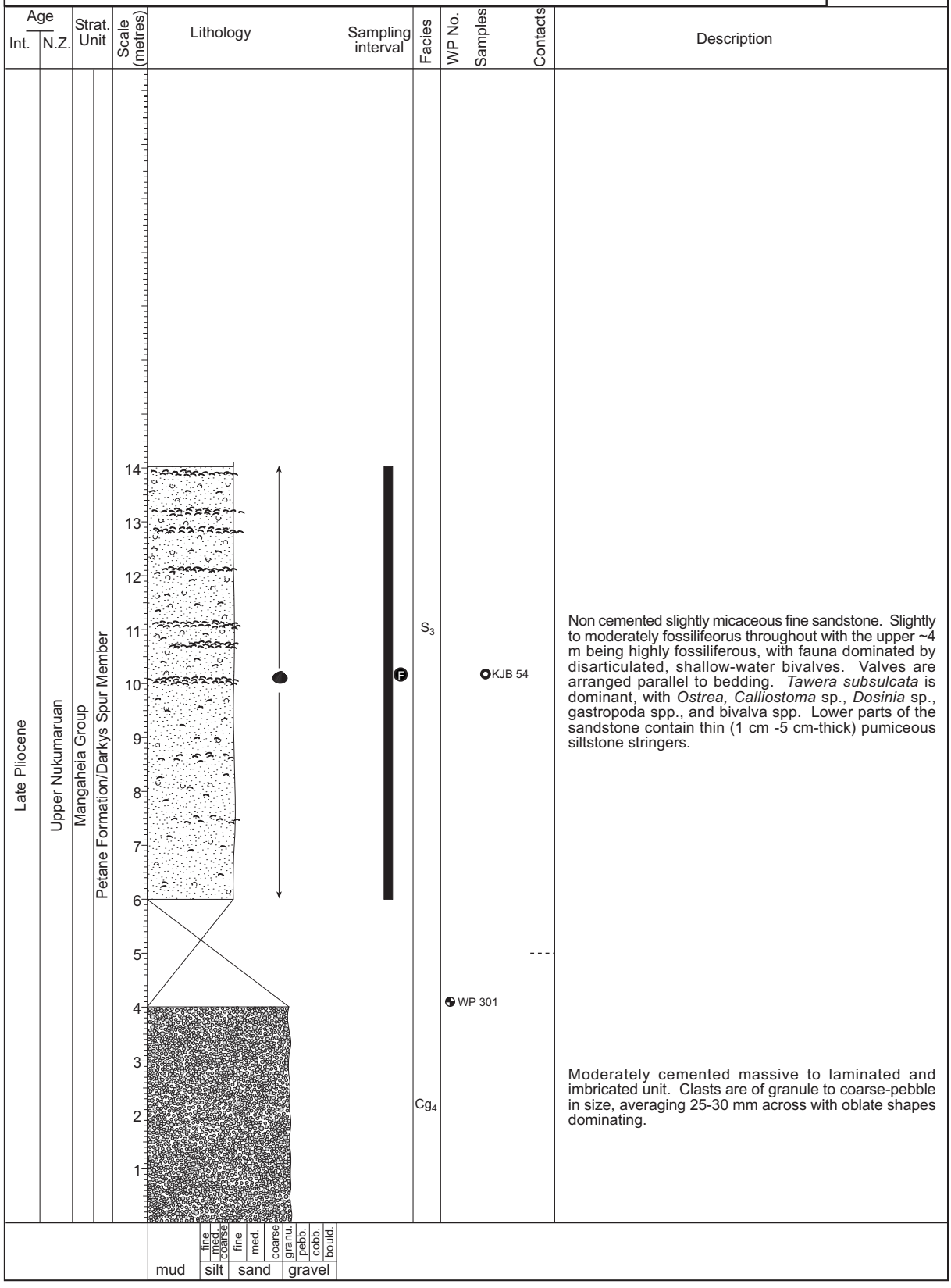
Stratigraphic Column No: *Ek-1* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 301 ***E:*** 2837487 -

Region: Eskdale ***N:*** 6198391 -

Location: Belmont Station overlooking Ellis Wallace Road ***Altitude:*** 173m -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1



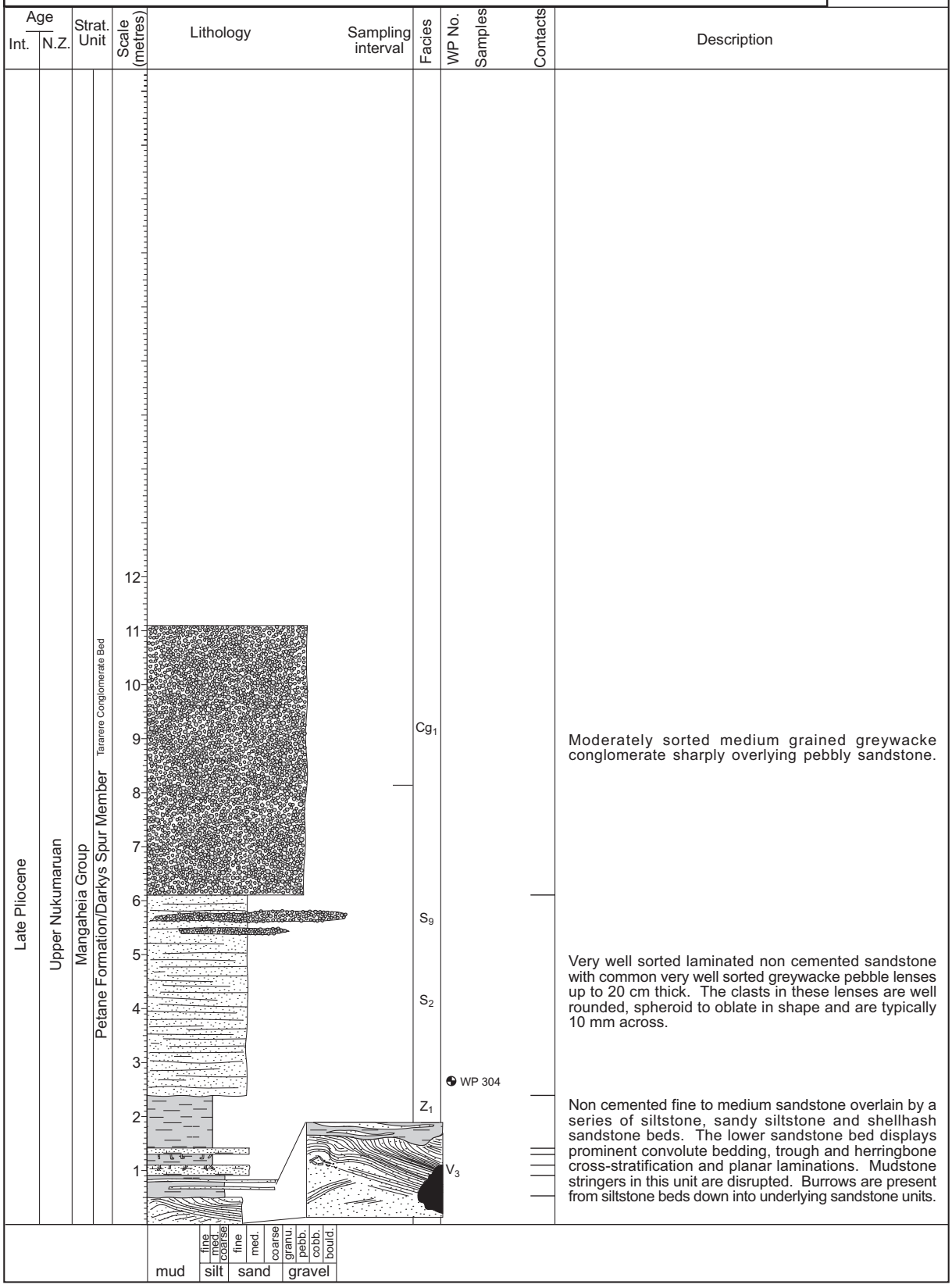
Stratigraphic Column No: Ek-2 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 304 ***E:*** 2837265 -

Region: Eskdale ***N:*** 6198589 -

Location: Belmont Station below trig overlooking SH5 ***Altitude:*** 171m -

NZMS 260 Sheet: V20 Esk



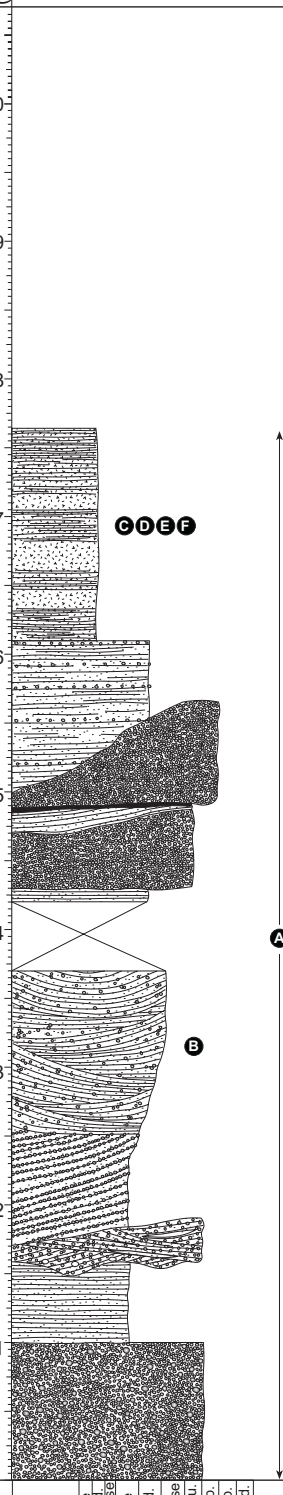
Stratigraphic Column No: Ek-3 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 319 ***E:*** 2836223 -

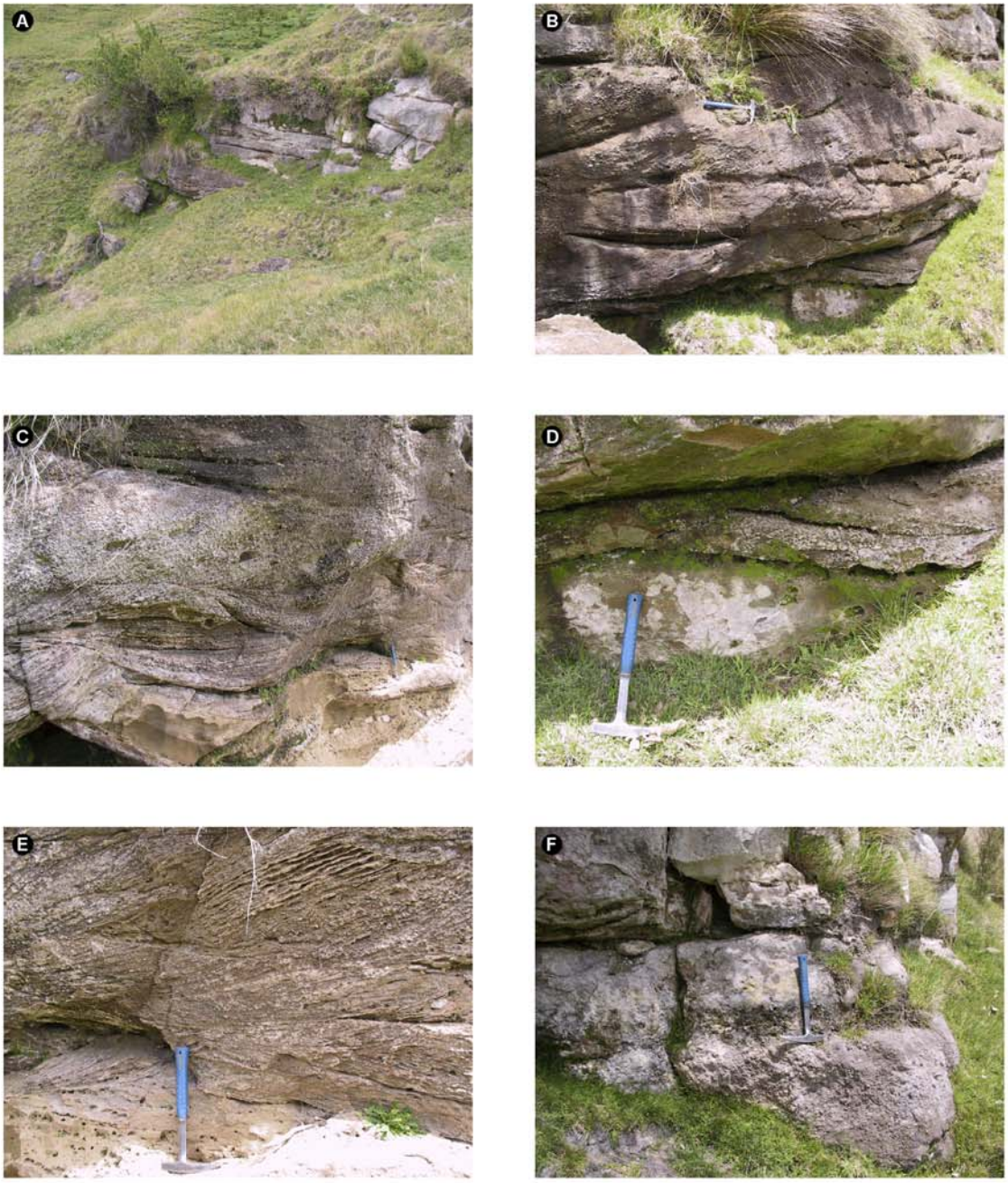
Region: Eskdale ***N:*** 6196746 -

Location: Section in hillside below farm track off the end of Beattie road ***Altitude:*** 91m -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1



Facies	WP No. / Samples / Contacts	Description
V_3		Greenish-grey to white, chalky to hard, strongly laminated to cross-stratified to massive volcaniclastic ash bed. The unit is dominated by fine ash with medium ash beds present. This unit sharply overlies the underlying sandstone.
S_9		Firm, well-sorted massive to laminated sandstone with the occasional beds of greywacke granules.
Cg_1/ Cg_2		Non cemented siltstone overlain by moderately sorted, moderately cemented coarsening upwards greywacke conglomerate. Clasts are subangular, and granule to fine pebble in size. Upper parts of the bed are clast supported with a coarse-grained gritty matrix of greywacke sand.
		Non cemented, bioturbated medium sandstone overlain by a well sorted greywacke grit (graunle-sized clasts) with scattered fine pebbles, and moderate-scale cross-stratification.
S_9		Non cemented, medium to coarse pebbly sandstone with abundant sub-angular greywacke granules and pebbles. The unit is strongly bi-directionally trough cross-bedded, greywacke clasts highlight the bedforms.
		Non cemented, well sorted, medium to coarse pebble sandstone with small to moderate-scale trough cross-bedding. Greywacke pebbles typically occur on top of foresets. This unit coarsens up into overlying bed.
		Cross-bedded granule to fine-pebble greywacke conglomerate erosionally overlying lower bed. Contains mudstone rip-up clasts.
		Non cemented, very well sorted non fossiliferous medium sandstone with common quartz and rock fragments.
Cg_1		Very well sorted moderately well cemented greywacke conglomerate. Clasts are 5-15mm across, well rounded, lensoidal to spheroid in shape and set in a medium to coarse sand matrix.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B
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F

Stratigraphic Column No: *Ek-4*

		Grid Reference:	**Top**	**Bottom**
GPS Waypoint No(s): Wp 329		***E:***	2837588	-
Region: Eskdale		***N:***	6200001	-
Location: Rautoitoi Stream near Ellis Wallace Road and Esk River		***Altitude:***	42m	-
NZMS 260 Sheet: V20 Esk			*Page* 1 *of* 1	

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Lower Nukumaruan	Mangaheia Group – Petane Fmn/Hikuroa Pumice Mbr	16–14						
			13			V_2/ V_3			White to pink-coloured pumiceous bed. Fine ash to lapilli-sized clasts.
			12–11						
		Petane Formation/Tutira Member	10–9						
			8			Cg_1			Non fossiliferous greywacke conglomerate with graunle to pebble-sized clasts. Lensoidal-shaped grains dominate with common oblate clasts.
			7–6						
			5–4			S_1			Non cemented,very well sorted, slightly micaceous fine to medium sandstone sharply overlying underlying siltstone.
			3–2						
		Esk Mst	1			Z_1	WP 329		Blue-grey, non cemented, non fossiliferous massive to laminated siltstone with rare water escape structures.

mud | silt (fine, med., coarse) | sand (fine, med., coarse) | gravel (granu., pebb., cobb., bould.)

Stratigraphic Column No: Ek-5 ***Grid Reference:*** ***Top*** ***Bottom***

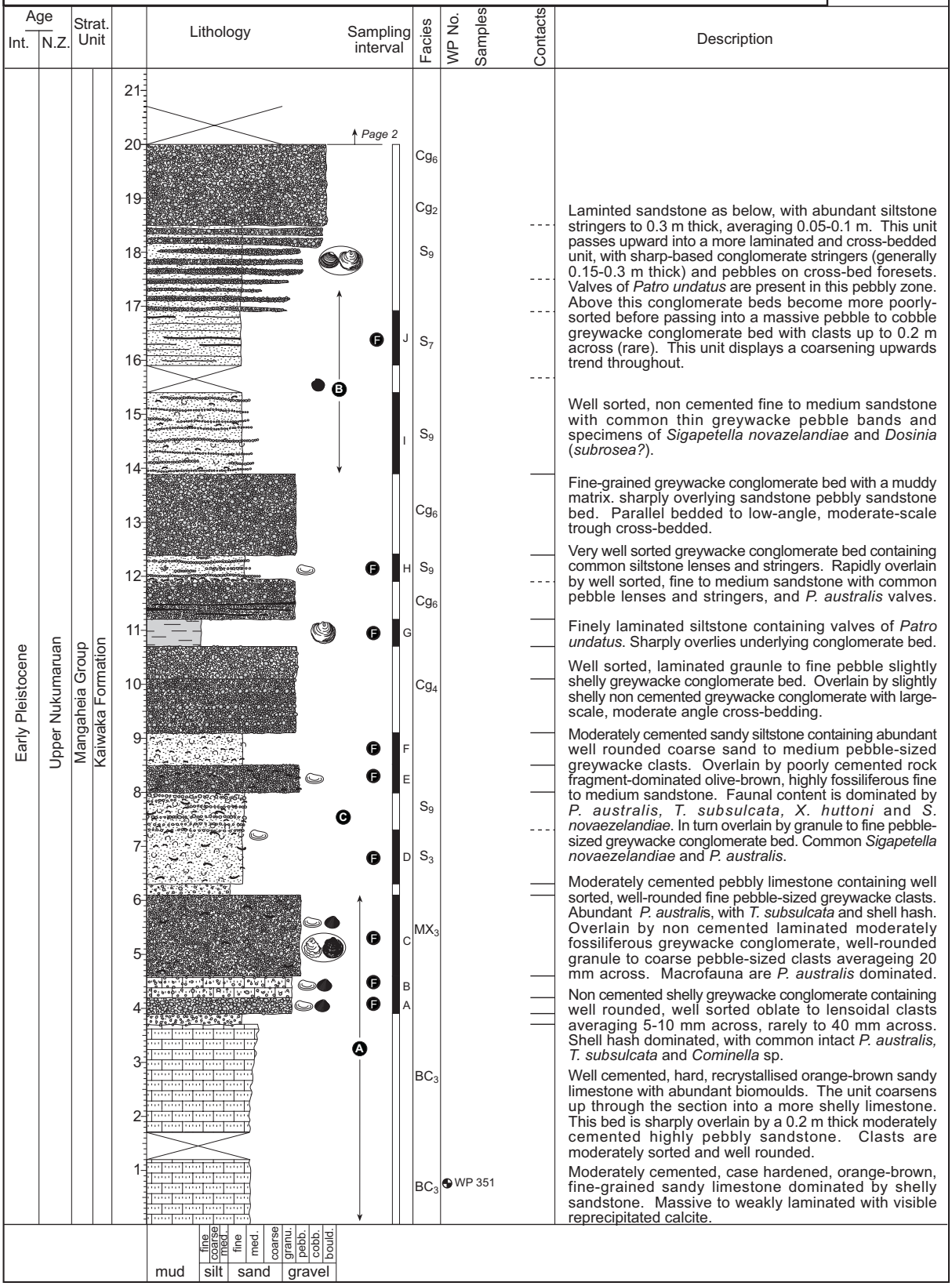
GPS Waypoint No(s): Wp 351-352 ***E:*** 2836612 2836660

Region: Eskdale ***N:*** 6191521 6191555

Location: Quarry in forest above Hedgely Station ***Altitude:*** 283m 243m

NZMS 260 Sheet: V20 Esk

Page 1 *of* 2



Laminted sandstone as below, with abundant siltstone stringers to 0.3 m thick, averaging 0.05-0.1 m. This unit passes upward into a more laminated and cross-bedded unit, with sharp-based conglomerate stringers (generally 0.15-0.3 m thick) and pebbles on cross-bed foresets. Valves of *Patro undatus* are present in this pebbly zone. Above this conglomerate beds become more poorly-sorted before passing into a massive pebble to cobble greywacke conglomerate bed with clasts up to 0.2 m across (rare). This unit displays a coarsening upwards trend throughout.

Well sorted, non cemented fine to medium sandstone with common thin greywacke pebble bands and specimens of *Sigapetella novazelandiae* and *Dosinia* (*subrosea?*).

Fine-grained greywacke conglomerate bed with a muddy matrix. sharply overlying sandstone pebbly sandstone bed. Parallel bedded to low-angle, moderate-scale trough cross-bedded.

Very well sorted greywacke conglomerate bed containing common siltstone lenses and stringers. Rapidly overlain by well sorted, fine to medium sandstone with common pebble lenses and stringers, and *P. australis* valves.

Finely laminated siltstone containing valves of *Patro undatus*. Sharply overlies underlying conglomerate bed.

Well sorted, laminated graunle to fine pebble slightly shelly greywacke conglomerate bed. Overlain by slightly shelly non cemented greywacke conglomerate with large-scale, moderate angle cross-bedding.

Moderately cemented sandy siltstone containing abundant well rounded coarse sand to medium pebble-sized greywacke clasts. Overlain by poorly cemented rock fragment-dominated olive-brown, highly fossiliferous fine to medium sandstone. Faunal content is dominated by *P. australis, T. subsulcata, X. huttoni* and *S. novaezelandiae*. In turn overlain by granule to fine pebble-sized greywacke conglomerate bed. Common *Sigapetella novaezelandiae* and *P. australis*.

Moderately cemented pebbly limestone containing well sorted, well-rounded fine pebble-sized greywacke clasts. Abundant *P. australis*, with *T. subsulcata* and shell hash. Overlain by non cemented laminated moderately fossiliferous greywacke conglomerate, well-rounded granule to coarse pebble-sized clasts averageing 20 mm across. Macrofauna are *P. australis* dominated.

Non cemented shelly greywacke conglomerate containing well rounded, well sorted oblate to lensoidal clasts averaging 5-10 mm across, rarely to 40 mm across. Shell hash dominated, with common intact *P. australis, T. subsulcata* and *Cominella* sp.

Well cemented, hard, recrystallised orange-brown sandy limestone with abundant biomoulds. The unit coarsens up through the section into a more shelly limestone. This bed is sharply overlain by a 0.2 m thick moderately cemented highly pebbly sandstone. Clasts are moderately sorted and well rounded.

Moderately cemented, case hardened, orange-brown, fine-grained sandy limestone dominated by shelly sandstone. Massive to weakly laminated with visible reprecipitated calcite.

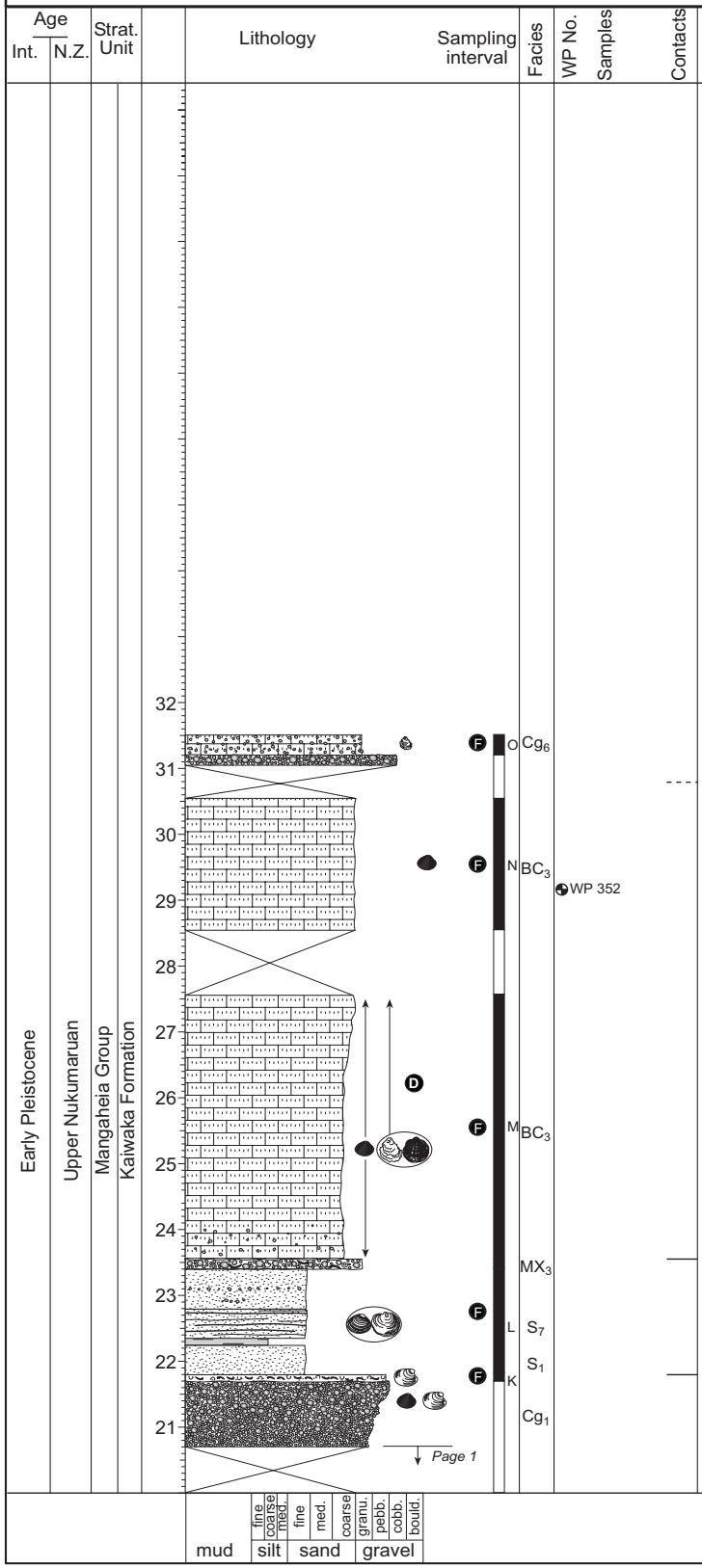
Stratigraphic Column No: *Ek-5* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 351-352 ***E:*** 2836612 2836660

Region: Eskdale ***N:*** 6191521 6191555

Location: Quarry in forest above Hedgely Station ***Altitude:*** 283m 243m

NZMS 260 Sheet: V20 Esk



Coarse-grained pebble greywacke conglomerate overlain by well sorted grey to cream-brown pebbly limestone. Fine- to medium-grained pebbles are present, as are abundant *Ostrea* valves.

Slightly to moderately cemented shelly limestone with abundant large *Ostrea* valves and a sandy matrix. Valves are typically concave down, or parallel to bedding. Biomoulds are common through this unit.

Non cemented 0.25 m-thick shellhash-rich shelly conglomerate with a silty sandy matrix. Rare large cobbles are present to 0.15 m across near the top. Sharply overlain by slightly to moderately cemented creamy-grey limestone containing abundant biomoulds. Lower 0.45 m are quite pebbly (lensoidal clasts to 40 mm across). Unit is whole shell bivalve-dominated, mainly by *Tawera*, many of which are articulated. The interval coarsens upwards and is characterised by large articulated *Ostrea* valves, with encrusting bryozoans also common. *Tawera* valves are present throughout the unit.

Tan, non cemented fine to medium sandstone sharply overlying a shellbed containing a bioturbated siltstone. Scattered shell fragments are common, with some greywacke pebbles present with attached barnacles. Overlying sandstone units are similar with more siltstone stringers, and *Ostrea* and *Patro* valves.

Granule to fine pebble-sized greywacke conglomerate passing upward into a medium-coarse pebble unit with a slightly muddy matrix. Clasts to 0.1 m across are present and are oblate dominated, to lensoidal in shape. The top of the conglomerate is marked by a 0.1 m-thick shellbed containing *Lutraria, X. huttoni, T. subsulcata, O. chilensis* and A. *stutchburyi.*

A- Very pebbly sandstone dominated by shellhash with some intact *Paphies australis, Tawera subsulcata, Cominella* sp., and *?Dosinia*.

B- Pebbly limestone containing abundant *Paphies australis*, with *Tawera subsulcata* and shellhash.

C- Moderately fossiliferous greywacke conglomerate containing *Paphies australis, Sigapetella novaezelandiae, Amalda* sp., *Tucetona laticostata, Tawera subsulcata* and gastropoda spp.

D- Highly fossiliferous fine to medium sandstone with common *Paphies australis, Tawera subsulcata, Sigapetella novaezelandiae* and some *Xenostrobus huttoni, Tucetona laticostata* and *Dosinia subrosea*.

E- Fine-grained greywacke conglomerate containing common *Sigapetella novaezelandiae* and some *Paphies australis*.

F- Fine to medium sandstone containing common *Sigapetella novaezelandiae*, with some *Crepidula radiata* and *Maorimactra* sp.?

G- Strongly laminated siltstone containing valves of *Patro undatus*.

H- Siliciclastic-dominated sandstone with a high calcareous fraction containing common *Paphies australis*.

I- Fine to medium sandstone with *Sigapetella novaezelandiae* and *Dosina* sp.

J- Laminated to cross-bedded sandstone with common siltstone and conglomerate stringers containing valves of *Patro undatus*.

K- 0.1 m-thick shellbed capping greywacke conglomerate bed. *Lutraria solida, Xeonstrobus huttoni, Tawera subsulcata, Ostrea chilensis* and *Austroveus stuchburyi* are present in this shellbed.

L- Fine to medium sandstone with common siltstone and greywacke pebble stringers. Articulated and disarticulated *Patro undatus* and *Ostrea chilensis* are present, as are common intact barnacles, some of which are attached to greywacke pebbles and oyster valves. Rare *Paphies australis* are also present, and the upper part of this unit is shellhash dominated.

M- Biomouldic, whole bivalve shell-dominated limestone. *Tawera subsulcata*, some of which may be articulated, dominates the faunal content. Upper parts of the unit contain common, very large articulated and disarticulated *Ostrea chilensis*. Encrusting bryozoans are also present.

N- Whole-shell dominated limestone, biomould rich, with abundant large *Ostrea chilensis* valves that are both disarticulated and articulated.

O- Well cemented pebbly limestone containing abundant *Ostrea chilensis* valves.



Stratigraphic Column No: *Gg-1*

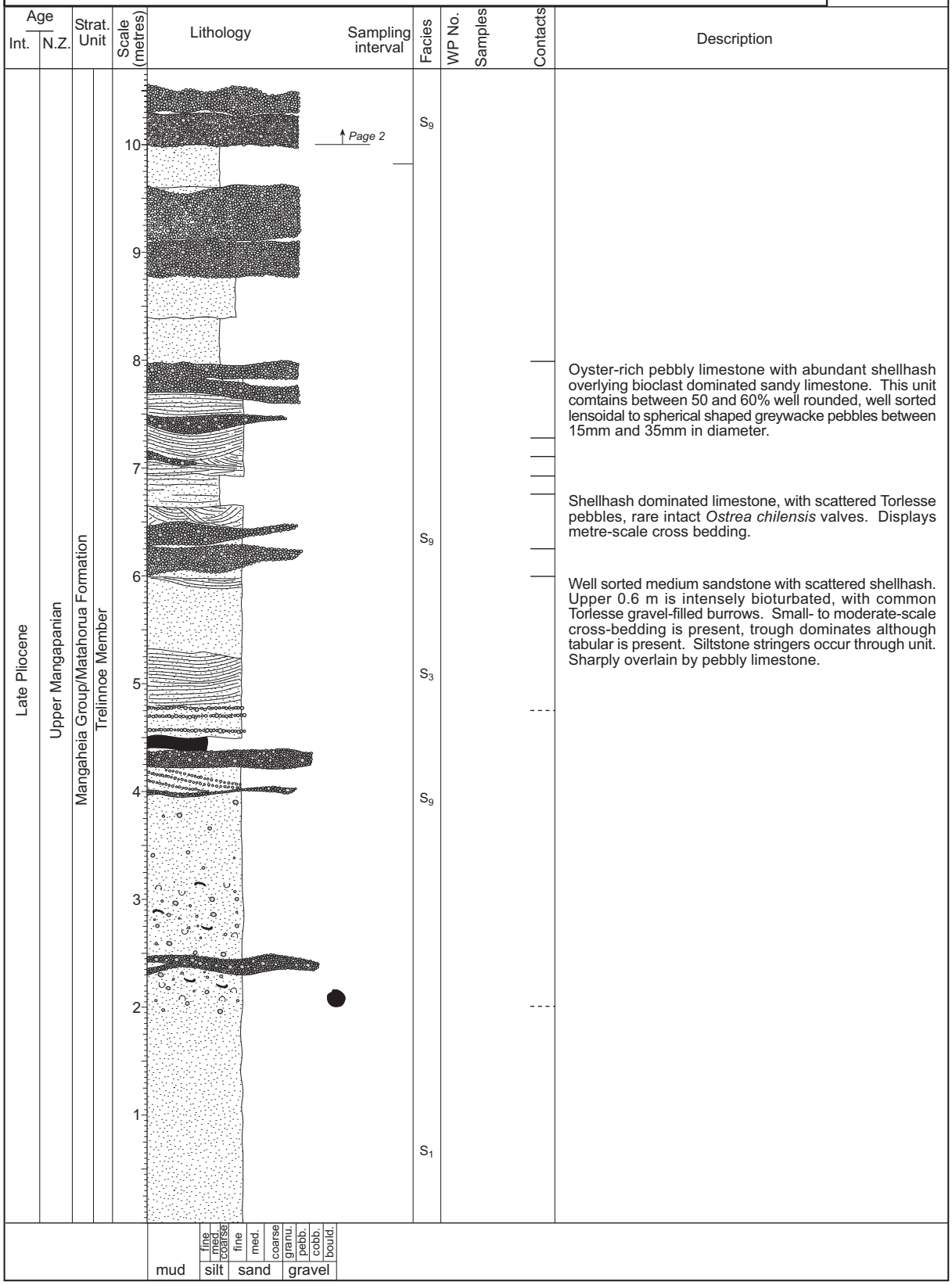
GPS Waypoint No(s): Wp 23-24

Region: Glengarry

Location: Glengarry Hill on SH5 north of entrance to Eland Station

NZMS 260 Sheet: V20 Esk

Grid Reference:	***Top***	***Bottom***
E:	2830925	2831200
N:	6203854	6203722
Altitude:	386 m	355 m



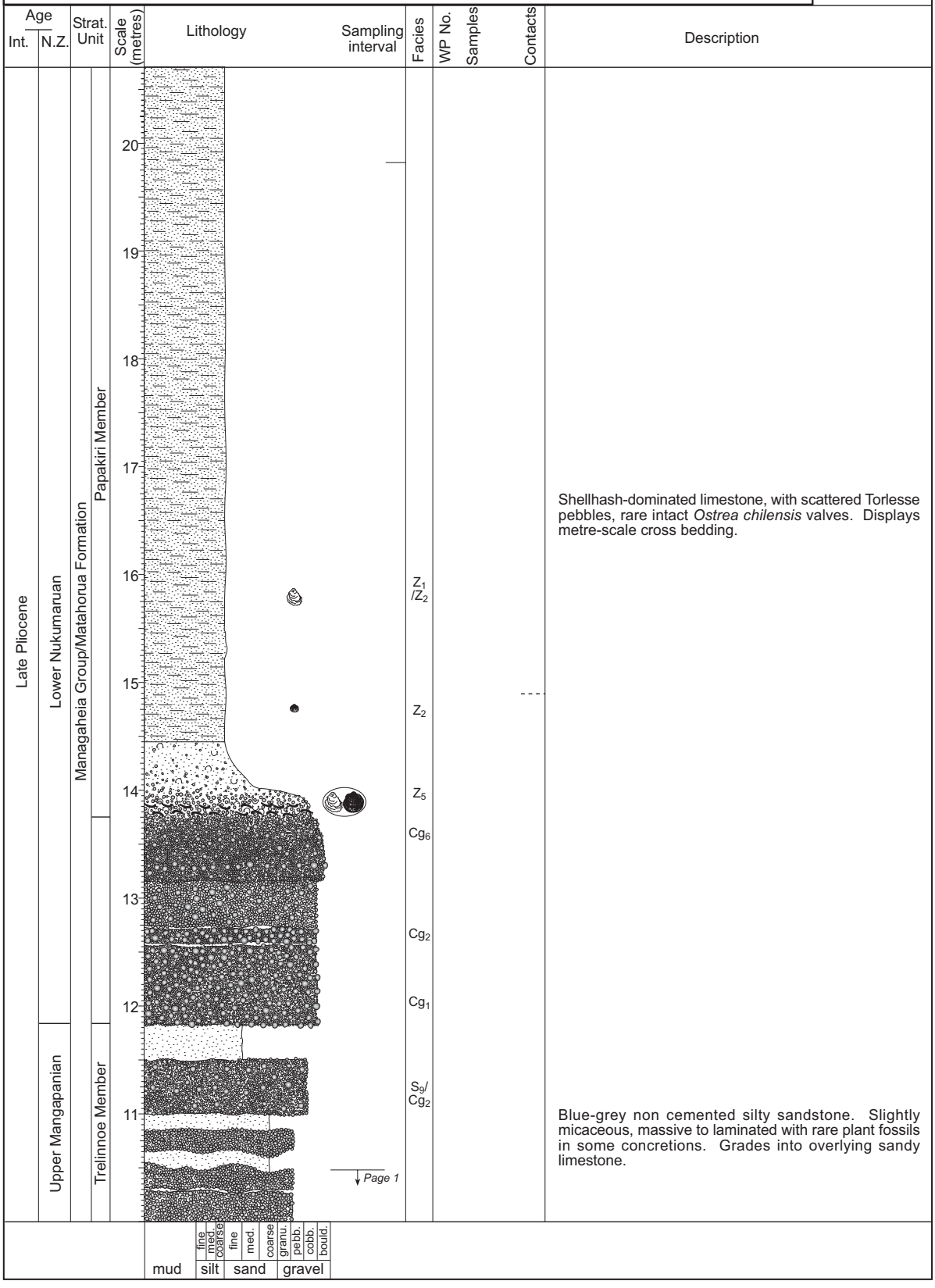
Stratigraphic Column No: Gg-1 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 23-24 ***E:*** 2830925 2831200

Region: Glengarry ***N:*** 6203854 6203722

Location: Glengarry Hill north of entrance to Eland Station ***Altitude:*** 386 m 355 m

NZMS 260 Sheet: V20 Esk *Page 2 of 2*



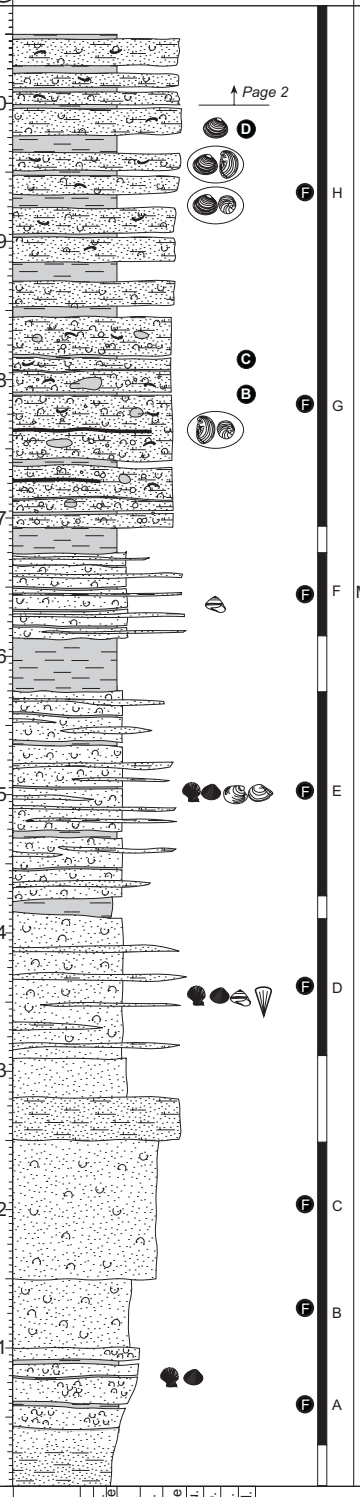
Stratigraphic Column No: Gg-2 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 61 ***E:*** 2833307

Region: Rissington ***N:*** 6188260

Location: Puketitiri Road immediately south of Glengarry Road. ***Altitude:*** 200m -

NZMS 260 Sheet: V21 Napier



Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Sampling interval	Facies	WP No. Samples	Description
Late Pliocene	Upper Nukumaruan	Mangaheia Group / Waipatiki Limestone Member	10	H			Alternating siltstone and shellhash beds. Beds are very continuous, and moderately to highly fossiliferous, becoming more shellhash-rich before grading up into a shellhash-dominated sandstone. The faunal content of this zone is dominated by bivalves such as *Tawera subsulcata, Austrovenus stuchburyi, Gari stangeri* and *Glycymeris modesta.*
			9				
			8	G			Non to slightly cemented, moderately to highly fossiliferous, shellhash-dominated sandstone with prominent siltstone stringers. Siltstone rip-up clasts up to 12 cm diameter are present, averaging 5 cm across, as are a few scattered, well rounded greywacke pebbles. Low-angle, moderate-scale cross-bedding is visible, especially in the siltstone stringers. Shellhash rip-up clasts are also present.
			7				Non cemented, non fossiliferous siliciclastic siltstone.
				F	MX_4		Non cemented, moderately to highly fossiliferous siliciclastic silty sandstone with laminated shellhash and siltstone stringers that show relief on their upper and lower contacts.
			6				Non cemented siliciclastic siltstone containing thin shellhash lenses.
			5	E			Non to slightly cemented silty sandstone with common siltstone stringers up to 10 cm thick, and shellhash lenses up to 5 cm thick. Moderately to highly fossiliferous with an estuarine-dominated fauna including *Austrovenus stutchburyi* and *Barytellina crassidens.*
							Non cemented siltstone lens that pinches out over 10 m.
			4	D			Non cemented silty sandstone with a bioclastc sandstone content. The unit is moderately fossiliferous. Shellhash lenses are common in this unit.
			3				Non cemented silty sandstone with a bioclastc sandstone content.
							Bioclastc medium sandstone.
			2	C			Non to slightly cemented, moderately fossiliferous shelly medium sandstone.
				B			Non to slightly cemented, moderately fossiliferous fine siliciclastic sandstone.
			1	A			Unfossiliferous blue-grey sandy siltstone grading up into medium sandstone with pockets of shellhash-rich in bivalve fossils. This sandstone contains mudstone stringers up to 0.1 m thick which are frequently laminated. The unit as a whole is intensely bioturbated and burrowed. The base of this section is not exposed.

mud | silt: fine, med, coarse | sand: fine, med, coarse | gravel: granu., pebb., cobb., bould.

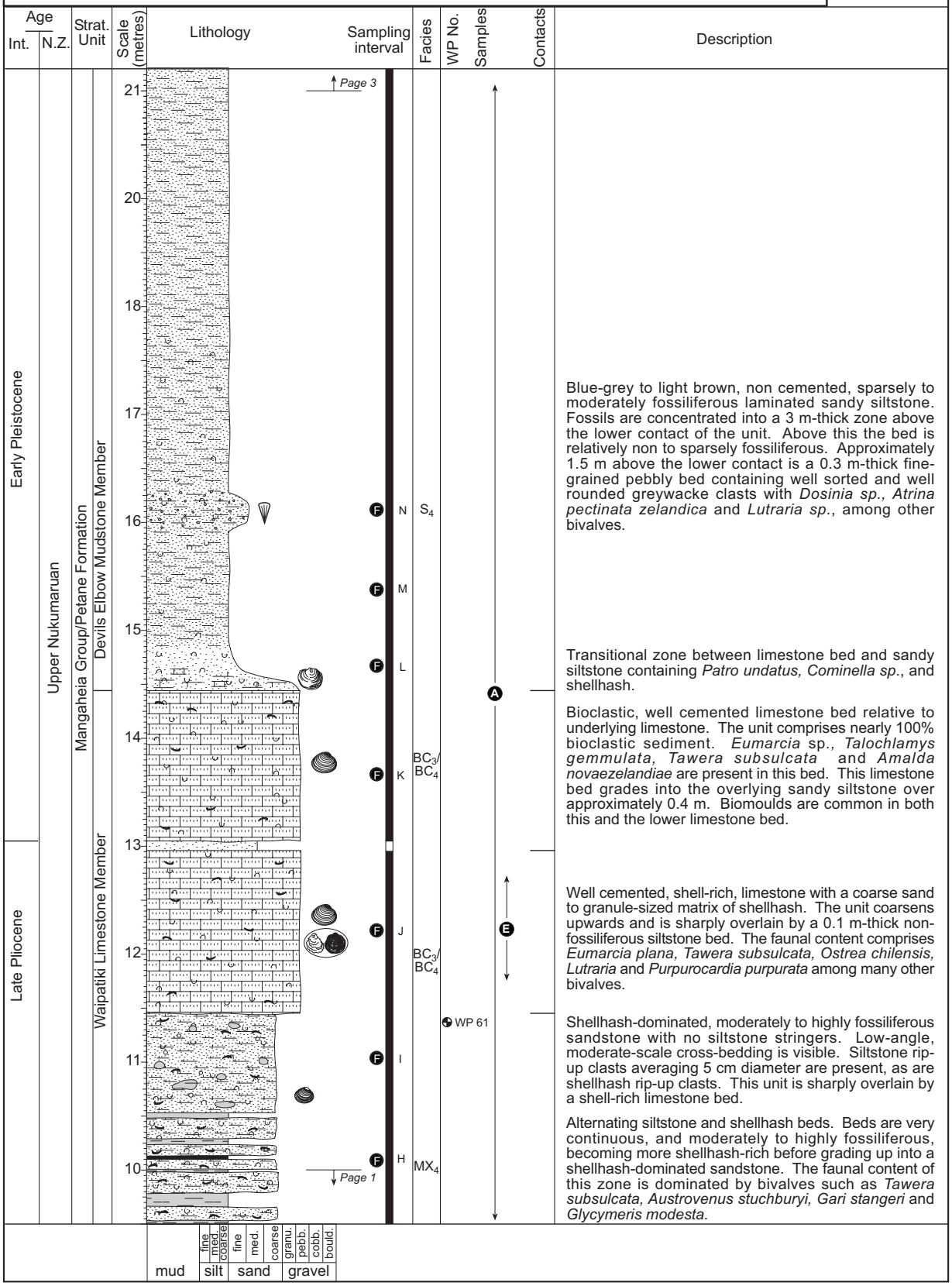
Stratigraphic Column No: Gg-2 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 61 ***E:*** 2833307

Region: Rissington ***N:*** 6188260

Location: Puketitiri Road immediately south of Glengarry Road. ***Altitude:*** 200m -

NZMS 260 Sheet: V21 Napier



Blue-grey to light brown, non cemented, sparsely to moderately fossiliferous laminated sandy siltstone. Fossils are concentrated into a 3 m-thick zone above the lower contact of the unit. Above this the bed is relatively non to sparsely fossiliferous. Approximately 1.5 m above the lower contact is a 0.3 m-thick fine-grained pebbly bed containing well sorted and well rounded greywacke clasts with *Dosinia sp., Atrina pectinata zelandica* and *Lutraria sp.*, among other bivalves.

Transitional zone between limestone bed and sandy siltstone containing *Patro undatus, Cominella sp.*, and shellhash.

Bioclastic, well cemented limestone bed relative to underlying limestone. The unit comprises nearly 100% bioclastic sediment. *Eumarcia* sp*., Talochlamys gemmulata, Tawera subsulcata* and *Amalda novaezelandiae* are present in this bed. This limestone bed grades into the overlying sandy siltstone over approximately 0.4 m. Biomoulds are common in both this and the lower limestone bed.

Well cemented, shell-rich, limestone with a coarse sand to granule-sized matrix of shellhash. The unit coarsens upwards and is sharply overlain by a 0.1 m-thick non-fossiliferous siltstone bed. The faunal content comprises *Eumarcia plana, Tawera subsulcata, Ostrea chilensis, Lutraria* and *Purpurocardia purpurata* among many other bivalves.

Shellhash-dominated, moderately to highly fossiliferous sandstone with no siltstone stringers. Low-angle, moderate-scale cross-bedding is visible. Siltstone rip-up clasts averaging 5 cm diameter are present, as are shellhash rip-up clasts. This unit is sharply overlain by a shell-rich limestone bed.

Alternating siltstone and shellhash beds. Beds are very continuous, and moderately to highly fossiliferous, becoming more shellhash-rich before grading up into a shellhash-dominated sandstone. The faunal content of this zone is dominated by bivalves such as *Tawera subsulcata, Austrovenus stuchburyi, Gari stangeri* and *Glycymeris modesta.*

Stratigraphic Column No: Gg-2 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 61 ***E:*** 2833307

Region: Rissington ***N:*** 6188260

Location: Puketitiri Road immediately south of Glengarry Road. ***Altitude:*** 200m -

NZMS 260 Sheet: V21 Napier *Page* 3 *of* 3

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description

A- Medium sandstone with pockets of shellhash containing *Sigapetella novaezelandiae, Crepidula radiata, Austrovenus stuchburyi, Tawera spissa, Notocallista sp., Talochlamys gemmulata*, *Tellinota edgari,* and in situ *Panopea* sp.

B- Moderately fossiliferous fine siliciclastic sandstone containing *Sigapetella novaezelandiae.*

C- Non to slightly cemented medium shelly sandstone dominated by *Maoriomactra ordinaria.*

D- Fine siliciclastic sandstone with a bioclastic component, containing *Callisotoma pellucidum*, *Talochlamys gemmulata, Tawera subsulcata, Patro undatus, Zenatia acinaces, Zethalia zelandica, Tellinota edgari, Glycymeris modesta,* and *Atrina pectinata zelandica.*

E- Non to slightly cemented sandstone with siltstone and shellhash lenses containing *Pelicaria convexa*, in situ *Panopea* sp., *Talochlamys gemmulata, Maoriomactra ordinaria, Bassina yatei, Crepidula radaiata, Barnea simmilis, Glycymeris ordinaria, Sigapetella novaezelandiae, Barytellina crassidens, Tawera subsulcata,* and *Austrovenus stutchburyi.*

F- Non cemented, moderately to highly fossiliferous siliciclastic silty sandstone with siltstone and shellhash lenses containing *Barnea simmilis, Cirrsotrema, Maoriomactra ordinaria, Sigapetella novaezelandiae, Crepidula radiata, Gari stangeri, Zethalia zelandica, Gari lineolata,* and *Lutraria* sp.

G- Non to slightly cemented shellhash-dominated sandstone with *Gari lineolata, Glycymeris modesta, Panopea* sp., *Gari stangeri, Tawera subsulcata, Sigapetella novaezelandiae, Crepidula radiata*, and *Austrovenus stutchburyi.*

H- Alternating siltstone and shellhash lenses containing *Tawera subsulcata, Austrovenus stutchburyi, Gari stangeri, Sigapetella novaezelandiae, Panopea* sp.*, Crepidula radiata, Glycymeris modesta, Lutraria* sp.*, Glycymeris* sp.*, Ostrea chilensis, Barytellina crassidens, Atrina pectinata zelandica, Purpurocardia purpurata, Zethalia zelandica,* and *Stiracolpus* sp.

I- Shellhash-dominated, moderately to highly fossiliferous sandstone with siltstone and shellhash rip-up clasts. The faunal content comprises *Purpurocardia purpurata, Stiracolpus, Austrovenus stutchburyi, Dosinia nukumaruensis, Gari stangeri, Zethalia zelandica, Glycymeris modesta, Tawera subsulcata, Caryocorbula, Eumarcia plana, Gari lineolata, Lamprodominea* sp.*, Dosina* sp.*,* and *Sigapatella novaezelandiae.*

J- Well cemented, shell-rich limestone bed with a matrix of coarse sand-sized shellhash. *Eumarcia plana, Tawera subsulcata, Ostrea chilensis, Gari stangeri, Dosinia nukumaruensis, Dosina* sp.*, Purpurocardia purpurata, Lutraria* sp.*,* and barnacle plates are present in the unit.

K- Bioclastic-dominated, well cemented limestone containing virtually no siliciclastic sediment. Fauna present include *Eumarcia plana, Talochlamys gemmulata, Tawera subsulcata,* and *Amalda novaezelandiae.*

L- Transitional zone between limestone bed and overlying sandy siltstone that contains *Patro undatus* and *Cominella* sp.

M- Non cemented sandy siltstone containing *Pelicaria convexa*, *Lutraria* sp.*, Notocallista multistriata,* and *Stiracolpus* sp.

N- Fine-grained pebble bed containing *Dosina* sp.*, Atrina pectinata zelandica, Lutraria* sp.*, Notiris* sp.*, Trachycardium* sp.*, Tellinota edgari, Tawera subsulcata,* and *Tucetona laticostata.*

Early Pleistocene | Upper Nukumaruan | Mangaheia Group/Petane Formation | Devils Elbow Mudstone Member

23
22
21

Page 2

A

S_4

Blue-grey, to light-brown, non cemented, non to sparsely fossiliferous sandy siltstone.

mud | silt: fine, med., coarse | sand: fine, med., coarse | gravel: granu., pebb., cobb., bould.


A
B
C
D
E
TOYOTA

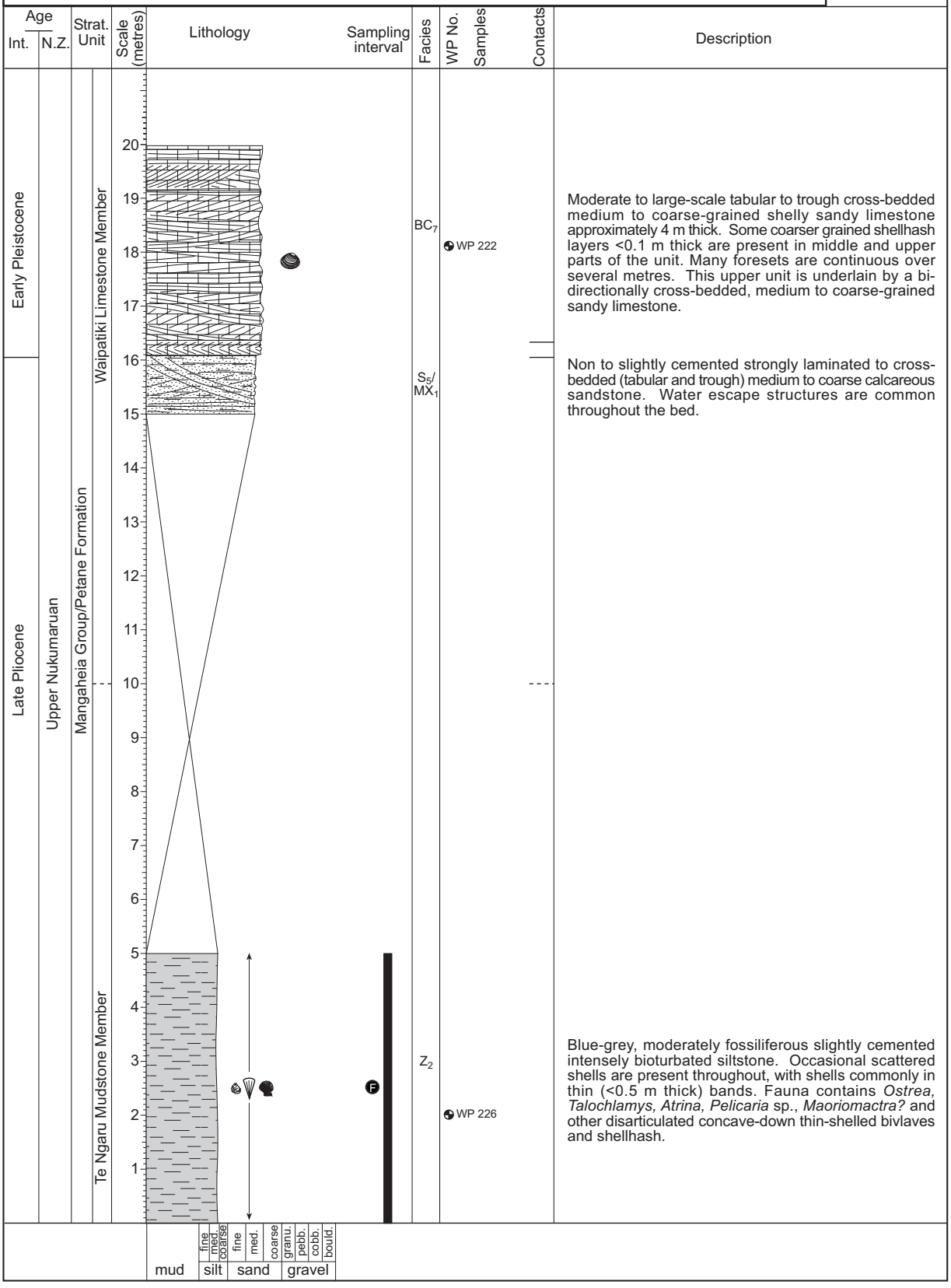
Stratigraphic Column No: Gg-3 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 222 and 226 ***E:*** 2833813 2833980

Region: Glengarry ***N:*** 6192389 6192389

Location: Awanui Farm off Glengarry Road, cuttings in farm track and hillsides ***Altitude:*** 308m 278m

NZMS 260 Sheet: V20 Esk



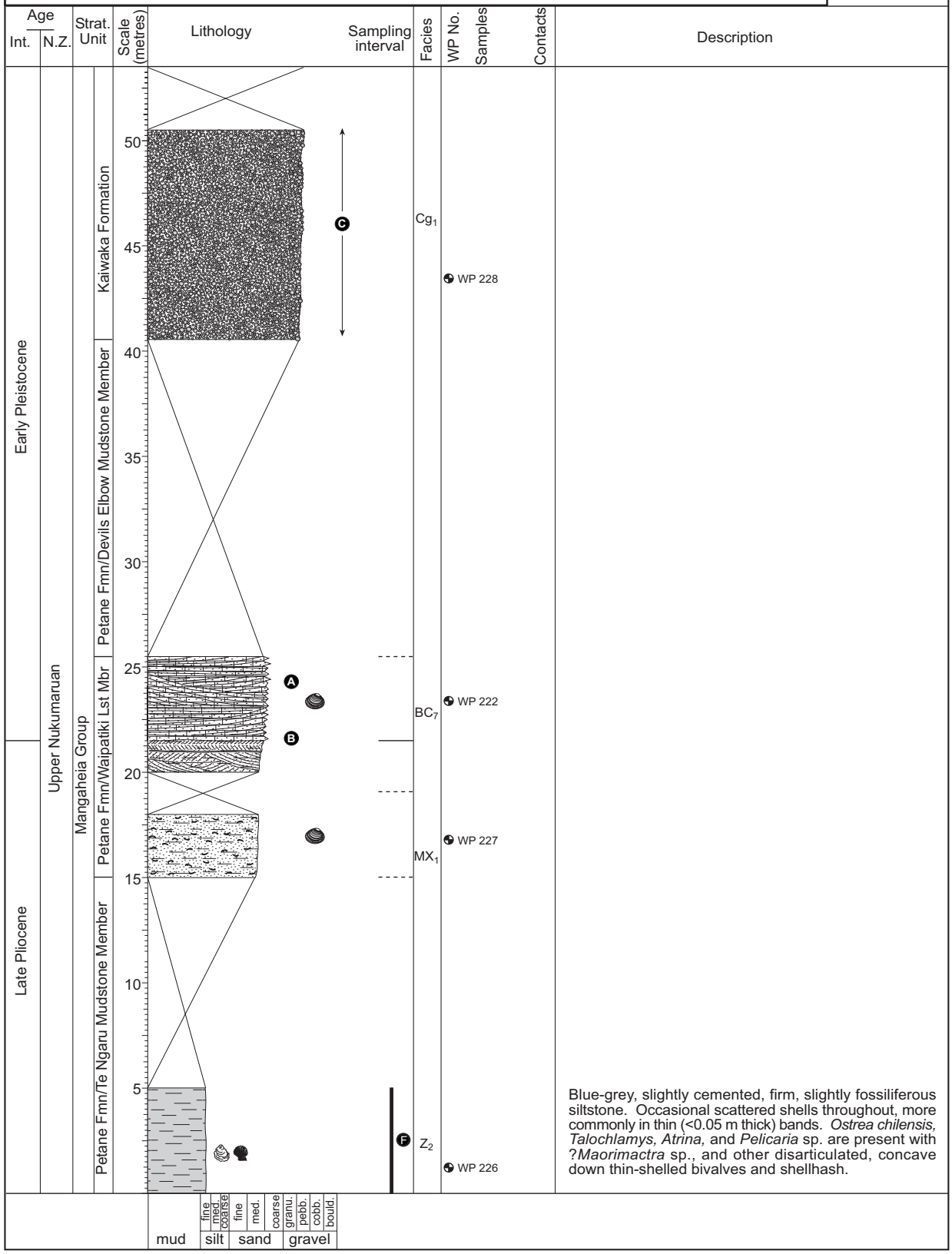
Stratigraphic Column No: Gg-4 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 222-230 ***E:*** 2834045 2833813

Region: Glengarry ***N:*** 6189871 6192389

Location: Matches farm above Glengarry Road and near "The Gums" ***Altitude:*** 319 m 308 m

NZMS 260 Sheet: V20 Esk, V21 Napier



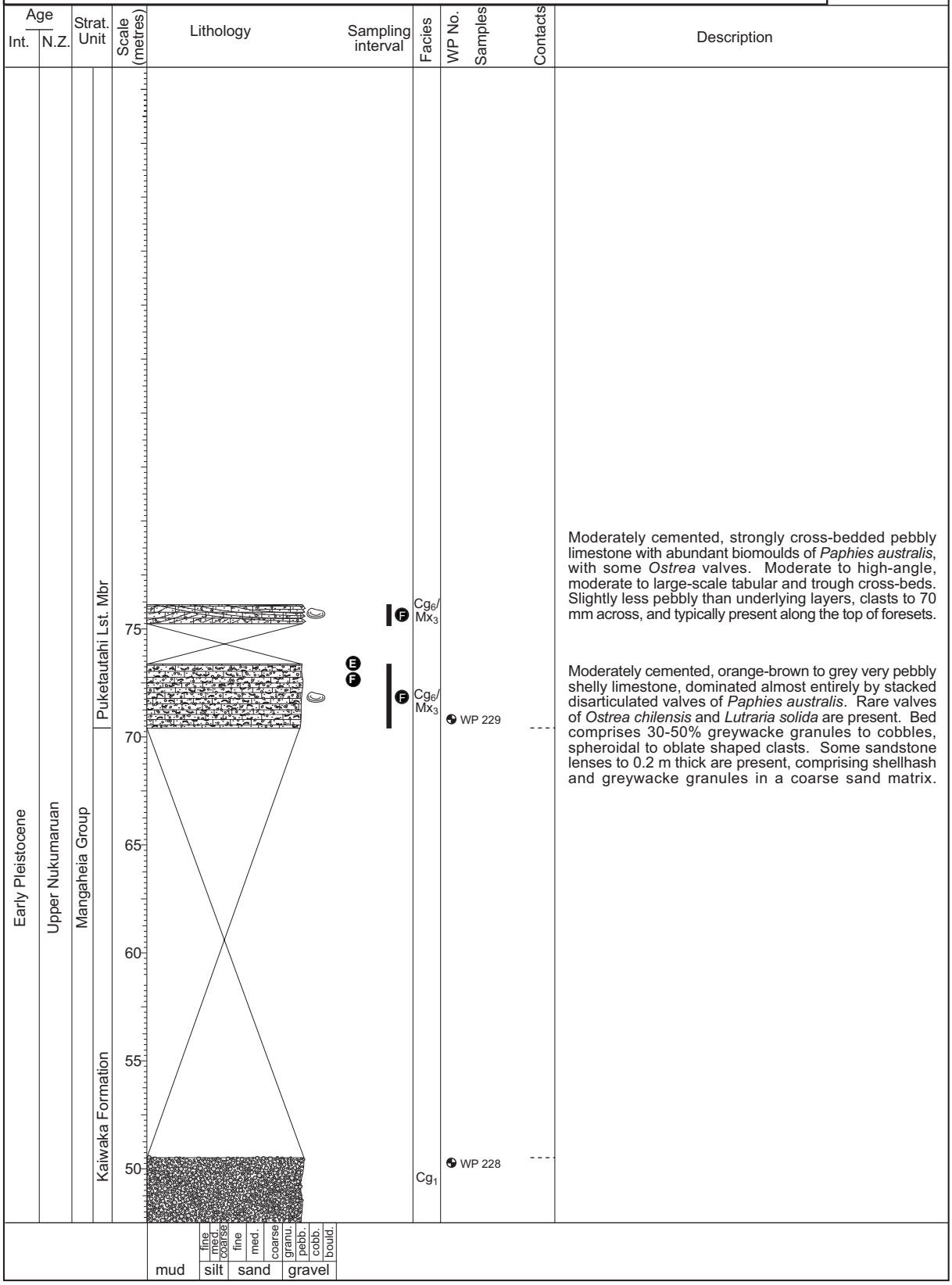
Stratigraphic Column No: *Gg-4* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 222-230 ***E:*** 2834045 2833813

Region: Glengarry ***N:*** 6189871 6192389

Location: Matches farm above Glengarry Road and near "The Gums" ***Altitude:*** 319 m 308 m

NZMS 260 Sheet: V20 Esk, V21 Napier




A


B


C


D


E


F

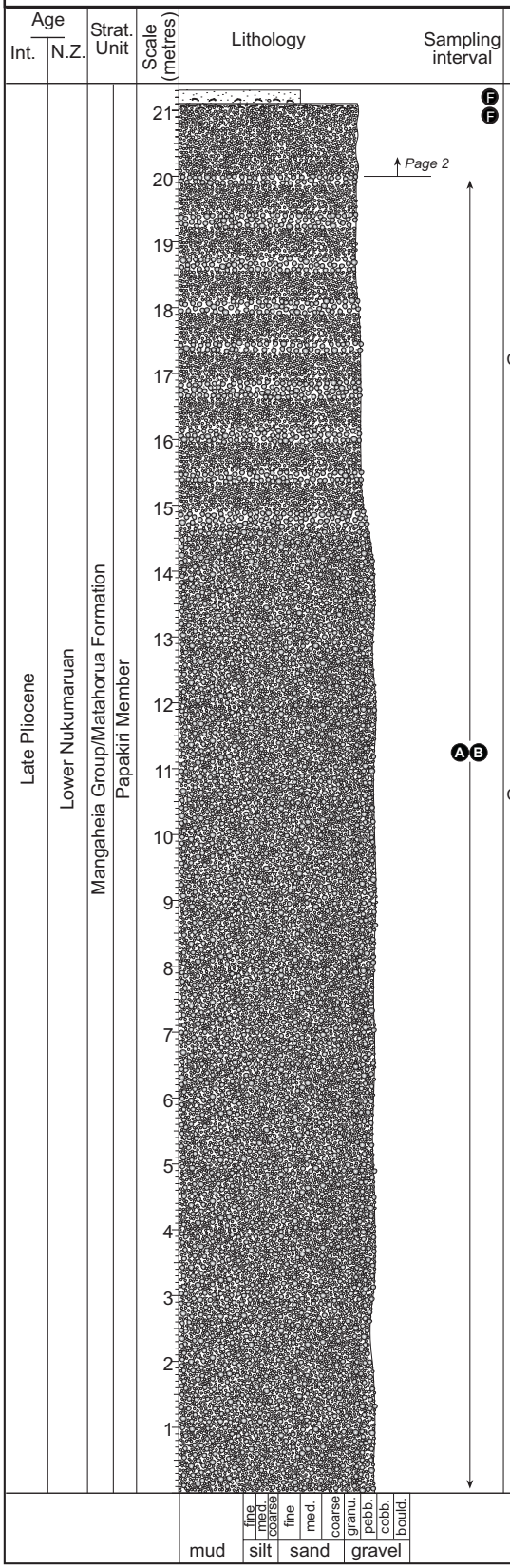
Stratigraphic Column No: *Gg-5* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 517-518 ***E:*** 2830375 -

Region: Glengarry ***N:*** 6197087 -

Location: Mangaone River upstream of Olsen's farm. ***Altitude:*** 98 m -

NZMS 260 Sheet: V20 Esk



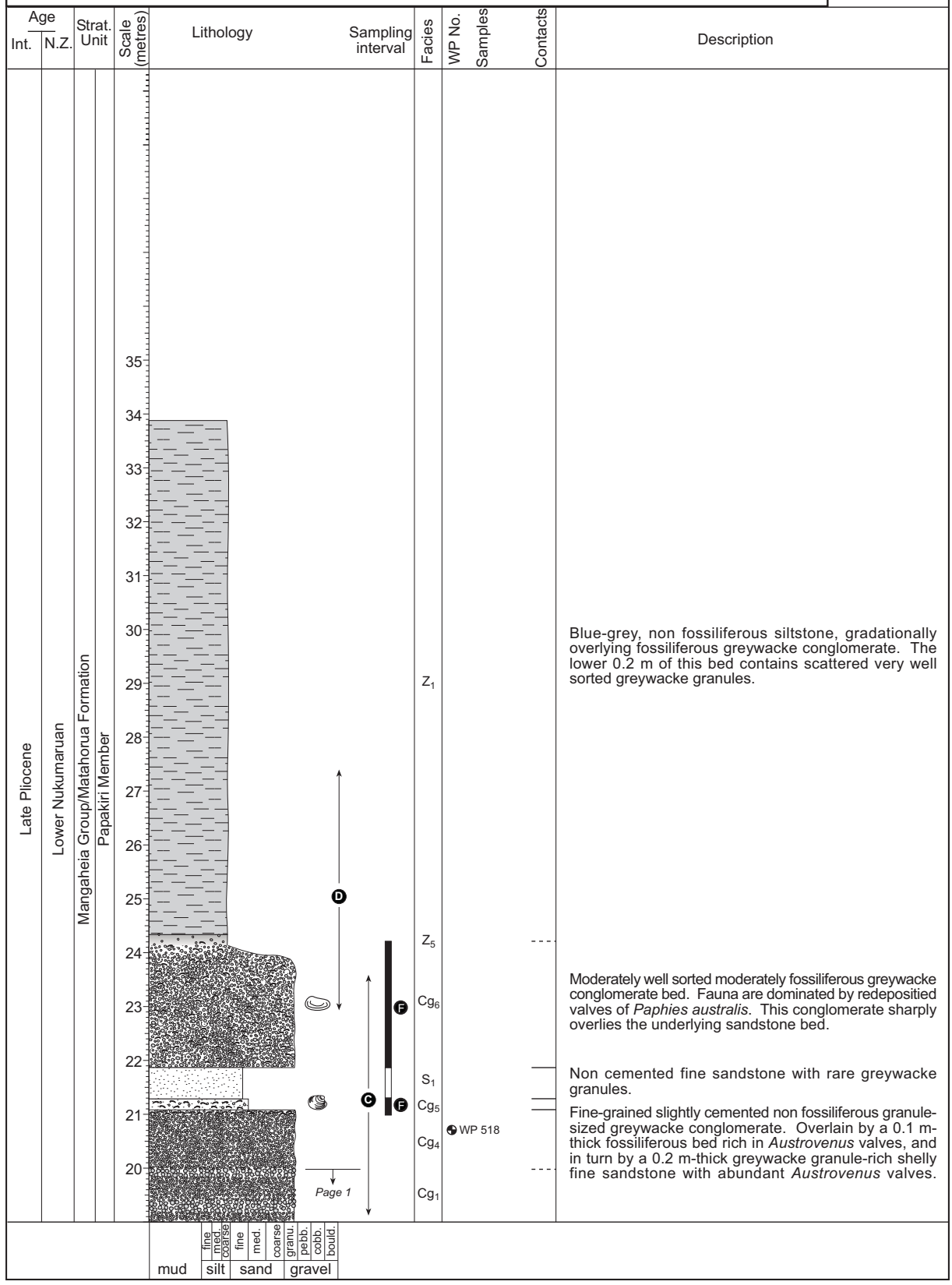
Stratigraphic Column No: Gg-5 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 517-518 ***E:*** 2830375 -

Region: Glengarry ***N:*** 6197087 -

Location: Mangaone River upstream of Olsen's farm. ***Altitude:*** 98m -

NZMS 260 Sheet: V20 Esk




A


B


C


D

Stratigraphic Column No: Gr-1 ***Grid Reference:*** ***Top*** ***Bottom***

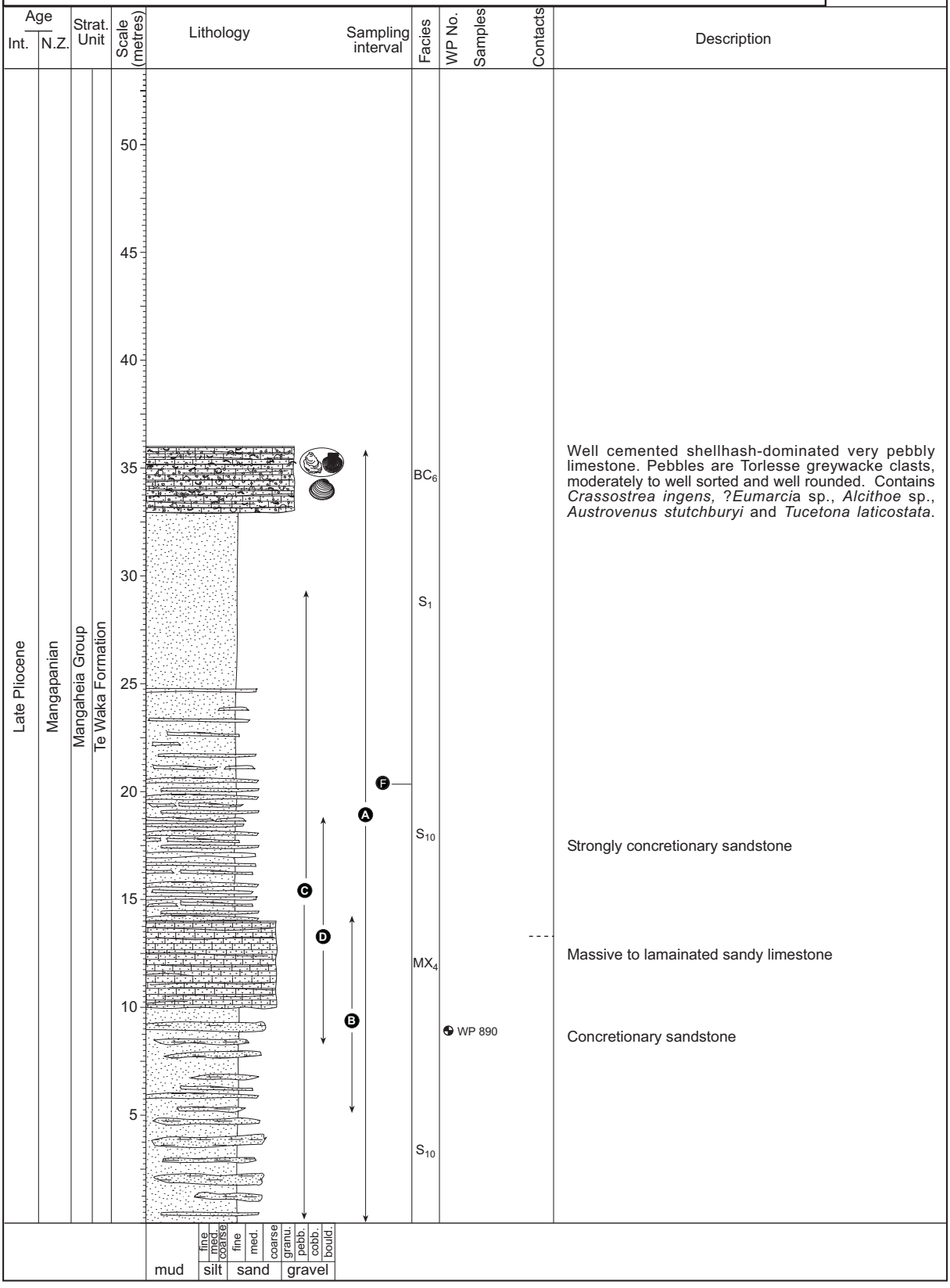
GPS Waypoint No(s): Wp 890 ***E:*** 2804013 -

Region: Glenross ***N:*** 6190395 -

Location: Lizard Road, Kaweka Forest, north end of Glenross Range ***Altitude:*** 796 m -

NZMS 260 Sheet: U20 Kaweka

Page 1 *of* 1




A
Glenross Range
Lizard Road Section


B


C


D

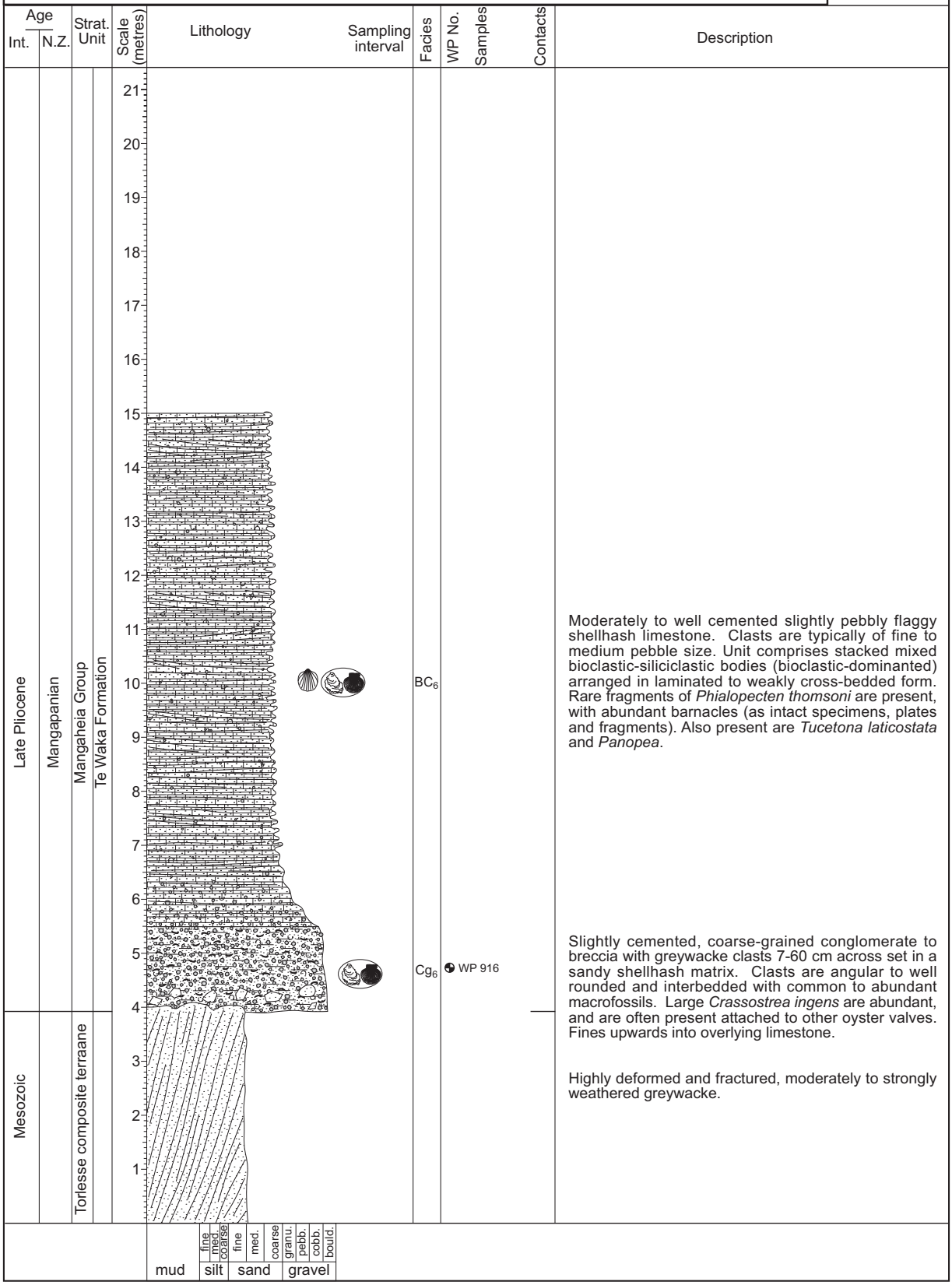
Stratigraphic Column No: Gr-2 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 916 ***E:*** 2804786 -

Region: Glenross ***N:*** 6192787 -

Location: Western side of Sandy Ridge, Kaweka Forest ***Altitude:*** 819 m -

NZMS 260 Sheet: U20 Kaweka *Page* 1 *of* 1



Stratigraphic Column No: *Gr-3*

GPS Waypoint No(s): Wp 939

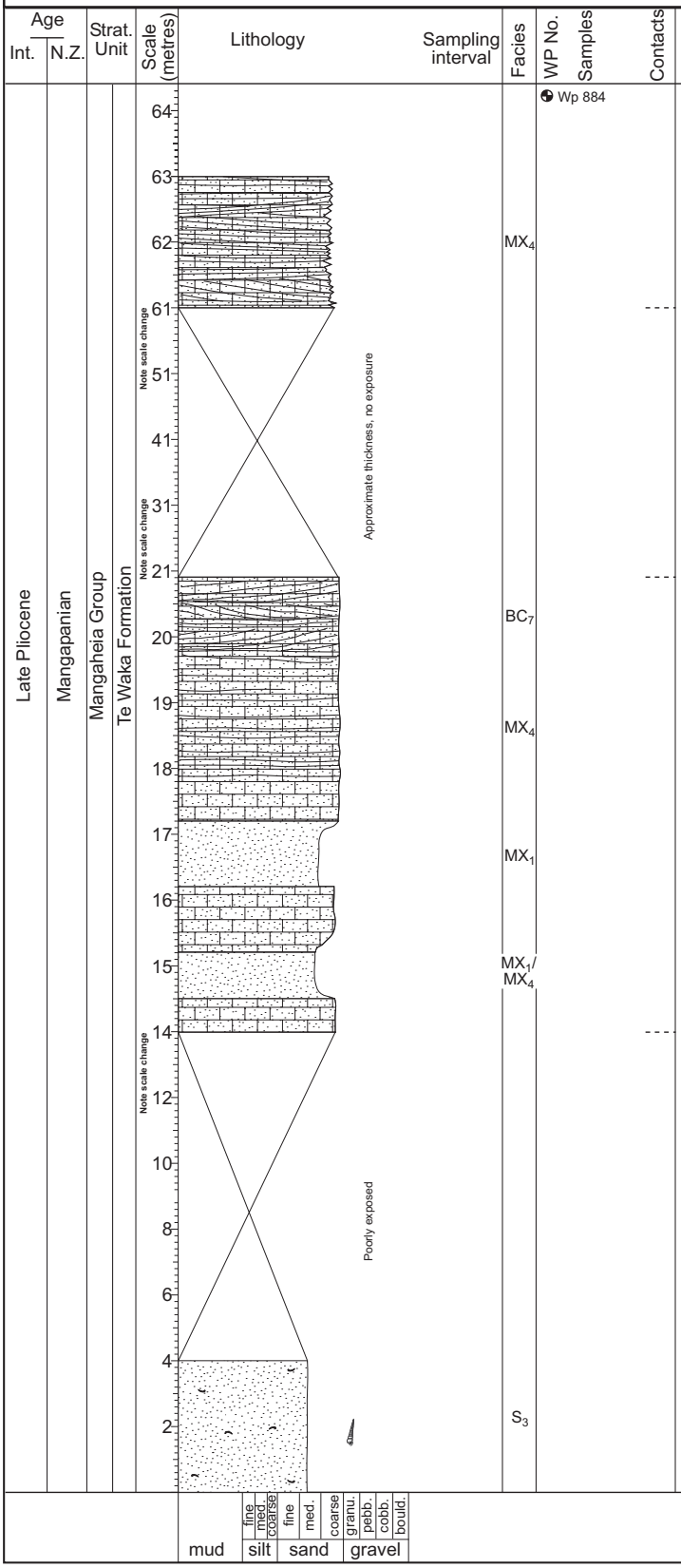
Region: Glenross

Location: Southern end of Glenross Range near Omahaki Road

NZMS 260 Sheet: U21 Kereru

Grid Reference:	***Top***	***Bottom***
E:	2803475	-
N:	6187674	-
Altitude:	575 m	-

Page 1 *of* 1



Stratigraphic Column No: Hw-1 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 159-162 ***E:*** 2815291 2815135

Region: Hawkeston ***N:*** 6197221 6197454

Location: Road cuttings up Price Cockburn Road at "The Incline" ***Altitude:*** 394 m 385 m

NZMS 260 Sheet: V20 Esk

Age: Int. / N.Z. | Strat. Unit | Scale (metres) | Lithology | Sampling interval | Facies | WP No. Samples | Contacts | Description

Late Pliocene / Mangapanian / Mangaheia Group / Te Waka Formation

Page 2

10 9 8 7 6 5 4 3 2 1

S_2

Well sorted, cross-bedded fine sandstone. This unit is bioturbated and burrowed. Burrows are infilled by finer-grained sediment. Mudstone stringers are present capping some of the foresets.

Intensely bioturbated, clean, well sorted fine to medium sandstone. Burrows are filled by finer-grained siltstone.

WP 160

S_1

S_7

Clean, well sorted, non cemented fine to medium sandstone with occasional thin mudstone stringers.

WP 159

mud | silt: fine, med., coarse | sand: fine, med., coarse | gravel: granu., pebb., cobb., bould.

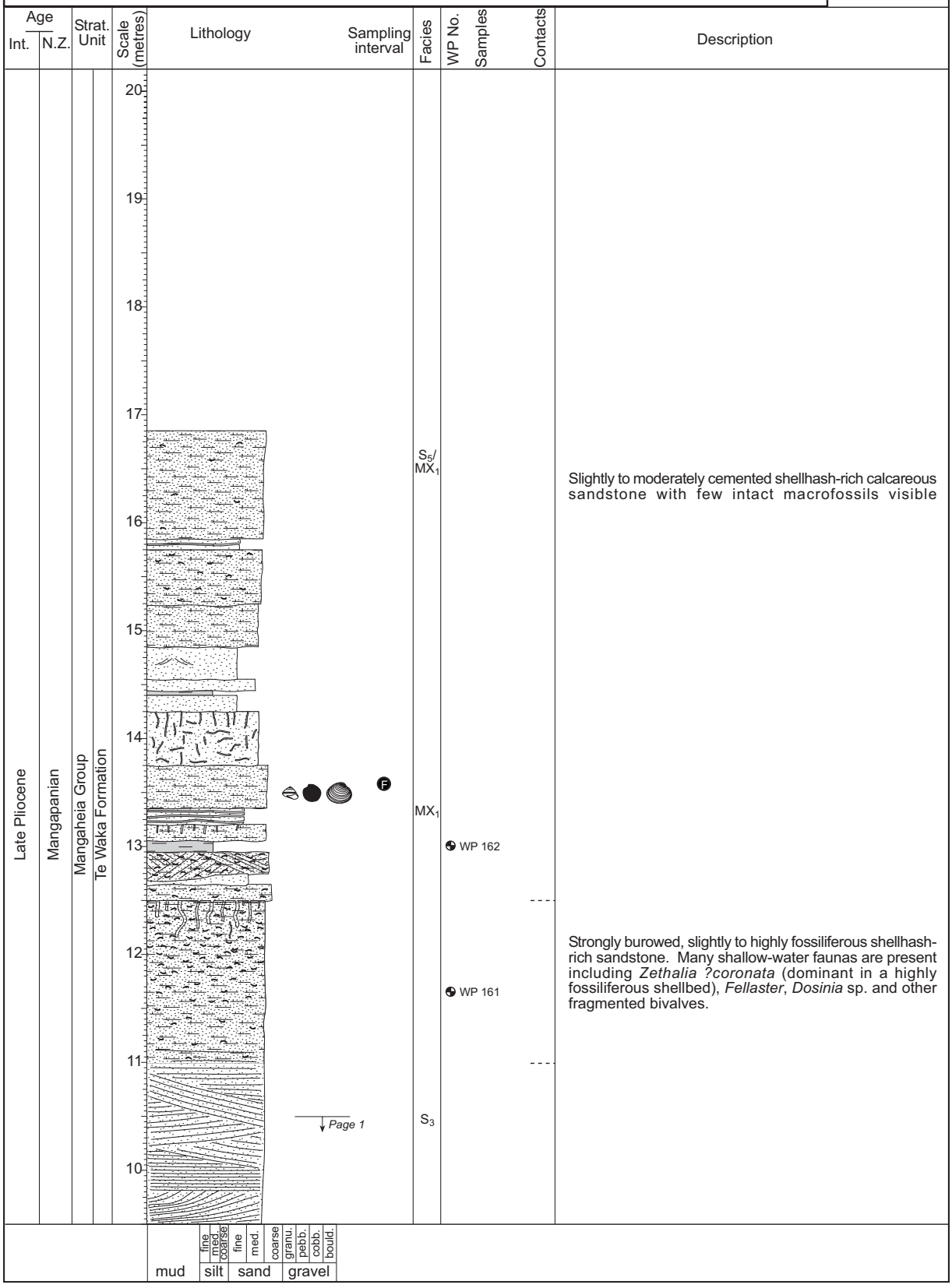
Stratigraphic Column No: *Hw-1* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 159-162 ***E:*** 2815291 2815135

Region: Hawkeston ***N:*** 6197221 6197454

Location: Road cuttings up Price Cockburn road at "The Incline" ***Altitude:*** 394 m 385 m

NZMS 260 Sheet: V20 Esk



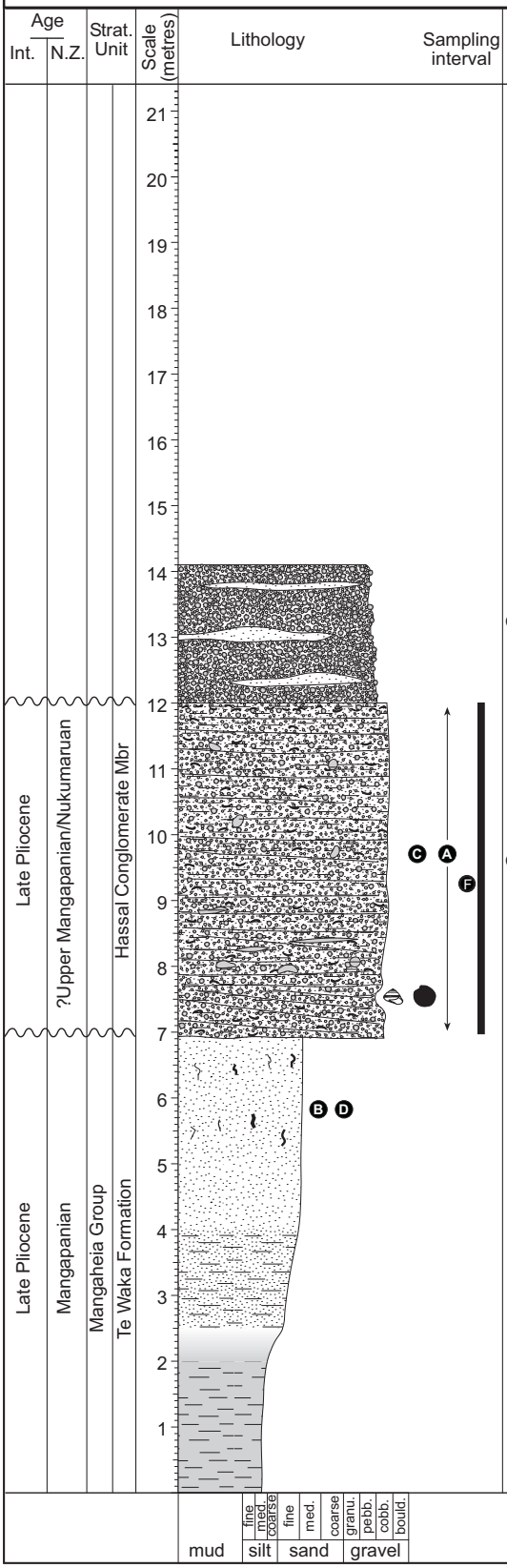
Stratigraphic Column No: Hw-2 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 782 ***E:*** 2816822 -

Region: Hawkston ***N:*** 6202740 -

Location: Top of Mount Hassal, Mount Hassal farm ***Altitude:*** 602 m -

NZMS 260 Sheet: V20 Esk



This section is inferred to immediately overlie the succession exposed in The Gorges approximately 2 km to the southeast.

Non cemented, laminated, well sorted non cemented greywacke conglomerate with some sandstone lenses. Some thin muddy horizons are present that contain lignite debris.

Pebbly limestone to greywacke conglomerate with a bioclastic sandstone matrix. Clasts are moderately to well supported, dominated by Torlesse greywacke but with some Tertiary mudstone clasts. Contains common *Zethalia ?zelandica,* especially in lower parts of the bed. Specimens are abraded and it is difficult to tell whether they are *Z. coronata* (Wm) or *Z. zelandica* (Wn-R). Also contains *Dosinia* sp. and *Panopea*. Abundant biomoulds are present and the matrix throughout is composed of bioclastic shellhash sandstone. Sharply overlies non cemented sandstone. The upper surface is sharp and marked by a concentration of bivalves and scattered large oyster shells.

Non cemented, clean well sorted, non fossiliferous, massive, burrowed, fine to medium sandstone.


A


B


C


D

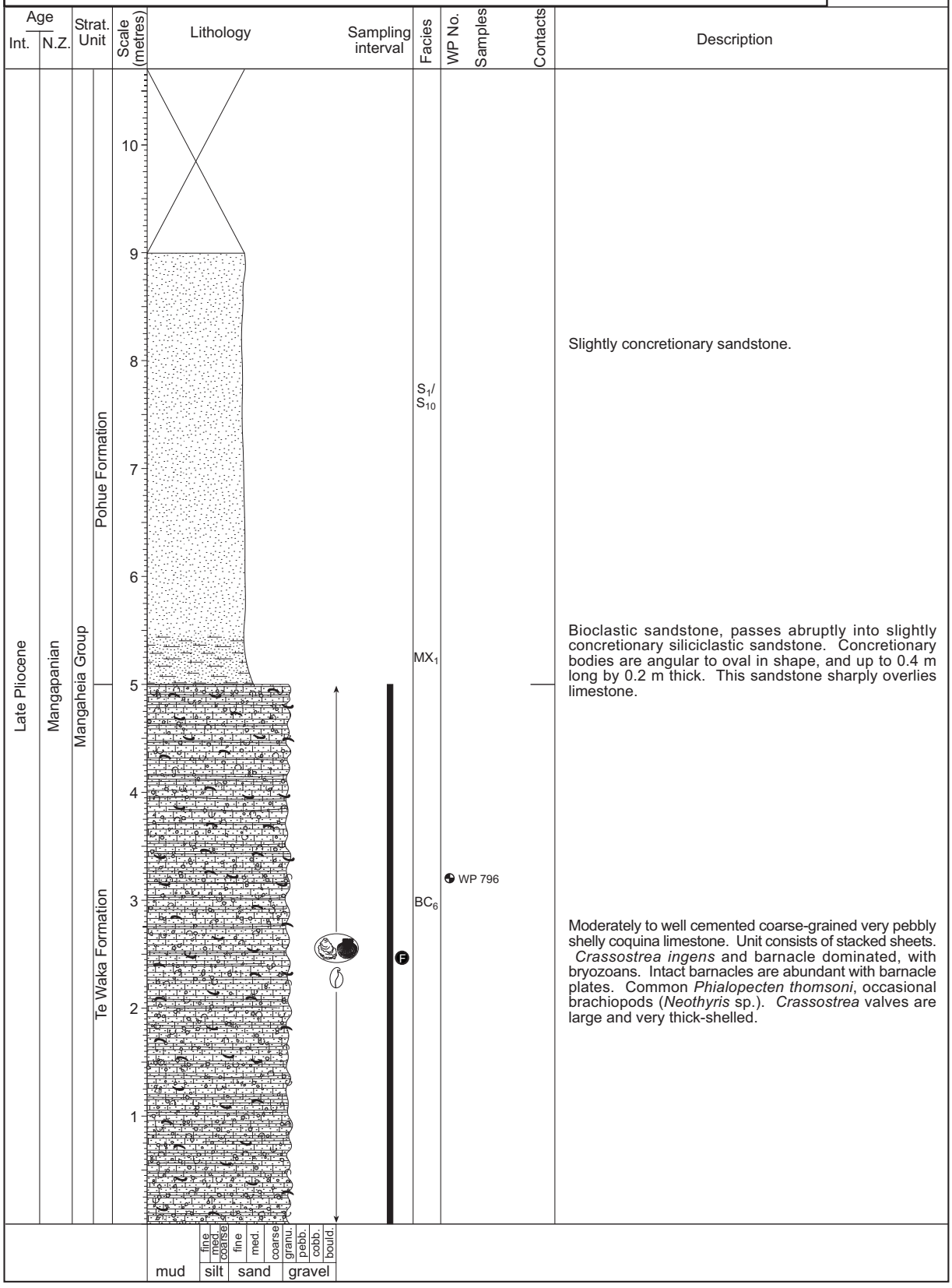
Stratigraphic Column No: Hw-3 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 796 ***E:*** 2813073 -

Region: Hawkston ***N:*** 6200358 -

Location: Seaview Station approximately 250 m west of Hawkston Road ***Altitude:*** 428 m -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1



Stratigraphic Column No: *Hw-4*

GPS Waypoint No(s): Wp 956

Region: Hawkston

Location: Hawkston Lake, Hawkston Station

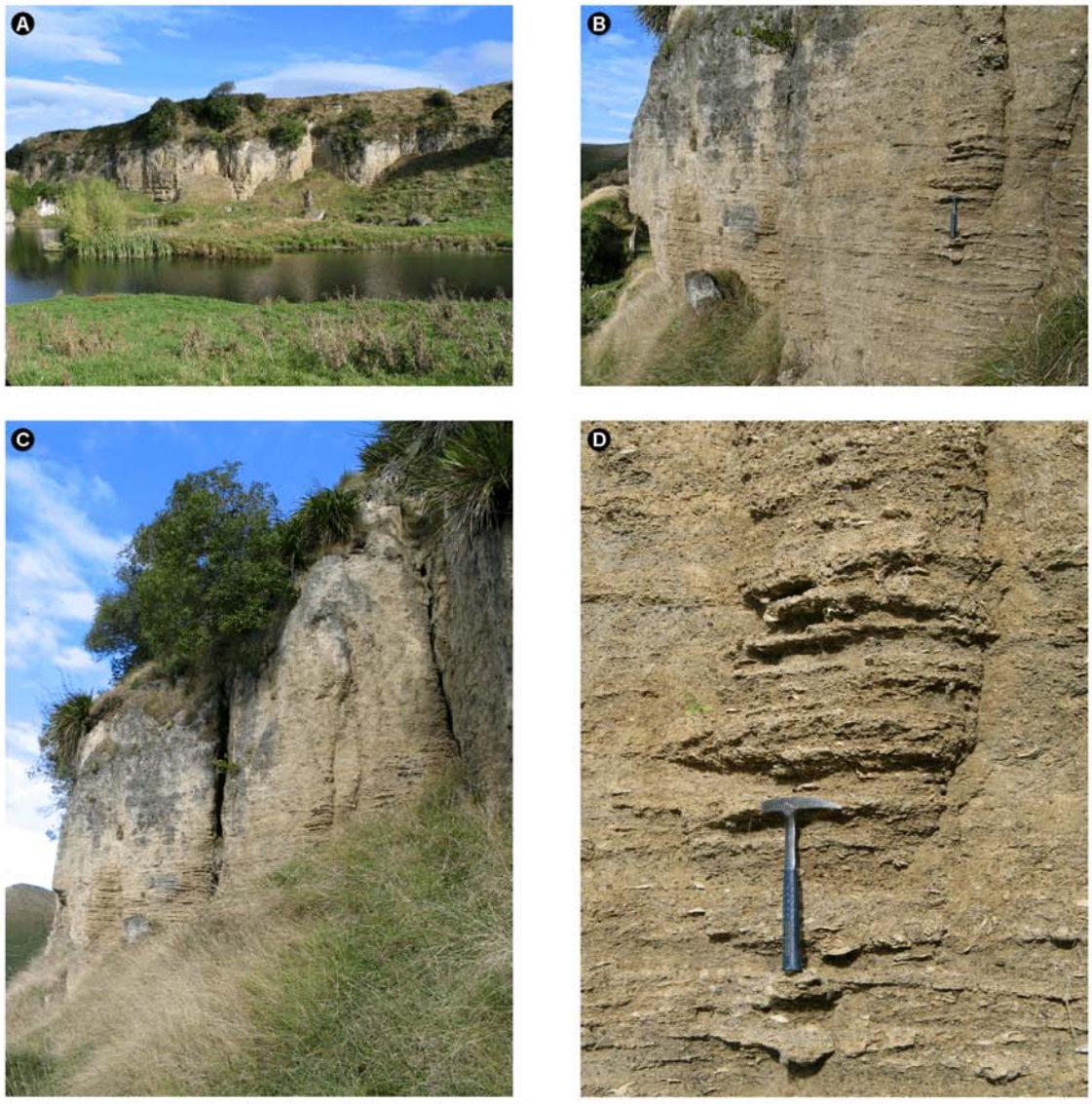
NZMS 260 Sheet: V20 Esk

Grid Reference:	***Top***	***Bottom***
E:	2812814	-
N:	6199510	-
Altitude:	333 m	-

Page 1 *of* 1

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Pliocene	Mangapanian	Mangaheia Group / Te Waka Formation	10–1		A C	BC_6			Massive to weakly laminated, moderately to well cemented shellhash pebbly limestone with abundant whole shells. Barnacle plates are fragmented and abundant. Pebbles are of granule to fine pebble size, greywacke composition and well rounded, lensoidal to spheroidal shapes. Common *Crassostrea ingens, Phialopecten triphooki* and *Patro undatus* are present throughout the unit.
					F				Barnacles commonly attached to shells, and more rarely pebbles.
					B D		WP 956		Stacked 2-5 cm thick pebbly shellhash bodies arranged in cross-straified to laminated patterns. Some broad, low-angle trough cross-bedding is evident. Contains common *Phialopecten thomsoni*.

mud | silt (fine, med., coarse) | sand (fine, med., coarse) | gravel (granu., pebb., cobb., bould.)


A
B
C
D

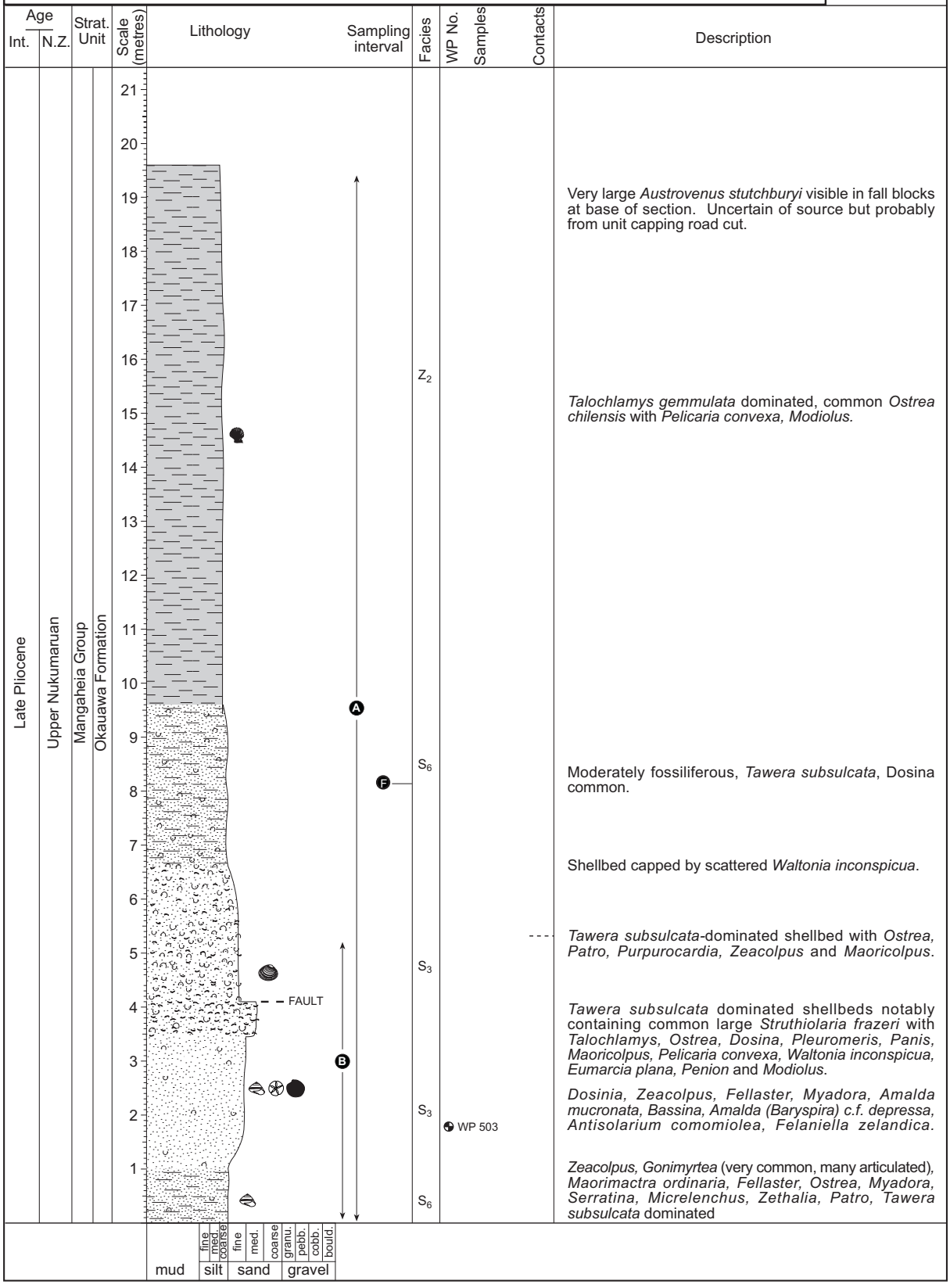
Stratigraphic Column No: Ke-1 **Grid Reference:** **Top** **Bottom**

GPS Waypoint No(s): Wp 503 **E:** 2809423 -

Region: Kereru **N:** 6168965 -

Location: Kereru Road at bridge over Whanakino Stream **Altitude:** 174 m -

NZMS 260 Sheet: V21 Napier




A


B
Struthiolaria frazeri bed

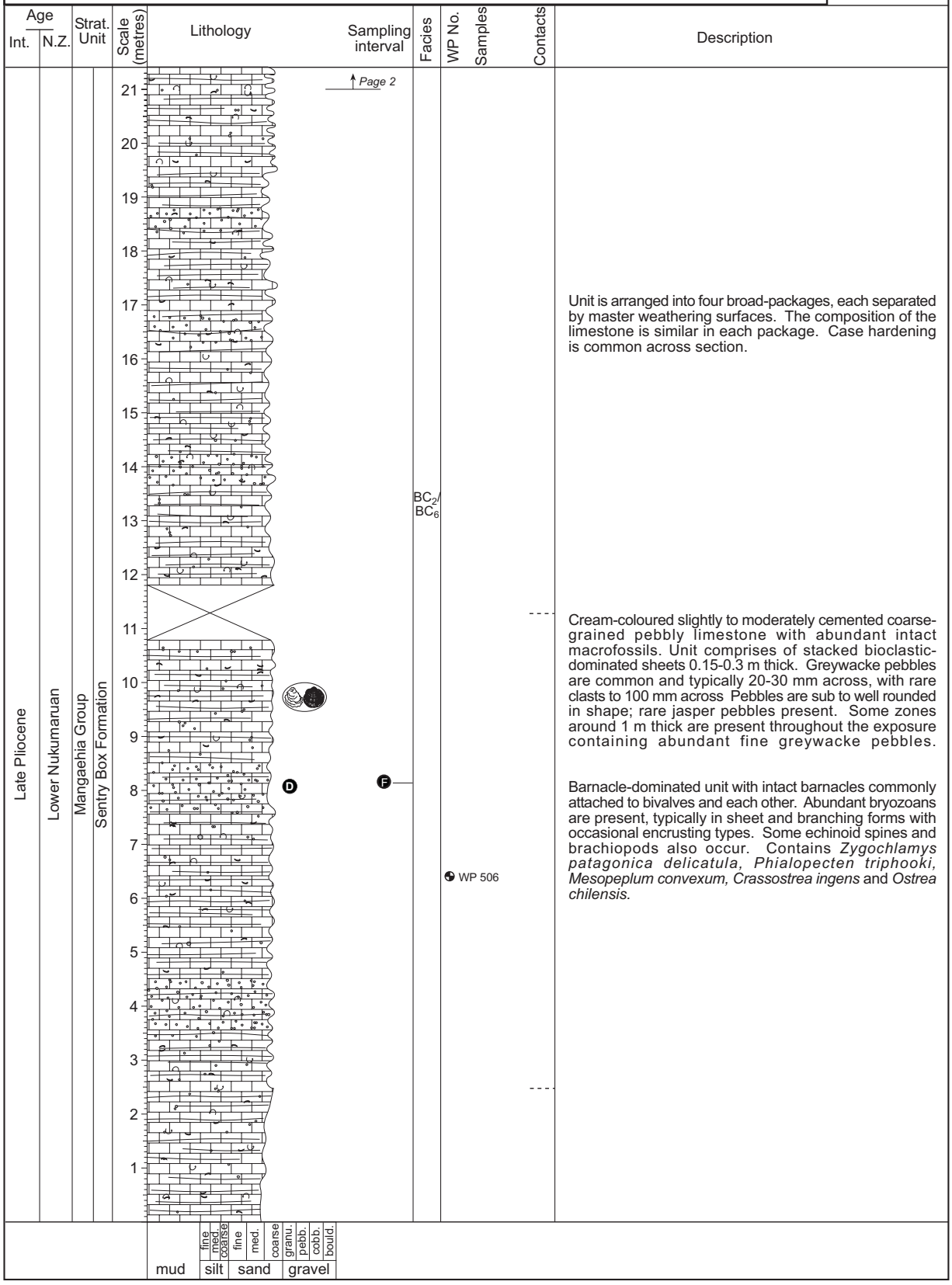
Stratigraphic Column No: Ke-2 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 506 ***E:*** - 2792572

Region: Kereru ***N:*** - 6166364

Location: Sentry Box Scenic Reserve off Mangleton Road, Ohara Depression ***Altitude:*** - 585 m

NZMS 260 Sheet: U21 Kereru



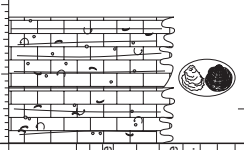
Stratigraphic Column No: Ke-2 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 506 ***E:*** - 2792572

Region: Kereru ***N:*** - 6166364

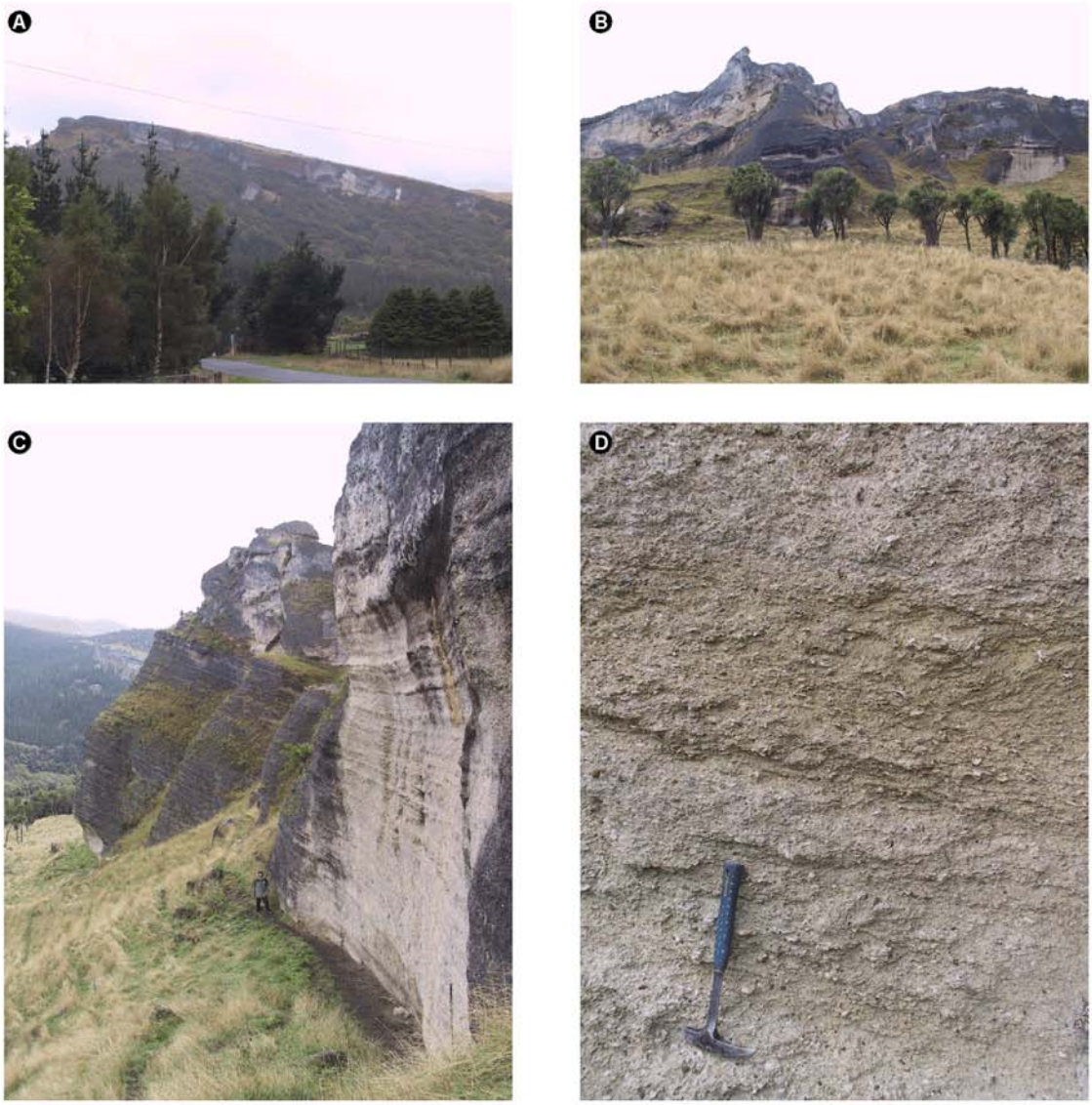
Location: Sentry Box Scenic Reserve off Mangleton Road, Ohara Depression ***Altitude:*** - 585 m

NZMS 260 Sheet: U21 Kereru

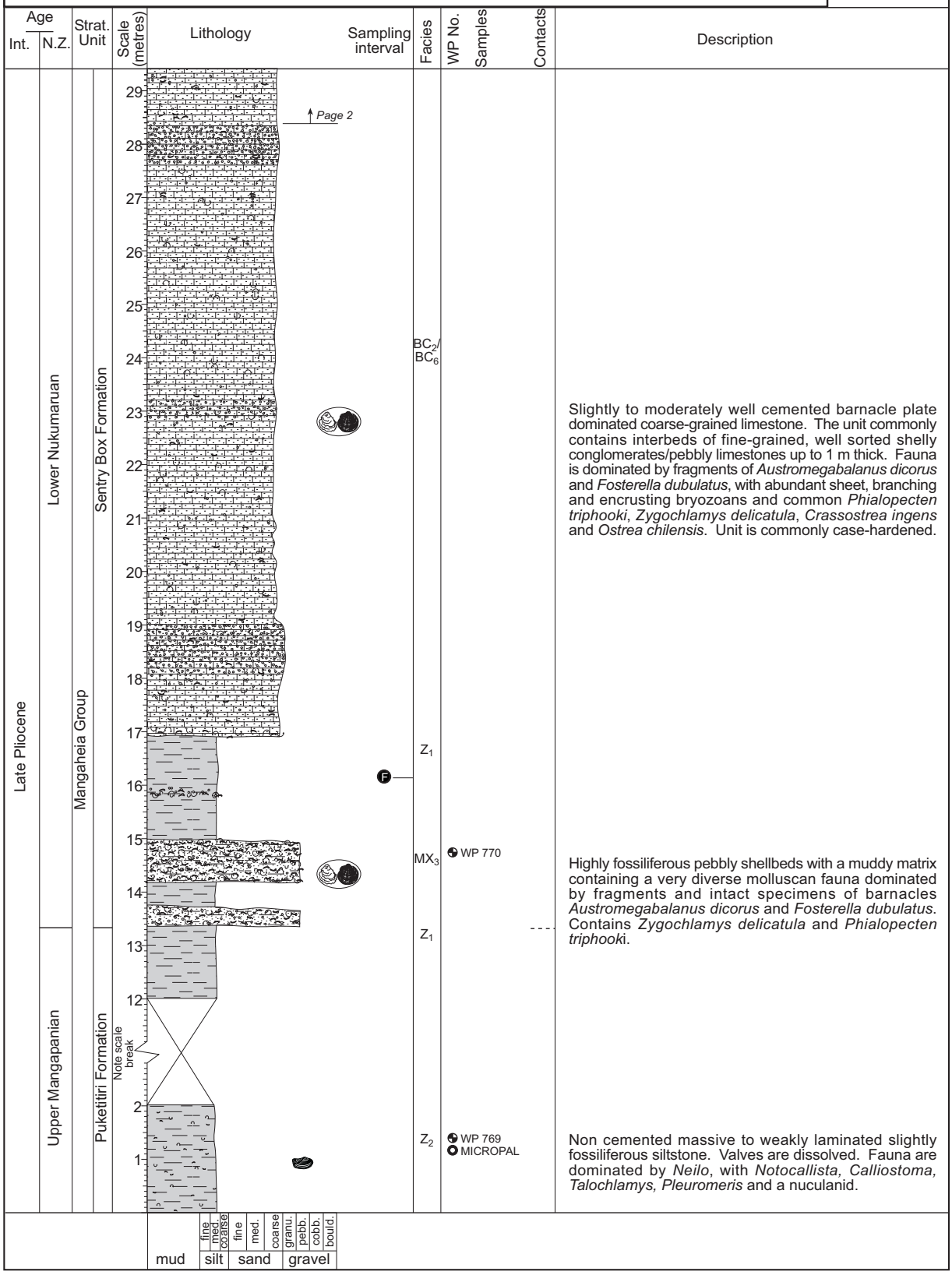
Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Lower Nukumaruan	Mangaehia Group / Sentry Box Formation	35 34 33 32 31 30 29 28 27 26 25 24 23 22		F	BC_2/ BC_6			Barnacle-dominated unit with intact barnacles commonly attached to bivalves and each other. Abundant bryozoans are present, typically in sheet and branching forms with occasional encrusting types. Some echinoid spines and brachiopods also occur. Contains *Phialopecten triphooki, Mesopeplum convexum, Crassostrea ingens* and *Ostrea chilensis*.

Page 1

mud | silt (fine, med, coarse) | sand (fine, med., coarse) | gravel (granu., pebb., cobb., bould.)


A
B
C
D

Stratigraphic Column No: Ke-3	***Grid Reference:***	***Top***	***Bottom***
GPS Waypoint No(s): Wp 506-507, 769-771	***E:***	2792572	2793509
Region: Kereru	***N:***	6166364	6166513
Location: Jumped Up Stream/Sentry Box Hill Composite	***Altitude:***	585 m	454 m
NZMS 260 Sheet: U21 Kereru	*Page* 1 *of* 3		



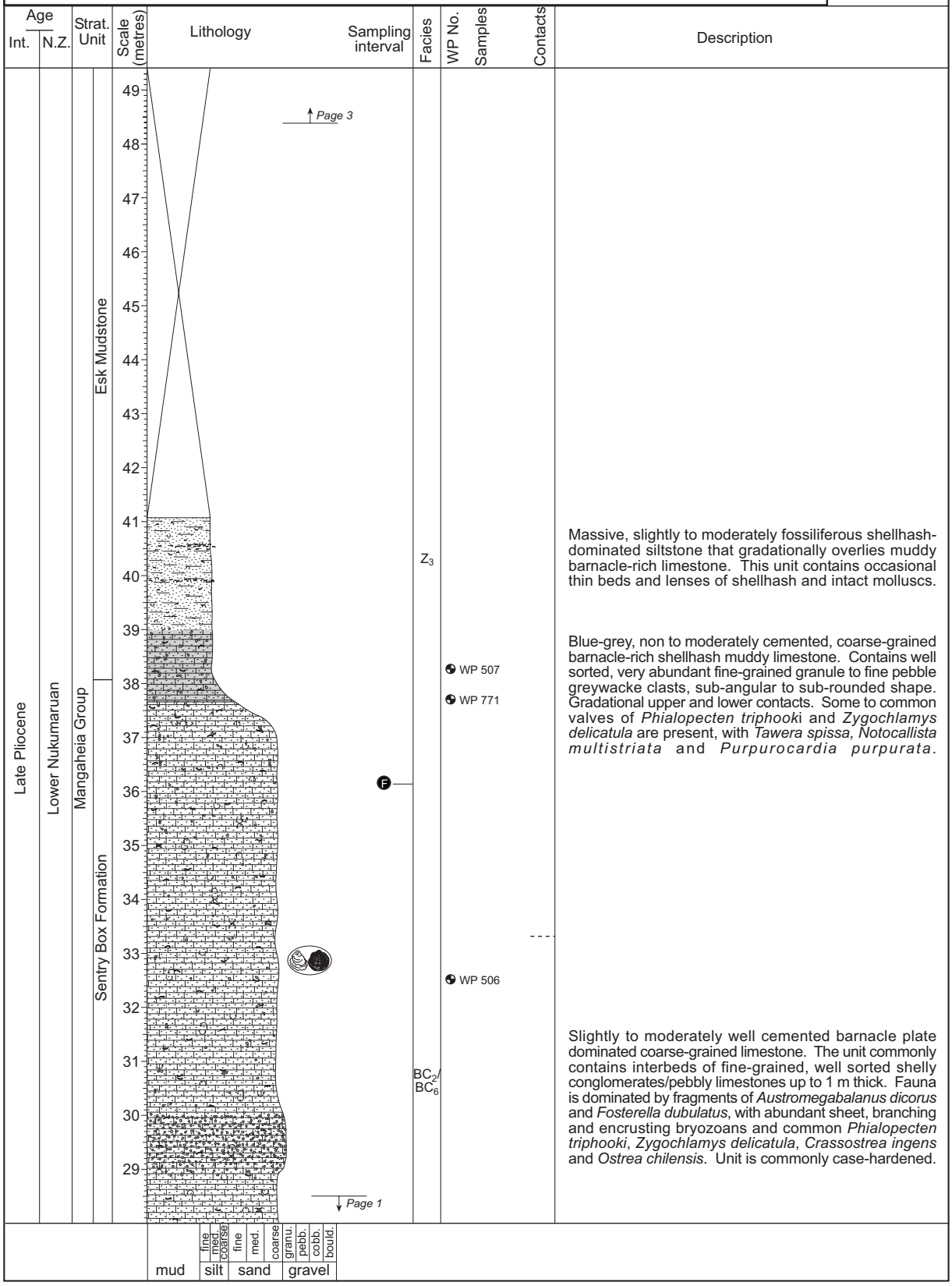
Stratigraphic Column No: *Ke-3* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 506-507, 769-771 ***E:*** 2793370 2793509

Region: Kereru ***N:*** 6166364 6166513

Location: Jumped Up Stream/Sentry Box Hill Composite ***Altitude:*** 585 m 454 m

NZMS 260 Sheet: U21 Kereru *Page* 2 *of* 3



Stratigraphic Column No: Ke-3 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 506-507, 769-771 ***E:*** 2793370 2793509

Region: Kereru ***N:*** 6166364 6166513

Location: Jumped Up Stream/Sentry Box Hill Composite ***Altitude:*** 585 m 454 m

NZMS 260 Sheet: U21 Kereru *Page* 3 *of* 3

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Lower Nukumaruan	Mangaheia Group / Esk Mudstone	69–49		F	Z_3			Massive, non cemented sparsely to moderately fossiliferous sandy siltstone. Fauna dominated by *Tawera subsulcata* with *Pratulum pulchellum, Zenatia acinaces, Atrina pectinata zelandica* and *Austrofusus* sp.

Page 2

mud | silt (fine, med., coarse) | sand (fine, med., coarse) | gravel (granu., pebb., cobb., bould.)

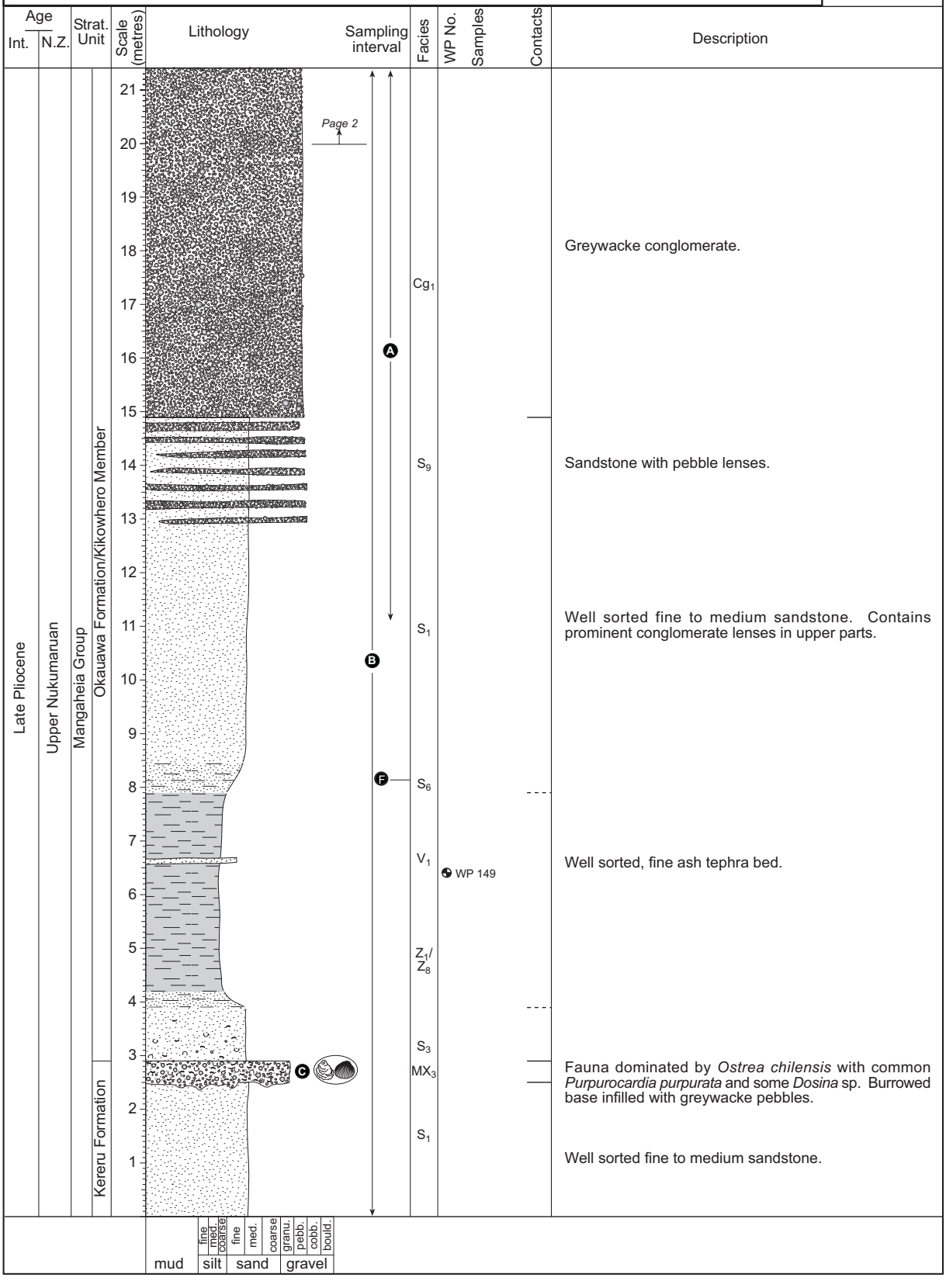
Stratigraphic Column No: *Ke-4* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 868 ***E:*** 2804656 -

Region: Kereru ***N:*** 6172771 -

Location: Ohara Stream several hundred metres below Big Hill Road bridge ***Altitude:*** 184 m -

NZMS 260 Sheet: U21 Kereru *Page* 1 *of* 2



Stratigraphic Column No: Ke-4 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 868 ***E:*** 2804656 -

Region: Kereru ***N:*** 6172771 -

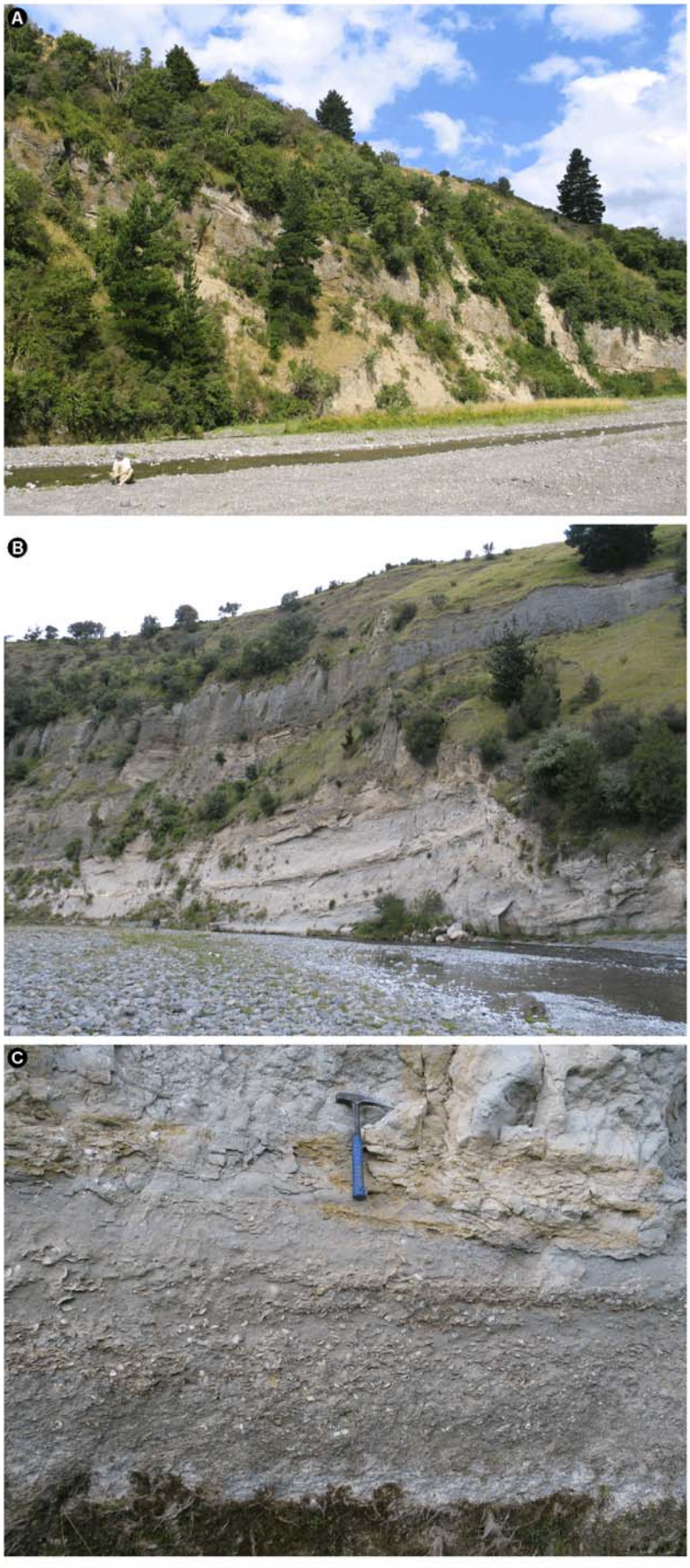
Location: Ohara Stream several hundred metres below Big Hill Road bridge ***Altitude:*** 184 m -

NZMS 260 Sheet: U21 Kereru

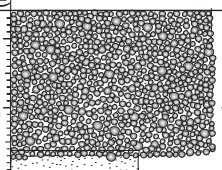
Page 2 of 2

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Quaternary	Haweran	Recent gravels	42–21				WP 149		Terrace gravels.
						Cg_1			
Late Pliocene	Upper Nukumaruan	Okauawa Formation				Z_1			
		Whaka. Mbr			A B				
		Kikowhero Mbr							Greywacke conglomerate.
					Page 1	Cg_1			

mud | silt (fine, med., coarse) | sand (fine, med., coarse) | gravel (granu., pebb., cobb., bould.)


A
B
C

Stratigraphic Column No: Ke-5	***Grid Reference:***	***Top***	***Bottom***
GPS Waypoint No(s): WP 871	***E:***	2805591	-
Region: Kereru	***N:***	6173792	-
Location: Poporangi Stream-Ohara Stream confluence	***Altitude:***	180 m	-
NZMS 260 Sheet: U21 Kereru		*Page* 1 *of* 2	

Age Int.	Age N.Z.	Strat. Unit		Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Lower Nukumaruan	Mangaheia Group/Okauawa Formation	Whakamarumaru Member	50		Page 2	Cg_1			Slightly cemented greywacke conglomerate. Sharp slightly erosional base.
				45			S_1			Non fossiliferous massive to weakly laminated, fine to medium sandstone.
				40						
				35			S_6			
				30						
				25		A	Z_1			Non cemented coarsening-upwards siltstone
			Kikowhero Member	20		F	Cg_6			Moderately to highly fossiliferous pebbly shellbed.
				15			Cg_1			Slightly cemented greywacke conglomerate. Sharp slightly erosional base.
				10						
				5			S_1	WP 871		Non fossiliferous massive to weakly laminated fine to medium sandstone.

mud	silt	sand	gravel
	fine, med., coarse	fine, med., coarse	granu., pebb., cobb., bould.

Stratigraphic Column No: Ke-5 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): WP 871 ***E:*** 2805591 -

Region: Kereru ***N:*** 6173792 -

Location: Poporangi Stream-Ohara Stream confluence ***Altitude:*** 180 m -

NZMS 260 Sheet: U21 Kereru *Page 2 of 2*



Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Recent	Haweran	Recent gravels	65						Non cemented moderately to poorly sorted terrace gravels. Clasts are sub to well rounded and of pebble to boulder size.
Late Pliocene	Upper Nukumaruan	Mangaheia Group (Okauawa Fm/Whakamarumaru Mbr)	60			Cg_1			
			55						Slightly cemented greywacke conglomerate. Sharp slightly erosional base.
			50			S_1			

Page 1

mud | silt (fine, med., coarse) | sand (fine, med., coarse) | gravel (granu., pebb., cobb., bould.)

Stratigraphic Column No: Ke-6 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 873 ***E:*** 2797172 -

Region: Kereru ***N:*** 6171783 -

Location: Gull Flat Road immediately below Rocky Outcrop ***Altitude:*** 401 m -

NZMS 260 Sheet: U21 Kereru *Page* 1 *of* 1

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Lower Nukumaruan	Mangaheia Group / Sentry Box Formation	5–6		F	BC_7			Slightly to moderately cemented massive to laminated sandy limestone with occasional areas of trough cross-bedding. Slightly pebbly, clasts are of granule to fine pebble size and are well rounded and well sorted. Bryozoan fragments are common through the bed with some barnacles.
	Upper Mangapanian	Puketitiri Formation	1–2			Cg_7	WP 873		Greywacke conglomerate/breccia comprising angular to subrounded clasts 0.4-0.5 m across.
						MX_1			Non cemented massive fine to medium sandstone with scattered shellhash throughout the bed.

mud | silt (fine, med, coarse) | sand (fine, med, coarse) | gravel (granu., pebb., cobb., bould.)

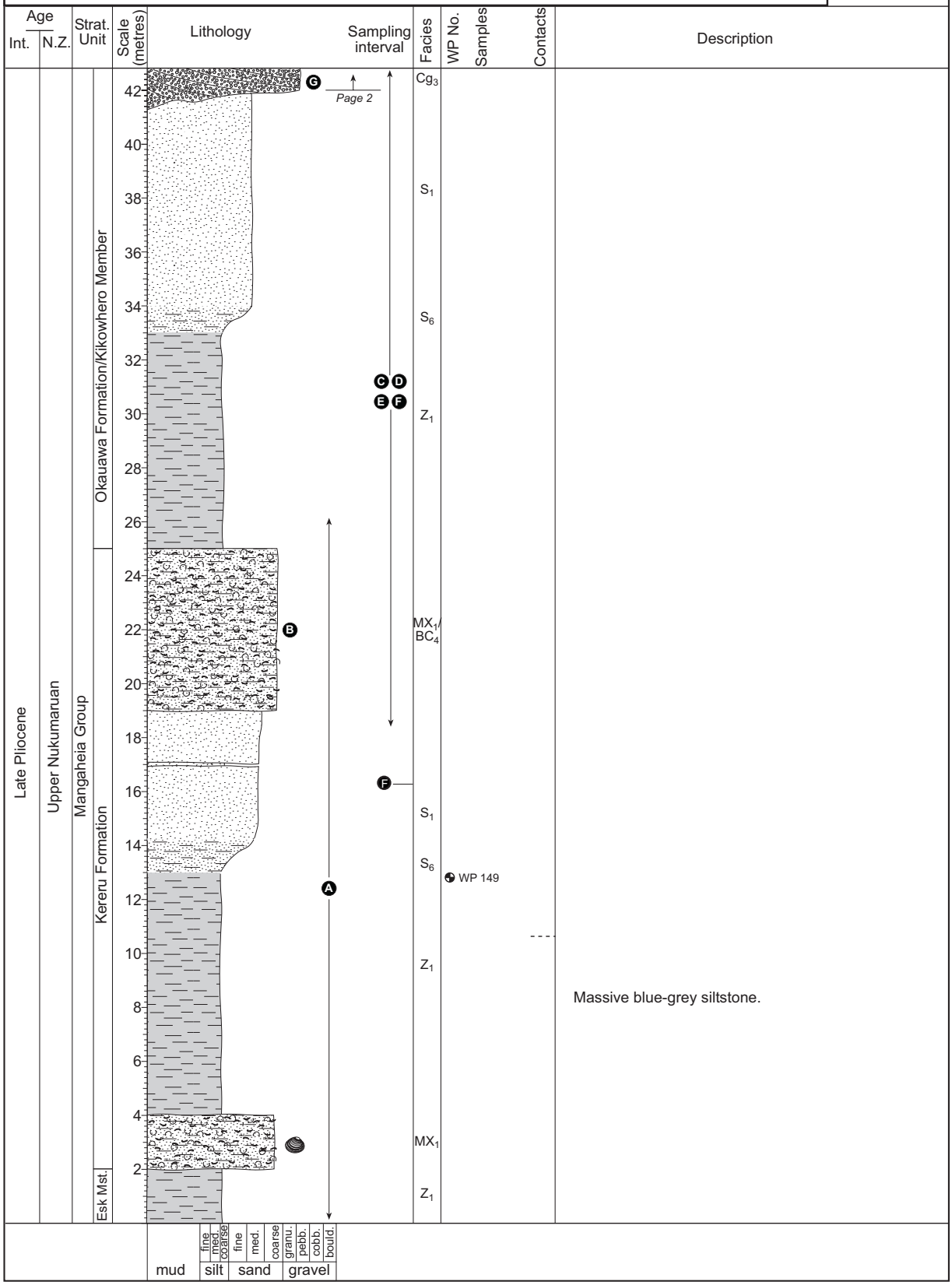
Stratigraphic Column No: *Ke-7* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 877 ***E:*** 2802643 -

Region: Kereru ***N:*** 6172062 -

Location: Ohara Stream at Big Hill Stream confluence ***Altitude:*** 205 m -

NZMS 260 Sheet: U21 Kereru



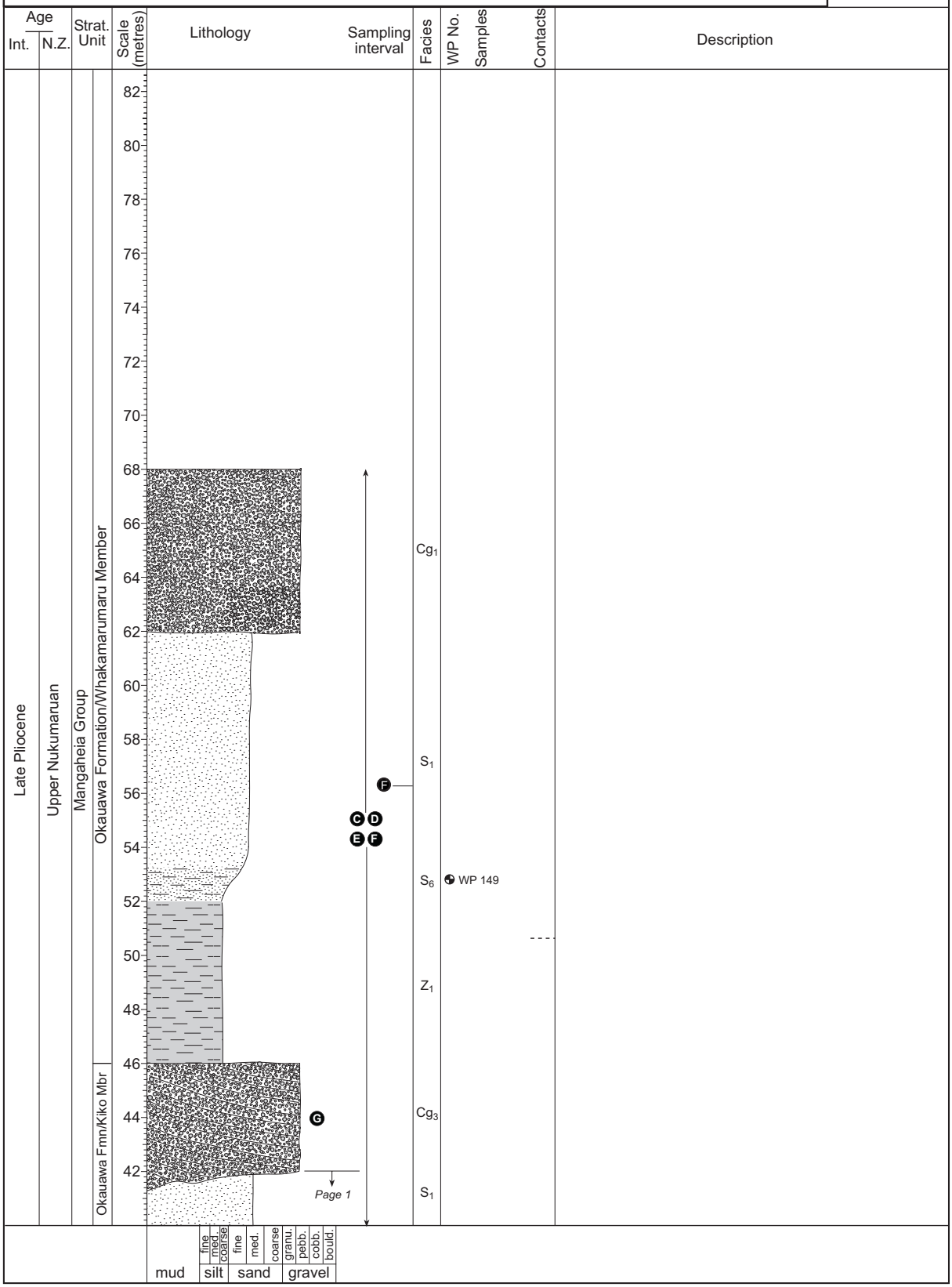
Stratigraphic Column No: Ke-7 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 877 ***E:*** 2802643 -

Region: Kereru ***N:*** 6172062 -

Location: Ohara Stream at Big Hill Stream confluence ***Altitude:*** 205 m -

NZMS 260 Sheet: U21 Kereru *Page 2 of 2*




A


B


C


D


E


F


G

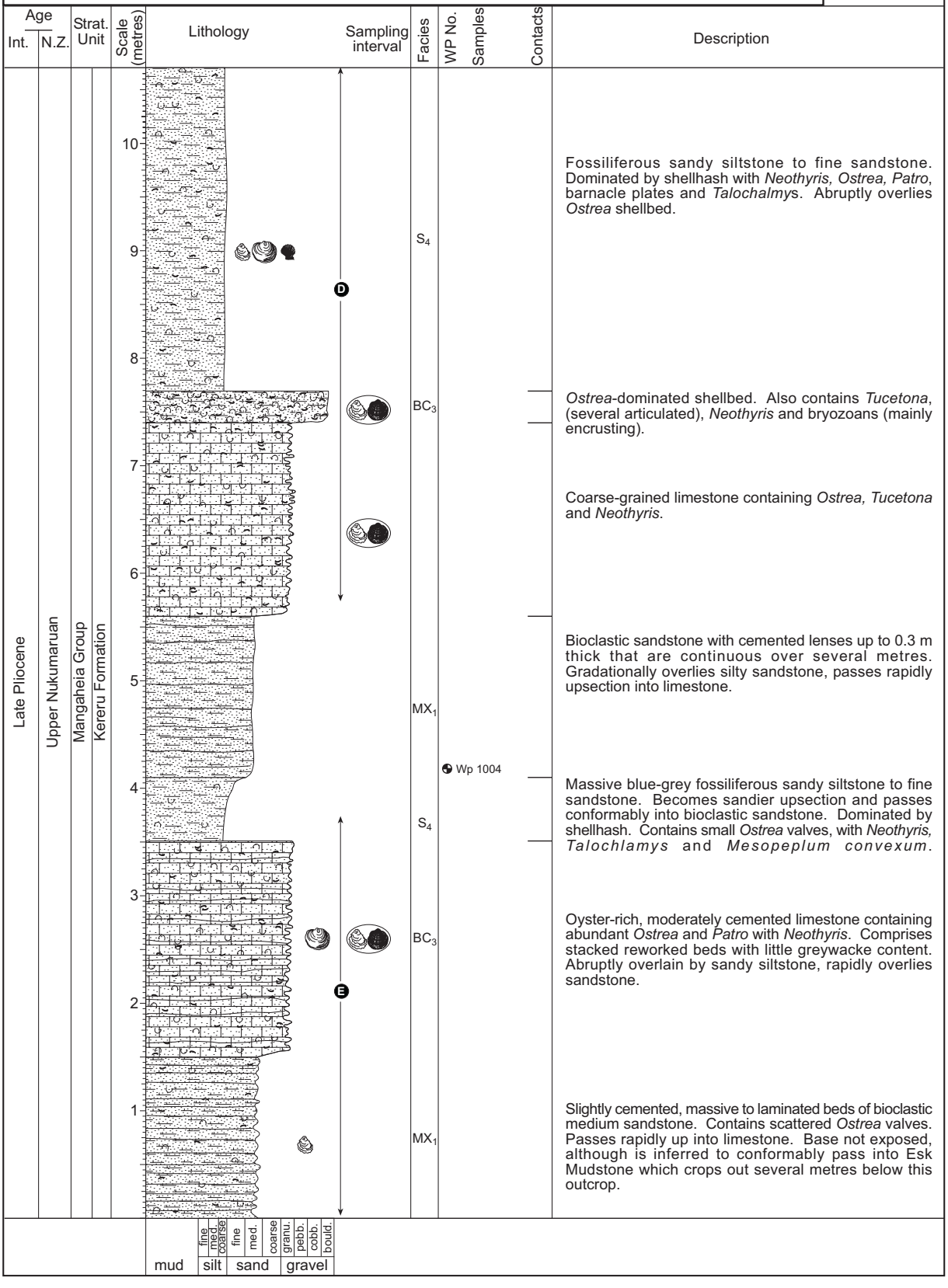
Stratigraphic Column No: Ke-8 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): 1004 ***E:*** 2796869 -

Region: Kereru ***N:*** 6168447 -

Location: Glendale Farm below Mount Mary on farm track beside Mohaka Fault ***Altitude:*** 484 m -

NZMS 260 Sheet: U21 Kereru



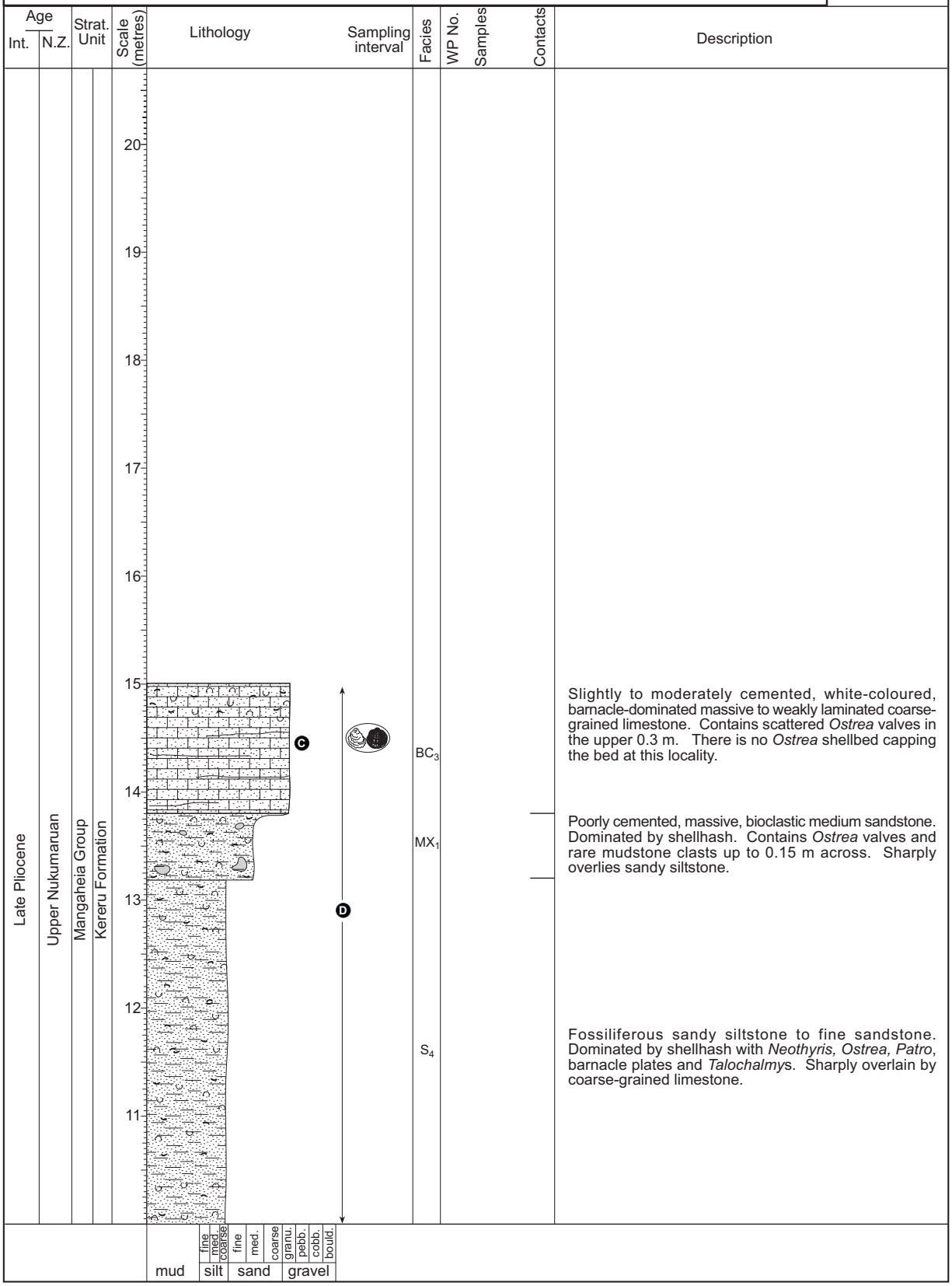
Stratigraphic Column No: *Ke-8* ***Grid Reference:*** ***Top*** ***Bottom***

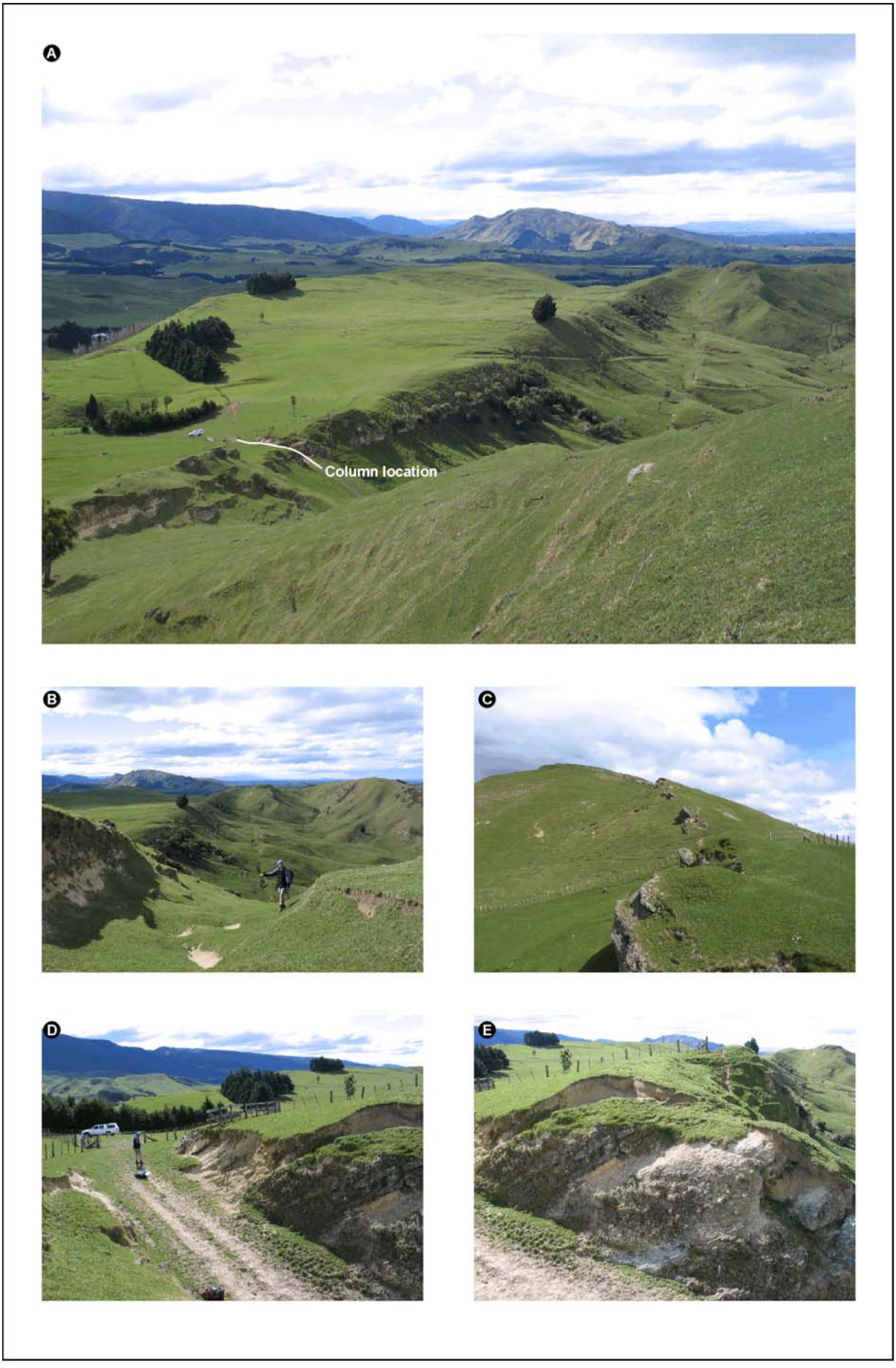
GPS Waypoint No(s): 1004 ***E:*** 2796869 -

Region: Kereru ***N:*** 6168447 -

Location: Glendale Farm below Mount Mary on farm track beside Mohaka Fault ***Altitude:*** 484 m -

NZMS 260 Sheet: U21 Kereru




A
Column location
B
C
D
E

Stratigraphic Column No: *Ku-1*

GPS Waypoint No(s): Wp 487

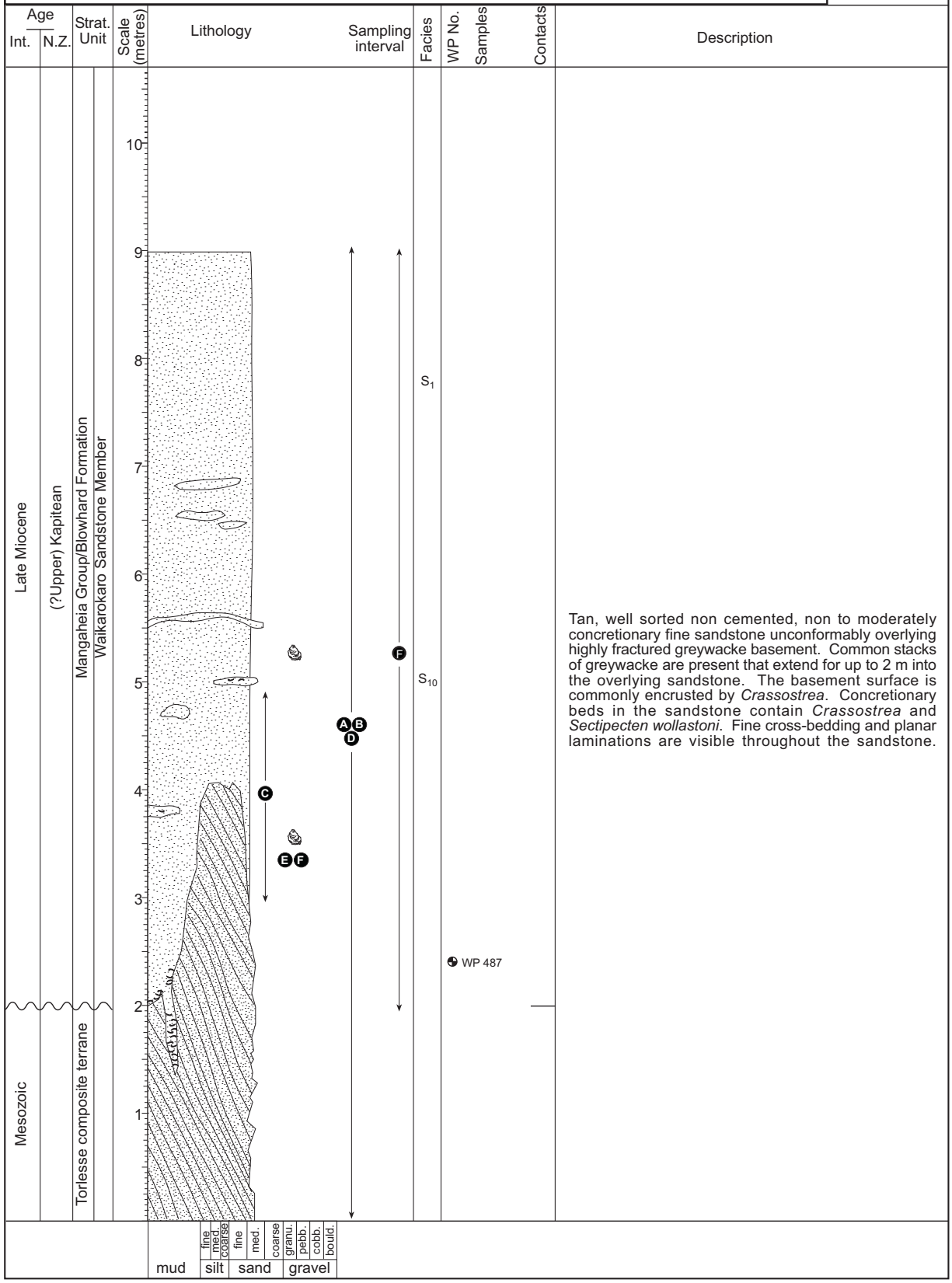
Region: Kuripapango

Location: Quarry off Kuripapango Road towards Kuripapango lakes

NZMS 260 Sheet: V20 Esk

Grid Reference:	***Top***	***Bottom***
E:	2799440	-
N:	6198184	-
Altitude:	641m	-

Page 1 *of* 1




A


B


C


D


E


F

Stratigraphic Column No: *Ku-2*

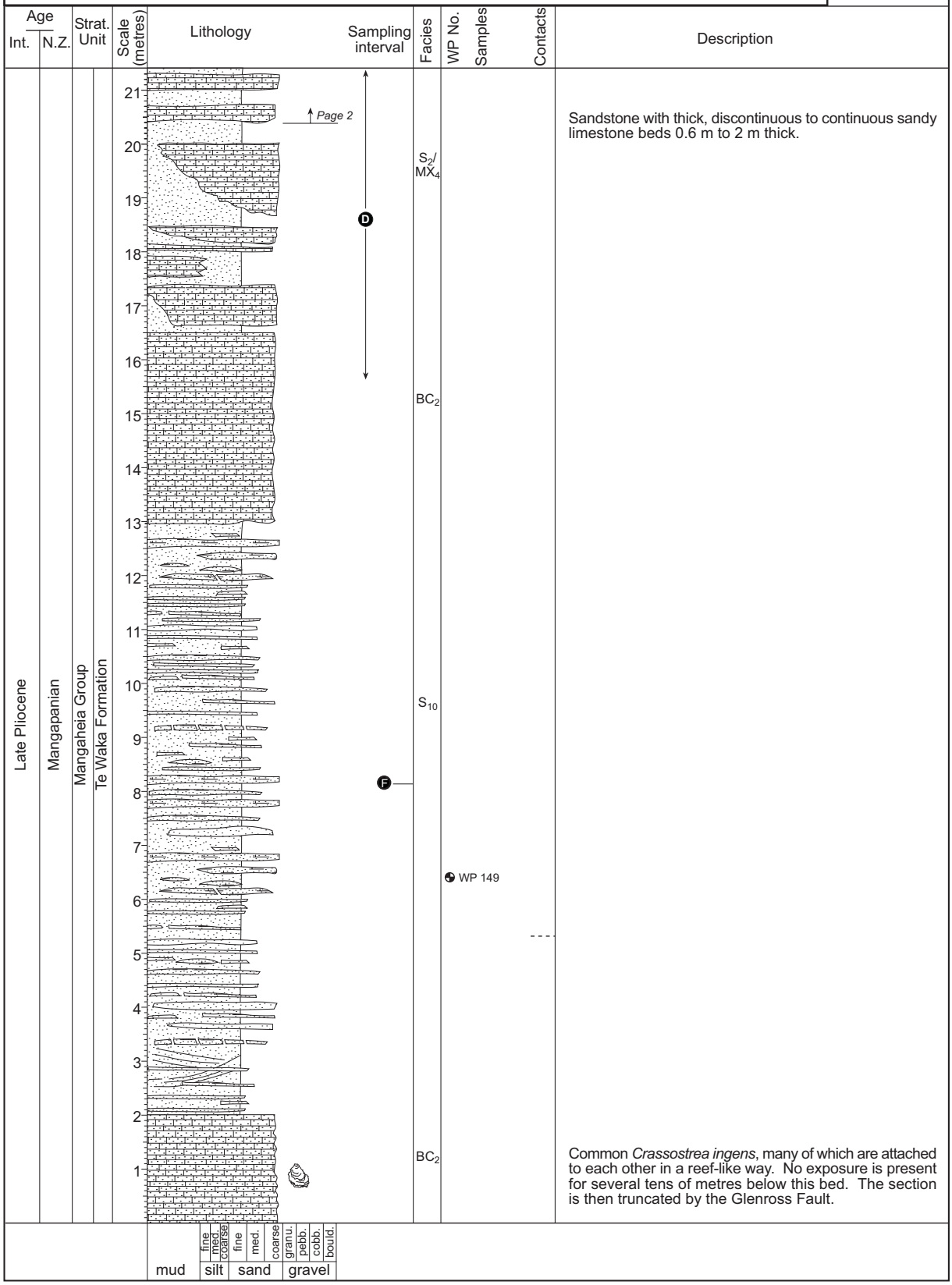
GPS Waypoint No(s): Wp 862-863

Region: Kuripapango

Location: The Lizard, Glenross Range

NZMS 260 Sheet: U20 Kaweka

Grid Reference:	***Top***	***Bottom***
E:	2803477	2803566
N:	6191166	6191203
Altitude:	818 m	834 m



Stratigraphic Column No: Ku-2 ***Grid Reference:*** ***Top*** ***Bottom***
GPS Waypoint No(s): Wp 862-863 ***E:*** 2803477 2803566
Region: Kuripapango ***N:*** 6191166 6191203
Location: The Lizard, Glenross Range ***Altitude:*** 818 m 834 m

NZMS 260 Sheet: U20 Kaweka *Page* 2 *of* 3

Age: Int. / N.Z. | Strat. Unit | Scale (metres) | Lithology | Sampling interval | Facies | WP No. Samples | Contacts | Description

Late Pliocene / Mangapanian / Mangaheia Group / Te Waka Formation

Page 3

41 40 39 38 37 36 35 34 33 32 31 30 29 28 27 26 25 24 23 22 21

F G I A B C

F

WP 149

S_{10}

Bioturbated yellow-brown, non to slightly cemented muddy fine sandstone. Occasional concretionary bodies and horizons are present, as are common mudstone stringers.

BC_1

Sandy shellhash-dominated limestone with common bryozoan fragments.

MX_4

Stacked bioclastic-dominated - siliciclastic-dominated grainstone and rudstone beds 0.3-0.6 m thick. Bioclastic content rich in barnacle and encrusting bryozoan fragments. Contains rare *Phialopecten thomsoni*.

BC_1

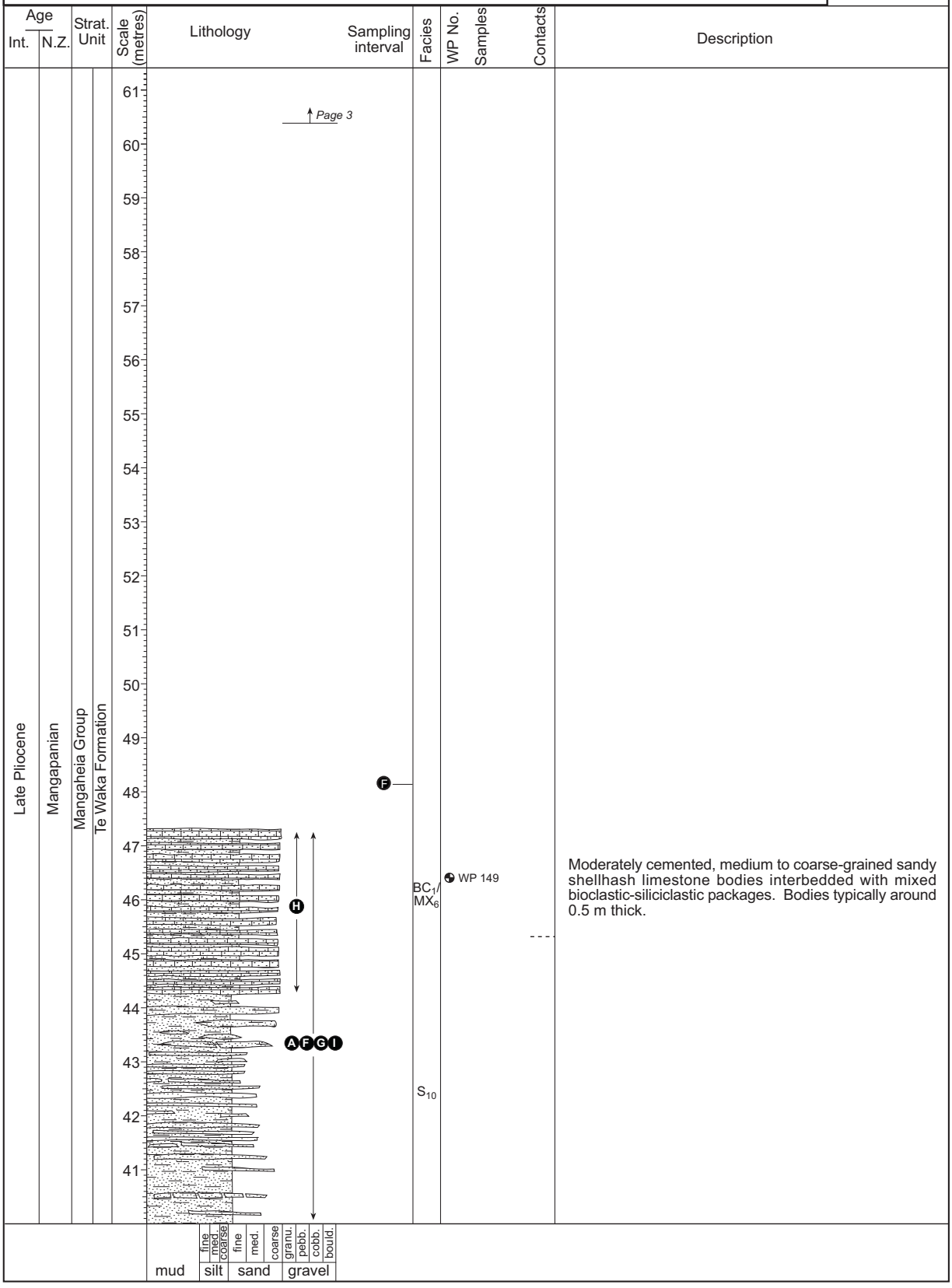
MX_4

Yellow-brown, non cemented, non to slightly fossiliferous fine sandstone. Small clusters of shells are present dominated by *Ostrea* and *Talochlamys* with some *Eumarcia* sp. and gastropods. Shell clusters are more common towards the top of the bed. This unit contains a prominent shellhash component and is intensely bioturbated. Burrows underneath the overlying shellbed are commonly filled with shellhash.

mud | silt: fine, med., coarse | sand: fine, med., coarse | gravel: granu., pebb., cobb., bould.

Stratigraphic Column No: Ku-2 **Grid Reference:** **Top** **Bottom**
GPS Waypoint No(s): Wp 862-863 **E:** 2803477 2803566
Region: Kuripapango **N:** 6191166 6191203
Location: The Lizard, Glenross Range **Altitude:** 818 m 834 m

NZMS 260 Sheet: U20 Kaweka *Page* 3 *of* 3




A
B
C
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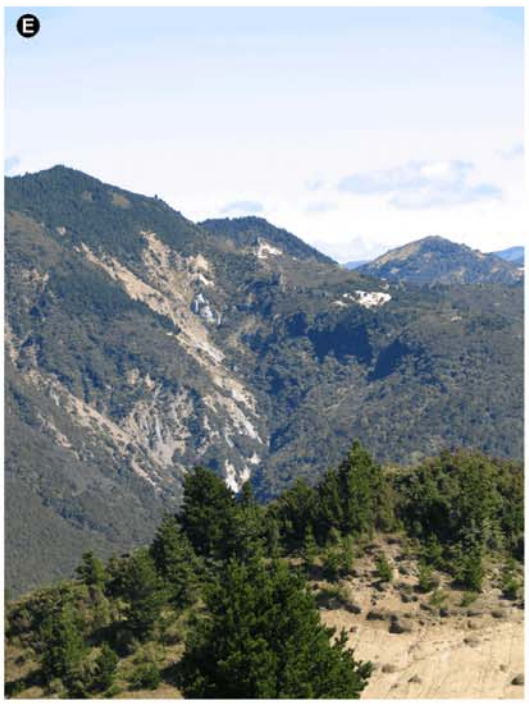

E


F


G


H


I


J

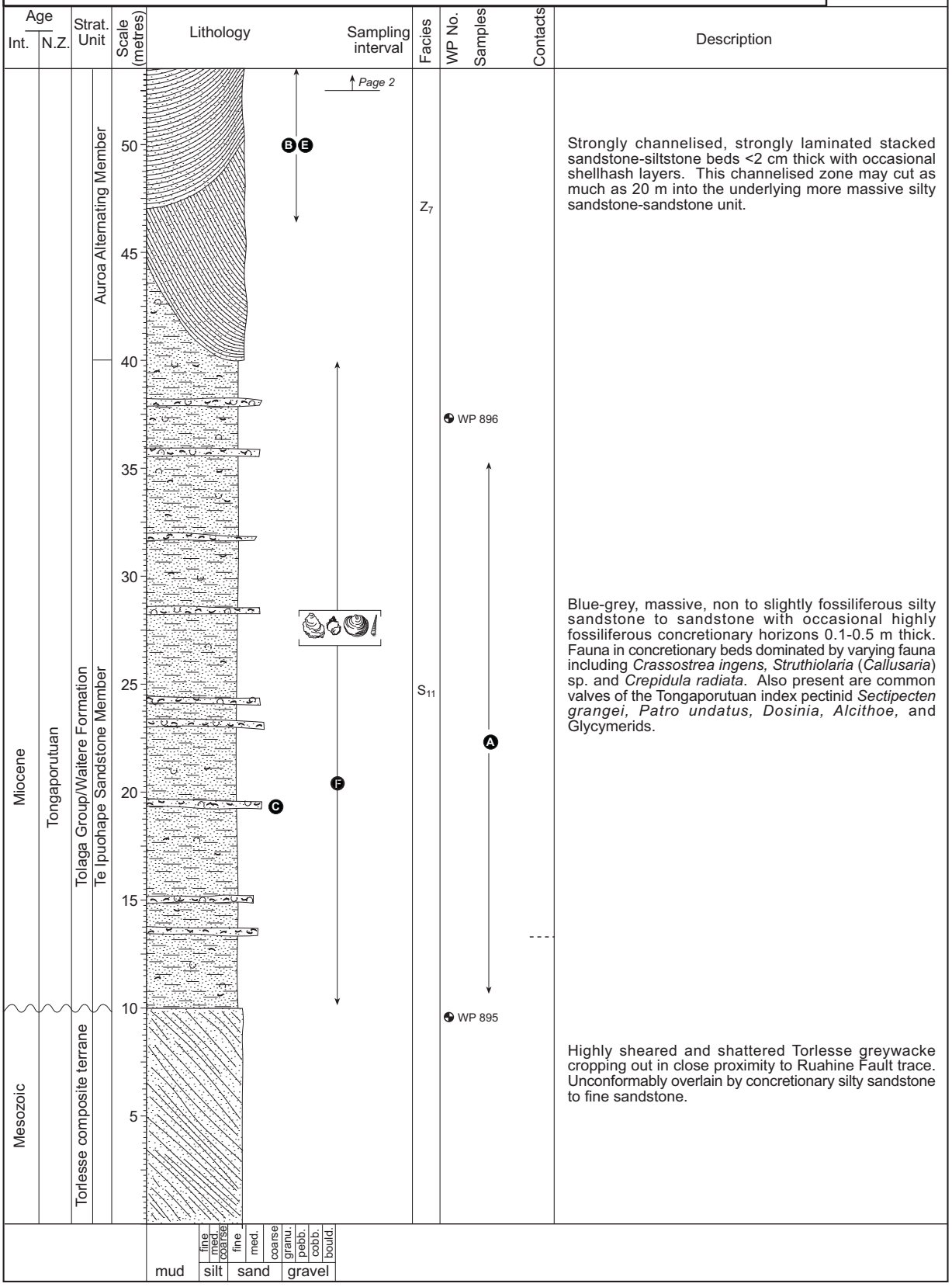
Stratigraphic Column No: Ku-3 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 895, 920 ***E:*** 2806147 2805519

Region: Kuripapango ***N:*** 198029 6198220

Location: Tutaekuri River upstream of Lawerence Road swingbridge ***Altitude:*** 358 m 363 m

NZMS 260 Sheet: U20 Kaweka



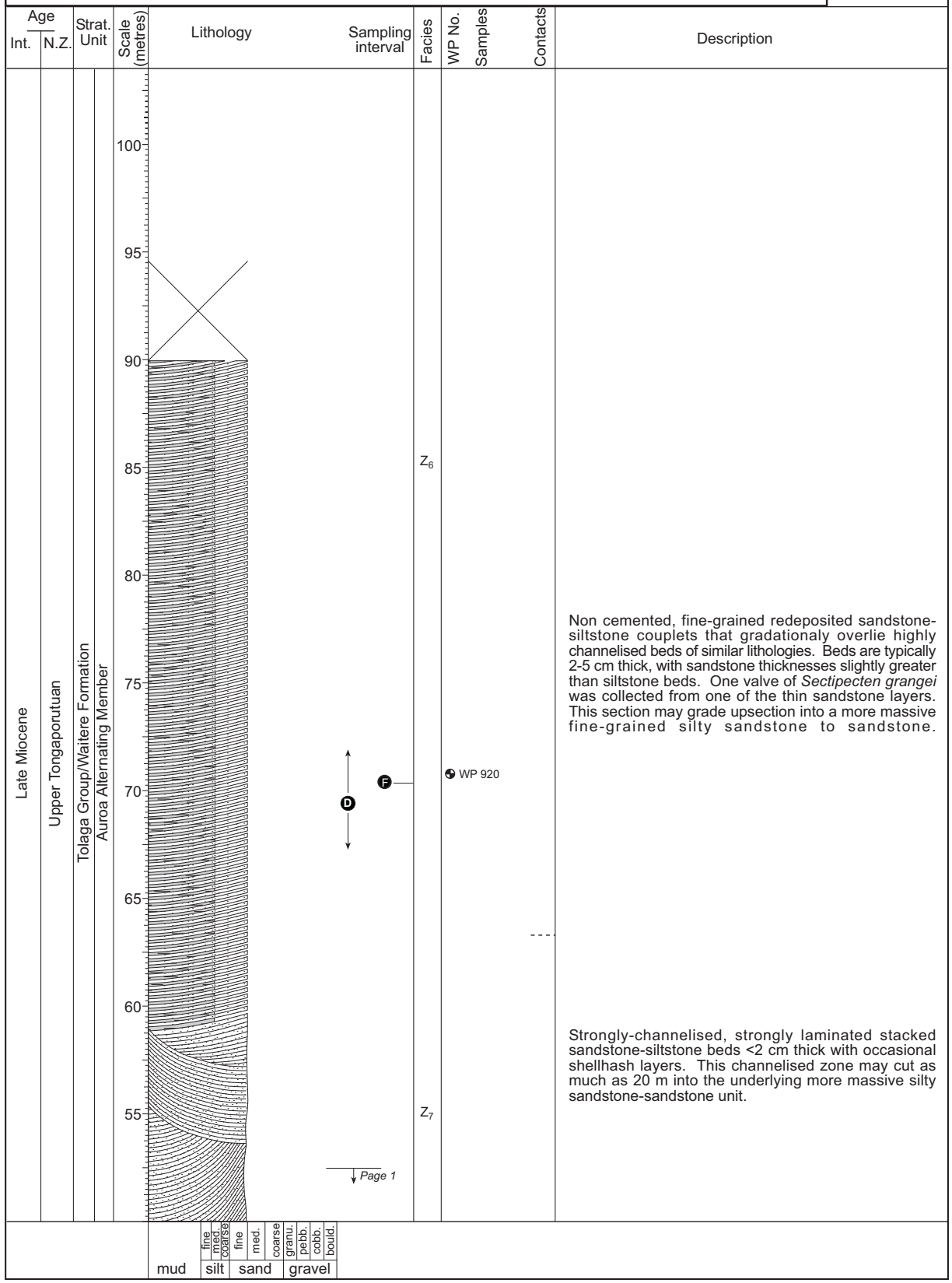
Stratigraphic Column No: *Ku-3* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 895, 920 ***E:*** 2806147 2805519

Region: Kuripapango ***N:*** 198029 6198220

Location: Tutaekuri River upstream of Lawerence Road swingbridge ***Altitude:*** 358 m 363 m

NZMS 260 Sheet: U20 Kaweka




A


B


C


D


E

Stratigraphic Column No: *Mg-1*

GPS Waypoint No(s): Wp 54

Region: Maungaharuru

Location: Bluffs at end of Maungaharuru Ridge Track, Waitara Station.

NZMS 260 Sheet: V20 Esk

Grid Reference: Top / Bottom

E: 2829193

N: 6219148

Altitude: 825m / -

Page 1 *of* 2

Age Int.	Age N.Z.	Strat. Unit	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Waipipian	Mangaheia Group / Titiokura Formation	36		BC_1			Massive to blocky limestone with a coarse sand-sized matrix and common shells and greywacke pebbles.
			34					
			32					
			30				----	
			28				----	
			26					
			24					
			22					Moderately cemented slightly flaggy calcareous sandstone, grading up into sandy limestone.
			20		S_5			
			18					
			16					
			14				----	
			12					
			10		S_{10}			Light-brown, moderately cemented, slightly cross-bedded medium sandstone with rare water escape structures. More strongly cemented layers are present up to 1.5 m thick, that are often continuous over many metres. Concretions are common and are up to 0.1 m thick and non fossiliferous.
			8					
			6			WP 54		
			4				----	Moderately cemented, medium-grained calcareous sandstone. Units such as this one are quite discontinuous through the section. The entire section is underlain by a very poorly sorted and coarse-grained conglomerate with very round sandstone and mudstone clasts up to 2 m in diameter, with abundant shell hash, *Talochlamys gemmulata*, oyster, barnacles and greywacke clasts up to 0.05 m in diameter.
			2		S_5			

mud | silt (fine, med., coarse) | sand (fine, med., coarse) | gravel (granu., pebb., cobb., bould.)

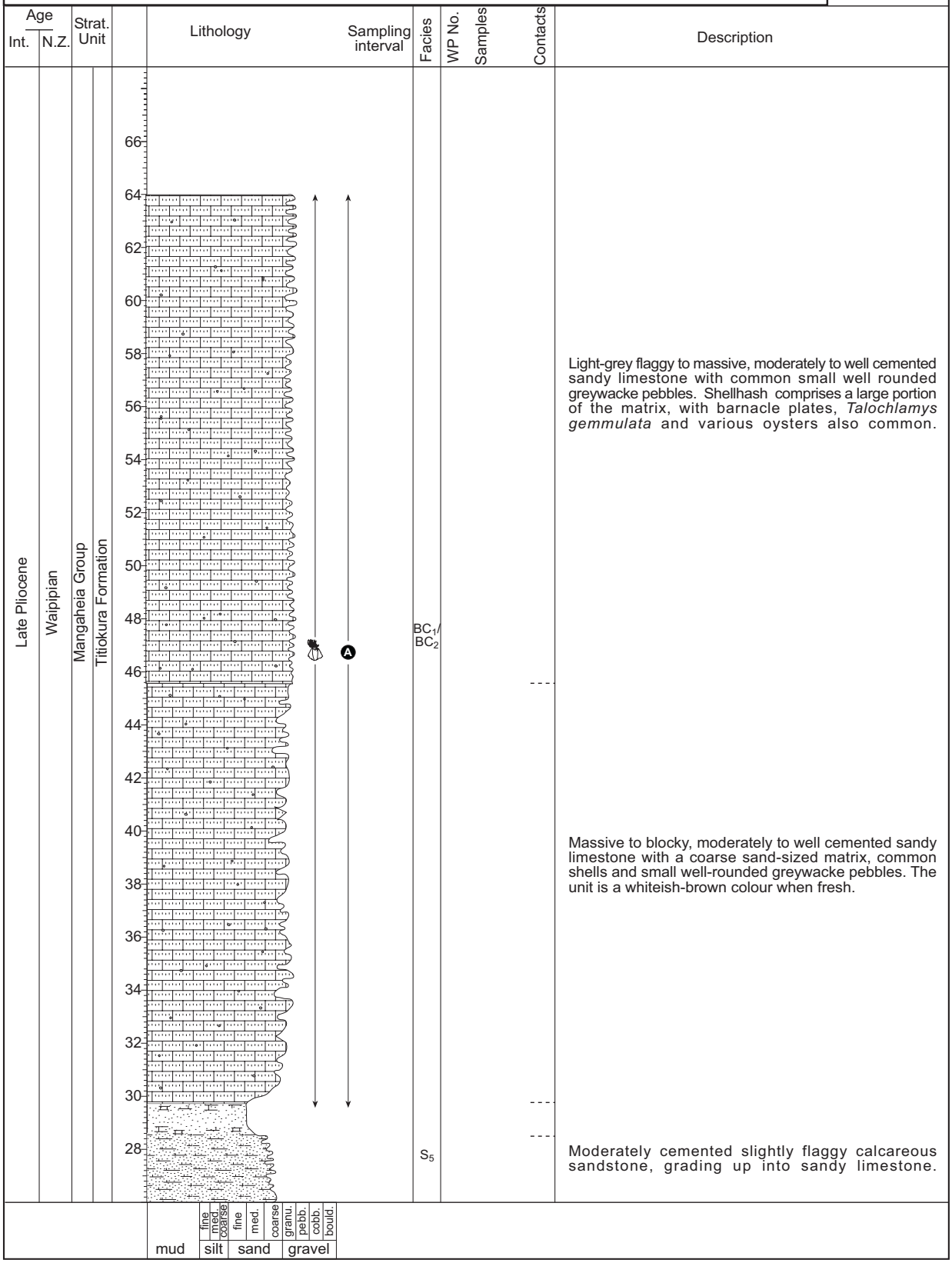
Stratigraphic Column No: *Mg-1* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 54 ***E:*** 2829193

Region: Maungaharuru ***N:*** 6219148

Location: Bluffs at end of Maungaharuru Ridge Track, Waitara Station. ***Altitude:*** 825m -

NZMS 260 Sheet: V20 Esk




A
B
C

Stratigraphic Column No: Mk-1 ***Grid Reference:*** ***Top*** ***Bottom***

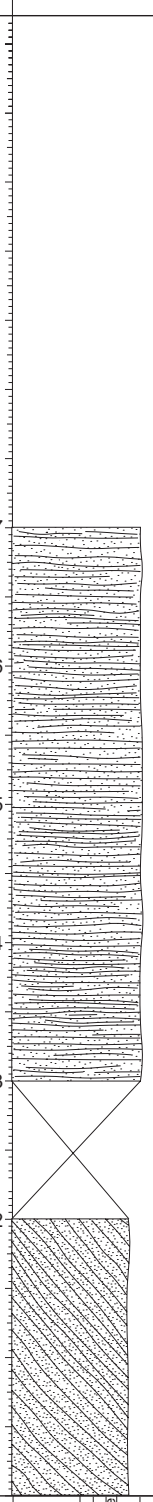
GPS Waypoint No(s): Wp 84 ***E:*** 2809407

Region: Makahu ***N:*** 6216474

Location: Mangatutu Hot Springs access road, Kaweka Forest Park. ***Altitude:*** 628m -

NZMS 260 Sheet: V21 Napier

Age Int.	Age N.Z.	Strat. Unit	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Early Pliocene	Upper Opoitian	Mangaheia Group / Pakututu Formation			S_2			Moderately weathered, ripple to parallel-laminated fine to medium sandstone. Unit appears to overlie greywacke, although the contact is obscured. Unconfident age and stratigraphic correlation.
Mesozoic		Torlesse composite terrane						Very indurated, moderately to strongly deformed, moderately to strongly weathered greywacke basement. The unit at this locality is also moderately fractured.



mud | silt (fine, med., coarse) | sand (fine, med., coarse) | gravel (granu., pebb., cobb., bould.)

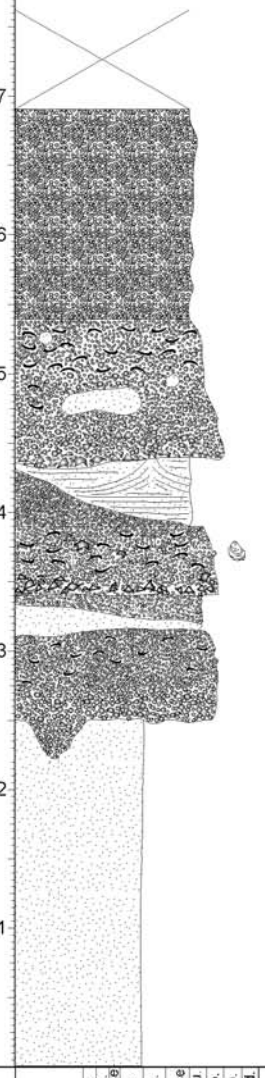
Stratigraphic Column No: *Mk-2* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 86 ***E:*** 2809645

Region: Makahu ***N:*** 6213409

Location: Hillside on Jack Nicholas' Farm. ***Altitude:*** 646m -

NZMS 260 Sheet: V21 Napier *Page* 1 *of* 1



Well sorted, non to slightly cemented granule-sized greywacke conglomerate bed conformably overlying coarser-grained greywacke conglomerate bed.

Poorly sorted, non to slightly cemented greywacke conglomerate bed. Very angular clasts are present at the base, up to 80-100mm in diameter. The unit fines up into a well sorted greywacke conglomerate comprising coarse sand to granule-sized clasts in a shellhash matrix. The unit contains common moderately to well rounded sandstone rip-up clasts up to 0.3 m in diameter.

Non cemented, laminated fine sandstone lens with some water escape structures visible.

Poorly sorted greywacke conglomerate comprising very angular clasts up to 80 mm diameter in basal parts. The unit fines up into well rounded clasts up to 20 mm diameter, averaging 10 mm in diameter at the top, with occasional larger angular clasts present. Shell hash and *Crassostrea ingens* valves are present.

Non to moderately cemented shelly greywacke conglomerate bed. Clasts at base are up to 50 mm in diameter, fining up to clasts 10 mm in diameter. Shellhash and the occasional intact valve are present in the upper two-thirds of the bed. A sharp erosional base to the unit is present. The unit is overlain by fine sandstone and shellhash-rich greywacke conglomerate lenses.

Non cemented, non fossiliferous fine to medium siliciclastic sandstone. Base of the unit is not exposed.

Stratigraphic Column No: *Mt-1*

GPS Waypoint No(s): Wp 821

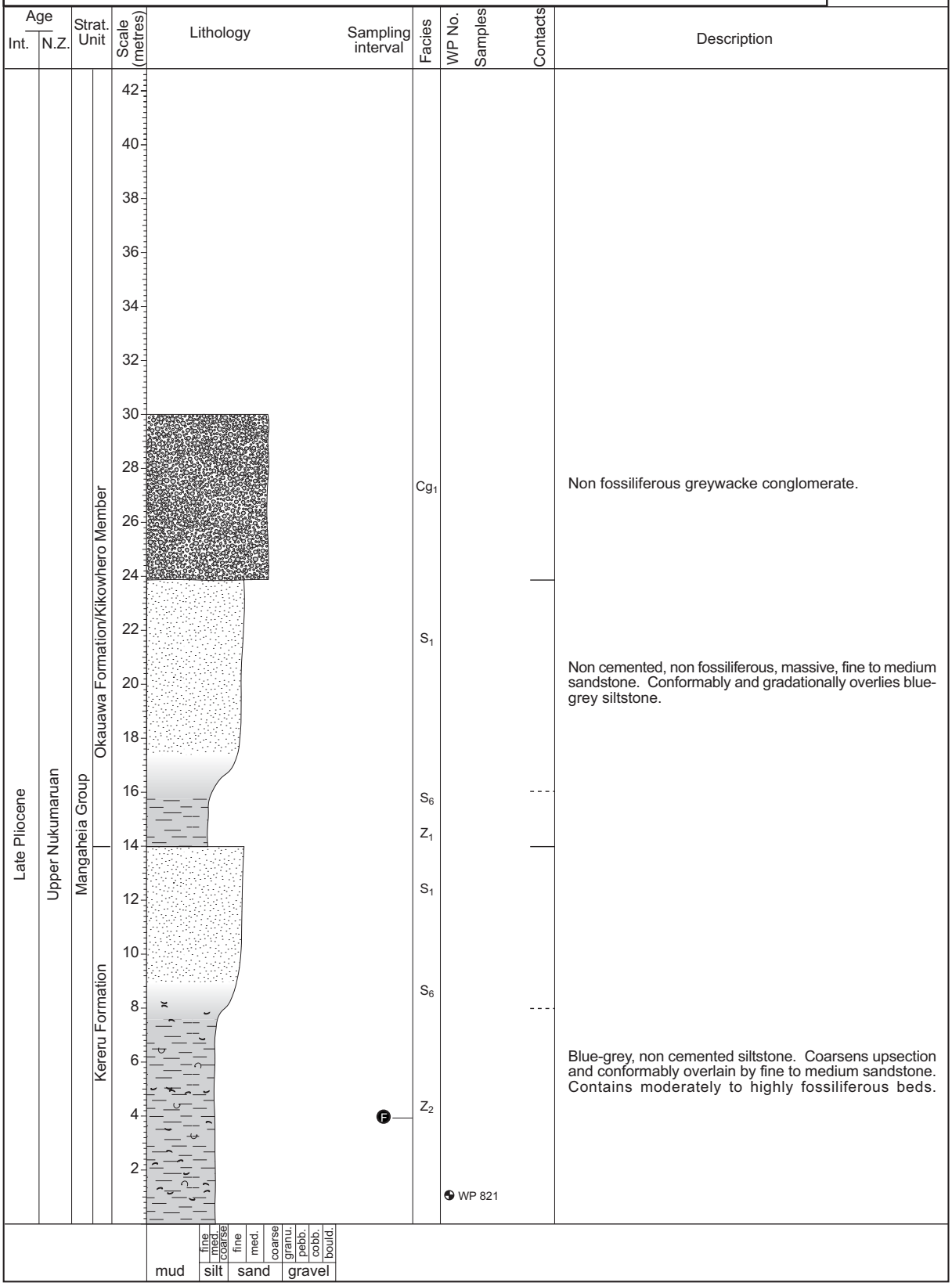
Region: Matapiro

Location: Ngaruroro River downstream of Whana Valley

NZMS 260 Sheet: V21 Napier

Grid Reference:	***Top***	***Bottom***
E:	-	2809276
N:	-	6188366
Altitude:	-	75 m

Page 1 *of* 1



Stratigraphic Column No: *Mt-2*

GPS Waypoint No(s): Wp 823

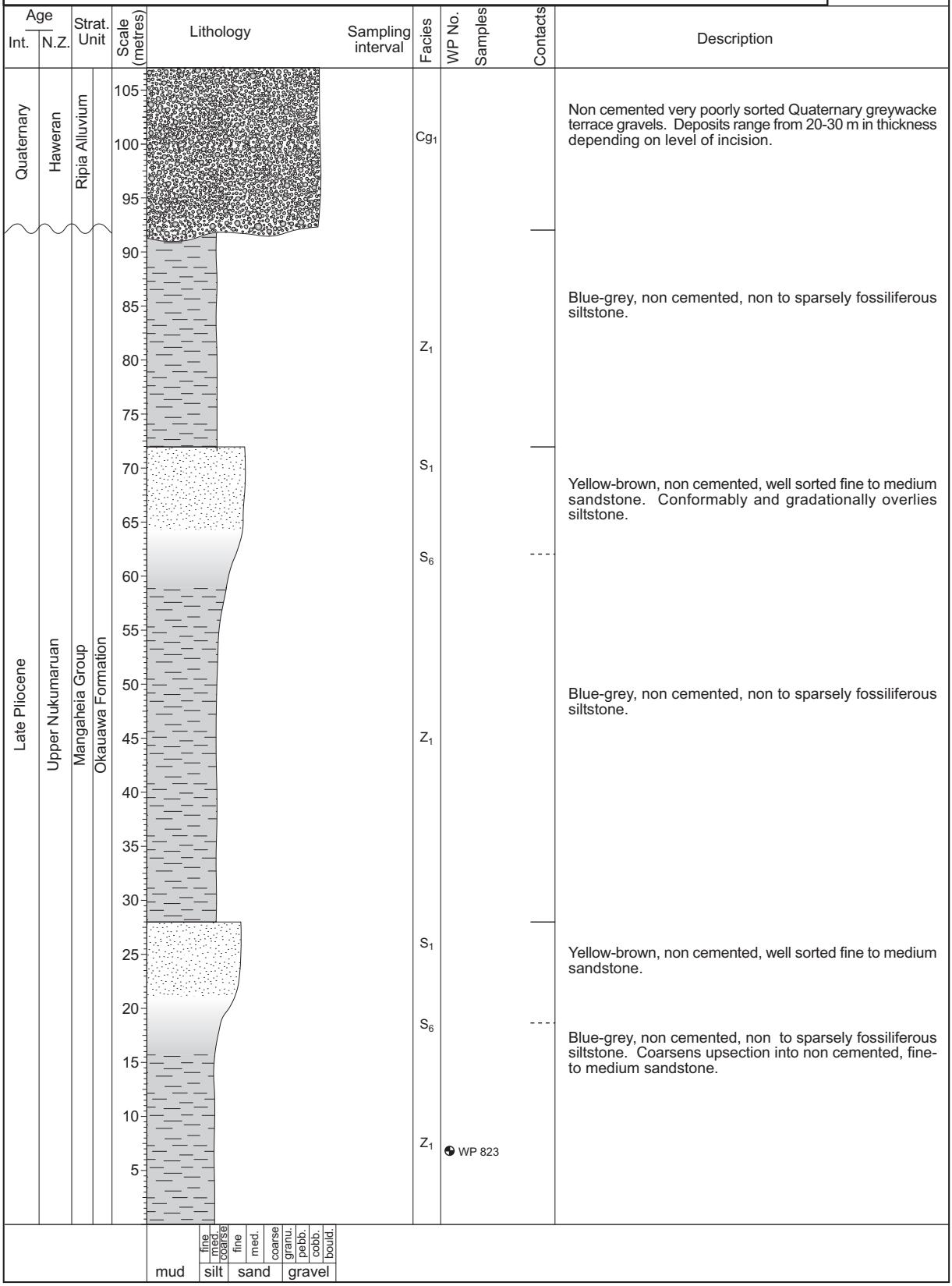
Region: Matapiro

Location: Ngaruroro River downstream of Whana Valley

NZMS 260 Sheet: V21 Napier

Grid Reference:	***Top***	***Bottom***
E:	-	2811605
N:	-	6173996
Altitude:	-	123 m

Page 1 *of* 1



Stratigraphic Column No: *Mt-3*

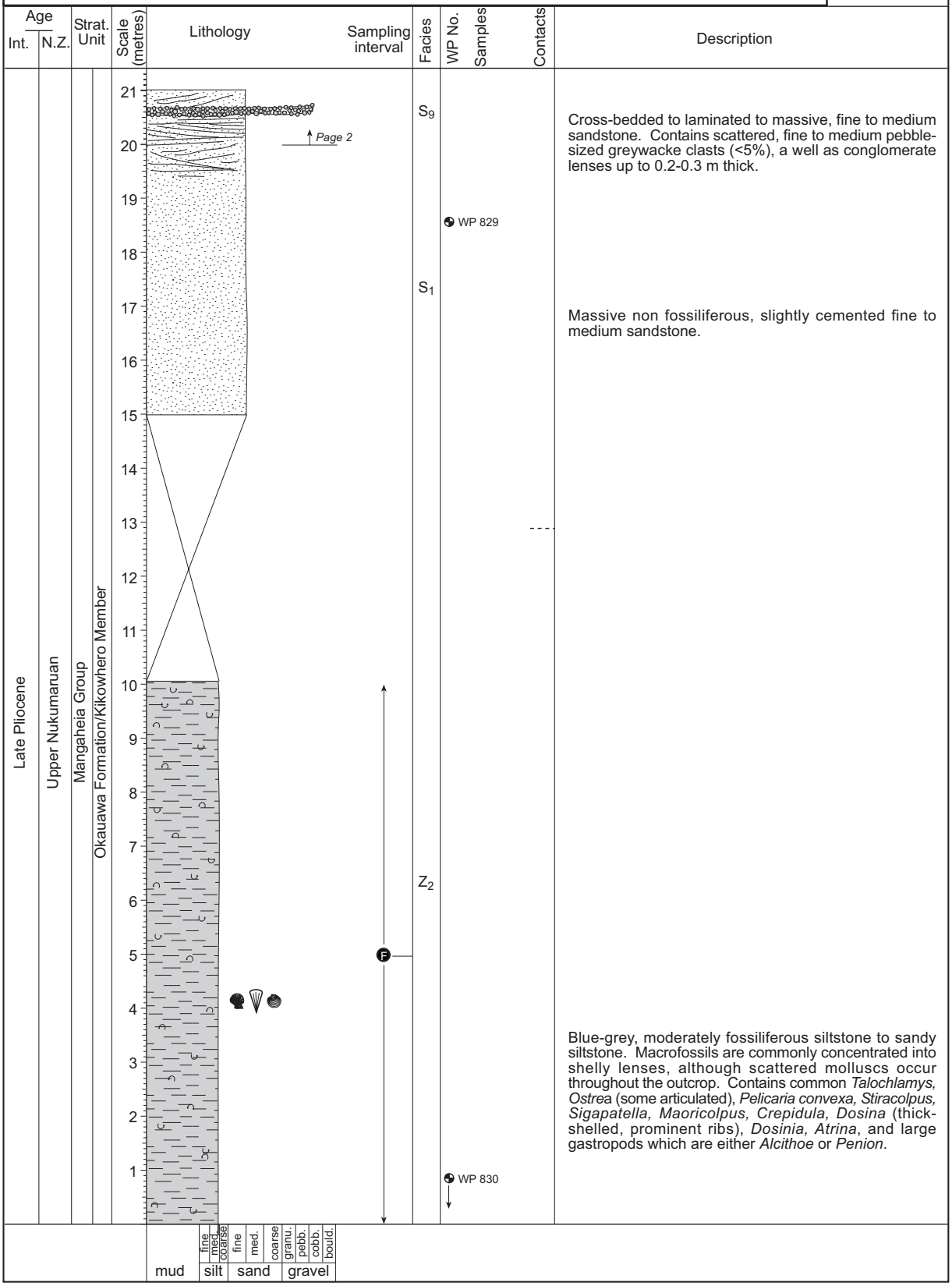
GPS Waypoint No(s): 827-829

Region: Whanawhana

Location: Matapiro Road on Napier side of Whana Valley

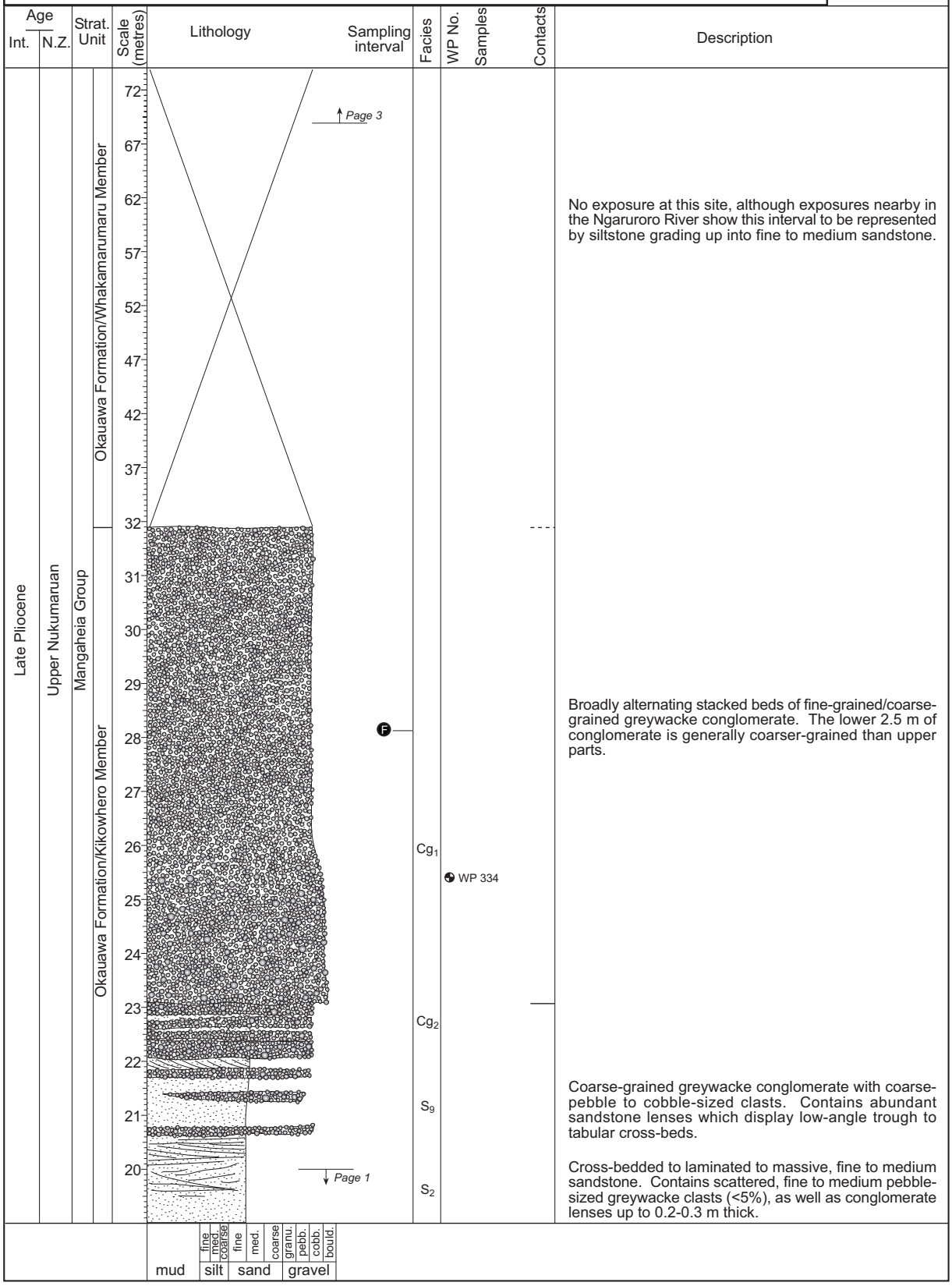
NZMS 260 Sheet: V21 Napier

Grid Reference:	***Top***	***Bottom***
E:	2809666	2809409
N:	6177152	6177489
Altitude:	287 m	262 m



Stratigraphic Column No: *Mt-3*

		Grid Reference:	**Top**	**Bottom**
GPS Waypoint No(s): Wp 827-829		***E:***	2809666	2809409
Region: Whanawhana		***N:***	6177152	6177489
Location: Matapiro Road on Napier side of Whana Valley		***Altitude:***	287 m	262 m
NZMS 260 Sheet: V21 Napier	*Page* 2 *of* 3			



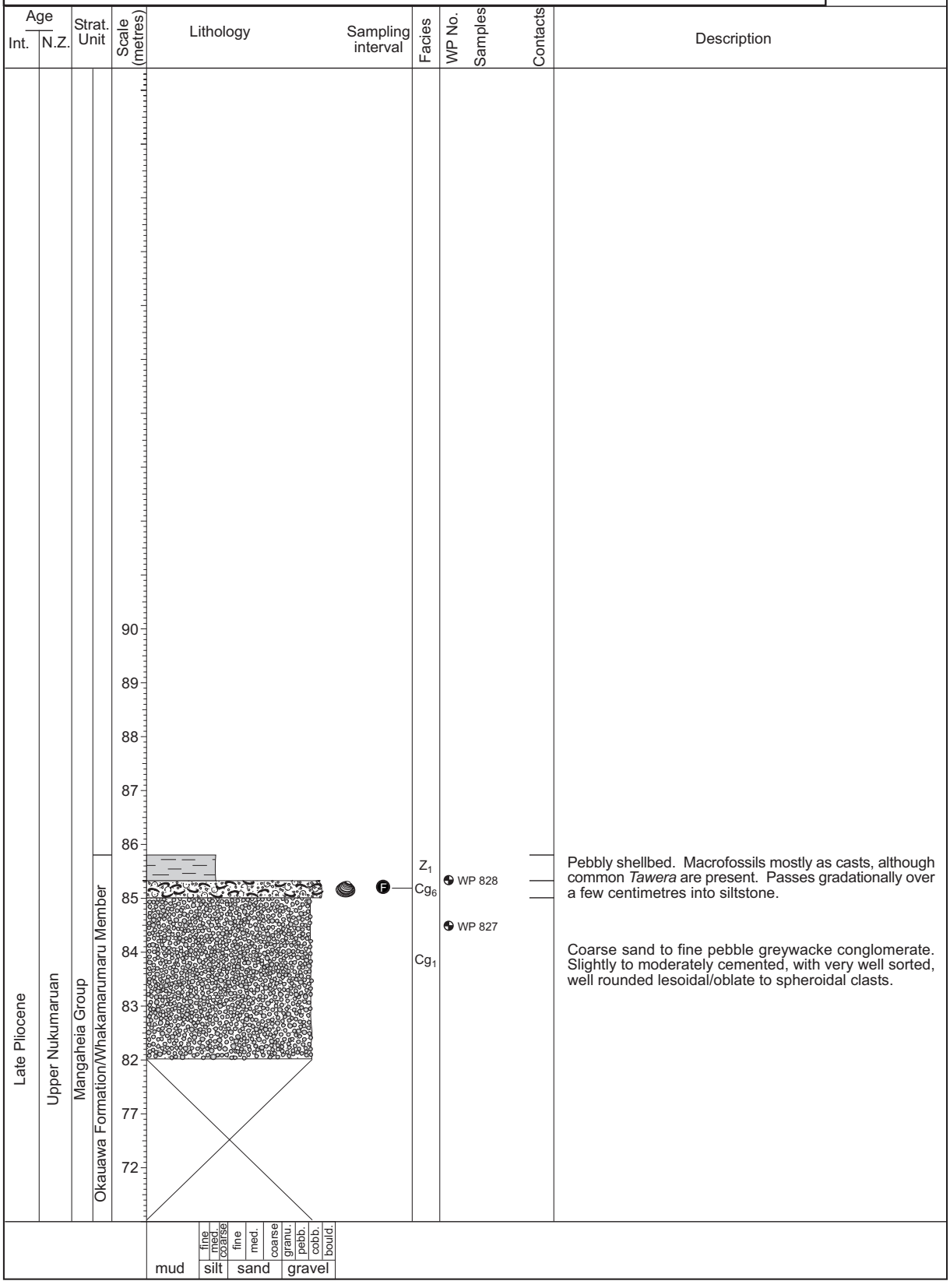
Stratigraphic Column No: *Mt-3* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 827-829 ***E:*** 2809666 2809409

Region: Whanawhana ***N:*** 6177152 6177489

Location: Matapiro Road on Napier side of Whana Valley ***Altitude:*** 287 m 262 m

NZMS 260 Sheet: V21 Napier



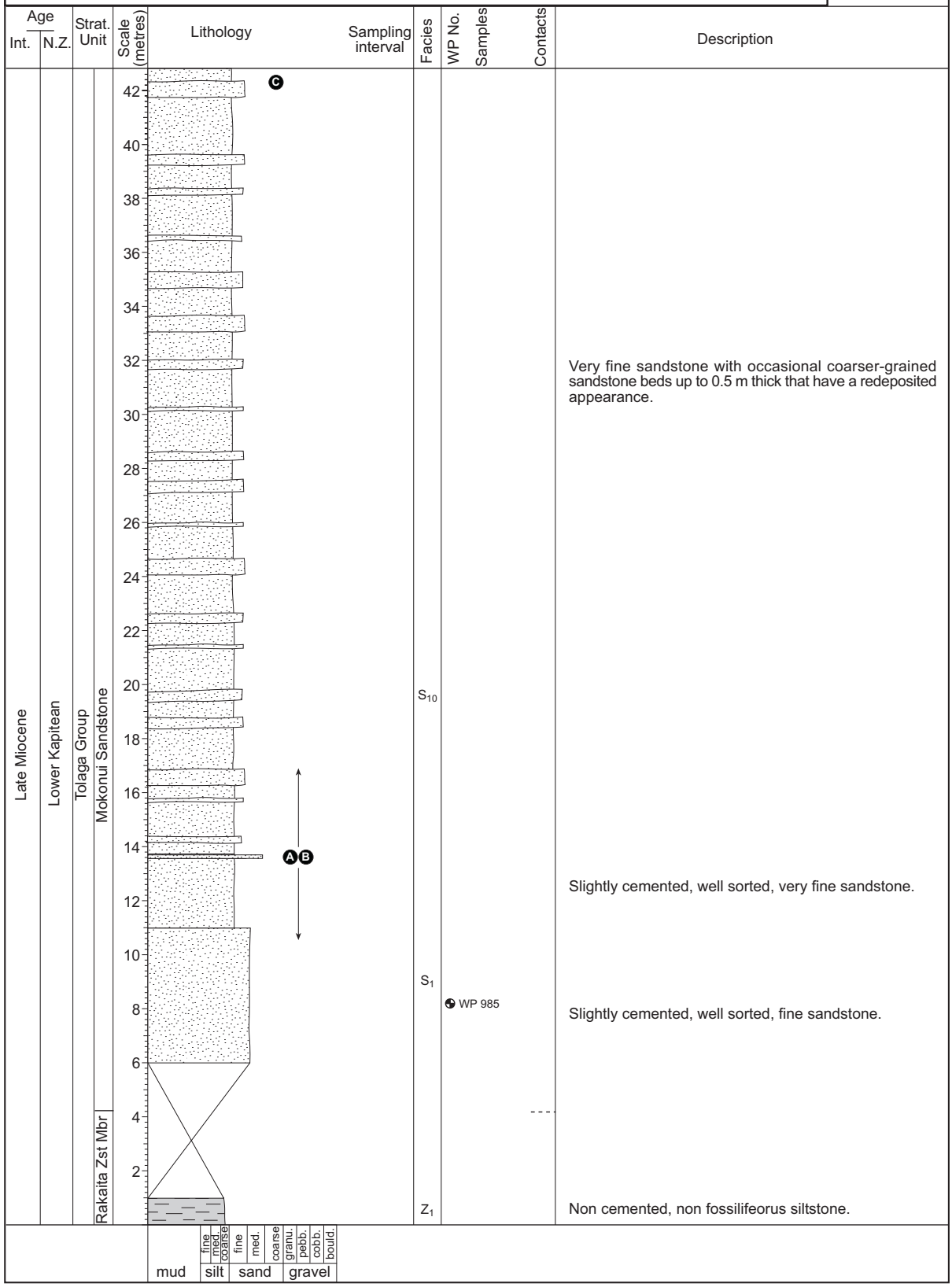
Stratigraphic Column No: Na-1 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 984 ***E:*** 2837583 -

Region: Naumai ***N:*** 6227623 -

Location: Pohokura Road near Woodstock Road ***Altitude:*** 681 m -

NZMS 260 Sheet: V19 Te Haroto



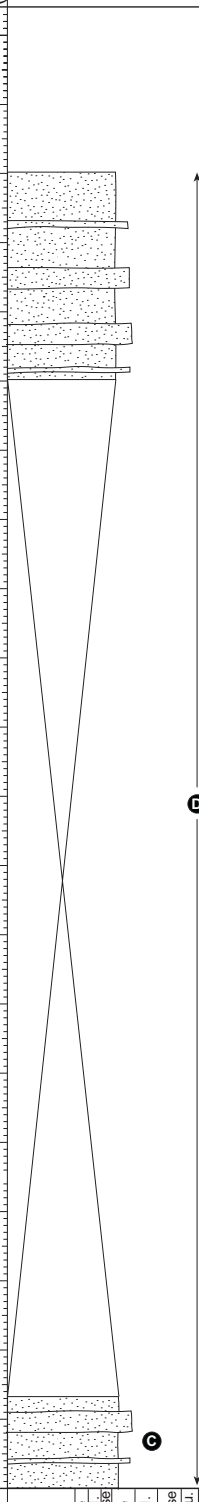
Stratigraphic Column No: Na-1 ***Grid Reference:*** ***Top*** ***Bottom***

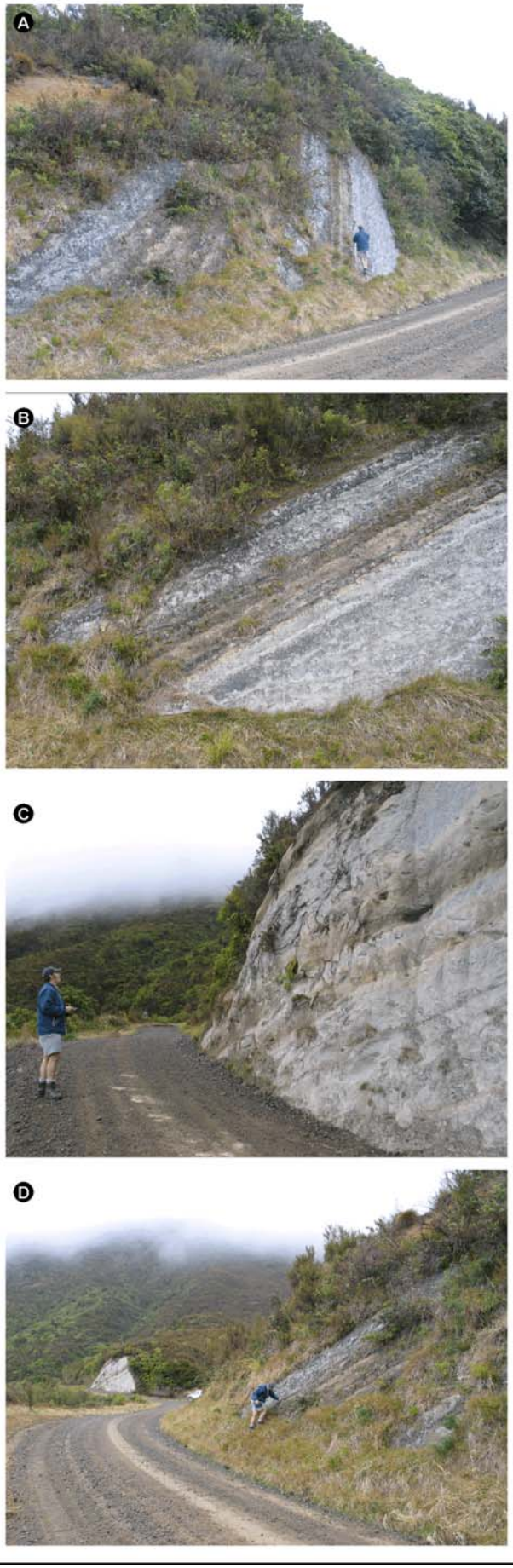
GPS Waypoint No(s): Wp 984 ***E:*** 2837583 -

Region: Naumai ***N:*** 6227623 -

Location: Pohokura Road near Woodstock Road ***Altitude:*** 681 m -

NZMS 260 Sheet: V19 Te Haroto *Page* 1 *of* 2

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Miocene	Lower Kapitean	Tolaga Group / Mokonui Sandstone / Rakaita Zst Mbr	84 82 80 78 76 74 72 70 68 66 64 62 60 58 56 54 52 50 48 46 44		D C	S_{10}			Very fine sandstone with common concretionary horizons up to 0.2 m thick. Concretions mark boundaries between coarser-grained sandstone beds in this interval. Very fine sandstone with occasional coarser-grained sandstone beds up to 0.5 m thick that have a redeposited appearance.


A
B
C
D

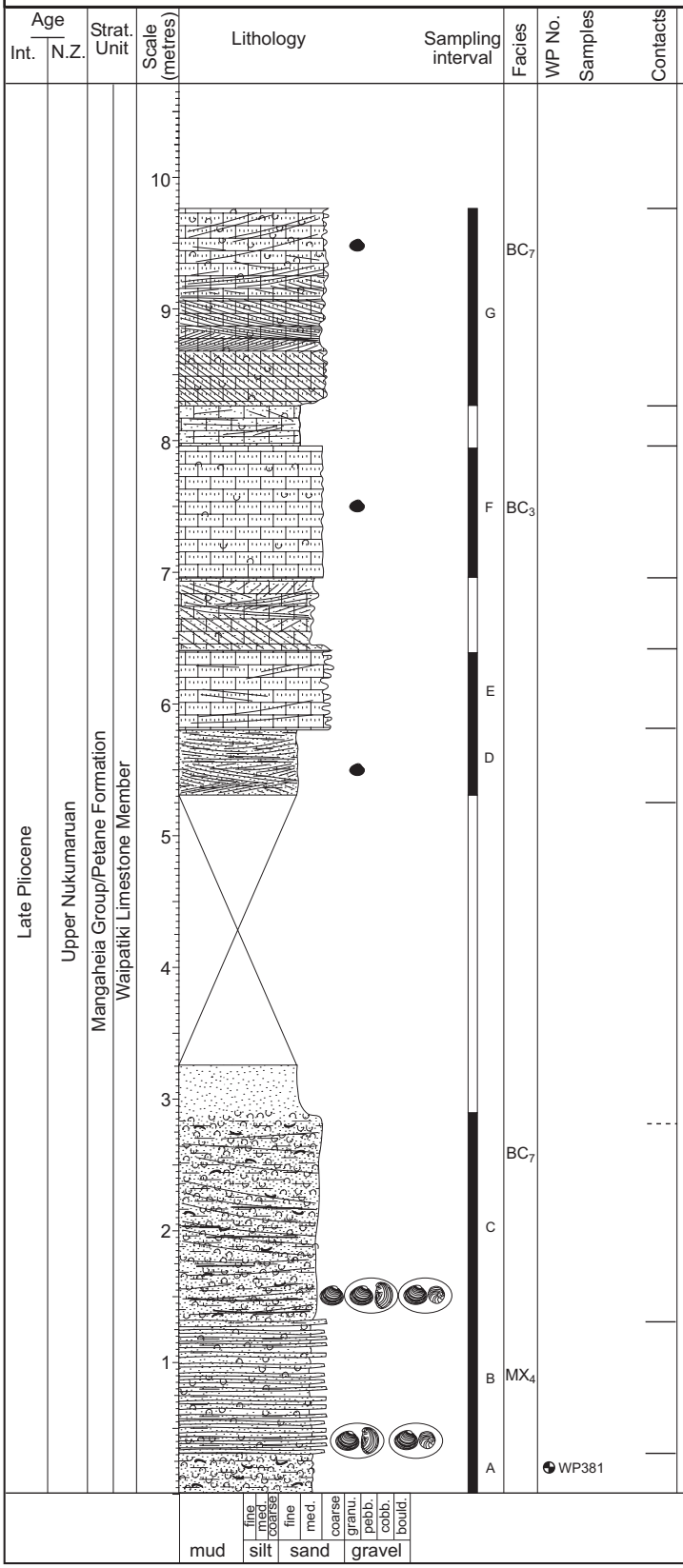
Stratigraphic Column No: Ok-1 **Grid Reference:** **Top** **Bottom**

GPS Waypoint No(s): Wp 381 **E:** 2827357 -

Region: Okawa **N:** 6181193 -

Location: Ngamahanga Station along Kawera Road **Altitude:** 69m -

NZMS 260 Sheet: V21 Napier



Grey, weathered, moderately cemented pebbly shelly limestone. Strongly cross-bedded, moderate scale, low to high-angle. Herringbone and bi-directional cross-stratification are visible. The bed becomes sandier upsection and upper parts comprise well cemented, shelly sandy limestone with aragonitic bivalves and biomoulds throughout. Greywacke granules to fine pebble-sized clasts are scattered through this bed.

Massive, weathered, greywacke granule and pebble-rich partially recrystallised, moderately well cemented shelly limestone. Pebbles are sub-rounded to well-rounded. The bed contains abundant shell moulds of infaunal aragonitic bivalves such as *Tawera*. Underlying this unit is a bed comprising moderately well cemented fine-grained partially recrystallised sandy limestone displaying bi-directional cross-bedding with scattered, well rounded greywacke granules. Cross-beds are small to moderate-scale, moderate angle and dominated by tabular bedforms, with minor trough cross-beds. Small biomoulds are common.

Moderately cemented, flaggy, slightly-pebbly, coarse-grained partially recrystallised limestone. Shell fragments and disarticulated bivalve shells are common, as are biomoulds and *Ostrea* valves. Weakly cross-bedded in places

Yellowish-brown, slightly to moderately cemented well sorted calcareous sandstone with abundant shell hash. Thin discrete shell layers are present containing *Tawera* and *Purpurocardia.* Tabular to trough cross-bedding is present.

Poorly exposed interval containing yellow-brown, massive to cross-bedded, fine to medium sandstone with shell lenses.

Coarsening-upwards highly fossiliferous medium calcareous sandstone with closely packed bivalves and abundant gastropods. Fine greywacke pebbles become more common in the upper 0.5 m of the bed, with large *Ostrea* valves common in the upper 0.3 m. The unit is *Tawera* dominated with articulated *Tawera* valves common in the upper 1 m. Very large-scale, low-angle trough cross-bedding is present through the unit. Thin (<0.02 m thick) laminated siltstone stringers are present. Other common faunas include *Amalda, Talochlamys*, large *Zethalia, Purpurocardia*, *Crepidula* and *Sigapetella*. Over 0.15 m this bed is abruptly diluted by siliciclastic sediments and passes in to a yellowish-brown, well-sorted, fine calcareous sandstone with a shell hash content.

Alternating medium-grained siliciclastic/bioclastic sandstone-dominated sheets to 0.1 m thick. Greywacke granules and fine pebbles are concentrated in shellhash lenses. Low-angle, moderate-scale cross-bedding is present through the bed. Abundant disarticulated bivalves and gastropods present. *Tawera* common, as is *Sigapetella* and *Crepidula*. Many valves have been bored. Passes abruptly into overlying bed.

Light-brown, highly fossiliferous, shelly medium sandstone rich in shellhash and intact, disarticulated bivalves. Approx. 5% well rounded and well sorted greywacke granules in unit. The bed is laminated and shell debris have been reworked. Fauna dominated by *Tawera, Crepidula* and *Sigapetella*.

Stratigraphic Column No: Ok-1 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 381 ***E:*** 2827357 -

Region: Okawa ***N:*** 6181193 -

Location: Ngamahanga Station along Kawera Road ***Altitude:*** 69m -

NZMS 260 Sheet: V21 Napier

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description

A- Shellhash-rich medium sandstone, dominated by *Tawera*, with common *Crepidula radiata and Sigapetella novaezelandiae.* Also present are *Zethalia zelandica, Purpurocardia purpurata, Eumarcia ?plana* and *Zenatia ?acinaces.*

B- Alternating medium-grained siliciclastic/bioclastic sandstone dominated sheets. Fauna is dominated by *Tawera*, with *Crepidula radiata* and *Sigapetella novaezelandiae* also common. *Maoricolpus roseus*, *Patro undatus*, juvenille *Pupurocardia purpurata, Amalda mucronata, Atrina pectinata zelandica* (in transported alignment), *Ostrea chilensis* and *Anomia trigonopsis* are also present. Valves of *Talochlamys gemmulata* were found in a wide range of sizes.

C- Medium-grained calcareous sandstone with closely-packed bivalves and abundant gastropods. *Tawera* is the dominant faunal type, with common *Ostrea chilensis*, particularly towards the top of the bed. Also present are *Amalda mucronata, Purpurocardia purpurata, Patro undatus, Crepidula radiata,* large *Zethalia zelandica, Sigapetella novaezelandiae, Alcithoe* sp., *Anomia trigonopsis, Maoricolpus roseus, Austrofusus sp., Talochlamys gemmulata, Stiracolpus, Atrina pectinata zelandica,* fragmented *Pelicaria* sp., and branching bryozoans. Articulated *Tawera* valves are common in the upper 1 m of this bed.

D- Well sorted calcareous sandstone with abundant shellhash. Discrete shell lenses are present containing *Tawera* and *Purpurocardia purpurata*. *Ostrea chilensis* valves are also present through the unit.

E- Slightly pebbly, coarse-grained partially recrystallised limestone rich in shell fragments and disarticulated bivalve shells. Abundant biomoulds occur through the bed with some *Ostrea chilensis* valves present.

F- Massive greywacke granule to pebble-rich, partially recystallised well cemented shelly limestone. Abundant biomoulds are present with scattered, partially dissolved infaunal aragonitic bivalves such as *Tawera.*

G- Strongly cross-bedded pebbly shelly limestone rich in biomoulds of aragonitic infaunal bivalves.

mud	silt			sand			gravel		
	fine	med.	coarse	fine	med.	coarse	granu.	pebb.	cobb.	bould.

Stratigraphic Column No: *Ok-2*

GPS Waypoint No(s): Wp 867

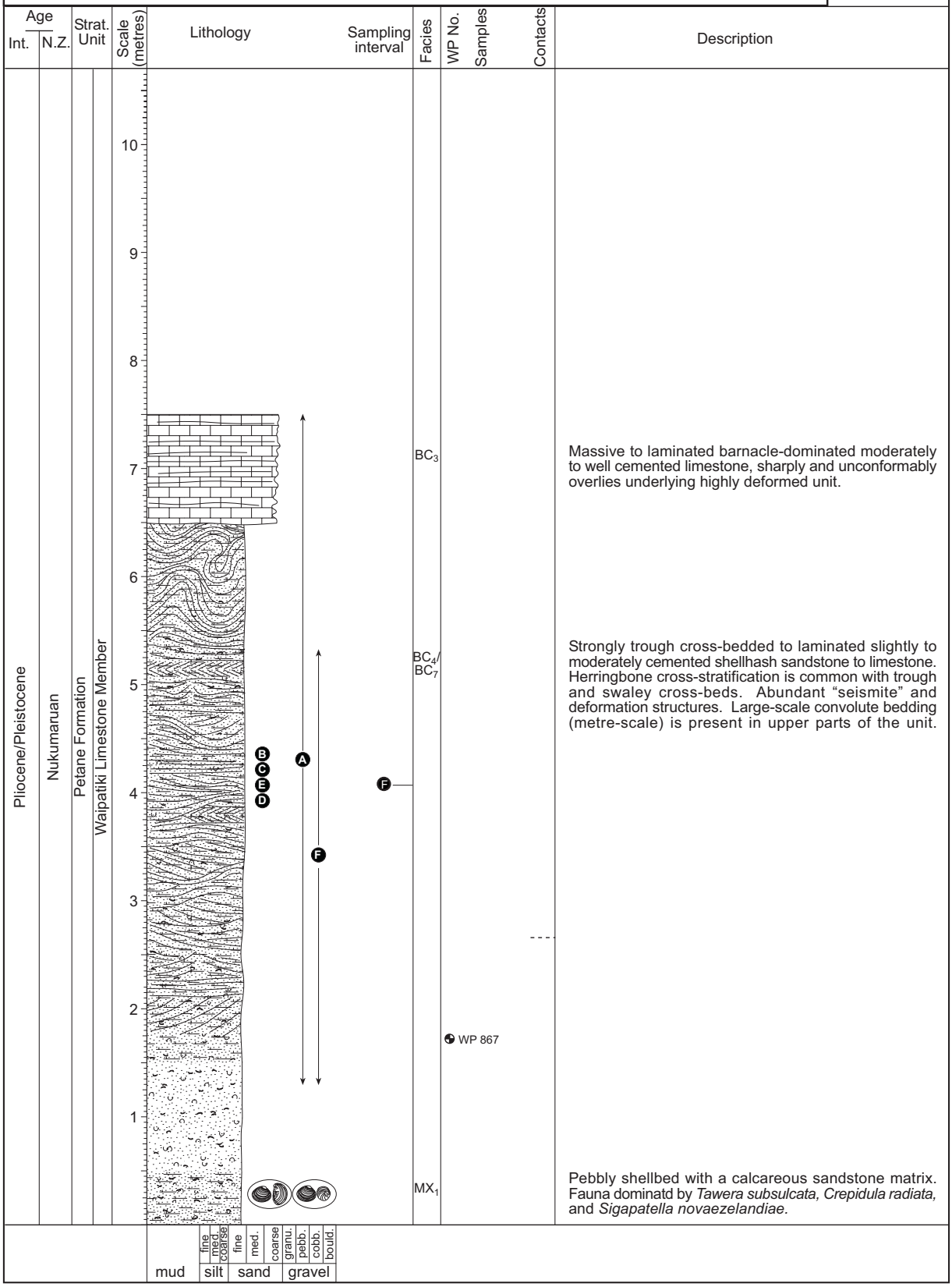
Region: Okawa

Location: Ohiwia Farm, Okawa Stream near Matapiro-Taihape Road intersection

NZMS 260 Sheet: V21 Napier

	Grid Reference:	***Top***	***Bottom***
	E:	2825080	-
	N:	6178126	-
	Altitude:	68 m	-

Page 1 *of* 1




A


B


C


D


E


F

Stratigraphic Column No: Om-1 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 921-928 ***E:*** 2800886 2801131

Region: Omahaki ***N:*** 6186648 6186642

Location: Omahaki Station composite, Omahaki Depression ***Altitude:*** 433 m 391 m

NZMS 260 Sheet: U21 Kereru

Page 1 *of* 2

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Early Pliocene	Opoitian	Mangaheia Group / Mangatoro Formation	21–11		Page 2	Z_2/ Z_6			
			11				WP 922		Blue-grey non cemented, strongly laminated siltstone. Some mica flakes are present.
			10–9						
			8				F — MICROPAL		
			7–6						
			5				WP 921		
Mesozoic		Torlesse composite terrane	4–1						Moderately weathered and fractured, relatively intact greywacke basement.

mud | silt: fine, med., coarse | sand: fine, med., coarse | gravel: granu., pebb., cobb., bould.

Stratigraphic Column No: *Om-1*

GPS Waypoint No(s): Wp 496

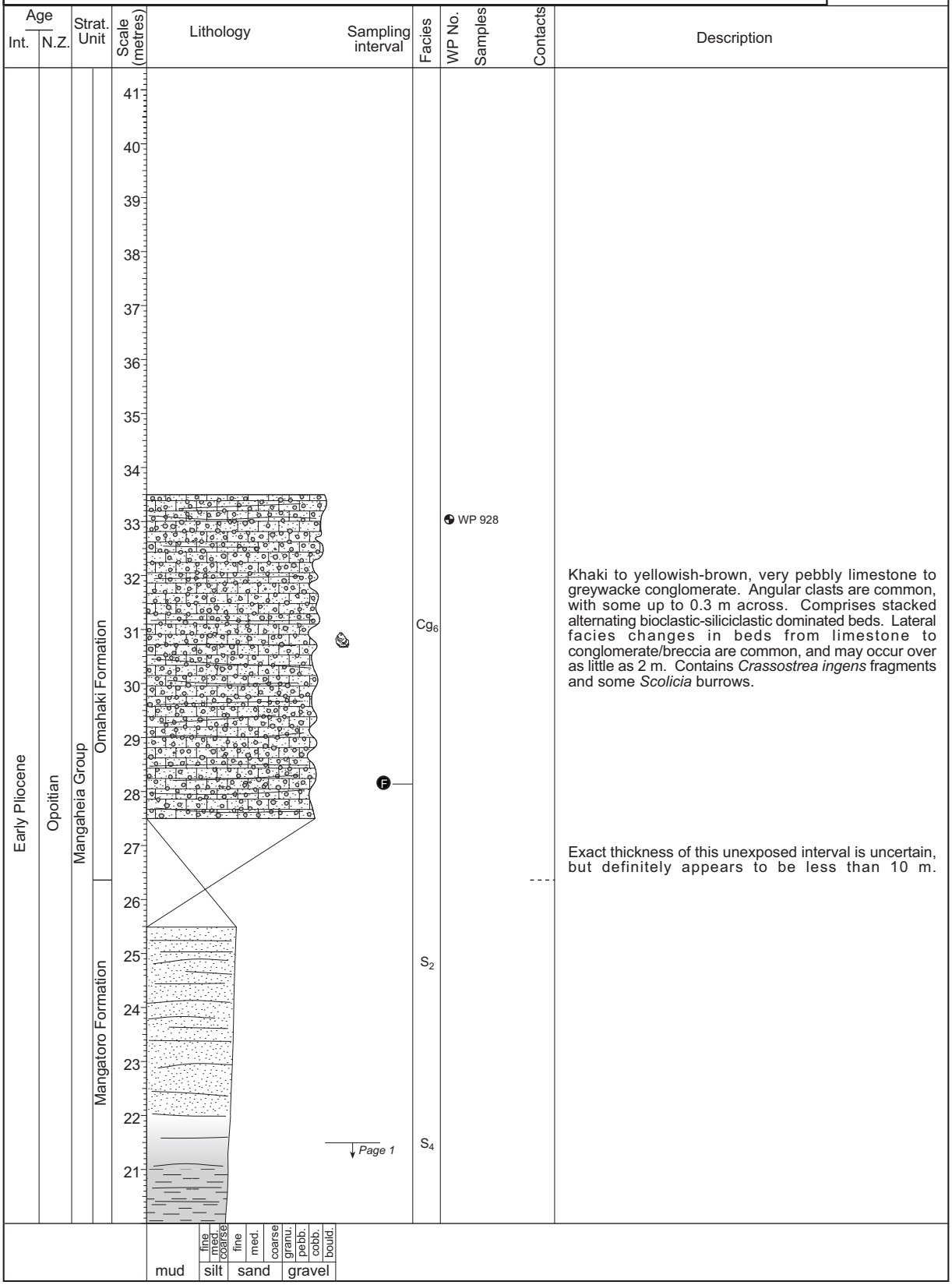
Region: Omahaki

Location: Omahaki Station composite, Omahaki Depression

NZMS 260 Sheet: U21 Kereru

	Grid Reference:	***Top***	***Bottom***
	E:	2800886	2801131
	N:	6186648	6186642
	Altitude:	433 m	391 m

Page 2 of 2



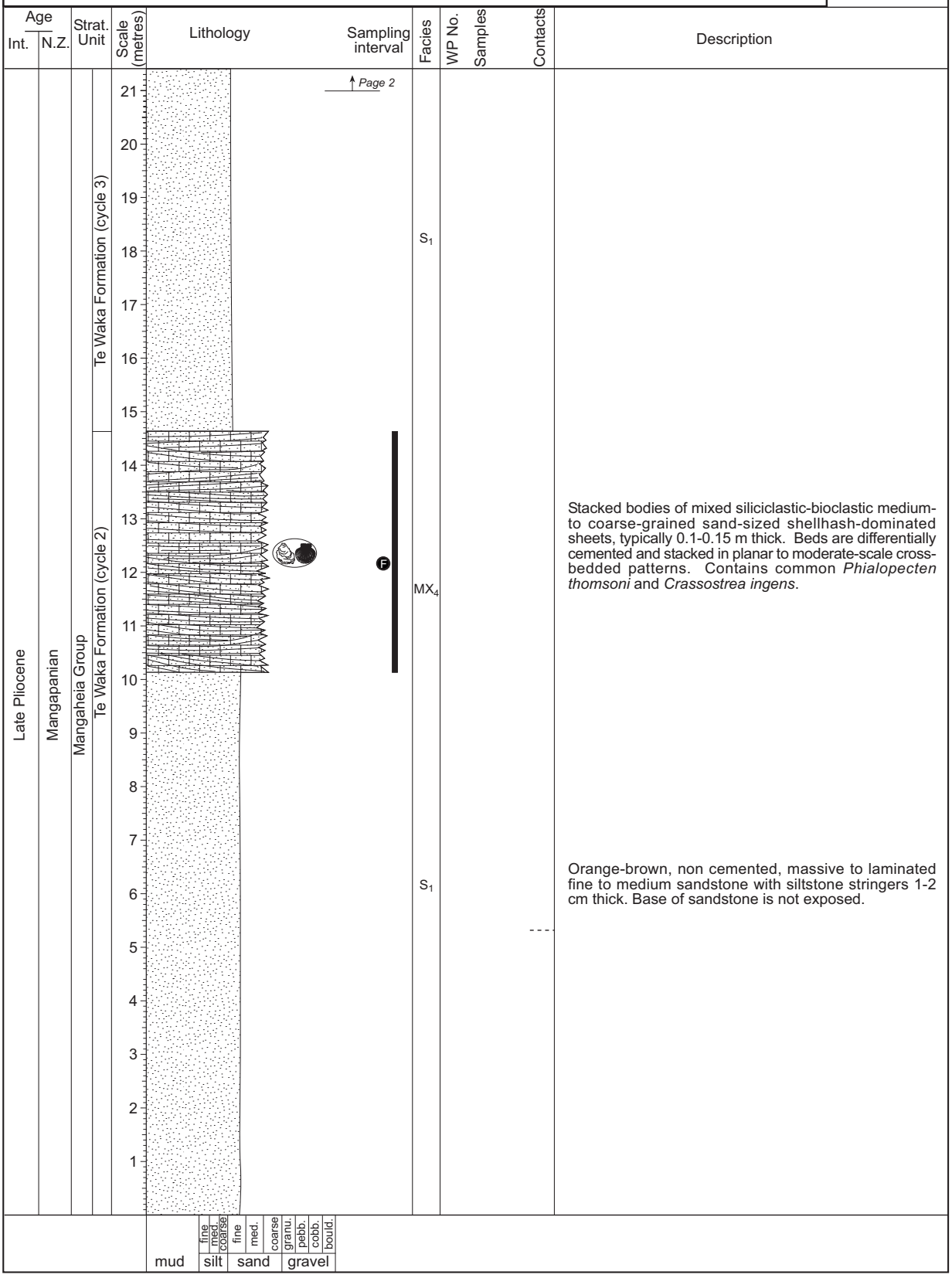
Stratigraphic Column No: Om-2 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 936 ***E:*** 2803002 -

Region: Omahaki ***N:*** 6185832 -

Location: Southern end of Glenross Range south of airstrip, Kohurau Station ***Altitude:*** 675 m -

NZMS 260 Sheet: V21 Kereru



Stratigraphic Column No: *Om-2*

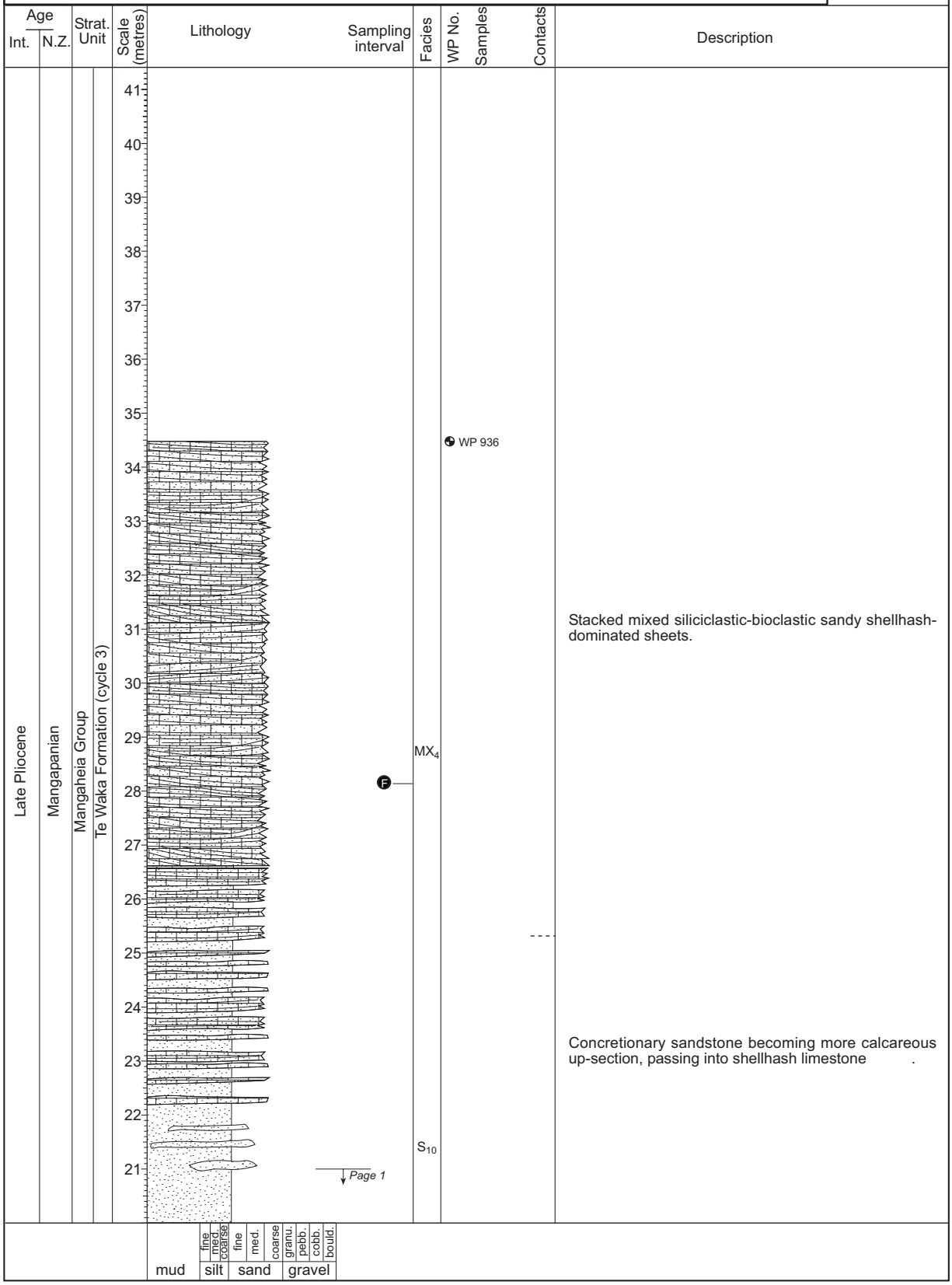
GPS Waypoint No(s): Wp 936

Region: Omahaki

Location: Southern end of Glenross Range south of airstrip, Kohurau Station

NZMS 260 Sheet: V21 Kereru

	Top	***Bottom***
Grid Reference:		
E:	2803002	-
N:	6185832	-
Altitude:	675 m	-



Stratigraphic Column No: Ot-1 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 825-826 ***E:*** 2810746 2810532

Region: Otamauri ***N:*** 6188233 6188531

Location: Taihape Road near Waikonini Stream bridge ***Altitude:*** 280 m 297 m

NZMS 260 Sheet: V21 Napier *Page* 1 *of* 1

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Lower Nukumaruan?	Mangaheia Group / ?Sentry Box Formation	1–20		F	Z_2			Blue-grey, non cemented slightly fossiliferous siltstone. Fauna dominated by *Ostrea chilensis* and shell hash. This siltstone gradationally overlies the underlying limestone through a 0.4 m-thick shelly fine sandstone interval that fines up into overlying siltstone.
						BC_3	WP 825		*?Eumarcia*-dominated shellbed, with *Ostrea chilensis*, *Purpurocardia, Talochlamys, Tawera,* and possible *Maoricardium*.
							WP 826		
						MX_4			Alternating sandy siliciclastic-bioclastic dominated sheets. Siliciclastic-dominated beds are typically thicker than bioclastic beds. Occasional shell horizons occur throughout the unit.
						S_1			Brown, fine to medium siliciclastic sandstone gradationally underlying limestone. The sandstone gradationally overlies massive, non fossiliferous siltstone.
						Z_2	MICROPAL		

mud | silt: fine, med., coarse | sand: fine, med., coarse | gravel: granu., pebb., cobb., bould.

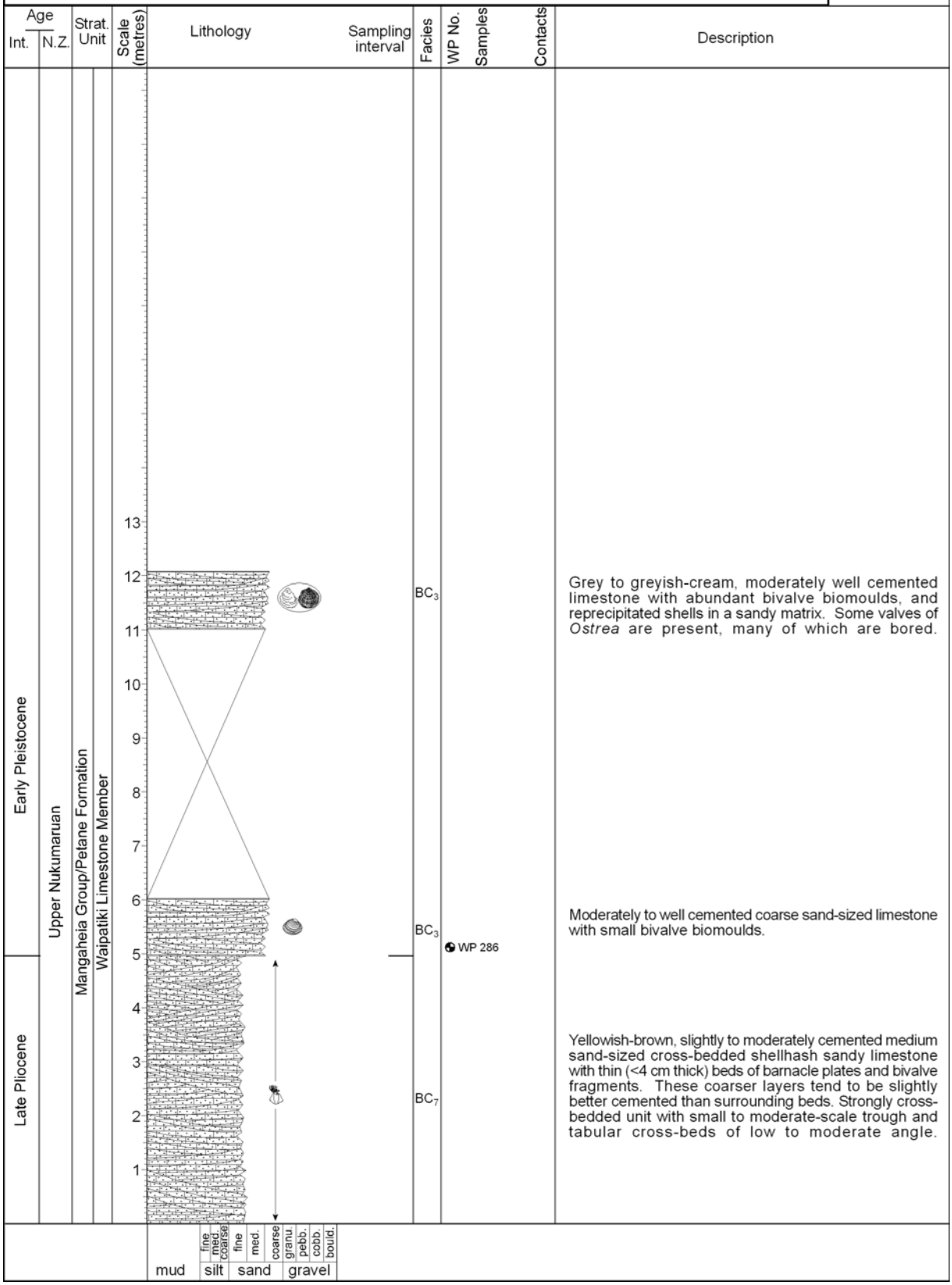
Stratigraphic Column No: Ou-1 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 286 ***E:*** 2834530 -

Region: Omahu ***N:*** 6175121 -

Location: Farm track off Taihape Road east of Omahu ***Altitude:*** 34m -

NZMS 260 Sheet: V21 Napier *Page* 1 *of* 1



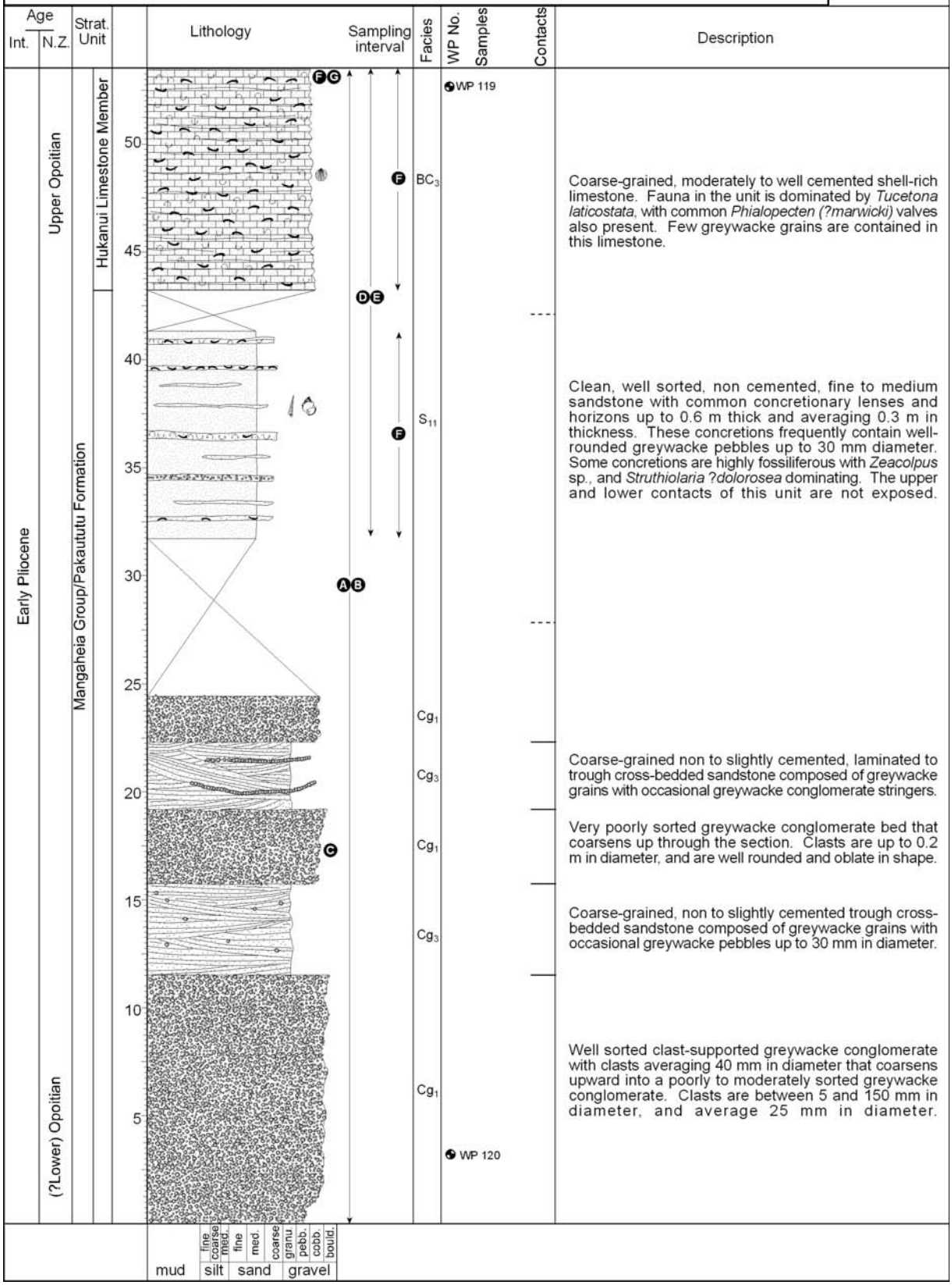
Stratigraphic Column No: Pa-1 **Grid Reference:** **Top** **Bottom**

GPS Waypoint No(s): Wp 120 **E:** 2812713 -

Region: Pakaututu **N:** 6212372 -

Location: Bluffs above Pakaututu Road overlooking switchback **Altitude:** 741m -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1




A


B


C


D


E


F


G

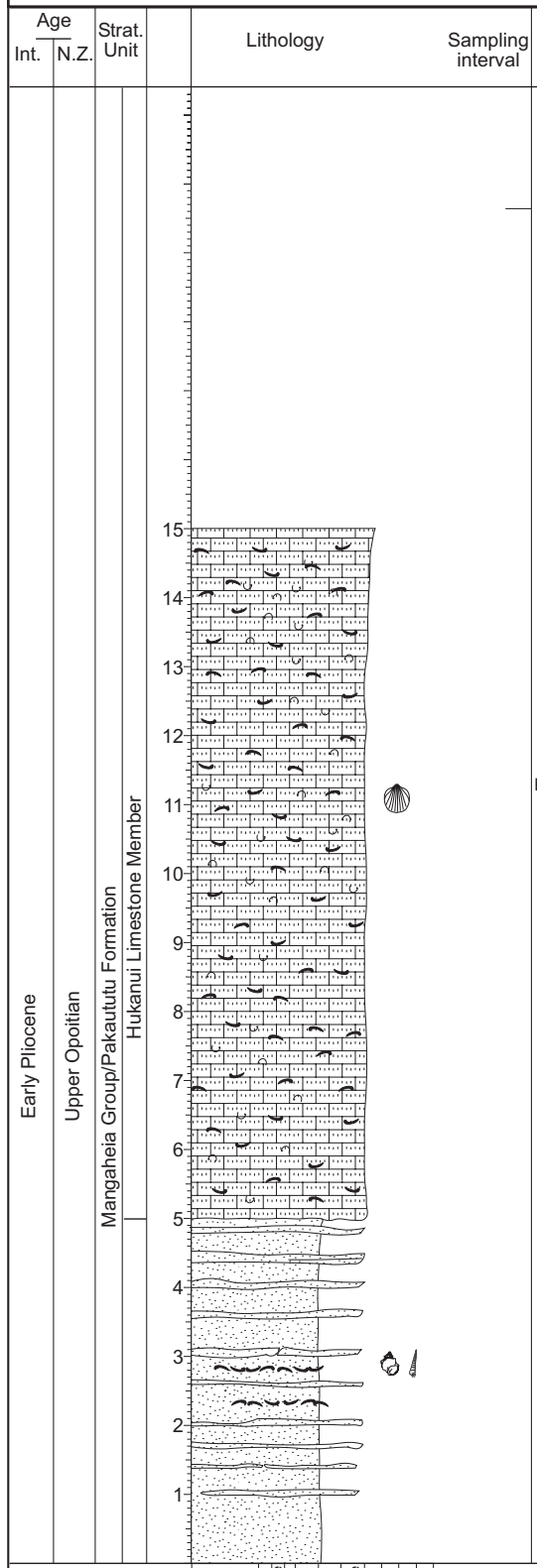
Stratigraphic Column No: Pa-2 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 122 ***E:*** 2813055

Region: Pakaututu ***N:*** 6212369

Location: Limestone sections in hills above Pakaututu Road. ***Altitude:*** 748m -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1



Moderately to well cemented coarse-grained whole shell-rich sandy limestone. Dominated by *Tucetona laticostata.* Lower contact with underlying sandstone is sharp. *Panopea sp.* valves were found protruding from the lower contact.

Clean, well sorted non to well cemented, non to highly fossiliferous siliciclastic sandstone with common concretionary lenses and horizons. Concretions are up to 0.6 m thick, average 0.3 m in thickness and are typically non fossiliferous. Shell lenses are common and are generally 0.2-0.3 m thick, though they show thickness changes through them. They were found to contain *Glycymeris (Mania) mahiana,* the Opotian-restricted gastropod *Struthotaria dolorosa, Struthilaria (Callusaria)* sp., *Lamprodominea* sp., *Amalda* sp., *Oraria* sp., *Zeocolpus/Stiracolpus* sp., barnacles *(Tasmanomegabalanus)* and *Crepidula radiata*. Shellhash and fragments are common, although articulated and disarticulated valves are present.

Well sorted, non to poorly cemented siliciclastic sandstone.

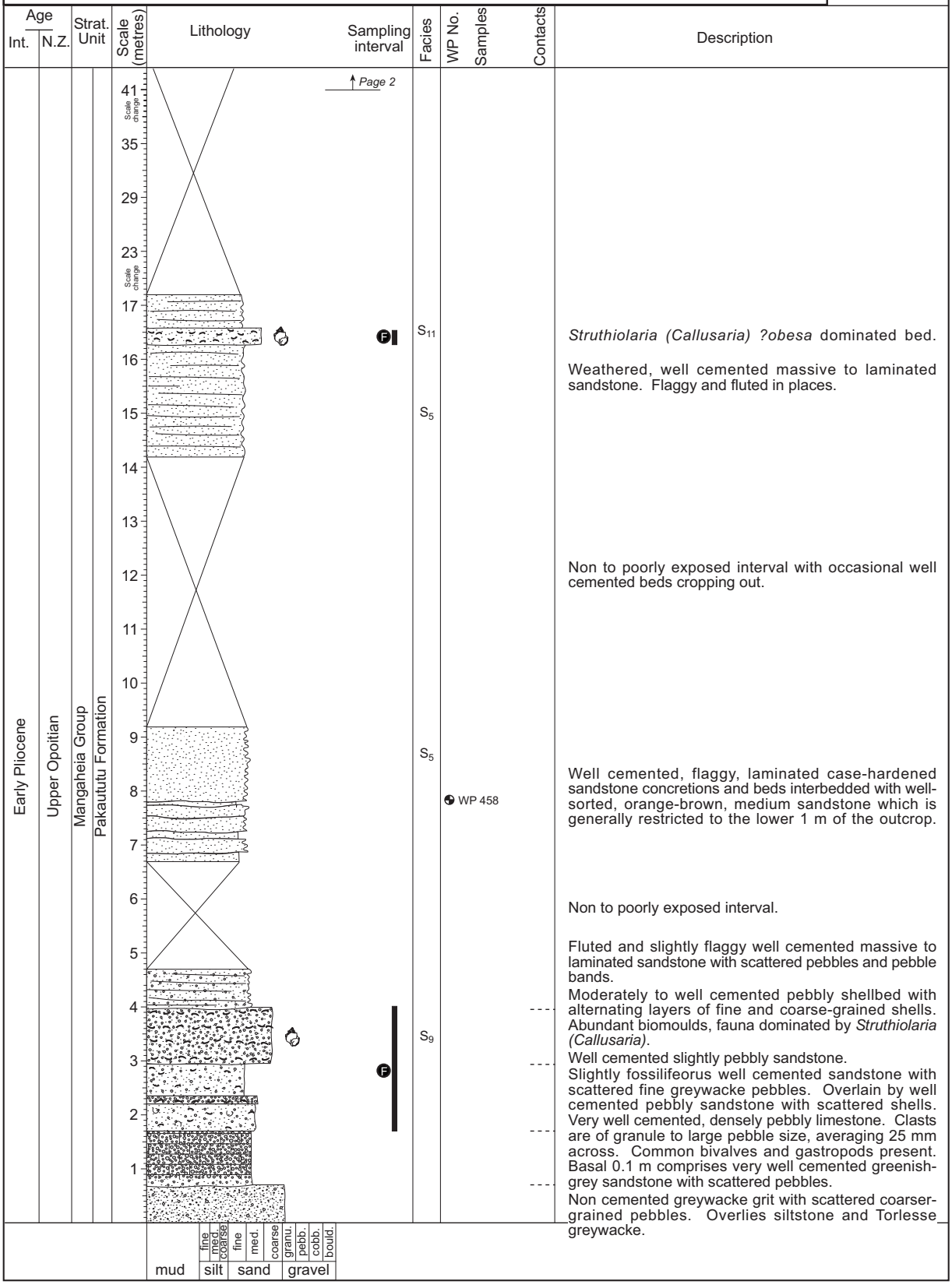
Stratigraphic Column No: *Pa-3* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 458, 459 ***E:*** 2815949 2815869

Region: Pakaututu ***N:*** 6212682 6212915

Location: Hukanui Station at northern boundary fences ***Altitude:*** 845 m 785 m

NZMS 260 Sheet: V20 Esk



Stratigraphic Column No: Pa-3 ***Grid Reference:*** ***Top*** ***Bottom***

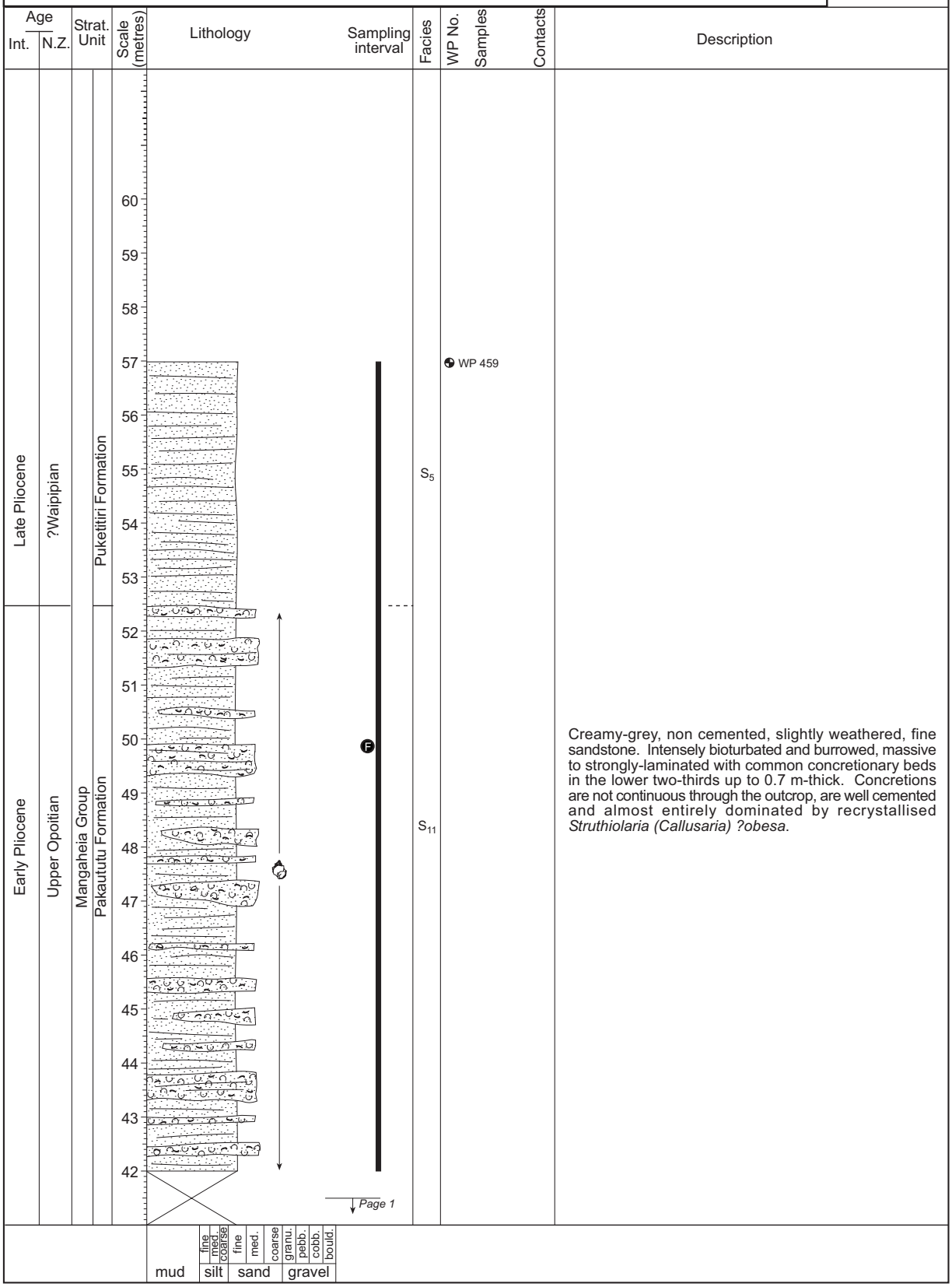
GPS Waypoint No(s): Wp 458, 459 ***E:*** 2815949 2815869

Region: Pakaututu ***N:*** 6212682 6212915

Location: Hukanui Station at northern boundary fences ***Altitude:*** 845 m 785 m

NZMS 260 Sheet: V20 Esk

Page 2 of 2



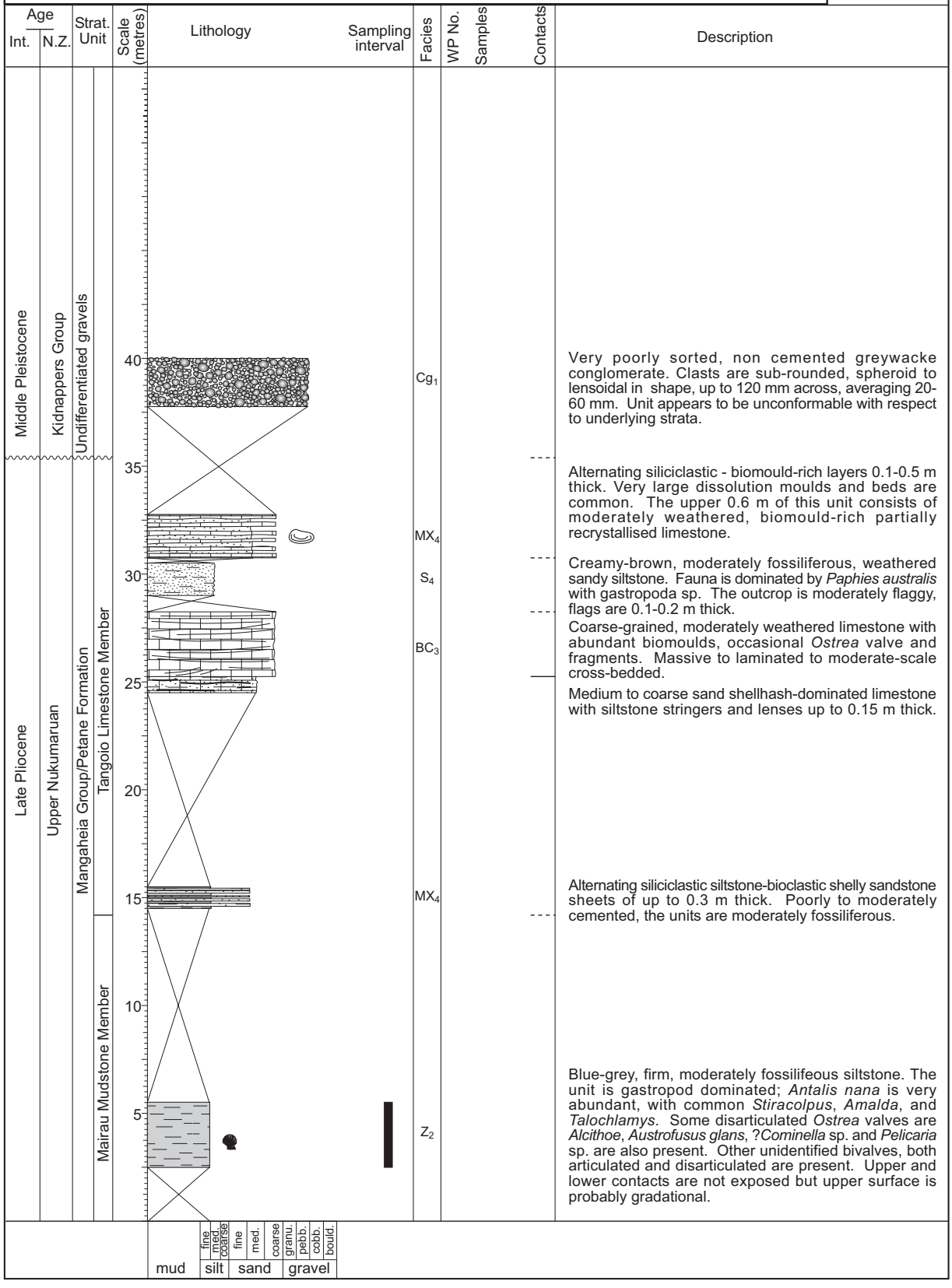
Stratigraphic Column No: *Pk-1* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 371-373 ***E:*** 2836553 2836357

Region: Puketapu ***N:*** 6187257 6187021

Location: Farm track at Bayliss Bros. drilling depot above Puketitiri Road. ***Altitude:*** 143m 126m

NZMS 260 Sheet: V21 Napier



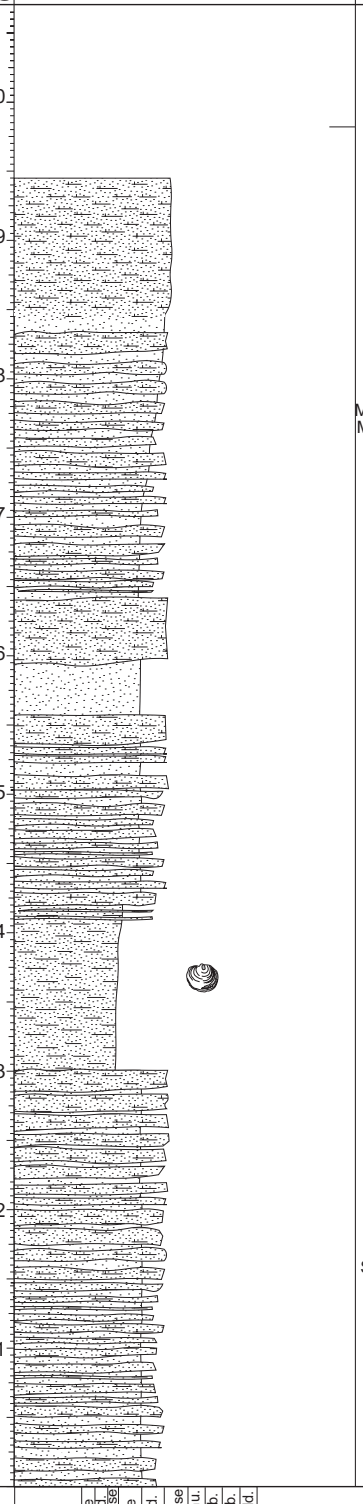
Stratigraphic Column No: *Pk-2* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 377 ***E:*** 2838141 -

Region: Puketapu ***N:*** 6181999 -

Location: Farm track off Silverton Road near Puketapu ***Altitude:*** 36 -

NZMS 260 Sheet: V21 Napier *Page* 1 *of* 1



This bed is thought to pass conformably into a well cemented shelly limestone bed of several metres thickness.

Dirty creamy-yellow, firm, massive, silty sandstone with a volcaniclastic content. Slightly fossiliferous with *Patro undatus, Crepidula radiata* and intact barnacles. Occasional thin, more cemented units are present towards the top of this unit, with the bed displaying a slight coarsening-upwards trend.

Rusty-yellow, non cemented calcareous sandstone similar to underlying unit, with slightly cemented layers that get progressively thicker (up to 0.15-0.2 m thick) upsection. Cemented layers are weakly laminated in places.

Rusty-yellow, non cemented, non fossiliferous, shelly, calcareous sandstone with common creamy-yellow slightly cemented layers 0.05-0.1 m thick. These cemented layers are similar in composition to the surrounding non cemented sediments.

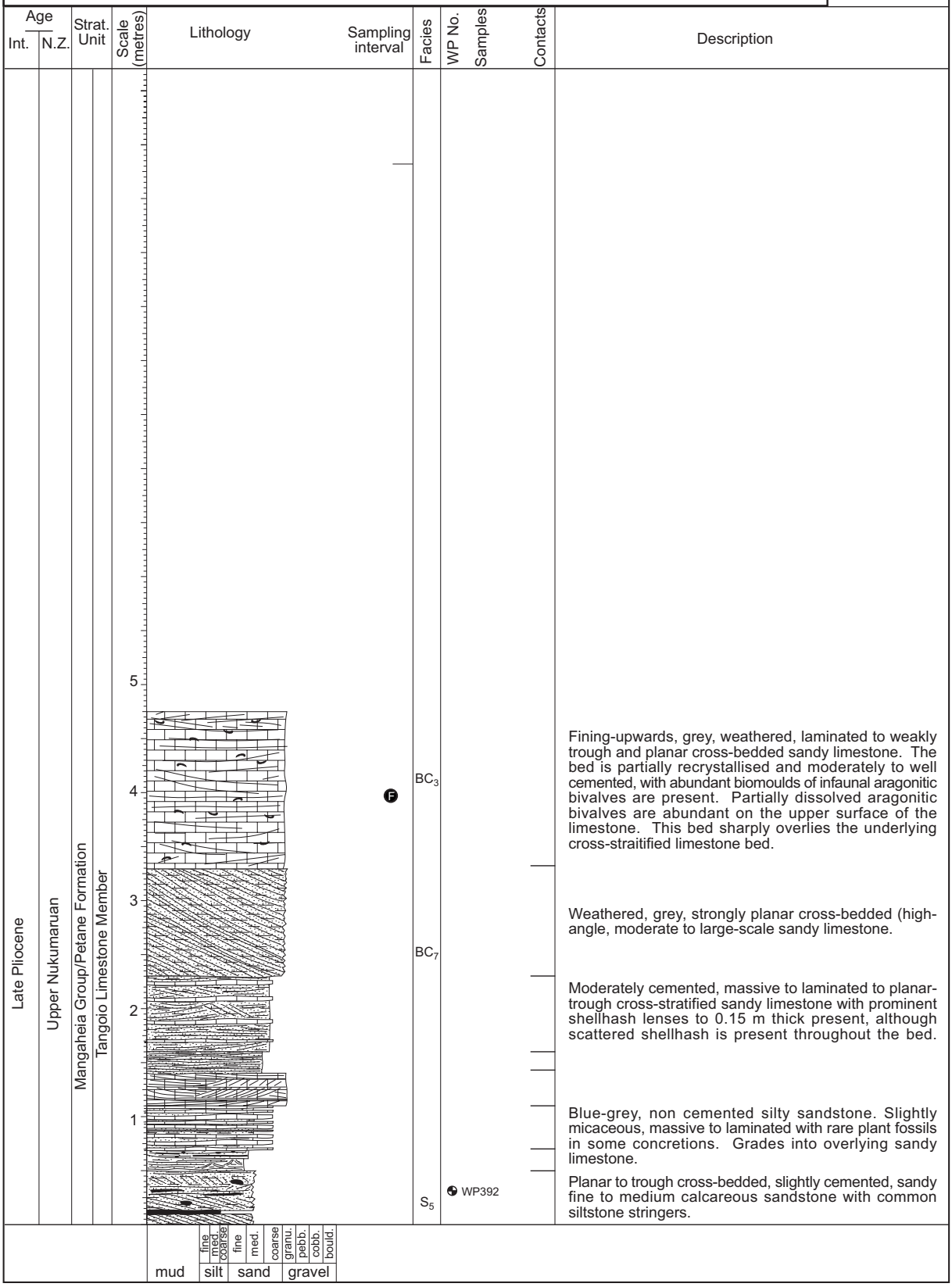
Stratigraphic Column No: *Pk-3* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 392 ***E:*** 2837029 -

Region: Puketapu ***N:*** 6183535 -

Location: Springvale Station at Puketapu Road end ***Altitude:*** 37m -

NZMS 260 Sheet: V21 Napier *Page* 1 *of* 1



Stratigraphic Column No: Pt-1 ***Grid Reference:*** ***Top*** ***Bottom***

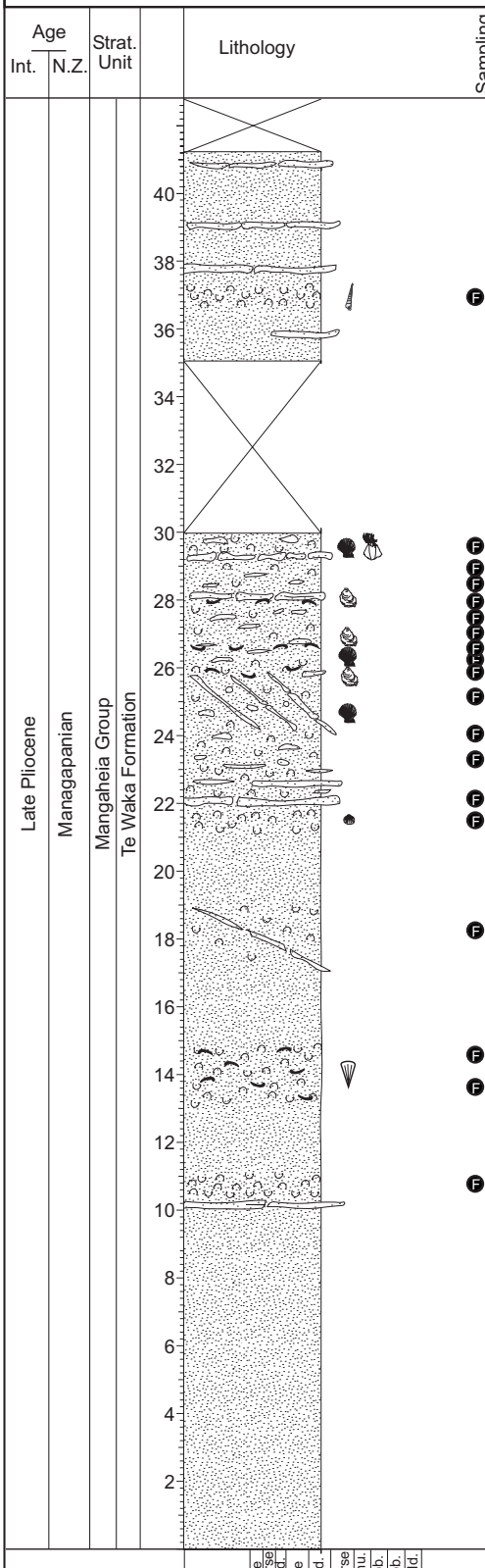
GPS Waypoint No(s): Wp 129-132 ***E:*** 2820819 2820651

Region: Patoka ***N:*** 6204046 6204204

Location: Opau Station, on track at "The Bend". ***Altitude:*** - 537m

NZMS 260 Sheet: V20 Esk

Page 1 *of* 2



Well-sorted, clean, moderately weathered and leached concretionary sandstone. The unit is strongly bioturbated with common bioturbated "blebs" arranged in bands 7 cm thick. Concretions are generally unfossiliferous, with *Zeacolpus vitattus* and *Dosinia* sp. present in the sandstone.

Moderately fossiliferous, concretionary medium sandstone with occasional sparsely-packed oyster beds. Barnacle fragments and plates become more common in this interval.

Non cemented, concretionary, medium sandstone that shows an increase in both mica and bioclastic content compared with underlying beds. Concretions are generally small (up to 5 cm diameter).

Slightly concretionary, non cemented, slightly micaceous moderately to strongly bioturbated sandstone. Tube worm casts are present through this interval. Concretionary bodies have often developed along joints in the rock.
Moderately weathered, non fossiliferous, non cemented, well sorted, slightly micaceous sandstone with rare concretions.

Slightly to moderately fossiliferous, non cemented, slightly micaceous sandstone. Many of the *Atrina pectinata zelandica* and *Panopea* sp. fossils in this interval are articulated and *in situ.*

Non fossiliferous, moderately to strongly weathered, slightly micaceous, massive, well sorted fine to medium sandstone.

Stratigraphic Column No: Pt-1 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 129-132 ***E:*** 2820819 2820651

Region: Patoka ***N:*** 6204046 6204204

Location: Opau Station, on track at "The Bend". ***Altitude:*** - 537m

NZMS 260 Sheet: V20 Esk

Age Int.	Age N.Z.	Strat. Unit	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description

A- Slightly fossiliferous sandstone containing *Dosinia lambata, Atrina (pectinata) zelandica, Pratulum pulchellum, Sigapatella novaezelandiae*, shell hash.

B- Moderately fossiliferous sandstone dominated by *Atrina pectinata zelandica* which appear to be *in situ* and are articulated. Also present are *Nucula nitidula, Talochlamys gemmulata*, and *Polinicies scalptus*.

C- Non cemented sandstone containing *Talochlamys gemmulata*, articulated *Panopea* sp.*, Dosina* sp.*, Gari lineolata* and *Pratulum pulchellum.*

D- Slightly concretionary, moderately to strongly bioturbated sandstone dominated by *Talochlamys gemmulata*, with common *Atrina pectinata zelandica* and *Crepidula radiata. Zeacolpus, Gari* sp. *and* polychate tube worm casts are also present.

E- Moderately fossiliferous sandstone containing *Talochlamys gemmulata, Serratina* sp.*, Dosinia greyi, Pratulum pulchellum, Pteromyrtea dispar, ?Maoricolpus/?Zeacolpus* and *Gari lineloata.*

F- Moderately concretionary, non cemented sandstone that coarsens upward through the sampling interval. Dominated by *Pratulum pulchellum*, with common *Talochlamys gemmulata*. Also present are *Zeacolpus vitattus* and *Maoricolpus roseus.*

G- Non cemented sandstone with an increasing bioclastic and mica content compared with underlying beds. *Atrina pectinata zelandica, Pratulum pulchellum, Xymene* sp.*, Pteromyrtea dispar* and *Notocallista ?notostriata* are present.

H- *Polinices* sp.*, Crassostrea ingens, Pratulum pulchellum, Struthiolaria* sp. An articulate*d Atrina pectinata zelandica* is present, although is not in life position.

I- *Zenatia acinaces, Notocallista* sp.*, Dosinia lambata, Maoricardium spatiosum.*

J- A sparse *Crassostrea ingens* bed with some *Atrina pectinata zelandica.*

K- Numerous *Talochlamys gemmulata* with *Dosinia greyi* and *Sigapatella novaezelandiae.*

L- *Atrina pectinata zelandica* present in a hydrodynamically stable position.

M- A 0.15-0.2 m-thick, moderately fossiliferous *Crassostrea ingens* shellbed.

N- *Crepidula radiata, Crassostrea ingens* and the barnacle *Austromegabalanus* sp.

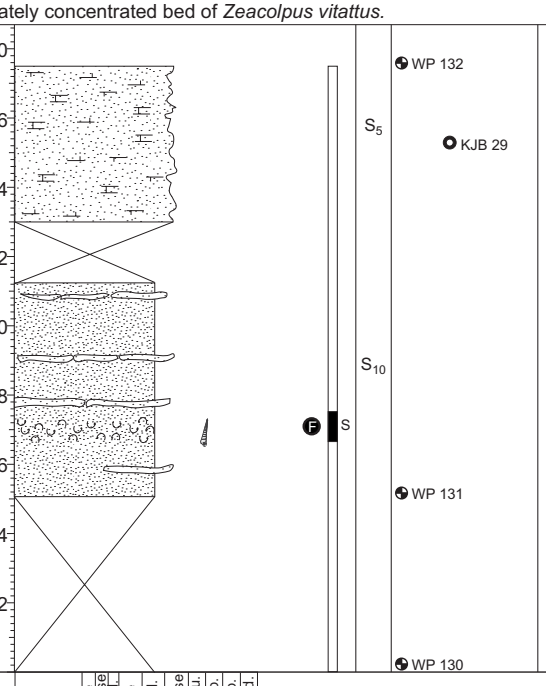
O- Dominated by *Sigapatella novaezelandiae*, with *Atrina pectinata zelandica, Lamprodominea* sp.*, Patro undatus* and *Talochlamys gemmulata.*

P- *Zeacolpus vitattus* and *Atrina pectinata zelandica.*

Q- A 0.5 m-thick concretionary bed with abundant *Crassostrea ingens* and *Maoricolpus roseus.*

R- *Taloclamys gemmulata, Atrina pectinata zelandica, Crepidula radiata, Sigapatella novaezelandiae* and barnacles.

S- A moderately concentrated bed of *Zeacolpus vitattus.*



Moderately- to well-cemented, calcareous sandstone. The bed is unfossiliferous, although there is some evidence of bioturbation and burrowing visible.

Well-sorted, clean, moderately weathered and leached concretionary sandstone. The unit is strongly bioturbated with common bioturbated "blebs" arranged in bands 7 cm thick. Concretions are generally unfossiliferous, with *Zeolcolpus vitatus* and *Dosinia sp*. present in the sandstone.

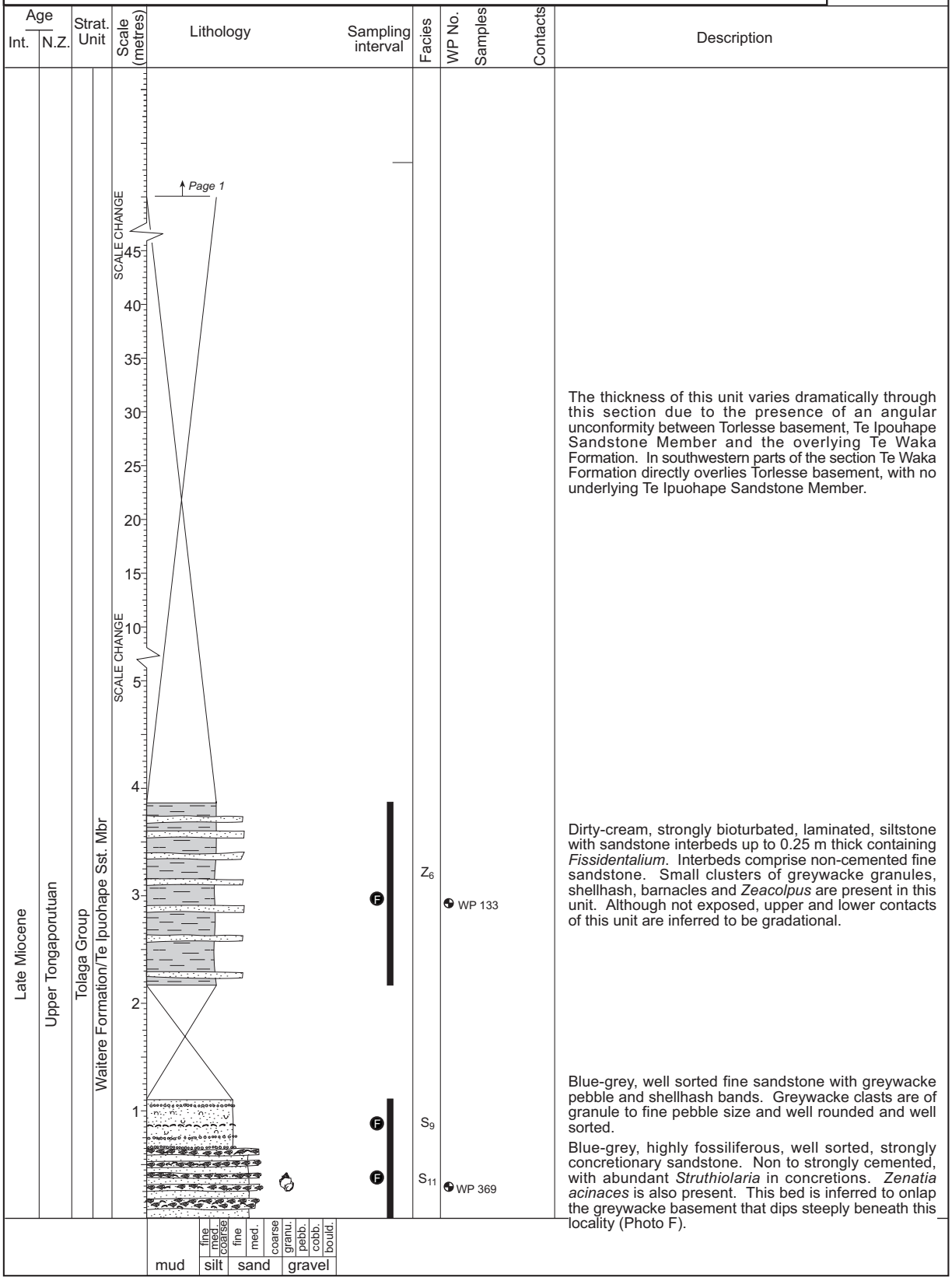
Stratigraphic Column No: Pt-2 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 133, 137, 138 and 369 ***E:*** 2820891 2820709

Region: Patoka ***N:*** 6204875 6204975

Location: Opau Stream section near metal pit off Puketitiri Road. ***Altitude:*** 540m -

NZMS 260 Sheet: V20 Esk



The thickness of this unit varies dramatically through this section due to the presence of an angular unconformity between Torlesse basement, Te Ipouhape Sandstone Member and the overlying Te Waka Formation. In southwestern parts of the section Te Waka Formation directly overlies Torlesse basement, with no underlying Te Ipuohape Sandstone Member.

Dirty-cream, strongly bioturbated, laminated, siltstone with sandstone interbeds up to 0.25 m thick containing *Fissidentalium*. Interbeds comprise non-cemented fine sandstone. Small clusters of greywacke granules, shellhash, barnacles and *Zeacolpus* are present in this unit. Although not exposed, upper and lower contacts of this unit are inferred to be gradational.

Blue-grey, well sorted fine sandstone with greywacke pebble and shellhash bands. Greywacke clasts are of granule to fine pebble size and well rounded and well sorted.

Blue-grey, highly fossiliferous, well sorted, strongly concretionary sandstone. Non to strongly cemented, with abundant *Struthiolaria* in concretions. *Zenatia acinaces* is also present. This bed is inferred to onlap the greywacke basement that dips steeply beneath this locality (Photo F).

Stratigraphic Column No: Pt-2 ***Grid Reference:*** ***Top*** ***Bottom***

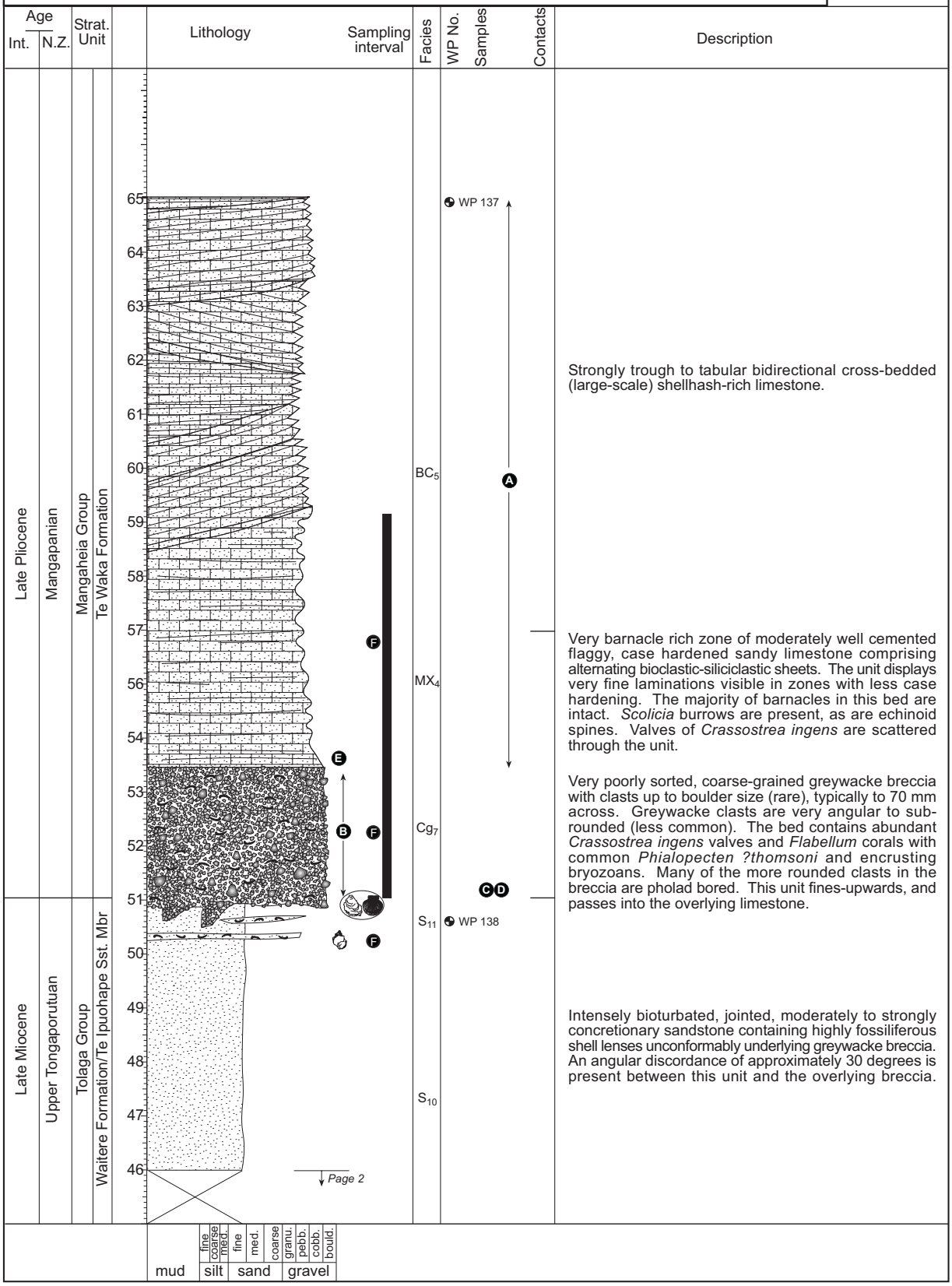
GPS Waypoint No(s): Wp 133, 137, 138 and 369 ***E:*** 2820891 2820709

Region: Patoka ***N:*** 6204875 6204975

Location: Opau Stream section near metal pit off Puketitiri Road. ***Altitude:*** 540m -

NZMS 260 Sheet: V20 Esk

Page 2 of 2



Strongly trough to tabular bidirectional cross-bedded (large-scale) shellhash-rich limestone.

Very barnacle rich zone of moderately well cemented flaggy, case hardened sandy limestone comprising alternating bioclastic-siliciclastic sheets. The unit displays very fine laminations visible in zones with less case hardening. The majority of barnacles in this bed are intact. *Scolicia* burrows are present, as are echinoid spines. Valves of *Crassostrea ingens* are scattered through the unit.

Very poorly sorted, coarse-grained greywacke breccia with clasts up to boulder size (rare), typically to 70 mm across. Greywacke clasts are very angular to sub-rounded (less common). The bed contains abundant *Crassostrea ingens* valves and *Flabellum* corals with common *Phialopecten ?thomsoni* and encrusting bryozoans. Many of the more rounded clasts in the breccia are pholad bored. This unit fines-upwards, and passes into the overlying limestone.

Intensely bioturbated, jointed, moderately to strongly concretionary sandstone containing highly fossiliferous shell lenses unconformably underlying greywacke breccia. An angular discordance of approximately 30 degrees is present between this unit and the overlying breccia.


A


B


C


D


E


F

Stratigraphic Column No: *Pt-3*

GPS Waypoint No(s): Wp 171

Region: Patoka

Location: Farm track above Maingarangiora Stream.

NZMS 260 Sheet: V20 Esk

Grid Reference:	***Top***	***Bottom***
E:	2824798	
N:	6203236	
Altitude:	321m	-

Page 1 *of* 1

Age Int.	Age N.Z.	Strat. Unit	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Upper Mangapanian	Mangaheia Group/Matahorua Formation, Deep Stream Member			S_4			Clean, non cemented, well sorted silty sandstone.
					Cg_4			
					Cg_1			Slightly to moderately cemented, moderately to well sorted, greywacke conglomerate bed dominated by granule to fine pebble-sized clasts set in a coarse sand-sized greywacke matrix. Laminations visible in unit, finer-grained beds are generally thicker than coarser-grained beds (up to 0.7 m thick, average 0.25 m thick). Clasts are very well rounded and dominantly oblate in shape, with rare grains up to 0.1 m in diameter. The largest and smallest clasts tend to be more spheroid in shape, and imbrication towards the southeast is visible in the largest cobbles.
					Cg_2			
					Cg_1	WP 171		Coarse-grained large pebble to cobble-sized, poorly sorted (granule to 0.08 m diameter clasts) greywacke conglomerate sharply overlying sandstone. Clasts are moderately rounded, and are dominated by spheroid shaped grains.
		Pohue Fmn			S_9			Non cemented, fine to medium sandstone with common greywacke pebble stringers. The unit is laminated to trough cross-bedded. Cross-beds are small-scale and low angle. Rare scattered greywacke pebbles are present, as are moderately common fine-grained sandstone rip-up clasts. Greywacke pebbles are well sorted and well rounded.

13 12 11 10 9 8 7 6 5 4 3 2 1

mud | silt (fine, coarse, med.) | sand (fine, med., coarse) | gravel (granu., pebb., cobb., bould.)

Stratigraphic Column No: Pt-4 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 178 ***E:*** 2825961

Region: Patoka ***N:*** 6200233

Location: Gravel pit on Huiarangi Road near Newark Farm. ***Altitude:*** 369m -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1

Age Int.	Age N.Z.	Strat. Unit	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Upper Mangapanian	Mangaheia Group/Matahorua Formation, Papakiri Member, Trelinnoe Mbr	Z_{10}			Creamy to rusty-coloured, massive to laminated siltstone with abundant, very well preserved leaves and leaf impressions.
			Cg_2			
			Cg_1	WP 178		Crudely-bedded, poorly to well sorted greywacke conglomerate bed with common fine to medium sandstone lenses and stringers up to 0.3 m thick and 2 m in length. Average thickness of sandstone lenses is 0..1 m thick by 1.5 m in length, with lenses more common in lower portions of the exposure. Greywacke clasts are well rounded and dominantly oblate in shape, and range from medium pebble to medium cobble in size. Unit is underlain by a silty sandstone very rich in fossilised plant leaves.
			Cg_6	KJB 36		0.5 m-thick, highly- ossiliferous greywacke conglomerate bed dominated by *Phialopecten triphooki* and *Glycymeris* sp., with common *Purpurocardia purpurata* in the lower half. Occasional *Maoricolpus, Tucetona laticostata*, *Alcithoe* sp., and *Zeacolpus* are present, as well as rare *Ostrea chilensis* valves. The conglomerate is poorly to moderately sorted, with clasts from granule to pebble in size (up to 60mm diameter) that are moderately to well rounded and spherical to oblate in shape. *Phialopecten triphooki* is more common in the middle half of the unit. Also contains rare abraded *Austrovenus stutchburyi*.
	Lower Nukumaruan		Z_5			Massive moderately fossiliferous pebbly siltstone. Clasts are greywacke dominated. Macrofauna are dominated by *Neilo*, with *Dosinia greyi*.
			Z_1			Massive non to sparsely fossiliferous siltstone.

Lithology: 7, 6, 5, 4, 3, 2, 1; A, B, C, F

Sampling interval

mud | silt (fine, coarse, med.) | sand (fine, med., coarse) | gravel (granu., pebb., cobb., bould.)


A


B
Canon


C

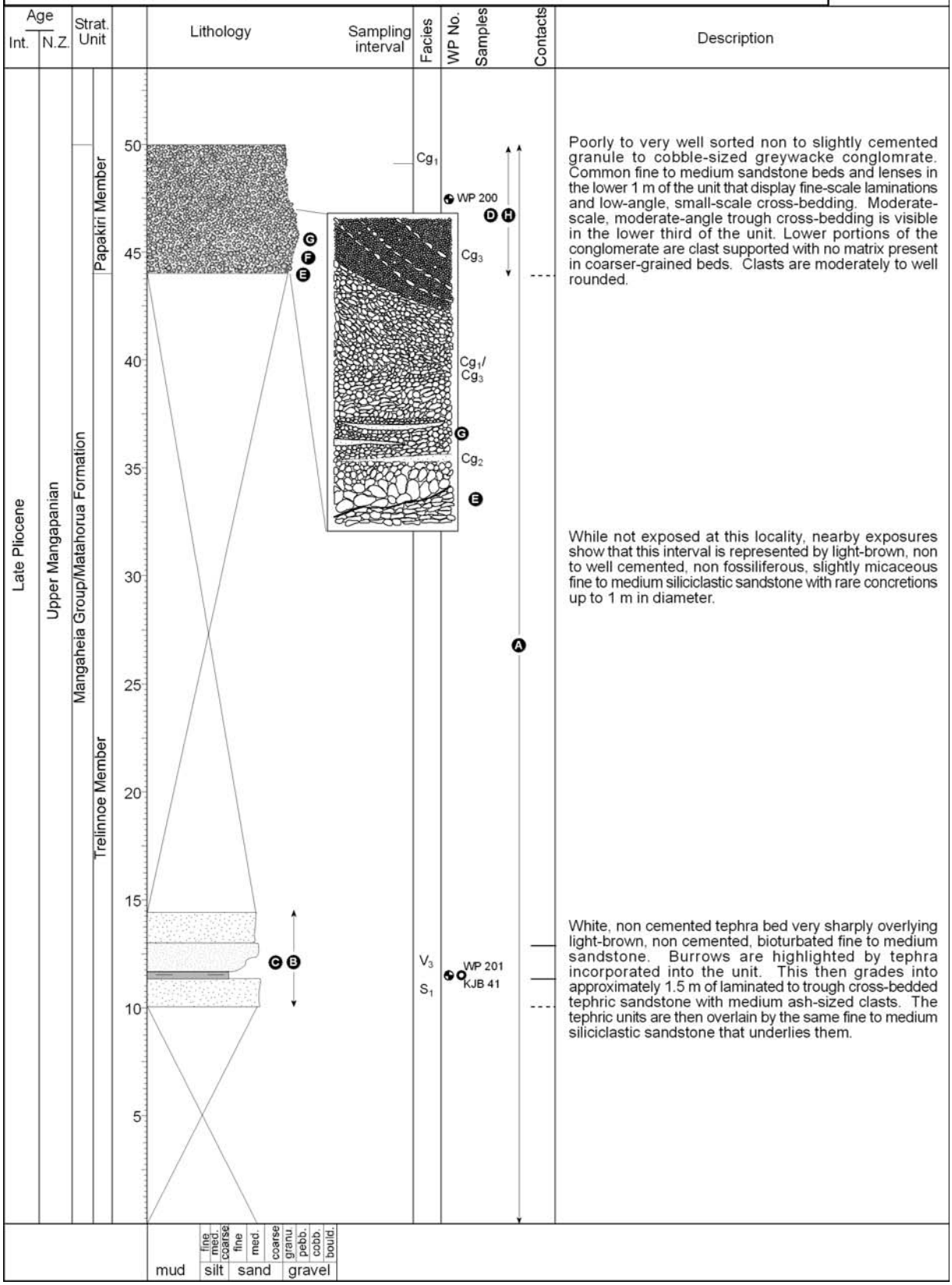
Stratigraphic Column No: *Pt-5* ***Grid Reference:*** ***Top*** ***Bottom***

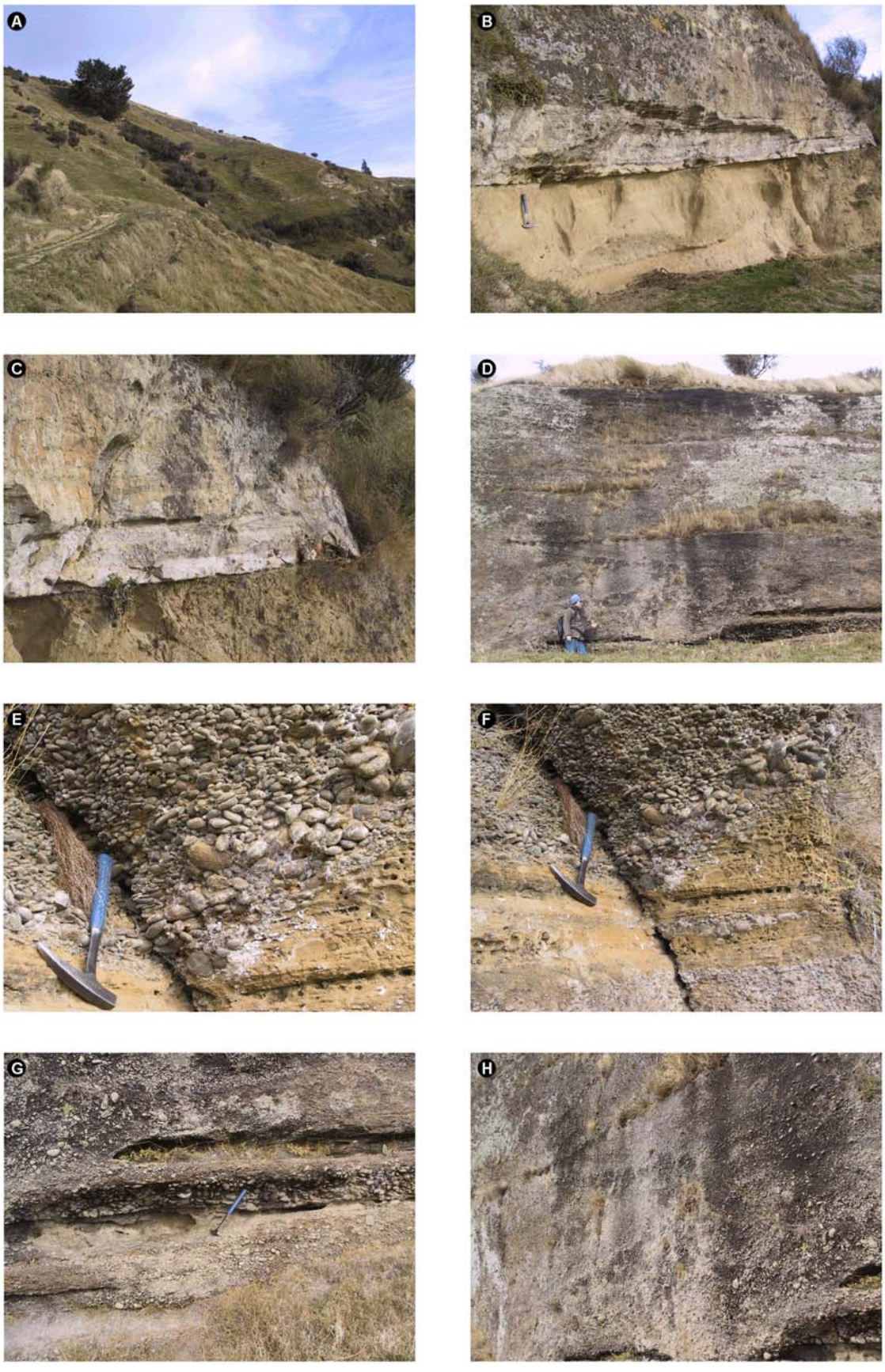
GPS Waypoint No(s): Wp 200-201 ***E:*** 2825425 2825602

Region: Patoka ***N:*** 6200362 6200556

Location: Steep hillside beside spiral on Huiarangi Road. ***Altitude:*** 395m 358m

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1




A
B
C
D
E
F
G
H

Stratigraphic Column No: Pt-6 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 202 ***E:*** 2821431 2813950

Region: Patoka ***N:*** 6198020 6206000

Location: Gravel pit off Waihau Road near Puketitiri Road. ***Altitude:*** 278 -

NZMS 260 Sheet: V20 Esk

Age Int.	Age N.Z.	Strat. Unit	Lithology / Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Upper Mangapanian	Mangaheia Group/Matahorua Formation, Papakiri Member	7	Cg_1/ Cg_3			Well sorted, massive to laminated, slightly cemented greywacke conglomerate. Clasts range from granule to fine pebble in size, and are well-rounded and spheriodal in shape.
		Trelinnoe Member	4		WP 202		Clean, well sorted fine to medium sandstone with common thin (<0.03 m thick) siltstone stringers and common greywacke conglomerate lenses. The conglomerate lenses are up to 0.5 m thick, and up to several metres in length, though average 15cm in thickness and <1.5 m in length. Gravel clasts are well sorted and well rounded, averaging 12 mm in diameter, though may be up to 40 mm across. Spherical shaped grains dominate, though oblate clasts are present. The sandstone commonly displays low-angle, small-scale trough cross-bedding, as well as laminations. Portions of the sandstone also contain common scattered greyewacke pebbles, and thin beds of mudstone rip-up clasts which are up to 70 mm in diameter.
			3	S_9			
			1	S_1			

mud | silt: fine, med., coarse | sand: fine, med., coarse | gravel: granu., pebb., cobb., bould.

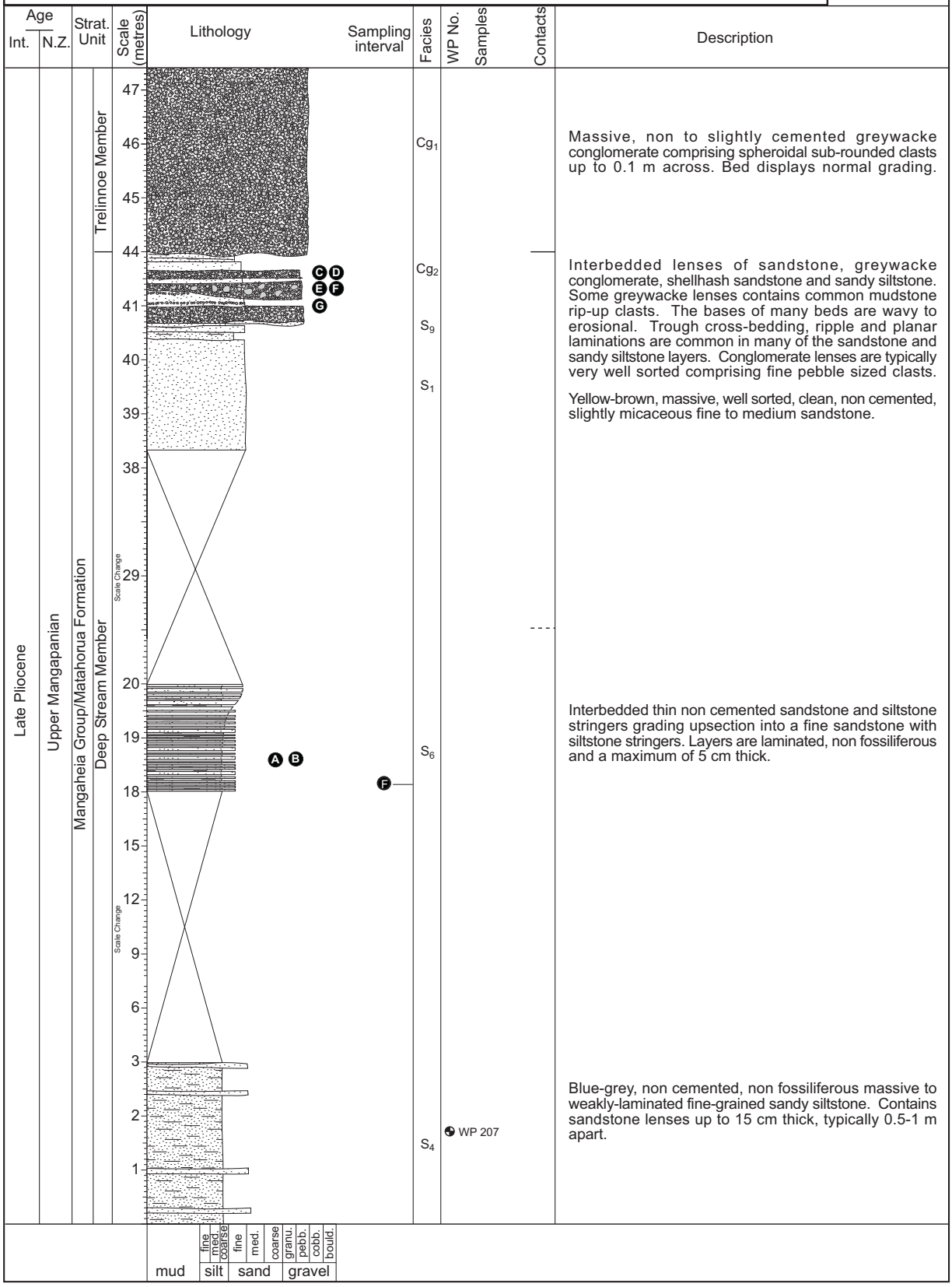
Stratigraphic Column No: *Pt-7* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 205-207 ***E:*** 2820521 2820468

Region: Patoka ***N:*** 6196749 6196666

Location: Farm track below trig on Cascades Farm off Waihau Road ***Altitude:*** 355 m 311 m

NZMS 260 Sheet: V20 Esk




A


B


C


D


E
Canon


F


G
Canon

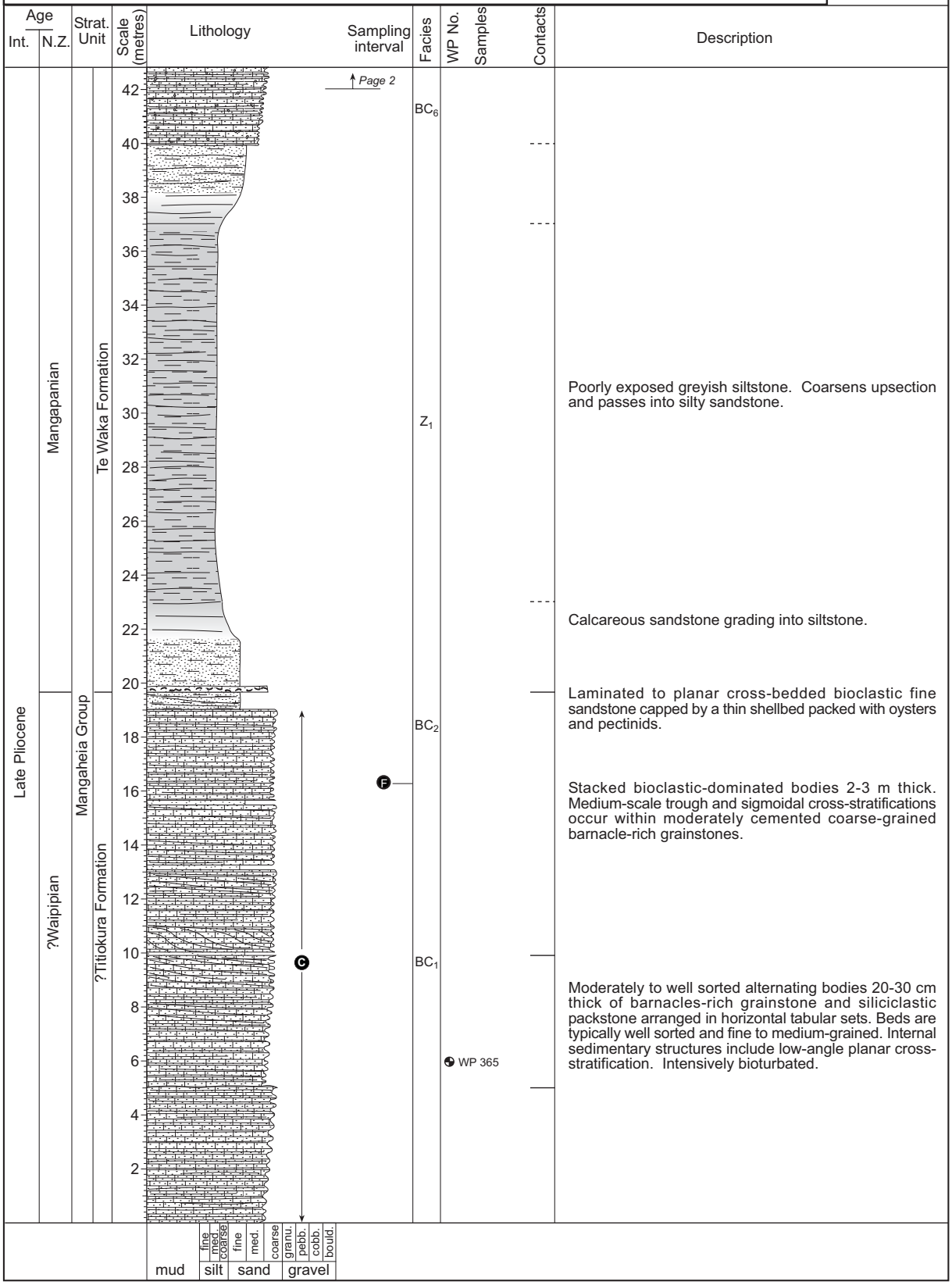
Stratigraphic Column No: *Pt-8* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 365, 627 ***E:*** 2819716 2818656

Region: Patoka: **Logged by V. Caron (2002)** ***N:*** 6201109 6201140

Location: The Gorges, headwaters of Wai-iti Stream below Puketitiri Road ***Altitude:*** 417 m 363 m

NZMS 260 Sheet: V20 Esk



Stratigraphic Column No: Pt-8 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 365, 627 ***E:*** 2819716 2818656

Region: Patoka ***N:*** 6201109 6201140

Location: The Gorges, headwaters of Wai-iti Stream below Puketitiri Road ***Altitude:*** 417 m 363 m

NZMS 260 Sheet: V20 Esk

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Mangapanian	Mangaheia Group / Te Waka Formation	84–44						Siltstone grading into sandstone, in turn overlain by fossiliferous greywacke conglomerate and fluvial gravel beds. This interval is partially exposed on Mount Hassal north of this section.
									Moderately to well cemented, moderately sorted coarsening-upwards package from laminated siliciclastic packstone to coarse-grained barnacle-rich grainstone. Beds are 0.3-0.4 m thick and moderately bioturbated Sharply overlies similar package below.
							WP 627		Moderately to well cemented, moderately-sorted coarsening-upwards bioturbated package from laminated siliciclastic packstone to coarse-grained barnacle-rich grainstone. Individual beds 0.3-0.4 m thick.
						MX_4			Well cemented, sharp based shellbed containing scattered greywacke pebbles, oyster and sparse *Phialopecten thomsoni* valves.
					F	BC_6			Poorly sorted, moderately to well cemented pebbly and barnacle-rich grainstone containing common, well rounded Torlesse greywacke granules and pebbles up to 1 cm across. This package comprises thickening-upwards tabular sets that display low-angle planar and tangential cross-stratifications.
						Z_1			Poorly exposed silty sandstone.
						BC_6			Coarsening-upwards succession from alternating, discontinuous medium-grained skeletal lenses and interlayered, laminated siliciclastic packstone to horizontal tabular sets of alternating grainstone and packstone. Section capped by a coarse grainstone comprising shell and barnacle fragments and Torlesse greywacke pebbles.

Page 1

mud | silt (fine, med., coarse) | sand (fine, med., coarse) | gravel (granu., pebb., cobb., bould.)


A


B


C


D

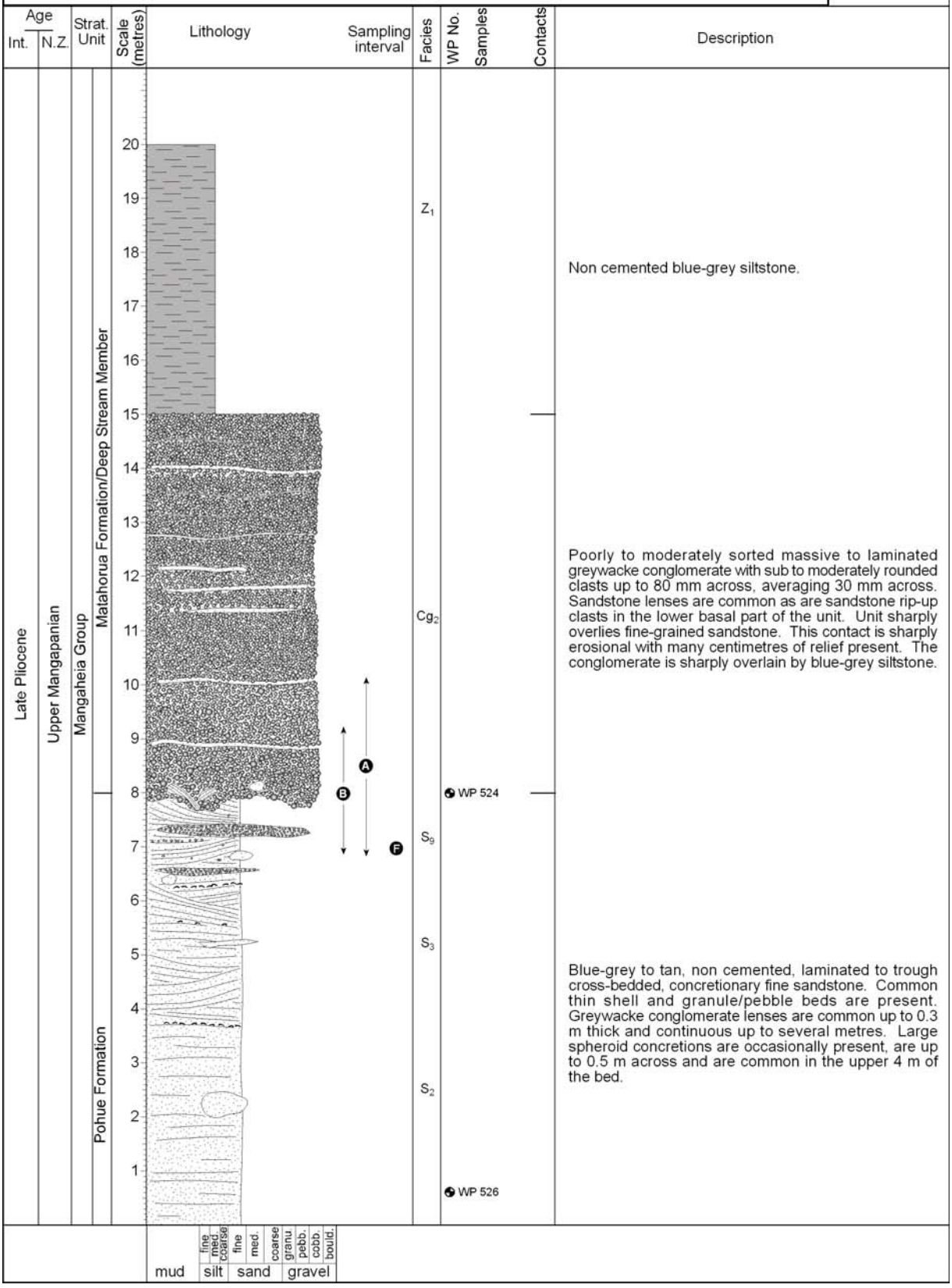
Stratigraphic Column No: Pt-9 **Grid Reference:** **Top** **Bottom**

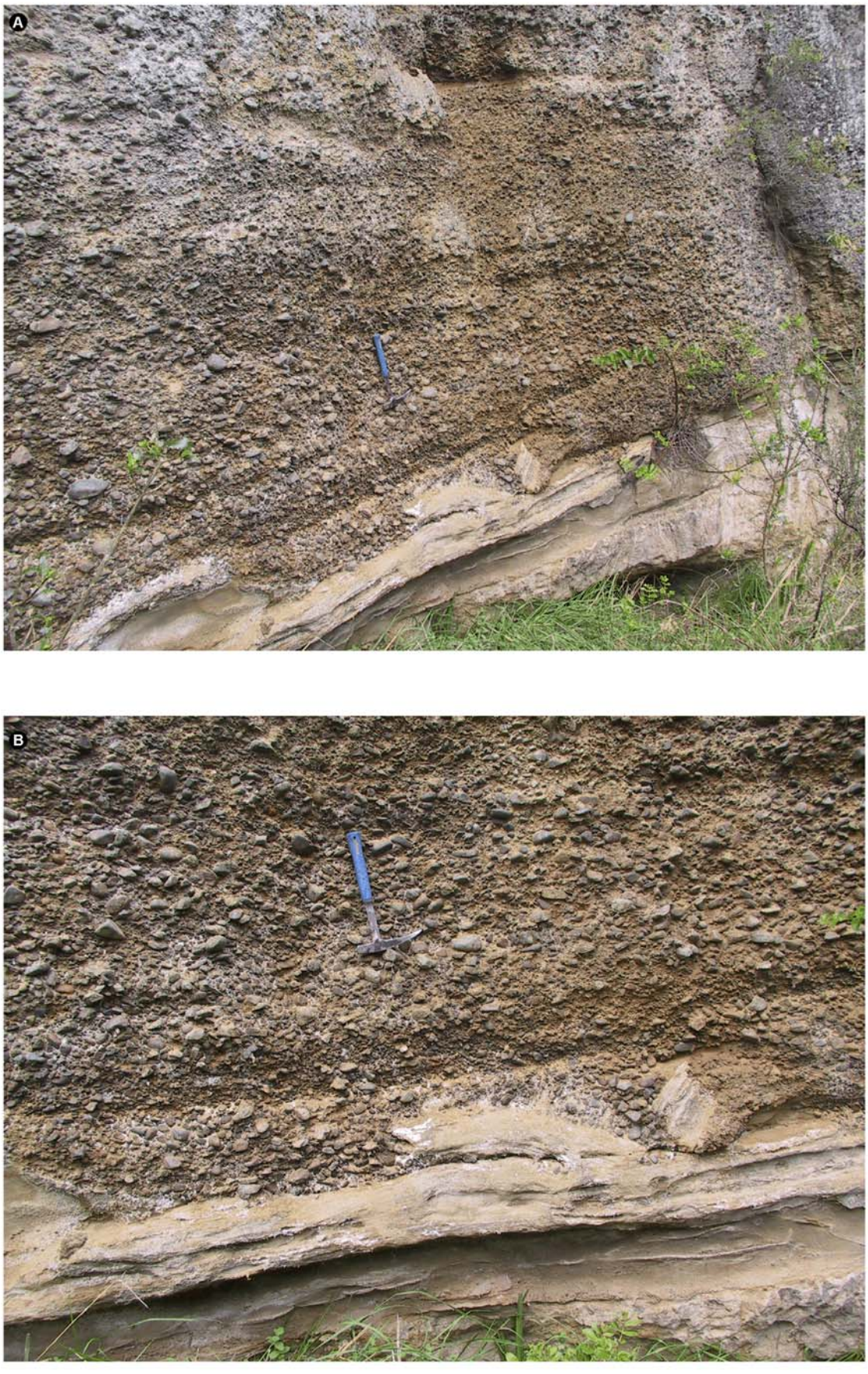
GPS Waypoint No(s): Wp 524-525 **E:** 2827201 2826952

Region: Patoka **N:** 6201919 6202255

Location: Mangaone River upstream of Patoka Stream **Altitude:** 260m 260m

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1




A
B

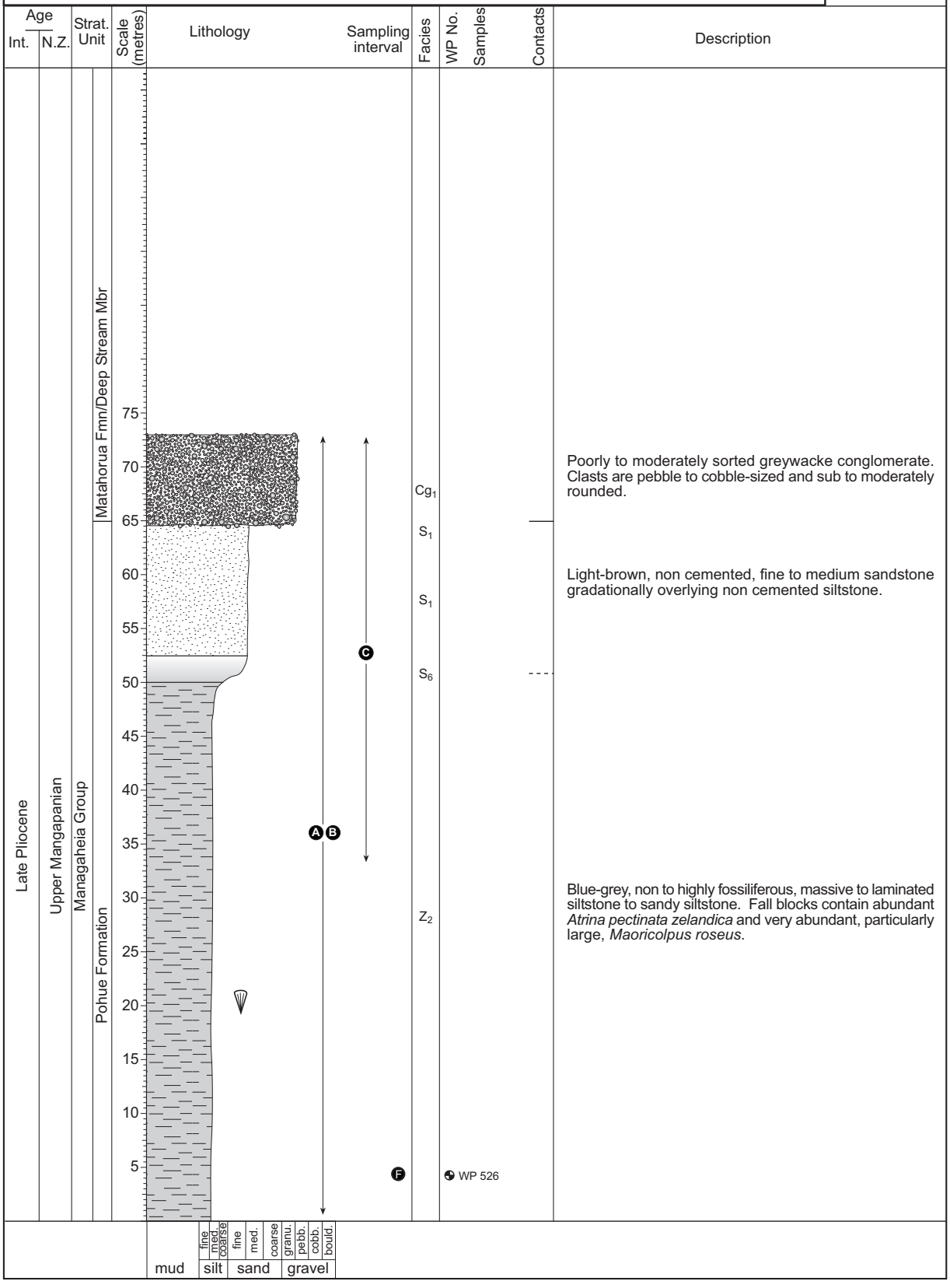
Stratigraphic Column No: *Pt-10* ***Grid Reference:*** ***Top*** ***Bottom***

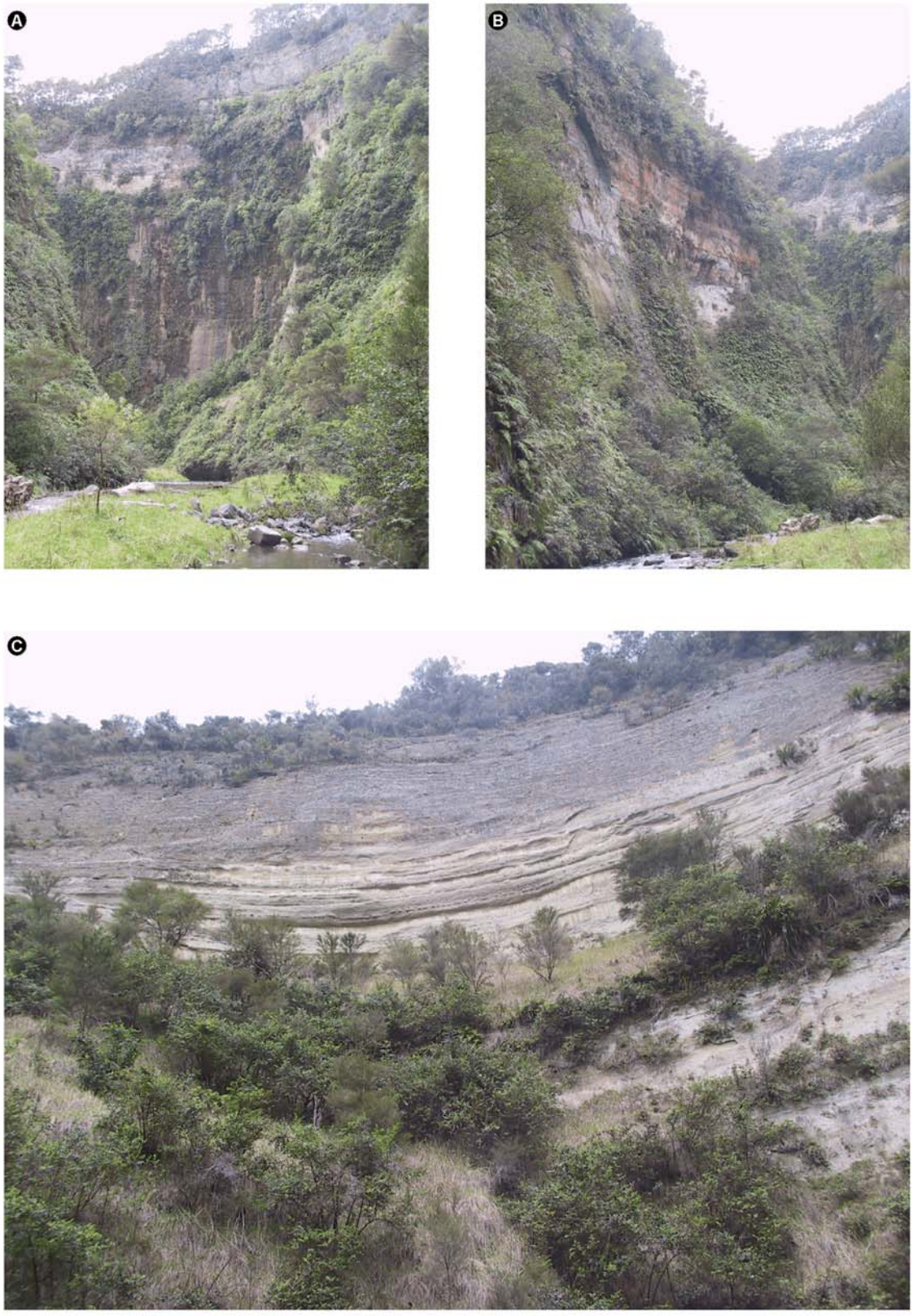
GPS Waypoint No(s): Wp 526 ***E:*** 2826799 -

Region: Patoka ***N:*** 6202918 -

Location: River cutting in Mangaone River upstream of Patoka Stream ***Altitude:*** 66 m? -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1




A
B
C

Stratigraphic Column No: Pu-1 ***Grid Reference:*** ***Top*** ***Bottom***

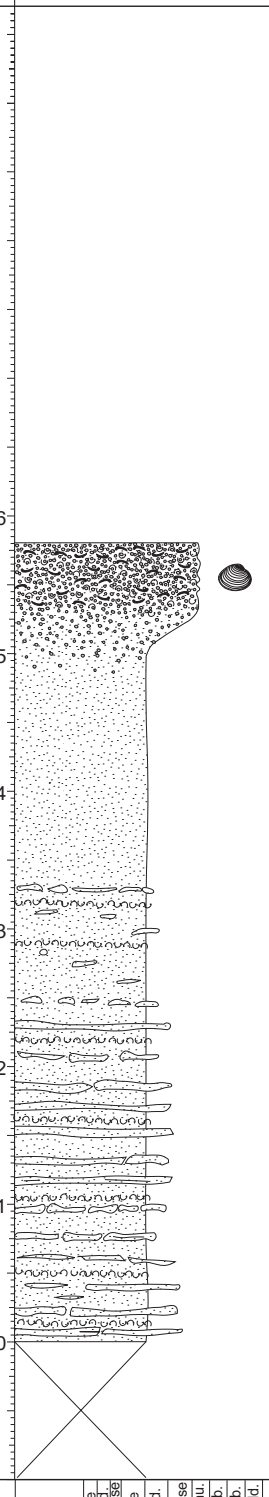
GPS Waypoint No(s): Wp 76 ***E:*** 2817898

Region: Puketitiri ***N:*** 6207027

Location: Potter Road near Puketitiri Road intersection. ***Altitude:*** 515 m -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1

Age Int.	Age N.Z.	Strat. Unit	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Mangapanian	Mangaheia Group / Te Waka Formation						Very pebbly, non cemented shellbed with well sorted and well-rounded greywacke granules to fine-pebbles.
	?Waipipian-Mangapanian	Mangaheia Group / Puketitiri Formation			MX_3			Non-cemented, calcareous pebbly medium sandstone, with common well sorted and well rounded greywacke granules and pebbles 3-8mm in diameter.
					S_1			
					S_{10}	WP 76		Orange-brown to light-brown, concretionary calcareous medium sandstone. Dispersed shellhash is present through the unit with distinct shellhash beds 0.02-0.1 m thick that are continuous over at least 1 m. Concretionary lenses and layers are present, averaging 0.04 m thick, rarely up to 0.2 m thick.



mud | silt: fine, med., coarse | sand: fine, med., coarse | gravel: granu., pebb., cobb., bould.

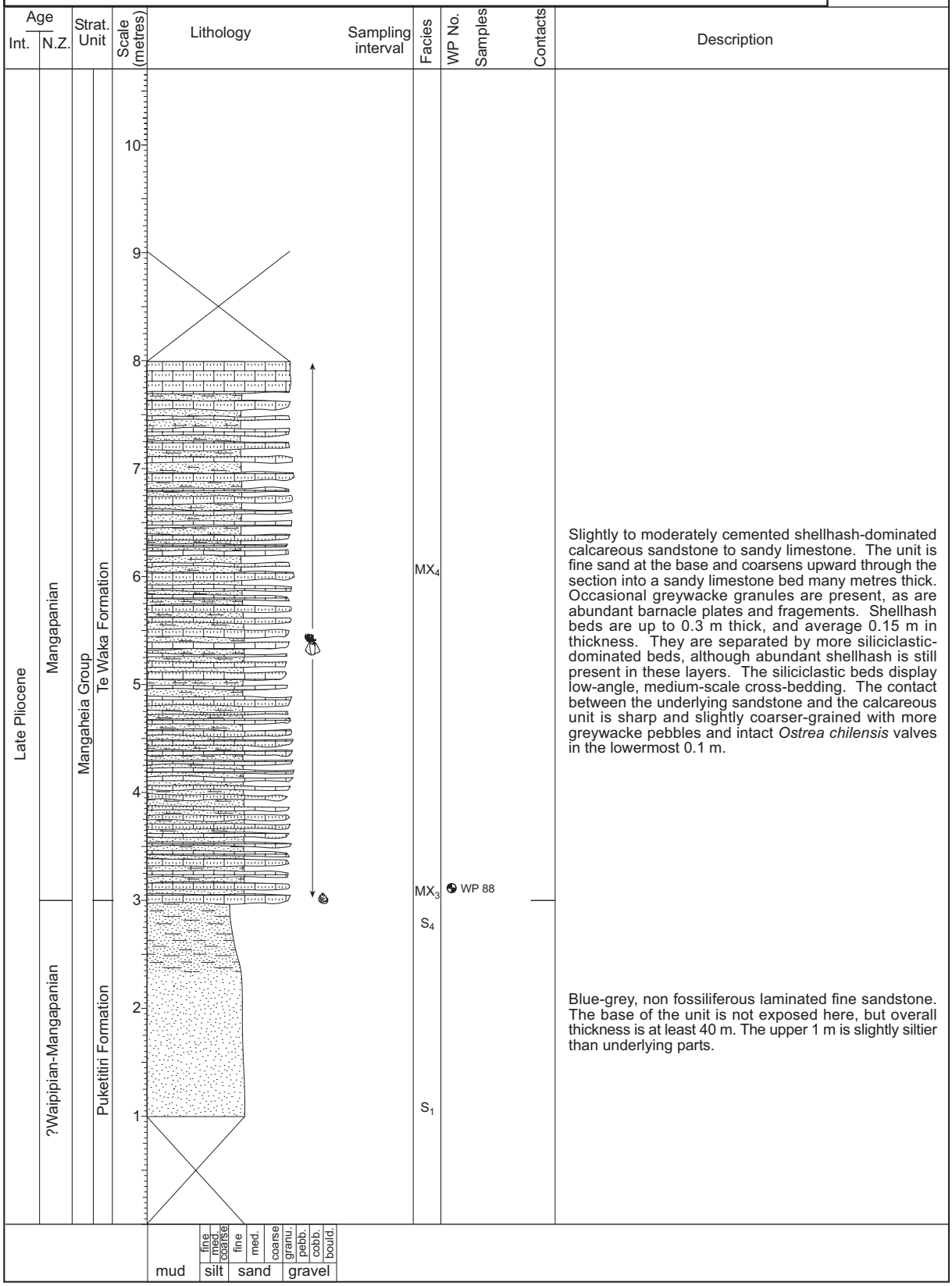
Stratigraphic Column No: *Pu-2* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 88 ***E:*** 2815569

Region: Puketitiri ***N:*** 6211418

Location: Hukanui Station below Hukanui Trig. ***Altitude:*** 977m -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1



Stratigraphic Column No: Pu-3 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 91 ***E:*** 2815665

Region: Puketitiri ***N:*** 6211514

Location: Hukanui Station below Hukanui Trig. ***Altitude:*** 965 m -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1

Age: Int. / N.Z. | Strat. Unit | Scale (metres) | Lithology | Sampling interval | Facies | WP No. Samples | Contacts | Description

Late Pliocene | Managapanian | Mangaheia Group | Te Waka Formation

BC$_5$

WP 91

Moderately cemented, coarse-grained barnacle plate-dominated coquina. Grains are coarse sand in size with rare to some well-sorted, well-rounded greywacke pebbles. The unit is flaggy in outcrop, with each flag being 0.15-0.2 m thick, although this is variable. Some mudstone and sandstone rip-up clasts are present, as are valves of *Talochlamys gemmulata*, some *Phialopecten thomsoni, Crassostrea ingens, Ostrea chilensis, Mesopeplum* sp. and other bivalves. The unit is characterised by centimetre to metre-scale trough cross bedding that is present throughout the outcrop thickness. Some giant-scale cross-beds are present, many metres in size.

mud | silt: fine, med., coarse | sand: fine, med., coarse | gravel: granu., pebb., cobb., bould.

Stratigraphic Column No: *Pu-4*

GPS Waypoint No(s): Wp 144-145

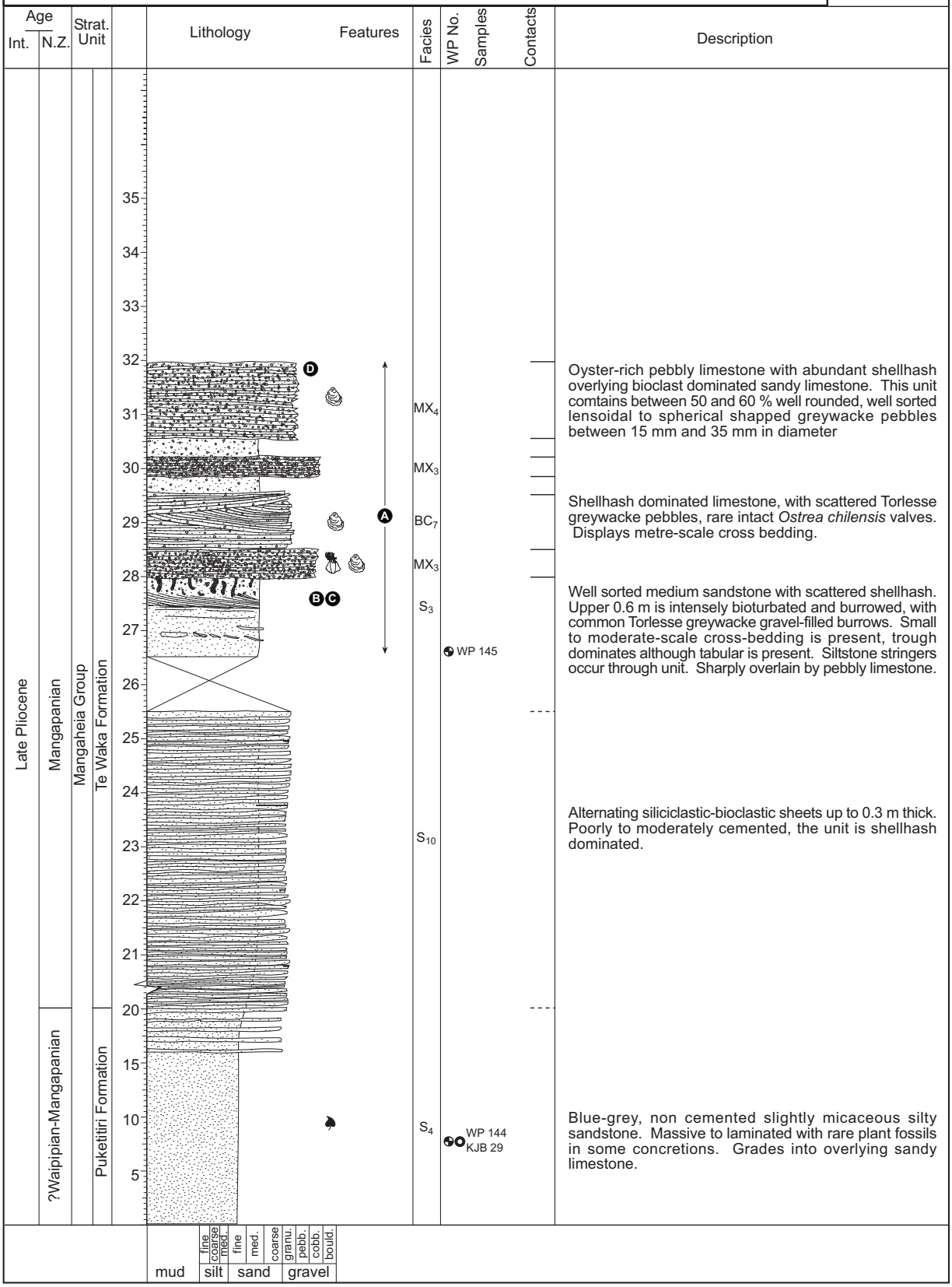
Region: Puketitiri

Location: Rocky Hill Station near top of Limestone bluffs

NZMS 260 Sheet: V20 Esk

	Grid Reference:	***Top***	***Bottom***
	E:	2813950	2813950
	N:	6205900	6206000
	Altitude:	-	-

Page 1 *of* 1




A


B


C


D

Stratigraphic Column No: *Pu-5*

GPS Waypoint No(s): Wp 154

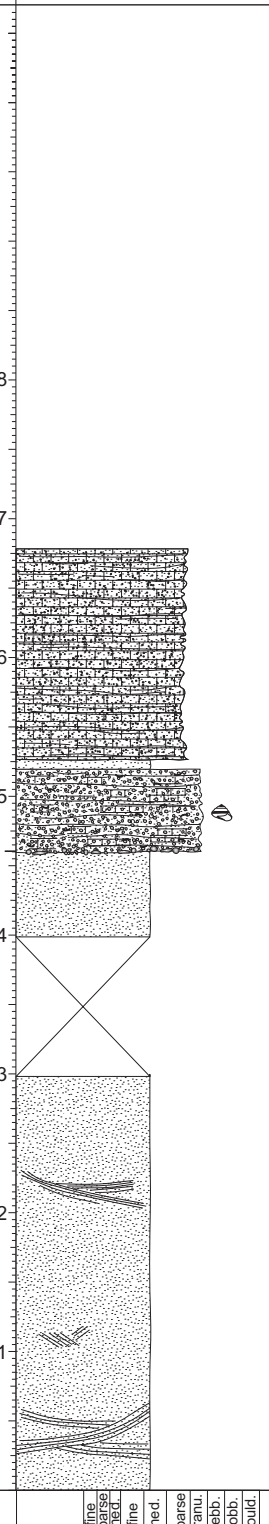
Region: Puketitiri

Location: Farm paddock 20m north of Puketitiri Road.

NZMS 260 Sheet: V20 Esk

Grid Reference:	Top	Bottom
E:	2817361	-
N:	6206811	-
Altitude:	570 m	-

Page 1 of 1



Age Int.	Age N.Z.	Strat. Unit	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Mangapanian	Mangaheia Group / Te Waka Formation	BC_6			Moderately cemented shellhash-dominated pebbly limestone. Pebbles are composed of well sorted, well rounded spherical shaped greywacke clasts that are 4-5 mm in diameter. No intact valves were observed. This bed is separated from the underlying calcareous sandstone sheet by a thin (0.1 m-thick) medium siliciclastic sandstone bed.
			MX_3	KJB 30		Moderately well cemented greywacke gravel-rich calcareous sandstone. Greywacke clasts are well rounded and well sorted, are between 3-8 mm in diameter, spherical to lensoidal in shape and are set in a siliciclastic-dominated matrix with shellhash and intact, disarticulated bivalves. Specimens of *Zethalia coronata* are present in this bed. Larger greywacke clasts up to 0.7 m in diameter occur on the sharp erosional basal contact.
	?Waipipian-Mangapanian	Puketitiri Formation	S_3			
			S_3			Olive-brown, non cemented, well sorted, slightly micaceous fine to medium sandstone. The unit is non-fossiliferous, massive to sparsely trough cross-bedded; cross-beds are low-angle and of small to moderate scale.

Stratigraphic Column No: Pu-6 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 155 ***E:*** 2817463

Region: Puketitiri ***N:*** 6206812

Location: Outcrop in farm paddock 20m north of Puketitiri Road ***Altitude:*** 564m -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1

Age Int.	Age N.Z.	Strat. Unit	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Mangapanian	Mangaheia Group / Te Waka Formation			BC_6			Moderately cemented pebbly limestone with up to 50% greywacke pebbles that are generally between 3-8 mm in diameter, are well rounded and very well sorted. Pebbles are spheriod to lensoidal in shape. The matrix of the limestone comprises siliciclastic-dominated sandstone with shellhash. The unit is moderately fossiliferous with *Zethalia coronata* present. The lower contact of this bed is very sharp and intensely burrowed.
	?Waipipian-Mangapanian	Puketitiri Formation						Moderately to highly fossiliferous non cemented pebbly shellbed dominated by large aragonitic bivalves (*Maoricardium spatiosum*), with common oysters and gastropods. The shellbed contains 30-40% well rounded greywacke pebbles, with a fine to medium sandstone and shellhash matrix.
					S_9	WP 155		Pebbly, clean, well sorted, non cemented intensely bioturbated and burrowed fine to medium sandstone. Pebbles are 5-8 mm in diameter, well sorted and well rounded and are scattered through the unit with shellhash. Large burrows are common and are commonly infilled by greywacke pebbles in upper parts of the unit. These burrows are up to 0.2 m long by 0.04 m wide.

mud | silt (fine, coarse, med.) | sand (fine, med., coarse) | gravel (granu., pebb., cobb., bould.)

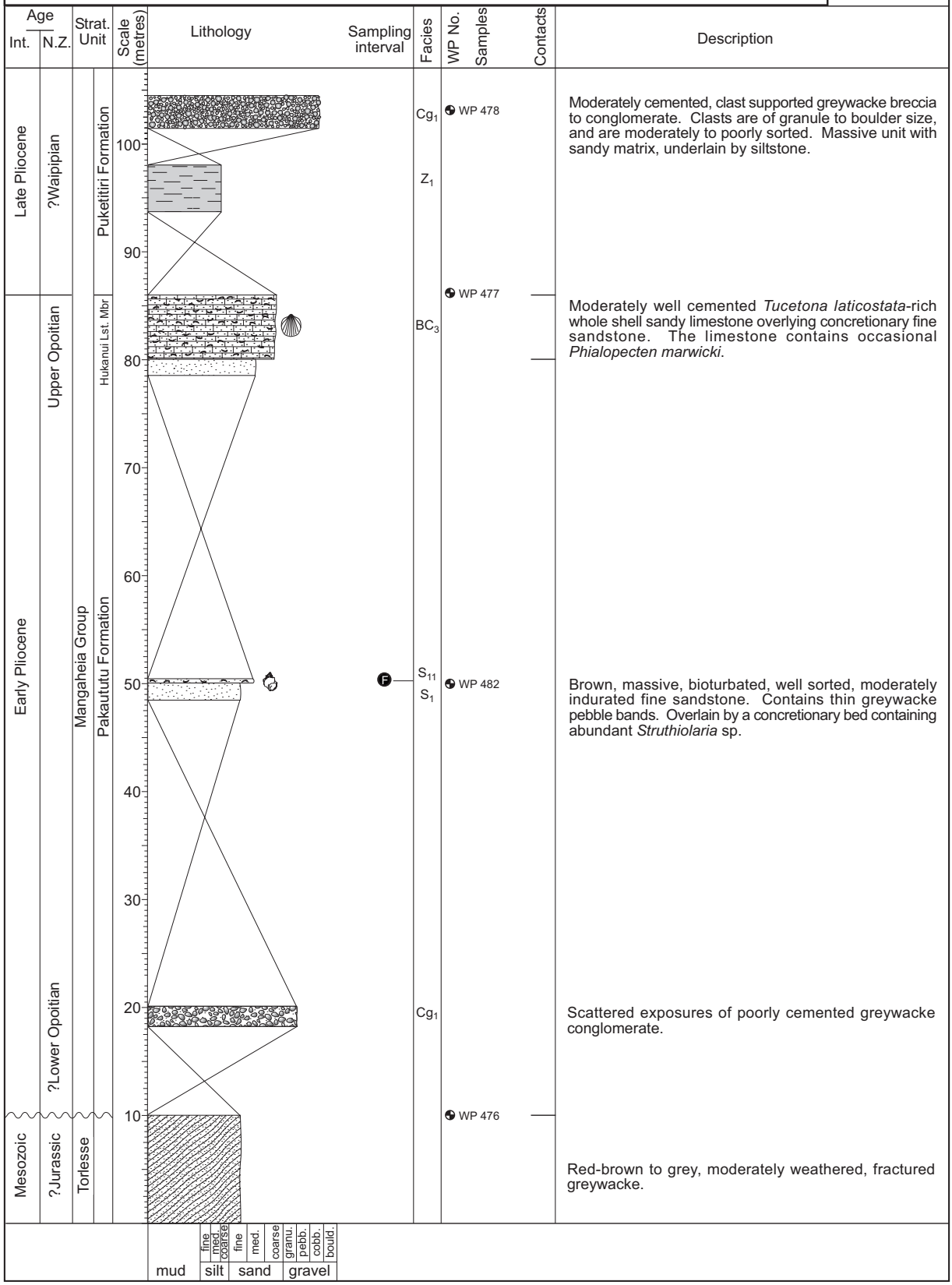
Stratigraphic Column No: *Pu-7* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 472-476 ***E:*** 2814120 2813663

Region: Puketitiri ***N:*** 6211746 6212952

Location: North face of Hukanui Hill, northeast of Puketitiri ***Altitude:*** 915 m 715 m

NZMS 260 Sheet: V20 Esk



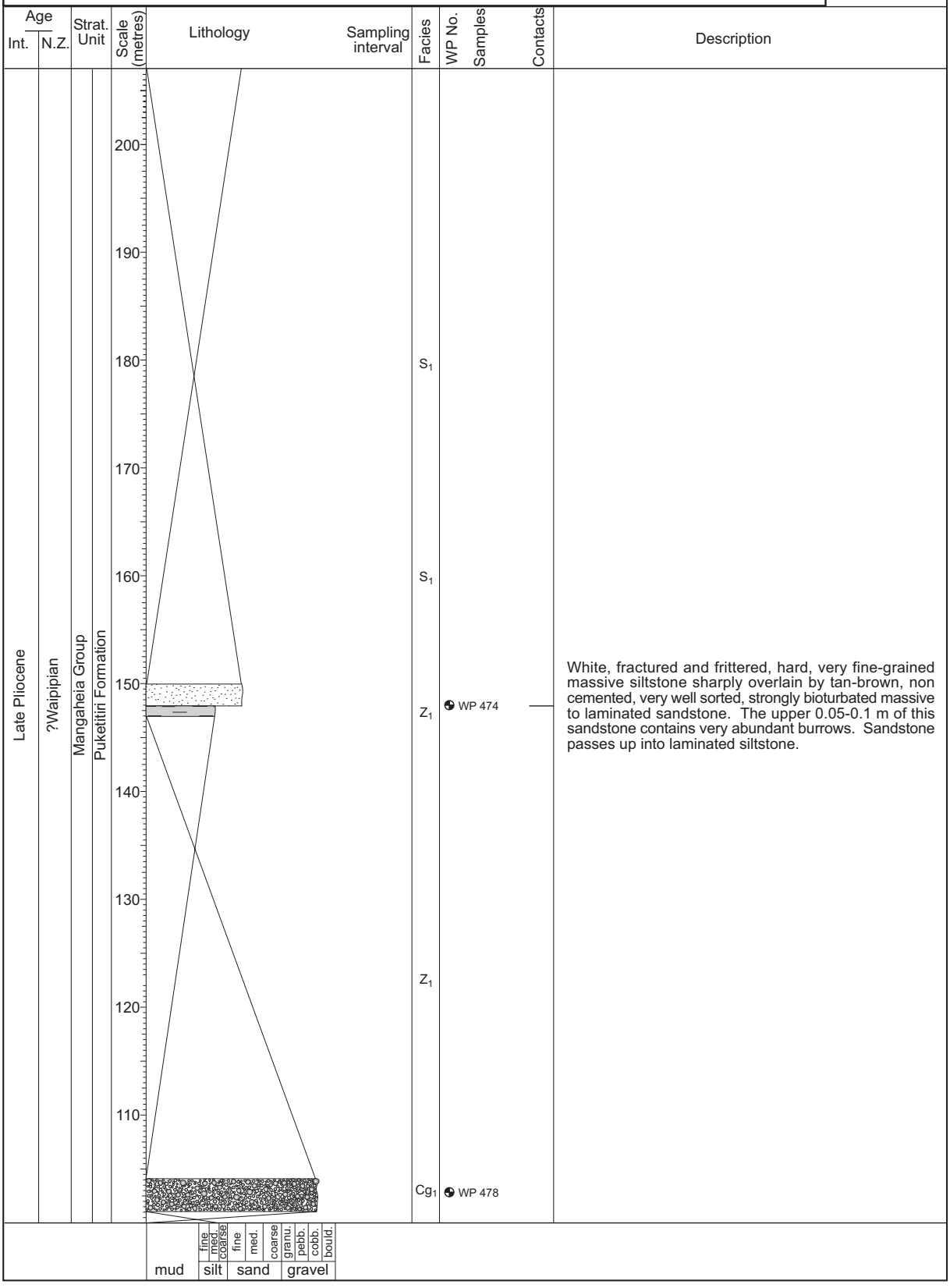
Stratigraphic Column No: Pu-7 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 472-476 ***E:*** 2814120 2813663

Region: Puketitiri ***N:*** 6211746 6212952

Location: North face of Hukanui Hill, northeast of Puketitiri ***Altitude:*** 915 m 715 m

NZMS 260 Sheet: V20 Esk



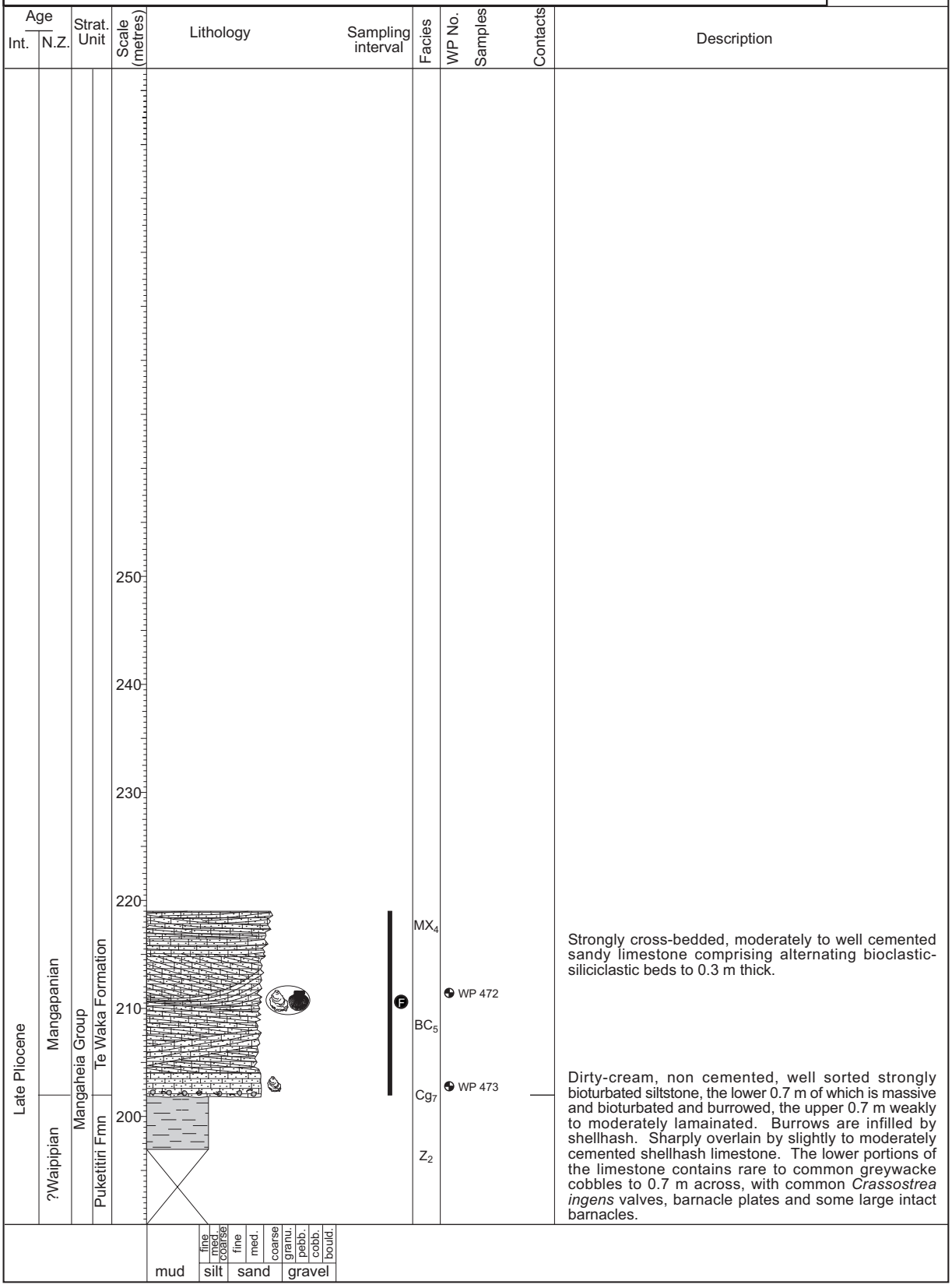
Stratigraphic Column No: *Pu-7* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 472-476 ***E:*** 2814120 2813663

Region: Puketitiri ***N:*** 6211746 6212952

Location: North face of Hukanui Hill, northeast of Puketitiri ***Altitude:*** 915 m 715 m

NZMS 260 Sheet: V20 Esk



Stratigraphic Column No: *Pu-8* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 484-485 ***E:*** 2809922 2809961

Region: Puketitiri ***N:*** 6205216 6205368

Location: Summit of hill 930 m in southern corner of Anawhenua Station ***Altitude:*** 922 m 852 m

NZMS 260 Sheet: V20 Esk

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology / Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Mangapanian	Mangaheia Group / Te Waka Formation	66–54	Page 2	BC_2			Cream, moderately cemented, moderately weathered, flaggy, sandy, slightly pebbly shellhash limestone. Comprises coarse sand-sized, well sorted stacked bioclastic-dominated sheets up to 0.2 m thick. Partial recrystallisation of some bioclastic components is evident. Scattered greywacke clasts of granule to fine pebble size are scattered through the unit (<5%). Laminations, trough and tabular cross-stratifications are present through the limestone, with occasional *Ostrea chilensis* valves, and scattered disarticulated blivalves.
	?Waipipian	Puketitiri Formation	53–43		S_2			Patchy exposure up hillside through non cemented, non fossiliferous fine sandstone.
			33–23–13–3–2–1			WP 484		Blue-grey, non cemented, finely laminated non fossiliferous sandstone.

mud | silt (fine, med., coarse) | sand (fine, med., coarse) | gravel (granu., pebb., cobb., bould.)

Stratigraphic Column No: *Pu-8*

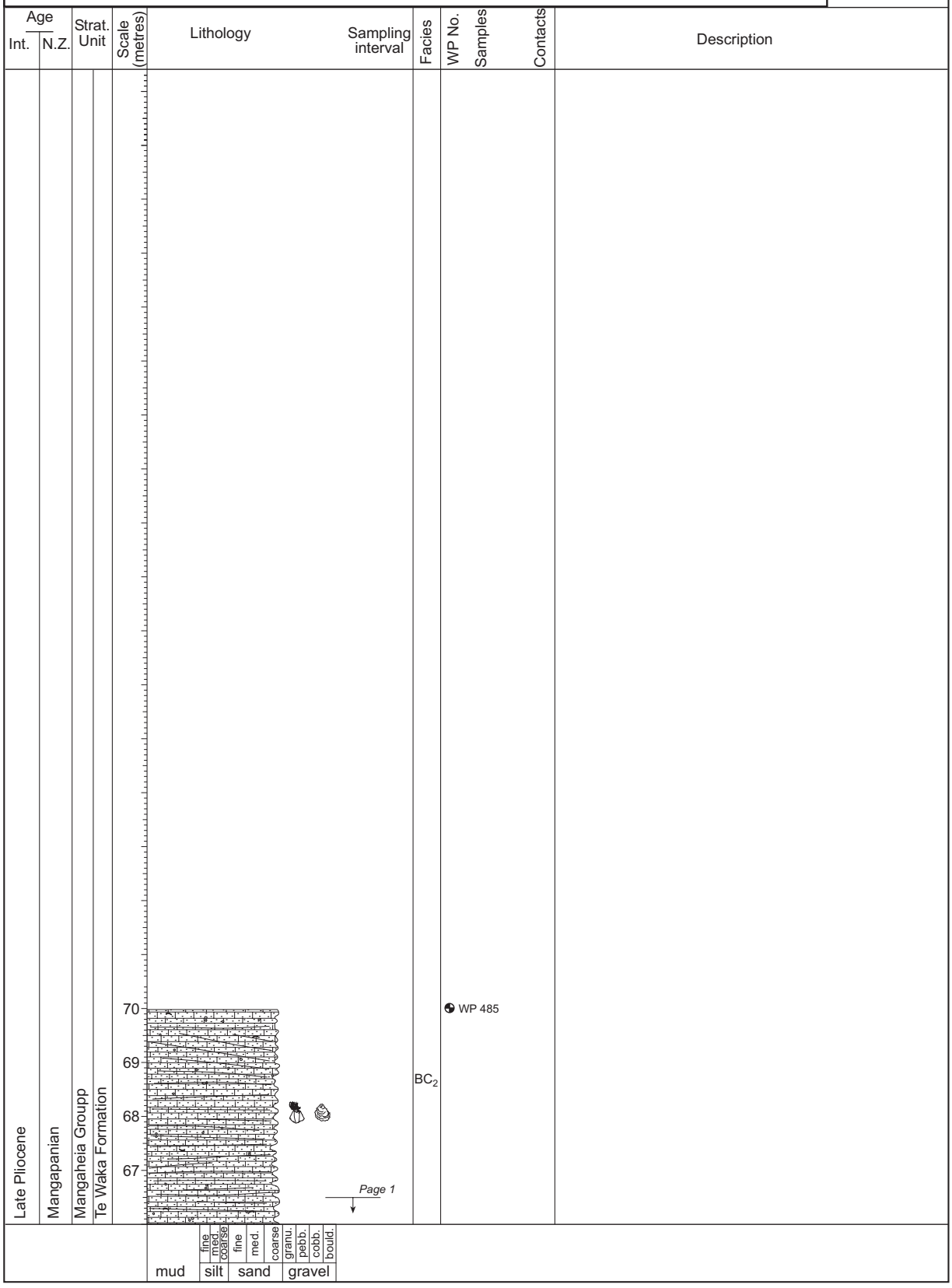
GPS Waypoint No(s): Wp 484-485

Region: Puketitiri

Location: Summit of hill 930 m in southern corner of Anawhenua Station

NZMS 260 Sheet: V20 Esk

Grid Reference:	***Top***	***Bottom***
E:	2809922	2809961
N:	6205216	6205368
Altitude:	922 m	852 m



Stratigraphic Column No: *Pu-9* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 628, 764 ***E:*** 2817137 2817075

Region: Puketitiri ***N:*** 6206771 6206795

Location: Puketitiri Road near Misty Valley on Puketitiri side of Potter Road ***Altitude:*** - 567 m

NZMS 260 Sheet: V20 Esk

Page 1 *of* 1

Age: Int. / N.Z. | Strat. Unit | Scale (metres) | Lithology | Sampling interval | Facies | WP No. | Samples | Photos | Contacts | Description

Late Pliocene / ?Mangapanian | Mangaheia Group | Puketitiri Formation

21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

Pebbly limestone crops out in low bluffs 40-50 m above this section with no exposures between the two outcrop areas.

Light tan-brown, non cemented, non fossiliferous, well sorted fine to medium sandstone. — S_1

Coarsening-upwards succession of alternating decimetre to metre-scale sandy siltstone to fine sandstone bodies. Sandy siltstone layers are blue-grey in colour, massive to laminated with scattered macrofossils. Fine sandstone beds are light tan-brown in colour and non fossiliferous. Fauna in sandy siltstone beds is similar to that for the unit below. Conformable upper and lower contacts. — S_4 — A

Blue-grey non cemented, slightly to moderately fossiliferous fine sandstone with a diverse bivalve and gastropod fauna. *Maoricolpus roseus, Atrina pectinata zelandica, Amalda mucronata, Ostrea chilensis, Fissidentalium, Talochlamys gemmulata* and *Dosinia greyi* are common in the unit among many other species. Fauna suggests a Mangapanian age as many species show transitional features between other species. — F, B — S_3 — Wn-H-10 — B

Highly fossiliferous shellbed with a fine sandstone matrix. Fauna notably contains common large *Maoricardium spatiosum* and abundant *Crassostrea ingens*, many of which are articulated. — A — BC_3 — Wn-T-02 — C

Blue-grey, non cemented, non fossiliferous, firm sandy siltstone. Sharply overlain by highly fossiliferous shellbed. A noticable textural change occurs between this bed and the overlying fine sandstone and shellbed. — S_4 — WP 764, MICROPAL

mud | silt: fine, med., coarse | sand: fine, med., coarse | gravel: granu., pebb., cobb., bould.

FAUNAL LIST

A- Highly fossiliferous shellbed containing *Crassostrea ingens* (some articulated and *in situ*), *Maoricardium spatiosum* (some articulated), *Trachycardium rossi, Alcithoe* sp., *Crepidula, Maoricolpus roseus, Stiracolpus, Panopea, Eumarcia benhami, Dosinia* sp. (fine ribbed, **not** *D. greyi*), *Notocallista multistriata, Atrina pectinata zelandica, Phialopecten* undet. sp., Pectinidae undet. gen. (resembles *Sectipecten*), and barnacles undet. gen.

B-Non cemented fine sandstone. Contains *Atrina pectinata zelandica, Talochlamys gemmulata, Chlamys ?zelandiae, Pelicaria acuminata/caniculata, Poririeria zelanica, Struthiolaria (Struthiolaria) papulosa/orata, Zeacolpus vittatus, Maoricolpus roseus, Austrofusus pliocenicus* (fat, strongly built species), *Crepidula radiata, Sigapatella novaezelandiae, Divaricella huttoniana, Pratulum pulchellum, Lamprodominea neozelandica, Amalda mucronata, Glycymeris* c.f. *shrimptoni, Dosinia greyi, Patro undatus, Serratina, Fissidentalium,* and articulated, *in situ Panopea.*







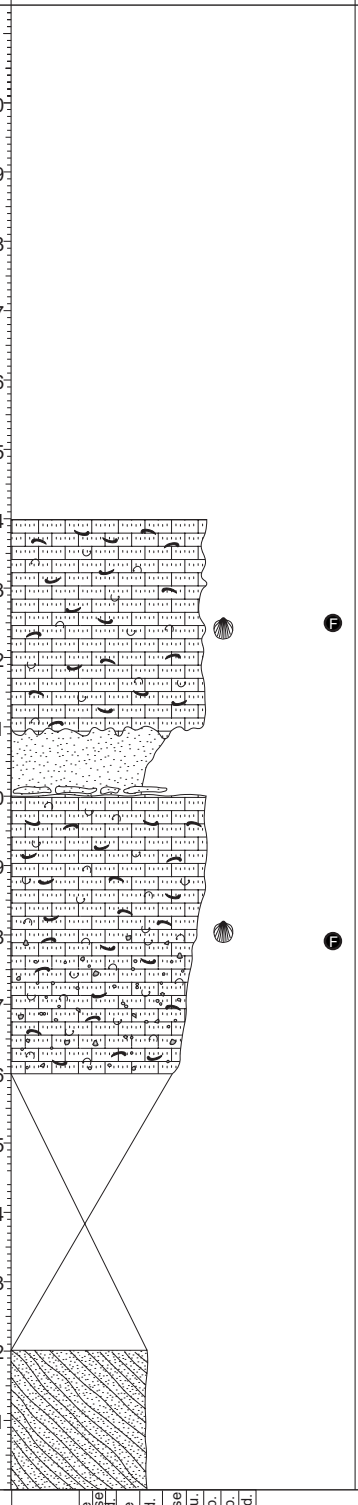
Stratigraphic Column No: *Ri-1* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 110 ***E:*** 2813013

Region: Ripia ***N:*** 6220634

Location: Simmonds Farm above Ripia River on "Ripia Face". ***Altitude:*** 695m -

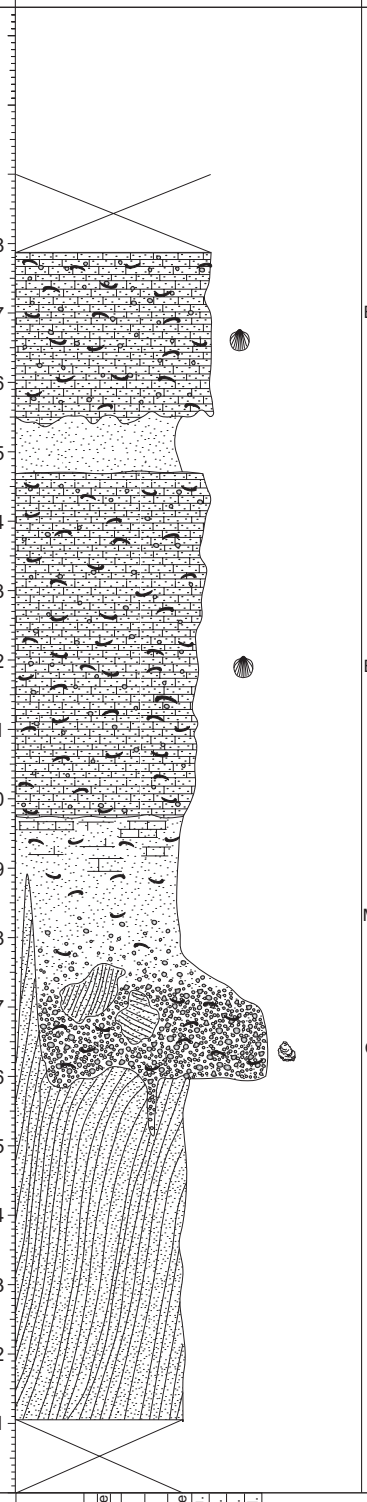
NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1



Age Int.	Age N.Z.	Strat. Unit	Facies	WP No. Samples	Description
Early Pliocene	Upper Opoitian	Mangaheia Group/Pakaututu Formation / Hukanui Limestone Member	BC_3		Whole-shell sandy limestone, very similar to lower limestone sheet at this locality. The lower contact of this unit is intensely burrowed with large bulbous burrows present into the underlying greywacke sandstone. Fauna is dominated by *Tucetona laticostata.*
			S_1		Gritty coarse sand to granule-sized greywacke sandstone. Concretions are present immediately above the lower boundary of this interval.
			S_{10}		
			BC_3		Whole-shell sandy limestone with common greywacke pebbles. The basal 1.5-2 m contains common rounded and some angular clasts. Larger clasts (50-60 mm diameter) tend to be more rounded. Most clasts are well-rounded and moderately well sorted. Angular clasts typically average 25 mm in diameter. A gritty coarse sand-sized greywacke matrix is present in this unit. Fauna is dominated by *Tucetona laticostata.*
Mesozoic	?Jurassic	Torlesse composite terrane			Extremely indurated, intensely deformed basement. Flysch-type facies.

Lithology: mud; silt (fine, coarse, med.); sand (fine, med., coarse); gravel (granu., pebb., cobb., bould.)

Stratigraphic Column No: Ri-2	***Grid Reference:***	***Top***	***Bottom***
GPS Waypoint No(s): Wp 111	***E:***	2812863	
Region: Ripia	***N:***	6220750	
Location: Simmonds farm above Ripia River on "Ripia Face"	***Altitude:***	696 m	-
NZMS 260 Sheet: V20 Esk		*Page* 1 *of* 1	



Age Int.	Age N.Z.	Strat. Unit		Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Early Pliocene	Upper Opoitian	Mangaheia Group/Pakaututu Formation	Hukanui Limestone Member			BC_3			Highly fossiliferous bioclastic sandstone bed very similar in characteristics to lower bed. Fossil content is dominated by *Tucetona laticostata.* The upper contact is obscured by vegetation.
						S_1			Non cemented, very well sorted fine to medium siliciclastic sandstone sharply overlying limestone bed.
						BC_3			Highly fossiliferous shell-rich sandy limestone dominated by *Tucetona laticostata*, with some *Phialopecten* sp (prob. *P. marwicki*)., *Glycymeris* sp. and *Eucrassiatella* sp.
						S_5			Greywacke conglomerate bed directely overlying basment. The conglomerate comprises well rounded and lensoiodal clasts set in a gritty coarse-sand matrix of greywacke clasts. Grains average 30 mm in diameter and are between ~8 and 50 mm across. The unit is almost clast supported in places. Many angular clasts of a similar size to the rounded ones are present, as are some greywacke boulders up to 0.6 m diameter. Occasional *Crassostrea ingens* valves are present, as well as some *Phialopecten* sp. and *Glycymeris* sp. The unit then fines up over 1.1 m into a gritty coarse sand-sized greywacke sandstone with occasional greywacke pebbles and shell fragements before grading into the overlying shelly sandy limestone.
						MX_1			
						S_9	WP 111		
						Cg_7			
Mesozoic	?Jurassic	Torlesse composite terrane							Intensely deformed basement comprising alternating sandstone-mudstone beds of several centimetres thickness. Tens of centimetres of relief is present on the upper boundary with the overlying conglomerate bed, and in places small stacks of greywacke extend up to 2.5 m into the overlying deposits. Cracks and fissures in the greywacke are frequently infilled with greywacke pebbles and sandstone from the overlying conglomerate. No encrusting fauna is visible on the upper surface of the greywacke.

mud	silt		sand		gravel			
	fine	coarse	med.	fine	med.	coarse	granu.	pebb.	cobb.	bould.

Stratigraphic Column No: Ri-3 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 113 ***E:*** 2812311

Region: Ripia ***N:*** 6219522

Location: Limestone bluffs above Ripia River near Pakaututu Road ***Altitude:*** 644m -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1

Age Int.	Age N.Z.	Strat. Unit	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Early Pliocene	Upper Opoitian	Mangaheia Group/Pakaututu Formation / Hukanui Limestone Member			BC_3			Coarse-grained, moderately to well cemented shelly limestone with abundant intact bivalve shells. *Tucetona laticostata*-dominated
					S_9			Non to slightly cemented coarse-grained gritty sandstone composed of greywacke grains.
					BC_3			Moderately to well cemented shelly limestone. This unit is finer-grained than the lower limestone bed at this section, containing fewer large shells, and more siliciclastic-dominated zones. The unit is dominated by shellhash.
					S_9			Non to slightly cemented, coarse-grained, gritty sandstone composed of greywacke clasts. The unit contains occasional shell fragments and greywacke pebbles. Upper contact with overlying unit is gradational.
					BC_3	WP 113		Moderately to well cemented, coarse-grained shelly limestone with abundant greywacke pebbles up to 60 mm diameter set in a matrix of coarse-sand sized greywacke clasts. The greywacke pebbles are both well rounded and angular.
Mesozoic	?Jurassic	Torlesse composite terrane						Strongly deformed, moderately to strongly weathered basement flysch. Up to 1.8 m of relief is present on the upper surface of this unit at this locality. No encrusting faunas were visible on the upper contact.

mud | silt: fine, coarse, med. | sand: fine, med., coarse | gravel: granu., pebb., cobb., bould.

Stratigraphic Column No: *Ri-4*

GPS Waypoint No(s): Wp 142

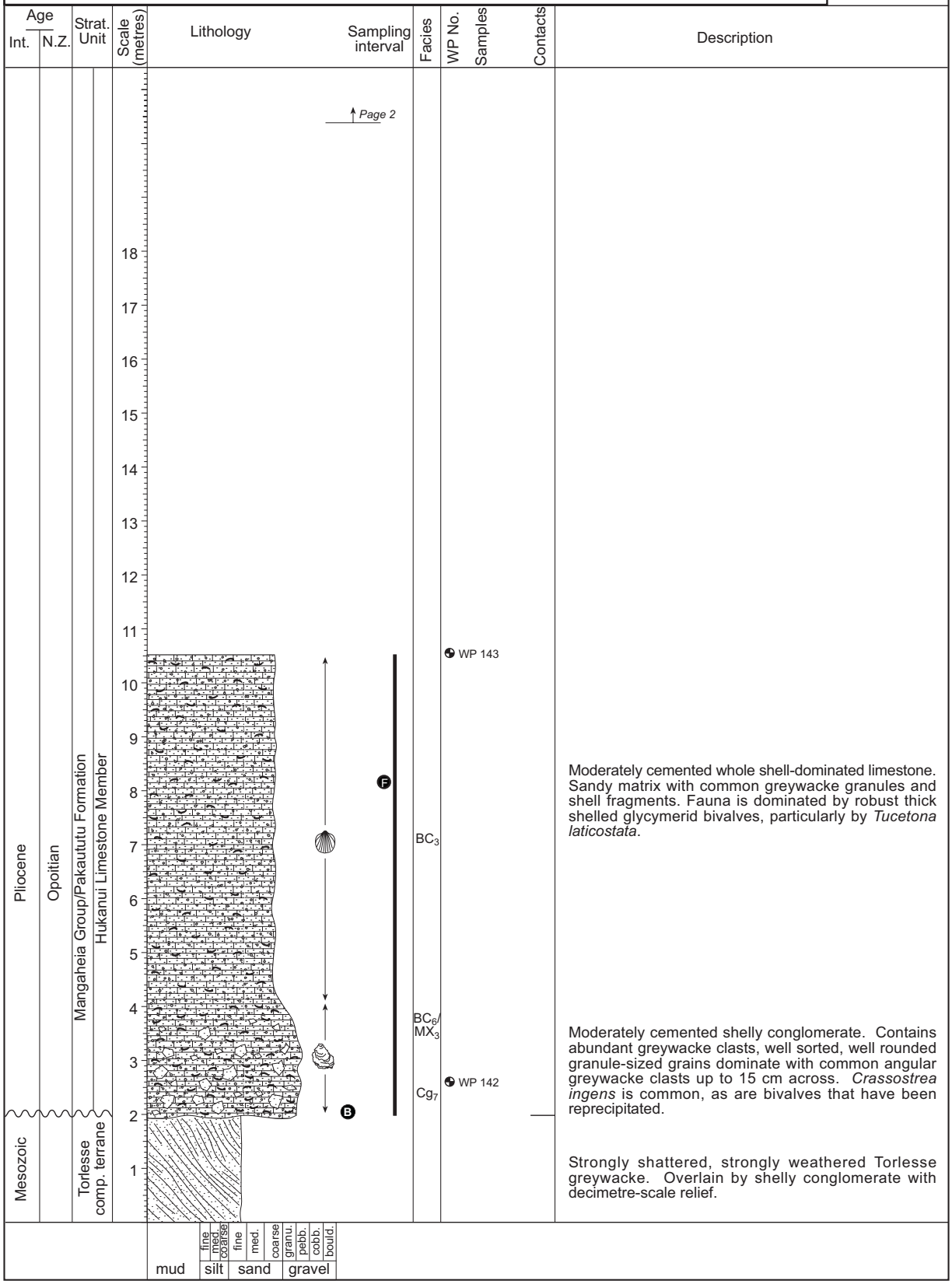
Region: Pakaututu

Location: Mohaka River below Makahu River confluence, near Kaweka Fault trace

NZMS 260 Sheet: V20 Esk

Grid Reference:	***Top***	***Bottom***
E:	-	2812300
N:	-	6216500
Altitude:	-	420 m

Page 1 *of* 1




A


C


B

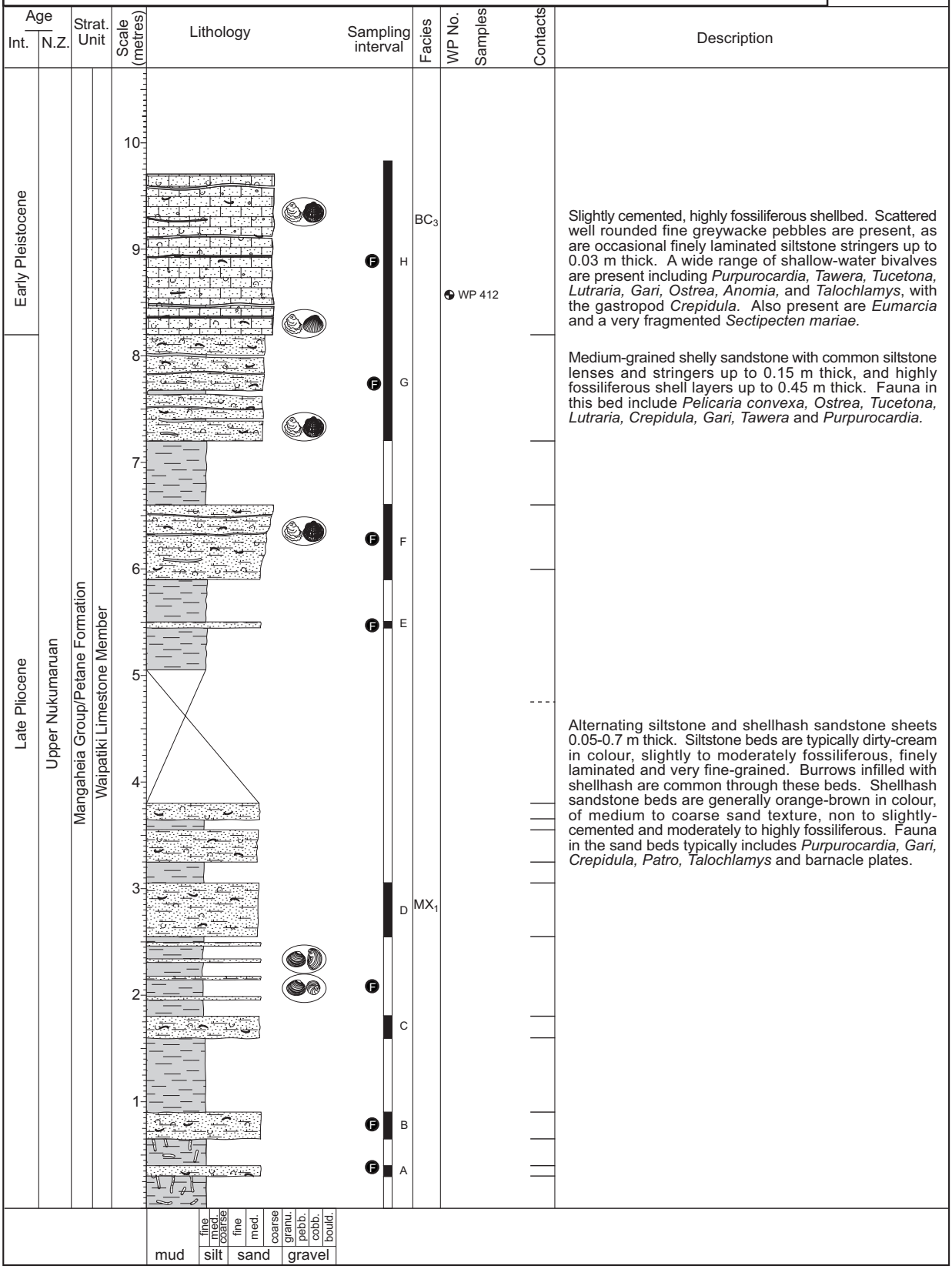
Stratigraphic Column No: Rs-1 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 412 ***E:*** 2832289 -

Region: Rissington ***N:*** 6187548 -

Location: Pukenoa Farm near Apley Road, farm track through forest block ***Altitude:*** 164 m -

NZMS 260 Sheet: V21 Napier



Slightly cemented, highly fossiliferous shellbed. Scattered well rounded fine greywacke pebbles are present, as are occasional finely laminated siltstone stringers up to 0.03 m thick. A wide range of shallow-water bivalves are present including *Purpurocardia, Tawera, Tucetona, Lutraria, Gari, Ostrea, Anomia,* and *Talochlamys*, with the gastropod *Crepidula.* Also present are *Eumarcia* and a very fragmented *Sectipecten mariae.*

Medium-grained shelly sandstone with common siltstone lenses and stringers up to 0.15 m thick, and highly fossiliferous shell layers up to 0.45 m thick. Fauna in this bed include *Pelicaria convexa, Ostrea, Tucetona, Lutraria, Crepidula, Gari, Tawera* and *Purpurocardia.*

Alternating siltstone and shellhash sandstone sheets 0.05-0.7 m thick. Siltstone beds are typically dirty-cream in colour, slightly to moderately fossiliferous, finely laminated and very fine-grained. Burrows infilled with shellhash are common through these beds. Shellhash sandstone beds are generally orange-brown in colour, of medium to coarse sand texture, non to slightly-cemented and moderately to highly fossiliferous. Fauna in the sand beds typically includes *Purpurocardia, Gari, Crepidula, Patro, Talochlamys* and barnacle plates.

FAUNAL LIST

A- Shellhash-dominated sandstone with *Crepidula radiata* and *Talochlamys gemmulata*.

B - Non cemented shellhash sandstone withcommon *Gari* sp., barnacle plates, *Crepidula radiata, Anomia trigonopsis,* and *Patro undatus.*

C - Shellhash sandstone containing barnacle fragements and *Purpurocardia purpurata*.

D - Shellhash sandstone with common *Gari* sp., and *Talochlamys gemmulata*, with branching bryozoans, *Tawera* sp., and *Anomia trigonopsis.*

E - Shellhash sandstone containing *Purpurocardia purpurata*.

F - Coarsening-upwards shellhash sandstone bed with occasional thin siltstone stringers. Unit contains *Gari* sp., some of which are articulated, *Tawera* sp., *Alcithoe* sp., *Tucetona laticostata* and Gastropoda spp.

G - Shellhash sandstone-dominated unit with common siltstone lenses. Fauna includes *Pelicaria convexa, Ostrea chilensis, Lutraria, Crepidula radiata, Lamprodominea, Gari* sp., *Tawera* sp., *Taloclamys gemmulata,* and *Purpurocardia purpurata*.

H - Highly fossiliferous, slightly cemented limestone with scattered fine pebble, well rounded greywacke pebbles. Fauna includes *Purpurocardia purpurata*, *Tawera* sp., *Tucetona laticostata*, *Lutraria, Gari* sp., *Anomia trigonopsis, Talochlamys gemmulata,* and *Crepidula radiata*.

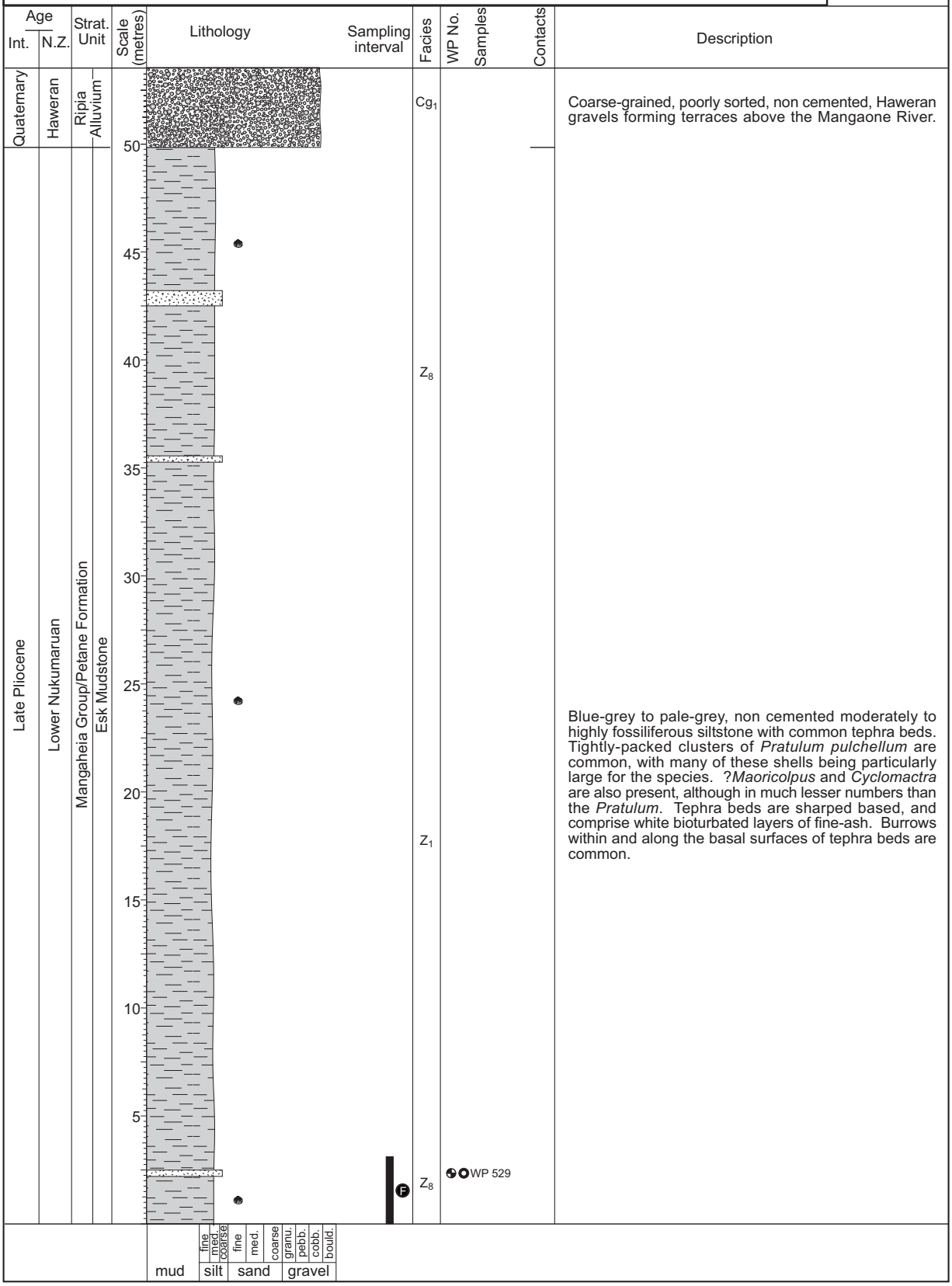
Stratigraphic Column No: *Rs-2* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 529 ***E:*** 2830523 -

Region: Rissington ***N:*** 6189643 -

Location: Mangaone River upstream of Rissington Bridge ***Altitude:*** 68 m -

NZMS 260 Sheet: V21 Napier *Page* 1 *of* 1



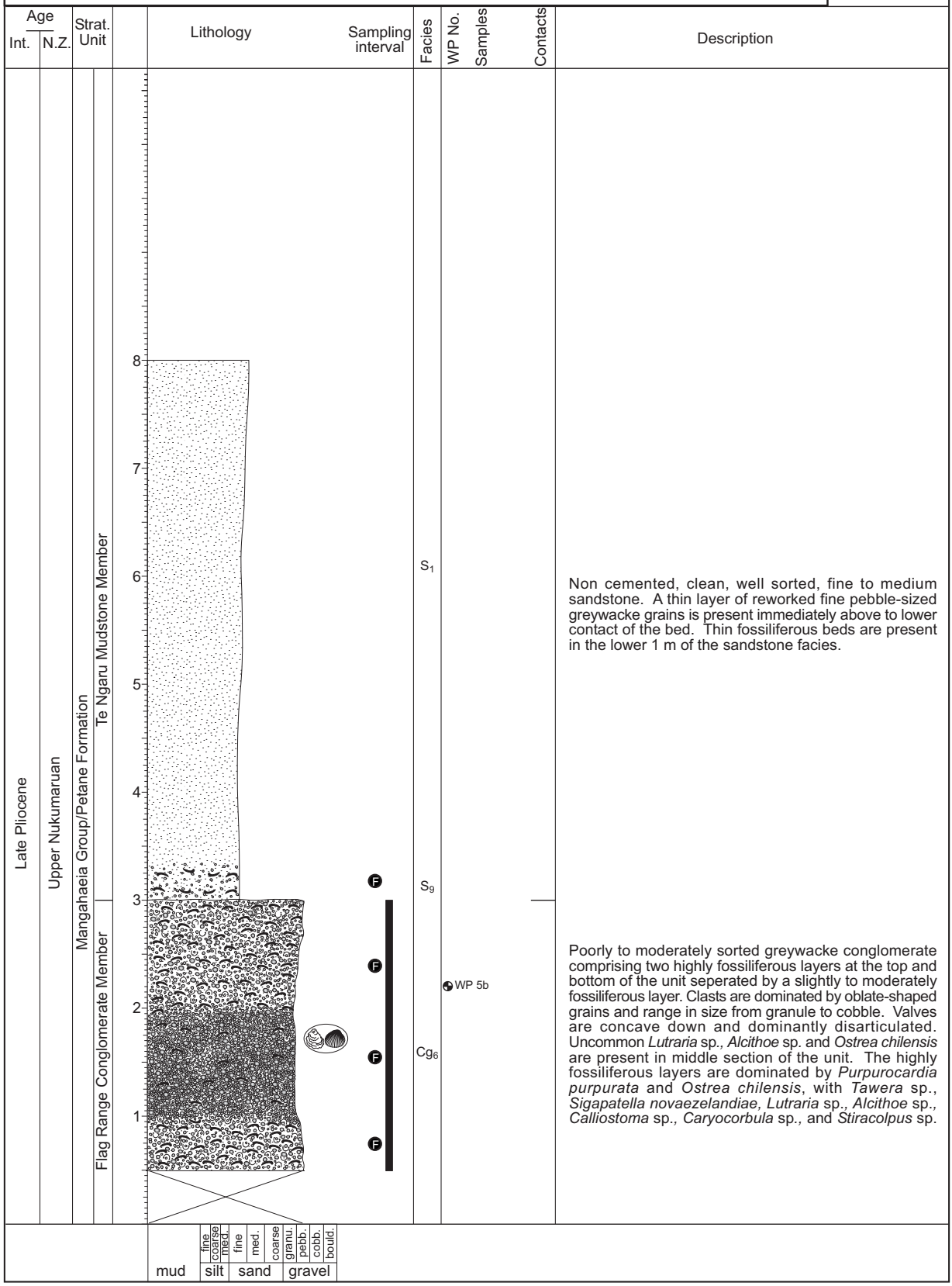
Stratigraphic Column No: Sh-1 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 5b ***E:*** 2818700

Region: Sherenden ***N:*** 6282700

Location: Taihape Road immediately south of Flag Range Road intersection. ***Altitude:*** - -

NZMS 260 Sheet: V21 Napier *Page* 1 *of* 1



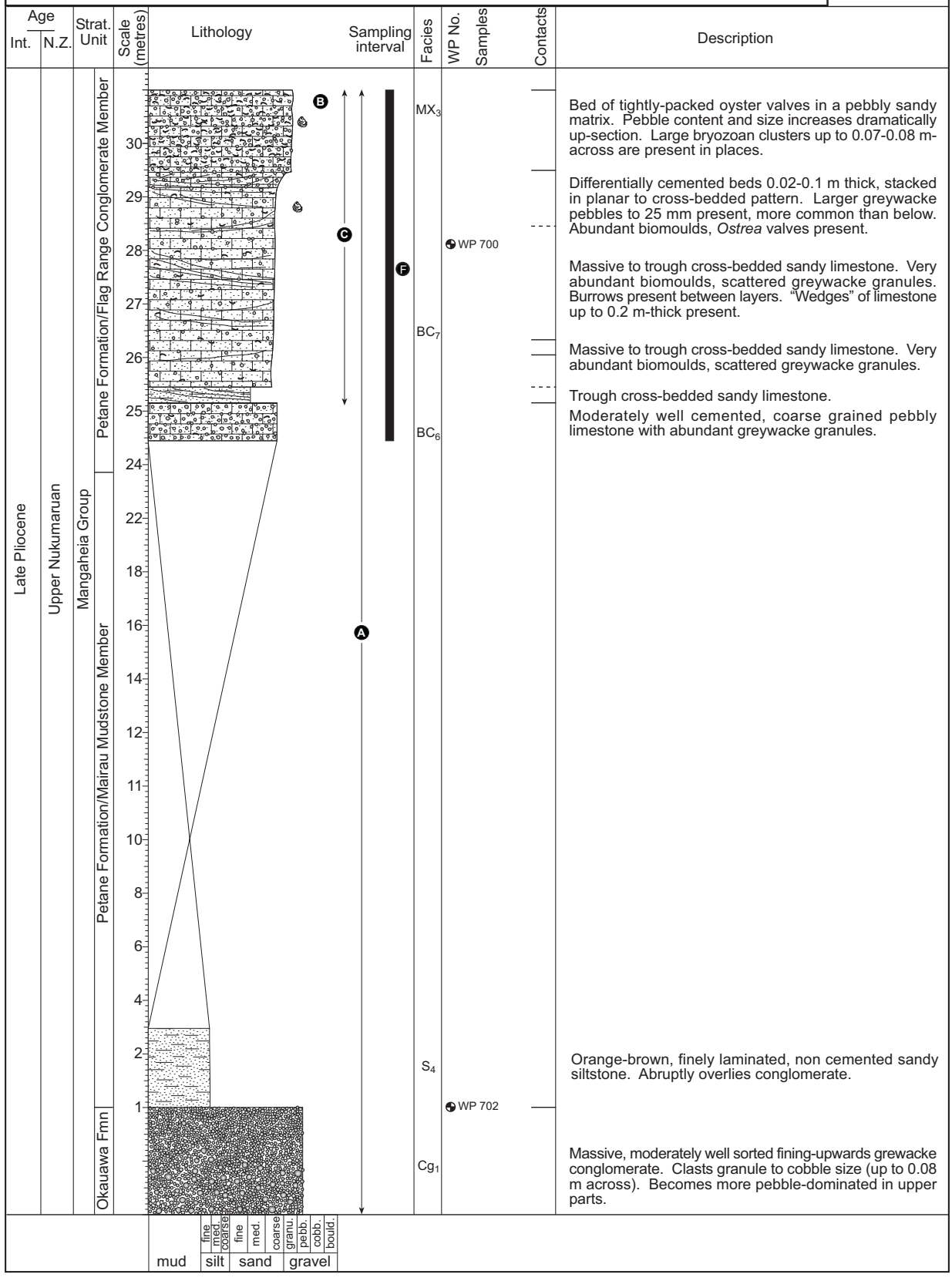
Stratigraphic Column No: Sh-2 ***Grid Reference:*** ***Top*** ***Bottom***

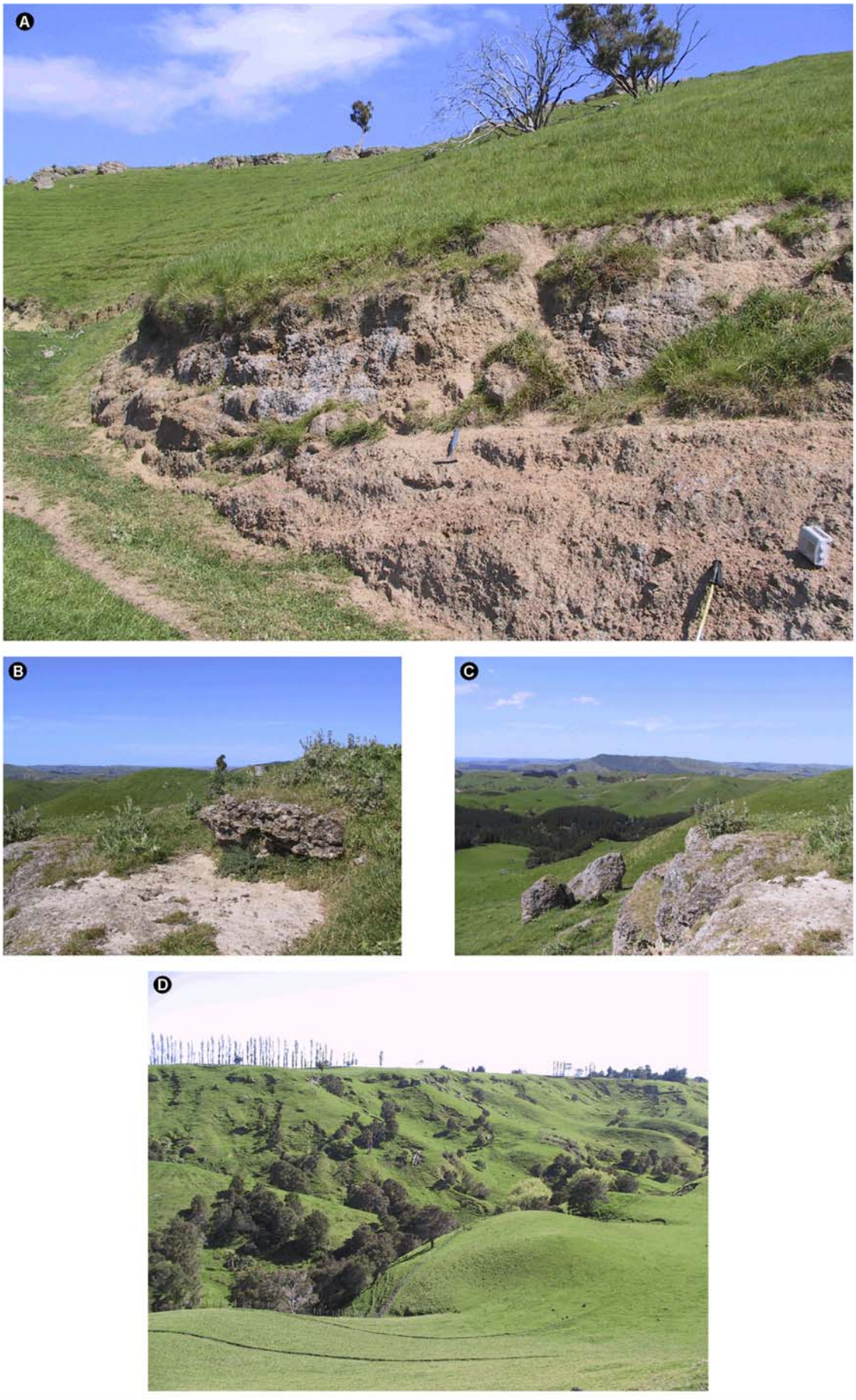
GPS Waypoint No(s): Wp 700 and 702 ***E:*** 2819493 2819387

Region: Sherenden ***N:*** 6184873 6184658

Location: Tunanui Station on southeastern face of Flag Range near poplars ***Altitude:*** 318 m 269 m

NZMS 260 Sheet: V21 Napier *Page* 1 *of* 1




A
B
C
D

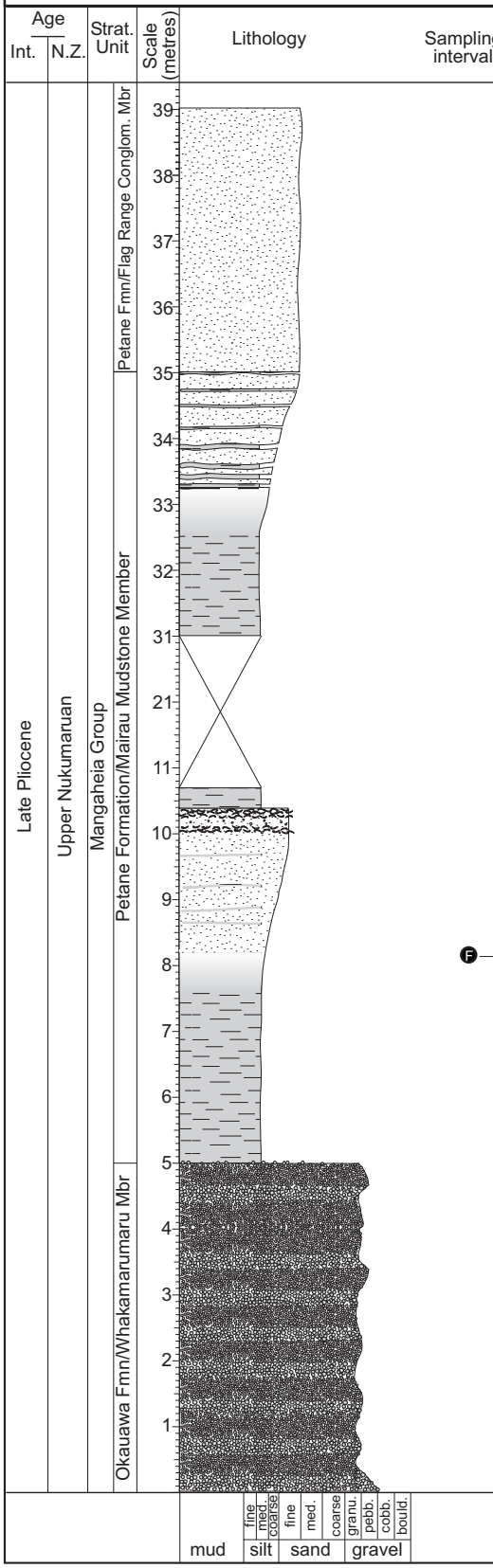
Stratigraphic Column No: Sh-3 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 729-734 ***E:*** 2820827 2820598

Region: Sherenden ***N:*** 6186043 6186291

Location: Section along driveway on Bilby's Block, east of Flag Range crest ***Altitude:*** 260 m 233 m

NZMS 260 Sheet: V21 Napier *Page* 1 *of* 1



Stratigraphic Column No: Sh-4 ***Grid Reference:*** ***Top*** ***Bottom***

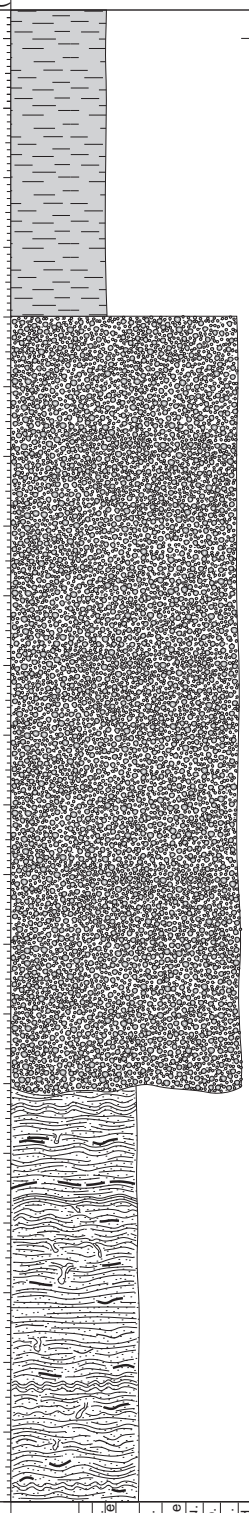
GPS Waypoint No(s): Wp 819 ***E:*** - 2820362

Region: Sherenden ***N:*** - 6187725

Location: Tutaekuri River below Waldon Road near Waikonini Stream confluence ***Altitude:*** - 102 m

NZMS 260 Sheet: V20 Esk

Page 1 *of* 2

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Lower Nukumaruan	Mangaheia Group	21–1		↑ Page 2	Z_2			Blue-grey, non cemented, non to sparsely fossiliferous siltstone. Sharply overlies greywacke conglomerate.
		Esk Mudstone							
		Matahorua Formation/Grassy Knoll Conglomerate Member				Cg_1			Decimetre-scale relief present on lower surface of conglomerate.
		Matahorua Formation/Papakiri Member			F	S_8	WP 819		Non cemented, non fossiliferous, strongly ripple to flaser-bedded fine to medium sandstone. Unit is intensely bioturbated and burrowed. Detached mud lenses and mudstone stringers are common. Erosionally overlain by greywacke conglomerate.

mud | silt: fine, med., coarse | sand: fine, med., coarse | gravel: granu., pebb., cobb., bould.

Stratigraphic Column No: *Sh-4*

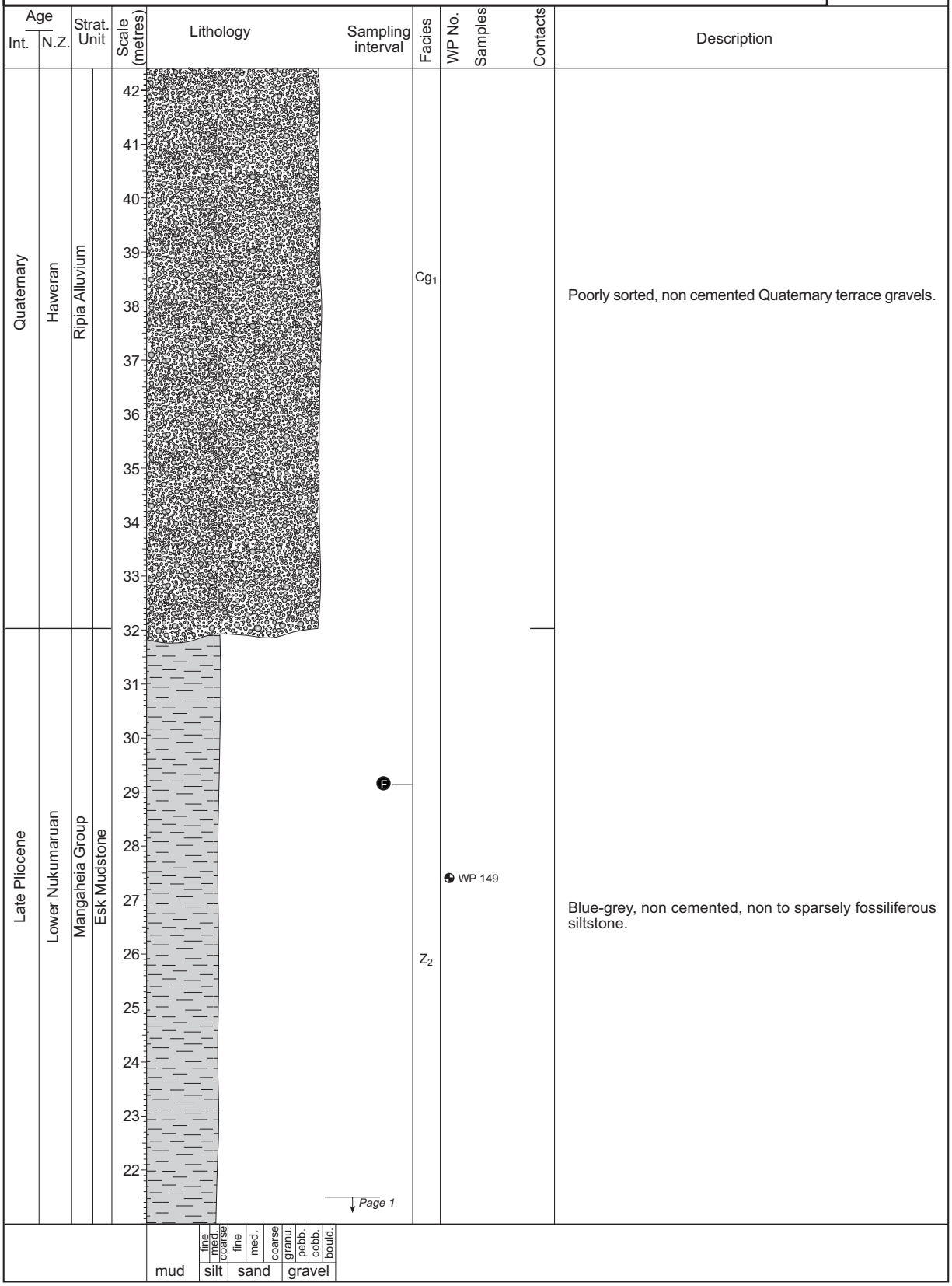
GPS Waypoint No(s): Wp 819

Region: Sherenden

Location: Tutaekuri River below Waldon Road near Waikonini Stream confluence

NZMS 260 Sheet: V20 Esk

Grid Reference:	***Top***	***Bottom***
E:	-	2820362
N:	-	6187725
Altitude:	-	102 m



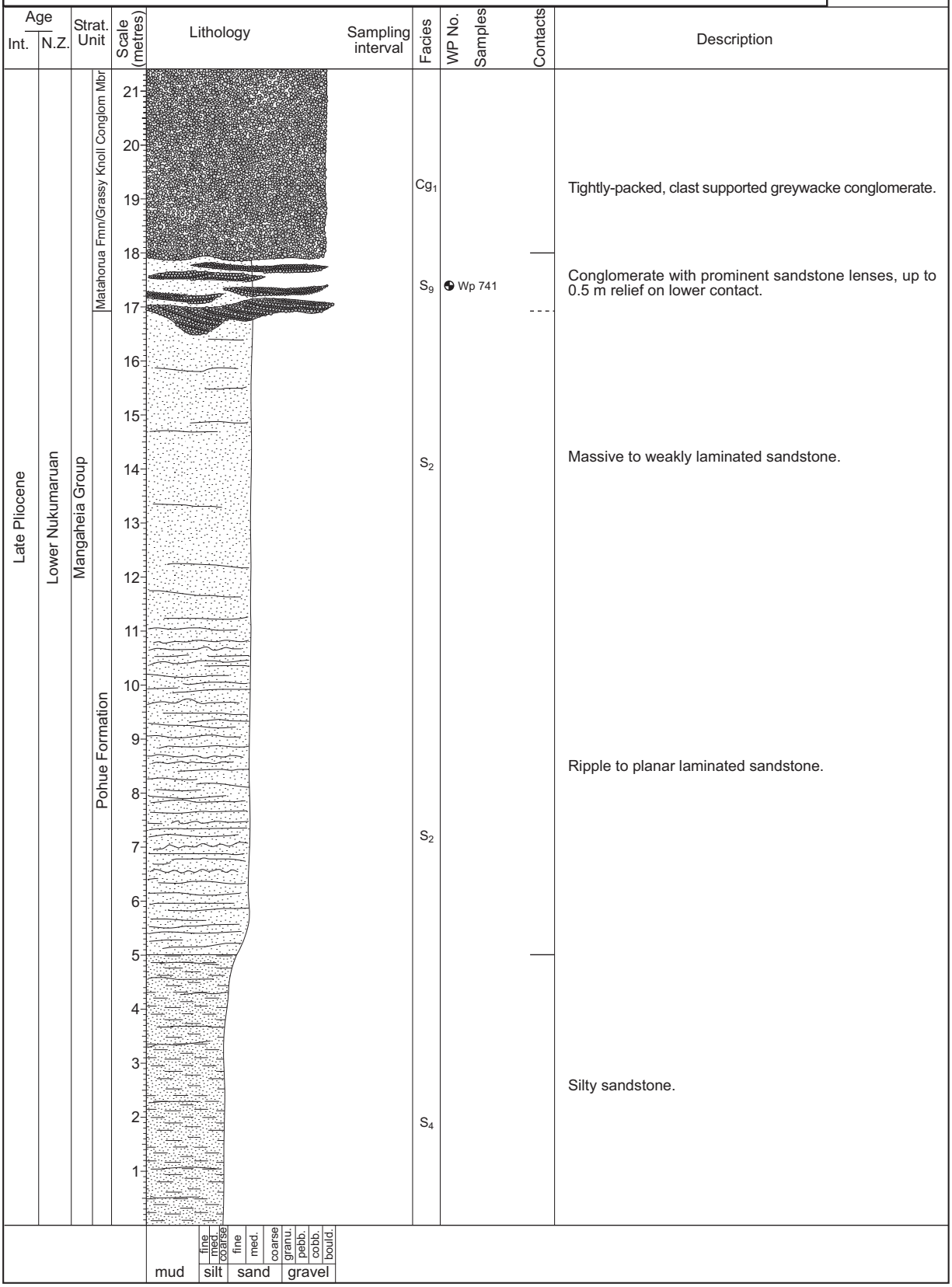
Stratigraphic Column No: Sh-5 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 736-745 ***E:*** 2820739 2821392

Region: Sherenden ***N:*** 6186988 6188373

Location: Waikonini Stream below Flag Range in to Tutaekuri River ***Altitude:*** 115 m 82 m

NZMS 260 Sheet: V21 Napier



Stratigraphic Column No: *Sh-5*

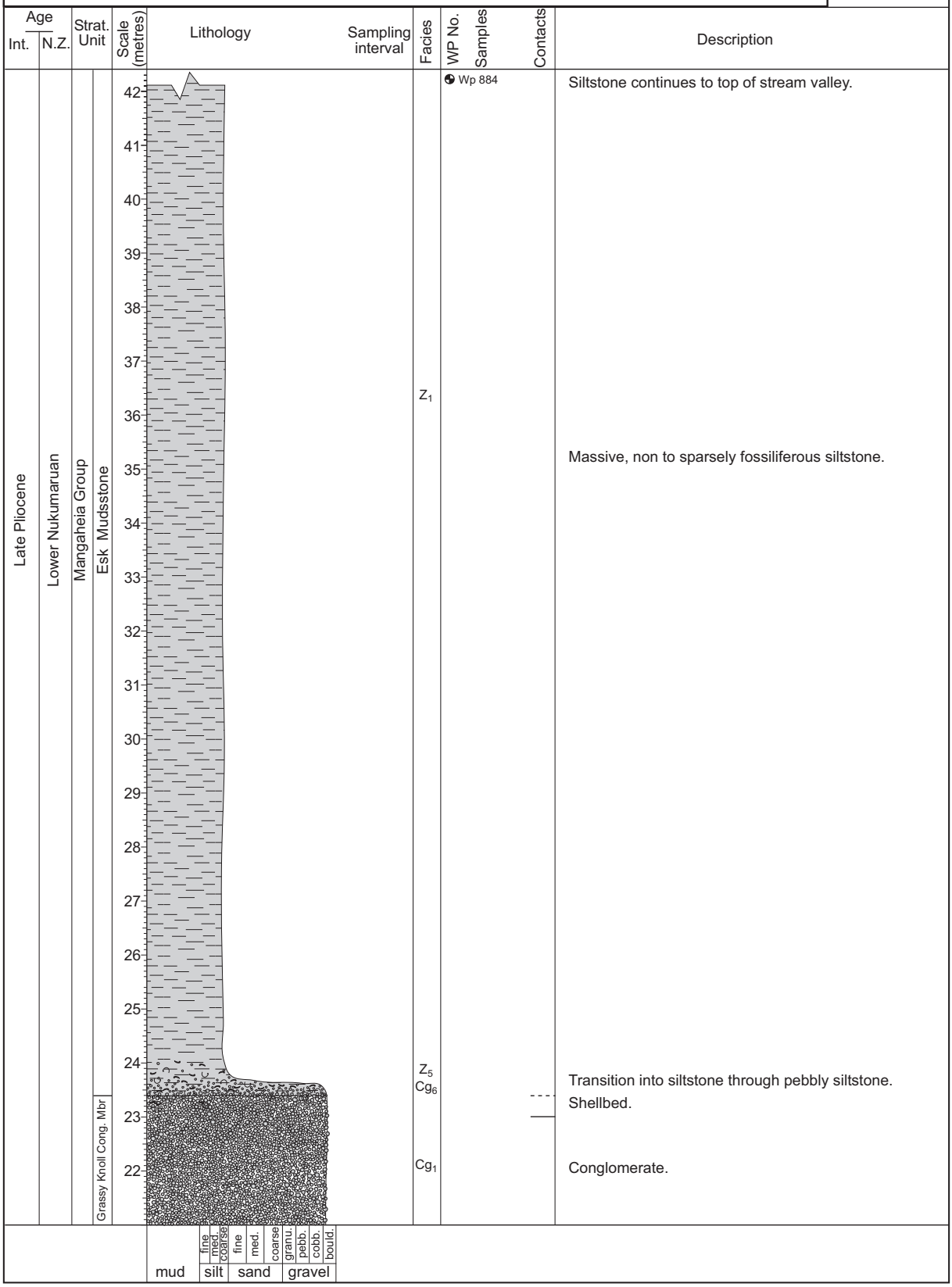
GPS Waypoint No(s): Wp 736-745

Region: Sherenden

Location: Waikonini Stream below Flag Range in to Tutaekuri River

NZMS 260 Sheet: V21 Napier

Grid Reference:	***Top***	***Bottom***
E:	2820739	2821392
N:	6186988	6188373
Altitude:	115 m	82 m



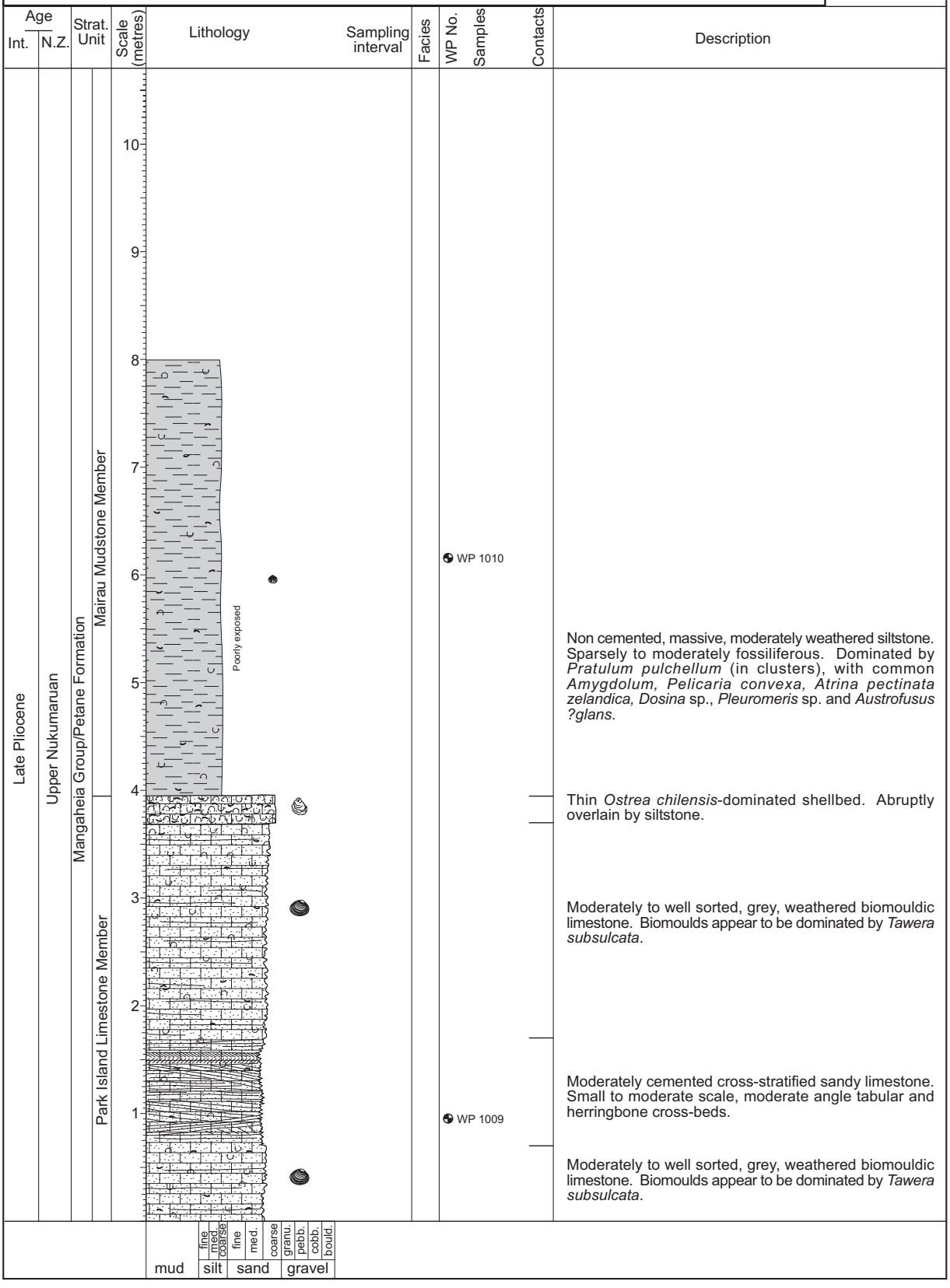
Stratigraphic Column No: Td-1 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 1009-1010 ***E:*** 2841350 2841844

Region: Taradale ***N:*** 6182014 6181832

Location: Northern end of Park Island, Greenmeadows ***Altitude:*** -5 m -7 m

NZMS 260 Sheet: V21 Napier



Stratigraphic Column No: Tg-1 **Grid Reference:** **Top** **Bottom**

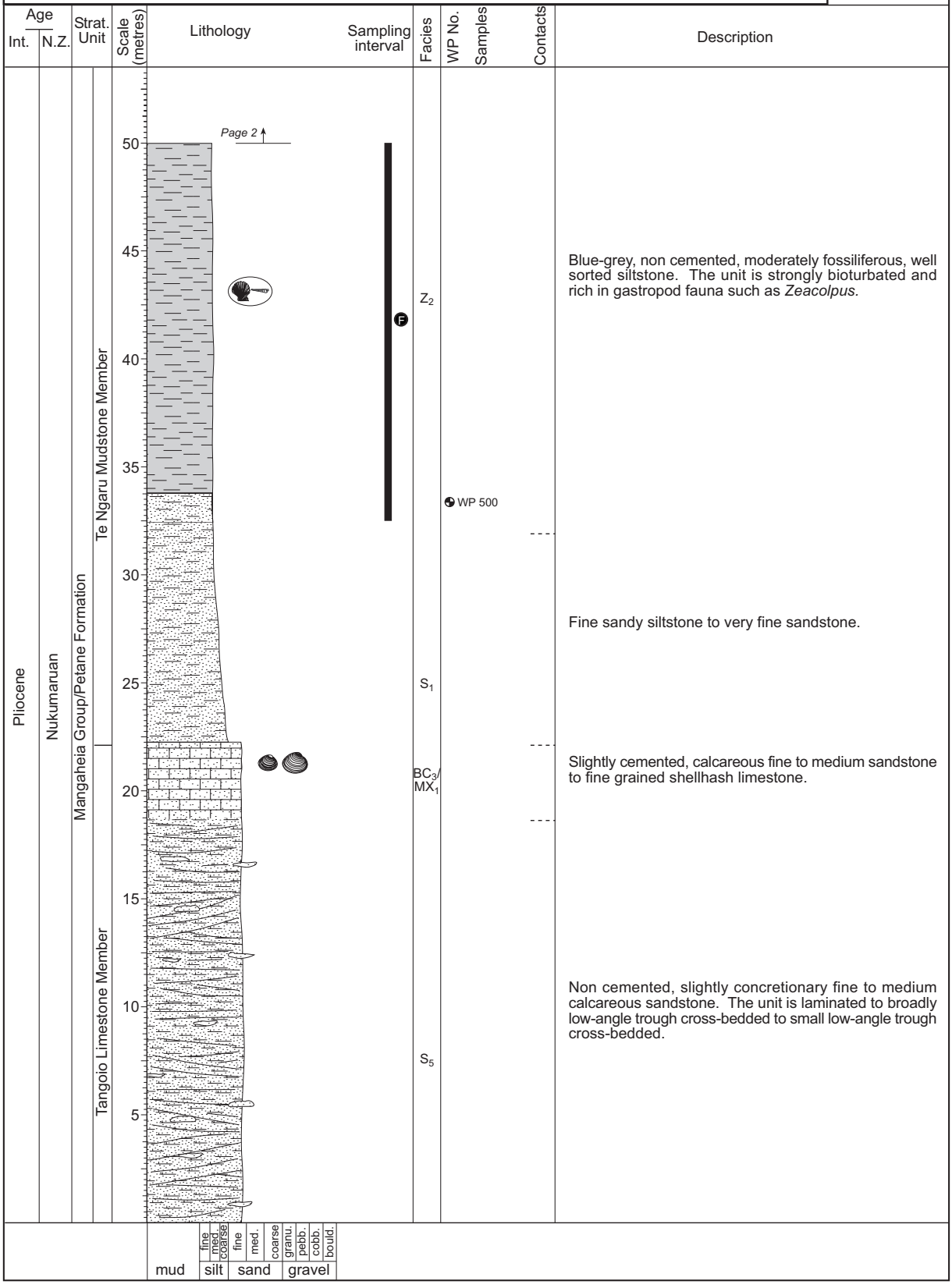
GPS Waypoint No(s): Wp 500 **E:** 2853625 -

Region: Tangoio **N:** 6206830 -

Location: Aropaoanui Road near Aropaoanui Stream and road end **Altitude:** - -

NZMS 260 Sheet: W20 Aropaoanui

Page 1 *of* 2



Stratigraphic Column No: Tg-1 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 500 ***E:*** 2853625 -

Region: Tangoio ***N:*** 6206830 -

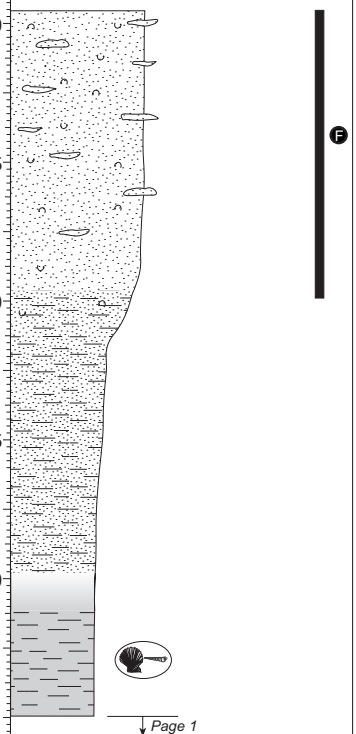
Location: Aropaoanui Road near Aropaoanui Stream and road end ***Altitude:*** - -

NZMS 260 Sheet: W20 Aropaoanui

Age: Int. Pliocene; N.Z. Nukumaruan

Strat. Unit: Mangaheia Group/Petane Formation; Te Ngaru Mudstone Member | Waipatiki Limestone Member

Scale (metres): 75, 70, 65, 60, 55, 50

Lithology / Sampling interval: 

Facies: S_{10}, Z_4, Z_2

WP No. Samples: F

Contacts

Description

Blue-grey, non cemented, non fossiliferous siltstone, coarsening upwards into a sandy siltstone, and in turn a slightly fossiliferous sandstone with occasional moderately cemented concretions. Concretions have frequently developed around valves of *Patro* and *Ostrea*. *In situ* and re-deposited *Atrina* valves are common. Fauna dominated by *Talochlamys*, with *Stiracolpus* and *Zeacolpus*.

mud | silt: fine, med., coarse | sand: fine, med., coarse | gravel: granu., pebb., cobb., bould.

Stratigraphic Column No: *Tg-2*

GPS Waypoint No(s): Wp 511

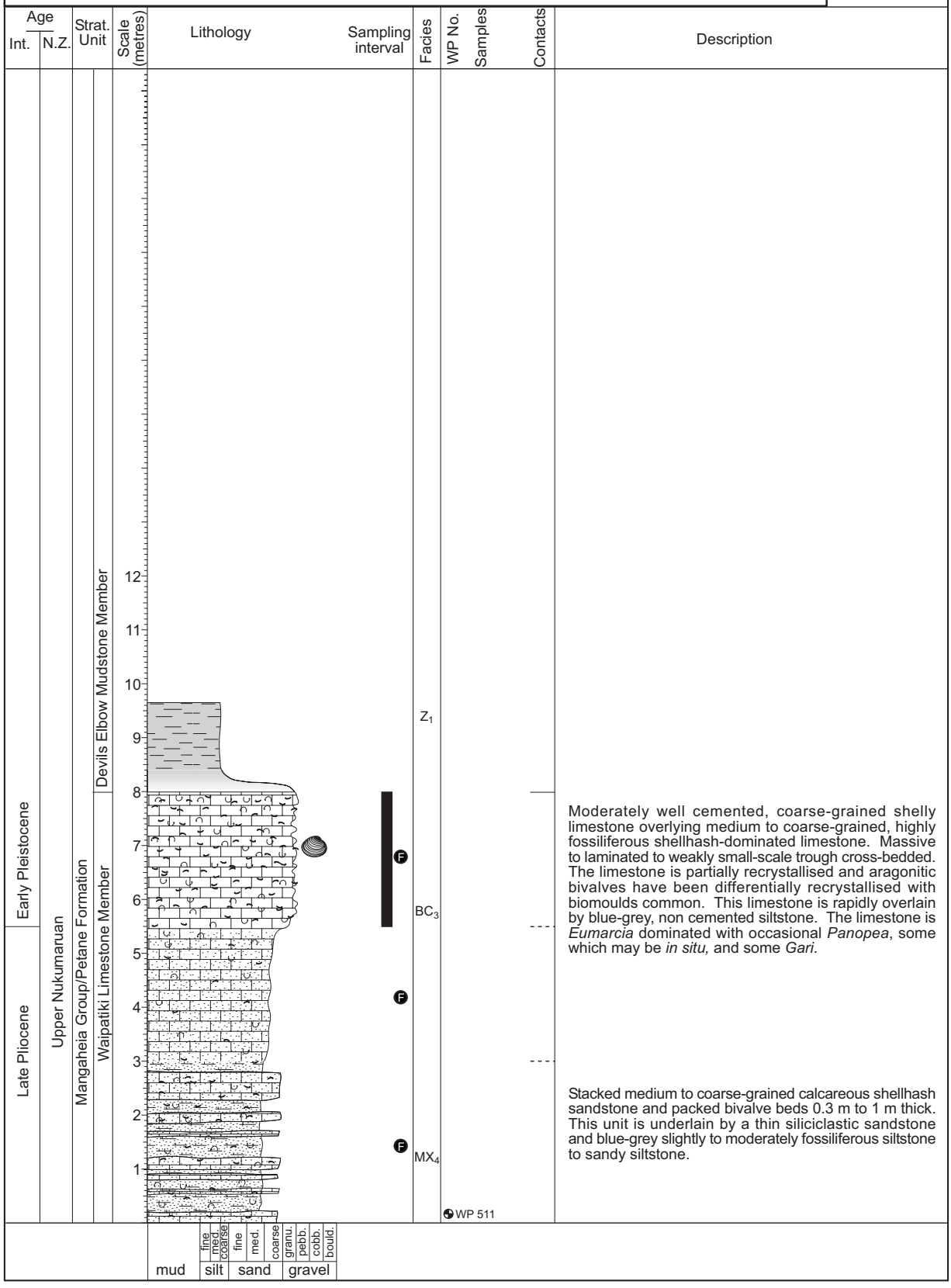
Region: Tangoio

Location: Road cutting near top of Ridgemount Road

NZMS 260 Sheet: W 20 Aropaoanui

Grid Reference:	***Top***	***Bottom***
E:	2850741	-
N:	6214895	-
Altitude:	438m	-

Page 1 *of* 1



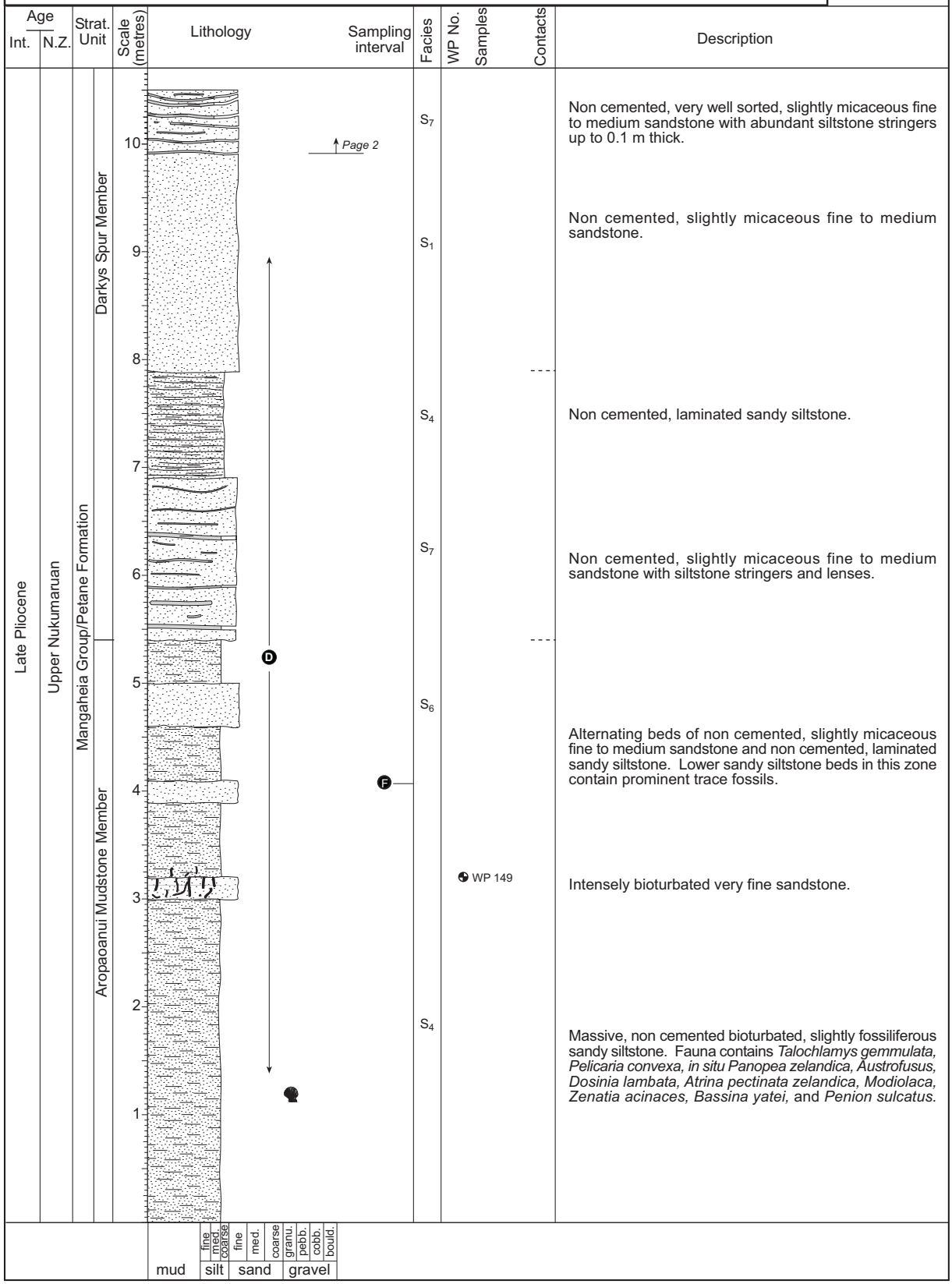
Stratigraphic Column No: Tg-3 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 586-589, 775-776 ***E:*** 2840702 2839726

Region: Tangoio ***N:*** 6210500 6210752

Location: Road section up Darkys Spur Road on northwest side of Tangoio Block ***Altitude:*** 444 m 356 m

NZMS 260 Sheet: V20 Esk



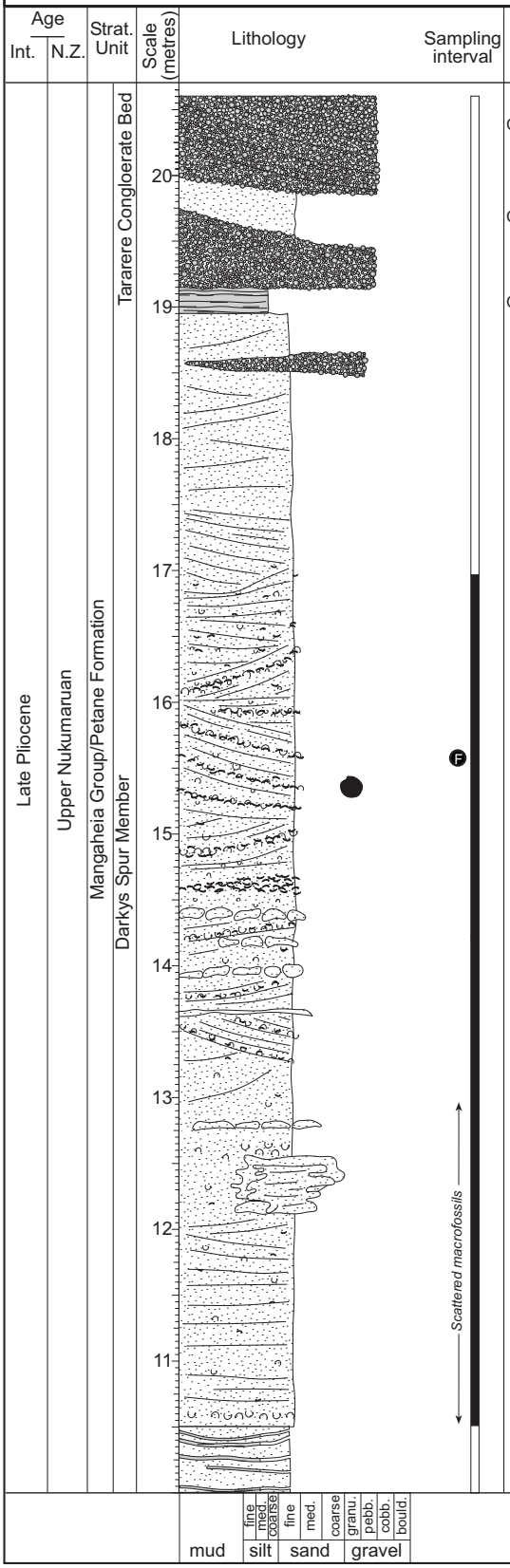
Stratigraphic Column No: Tg-3 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 586-589, 775-776 ***E:*** 2840702 2839726

Region: Tangoio ***N:*** 6210500 6210752

Location: Cliff section up Darkys Spur Road on northwest face of Tangoio Block ***Altitude:*** 444 m 356 m

NZMS 260 Sheet: V20 Esk



Stratigraphic Column No: Tg-3 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 586-589, 775-776 ***E:*** 2840702 2839726

Region: Tangoio ***N:*** 6210500 6210752

Location: Road section up Darkys Spur Road on northwest side of Tangoio Block ***Altitude:*** 444 m 356 m

NZMS 260 Sheet: V20 Esk

Age: Int. — N.Z. | Strat. Unit | Scale (metres) | Lithology | Sampling interval | Facies | WP No. Samples | Contacts | Description

Late Pliocene — Upper Nukumaruan — Mangaheia Group/Petane Formation — Darkys Spur Member/Tararere Conglomerate Bed

30 — Z_1: Non fossiliferous siltstone with scattered fine lapilli-sized pumice clasts.

V_3: Ripple and flaser-bedded non fossiliferous pumiceous siltstone.

Cg_1: Fine-grained greywacke conglomerate lens with angular pebble-sized clasts.

29 — V_3: Non fossiliferous siltstone with pumiceous lapilli and fine ash.

Massive, highly carbonaceous very fine siltstone with occasional plant fragments. Contains no marine fossils.

Z_1

28 — Massive, non fossiliferous, very fine siltstone.

27

Cg_1: Massive, moderately well sorted medium pebble-dominated greywacke conglomerate. This bed truncates a massive non fossiliferous siltstone.

26

25

24 — Laminated, very well sorted fine pebble-dominated greywacke conglomerate. Bed comprises alternating packages of granule and fine pebble-dominated beds up to 0.5 m thick.

F

Cg_4

23 — WP 149

22 — Crudely trough cross-bedded (broad-scale, low to moderate angle) coarse pebble conglomerate. Clasts are moderately sorted, well rounded lensoidal to spheroidal grains.

21

Cg_2

Cg_4

mud | silt: fine, med., coarse | sand: fine, med., coarse | gravel: granu., pebb., cobb., bould.

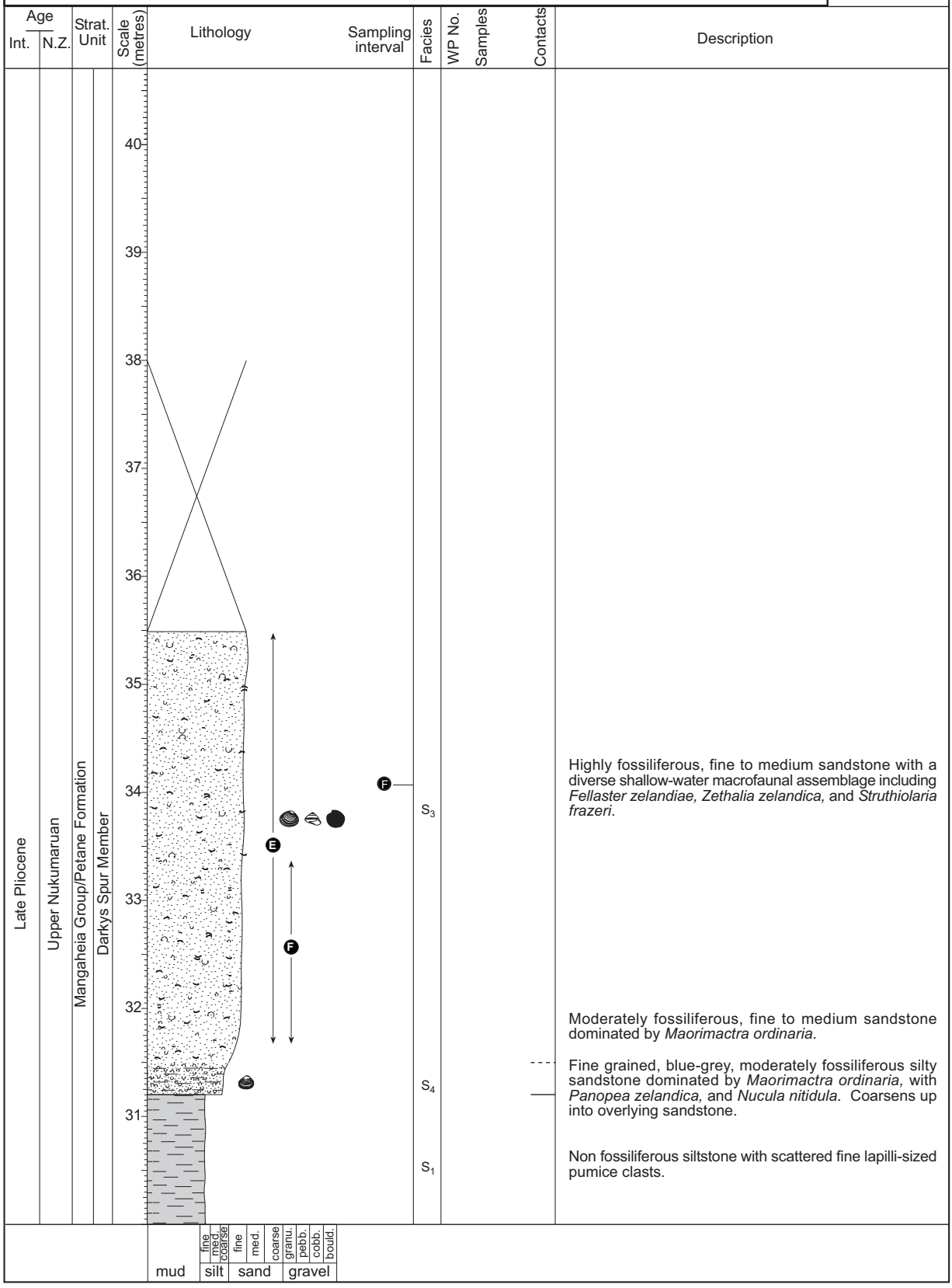
Stratigraphic Column No: *Tg-3* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 586-589, 775-776 ***E:*** 2840702 2839726

Region: Tangoio ***N:*** 6210500 6210752

Location: Road section up Darkys Spur Road on northwest side of Tangoio Block ***Altitude:*** 444 m 356 m

NZMS 260 Sheet: V20 Esk




A


B


C


D


E


F

Stratigraphic Column No: *Tg-4* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 750-759 ***E:*** 2846139 2844776

Region: Tangoio ***N:*** 6207878 6208068

Location: Road cuttings along Devils Elbow, Napier-Wairoa highway (SH2). ***Altitude:*** 259 m 150 m

NZMS 260 Sheet: V20 Esk

Page 1 *of* 6

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology / Sampling interval	Facies	WP No. Samples Contacts	Description
Late Pliocene	Upper Nukumaruan	Mangaheia Group/Petane Formation — Mairau Mudstone Member	21–16	Page 2	Z_2	Wn-H-22a,b,c	Blue-grey to rusty-grey, slightly fossiliferous, massive, non cemented, bioturbated siltstone.
			18			WP 751	Blue-grey to rusty-grey, massive, non cemented moderately fossiliferous bioturbated siltstone. *Talochlamys gemmulata* dominated, common *Ostrea chilensis*, with *Pratulum pulchellum, Pelicaria convexa, Zeacolpus vitattus, Maoricolpus roseus* and *Dosinia greyi* among many other molluscs.
			17			Wn-H-16a,b,c	
			16			Wn-H-15a,b,c	
		Darkys Spur Member	15		S_{10}		Non to slightly cemented concretionary sandstone.
			14–13		S_5		Crudely and broadly laminated, slightly cemented bioclastic sandstone.
			12–11		S_3		Slightly to moderately fossiliferous, well sorted, non cemented fine to medium sandstone.
			10				Moderately cemented concretionary horizon.
			9	A F			Slightly cemented, well sorted bioclastic-rich medium sandstone with scattered macrofossils. A noticeable change in fauna is visible, bed contains *Oxyperis komakoensis.*
			8				Contains ripple-bedded to laminated siltstone stringers with common, detached siltstone bodies.
			7			Wn-H-14a,b,c	Slightly to moderately cemented, medium sandstone. Fauna dominated by *Sigapatella novazelandiae.*
			6				
			5			Wn-H-13c	Slightly to moderately cemented, well sorted slightly fossiliferous, medium sandstone. Fauna is dominated by *Fellaster zelanidae.*
			4			Wn-H-13b	Concretionary sandstone.
			3				
			2			Wn-H-13a	Orange-brown, non cemented, bioturbated fine to medium sandstone with scattered macrofossils and common burrows. Contains scattered macrofossils, and clusters macrofossils and shellhash. Fauna dominated by *Fellaster novaezelandiae*, with *Gonimyrtea, Calliostoma* sp., *Sigapatella novaezelandiae, Tanea, Gari lineolata, Maorimactra ordinaria, Stiracolpus* sp. and barnacles (both intact and fragmented).
			1			WP 750	

mud | silt (fine, med., coarse) | sand (fine, med., coarse) | gravel (granu., pebb., cobb., bould.)

Stratigraphic Column No: Tg-4 ***Grid Reference:*** ***Top*** ***Bottom***

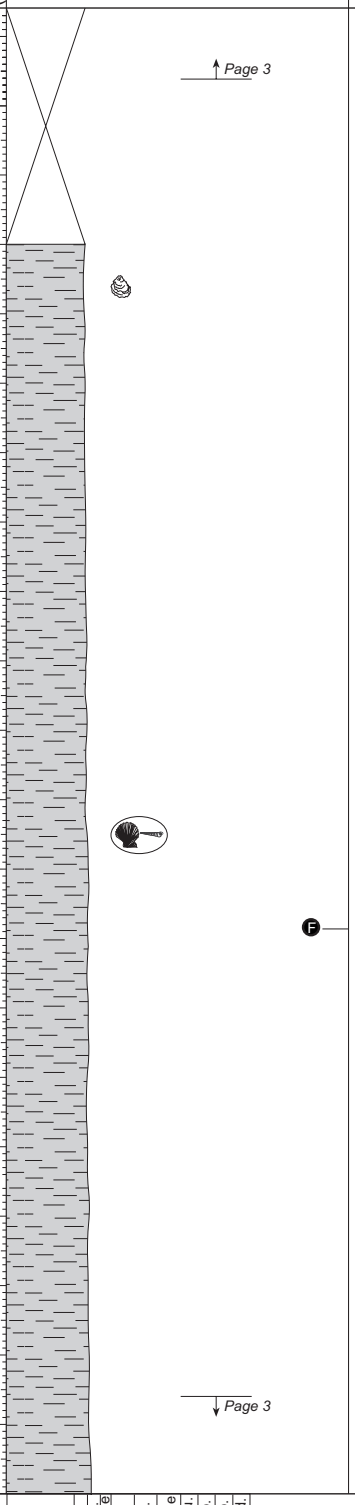
GPS Waypoint No(s): Wp 750-759 ***E:*** 2846139 2844776

Region: Tangoio ***N:*** 6207878 6208068

Location: Road cuttings along Devils Elbow, Napier-Wairoa highway (SH2). ***Altitude:*** 259 m 150 m

NZMS 260 Sheet: V20 Esk

Page 2 *of* 6

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Upper Nukumaruan	Mangaheia Group/Petane Formation / Mairau Mudstone Member	41–21		F	Z_2	WP 753 Wn-H-25c		Blue-grey to dirty-cream, non cemented slightly fossiliferous, massive siltstone. Contains *Ostrea chilensis, Talochlamys gemmulata* and *Amalda novaezelandiae* among many other molluscs. *Pelicaria convexa* present with sutures characteristic of *P. convexa* form *"fossa"*.
							Wn-H-24c		
									Blue-grey, non cemented, slightly fossiliferous massive siltstone. Fauna dominated by *Stiracolpus* spp., with *Ostrea chilensis, Neilo* sp., *Amalda novaezelandiae, Taniella, Maoricolpus roseus* and *Dosinia greyi*.
							WP 752		Blue-grey, non cemented, slightly fossiliferous, massive siltstone.
							Wn-H-13c		

mud | silt (fine, med., coarse) | sand (fine, med., coarse) | gravel (granu., pebb., cobb., bould.)

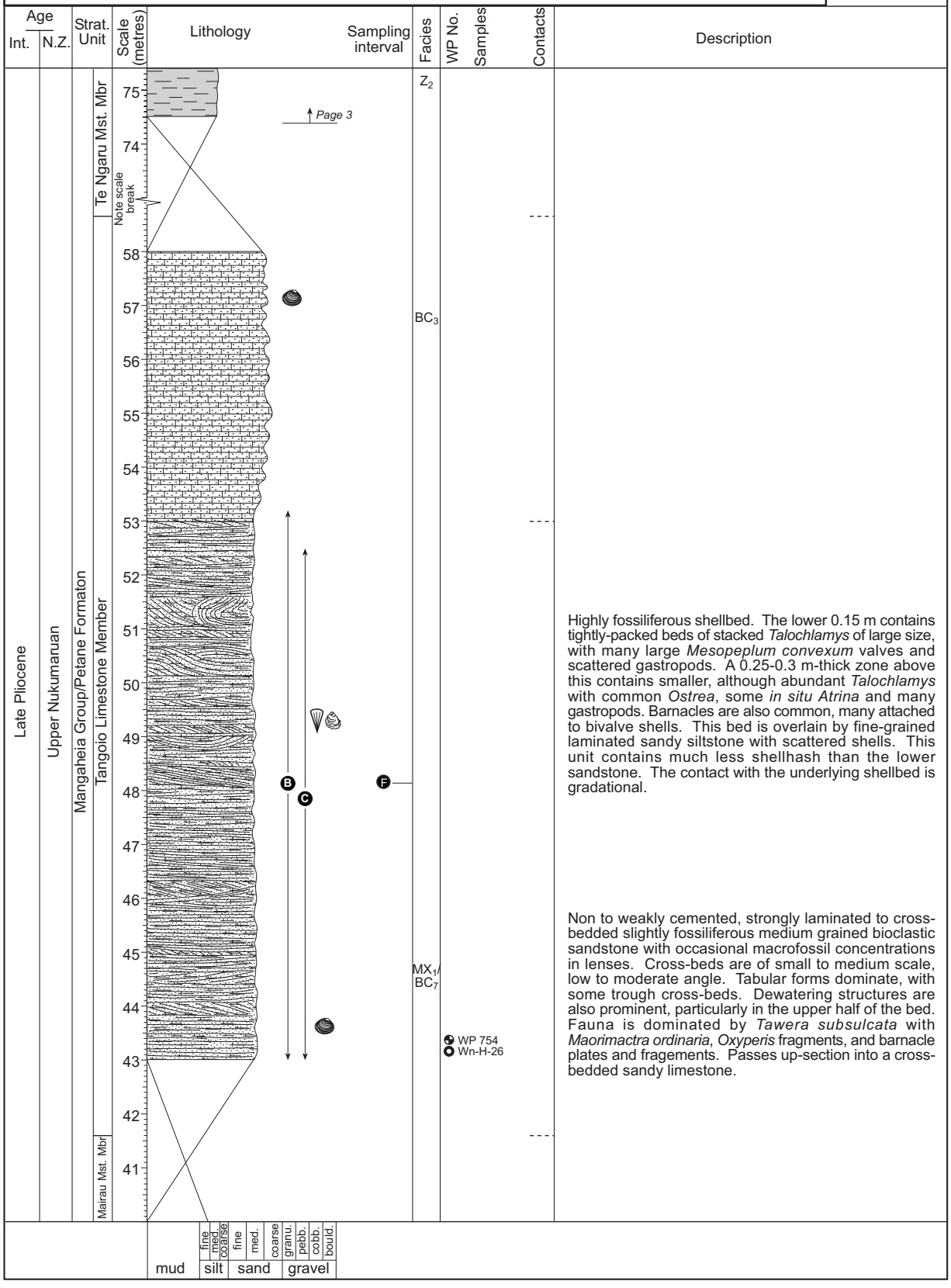
Stratigraphic Column No: *Tg-4* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 750-759 ***E:*** 2846139 2844776

Region: Tangoio ***N:*** 6207878 6208068

Location: Road cuttings along Devils Elbow, Napier-Wairoa highway (SH2). ***Altitude:*** 259 m 150 m

NZMS 260 Sheet: V20 Esk



Highly fossiliferous shellbed. The lower 0.15 m contains tightly-packed beds of stacked *Talochlamys* of large size, with many large *Mesopeplum convexum* valves and scattered gastropods. A 0.25-0.3 m-thick zone above this contains smaller, although abundant *Talochlamys* with common *Ostrea*, some *in situ Atrina* and many gastropods. Barnacles are also common, many attached to bivalve shells. This bed is overlain by fine-grained laminated sandy siltstone with scattered shells. This unit contains much less shellhash than the lower sandstone. The contact with the underlying shellbed is gradational.

Non to weakly cemented, strongly laminated to cross-bedded slightly fossiliferous medium grained bioclastic sandstone with occasional macrofossil concentrations in lenses. Cross-beds are of small to medium scale, low to moderate angle. Tabular forms dominate, with some trough cross-beds. Dewatering structures are also prominent, particularly in the upper half of the bed. Fauna is dominated by *Tawera subsulcata* with *Maorimactra ordinaria*, *Oxyperis* fragments, and barnacle plates and fragements. Passes up-section into a cross-bedded sandy limestone.

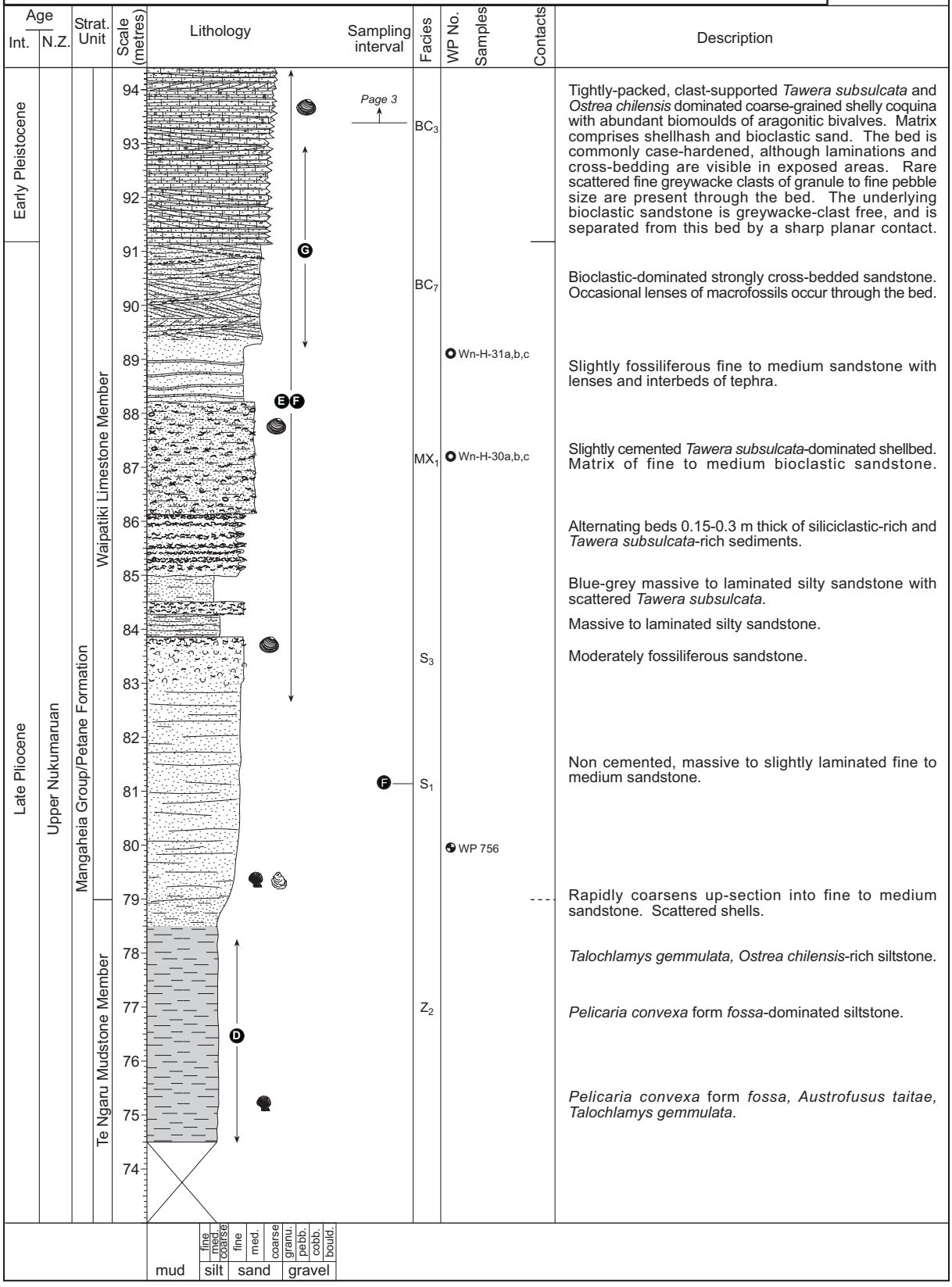
Stratigraphic Column No: Tg-4 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 750-759 ***E:*** 2846139 2844776

Region: Tangoio ***N:*** 6207878 6208068

Location: Road cuttings along Devils Elbow, Napier-Wairoa highway (SH2). ***Altitude:*** 259 m 150 m

NZMS 260 Sheet: V20 Esk



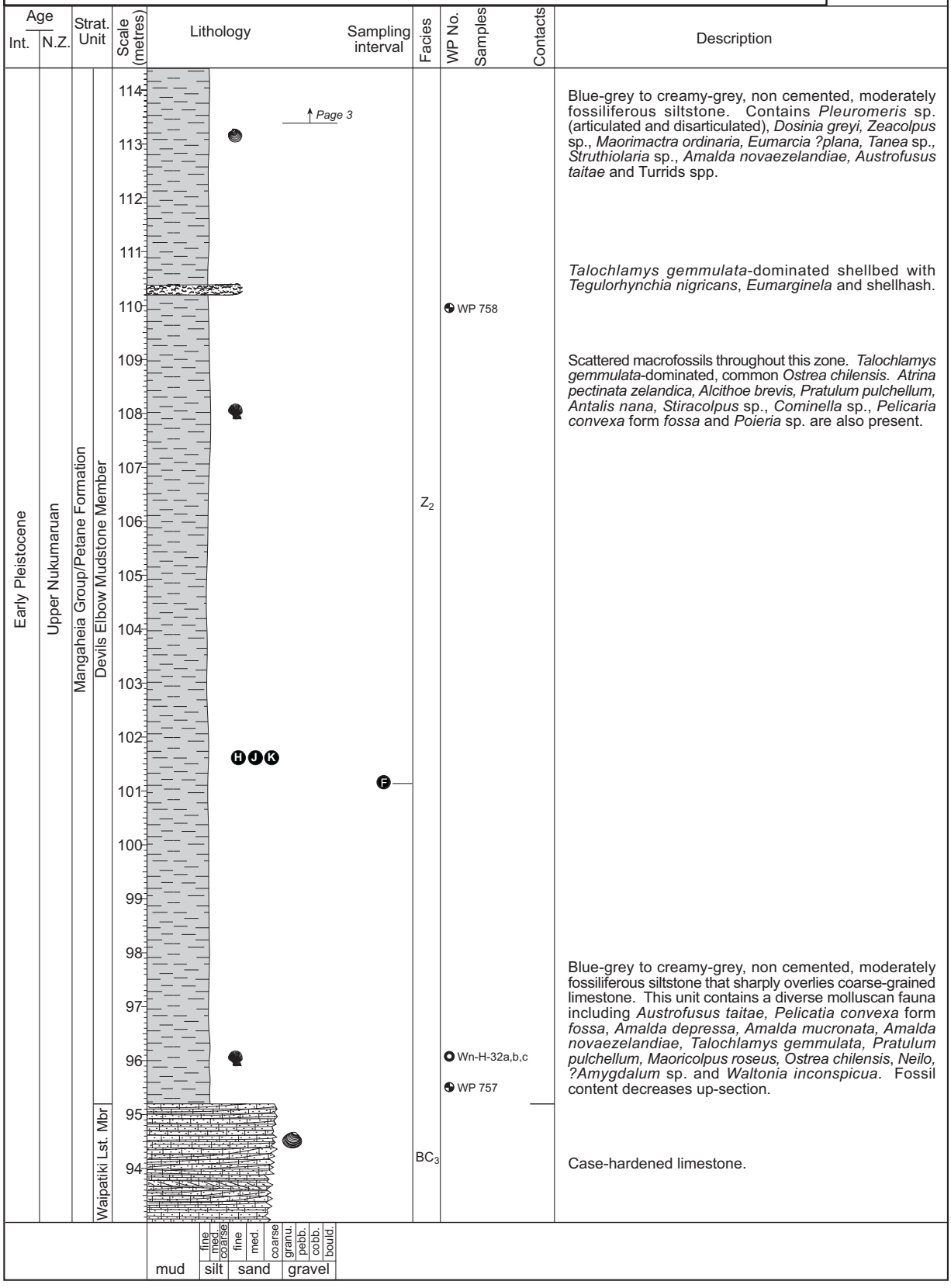
Stratigraphic Column No: *Tg-4* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 750-759 ***E:*** 2846139 2844776

Region: Tangoio ***N:*** 6207878 6208068

Location: Road cuttings along Devils Elbow, Napier-Wairoa highway (SH2). ***Altitude:*** 259 m 150 m

NZMS 260 Sheet: V20 Esk



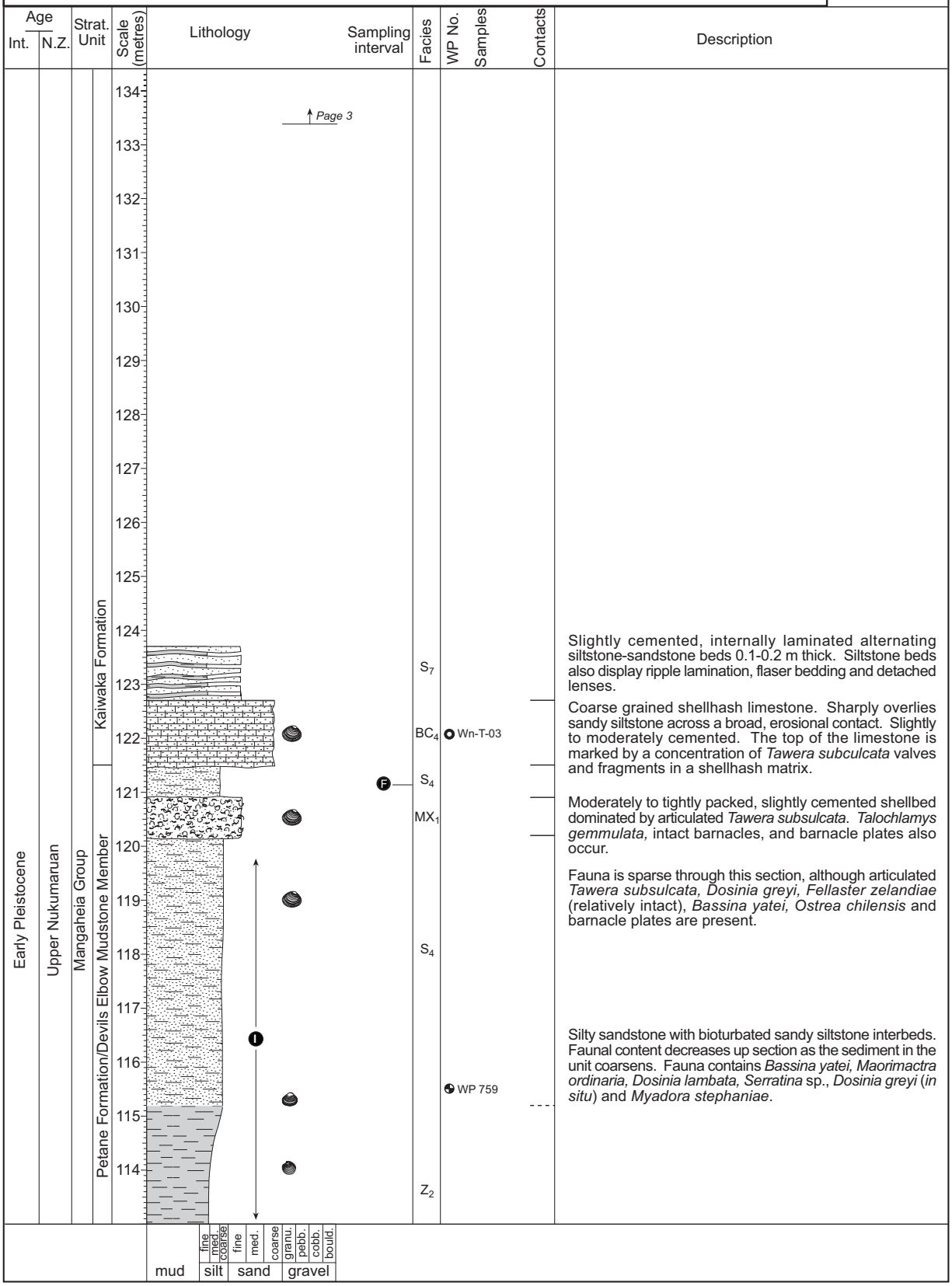
Stratigraphic Column No: *Tg-4* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 750-759 ***E:*** 2846139 2844776

Region: Tangoio ***N:*** 6207878 6208068

Location: Road cuttings along Devils Elbow, Napier-Wairoa highway (SH2). ***Altitude:*** 259 m 150 m

NZMS 260 Sheet: V20 Esk




A


B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D


E


F


G


H


I


J


K

Stratigraphic Column No: *Tg-5*

GPS Waypoint No(s): Wp 558

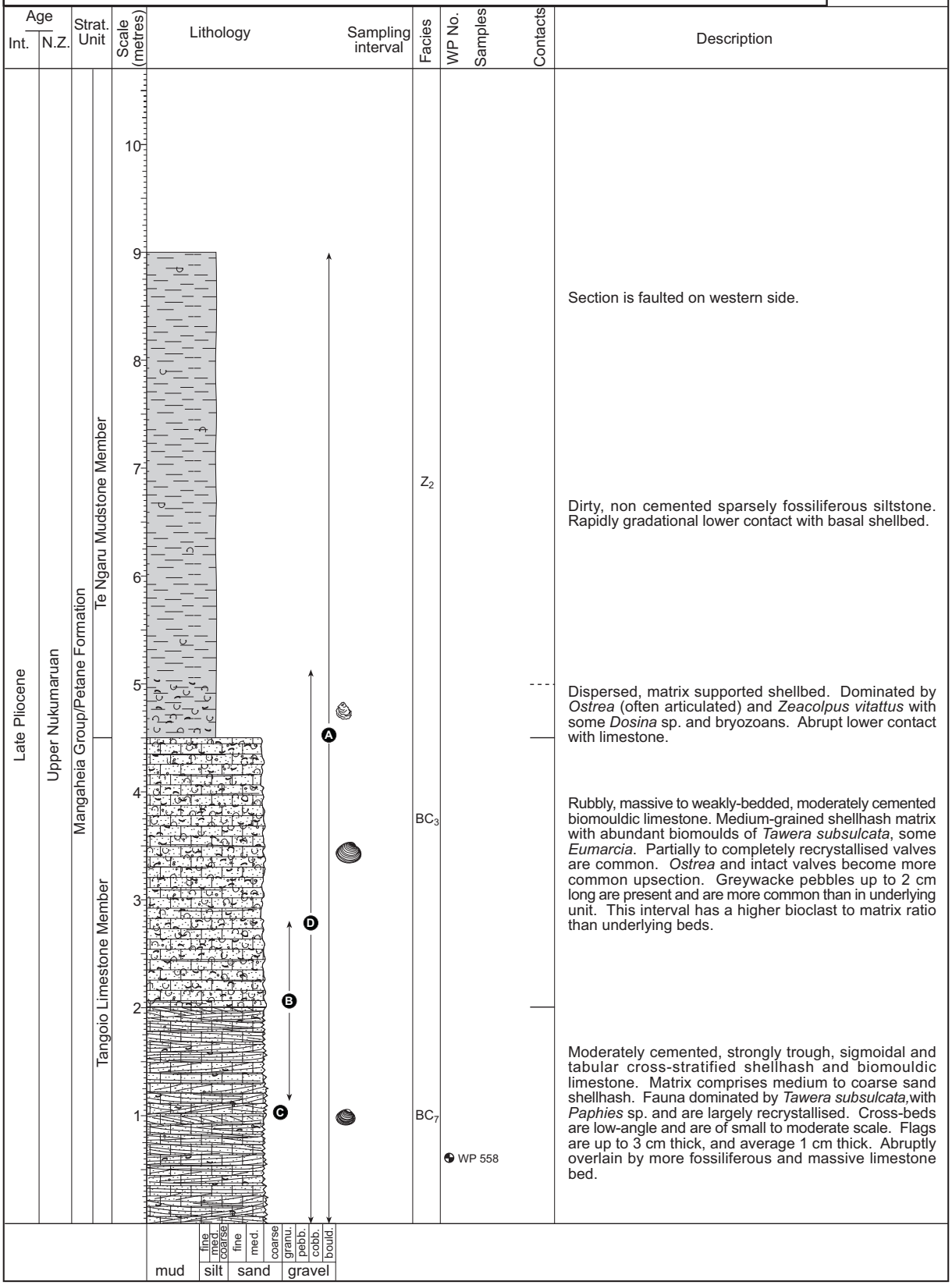
Region: Tangoio

Location: North end of Whirinaki Beach, outlier on beach

NZMS 260 Sheet: V20 Esk

	Grid Reference:	***Top***	***Bottom***
	E:	-	2846961
	N:	-	6198520
	Altitude:	-	0 m

Page 1 *of* 1




A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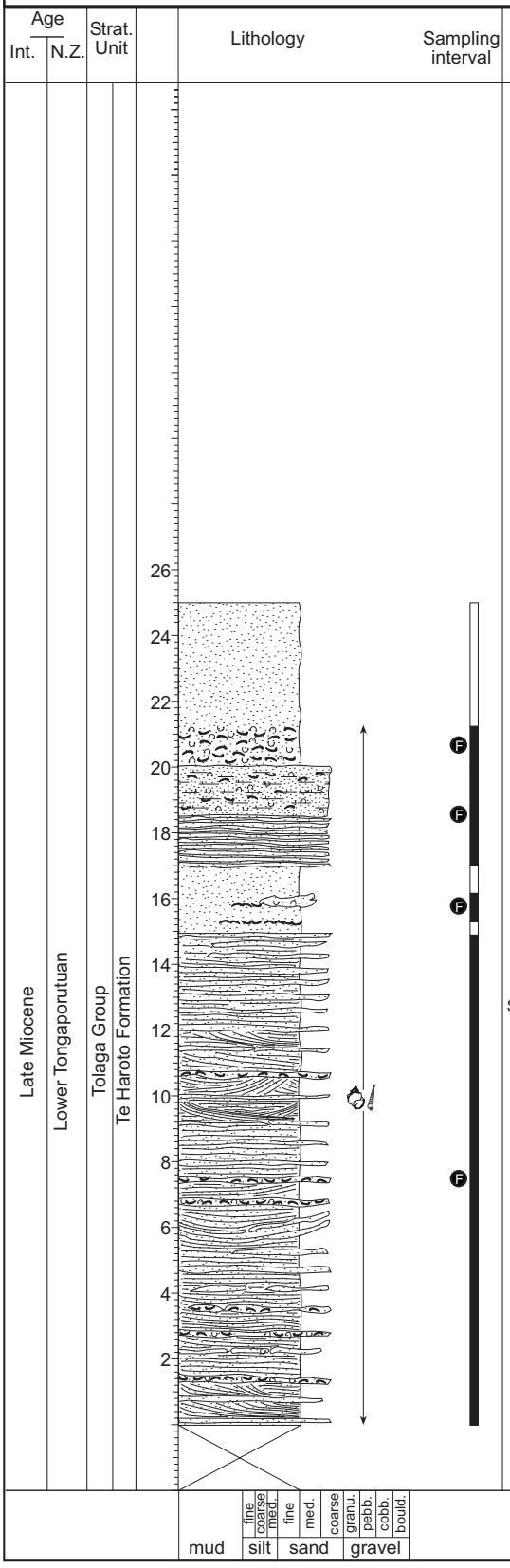
Stratigraphic Column No: *Th-1* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 93 ***E:*** 2819661

Region: Te Haroto ***N:*** 6226539

Location: Napier-Taupo Road approx. 1km north of Te Haroto. ***Altitude:*** 712m -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1













Stratigraphic Column No: *Ti-1* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 29-35, 38, 779 ***E:*** 2828727 2826720

Region: Titiokura ***N:*** 6214418 6216336

Location: Road cuttings on SH5 around Titiokura Saddle ***Altitude:*** 681 m 535 m

NZMS 260 Sheet: V20 Esk

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Miocene	Lower Kapitean	Tolaga Group/Waitere Formation, Rakaita Siltstone Member	1010 – 50 (SCALE CHANGE at 1000)		Page 2	Z_1	WP 32		Blue-grey to white-grey, non cemented, massive to weakly laminated, non fossiliferous siltstone. Occasional spheroidal concretions are present up to 0.4 m across. The unit is bioturbated with occasional burrows visible. Unit continues to base of section where it is intersected by the Mohaka Fault at the Napier-Taupo Road bridge, although exposures are very patchy. Inferred to be gradationally underlain by non cemented, massive to laminated fine to medium concretionary sandstone of the Te Ipuohape Sandstone Member. This underlying unit is exposed in Mohaka River in the vicinity of the Napier-Taupo Road bridge.

mud | silt (fine, med., coarse) | sand (fine, med., coarse) | gravel (granu., pebb., cobb., bould.)

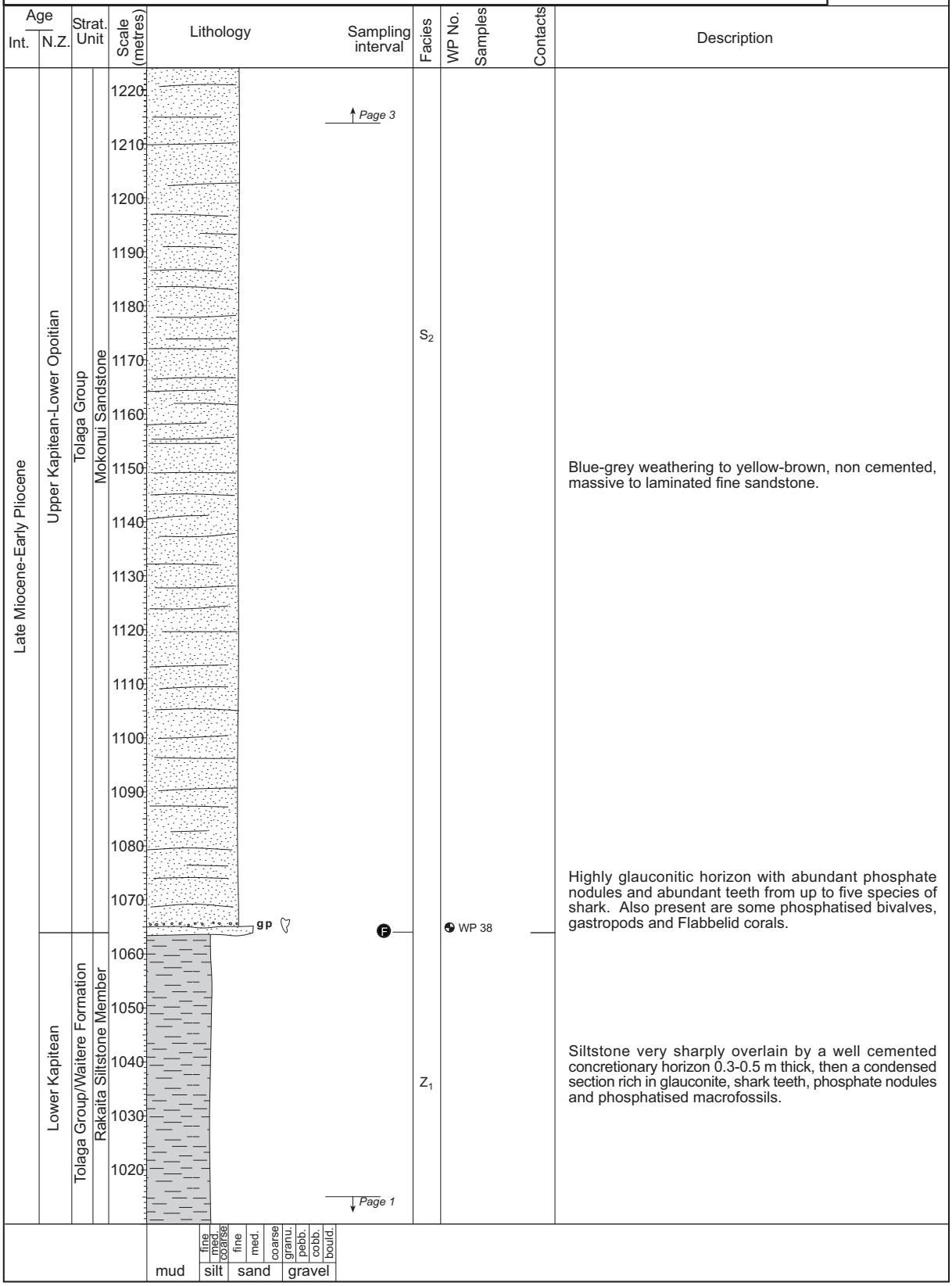
Stratigraphic Column No: *Ti-1* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 29-35, 38, 779 ***E:*** 2828727 2826720

Region: Titiokura ***N:*** 6214418 6216336

Location: Road cuttings on SH5 around Titiokura Saddle ***Altitude:*** 681 m 535 m

NZMS 260 Sheet: V20 Esk



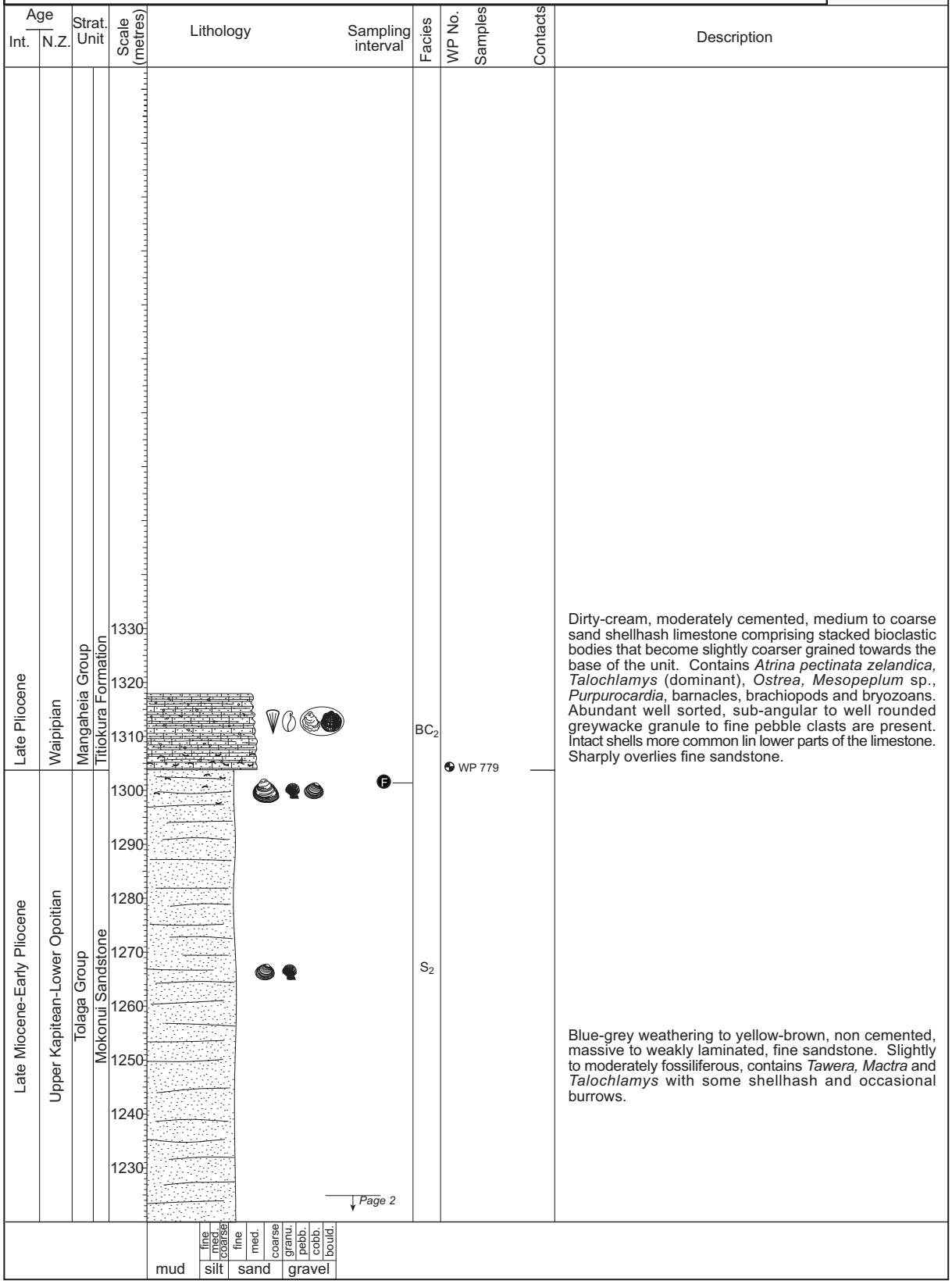
Stratigraphic Column No: Ti-1 **Grid Reference:** **Top** **Bottom**

GPS Waypoint No(s): Wp 29-35, 38, 779 **E:** 2828727 2826720

Region: Titiokura **N:** 6214418 6216336

Location: Road cuttings on SH5 around Titiokura Saddle **Altitude:** 681 m 535 m

NZMS 260 Sheet: V20 Esk



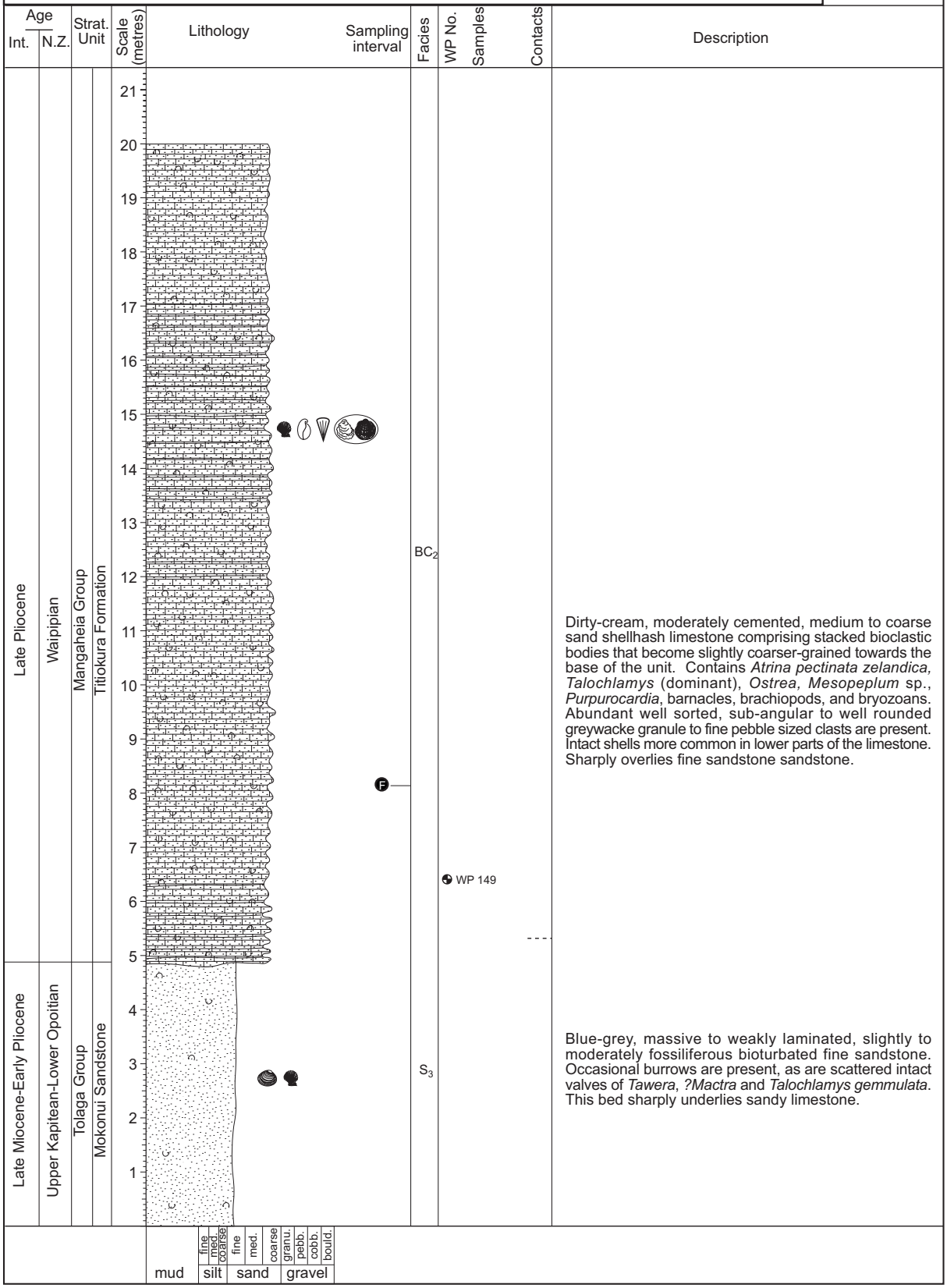
Stratigraphic Column No: Ti-2 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 777-779 ***E:*** 2828954 2828727

Region: Titiokura ***N:*** 6214200 6214418

Location: SH5 on Napier side of Titiokura Saddle ***Altitude:*** 654 m 681 m

NZMS 260 Sheet: V20 Esk



Stratigraphic Column No: *Tk-1* ***Grid Reference:*** ***Top*** ***Bottom***

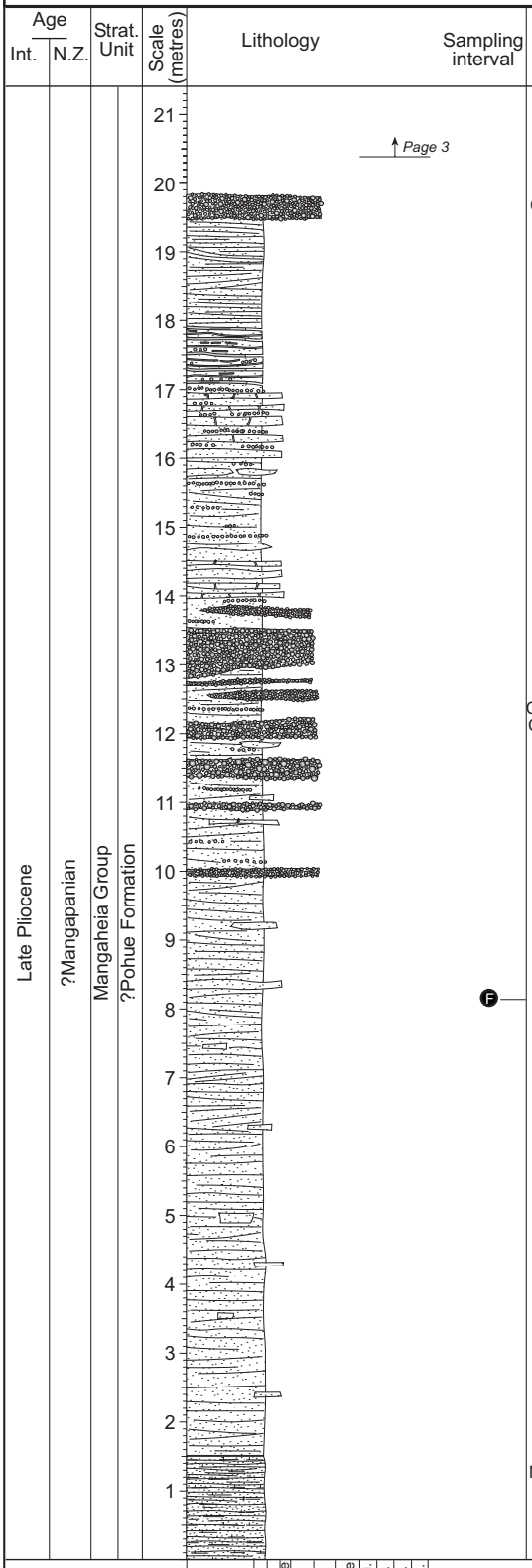
GPS Waypoint No(s): Wp 794 ***E:*** 2810803 -

Region: Te Kowhai ***N:*** 6200034 -

Location: Cuttings near crest of M6 Road, Te Kowhai Forest ***Altitude:*** 628 m -

NZMS 260 Sheet: V20 Esk

Page 1 *of* 1



Strongly laminated to broadly trough cross-bedded, non cemented, non fossiliferous, fine to medium sandstone.

Strongly laminated, non cemented fine to medium sandstone with abundant, ripple and flaser-bedded siltstone lenses.

Massive to strongly laminated fine to medium sandstone with common concretionary horizons up to 0.25 m thick, averaging 0.08 m thick. Thin fine pebble greywacke conglomerate lenses and stringers are present between concretions.

Well sorted greywacke conglomerate lenses comprising well rounded clasts averaging 10 mm across in a shellhash matrix. Occasional concretions are present between the conglomerate lenses, which themselves are up to 0.7 m thick. Conglomerate beds become less prominent and poorly sorted down section.

Non cemented, laminated, non fossiliferous, well sorted fine to medium sandstone with scattered concretions.

Non to slightly cemented, laminated to swaley cross-bedded, slightly fossiliferous, bioclastic-dominated medium sandstone. Small-scale, moderate angle herringbone cross-stratification is visible in some parts of the bed. Contains *Crepidula* and unidentified bivalves.

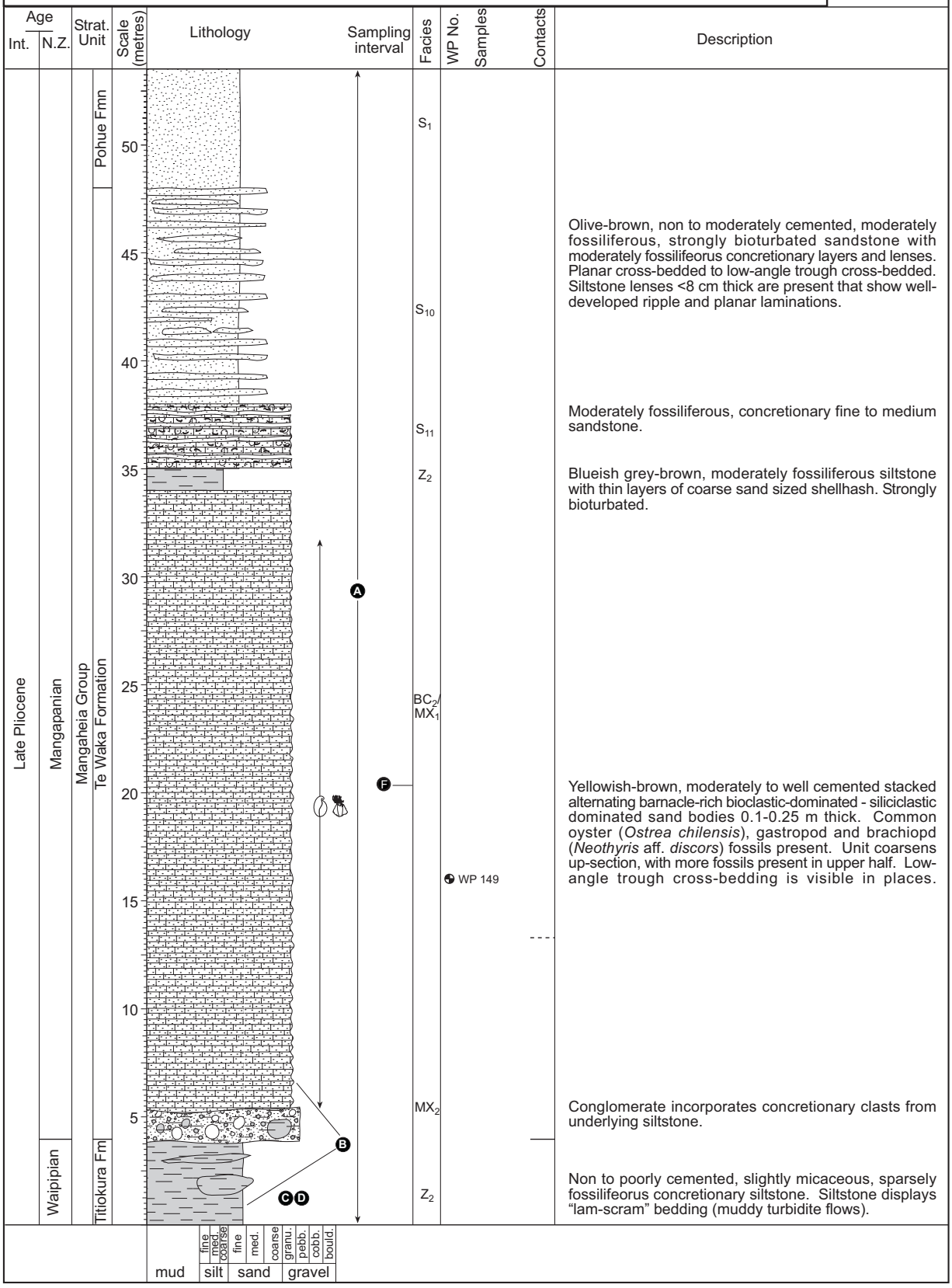
Stratigraphic Column No: Tp-1 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Oakmere Station ***E:*** 2827100 -

Region: Te Pohue ***N:*** 6210600 -

Location: Limestone bluffs beside Translator Road, Oakmere Station ***Altitude:*** - -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1




A


B


C


D

Stratigraphic Column No: Tp-2 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Oakmere Station ***E:*** 2827000 -

Region: Te Pohue ***N:*** 6211500 -

Location: Oakmere Stationin ampitheatre near Rock Station boundary ***Altitude:*** - -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology / Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Waipipian	Mangaheia Group / Titiokura Formation	50	↑ Page 2	BC_6 BC_2			Stacked barnacle-rich bioclastic-dominated bodies capped by highly fossiliferous shellbed conspicuously dominated by the brachiopd *Neothyris* aff. *discors*. Also contains *Ostrea chilensis*, rare *Meospeplum crawfordi*, common indeterminate bivalves and echinoids.
			45					
					S_{10}			
			40					Non to slightly cemented, concretionary fine sandstone. Poorly exposed through this interval.
			35					
					BC_6			Moderately to well cemented conglomeratic sandy limestone to sandy coquina. Contains sandstone and mudstone pebbles.
			30					
			25		BC_1/ BC_2			
			20	F				Yellowish-brown stacked barnacle-rich bioclastic-dominated sheets. Planar to low-angle cross-bedded bodies averaging 0.1 m thick. Contains *Ostrea chilensis* and *Neothyris* aff. *discors*.
						WP 149		
			15					
			10					
					S_5/ MX_3			Poorly to moderately cemented, concretionary calcareous sandstone with a thin, basal conglomerate bed. Clasts are dominated by sandstone and mudstone lithologies of fine to coarse pebble size with rare greywacke pebbles. Common bioturbation trails and "blebs".
			5					
Early Pliocene	Lower Opoitian	Tolaga Grp / Mokonui Sst.			S_1			

mud | silt: fine, med., coarse | sand: fine, med., coarse | gravel: granu., pebb., cobb., bould.

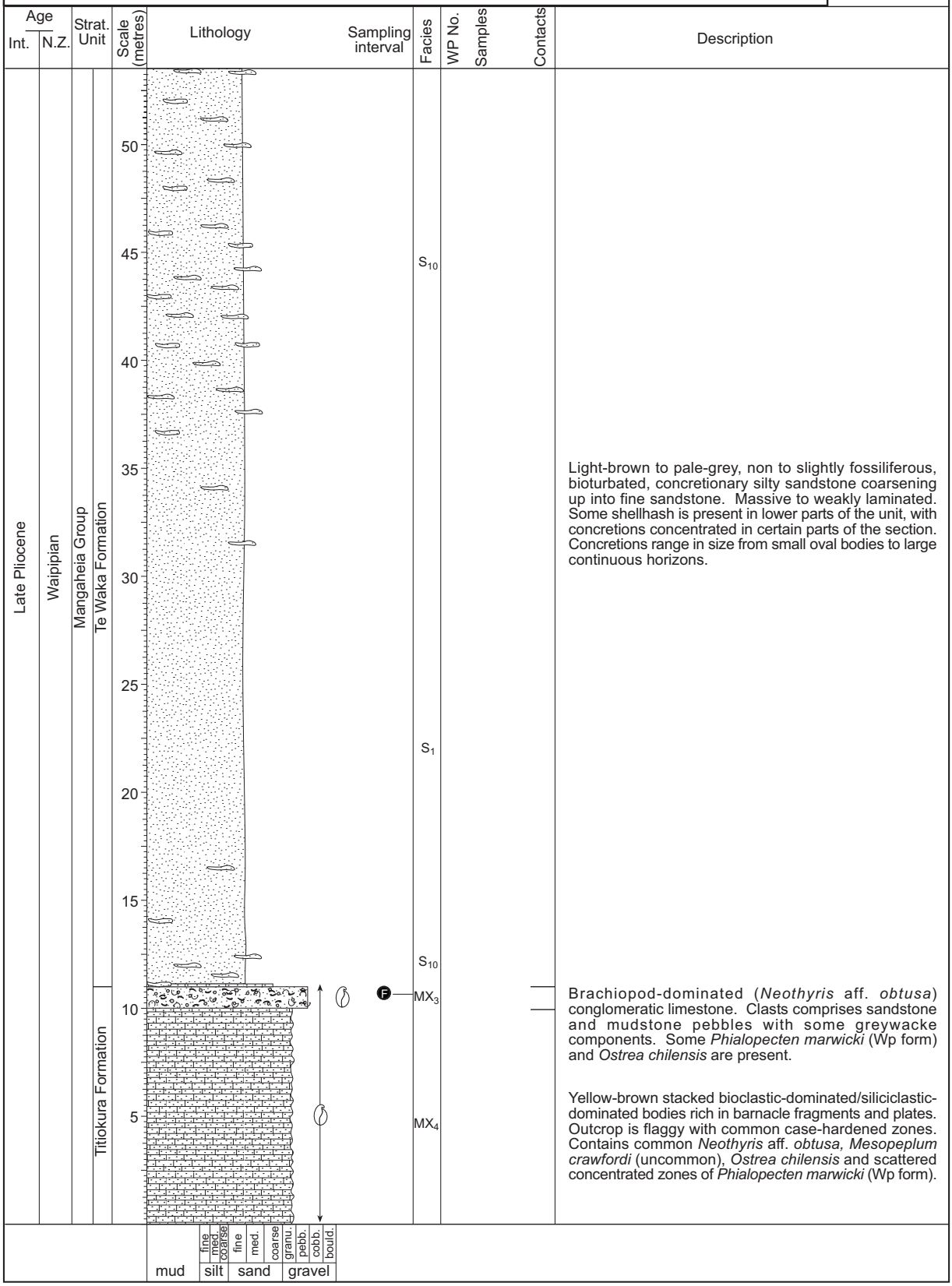
Stratigraphic Column No: *Tp-3* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Te Waka Trig ***E:*** 2825600 -

Region: Te Pohue ***N:*** 6213100 -

Location: Section below repeater towers, north end Te Waka Range, Te Waka Trig ***Altitude:*** 1021 m -

NZMS 260 Sheet: V20 Esk



Stratigraphic Column No: *Tp-3* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Te Waka Trig ***E:*** 2825600 -

Region: Te Pohue ***N:*** 6213100 -

Location: Section below repeater towers, north end Te Waka Range, Te Waka Trig ***Altitude:*** 1021 m -

NZMS 260 Sheet: V20 Esk

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Waipipian	Mangaheia Group / Te Waka Formation	100			S_{10}			Yellowish-brown, poorly to slightly cemented, moderately fossiliferous concretionary sandstone. The unit comprises alternating bioclastic/siliciclastic-dominated sand bodies. Calcareous packages become thicker and more dominant down-dip. Contains *Antalis pareorensis*, *Phialopecten marwicki* (Wp form) *Atrina pectinata zelandica* and *Mesopeplum convexum.*
	Mangapanian		95			MX_4			Yellowish-brown, sandy barnacle-rich bioclastic sheets alternating with siliciclastic-dominated beds. Prominent burrows and other bioturbation features present through layers.
			90						
			85						
			80			S_{10}			
			75						
			70						Light-brown to pale-grey, non to slightly fossilifeorus bioturbated concretionary silty sandstone coarsening up into fine sandstone. Massive to weakly laminated. Some shellhash is present in lower parts of the unit, with concretions concentrated in certain parts of the section. Concretions range in size from small oval bodies to large continuous horizons.
			65						
			60						
			55						

mud | silt: fine, med., coarse | sand: fine, med., coarse | gravel: granu., pebb., cobb., bould.

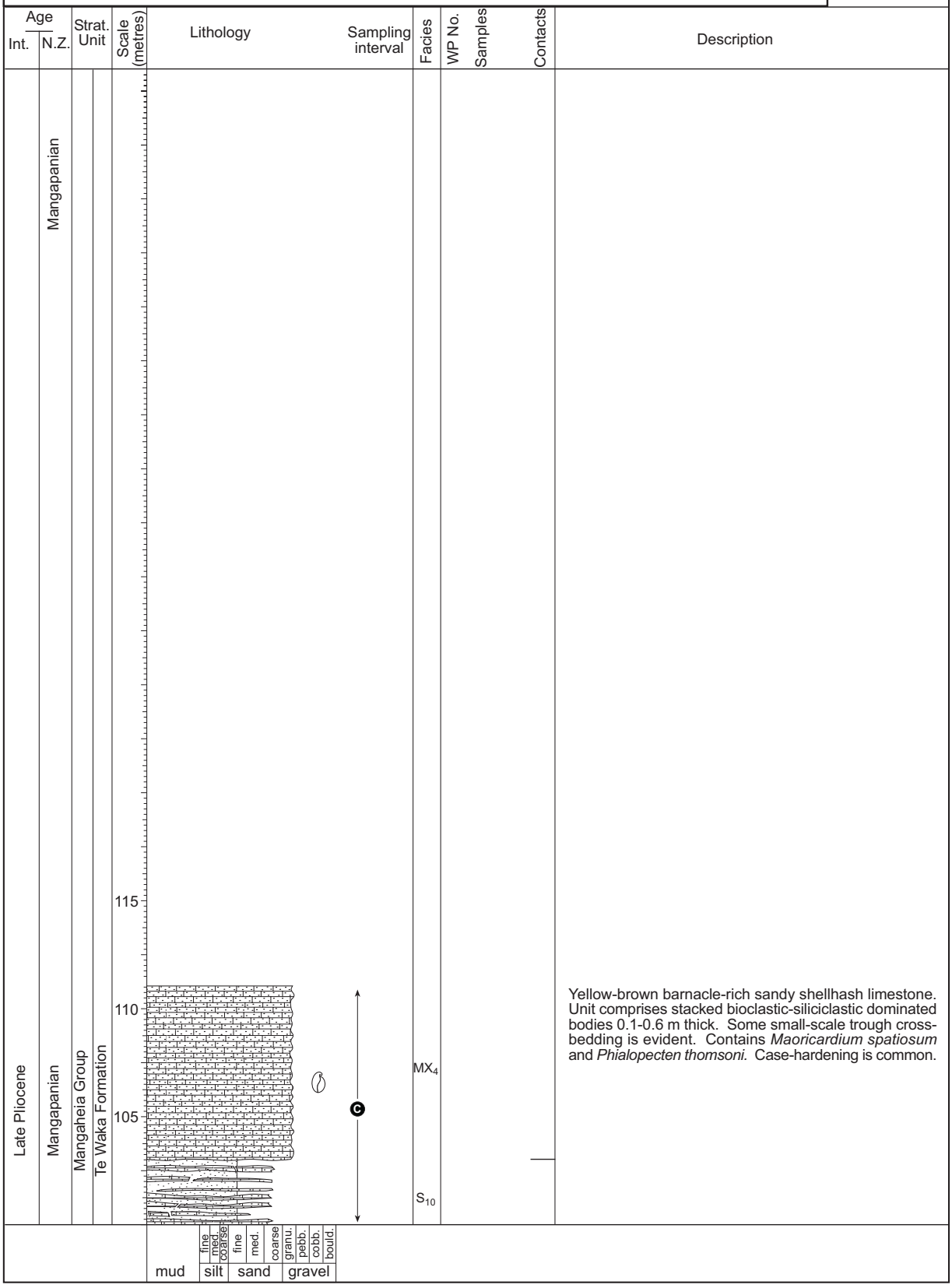
Stratigraphic Column No: *Tp-3* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Te Waka Trig ***E:*** 2825600 -

Region: Te Pohue ***N:*** 6213100 -

Location: Section below repeater towers, north end Te Waka Range, Te Waka Trig ***Altitude:*** 1021 m -

NZMS 260 Sheet: V20 Esk *Page* 3 *of* 3




Translator Road Section
(Column Tp-1)
Te Waka Trig Section
(Column Tp-3)
A
Oakmere Ampitheatre Section
(Coulmn Tp-2)


B


C

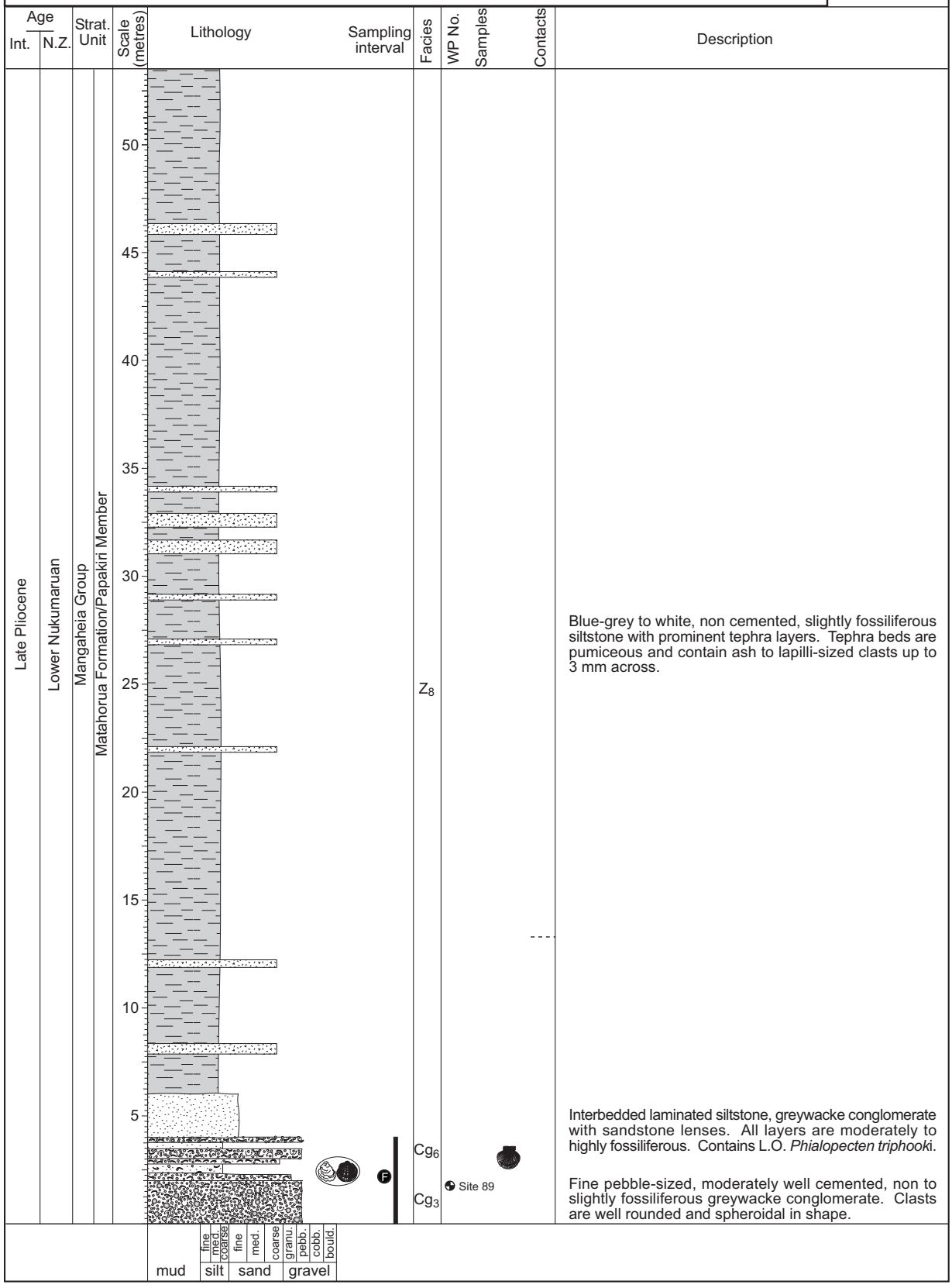
Stratigraphic Column No: *Tp-4* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Site 89 ***E:*** 2837100 -

Region: Te Pohue ***N:*** 6208400 -

Location: Esk River above Deep Stream confluence ***Altitude:*** - -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1



Stratigraphic Column No: Tp-5 **Grid Reference:** **Top** **Bottom**

GPS Waypoint No(s): Site 107 **E:** - 2836100

Region: Te Pohue **N:** - 6207300

Location: Deep Stream upstream of Alexander Road ford **Altitude:** - -

NZMS 260 Sheet: V20 Esk

Page 1 of 1

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Lower Nukumaruan	Mangaheia Group / Matahorua Formation/Papakiri Member	10			z_3			Siltstone approximately 40 m thick.
			9			V_1 z_8			Fine ash, airfall tephra bed.
			8						
			7			z_3			Non cemented siltstone. Contains *Maoricolpus roseus, Atrina pectinata zelandica.*
			6		F				
			5			z_2			
						z_5			Pebbly siltstone containing fine greywacke pebbles reworked from underlying conglomerate. Gradational contact between the two beds.
			4			Cg_6	Site 107		Highly fossiliferous pebbly shellbed containing lowest occurence of *Phialopecten triphooki* with *Tucetona laticostata, Paphies australis,* and *Austrovenus stutchburyi.*
	Upper Mangapanian		3						
			2			Cg_6			Non cemented greywacke conglomerate with moderately well-sorted clasts averaging 30 mm across. Macrofossils are scattered throughout the unit, with several continuous shell layers ~ 0.15 m thick spaced about 1 m apart. Contains *Tucetona laticostata* (dominant, some articulated), *Austrovenus stutchburyi, Paphies australis, Paphies subtriangulata,* ?*Lamprodominea* and *Amalda.*
			1						

mud | silt: fine, med., coarse | sand: fine, med., coarse | gravel: granu., pebb., cobb., bould.

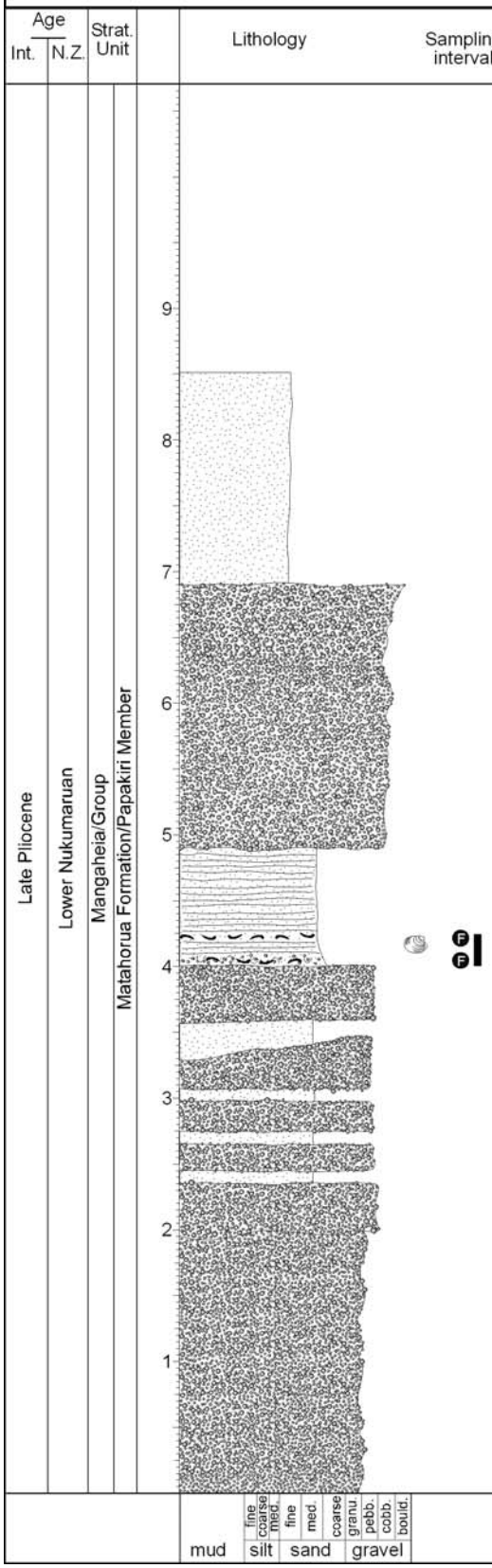
Stratigraphic Column No: *Tp-6* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 166 ***E:*** 2833682

Region: Te Pohue ***N:*** 6207160

Location: Gravel pit on Old Coach Road near Trelinnoe Station ***Altitude:*** 343 -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1



Facies	WP No. / Samples	Contacts	Description
S_4			Dirty-coloured, silty sandstone sharply overlying greywacke conglomerate bed.
Cg_1			Poorly to moderately sorted, crudely laminated, greywacke conglomerate. Clasts are moderately to well rounded and from granule up to 60 mm in diameter, averaging 30 mm across in lower portions of the bed. The upper 0.6 m is moderately well sorted and coarser-grained with clasts up to 100 mm diameter. Sandstone rip-up clasts are common in poorly sorted portions of the conglomerate. This bed sharply overlies the underlying silty sandstone.
S_7	WP 166 KJB 34		Dirty-coloured, laminated silty sandstone with common thin (<0.01 m thick) siltstone stringers. The basal 0.1 m of this unit comprises a pebbly shellbed containing abundant *Austrovenus stutchburyi* and *Patro undatus*. Pebbles are up to 30 mm diameter. A second shellbed is present 0.4 m above the basal one containing disarticulated bivalves including *Austrovenus*.
Cg_2			Very poorly to moderately sorted massive greywacke conglomerate. Sharp erosional boundary with underlying unit, with tens of centimetres of relief on the contact. Clasts are up to 150 mm in diameter and average 30-40 mm across. Many sandstone stringers are present, generally up to 0.15 m thick comprising well sorted, fine to medium sandstone. These stringers are continuous over several metres.
Cg_4			Slightly cemented, moderately to very well sorted, granule to fine pebble sized greywacke conglomerate bed. Clasts are arranged in beds of similar sized grains, and are well rounded and typically oblate in shape, although spheroid shaped grains are present. Occasional sandstone rip-up clasts are present in the upper 1 m of this unit. Internal beds are up to 0.5 m thick, with finer-grained beds generally thicker than coarser-grained ones.

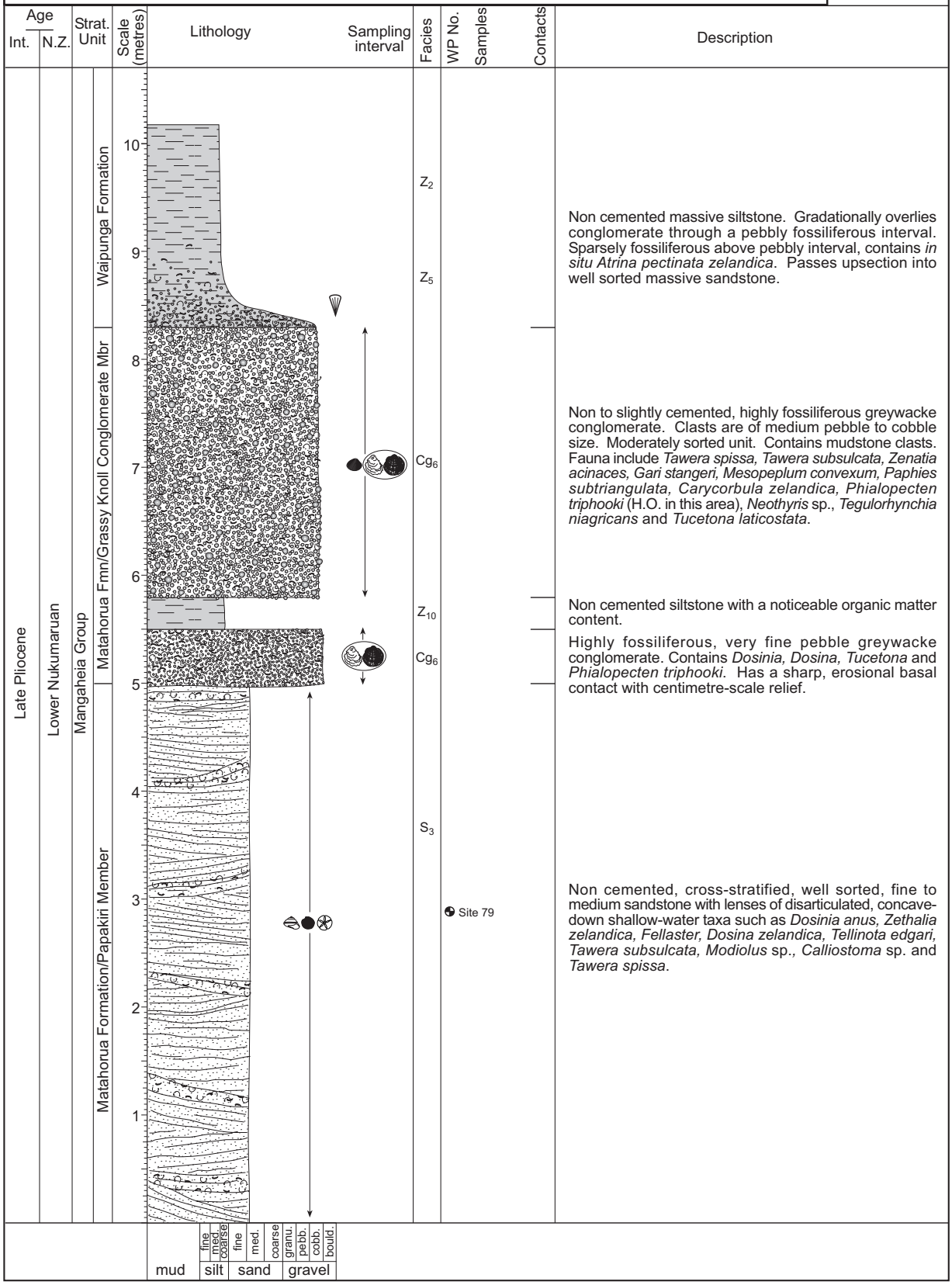
Stratigraphic Column No: Tp-7 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Site 79 ***E:*** 2846961 -

Region: Te Pohue ***N:*** 6198520 -

Location: Esk River downstream of Deep Stream confluence ***Altitude:*** - -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1



Stratigraphic Column No: *Tu-1* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 509 ***E:*** 2849891 -

Region: Tutira ***N:*** 6214526 -

Location: Ridgemount Road, Tangoio Block ***Altitude:*** 347 m -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Upper Nukumaruan	Mangaheia Group / Petane Formation/Darkys Spur Member	1–10			S_4	WP 509		Reddish-tan, strongly calcareous, slightly to moderately fossiliferous silty sandstone. Massive, slightly to moderately concretionary with horizons 0.1-0.15 m thick. Upper and lower contacts are not exposed in this section. Common *Divaricella huttoniana* and *Pteromyrtea dispar*, and *Calliostoma* sp. with some *Pelicaria convexa* (aff. form *fossa*), scattered small *Ostrea chilensis*, with *Fellaster* fragments, *Panopea, Cyclomactra ovata, Bassina, Paphies crassiformis, ?Zegalerus*, and *Tawera subsulcata*.

mud | silt: fine, med., coarse | sand: fine, med., coarse | gravel: granu., pebb., cobb., bould.


A


B
Canon

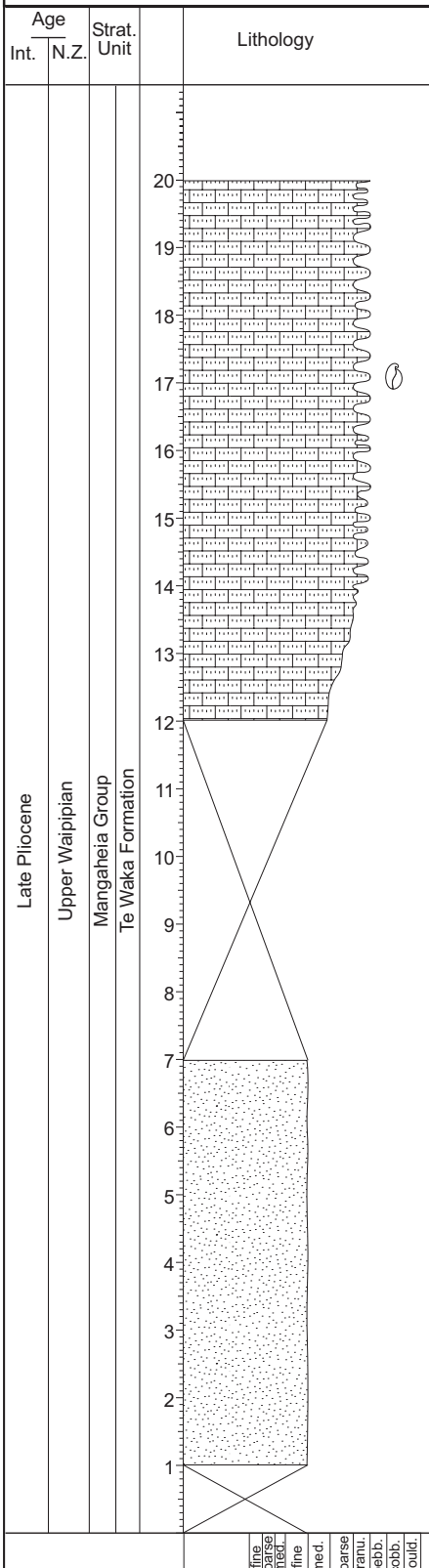
Stratigraphic Column No: *Tw-1* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 40 ***E:*** 2825217

Region: Te Waka ***N:*** 6212916

Location: Te Waka Range west of Transmitter ***Altitude:*** 955 m -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1



Facies	WP No. Samples	Contacts	Description
BC_1/ BC_2			Yellow-brown, moderately to well cemented, fine to coarse calcareous sandstone grading upward into sandy limestone. The unit is dominated by shellhash and siliciclastic sand. The upper 6 m of section in this unit is flaggy due to preferential weathering. The lower contact with the underlying sandstone is not exposed.
	WP 40 KJB 15		
S_1			Non cemented, non fossiliferous, well sorted, moderately weathered, fine to medium siliciclastic sandstone. The sandstone is non concretionary. Base of unit is not exposed.

Stratigraphic Column No: Tw-2 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 41 ***E:*** 2824874

Region: Te Waka ***N:*** 6213393

Location: North face of the Te Waka Range overlooking the Mohaka River. ***Altitude:*** 991m -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1

Age Int.	Age N.Z.	Strat. Unit	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Waipipian	Te Waka Formation	100–90	F	MX_4	WP 41		Yellow-brown, non to moderately cemented, fine to medium sandstone with very common concretionary lenses 0.15-0.2 m thick. Concretionary lenses become further apart (up to 0.7 m apart) up-section. Moderately well-cemented horizons are present within the concretionary sandstone section. The sandstone displays small-scale, low angle cross-bedding. The thickness of concretionary horizons and lenses has been exaggerated in this column. The sandstone is sparsely fossiliferous, with most fauna present in cemented layers. *Phialopecten marwicki* and *Atrina pectinata zelandica* dominate the fossil content with assorted gastropods.
		Titiokura Formation	90–80–70–60					
			60–50		BC_1/ BC_2			Moderately to well cemented, medium to coarse grained sandy limestone, rich in shell-hash and barnacle fragements. The unit sharply overlies sandstone, and grades into the overlying sandstone facies through a series of concretionary horizons over 1-2 m.
	Lower Opoitian	Mokonui Sandstone	50–40–30–20–10		S_{10}			Non to slightly cemented, fine to medium siliciclastic sandstone with common concretionary lenses and horizons. The base of the sandstone is not exposed, but the unit is thought to be at least 150 m thick.

mud | silt (fine, coarse, med.) | sand (fine, med., coarse) | gravel (granu., pebb., cobb., bould.)


A


B


C


D
Phialopecten marwicki (Wp form)

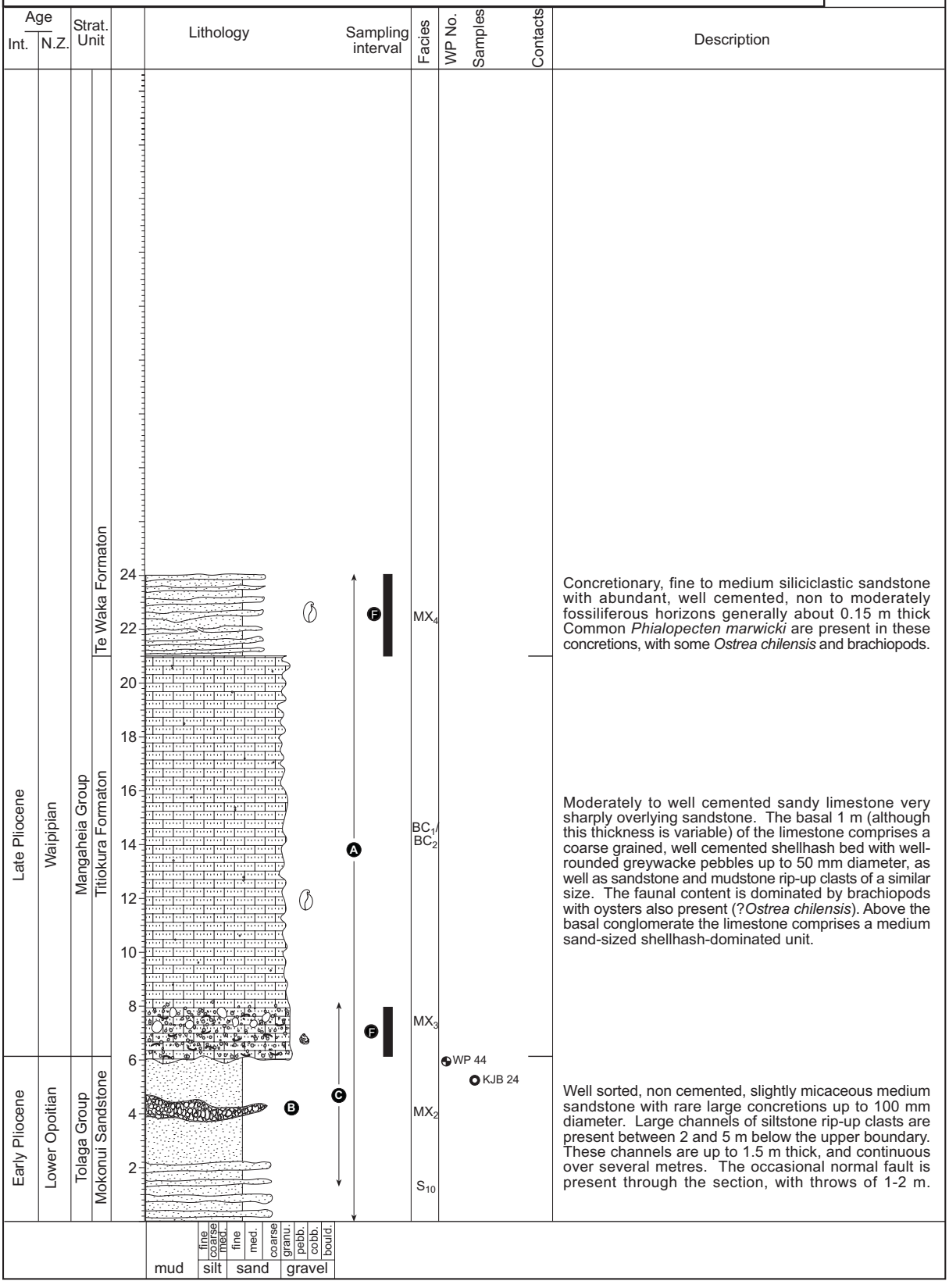
Stratigraphic Column No: *Tw-3* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 44 ***E:*** 2823966

Region: Te Waka ***N:*** 6212811

Location: Te Waka Range southwest of transmitter. ***Altitude:*** 937 -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1




A


B


C

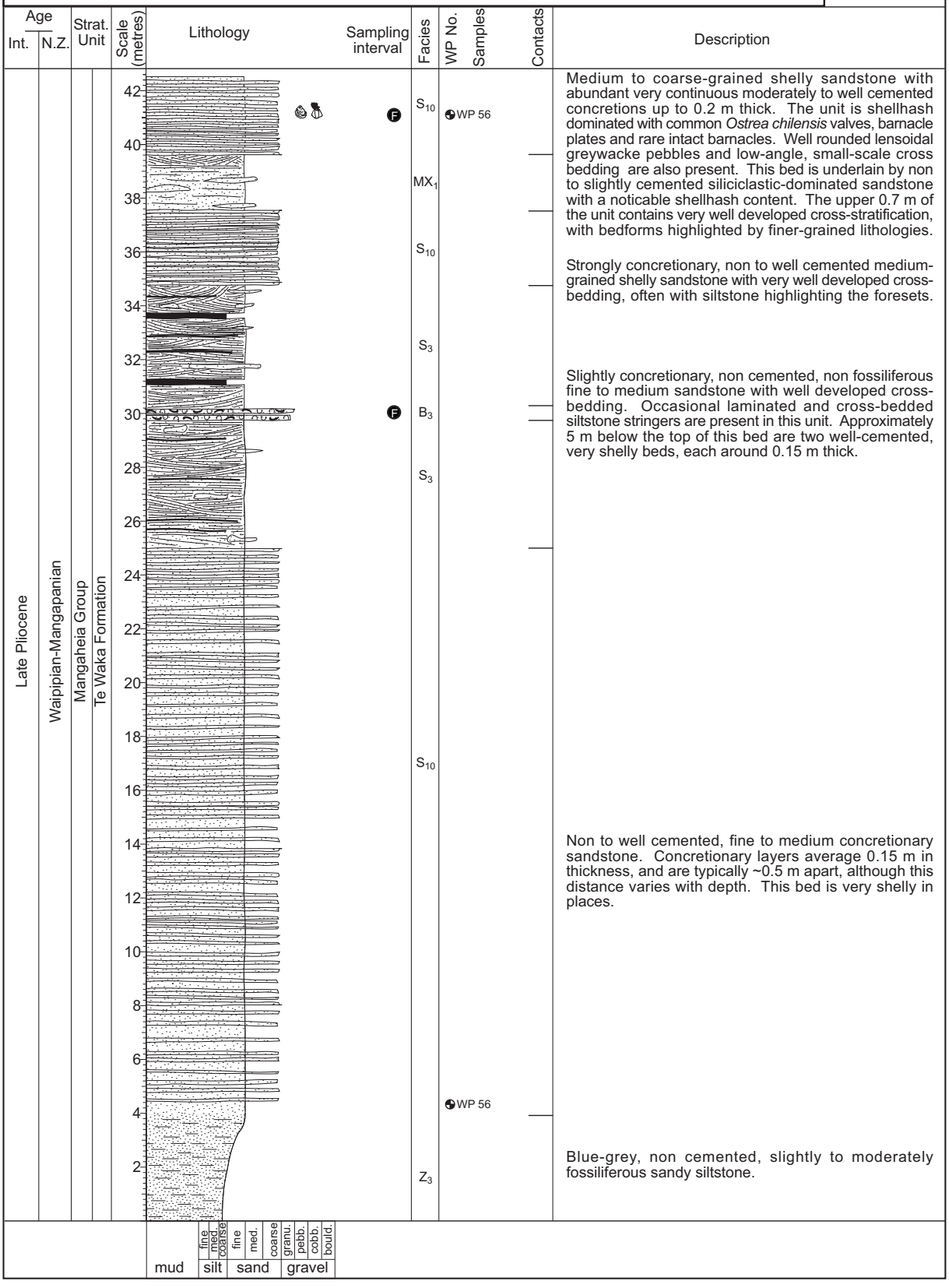
Stratigraphic Column No: *Tw-4* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 56 ***E:*** 2823535 2823540

Region: Te Waka ***N:*** 6209426 6209477

Location: Section on Kurowski Road, Te Waka Forest, Te Waka Range. ***Altitude:*** 615 m 614 m

NZMS 260 Sheet: V20 Esk



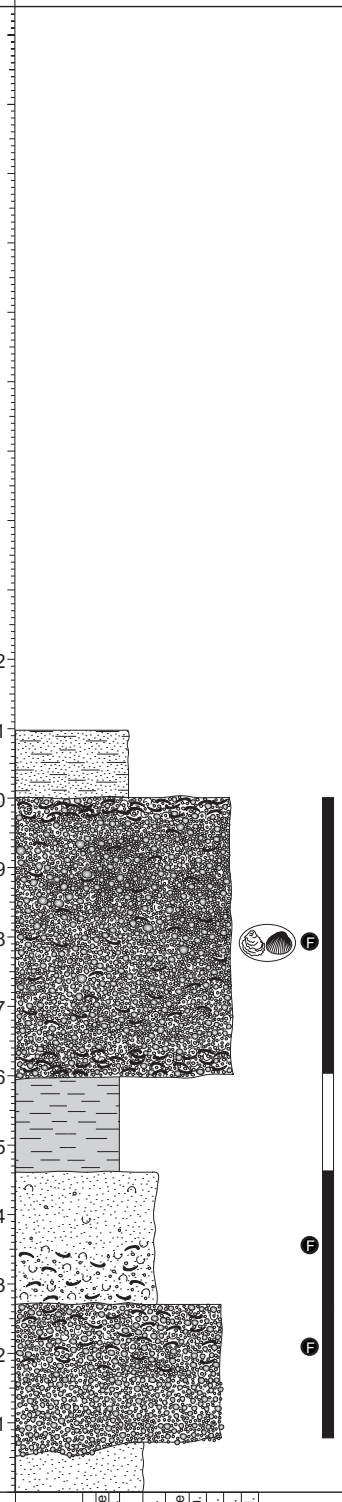
Stratigraphic Column No: *Wa-1* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 21 ***E:*** 2813950

Region: Waihau ***N:*** 6205900

Location: Cutting on Waihau Road near Te Puna Farm ***Altitude:*** - -

NZMS 260 Sheet: V20 Esk *Page* 1 *of* 1



Facies	WP No. Samples	Contacts	Description
S_4			Non cemented sandy siltstone.
Cg_6			Slightly to highly fossiliferous greywacke conglomerate. Most of the bed is slightly to moderately fossiliferous, with 0.2 m thick highly fossiliferous beds at the interfaces between sandstone and conglomerate facies. *Ostrea chilensis* dominates the faunal content, with *Purpurocardia purpurata, Caryocorbula* sp. and *Lutraria* sp. also present. Some *Ostrea* valves were found to be encrusted with barnacles.
Z_1			Blue-grey, non cemented, slightly weathered sandy siltstone.
S_4			Moderately fossiliferous silty sandstone grading upward into slightly fossiliferous silty sandstone with rare scattered greywacke pebbles.
S_9			
Cg_6	WP 21 KJB 4		Non fossiliferous greywacke conglomerate bed passing upsection into a highly fossiliferous greywacke conglomerate. Metre-scale relief is present on the lower boundary of this unit.
Cg_1			Tan, non cemented, clean, well sorted fine to medium siliciclastic sandstone. Base of the sandstone is not exposed.
S_1			

Stratigraphic Column No: Wa-2 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 816 ***E:*** 2817412 -

Region: Waihau ***N:*** 6189043 -

Location: Tutaekuri River below Waldon Road ford, above Waikonini Stream ***Altitude:*** 129 m -

NZMS 260 Sheet: V21 Napier *Page* 1 *of* 1

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Lower Nukumaruan	Mangaheia Group / Esk Mudstone	100–5			S_1			Non cemented fine to medium sandstone. Gradationally overlies siltstone.
						S_4			
						Z_2	WP 816		Massive to laminated siltstone with common clusters of *Pratulum pulchellum* (dominant macrofauna). Coarsens up-section and passes conformably into sandstone.

mud | silt: fine, med., coarse | sand: fine, med., coarse | gravel: granu., pebb., cobb., bould.

Stratigraphic Column No: *Wh-1*

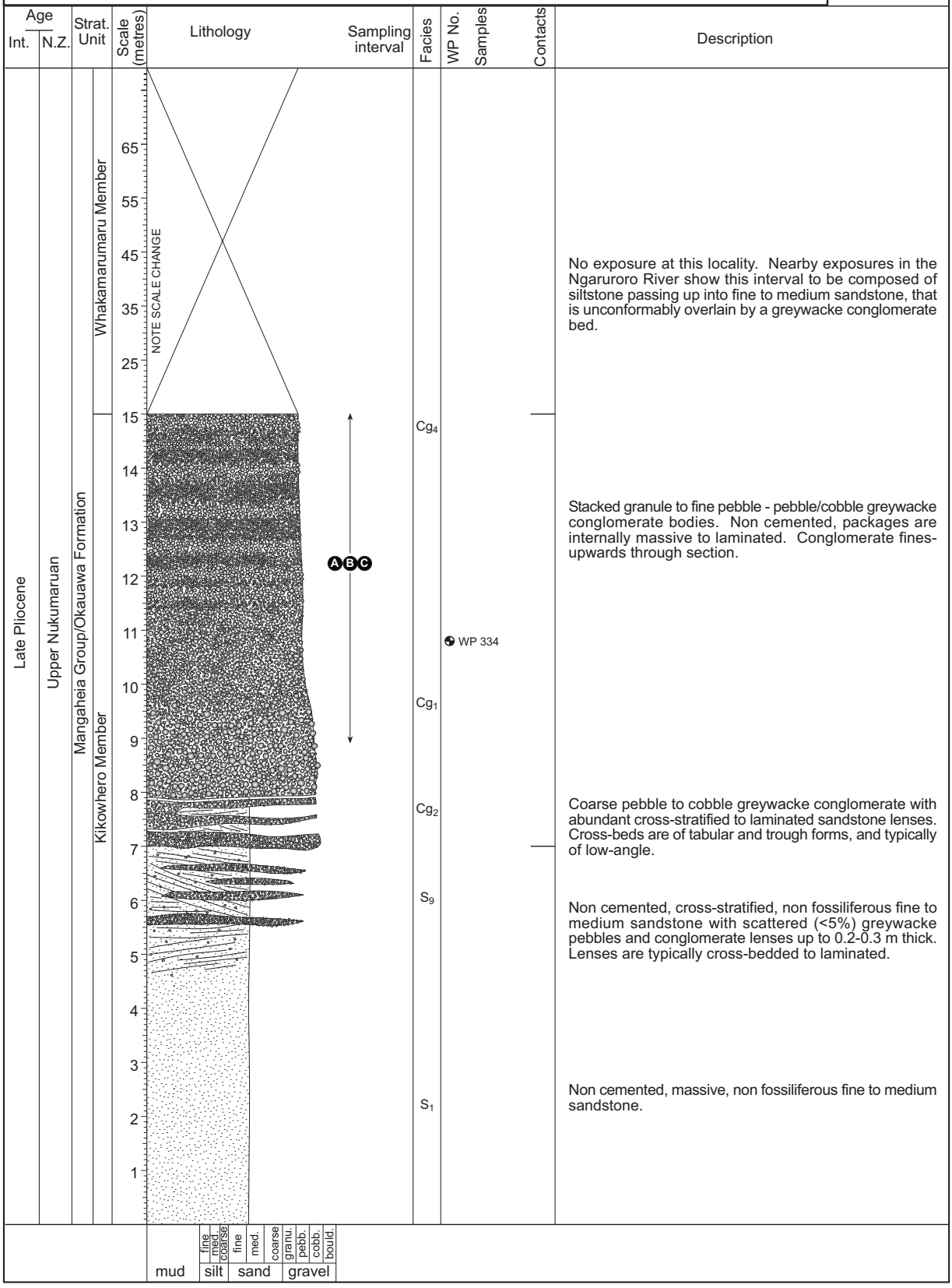
GPS Waypoint No(s): Wp 334

Region: Whanawhana

Location: Matapiro Roadgravel pit near Otamauri Road intersection

NZMS 260 Sheet: U21 Kereru

Grid Reference:	***Top***	***Bottom***
E:	2809409	-
N:	6177484	-
Altitude:	262 m	-




A


B


C

Stratigraphic Column No: *Wh-2*

GPS Waypoint No(s): Wp 838

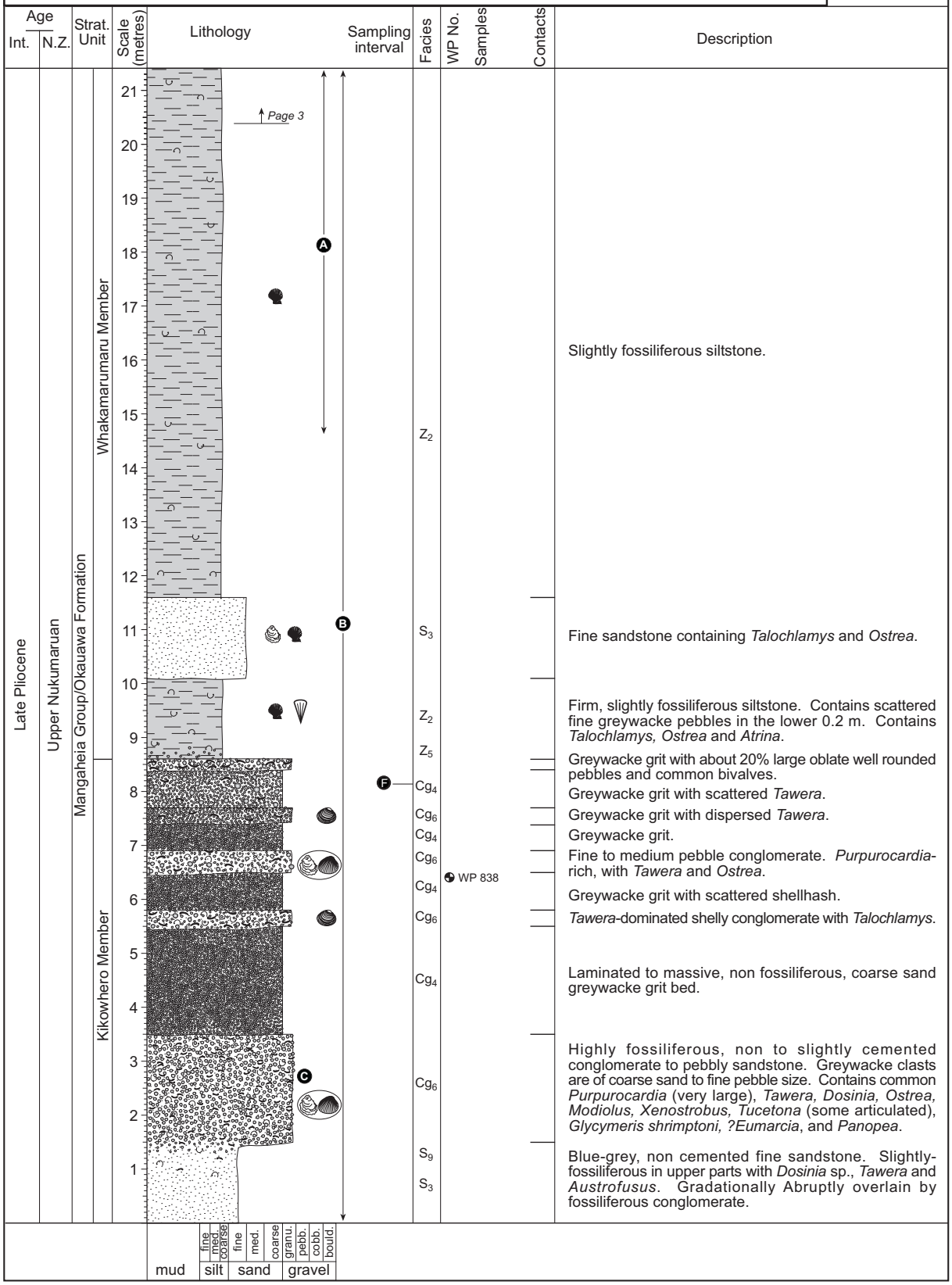
Region: Whanawhana

Location: Kikowhero Stream, Whakamarumaru Station

NZMS 260 Sheet: V21 Napier

	Grid Reference:	***Top***	***Bottom***
	E:	2812410	-
	N:	6177310	-
	Altitude:	180 m	-

Page 1 *of* 3



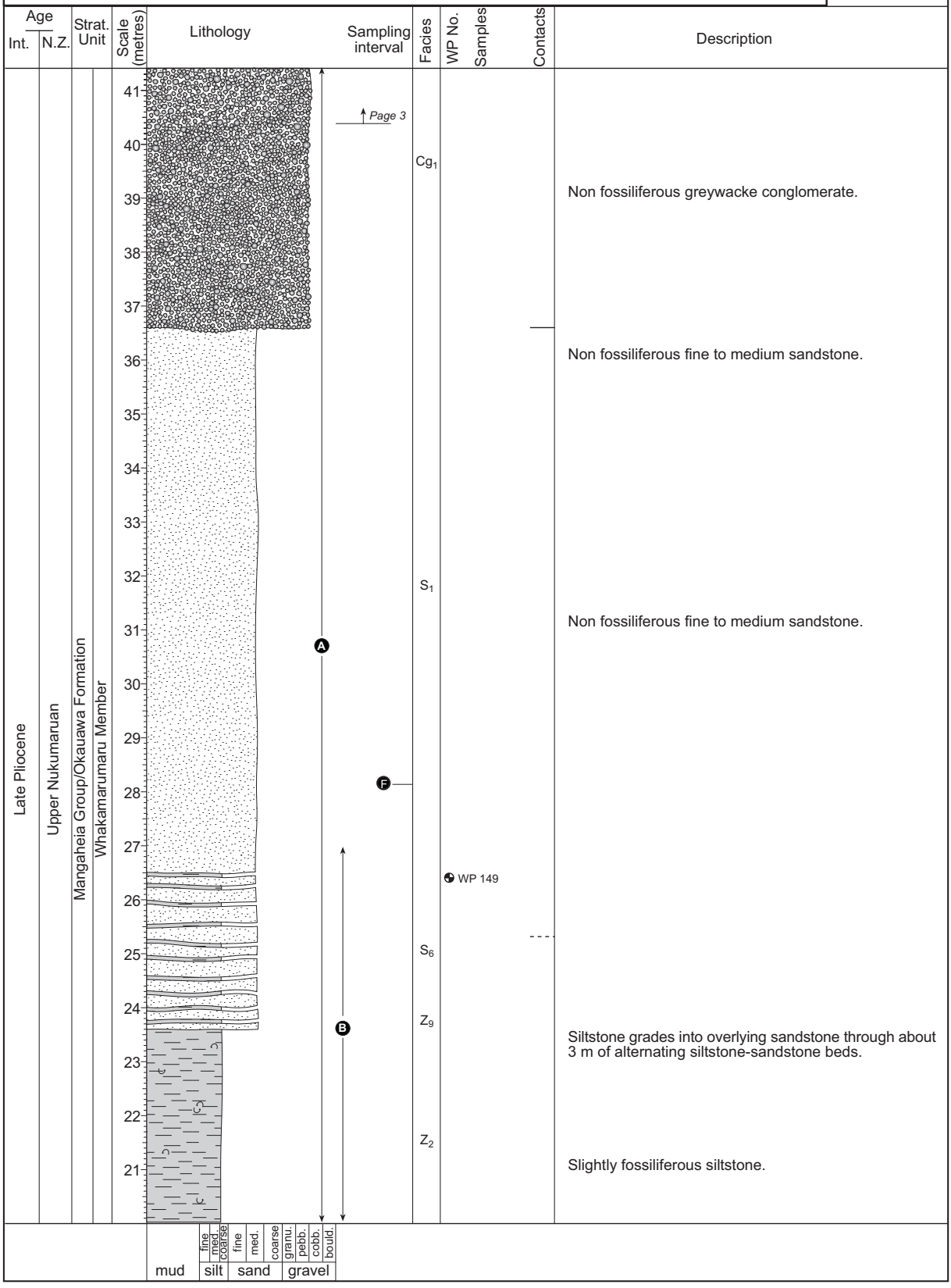
Stratigraphic Column No: Wh-2 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 838 ***E:*** 2812410 -

Region: Whanawhana ***N:*** 6177310 -

Location: Kikowhero Stream, Whakamarumaru Station ***Altitude:*** 180 m -

NZMS 260 Sheet: V21 Napier



Stratigraphic Column No: *Wh-2* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 838 ***E:*** 2812410 -

Region: Whanawhana ***N:*** 6177310 -

Location: Kikowhero Stream, Whakamarumaru Station ***Altitude:*** 180 m -

NZMS 260 Sheet: V21 Napier

Page 3 *of* 3

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Pliocene	Upper Nukumaruan	Mangaheia Group/Okauawa Fmn, Whakamarumaru Member	48, 47, 46, 45, 44, 43, 42, 41	Page 3	A	Cg_1			Non fossiliferous greywacke conglomerate.

mud | silt (fine, med., coarse) | sand (fine, med., coarse) | gravel (granu., pebb., cobb., bould.)


A
B
C

Stratigraphic Column No: Wh-3 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 887 ***E:*** 2804042 -

Region: Whanawhana ***N:*** 6180637 -

Location: Awapai Station above entrance gate ***Altitude:*** 446 m -

COLUMN 44 OF V. CARON (2002) INCORPORATED INTO THIS SECTION

NZMS 260 Sheet: U21 Kereru





Late Pliocene

Lower Nukumaruan

Mangaheia Group

Sentry Box Formation

WP 887

BC$_3$

BC$_1$

Well cemented, highly fossiliferous shellbed rich in *Ostrea chilensis* and *Phialopecten triphooki* in a fine sandy matrix.

Coarsening-upwards package comprises stacked bodies of fine to medium grained, slightly to moderately cemented mixed bioclastic-siliciclastic packstone.

Coarsening-upwards, moderately to well sorted, moderately cemented barnacle grainstone. Internal low-angle planar to trough cross-stratifications are present at the base of the unit, with medium-scale trough cross-beds present towards the top. This unit is sharply overlain by mixed bioclastic-siliciclastic packstone bodies.

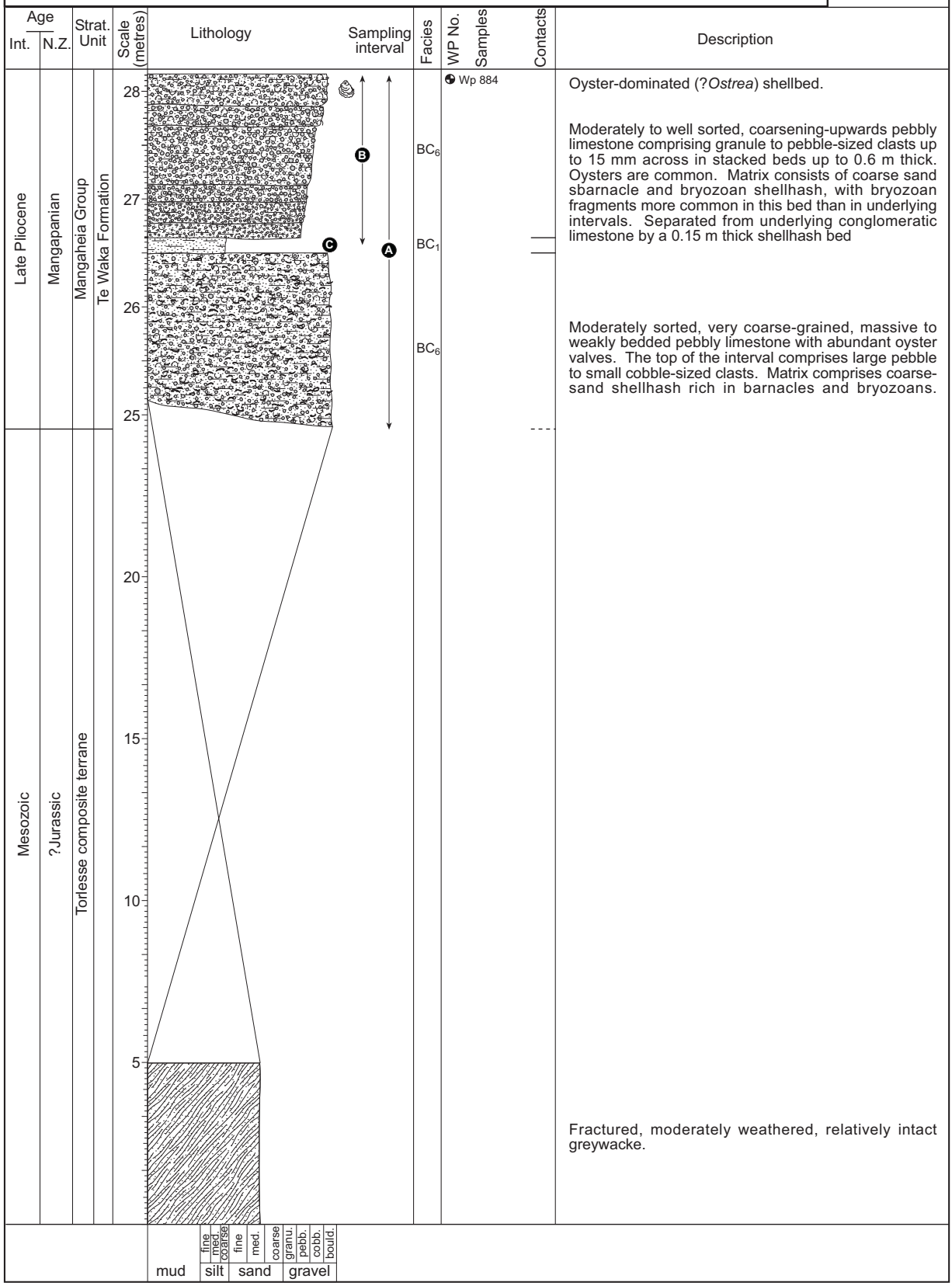
This section is probably underlain by non cemented, non fossiliferous, fine to medium sandstone.

mud | silt: fine, med., coarse | sand: fine, med., coarse | gravel: granu., pebb., cobb., bould.

Stratigraphic Column No: *Wh-4*
GPS Waypoint No(s): Wp 884
Region: Glenross
Location: Awapai Station

NZMS 260 Sheet: U21 Kereru

	Grid Reference:	***Top***	***Bottom***
	E:	2801599	-
	N:	6180930	-
	Altitude:	351 m	-







Top left: overview of limestone portion of section.

Top right: Contact between lower oyster-rich bed and upper pebbly limestone interval, separated by 0.15 m of shellhash.

Bottom right: Close-up of contact between upper and lower limestone intervals. Note the abundant oyster valves in the lower interval.

Bottom left: Close-up of a sample of the limestone.





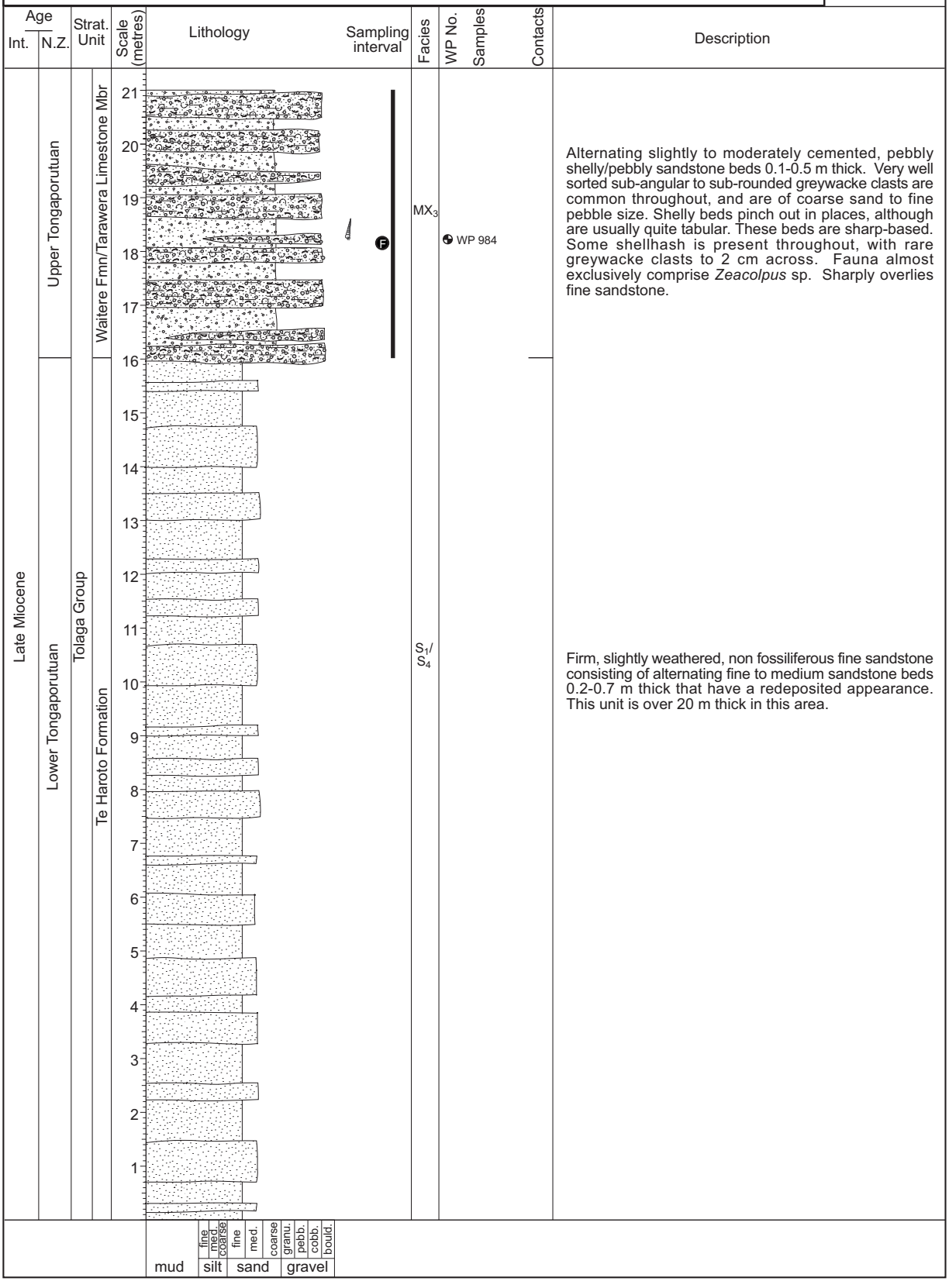
Stratigraphic Column No: *Wi-1* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 984 ***E:*** 2827073 -

Region: Waitara ***N:*** 6222491 -

Location: Waitara Road near Glenfalls Reserve ***Altitude:*** 301 m -

NZMS 260 Sheet: V19 Te Haroto *Page* 1 *of* 1



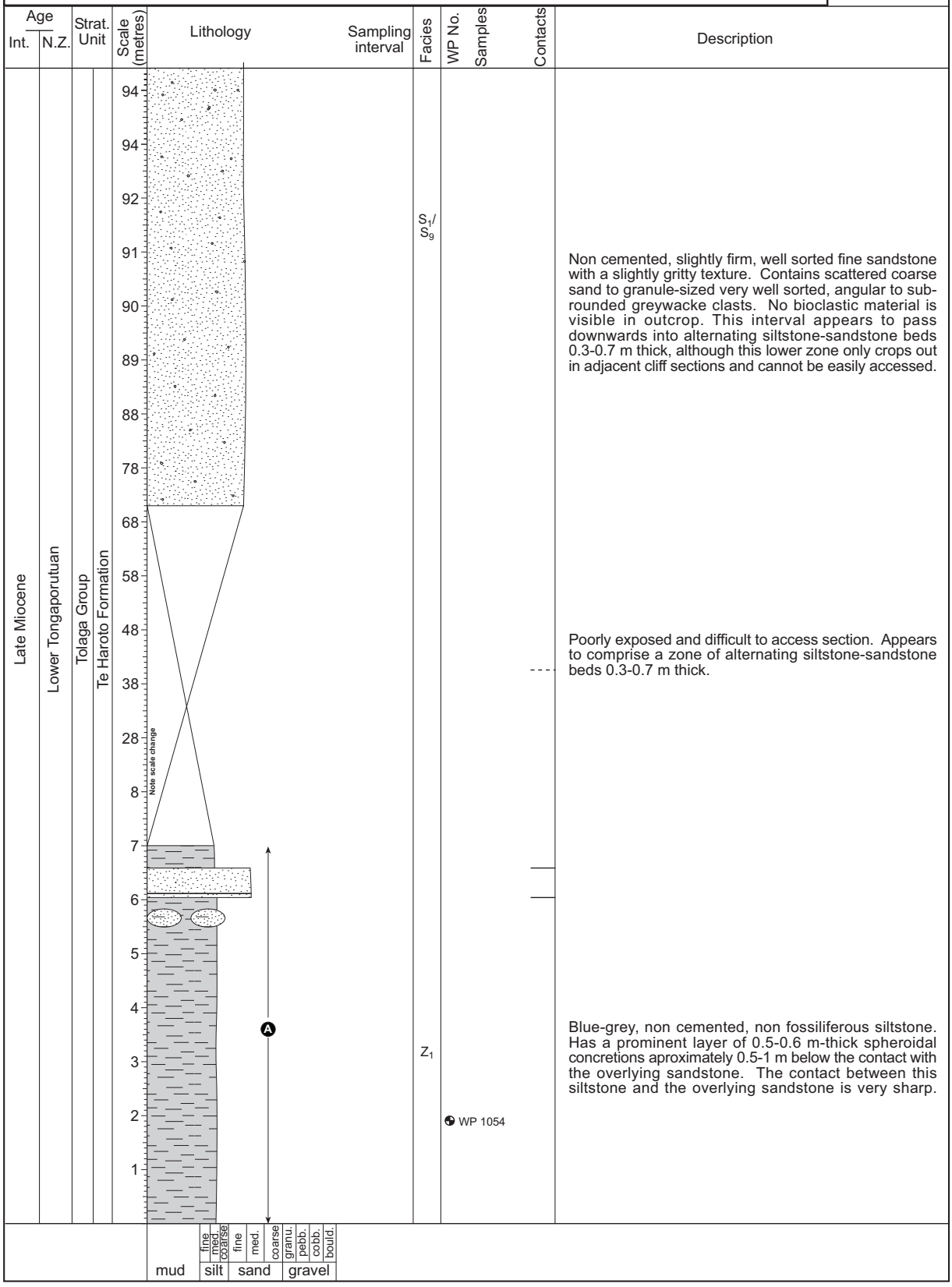
Stratigraphic Column No: *Wi-2* ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 1053-1054 ***E:*** 2824799 2824624

Region: Waitara ***N:*** 6222035 6222154

Location: Track off main farm road, Tarawera Station ***Altitude:*** 385 m 390 m

NZMS 260 Sheet: V19 Te Haroto



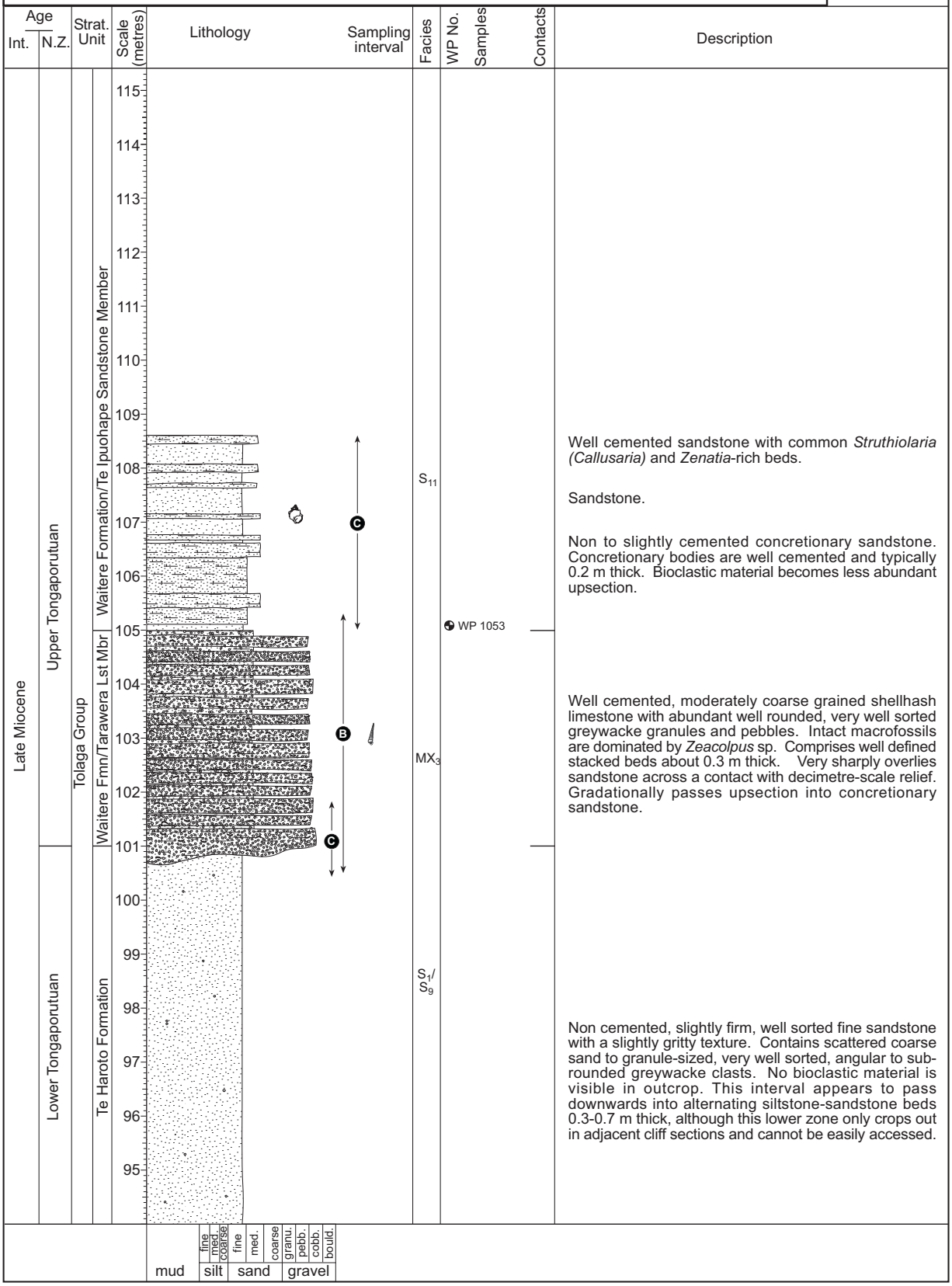
Stratigraphic Column No: Wi-2 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 1053-1054 ***E:*** 2824799 2824624

Region: Waitara ***N:*** 6222035 6222154

Location: Track off main farm road, Tarawera Station ***Altitude:*** 385 m 390 m

NZMS 260 Sheet: V19 Te Haroto




A


B


C


D

Stratigraphic Column No: Wi-3 ***Grid Reference:*** ***Top*** ***Bottom***

GPS Waypoint No(s): Wp 574 ***E:*** 2840049 -

Region: Waitara ***N:*** 6235605 -

Location: Mohaka River above Te Hoe River at bridge into forest, Waitara Station ***Altitude:*** 185 m -

NZMS 260 Sheet: V19 Te Haroto

Page 1 *of* 1

Age Int.	Age N.Z.	Strat. Unit	Scale (metres)	Lithology	Sampling interval	Facies	WP No. Samples	Contacts	Description
Late Quaternary	Hawearan	Taupo Pumice Alluvium	21–1			V_3			Coarse grained, planar laminated bed of lapilli-sized pumice clasts.
									Strongly planar laminated to trough cross-stratified laminated light-grey ash to fine lapilli sized non welded pumiceous clasts.
						$?V_2$			Non welded, massive, fine to medium ash pumiceous interval. Sharply overlies mudstone with decimetre to metre-scale relief. Carbonised logs are common in this bed.
Early Miocene	Otaian-Altonian	Tolaga Group				Z_6	Wp 574		Grey, very fine-grained, frittery massive to weakly bedded siltstone with prominent sharp-based fine sandstone interbeds up to 0.5 m thick. Prominently faulted interval with several small-scale (<1 m throw) reverse and normal faults.
		Whakamarino Formation							

mud | silt: fine, med., coarse | sand: fine, med., coarse | gravel: granu., pebb., cobb., bould.


A


B

Sample site(s) information:

Location description

Alexander Road above Deep Stream
Downstream of Deep Stream ford
Esk River below Deep Stream confluence

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 1	2836600	6206700	
WP 2	2837300	6207000	
Site 79	3837900	6206800	

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 1	*Neothyris sp.*	
	Tucetona laticostata	
	Phialopecten triphooki	
	Ostrea chilensis	
	Amalda sp.	
	Tegulorynchus	
	Purpurocardia purpurata	
	Mesopeplum convexum	Common
	Talochlamys gemmulata	
	Glycymeris shrimptoni	
	Sigapetella novaezelandiae	
	Alcithoe arabica	
	Eumarcia plana	
	Pelicaria sp.	
WP 2	*Pleuromeris* sp.	
	Phialopecten triphooki	Common
	Towaipecten mariae	
	Tawera subsulcata	
	Tawera spissa	
	Tucetona laticostata	
	Barytellina crassidens	
	Penion sulcatus	
	Cominella glandiformis	
	Patro undatus	
	Lutraria solida	
	Dosina zelandica	
	Oxyperis komakoensis	
	Mesopeplum convexum	Very common
	Neothyris sp.	
	Tegulorynchus	
	Crepidula radiata	
	Crepidula monoxyla	
Site 79	*Dosinia anus*	Common
	Zethalia zelandica	Abundant
	Fellaster zelandiae	Common
	Dosina zelandica	
	Gari stangeri	
	Sigapatella novaezelandiae	
	Zegalerus sp.	
	Patro undatus	
	Dosinia subrosea	
	Tucetona laticostata	
	Perveracia tristis	
	Pleuromeris marshalli	
	Pectinidae indet. sp.	
	Tellinota sp.	
	Modiolus sp.	
	Calliostoma sp.	Uncommon
	Tawera spissa	

Additional Remarks

WP 1 (Grassy Knoll Conglomerate Member, Matahorua Formation): Many pectinids have regrown old shell injuries and display growth ridges indicating growth in a high energy, at time stressful environment. The presence of *Phialopecten triphooki* and *Towaipecten mariae* confirms a lowermost Wn age for this bed. The assemblage is characteristic of coarse-substrate, high current energy environments throughout Hawke's Bay. Probably part of TST shellbed.

WP 2 (Grassy Knoll Conglomerate Member, Matahorua Formation: Many *Mesopeplum* valves are irregular shapes and have prominent growth ridges indicating growth in a high-energy, stressful environment. Probably part of TST shellbed.

SITE 79 (Grassy Knoll Conglomerate Member, Matahorua Formation): Fauna represents upper part of RST sandstone below late RST-LST greywacke conglomerate. Confident lowermost Wn age based on presence of *Zethalia zelandica* and proximal stratigraphic position near beds containing *Phialopecten triphooki*.

Sample site(s) information:

Location description
Esk River below Deep Stream confluence
Taihape road near Waiwhare

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
Site 80	2837800	6206700	
WP 3	2810500	6188600	

Faunal List

Waypoint Number	Taxonomic Name	Comment
Site 80	UPPER "BACKLAP" SHELLBED	
	Tawera spissa	
	Zenatia	
	Gari stangeri	
	Mesopeplum convexum	
	Dosinia subrosea	
	Paphies subtrianulata	
	Tawera subsulcata	
	Carycorbula sp.	
	Neothyris sp.	
	Phialopecten triphooki	
	Tegulorhyncha sp.	
	Tucetona laticostata	
	LOWER "ONLAP" SHELLBED	
	Dosinia sp.	
	Dosina zelandica	
	Tucetona laticostata	
	Phialopecten triphooki	
WP 3	CONGLOMERATE	
	Tawera subsulcata	
	Dosinia ?nukumaruensis	
	Ostrea chilensis	
	Xymene sp.	
	Eumarcia sp.	
	Anomia trigonopsis	
	Paphies crassiformis	
	SILTSTONE	
	Pratulum pulchellum	
	Atrina pectinata zelandica	
	Serratina	

Additional Remarks

SITE 80 (Grassy Knoll Conglomerate Member, Matahorua Formation): The presence of *P. triphooki* confirms a lowermost Wn age for this bed. The assemblage is characteristic of coarse-substrate, high-energy environments throughout Hawke's Bay.

WP 3 (Te Waka Formation): Sandstone with shellbeds overlain by fossiliferous siltstone.

Sample site(s) information:

Location description
Glengarry Road
Taihape Road just north of Flag Range Road
Taihape Road east of Flag Range Road
Deep Stream above Alexandra Road Ford

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 4	2815811	6179332	267
WP 5b	2818908	6182877	281
WP 6	2819600	6182600	
Site 107	2836100	6207300	

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 4	*Tawera subsulcata*	
	Glycymeris shrimptoni	
	Ostrea chilensis	
	Purpurocardia purpurata	
	Crepidula costata	
	Zeacolpus sp.	
	Stircolpus sp.	
	Calliostoma sp.	
	Sigapetella novaezelanidae	
	Modiolus sp.	
	Austrovenus stutchburyi	
	Paphies ?australis	
WP 5b	*Purpurocardia purpurata*	Co-dominant, abundant
	Ostrea chilensis	Co-dominant, abundant
	Tawera subsulcata	Common
	Sigapetella novaezelandiae	Common
	Lutraria solida	Some
	Alcithoe arabica	Some
	Calliostoma sp.	
	Caryocorbula	
	Stiracolpus	
WP 6	*Paphies ?australis*	
	Mesopeplum convexum	
	Purpurocardia purpurata	
Site 107	*Tucetona laticostata*	Common, some articulated
	Austrovenus stutchburyi	
	Phialopecten triphooki	One specimen
	Paphies australis	
	Paphies subtriangulata	
	Amalda sp.	
	Maoricolpus roseus	Present in overlying siltstone

Additional Remarks

WP 4 (Flag Range Conglomerate Member): The assemblage is characteristic of coarse-substrate, high-energy environments throughout Hawke's Bay.

WP 5b (Flag Range Conglomerate Member): The assemblage is characteristic of coarse-substrate, high-current energy environments throughout Hawke's Bay.

WP 6 (Flag Range Conglomerate Member)

Site 107 (Matahorua Formation, base Papakiri Member): This bed contains L.O. of *Phialopecten triphooki*, and marks the base of the Wn stage.

Sample site(s) information:

Location description
Waipunga Road above Esk River
Glengarry Road
Puketitiri Road just north of Apley Road
Waihau Road
Waihau Road near Ngaroto Station

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 7	2839850	6198316	288
WP 8	2833021	6192828	304.
WP 9	2831564	6188457	244
WP 18	2818030	6192388	287
WP 21	2820686	6190605	252

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 7	*Sigapetella novaezelandiae*	
	Crepidula radiata	
	Ostrea chilensis	Co-dominant
	Talochlamys gemmulata	Co-dominant
	Atrina pectinata zelandica	
	Amalda sp.	
	Zeacolpus/Stirocolpus sp.	
	Glycymeris shrimptoni	
	Pelicaria sp.	
	Alcithoe sp.	
	Dosinia sp.	
	?Maorimactra ordinaria	
	Zenatia ?acinaces	
	Paphies australis	
	Tawera sp.	
	Mesopeplum convexum	
	Fissidentalium ?solidum	
	Austromegabalanus (notobalnus) decorus	
	Crepidula radiata	
	Tawera subsulcata	
WP 8	*Maoricolpus roseus*	
	Patro undatus	
	Austrofusus taitae	
WP 9	*Xenostrobus huttoni*	Very common
	Austrovenus stutchburyi	Common
	Ostrea chilensis	
	Paphies australis	Rare
	Alcithoe sp.	
	Dosinia sp.	
	Gastropoda indet. gen. spp.	
WP 18	*Ostrea chilensis*	Co-dominant
	Talochlamys gemmulata	Co-dominant
	Gastropoda indet. gen. spp.	
WP 21	*Ostrea chilensis*	Dominant
	Purpurocardia purpurata	Common
	?Caryocorbula sp.	
	Cirripidea indet. gen.	

Additional Remarks

WP 7 (Kaiwaka Formation): Life-position fauna generally near top of bed. Fauna suggest a relatively shallow-water nearshore to inner shelf environment.
WP 8 Waipatiki Limestone Member)
WP 9 (Flag Range Conglomerate Member): Diagnostic estuarine fauna, probably part of late LST/TST part of sea-level cycle. Confident Wn age based on stratigraphic position.
WP 18 (Trelinnoe Member)
WP 21 (Grassy Knoll Conglomerate Member)

Sample site(s) information:

Location description
Waihau Road near Mt Cameron Farm
Glengarry Hill, Napier-Taupo Road
Titiokura Saddle, Napier-Taupo Road
Te Waka Range below Te Waka Trig
Te Waka Range below Te Waka Trig
Te Waka Range below Te Waka Trig
Waitara Station below Ahuateatua Trig

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 22	2826582	6188383	212
WP 23	2831200	6203722	355
WP 38	2827850	6215292	713
WP 41	2824874	6213393	991
WP 43	2824153	6212907	967
WP 44	2823966	6212817	937
WP 54	2823567	6212731	902

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 22	*Ostrea chilensis*	
	Anomia trigonopsis	
	Paphies australis	
	Alcithoe sp.	
	Tawera subsulcata	
	Zethalia zelandica	
	Dosinia sp.	
WP 23	*Dosina* sp.	
	Marama murdochi	
	Austrovenus stutchburyi	
	Phialopecten triphooki	
	Stiracolpus sp.	
	Glycymeris shrimptoni	
	Limatula sp.	
	Offasdesma angasai	
WP 38	Shark teeth spp.	
WP 41	*Atrina pectinata zelandica*	Common
	Phialopecten marwicki (Wp form)	
	Gastropoda indet. gen. spp.	Some, dominant
WP 43	*Neothyris aff. discors*	Common
	Phialopecten marwicki (Wp form)	Common
WP 44	*Neothyris aff. discors*	Dominant
	Ostreids *(Ostrea chilensis?)*	Some
WP 54	*Cominella elegantula*	
WP 65	*Austrovenus stutchburyi*	Abundant
	Tawera subsulcata	Common
	Ostrea chilensis	Some
	Cominella kereruensis	

Additional Remarks

WP 22 (Okauawa Formation)
WP 23 (Matahorua Formation, Trelinnoe Member overlain by Papakiri Member): Slightly fossiliferous sandstone overlain by non fossiliferous greywacke conglomerate. Capped by pebbly shellbed rich in robust shallow-water bivalves, and gradationally overlain by siltstone, pebbly at base. The presence of *P. triphooki* L.O.)confirms a lowermost Wn age for this bed. The assemblage is characteristic of coarse-substrate, high-energy environments throughout Hawke's Bay Wn rocks.
WP 38 (contact between Rakaita Siltstone Member (Waitere Formation) and Mokonui Sandstone)
WP 41 (contact between Te Waka and Titiokura Formations)
WP 43 (contact between Te Waka and Titiokura Formations)
WP 44 (contact between Te Waka and Titiokura Formations)
WP 54 (Mokonui Sandstone)

Sample site(s) information:

Location description
Puketitiri Road near Glengarry Road

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 61	2833307	6188260	200

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 61	SANDSTONE AND LIMESTONE	
	Sigapetella noveazelandiae	
	Crepidula radiata	
	Austrovenus stutchburyi	
	Tawera spissa	
	Tawera subsulcata	
	Notocallista sp.	*In situ*
	Panopea sp.	
	Talochlamys gemmulata	
	Maorimactra ordinaria	
	Calliostoma pellucidim	
	Patro undatus	
	Zenatia acinaces	
	Zethalia zelandica	
	Tellinota edgari	
	Glycymeris modesta	
	Atrina pectinata zelandica	
	Pelicaria convexa	
	Dosina yatei	
	Barnea simmilis	
	Barytellina crassidens	
	Cirrsotrema sp.	
	Gari lineolata	
	Gari stangeri	
	Lutraria solida	
	Purpurocaridia purpurata	
	Stiracolpus sp.	
	Dosinia nukumaruensis	
	Caryocorbula sp.	
	Eumarcia plana	
	SANDY SILTSTONE	
	Pelicaria convexa	
	Lutraria solida	
	Notocallista multistriata	
	Stiracolpus	
	Dosina sp.	
	Atrina pectinata zelandica	
	Notiris sp.	
	Trachycardium sp.	
	Tellinota ?edgari	
	Tawera subsulcata	
	Tucetona laticostata	

Additional Remarks

WP 61 (Waipatiki Limestone Member overlain by Devils Elbow Mudstone Member): Interbedded siliciclastic-dominated and bioclastic shellhash beds sharply overlain by limestone beds. Limestone package gradationally overlain by fine sandy siltstone. Mixture of *in situ* and reworked fossils throughout section. Confident middle-late Wn age for these units based on the presence of *Pelicaria convexa*.

Sample site(s) information:

Location description
Crownethorpe Settlement Road
Church Bush Road, Crohane Forest
Church Bush Road, Crohane Forest
Hukanui Station above Pakaututu Road
Makahu Station southeast of Makahu Road
Hukanui Station below Hukanui Trig
Hukanui Station near Hukanui Trig
Napier-Taupo Road near Te Haroto village

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 66	2818220	6177280	195
WP 70	2820996	6213341	473
WP 74	2820543	6212478	517
WP 83	2809407	6216471	628
WP 86	2809645	6215409	646
WP 88	2815569	6211418	977
WP 92	2815589	6211520	964
WP 93	2819661	6226539	712

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 66	*Tawera subsulcata*	Abundant, dominant
	Ostrea chilensis	Common
	Penion sulcatus	
	Cominella kereruensis	Some
	Gastropoda indet. gen. spp.	
WP 70	*Zenatia acinaces*	Abundant, dominant
	Struthiolaria (Callusaria) sp.	
WP 74	Serpulids	Common, dominant
	Crassostrea ingens	Uncommon
	Bryozoans	
	Tasmanomegabalanus	
	Fosterella tuberculatus	
WP 83	*Ostrea chilensis*	Common, dominant
	Tucetona laticostata	Common, typically articulated
	Phialopecten marwicki (Wo form)	
WP 86	*Crassostrea ingens*	Some
WP 88	*Ostrea chilensis*	Some
WP 92	*Ostrea chilensis*	Some
	Crassostrea ingens	Some
	Mesopeplum sp.	
	Phialopecten sp. (prob *thomsoni*)	Rare
WP 93	*Zeacolpus* sp.	Common
	Zenatia acinaces	Common
	Dosinia sp.	
	Glycymeris modesta	
	Struthiolaria (Callusaria) sp.	Common

Additional Remarks

WP 66 (Te Ngaru Mudstone Member): Highly fossiliferous shellbeds in sandy siltstone
WP 70 (Te Ipuohape Sandstone Member)
WP 74 (contact between Te Ipuohape Sandstone Member and Torlesse basement)
WP 83 (Hukanui Limestone Member, Pakaututu Formation)
WP 86 (Pakaututu Formation): Coarse-grained greywacke breccia, near contact with Torlesse basement
WP 88 (contact between Puketitiri Formation and Pakaututu Formation)
WP 92 (Te Waka Formation)
WP 93 (basal beds of Te Haroto Formation)

Sample site(s) information:

Location description
Farm below Pakaututu Road
Ripia Station above Ripia River
Pakaututu Road near Kaweka Fault crossing
Ripia Station above Ripia River
Ripia Station above Ripia River

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 94	2811543	6211569	712
WP 95	2811890	6220632	734
WP 97	2812512	6218087	599
WP 98	2813491	6219580	613
WP 107	2813428	6219888	604

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 94	*Tucetona laticostata*	Abundant, dominant
	Phialopecten ?marwicki (Wo form)	Rare to some
WP 95	*Eucrassiatella sp.*	All articulated
	Oxyperis/Eumarcia sp.	
	Dosinia sp.	
	Purpurocardia purpurata	Sparse
	Phialopecten sp. (*?marwicki* (Wo form))	
	Talochlamys gemmulata	
	Zeacolpus sp.	
	Panopea sp.	
	Mesopeplum sp.	
	Glycymeris sp.	Common
	Tucetona laticostata	Common, dominant
	Tawera sp.	Sparse
	Eumarcis benhami	
WP 97	*Mesopeplum* sp.	
	Oxyperis/Eumarcia sp.	
	Crassostrea ingens	Relatively uncommon, restricted to base of bed
WP 98	*Eucrassiatella*	Common
	Tucetona	Common
	Oxyperis/Eumarcia	Some
	Phialopecten sp. (*?marwicki* (Wo form))	Some
	Glycymeris sp.	Some
	Anomia trigonopsis	Some
WP 107	Echinoid spines	
	Cirripidea indet. gen.	
	Tucetona laticostata	Common
	Crassostrea ingens	Rare, restricted to base of bed

Additional Remarks

WP 94 (Pakaututu Formation): *Tucetona laticostata* valves intact, commonly articulated and become more dominant towards top of the unit.
WP 95 (contact between Torlesse basement and Hukanui Limestone Member)
WP 97 (Pakaututu Formation)
WP 98 (Pakaututu Formation)
WP 107 (Pakaututu Formation): Fauna overlies greywacke basement with significant relief.

Sample site(s) information:

Location description
Ripia Station on Ripia Face above Ripia River
Ripia Station
Hukanui Station above Pakaututu Rd
Hukanui Station above Pakaututu Rd
Hukanui Station above Pakaututu Rd

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 111	2812863	6220750	696
WP 115	2812464	6219102	642
WP 116	2812393	6212119	777
WP 120	2812715	6212372	741
WP 122	2813055	6212369	748

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 111	*Tucetona laticostata*	Abundant, dominant
	Glycymeris sp.	Some
	Phialopecten sp. (*?marwicki* (Wo form))	Some
	Crassostrea ingens	Rare
WP 115	*Resania lanceolata*	
	Zenatia acinaces	
	Gari lineolata	
	Dosinia sp.	Large Dosinia
WP 116	*Tucetona laticostata*	Abundant, dominant
	Phialopecten sp. (*?marwicki* (Wo form))	Some
WP 120	*SANDSTONE*	
	Zeacolpus/Stircolpus sp.	Common
	Struthiolaria (?callusaria) sp.	Common
	LIMESTONE	
	Tucetona laticostata	Abundant (dominant)
	Phialopecten sp. (*?marwicki* (Wo form))	Common
	Fissidentalium	Rare
WP 122	*Zeacolpus/Stiracolpus* sp.	
	Tasmanomegabalanus	
	Struthiolaria ?dolorosea	
	Struhtiolaria (Callusaria) obesa	
	Lamprodominea sp.	
	Amalda oraria	
	Glycymeris (Mania) mahiana	
	Panopea sp.	
	Tucetona laticostata	

Additional Remarks

WP 111 (Pakaututu Formation): *Crassostrea ingens* restricted to basal zone above contact with greywacke.
WP 115 (Pakaututu Formation): Fauna indicative of nearshore, sandy high-energy environments, 10-30 m water depth.
WP 116 (top of Pakaututu Formation)
WP 120 (Pakaututu Formation)
WP 122 (Pakaututu Formation)

Sample site(s) information:

Location description	Waypoint Name/No.	Eastings	Northings	Altitude (m)
Limestone bluffs above Pakaututu Road	WP 125	2813218	6212882	792
Opau Station near Opau Stream	WP 129	2820651	6204204	537

GPS Waypoint information:

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 125	*Panopea sp.*	Articulated
	Eucrassiatella sp.	
	Eumarcia ?benhami	
	Tucetona laticostata	
	Dosinia sp.	Small *Dosinia*
	Phialopecten sp. (*?marwicki* (Wo form))	
	Mesopeplum sp.	
	Talochlamys gemmulata	
	Maoricolpus roseus	
	Maoricardium spatiosum	
	Tawera barterimi	
	Fissidentalium sp.	
WP 129	*Atrina pectinata zelandica*	Common, dominant in place, often articulated
	Serratina sp.	
	Dosinia greyi	
	Dosinia lambata	
	Pratulum pulchellum	Common
	Pteromyrtea dispar	
	Turritilidae indet gen.	
	Gari lineolata	
	Gari sp.	Common, dominant
	Talochlamys gemmulata	
	Zeacolpus vittatus	
	Zeacolpus sp.	
	Crepidula radiata	
	Polychate worm cast	
	Glycymeris sp.	
	Panopea sp.	Some, often articulated
	Austrofusus sp.	
	Polinices scalptus	
	Nucula ?nitidula	
	Sigapetella novaezelandiae	
	Crassostrea ingens	
	Austromegabalnus	

Additional Remarks

WP 125 (Pakaututu Formation): Fossils sampled immediately at base of limestone.
WP 129 (Te Waka Formation): *Crassostrea* more common towards top of section, *Atrina* common throughout.

Sample site(s) information:

Location description
Rocky Hill Station at top of bluffs
Pakaututu Road near Brownlie Road
Price-Cockburn road the "The Incline"
Trelinnoe gravel pit, Old Coach Road
Hendley Road near Patoka

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 145	2813950	6205900	
WP 146	2813300	6207450	
WP 161	2815205	6197232	402
WP 166	2833682	6207160	343
WP 167	2821930	6204798	406

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 145	*Ostrea chilensis*	Common
	Cirripidea indet. gen.	Abundant
WP 146	*Tucetona laticostata*	
	Maoricardium spatiosum	
	Phialopecten sp. (*?marwicki* (Wo form))	
WP 161	*Zethalia ?coronata*	Abundant, dominant
	Fellaster sp.	
	Dosinia sp.	
	Dosinia (Asa) lambata	
	Amalda depressa	
	Tawera subsulcata	Rare
	Eumarcia plana	
	Mactra c.f. *discors*	
	Bassina sp.	
	Scalpomactra scalpellum	
	Myadora stephaniae	
	Divaricella huttoni	
	?Oxyperis komakoensis	
	Tellinota edgari	
	Peronaea gaimardi (Wn-R)	
WP 166	*Austrovenus stutchburyi*	Common, dominant
	Patro undatus	Common
WP 167	*Crassostrea ingens*	Common
	Talochlamys gemmulata	Common
	?Maoricardium spatiosum	
	Ostrea chilensis	
	Turitillidae indet. gen.	
	Penion sulcatus	
	Atrina pectinata zelandica	Very common
	Dosinia sp.	

Additional Remarks

WP 145 (Te Waka Formation)
WP 146 (Pakaututu Formation)
WP 161 (Near top of Te Waka Formation): Offshore, open-ocean fauna, <20 m water depth. Probably of Upper Wm age, fauna has an almost Wn look, may be near Wm-Wn boundary. The presence of *P. gaimardi* suggests a Wn age.
WP 166 (base Papakiri Member): Majority of bivalves are articulated, although disarticulated valves present
WP 167 (Te Waka Formation): Very well sorted, non to highly fossiliferous, slightly concretionary fine to medium sandstone

Sample site(s) information:

Location description
Gravel pit above Trig Road
Gravel pit on Huiarangi Road

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 177	2822542	6201621	431
WP 178	2825961	6200233	369

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 177	*Paphies* c.f. *australis*	Abundant, dominant
	Lutraria solida	
	Gari stangeri	
	Spissula sp.	
	Ostrea chilensis	Single valve
	Tawera subsulcata	
	Penion sulcatus	
	Purpurocarida purpurata	
	Crepidula radiata	
WP 178	LOWER SILTSTONE	
	Abundant plant fossils, very well preserved	
	CONGLOMERATE	
	Glycymeris shrimptoni	Common, majority articulated. Dominant
	Tucetona laticostata	Common
	Phialopecten triphooki	Common
	Maoricolpus	Common
	Purpurocardia purpurata	Common
	Ostrea chilensis	Rare to some
	Alcithoe sp. *(?brevis)*	
	UPPER SILTSTONE	
	Neilo sp.	
	Notocallista ?multistriata	
	Talochlamys gemmulata	
	Pratulum pulchellum	
	Zegalerus sp.	
	Purpurocardia purpurata	
	Dosinia greyi	

Additional Remarks

WP 177 (Matahorua Formation, base Deep Stream Member): Shoreface faunal assemblage.
WP 178 (Matahorua Formation, base Papakiri Member): Presence of *P. triphooki* (L.O.) confirms a lowermost Wn age for this bed. *Glycymeris* more abundant at top of conglomeratic shellbed. *Neilo* and *Notocallista* in upper siltstone indicative of deep water, and suggest rapid deepening above conglomerate (TST-HST).

Sample site(s) information:

Location description
SH5 beside Mangakopikopiko Stream
SH5 near Ellis Wallace Road
Puketitiri Road north of Rissington
Petane corner, SH2-SH5
Glengarry Road south of Parakowhai

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 195	2836184	6198392	53
WP 196	2837721	6196960	48
WP 198	2826981	6193983	243
WP 217	2843730	6193795	4
WP 219	2831984	6196156	234

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 195	*Austrofusus* sp.	
	Alcithoe sp. (*?brevis*)	
	Atrina pectinata zelandica	
	Antalis nana	
WP 196	*Talochlamys gemmulata*	
	Cominella sp.	
	Pelicaria sp.	
WP 198	*Ostrea chilensis*	
	Patro undatus	
	Glycymeris sp. (*?shrimptoni*)	
	Tucetona laticostata	
	Tawera sp. prob *subsulcata*	
	Mesopeplum convexum	
WP 217	*Maoricolpus roseus*	Some
	Antalis nana	Common
	Pelicaria convexa	Rare to some
	Atrina pectinata zelandica	Common
	Talochlamys gemmulata	Common
	Amalda mucronata	Common
	Penion sulcatus	Rare
	Ostrea chilensis	Common
	Barnacles	Some
WP 219	*Talochlamys gemmulata*	
	Tawera sp.	
	Purpurocardia purpurata	
	Xymene sp.	
	Sigapatella novaezelandiae	
	Crepidula radiata	
	Zethalia zelandica	
	Patro undatus	

Additional Remarks

WP 195 (Esk Mudstone): Blue-grey, non to slightly fossiliferous silty sandstone.
WP 196 (Aropaoanui Mudstone Member): Blue-grey, non to highly fossiliferous silty sandstone.
WP 198 Grassy Knoll Conglomerate Member)
WP 217 (Te Ngaru Mudstone Member): Siltstone overlain by shelly limestone. Assemblage gastropod dominated.
WP 219 (contact between Darkys Spur Member and Aropaoanui Mudstone Member): Fauna poorly preserved.

Sample site(s) information:

Location description
Glengarry Road near Turua
Track off Glengarry Road, Matches property
Track to gravel pit, Matches Property

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 220	2832573	6193638	265
WP 226	2833980	6192389	278
WP 227	2833627	6191728	316

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 220	*Ostrea chilensis*	Common, dominant
	Zeacolpus/Stiracolpus sp.	
	Talochlamys gemmulata	
	?Perna/Xenstrobus sp.	
WP 226	*Ostrea chilensis*	
	Talochlamys gemmulata	
	Atrina pectinata zelandica	
	Pelicaria ?convexa	
	?Maorimactra ordinaria	
WP 227	*Paphies australis*	Very common
	Paphies subtriangulata	Very common
	Tawera subsulcata	Common
	Sigapatella novaezelandiae	Common to abundant
	Glycymeris sp.	Some
	Zethalia zelandica	Some
	Tucetona laticostata	Some
	Purpurocarida purpurata	Some
	Talochlamys gemmulata	Some
	Ostrea chilensis	Uncommon

Additional Remarks

WP 220 (Tangoio Limestone Member): Moderately fossiliferous fine to medium sandstone.
WP 226 Devils Elbow Mudstone Member): Bivalves typically concave-down and concentrated into thin (<5 cm thick) layers.
WP 227 (Waipatiki Limestone Member): Fauna dominated by shallow-water dwelling species.

Sample site(s) information:

Location description
The Gums, Matches property
Gravel pit on Valhella, Alec Olsen's farm
Alston Farm off Glengarry Road
Swamp Road at Puketapu end
Top of ridge above Tiokapu Stream
Top of ridge above Tiokapu Stream
Top of ridge above Tiokapu Stream
Top of ridge above Tiokapu Stream
Track to airstrip on Eland Station

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 229	2834045	6189871	319
WP 233	2830280	6196552	173
WP 241	2830873	6199761	227
WP 242	2834359	6178142	28
WP 246	2830430	6199473	258
WP 247	2830447	6199470	248
WP 250	2830057	6198959	250
WP 254	2830188	6199220	270
WP 255	2832495	6203338	295

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 229	*Paphies australis*	Very abundant, dominant
	Ostrea chilensis	Some
	Lutraria solida	Rare
WP 233	*Pralulum pulchellum*	Common in clusters
	Maoricolpus roseus	Rare
	Austrofusus sp.	Rare
WP 241	*Ostrea chilensis*	Common, dominant
	Austrovenus stutchburyi	Common
WP 242	?*Eumarcia plana*	Some
	Ostrea chilensis	Common
WP 246	*Ostrea chilensis*	Common, dominant
	Tawera sp.	Some
	Tucetona laticostata	Some
WP 247	*Austrovenus stutchburyi*	Common, dominant
WP 248	*Austrovenus stutchburyi*	Common, dominant
	Ostrea chilensis	Some
WP 254	*Austrovenus stutchburyi*	
	Panopea sp.	
	Patro undatus	
	Tucetona laticostata	
WP 255	*Purpurocardia purpurata*	
	Glycymeris shrimptoni	
	Mesopeplum convexum	
	?Anomia trigonopsis	
	Tucetona laticostata	
	Phialopecten triphooki	
	Gastropoda spp.	

Additional Remarks

WP 229 (Kaiwaka Formation): Limestone almost mono-specific, very large number of *Paphies australis* present.
WP 233 (Esk Mudstone overlain by Tutira Member)
WP 241 (Grassy Knoll Conglomerate Member)
WP 242 (Tangoio Limestone Member)
WP 246 (Grassy Knoll Conglomerate Member)
WP 247 (Grassy Knoll Conglomerate Member)
WP 250 (Grassy Knoll Conglomerate Member overlain by Esk Mudstone)
WP 254 (Grassy Knoll Conglomerate Member): Valves largely disarticulated.
WP 255 Grassy Knoll Conglomerate Member overlain by Esk Mudstone): Presence of *P. triphooki* (L.O.) confirms a lowermost Wn age for this bed. Typically gravel-substrate fauna for Nukumaruan rocks in Hawke's Bay.

Sample site(s) information:

Location description
Airstrip Road, Eland Station
Airstrip Road, Eland Station East of woolshed
Cellphone Tower Hill, Eland Station
Below cellphone tower, Eland Station
Waipunga Road near SH5 intersection
Waipunga Road, Tangoio Block

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 259	2832419	6203017	283
WP 261	2835981	6203698	233
WP 262	2834794	6202058	333
WP 265	2834884	6202036	334
WP 271	2838993	6196213	86
WP 272	2840173	6204450	289

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 259	*Glycymeris shrimptoni*	
	Ostrea chilensis	
	Sigapatella novaezelandiae	
	Talochlamys gemmulata	
WP 261	*Pratulum pulchellum*	Some
	Talochlamys gemmulata	Some
WP 262	*Tawera subsulcata*	Abundant
	Ostrea chilensis	Common
WP 265	*Tawera subsulcata*	
	Calliostoma sp.	
	Pelicaria convexa	
	Austrofusus sp.	
	Amalda sp.	
	Atrina pectinata zelandica	
WP 271	*Antalis nana*	Common, dominant
	Maoricolpus roseus	Common
	Talochlamys gemmulata	Some
	Pratulum pulchellum	Some
	Pelicaria convexa	Single specimen
	Ostrea chilensis	Some
WP 272	*Tawera subsulcata*	Abundant, dominant
	Purpurocardia purpurata	Common
	Bryozoa (encrusting)	Common
	Gastropoda spp.	Common

Additional Remarks

WP 259 (Grassy Knoll Conglomerate Member)
WP 261 (Aropaoanui Mudstone Member)
WP 262 (Darkys Spur Member): Valves typically disarticulated, commonly broken.
WP 265 (Darkys Spur Member): Mixture of articulated and disarticulated valves, many of which appear to be in life position.
WP 271 (Te Ngaru Mudstone Member)
WP 272 (Waipatiki Limestone Member): Common partially-dissolved bivalves.

Sample site(s) information:

Location description
Ellis Wallace Road near 1st ford
SH5 near Glengarry Hill
SH5 south of Northlands entrance
SH5 south of Northlands entrance
Mangakopikopiko Stream above Glenlands
Mangakopikopiko Stream above Glenlands

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 273	2838896	6200042	82
WP 276	2831993	6202496	255
WP 277	2832357	6201292	223
WP 278	2832384	6201154	223
WP 281	2833547	6200839	-
WP 282	2832789	6201436	131

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 273	*Maoricolpus roseus*	Some
	Ostrea chilensis	Some
	Alcithoe sp.	Some
WP 276	*Dosinia* sp.	Common, especially in small clusters
	Talochlamys gemmulata	Rare
WP 277	*Atrina pectinata zelandica*	Some
	Maoricolpus roseus	Some
	Pratulum pulchellum	Some
WP 278	*Pratulum pulchellum*	Common
	Ostrea chilensis	Some
WP 281	*Pratulum pulchellum*	Common in small clusters
WP 282	CONGLOMERTAE	Common
	Tucetona laticostata	
	Xenostrobus huttoni	Common
	Ostrea chilensis	
	Purpurocardia purpurata	
	Pleuromeris sp.	
	Patro undatus	
	Anomia trigonopsis	
	PEBBLY SILTSTONE	
	Ostrea chilensis	
	Purpurocardia purpurata	
	Pratulum pulchellum	
	Alcithoe sp.	

Additional Remarks

WP 273 (Aropaoanui Mudstone Member): Blue-grey, non to slightly fossiliferous siltstone to sandy siltstone
WP 276 (Papakiri Member): Non cemented, well sorted, fine to medium sandstone with moderately fossiliferous shell lenses.
WP 277 (Esk Mudstone): Non cemented slightly fossiliferous siltstone.
WP 278 (Esk Mudstone): Non cemented slightly fossiliferous siltstone.
WP 281 (Esk Mudstone): Non cemented siltstone with common clusters of *Pratulum.*
WP 282 (Esk Mudstone): Dominated by thick shelled, disarticulated bivalves.

Sample site(s) information:

Location description
Farm track off Taihape Road near Omahu
Farm track off Taihape Road near Omahu
Farm track off Taihape Road near Omahu
Farm track off Taihape Road near Omahu
Belmont Station above Ellis Wallace Rd
Top of hill near trig, Belmont Station
North side of trig, Belmont Station
Belmont Station below trig above SH5

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 286	2834530	6175121	34
WP 287	2834527	6175010	52
WP 288	2834337	6175145	43
WP 289	2834228	6175096	34
WP 301	2837487	6198391	173
WP 302	2837618	6198602	242
WP 303	2837412	6198724	223
WP 304	2837265	6198589	171

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 286	*Ostrea chilensis*	
	Barnacle plates and fragments	
WP 287	*Ostrea chilensis*	
WP 288	*Ostrea chilensis*	
WP 289	*Ostrea chilensis*	
WP 301	*Tawera subsulcata*	Abundant, dominant
	Ostrea chilensis	
	Calliostoma sp.	
	Dosinia sp.	
	Bivalvia indet. sp.	
	Gastropoda indet. sp.	
WP302	*Ostrea chilensis*	Some, scattered
WP 303	*Fellaster ?zelandiae*	Common
	Dosinia sp.	Common
	Lamprodominea neozelandica	
	Zethalia zelandica	
	Panopea sp.	
	Sigapatella novaezelandiae	
	Barnacles	
	Gastropoda indet. sp.	
	Mesopeplum convexum	
	Ostrea chilensis	
WP 304	*Austrovenus stutchburyi*	Abundant
	Patro undatus	Some
	Paphies australis	Some
	Dosinia sp.	Some
	Sigapatella novaezelandiae	Some

Additional Remarks

WP 286 (Tangoio Limestone Member): *Ostrea chilensis* concentrated in thin (<0.5 m thick) shellbed at top of shellhash-rich limestone with abundant biomoulds.
WP 287 (Tangoio Limestone Member)
WP 288 (Tangoio Limestone Member)
WP 289 (Tangoio Limestone Member)
WP 301 (Darkys Spur Member): Valves largely concave-down and paleocurrent aligned, appear storm emplaced.
WP 302 (Tangoio Limestone Member): Shellhash-dominated limestone with scattered *Ostrea* valves.
WP 303 (Tangoio Limestone Member): *Fellaster* are largely intact, suggesting they have not been transported too far. Fauna indicative of shoreface sandy beach environments. *Mesopeplum* and *Ostrea* valves are present in float blocks and probably from an overlying unit.
WP 304 (Darkys Spur Member): Fauna sampled from what appears to be slump deposits.

Sample site(s) information:

Location description
Belmont Station near SH5
Belmont Station above SH5 near Dillons Hill
Belmont Station on Thunderstorm Hill
Track off Beattie Rd above small stream
Hill Road near Seafield Road intersection

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 305	2836621	6199574	83
WP 308	2835726	6200142	106
WP 316	2836447	6200280	173
WP 321	2835474	6196579	102
WP 325	2841983	6192356	29

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 305	*Ostrea chilensis*	Common
	Tawera subsulcata	Common
	Bivalvia indet. sp.	Common
WP 308	*Ostrea chilensis*	Some
	Bivalvia indet. sp.	Some
WP 316	*Zeacolpus* sp.	Some, in clusters
WP 317	*Panopea* sp.	Some, articulated
	Pelicaria ?convexa	Single specimen
	?Penion sulcatus	Single specimen
	?Dosinia greyi	Some
	?Maorimactra ordinaria	Some
	Bivalvia indet. sp.	Common
	Gastropoda indet. sp.	Common
WP 321	*Patro undatus*	Common
	Tawera subsulcata	Abundant, dominant
	Sigapatella novaezelandiae	Some
	Dosinia sp.	Some
	Panopea sp.	Some
	Atrina pectinata zelandica	Some
	Purpurocardia purpurata	Some
	Pleuromeris sp.	Some
	Gastropoda indet. sp.	Some
WP 325	*Ostrea chilensis*	Common, dominant
	Atrina pectinata zelandica	Common
	Zenatia ?acinaces	Common
	Talochlamys gemmulata	Common
	Austrofusus sp.	Common
	Amalda ?depressa	Some
	Gonimyrtea sp.	Some
	Pelicaria sp. (prob *convexa*)	Rare
	Maoricolpus roseus	Some
	Stiracolpus sp.	Some
	Patro undatus	Some

Additional Remarks

WP 305 (Tutira Member)
WP 308 (Tutira Member and Hikuroa Pumice Member): *Ostrea chilensis* valves commonly articulated.
WP 316 (Darkys Spur Member)
WP 321 (Tutira Member and Hikuroa Pumice Member: Most valves intact although disarticulated.
WP 325 (Tangoio Limestone Member)

Sample site(s) information:

Location description
Rautoitoi Stream above Ellis Wallace Road
Matapiro Road east of Whanawhana Road
Whanawhana Road past Kohatunui Road
Glenross Road near Taihape Road
Taihape Road south of Koromiko Road

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 327	2837555	6199472	67
WP 334	2809409	6177489	262
WP 335	2804375	6180192	355
WP 337	2806870	6188520	389
WP 338	2810136	6185022	356

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 327	SHELLBED ABOVE ASH BED	
	Dosinia sp.	Common articulated mould
	Purpurocardia purpurata	Some
	Ostrea chilensis	Some
	Bivalvia indet. spp.	Some
	SILTSTONE	
	Patro undatus	Some
	Pelicaria sp. (prob *accuminata*)	Rare
	?Dosinia sp.	Rare
WP 334	*Ostrea chilensis*	Some
	Purpurocardia purpurata	Some
	Tawera subsulcatus	Some
	Gastropoda indet. sp.	Some
	Bivalvia indet. spp.	Some
WP 335	*Eumarcia ?plana*	Dominant
	Phialopecten triphooki	Some
WP 337	*Ostrea chilensis*	Fragments
	Zethalia sp. (prob. *coronata*)	Some
	Eumarcia sp.	Some
WP 338	*Pratulum pulchellum*	Common, in dense clusters. Dominant.
	Austrofusus taiate	Some
	Alcithoe brevis	Some
	Atrina pectinata zelandica	Some
	Mygdolum	Rare
	Amalda sp.	Some
	Ostrea chilensis	Some
	Penion sulcatus	Rare

Additional Remarks

WP 327 (Hikuroa Pumice Member): Shells are dominantly all dissolved with only shell moulds remaining.
WP 334 (Kikowhero Member, Okauawa Formation): Fall-blocks sampled above non fossiliferous conglomerate.
WP 335 (Sentry Box Formation): Whole shell-dominated shellbed, dominated by aragonitic bivalves that are partially to totally recrystallised. The presence of *P. triphooki* confirms a lower Wn age for this unit. *Zygochlamys patagonica delicatula* has been reported from this section (Beu 1995).
WP 337 (Te Waka Formation)
WP 338 (Esk Mudstone)

Sample site(s) information:

Location description
Flag Range Road near Kaweka Panorama
Hedgely Station beside forest block
Hedgely Station above lakes
Hedgely Station above lakes
Hedgely Station above lake on track
Hedgely Station above southernmost lake
Hedgely Station above southernmost lakeRoad to quarry above Hedgely Station

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 339	2818134	6184046	371
WP 343	2836295	6192880	253
WP 344	2836057	6192929	272
WP 345	2836111	6193013	259
WP 347	2835393	6192668	184
WP 348	2836368	6193626	240
WP 349	2836406	6193673	274
WP 350	2836896	6191513	225

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 339	*Purpurocardia purpurata*	Abundant
	Tawera subsulcata	Abundant
	Bivalvia indet. spp.	Common
	Gastropoda indet. spp.	Common
WP 343	*Ostrea chilensis*	Some
WP 344	*Paphies australis*	Adundant, dominant
	Ostrea chilensis	Some, valves of large size, often articulated
	Tawera subsulcata	Some
WP 345	*Paphies australis*	Very common, dominant
	Ostrea chilensis	Very common, often articulated
WP 347	*Dosinia* sp.	Rare
	Xenostrobus huttoni	Abundant, dominant
	Austrovenus stutchburyi	Some
	Zethalia zelandica	Rare but very large
WP 348	*Paphies australis*	Abundant, dominant
WP 349	*Ostrea chilensis*	Common, large valves
WP 350	*Sigapatella novaezelandiae*	Common, dominant
	Bivalvia indet. spp.	Common

Additional Remarks

WP 339 (Top Flag Range Conglomerate Member)
WP 343 (Kaiwaka Formation)
WP 344 (Kaiwaka Formation)
WP 345 (Kaiwaka Formation)
WP 347 (Tangoio Limestone Member)
WP 348 (Kaiwaka Formation)
WP 349 (Kaiwaka Formation)
WP 350 (Waipatiki Limestone Member)

Sample site(s) information:

Location description
Old quarry in forest off Seafield Road
Top of old quarry in forest off Seafield Road
Bottom of driveway off Apley Road

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 351	2836660	6191555	243
WP 352	2836612	6191521	283
WP 353	2832034	6186024	274

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 351	*Paphies australis*	Some to abundant
	Tawera subsulcata	Some to common
	Cominella sp.	Some to common
	Dosinia subrosea	Some to common
	Dosinia sp.	Some to common
	Sigapatella novaezelandiae	Some
	Amalda sp.	Some
	Tucetona laticostata	Some to common
	Gastropoda spp.	Some to common
	Xentrostrobus huttoni	Some
	Crepidula radiata	Some to common
	?Maorimactra ordinaria	Some
	Patro undatus	Some to common
	Lutraria solida	Some
	Austrovenus stutchburyi	Some
	Ostrea chilensis	Some to abundant
	Barnacles (often intact and attached to shells)	Some to common
WP 352	*Ostrea chilensis*	Common to abundant. Noticeably large specimens
WP 353	*Mactra* sp.	
	Paphies australis	
	Tucetona laticostata	
	Zenatia acinaces	
	Purpurocardia purpurata	
	Ostrea chilensis	
	Patro undatus	
	Tawera subsulcatus	
	Lutraria solida	
	Crepidula radiata	
	Gari sp.	
	Sigapatella novaezelandiae	Some
	Eumarcia ?plana	Some
	Talochlamys gemmulata	Some
	Echinoid spines	Rare

Additional Remarks

WP 351 (Kaiwaka Formation)
WP 352 (Kaiwaka Formation): Biomoulds and partially dissolved shells common in section. *Ostrea* valves typically concave-down.
WP 353 (Waipatiki Limestone Member): Deeping-upwards pattern present in section based on faunal composition and grain size.

Sample site(s) information:

Location description
Newstead Farm above Seafield Road
Newstead Farm overlooking Seafield Road
Newstead Farm below "The Gums"
Newstead Farm overlooking Seafield Road
Newstead Farm overlooking Seafield Road
Newstead Farm below "The Gums"
Newstead Farm near Glengarry Road
Opau Stream downstream of quarry

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 355	2835264	6189172	231
WP 356	2835222	6189240	238
WP 357	2835088	6189453	231
WP 358	2835206	6189531	239
WP 360	2835906	6189478	224
WP 362	2834621	6189812	311
WP 366	2833654	6188182	167
WP 369	2820709	6204975	182

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 355	*Paphies australis*	Common
	Ostrea chilensis	Common
	Tawera ?subsulcatus (most likely)	Common
WP 356	*Paphies australis*	Common
WP 357	*Paphies australis*	Rare to common
	Paphies subtriangulata	Rare
	Ostrea chilensis	Common
WP 358	*Paphies australis*	Common
	Bivalvia spp.	Common
WP 360	*Paphies australis*	Abundant, dominant
	Patro undatus	Common
WP 362	*Paphies australis*	Abundant, dominant
WP 366	*Talochlamys gemmulata*	
	Zethalia zelandica	Uncommon to common
	Ostrea chilensis	Some
	Crepidula radiata	Common
	Sigapatella novaezelandiae	Common
	Paphies australis	Common
	Barnacles	Some
	Gari sp.	Common
	Pleuromeris ?marshalli	Some
WP 369	BASAL BEDS	
	Struthiolaria ?callusaria obesa	Common
	Zenatia acinaces	Common
	BRECCIA AT BASE OF LIMESTONE	
	Crassostrea ingens	Abundant, dominant
	Flabellid corals	Very common
	Phialopecten sp.	Common
	Encusting bryozoans	Common
	LIMESTONE	
	Crassostrea ingens	Some, scattered
	Barnacles	Very abundant
	Echinoid spines	Some
	Phialopecten sp.	Some

Additional Remarks

WP 355 (Waipatiki Limestone Member): Valves largely dissolved and only moulds remain making fossil identifications difficult.
WP 356 (Waipatiki Limestone Member
WP 357 (Waipatiki Limestone Member: Valves difficult to identify due to dissolution.
WP 358 (Waipatiki Limestone Member: Composition of breccia bed indicates deposition adjacent to a greywacke high.
WP 360 (Waipatiki Limestone Member
WP 362 (Kaiwaka Formation)
WP 366 (Waipatiki Limestone Member
WP 369 (Te Ipuohape Sandstone Member)

Sample site(s) information:

Location description
Track above Bayliss Drilling base
Bayliss' property above Puketitiri Road
Bayliss' property above Puketitiri Road
Pacific coastline south of Waipatiki Beach

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 371	2836357	6187021	126
WP 372	2830484	6187109	135
WP 373	2836553	6187257	143
WP 379	2852196	6202976	6

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 371	*Antalis nana*	Very abundant
	Stiracolpus sp.	Common
	Amalda sp.	Common
	Talochlamys gemmulata	Common
	Ostrea chilensis	Some, disarticulated
	Alcithoe sp.	Present
	Austrofusus glans	Present
	?Cominella sp.	Present
	Pelicaria ?convexa	Present
	?Dosinia greyi	Present
	Bivalvia indet. spp.	Present
WP 372	*Tawera subsulcata*	Some
	Gari sp.	Some
WP 373	*Ostrea chilensis*	Some
	Paphies australis	Some
	Gastropoda indet. spp.	Some
WP 379	CALCAREOUS SANDSTONE	
	Fellaster zelanidae	Common, all tests relatively intact
	SANDY SILTSTONE	
	Talochlamys gemmulata	Common, articulated
	Ostrea chilensis	Common, articulated

Additional Remarks

WP 371 (Te Ngaru Mudstone Member): Fauna gastropod dominated, typical of Wn siltstone facies through the basin.
WP 372 (Waipatiki Limestone Member)
WP 373 (Waipatiki Limestone Member)
WP 379 (Tangoio Limestone Member): Valves are of both adult and juvenille size.

Sample site(s) information:

Location description
Kawera Road, Ngamahanga Station

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 381	2827357	6181193	69

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 381	*Tawera subsulcata*	Abundant
	Crepidula radiata	Abundant
	Crepidula monoxyla	
	Sigapatella novaezelandiae	Common
	Paphies australis	
	Paphies subtriangulata	
	Micrelenchus sp. (very fine lines)	
	Trochus tiaratus	
	Diloma sp.	
	Ataxocerithium sp.	
	Amalda mucronata	
	Amalda novaezelandiae	
	Xymene ambiguis	
	Xymene plebieus	
	Xymene bonneti	
	Trivia sp. (Kauri shell)	Rare
	Notoacmaea sp.	
	Maoricolpus roseus	
	*Stiracolpus (*one characterisitc angulate sculpture)	
	Ostrea chilensis	Common
	Alcithoe (Leporemax) fusus	
	Alcithoe sp.	
	Austromegabalanus dicorus	
	Pelicaria convexa	Some
	Purpurocardia purpurata	Common
	Cirrsostrema sp.	Rare
	Marginellidae sp.	
	Proxubia/Taniella sp.	
	Glycymeris modesta	
	Talochlamys gemmulata	Some
	Penion sulcatus	
	Zegalures sp.	
	Zeacumantus lutelantus	
	Murexul sp.	Rare
	Cominella maculosa	
	Cominella (Josepha) sp. (squat Cominella*)*	
	Barytellina crassidens	
	Atrina pectinata zelandica	Some
	Patro undatus	Some
	Calliostoma sp.	
	Pleuromeris sp.	
	Splendrillia sp.	
	Fissidentalium zelandicum	

Additional Remarks

WP 381 (Waipatiki Limestone Member): Fauna suggests a depostional setting very near to an estuary as many species appear to have been washed out of such a setting. Perhaps a setting similar to the entrances to modern-day Tauranga and Whangarei Harbours.

Sample site(s) information:

Location description
Ngamahanga Station
Ngamahanga Station
Springvale Station near Puketapu Road
Springvale Station near Puketapu Road
Springvale Station
Springvale Station on Puketapu Hill
Springvale Station on Puketapu Hill above school

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 382	2827819	6181472	86
WP 384	2828551	6182350	95
WP 389	2836814	6182645	51
WP 390	2836827	6182705	59
WP 396	2835989	6183296	69
WP 401	2836478	6181886	92
WP 402	2836452	6181760	90

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 382	*Ostrea chilensis*	Common
	Bivalvia indet. gen. spp.	Common
WP 384	*Ostrea chilensis*	Common
	Bivalvia indet. gen. spp.	Common
WP 389	*Patro undatus*	Some
	Bivalvia indet. gen. spp.	Some
	Gastropoda indet. gen. spp.	Rare
WP 390	*Talochlamys gemmulata*	Abundant, adult and juvenilles present
	Ostrea chilensis	Common, juvenille
	Maoricolpus roseus	Common
	Brachiopoda indet. gen. sp.	Common
	Bivalvia indet. gen. spp.	Common
	Gastropoda indet. gen. spp.	Common
WP 396	Ostrea chilensis	Some
	Bivalvia indet. gen. spp.	Common, dominant
WP 401	*Mesopeplum convexum*	Common
	Sigapatella novaezelanidae	Common
	Talochlamys gemmulata	Some
	Encrusting bryozoans	Abundant
	Purpurocardia purpurata	Some
	Brachiopoda indet. gen. sp.	Some
	Bivalvia indet. gen. spp.	Common
	Gastropoda indet. gen. spp.	Common
WP 402	*Talochlamys gemmulata*	Common
	Sigapatella novaezelandiae	Common
	Bivalvia indet. gen. spp.	Common

Additional Remarks

WP 382 (Waipatiki Formation): Fauna largely partially to completely recrystallised, aragonitic dominated. *Ostrea* largely constrained to a capping oyster bed.
WP 384 (Top Waipatiki Formation): *Ostrea* bed capping limestone is quite prominent.
WP 389 (Tangoio Limestone Member)
WP 390 (Te Ngaru Mudstone Member): Fauna rich in partially to completely dissolved aragonitic bivalves and gastropods.
WP 396 (Waipatiki Limestone Member): Fauna dominated by partially to completely dissolved aragonitic bivalves and gastropods.
WP 401 (Waipatiki Limestone Member)
WP 402 (Waipatiki Limestone Member)

Sample site(s) information:

Location description
Springvale Station on Puketapu Hill above school
Springvale Station above Puketapu Road
Bluff off Penrith Rd near Puketapu Road
Pukenoa Farm near Apley Road

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 404	2836730	6181632	68
WP 407	2836476	6181443	62
WP 410	2837972	6182905	19
WP 412	2832289	6187548	164

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 404	*Tawera subsulcata*	Common
	Anomia trigonopsis	Common
	Bivalvia indet. gen. spp.	Common, dominant
WP 407	Bivalvia indet. gen. spp.	Common, dominant
	Tucetona laticostata	Some
	?Eumarcia ?plana	Some
	Lutraria solida	Some
	Zethalia zelandica	Some
	?Tawera subsulcata	Some, hard to identify due to dissolution of shell
WP 410	Bivalvia indet. gen. spp.	Abundant, dominant
	Patro undatus/Anomia trigonopsis	Some
	Zethalia zelandica	Some
	Serpulids	Some
WP 412	*Crepidula radiata*	Common to abundant
	Talochlamys gemmulata	Common to abundant
	Gari sp.	Common, some articulated
	Anomia trigonopsis	Some
	Patro undatus	Some
	Cirripedea sp.	Common
	Purpurocardia purpurata	Common
	Tawera subsulcata	Common
	Branching bryozoa	Some to common
	Alcithoe sp.	Some
	Tucetona laticostata	Some
	Gastropoda indet. spp.	Common
	Pelicaria convexa	Rare
	Ostrea chilensis	Common
	Lutraria solida	Some
	Lamprodominea ?neozelandica	Rare
	Eumarcia ?plana	Some
	Towaipecten mariae	Rare

Additional Remarks

WP 404 (Tangoio Limestone Member): Fauna dominated by partially to totally dissolved aragonitic bivalves and gastropods.
WP 407 (Tangoio Limestone Member)
WP 410 (Park Island Limestone Member)
WP 412 (Waipatiki Limestone Member): Fauna in outcrop typical for the Waipatiki Limestone Member throughout this area. The presence of *Pelicaria convexa* and *Towaipecten mariae* confirms a Wn age for this unit.

Sample site(s) information:

Location description
Pukenoa Farm near top boundary, Apley Rd
Pukenoa Farm at top boundary, Apley Rd
Apley Road at Puketitiri Road end

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 415	2832917	6187700	203
WP 416	2833001	6187863	245
WP 418	2831672	6187597	124

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 415	*Zethalia zelandica*	Abundant, dominant
	Anomia trigonopsis	
	Alcithoe sp.	
	Austrofusus sp.	
	Patro undatus	
	Austrovenus stutchburyi	Rare, restricted to top of bed
	Crepidula radiata	
	Amalda mucronata	
	?Cominella sp.	
	?Zeacolpus sp.	
	Gastropoda indet. gen. spp.	
WP 416	*Patro undatus*	Common
	Ostrea chilensis	Some, scattered
WP 418	SHELLBED	Dominant
(cont. over)	*Scalpomactra scapallum*	
	Maorimactra ordinaria	
	Mactra sp.	Mostly quite small
	Dosina sp.	
	Cominella kereruensis	
	Fellaster zelandica	
	Gari sp. (prob. *lineolata*)	
	Bassina sp.	Uncommon, present at top of shellbed
	Crepidula radiata	
	Tawera subsulcata	
	Talochlamys gemmulata	
	Anomia trigonopsis	
	Patro undatus	
	Ostrea chilensis	
	Pteromyrtea dispar	
	Bivalvia indet. gen. spp.	
	Gastropoda indet. gen. spp.	
	Murexsel sp.	
	Eumarcia plana	

Additional Remarks

WP 415 (Kaiwaka Formation)
WP 416 (Kaiwaka Formation)
WP 418 (Flag Range Conglomerate Member): Fauna suggests a reasonably high-energy sandy shelf setting, perhaps just offshore from a beach.

Sample site(s) information:

Location description
Apley Road at Puketitiri Road end
Farm track in valley, Brooklands Station
Brooklands Station near Puketitiri Road
Brooklands Station near Puketitiri Road

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 418	2831672	6187597	124
WP 421	2835762	6185270	60
WP 427	2835569	6186040	110
WP 428	2835744	6185754	117

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 418	SHELLBED (cont.)	
(cont.)	*Amalda mucronata*	
	Zeacolpus sp.	
	Atrina pectinata zelandica	
	Austrofusus sp.	
	Taniella sp.	
	SILTSTONE	
	Atrina pectinata zelandica	
	Neothyris sp.	
	Margasella sp.	
	Austrofusus sp.	
	Talochlamys gemmulata	
	Tawera subsulcata	
	Zeacolpus sp.	
	Crepidula radiata	
	Marama murdochi	
	Maoricolpus roseus	
	Alcithoe (Alcithoe) sp.	
WP 421	*Talochlamys gemmulata*	Common, dominant
	Ostrea chilensis	Some
	Maoricolpus roseus	Some
	Cirripedea spp. (plates and intact)	Some
	Crepidula radiata	Some
	Amalda mucronata	Single specimen
	Dosina sp.	Common, disarticulated
	Pelicaria sp. (prob *convexa*)	Single specimen, fragmented
WP 427	Talochlamys gemmulata	Some
	Bivalvia indet. gen. spp.	Abundant, dominant
WP 428	Bivalvia indet. gen. spp.	Abundant, dominant
	Alcithoe sp.	Rare

Additional Remarks

WP 418 (Flag Range Conglomerate Member): Fauna suggests a reasonably high-energy sandy shelf setting, prehaps just offshore from a beach.
WP 421 (Te Ngaru Mudstone Member)
WP 427 (Waipatiki Limestone Member): Fauna dominanted by partially to totally dissolved aragonitic bivalves.
WP 428 (Waipatiki Limestone Member): Fauna dominanted by partially to totally dissolved aragonitic bivalves.

Sample site(s) information:

Location description	Waypoint Name/No.	Eastings	Northings	Altitude (m)
Brooklands Station near homestead	WP 441	2836081	6184559	70
Avery Road near Seafield Road	WP 446	2840350	6161892	26
Hukanui Station at northern boundary fences	WP 458	2815869	6212915	785
Hukanui Station near northern boundary	WP 459	2815949	6212682	845
Glenhope Station below Pakaututu Road	WP 464	2811528	6211763	491
Hukanui Station overlooking Mohaka River	WP 472	2814527	6211787	913

GPS Waypoint information:

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 441	SILTSTONE	
	Talochlamys gemmulata	Abundant, dominant
	Antalis nana	Common
	Maoricolpus roseus	Some
	Ostrea chilensis	Some
	Alcithoe sp.	Some
	Bivalvia indet. spp.	Some
	Gastropoda indet. spp.	Some
	SHELLY LIMESTONE	
	Sigapatella novaezelandiae	Some
	Bivalvia indet. spp.	Partially to completely recrystallised shells
WP 446	*Pelicaria* sp. (?convexa)	Rare. Large, fragmented
	Stiracolpus sp.	Some
	?Cominella sp.	Some
	Austrofusus sp.	Some
	Bivalvia indet. spp.	Some
WP 458	*Struthiolaria ?(Callusaria) obesa*	Common , concentrated into concretionary beds
	Bivalvia indet. spp.	Largely dissolved, identification difficult
	Gastropoda indet. spp.	Largely dissolved, identification difficult
WP 459	*Struthioilaria ?(Callusaria) obesa*	Abundant, concretionary beds entirely Struthilarids
WP 464	*Tucetona laticostata*	Abundant, dominant
	Panopea sp.	Some
	Purpurocardia purpurata	Some
	Phialopecten sp. (?*marwicki* (Wo))	Common
WP 472	*Crassostrea ingens*	Abundant, restricted to base of limestone

Additional Remarks

WP 441 (Te Ngaru Mudstone Member overlain by Waipatiki Limestone Member)
WP 446 (Mairau Mudstone Member)
WP 458 (Pakaututu Formation)
WP 459 (Pakaututu Formation)
WP 464 (Hukanui Limestone Member, Pakaututu Formation: The presence of *Phialopecten marwicki* suggests an Upper Opoitian age for this unit.
WP 472 (Puketitiri Formation overlain by Te Waka Formation)

Sample site(s) information:

Location description
Hukanui Station overlooking Mohaka River
Hukanui Station above Pakaututu Road
Hukanui Station towards Pakaututu Road
Hukanui Station below hilltop
Quarry on Kuripapango Road
Top of Mount Kohinga, Kuripapango
SH2 south of Devils Elbow

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 473	2814120	6211746	915
WP 475	2813397	6212550	788
WP 476	2813663	6212952	715
WP 477	2813597	6212620	791
WP 487	2799440	6198184	641
WP 488	2798125	6193717	946
WP 490	2844266	6204416	159

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 473	*Crassostrea ingens*	Common
	Cirripeda indet. spp.	Common, intact and as large plates
WP 475	*Tucetona laticostata*	Abundant, dominant
	Bivalvia indet. spp.	Common
WP 476	*Tucetona laticostata*	Abundant, dominant
	Bivalvia indet. spp.	Common
WP 477	*Tucetona laticostata*	Abundant, dominant
	Phialopecten sp. (*?marwicki* (Wo))	Some
	Bivalvia indet. spp.	Common
WP 487	*Maorimactra ?ordinaria*	Dominant
	Crassostrea ingens	Some
	Sectipecten wollastoni	Some
	?Cominella sp.	
	Amalda sp.	
	Dosinia sp. (fine ribs)	
	Myadora sp.	
	Dosina sp.	
	Cirripeda indet. sp.	Specimens present are quite large
WP 488	Bryozoa indet. spp.	Abundant
	Brachiopoda indet. sp.	Abundant
	Cirripeda indet. spp.	Abundant
WP 490	*Pelicaria convexa* (form *fossa*)	Abundant, dominant. Large size range present
	Maoricolpus roseus	Some
	Ostrea chilensis	Some
	Alcithoe spp.	Some
	Atrina pectinata zelandica	Some
	Talochlamys gemmulata	Common
	Stiracolpus/Zeacolpus sp.	Some
	?Maorimactra ordinaria	Some
	Cominella sp.	Some
	Penion sulcatus	Rare
	Dosina zelandica	Some
	Amalda mucronata	Some

Additional Remarks

WP 473 (Te Waka Formation overlying Puketitiri Formation): *Crassostrea* present above erosional surface between limestone and underlying siltstone, interbedded with angular to well rounded pebbles and cobbles of various lithologies.
WP 475 (Top Hukanui Limestone Member, Pakaututu Formation): *Tucetona* largely intact, commonly articulated.
WP 476 (Top Hukanui Limestone Member, Pakaututu Formation): *Tucetona* largely intact, commonly articulated.
WP 477 (Top Hukanui Limestone Member, Pakaututu Formation): *Tucetona* largely intact, commonly articulated. The presence of *Phialopecten ?marwicki* perhaps indicates an Upper Opoitian age for this bed.
FOR WP 475, 476, 477: Fauna suggest deposition in a high-energy, current-swept environment, perhaps harbour channel. Similar assemblages presently exist in modern day Northland harbours e.g. Whangarei, Whangaroa etc.
WP 487 (Blowhard Formation, Waikorokoro Member): Unit unconformably overlies Torlesse basement with up to metre-scale relief. Fauna developed in proximity to greywacke sea-stacks. The presence of *Sectipecten wollastoni* confirms a Kapitean age for the unit.
WP 488 (Te Waka Formation): Fauna shellhash dominated, rare *Phialopecten thomsoni* reported here (Wm age).
WP 490: (Te Ngaru Mudstone Member): Fauna typical for soft-substrated, middle to outer shelf assemblages in Hawke's Bay Wn rocks. Confident Upper Wn age based on presence of *Pelicaria convexa*.

Sample site(s) information:

Location description
SH2 at top of Devils Elbow section
SH2 at Waikoau River bridge
Rorookiwa Hill, Bayview

GPS Waypoint information:

Waypoint	Name/No.	Eastings	Northings	Altitude (m)
WP 492		2846000	6207929	247
WP 494		2844669	6206342	58
WP 495		2842219	6189783	17

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 492	*Maoricolpus roseus*	
	Talochlamus gemmulata	
	Pratulum pulchellum	
	Ostrea chilensis	Some
	Atrina pectinata zelandica	Often present in life position
	Cominella excoriata	
	Austrofusus taitae	Common
	Penion sulcatus	
	Alcithoe brevis	
	Pelicaria convexa form *fossa*	
	Crepidula radiata	
	Aneator marshalli marshalli	
	Xymene ambigus	
	Aoeteadrilla finlayi	
	Splendrillia aegistriata	
	Amalda mucronata	
	Notosaria megricans	
	Brachiopoda indet. gen.	
	Bivalvia indet. gen.	
	Gastropoda indet. gen.	
WP 494	*Talochlamys gemmulata*	
	Ostrea chilensis	
	Maoricolpus roseus	
	Stiracolpus/Zeacolpus sp.	
	Pelicaria convexa	Sparse
	Bivalvia indet. gen.	Scattered
WP 495	*Ostrea chilensis*	Common
	Stiracolpus/Zeacolpus sp.	Common
	Talochlamys gemmulata	Abundant
	Dosinia spp.	Common
	Alcithoe sp.	Some
	Crepidula radiata	Some
	Maoricolpus roseus	Some
	Pleuromeris sp.	Some
	Tawera subsulcata	Some
	Anomia triginopsis	
	Pelicaria acuminata/convexa	Uncommon
	Patro undatus	
	Atrina pectinata zelandica	
	Amalda mucronata	
	Lutraria/Panopea sp.	
	Purpurocardia purpurata	
	Austrofusus sp.	
	Antalis nana	
	Sigapatella novaezelandiae	
	Murexsel	
	Barnacles indet. sp.	
	Bivalvia indet. sp.	
	Gastropoda indet. sp.	Common
	Encrusting and branching bryozoans	
	Echinoid spines	
	Limpet	Single specimen

Additional Remarks

WP 492 (Devils Elbow Mudstone Member): *Atrina* becomes more common upsection as the background sediment coarsens; *Pelicaria* becomes less common. Gastropod-dominated macrofauna.

WP 494 (Aropaoanui Mudstone Member)

WP 495 (Mairau Mudstone Member): Possible conch-type shell present. Some *Talochalmys* are particularly large, much bigger than others collected through the basin. *Pelicaria* seem to show characteristics of both *P. accuminata* and *P. convexa*.

Sample site(s) information:

Location description
Rorookiwa Hill, Bayview
Te Ana Falls, Tangoio Falls reserve
Aropaoanui Road above steep switchbacks
Pacific coast, north side Aropaoanui River mouth

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 496	2841846	6189837	-4
WP 499	2844917	6203568	90
WP 500	2853625	6206830	
WP 501	2855217	6206553	14

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 496	BASAL SANDSTONE	
	Ostrea chilensis	Common
	Talochlamys gemmulata	Common
	Eumarcia sp.	Some
	Gastropoda indet. spp.	Some
	SHELLBED	
	Talochlamys gemmulata	Abundant, dominant. Particulalrly large size
	Mesopeplum convexum	Some, quite large
	Ostrea chilensis	Abundant
	Atrina pectinata zelandica	Some, in situ
	Gastropoda indet spp.	Some
WP 499	*Talochlamys gemmulata*	Some, dominant
	Pelicaria convexa	Rare
WP 500	SILTSTONE	
	Talochlamys gemmulata	Common, dominant
	Ostrea chilensis	Some
	Stiracolpus/Zeacolpus	Some
	Atrina pectinata zelandica	Common, mixture of in situ and re-deposited
	SANDSTONE	
	Patro undatus	
	Ostrea chilensis	
WP 501	*Dosinia* sp.	Common, dominant
	Amalda sp.	
	Zegalerus sp.	
	Zethalia zelandica	Common
	Fellaster sp.	Common, present as fragments
	Gastropoda indet. gen. spp.	
	Bivalvia indet. gen spp.	

Additional Remarks

WP 496 (Mairau Mudstone Member): Shellbed sharply overlies fine sandstone. Comprises a very concentrated zone of large *Talochlamys* valves, many of which are intact.
WP 499 (Te Ngaru Mudstone Member): Sparse fauna in relatively massive, featurless siltstone.
WP 500 (Mairau Mudstone Member): Siltstone grading upsection into sandstone (HST-RST).
WP 501 (Darkys Spur Member): Fauna present in redeposited shell lenses in a well sorted sandstone (event-concentrated beds). Species present are typical of high-energy nearshore sandy beach environments.

Sample site(s) information:

Location description
Aropaonui Beach at cliffs to north of river
Kereru Road west of Whanakino Station gate
Kereru Road in last road cut before Kereru Station

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 502	2855556	6206726	0
WP 504	2806814	6168625	284
WP 505	2804490	6168219	257

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 502	*Austromegablanus dicorus*	Abundant, dominant, very large specimens
	Talochlamys gemmulata	Common
	Patro undatus	Common
	Ostrea chilensis	Common
	Amalda novaezelandiae	Some
	Atrina pectinata zelandica	in situ
	Alcithoe sp.	
	Tucetona laticostata	Some
	Bassina yatei	
	Divaricella huttoniana	
	Dosinia lambata	
	Eumarcia plana	
	Gari lineolata	
	?Myadora sp.	
	Panopea sp.	
	Tanea zelandica	
	Austrofusus glans	
	?Taniella sp.	
	Maoricolpus roseus	
	Gonimyrtea sp.	
	Struthiolaria c.f. *papulosa*	
	Glycymeris sp.	Large Glycymerid, species uncertain.
	?Cominella sp.	
WP 504	*Austrovenus stutchburyi/crassitesta*	Common, dominant. Many articulated
	Dosinia sp.	Single valve
	Xenostrobus ?huttoni	
	Barytellina crassidens	
	Barnacle indet. gen.	
	Turritalidae indet. gen.	
WP 505	Tawera sp.	Common, dominant
	Ostrea chilensis	Common
	Anomia trigonopsis	Common
	Pelicaria convexa	Some
	Poireria	Some
	Zeacolpus sp.	Some
	Atrina pectinata zelandica	Some

Additional Remarks

WP 502 (Aropaoanui Mudstone Member): Section in transitional zone (gradational) from Aropaoanui Mudstone Member to Darkys Spur Member (HST-RST). Most noticeably contains very large intact barnacles that are attached to each other forming large clusters. Fauna seem representative of inner-shelf water depths with moderate current energy.
WP 504 (Okauawa Formation): *Austrovenus*, many of which are articulated, dominate the faunal content. Flaser bedding and mud drapes are present throughout the outcrop. The presence of *Austrovenus, Barytellina* and *Xenostrobus* supports a confident estuarine depostional environment for this section.
WP 505 (Okauawa Formation): Fauna present in a massive siltstone.

Sample site(s) information:

Location description

Kereru Road at Whanakino Station gate

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 503	2809423	6168965	174

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 503	LOWER SILTY SANDSTONE	
	Gonimyrtea sp.	Very common, many articulated
	Tawera subsulcata	Abundant, dominant
	Zeacolpus sp.	
	Maorimactra ordinaria	
	Fellaster ?zelandiae	
	Ostrea chilensis	
	Myadora sp.	
	Serratina sp.	
	Micrelenchus	
	Zethalia zelandica	
	Patro undatus	
	FINE SANDSTONE	
	Dosinia subrosea	Becomes more common upsection
	Tawera subsulcata	
	Zethalia zelandica	
	Zeacolpus sp.	
	Fellaster ?zelanidae	
	Myadora sp.	
	Amalda mucronata	
	Amalda (Baryspira) c.f. *depressa*	
	Bassina sp.	
	Antisolarium comomiolea	
	Felaniella zelandica	
	SHELLBED	
	Tawera subsulcata	Abundant, dominant
	Talochlamys gemmulata	
	Ostrea chilensis	
	Dosina sp.	
	Pleuromeris sp.	
	Struthiolaria frazeri	Common, conspicuous
	Panis sp.	
	Maoricolpus roseus	
	Patro undatus	
	Pelicaria convexa	
	Waltonia inconspicua	
	Eumarica plana	
	Penion sulcatus	
	Modiolus sp.	
	UPPER SANDY SILTSTONE	
	Tawera subsulcata	Abundant, dominant
	Dosina subrosea	Common
	Patro undatus	
	Purpurocardia purpurata	
	Zeacolpus sp.	
	Maoricolpus roseus	
	Waltonia inconspicua	Scattered, present on top of shellbed
	SILTSTONE	
	Talochlamys gemmulata	Common, dominant
	Ostrea chilensis	Common
	Pelicaria convexa	Some
	Modiolus sp.	Rare

Additional Remarks

WP 503 (Okauawa Formation): Sandy siltstone coarsening upsection into fine sandstone. Overlain by shellbed, moderately fossiliferous sandy siltstone passing up into siltstone. Fauna decrease upsection into the finer-grained lithologies. *Tawera* and *Zethalia* become more common upsection towards the *Struthiolaria* shellbed. Fall-blocks from the top of the section contain very large *Austrovenus crassitesta*. The exact source of these blocks is uncertain however. The presence of *Pelicaria convexa* confirms a confident Upper Wn age for this unit.

Sample site(s) information:

Location description
Sentry Box hill in from Mangleton Road
Mangleton Road on south side of Jumped Up Stream bridge
Ridgemount Road, Tangoio Block
Ridgemount Road, Tangoio Block
Ridgemount Road, Tangoio Block

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 506	2792572	6166364	585
WP 507	2793446	6166514	427
WP 509	2849891	6214526	347
WP 510	2850521	6214848	404
WP 511	2850741	6214895	438

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 506	Cirripidea indet gen spp.	Abundant, dominant
	Sheet and branching bryozoans	Abundant
	Encrusting bryozoans	Uncommon
	Crassostrea ingens	Some
	Ostrea chilensis	Some
	Zygochlamys patagonica delicatula	Some
	Phialopecten triphooki	Some
	Mesopeplum convexum	Some
	Brachiopoda indet gen. spp.	Some
WP 507	Cirripidea indet gen spp.	Abundant, dominant
	Phialopecten triphooki	Rare
WP 509	*Divaricella huttoniana*	Common, frequently articulated and in situ
	Pteromyrtea dispar	Common, frequently articulated and in situ
	Calliostoma sp.	Common
	Pelicaria convexa	Some
	Pelicaria ?form *fossa*	
	Ostrea chilensis	Small valves
	Panopea	
	Paphies crassiformis	
	Zegalerus	
	Tawera sp.	
WP 510	*Ostrea chilensis*	Scattered valves
	Zeacolpus sp.	Some
	Dosina sp.	Uncommon
WP 511	*Eumarica* sp.	Abundant, dominant
	Panopea sp.	
	Gari sp.	
	Bivalvia indet gen spp.	Largely recrystallised

Additional Remarks

WP 506 (Sentry Box Formation): The co-occurrence of *Crassostrea ingens, Zygoclamys delicatula* and *Phialopecten triphooki* indicates a very basal Wn age for this unit. *Zygochlamys* also indicates a cold-water environment.
WP 507 (Top Sentry Box Formation): In gradational contact from Sentry Box Formation to mudstone of the Esk Formation. Muddy limestone, overlain by mudstone deposited in bathyal water depths. *Phialopecten triphooki* indicates an early Wn age.
WP 509 (Darkys Spur Member): Fauna suggestive of nearshore to inner-shelf environments with sandy substrates.
WP 510 (Mairau Mudstone Member): Blue-grey siltstone with scattered macrofossils.
WP 511 (Tangoio Limestone Member): Fauna dominated by aragonitic bivlaves which have mostly been recrystallised

Sample site(s) information:

Location description
Ridgemount Road near trig point
Ridgemount Road, Tangoio Block
Ridgemount Road, Tangoio Block
Ridgemount Road, Tangoio Block

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 512	2851843	6214035	486
WP 513	2852249	6214050	441
WP 514	2852955	6213316	360
WP 515	2853523	6213043	390

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 512	*Tawera subsulcata*	Common
	Gari	Some
	Ostrea chilensis	Some
	Dosinia	Some
	Eumarcia	Some
	Bivalvia undet. gen. spp.	Common, largely recrystallised
WP 513	*Ostrea chilensis*	
	Talochlamys gemmulata	
	Amalda sp.	
	Austrofusus sp.	
	Maoricolpus roseus	
	?Polincies sp.	
	Alcithoe sp.	
	Zethalia zelancia	
	Crepidula radiata	
	Bivalvia indet. spp.	Common
	Gastropoda indet. spp.	Common
WP 514	*Ostrea chilensis*	Common
	Patro undatus/Anomia trigonopsis	Common
	Gari sp.	
	Myadora sp.	
	Alcithoe sp.	
	Pteromyrtea dispar	
	Tawera subsulcata	Abundant
	Amalda sp.	
	Eumarcia sp.	
	Lutraria solida	
	Bivalvia indet spp.	Common, disarticulated and recrystallised
WP 515	*Ostrea chilensis*	Common
	Gari sp.	Common
	Purpurocardia purpurata	Some
	Bivalvia indet spp.	Common, disarticulated and recrystallised

Additional Remarks

WP 512 (Kaiwaka Formation): Coarse-grained shellhash-dominated limestone. Common greywacke pebbles and abundant disarticulated bivalves.
WP 513 (Devils Elbow Mudstone Member): Blue-grey to brown sandy siltstone. Probably represents the upper parts of an HST. Likely an inner- to middle-shelf environment of depostion.
WP 514 (Waipatiki Limestone Member): Shell lenses present, probably event-concentrated deposits in the upper part of a RST.
WP 515 (Kaiwaka Formation): Coarse-grained, moderately cemented limestone. Common disarticulated bivalves present. Fauna dominated by disarticulated recrystallised bivalves.

Sample site(s) information:

Location description
Mangaone River upstream of Olsen's
Mangaone River upstream of Olsen's
Mangaone River upstream of Olsen's
Mangaone River upstream of Patoka Stream
Mangaone River upstream of Rissington
Mangaone River upstream of Rissington
Mangaone River upstream of Rissington
Mangaone River downstream of Olsen's
Mangaone River downstream of Olsen's

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 518	2830375	6197087	98
WP 519	2829832	6197450	132
WP 522	2828833	6198081	110
WP 526	2826799	6202918	
WP 529	2830523	6189643	68
WP 530	2829714	6190864	
WP 532	2830161	6191404	63
WP 535	2829648	6195203	82
WP 538	2828909	6193775	77

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 518	*Paphies australis*	Common
	Austrovenus stutchburyi	Common
WP 519	*Pratulum pulchellum*	Common, present in small clusters
WP 522	*Pratulum pulchellum*	Some
WP 526	*Atrina pectinata zelandica*	Abundant
	Maoricolpus roseus	Very abundant, particularly large
WP 529	*Pralulum pulchellum*	Abundant, present in small clusters
	Maoricolpus roseus	Some
	?Cyclomactra	Uncommon
WP 530	*Pratulum pulchellum*	Dominant
	Alcithoe sp.	Some
WP 532	*Amalda mucronata*	Some
	Aneator marshalli marshalli	Some
WP 535	TOP OF CONGLOMERATE	
	Austrovenus stutchburyi	Common, intact disarticulated valves
	BASE SILTSTONE	
	Talochlamys gemmulata	Some
WP 538	*Paphies australis*	Common, articulated and disarticulated valves
	Purpurocardia purpurata	Common
	Crepidula radiata	Some
	Patro undatus/Anomia trigonopsis	Some
	Ostrea chilensis	Some

Additional Remarks

WP 518 (Matahorua Formation, Papakiri Member): *Paphies* occurs in a conglomerate bed that sharply overlies sandstone with conglomerate lenses that contain *Austrovenus*.
WP 519 (Matahorua Formation, Trelinnoe Member): Siltstone with *Pratulum* present in fall-blocks of this unit.
WP 522 (Matahorua Formation, Trelinnoe Member): Fine-grained massive to laminated sandy siltstone.
WP 526 (Pohue Formation): Non- to highly fossiliferous siltstone (HST). Passes upsection into sandstone and conglomerate. Fall-blocks rich in *Atrina* and *Maoricolpus*.
WP 529 (Esk Mudstone): Many *Pratulum* are quite large.
WP 530 (Esk Mudstone): Non to slightly fossiliferous siltstone.
WP 532 (Esk Mudstone): Siltstone with common tephra beds.
WP 535 (Matahorua Formation, Grassy Knoll Conglomerate Member): *Austrovenus* perhaps part of TST. *Talochlamys* present in pebbly siltstone marking transitional, gradational contact between TST shelly conglomerate and HST siltstone.
WP 538 (Top Matahorua Formation, Grassy Knoll Conglomerate Member): Fossils present in pebbly shelly layer capping non-fossilifeorus greywacke conglomerate, and gradationally underlying siltstone.

Sample site(s) information:

Location description
Glengarry Forest, track off Baker Road
Glengarry Forest, Tanks Road
Glengarry Forest, head of small stream
Glengarry Forest, Castle Hill Road quarry
SH5 south of Te Haroto
Big Hill Road at Poporangi Stream bridge
Taihape Road 300 m from Crownthorpe Rd

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 542	2829339	6202378	356
WP 547	2827589	6204652	393
WP 550	2827561	6204180	318
WP 552	2828057	6204529	359
WP 553	2821820	6223531	685
HB-B.D.12	2804868	6172364	201
HB-B.D.21	2815186	6182231	303

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 542	Bivalvia indet gen. spp.	Common, largely dissolved.
	Tucetona laticostata	
	Glycymeris sp. (prob. *shrimptoni*)	
	Phialopecten triphooki	Uncommon
	Mesopeplum convexum	
	Talochlamys gemmulata	
	Gari sp.	
	Gastropoda indet. gen. spp.	Common
WP 547	*Austrovenus stutchburyi*	Common
	Ostrea chilensis	Common
WP 550	*Austrovenus stutchburyi*	Some
	Ostrea chilensis	Some
	Perna canaliculis	Uncommon
WP 552	*Amalda* sp.	
	Crepidula	
	?Trochus sp.	
	Ostrea chilensis	
	Glycymeris sp. (prob. *shrimptoni*)	
	Barytellina sp.	
	Panopea sp.	
	Marama sp.	
WP 553	Flaballidae indet. gen.	Large specimens
HB-B.D.12	*Ostrea chilensis*	
	Austrofusus sp.	
	Pelicaria convexa	
	Maoricolpus roseus	
HB-B.D.21	*Pratulum pulchellum*	Sparse

Additional Remarks

WP 542 (Matahorua Formation, base Papakiri Member): Shelly conglomerate overlying non fossiliferous conglomerate (LST-TST). Contains L.O. *Phialopecten triphooki.* Fauna dominated by aragonitic bivalves that are largely dissolved, biomoulds common. Pectenids are more common in the upper 10-15 cm of the conglomerate.
WP 547 (Matahorua Formation, base Papakiri Member): Fauna present in fossiliferous conglomerate.
WP 550 (Matahorua Formation, base Trelinnoe Member): Fauna present in shelly conglomerate, likely to be slumped deposits from hill above.
WP 552 (Matahorua Formation, base Trelinnoe Member): Pebbly siltstone that gradationally overlies non fossiliferous conglomerate (LST-TST).
WP 553 (Waitere Formation, Rakaita Siltstone Member): Fine-grained sandstone. Fauna dominated by large solitary coral fossils.
H-B.B.D.12 (Okauawa Formation): The presence of *Pelicaria convexa* confirms an Upper Wn age for this unit.
H-B.B.D.21 (Okauawa Formation): Fauna sparse in unit.

Sample site(s) information:

Location description	Waypoint Name/No.	Eastings	Northings	Altitude (m)
Soldiers Settlement Road near 1st road cut	HB-B.D.22	2829334	6189195	75
Waipunga Road in sharp bend	WP 554	2840171	6204449	303
Waipunga Road in valley south of bridge	WP 556	2841087	6207233	348
Calstin Station, bluffs above Kikowhero Stm	WP 559	2812187	6170268	88
Kikowhero Stream below Omapere Rd bridge	WP 560	2820836	6170327	89

GPS Waypoint information:

Faunal List

Waypoint Number	Taxonomic Name	Comment
HB-B.D.22	*Pratulum pulchellum*	Abundant, dominant
	Atrina pectinata zelandica	Some
	Ostrea chilensis	Some
WP 554	*Tawera subsulcata*	Abundant, dominant
	Glycymeris shrimptoni	
	Tucetona laticostata	
WP 556	SANDSTONE	
	Perna canaliculis	Common
	Crepidula radiata	Common
	Tawera subsulcata	Some
	Penion sulcatus	Rare
	SHELLY SILTSTONE	
	Tawera sp.	Abundant, dominant. Small shell size
	Ostrea chilensis	
	Alcithoe sp.	
	Pelicaria convexa form *fossa*	
	MASSIVE SILTSTONE	
	Austrofusus sp.	
	Pelicaria convexa	
WP 559	*Tawera subsulcata*	Abundant, dominant
	Ostrea chilensis	Some
	Maoricolpus roseus	Some
	Amalda mucronata	
	Purpurocardia purpurata	
	Atrina pectinata zelandica	
	Talochlamys gemmulata	
	Zeacolpus/Stiracolpus sp.	
	Patro undatus	
	Austrofusus sp.	
	Penion sulcatus	
	Cominella sp.	
	Alcithoe brevis	
	Pelicaria convexa form *fossa*	
	Aneator marshalli marshalli	
	?Glaphyrina	
WP 560	*Pelicaria convexa*	
	Ostrea chilensis	
	Patro undatus	
	?Dosina sp.	
	Sigapatella novaezelandiae	

Additional Remarks

HB-B.D.22 (Esk Mudstone): Fauna dominated by *Pratulum*. Section located in farm paddock near road.
WP 554 (Waipatiki Limestone Member): Highly fossiliferous shelly limestone. Very similar in appearance to Waipatiki Limestone Member outcrops in the Matapiro-Ngamahanga regions. Fauna suggestive of a high-energy environment with relatively coarse bottom substrate.
WP 556 (Tangoio Limestone Member overlain by Te Ngaru Mudstone Member): Coarsening-upward package of sandstone-limestone, then siltstone-sandstone-limestone. Shelly siltstone overlies limestone. Fauna in massive siltstone are concentrated into thin (<10 cm thick) shell lenses. *Pelicaria convexa* confirms an Upper Wn age.
WP 559 (Te Ngaru Mudstone Member): Fauna changes upsection. *Tawera* remains dominant but beds of *Zeacolpus/Stiracolpus* and *Ostrea*-dominated faunas occur. *Pelicaria convexa* confirms an Upper Wn age.
WP 560 (Te Ngaru Mudstone Member): Scattered shells throughout with occasional highly fossiliferous beds. *Pelicaria convexa* confirms an Upper Wn age.

Sample site(s) information:

Location description
Kikowhero Stream, Matapiro Road bridge
Kikowhero Stream below Matapiro Road bridge

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 561	2819230	6172694	110
WP 562	2819623	6172419	110

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 561	*Tawera subsulcata*	Abundant, dominant and commonly articulated
	Ostrea chilensis	
	Dosinia ?nukumaruensis	Common
	Dosina zelandica	Some
	Lutraria solida	Common
	Gari stangeri	
	Gari lineolata	
	Patro undatus	
	Xenostrobus huttoni	
	Atrina pectinata zelandica	Some
	Paphies australis	
	Rhodoliths	
	Crepidula radiata	
	Alcithoe (Leporemax) fusus	
	Alcithoe arabica	
	Anomia trigonopsis	
	Purpurocardia purpurata	
	Cirripedea indet. gen.	Often encrusting pebbles
	Trochus viridus	
	Austrovenus stutchburyi	Uncommon, highly abraded
	Xymene plebieus	
	Calliostoma sp.	
	Maoricolpus roseus	
	Zeacolpus sp. (2 angular chords per whorl)	
WP 562	*Tawera subsulcata*	
	Ostrea chilensis	
	Paphies australis	Many articulated
	Lutraria solid	
	Modiolus areolatus	
	Calliostoma punctuata/granti	
	Alcithoe (Leporemax) fusus	
	Alcithoe arabica	
	Zeacumantus sp.	
	Xymene bonneti	
	Zethalia zelandica	Common
	Atrina pectinata zelandica	
	Pterymyrtea dispar	Small, very inflated
	Cominella (Josepha) sp.	
	Austrovenus stutchburyi	Rare, highly abraded
	Dosinia nukumaruensis	

Additional Remarks

WP 561 (Flag Range Conglomerate Member): Highly fossiliferous thick greywacke conglomerate. Mixture of reworked and *in situ* shellbeds. *Tawera* are abundantly articulated and in situ in silty interbeds within the conglomerate. Fauna suggest a harbour environment with shifting substrate. *Tawera* prefer sheltered environments e.g. Bay of Plenty, Hauraki Gulf with islands offshore, sandy substrates. Some *Lutraria* are encrusted with oyster spat.

WP 562 (Flag Range Conglomerate Member): Moderately fossiliferous conglomerate. This is a more reworked and sorted unit than the underlying site (WP 561) with less faunal diversity. Valves and shellhash are traction-current emplaced; previous waypoint largely *in situ*. Encrusting bryozoans are present on the inside of *Austrovenus* valves, which themselves are quite abraded.

Sample site(s) information:

Location description	Waypoint	Name/No.	Eastings	Northings	Altitude (m)
South end of Flag Range Road	WP 564		2818130	6184004	377
Taihape Road at Lambs Corners near Ohiti Rd	WP 565		2829392	6174954	40
Ohiti Road in cuttings just past Tauhara Rd	WP 566		2823356	6772228	77
Glengarry Rd near entrance to Tarua Farm	WP 569		2832901	6192959	285

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 564	*Tawera subsulcata*	Common
	Purpurocardia purpurata	Common
	Ostrea chilensis	Some
	Crepidula radiata	Some
	Bivalvia indet gen spp.	Common
	Gastropoda indet gen. spp.	Some
WP 565	*Zethalia zelandica*	Common
	Pteromyrtea dispar	
	Paphies australis	
	Tawera subsulcata	Abundant, dominant
	Xymene ambiguis	Some
	Xymene sp.	
	Crepidula radiata	Abundant
	Sigapatella novaezelandiae	Abundant
	Zeacolpus spp.	
	Stiracolpus spp.	
	Ostrea chilensis	Some
	Patro undatus	
	Serpulids	
	Nucula nitidula	Uncommon
	Calliostoma sp.	
	Cominella kereruensis	
	Cominella sp.	
	Zegalerus sp.	
	Dosinia sp.	
	Purpurocardia purpurata	
WP 566	*Tawera subsulcata*	Common, dominant
	Ostrea chilensis	
	Atrina pectinata zelandica	Rare
	Talochlamys gemmulata	
	Neothyris sp.	Common
	Brachiopoda indet. gen.	Common
	Stiracolpus sp.	
	Patro undatus	
WP 569	*Stiracolpus* sp.	
	Antalis nana	
	Talochlamys gemmulata	
	?Maorimactra ordinaria	
	?Neilo jugiferis	

Additional Remarks

WP 564 (Flag Range Conglomerate Member): Coarse-grained, highly fossiliferous shelly conglomerate, fauna dominated by aragonitic blivalves.
WP 565 (Waipatiki Limestone Member): *Tawera*-dominated and *Crepidula*-dominated shellbeds present, although *Tawera*-dominated beds are more common. Fauna well preserved, indicative of shallow-water, high-energy settings. *Zethalia zelandica* indicates a Wn age.
WP 566 (Kaiwaka Formation): Non fossiliferous fine sandstone sharply overlain by a highly-fossilifeorus shellbed across a vaugely irregular contact, which in turn grades into siltstone.
WP 569 (Te Ngaru Mudstone Member): Non- to slightly fossiliferous siltstone.

Sample site(s) information:

Location description
Pohokura Rd, Waitere Station above lake
Glenbrook Road near Waikari River, Putorino
Glenbrook Road near Glenbrook bridge
Waikare Road past Glenbrook Road
Kereru Rd west of Whanakino station gate
SH5 south of picnic area, Te Haroto side of Mohaka River

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 576	2838551	6233537	453
WP 578	2861731	6220319	30
WP 579	2857996	6221134	54
WP 580	2859130	6217784	110
WP 582	2806800	6168605	286
WP 584	2821378	6221951	606

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 576	Gastropoda indet gen spp.	Sparse
	Flabellidae indet gen.	Sparse
WP 578	*Antalis nana*	Sparse
	Pleuromeris sp.	Sparse
	Bivalvia indet gen spp.	Sparse
	Gastropoda indet. gen spp.	Sparse
WP 579	*Pratulum pulchellum*	Some
WP 580	*Panopea*	Common, articulated, reasonably in situ
	Atrina pectinata zelandica	Common
	Gastropoda indet gen. spp.	Common
WP 582	*Austrovenus stutchburyi*	Abundant, dominant
	Xenostrobus huttoni	Common
WP 584	*Struthiolaria (Callusaria) ?obesa*	Common
	Zeacolpus sp.	Abundant, dominant
	Tasmanomegabalanus	
	Austromegabalanus	
	Glycymerita sp.	
	Pelicaria ?nana	
	Divaricella huttoniana	
	Sigapatella novaezelandiae	
	Serpulids	
	Crepidula radiata	Common
	Zenatia acinaces	
	Eucrassatella sp.	
	Anomia trigonopsis	
	Eumarica benhami	
	Penion sp.	Uncommon
	Dosinia ?(Raina) sp.	Common
	?Kuia bellicata/Marama	
	?Crassostrea	
	Fissidentalium sp.	
	?Tucetona laticostata	

Additional Remarks

WP 576 (Waitere Formation, Te Ipuohape Member): Sparse macrofauna in a grey, firm siltstone.
WP 578 (Esk Mudstone): Barren to sparsely fossiliferous siltstone.
WP 579 (Esk Mudstone): Slightly fossiliferous siltstone with strongly bioturbated ash beds. Some *Pratulum* are present in burrows.
WP 580 (?Aropaoanui Mudstone Member): Strongly bioturbated fine sandstone to sandy siltstone. Scattered shellhash present throughout.
WP 582 (Okauawa Formation): Diagnostic estuarine fauna. Outcrop contains common mud drapes and flaser bedding. *Austrovenus* are often articulated.
WP 584 (?Pakaututu Formation): Fossiliferous blocks of coarse-grained shelly limestone, shelly sandstone and fossiliferous sandy siltstone. *Zeacolpus* very common in silty beds.

Sample site(s) information:

Location description
Kaiwaka Road, Tangoio Block
Top of McNeil, Rissington
Puketitiri Road east of Trigham Farm
Trigham Farm, Wai-iti Stream, base of cliff
Trigham Farm

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 591	2842081	6207855	472
WP 593	2828288	6188883	323
WP 599	2826151	6194925	291
WP 602	2823151	6194367	227
WP613	2825185	6194153	291

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 591	*Ostrea chilensis*	Some
	Gari/Paphies sp.	Some
	Talochlamys gemmulata	Some
	Eumarcia sp.	Some
	Encrusting bryozoans	Rare
WP 593	*Ostrea chilensis*	Common
	Perna canaliculis	One cast observed
WP 599	*Pratulum pulchellum*	
	Zeacolpus/Stiracolpus	
	Talochlamys gemmulata	
	?Maorimactra ordinaria	
	Maoricolpus roseus	
	Zenatia sp.	
WP 602	*Ostrea chilensis*	Common, dominant
	Patro undatus	Common
	Crepidula radiata	Common
	?Zegalerus sp.	
	Mesopeplum convexum	Common, many have growth ridges
	Purpurocardia purpurata	
	Talochlamys gemmulata	
	Sigapatella novaezelandiae	Common
	Maoricolpus roseus	
	Alcithoe sp.	
	?Phialopecten sp.	Possibly 1 small valve. Likely *P. triphooki*
	Limatula sp.	
	Xenostrobus huttoni	
	Atrina pectinata zelandica	
WP 613	LOWER 1/2 of SHELLBED	
	Xenostrobus huttoni	Common, dominant
	?Barytellina crassidens	
	UPPER 1/2 of SHELLBED	
	Tawera subsulcata	Common, co-dominant
	Ostrea chilensis	Common, co-dominant
	Purpurocardia purpurata	Some

Additional Remarks

WP 591 (Kaiwaka Formation): Limestone dominated by aragonitic bivalves, abundant biomoulds present in the unit. Very pebbly unit with abundant greywacke pebbles.
WP 593 (Flag Range Conglomerate Member): Very pebbly well cemented limestone. Only *Ostrea* valves and fragments observed, one *Perna* cast.
WP 599 (Esk Mudstone): Non to moderately fossiliferous, fine sandy siltstone. This unit (HST) overlies greywacke conglomerate (LST).
WP 602 (Matahorua Formation, base Trelinnoe Member): Fall-blocks sampled in stream, pebbly sandstone. Probably derived from top of greywacke conglomerate that caps cliff on opposite side of stream. Likely TST deposit.
WP 613 (Top Matahorua Formation, Grassy Knoll Conglomerate Member): Highly fossiliferous greywacke conglomerate capping non fossiliferous conglomerate (TST over LST). Shellbed divided into two parts with estuarine faunas in lower half, and more oceanic-type species in upper half. This is probably reflecting rising sea-level during sea-level transgression.

Sample site(s) information:

Location description
Trigham Farm
Top of Taradale Sugarloaf
Taihape Road, Flag Range side of Porthkenny
Flag Range Road near upper trig

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 614	2825106	6194303	287
WP 620	2839998	6179749	126
WP 621	2819771	6182149	261
WP 625	2820784	6185779	277

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 614	*Ostrea chilensis*	Common, dominant
	Bivalvia indet. gen. spp.	
WP 620	Bivalvia indet. gen. spp.	Abundant, dominant. Largely dissolved.
	Ostrea chilensis	Some
WP 621	*Zethalia zelandica*	Common, dominant
	Panopea/Lutraria	Some
	Austrovenus stutchburyi	Common
	Purpurocardia purpurata	Common
	Tawera subsulcata	Some
	Zeacolpus/Stiracolpus	Common
	Crepidula radiata	Common
	Ostrea chilensis	Common
	Dosinia ?anus	Common
WP 625	*Ostrea chilensis*	Common
	Eumarcia sp.	Common
	Purpurocarida purpurata	Common
	Tucetona laticostata	Common, some articulated
	Tawera subsulcata	Common
	Patro undatus	Some
	Alcithoe sp.	Uncommon

Additional Remarks

WP 614 (Top Matahorua Formation, Grassy Knoll Conglomerate Member): *Ostrea*-dominated pebbly shellbed (TST) capping non fossilifeorus greywacke conglomerate (LST).
WP 620 (Park Island Limestone Member): Pebbly limestone. Fauna dominated by aragonitic bivalves that have largely been dissolved with many biomoulds. Imprints of encrusting bryozoans visible on some shell moulds.
WP 621 (Flag Range Conglomerate Member): Highly fossiliferous conglomerate capping thick non fossiliferous conglomerate. Fauna dominated by shallow-water taxa such as *Zethalia, Dosinia* and *Austrovenus*. Most species present favour moderate to high-energy environments.
WP 625 (Flag Range Conglomerate Member): Fossiliferous greywacke conglomerate to pebbly limestone. *Ostrea* and *Eumarcia* more common in basal parts of the unit. Many valves show evidence of polychate bioerosion.

Sample site(s) information:

Location description
Puketitiri Road on Puketitiri side of Misty Valley

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 628	2817127	6206771	393

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 628	SHELLBED	
	Crassostrea ingens	Very common, some articulated and in situ
	Maoricardium spatiosum	Common, some articulated
	Trachycardium rossi	
	Alcithoe sp.	
	Crepidula sp.	
	Maoricolpus roseus	
	Stiracolpus sp.	
	Panopea sp.	
	Eumarcia benhami	Some
	Dosinia sp. (fine ribbed, not *Dosinia greyi*)	
	Notocallista multistriata	
	Atrina pectinata zelandica	
	Phialopecten indet. sp.	Rare
	Pectinidae indet. gen. (resembles *Sectipecten*)	Rare
	Cirripidea indet gen.	Some
	SANDSTONE	
	Atrina pectinata zelandica	
	Talochlamys gemmulata	Common
	Chlamys ?zelandiae	
	Pelicaria acuminata/caniculata	
	Poirireria zelandica	
	Struthiolaria (Struthiolaria) papuloa/orata	
	Zeacolpus vittatus	
	Maoricolpus roseus	Common
	Austrofusus pliocenicus	
	Crepidula radiata	
	Sigapatella noveazelandiae	
	Divaricella huttoniana	
	Pratulum pulchellum	
	Lamprodoninea neozelandica	
	Amalda mucronata	
	Glycymeris c.f. *shrimptoni*	
	Dosinia greyi	Common
	Patro undatus	
	Serratina sp.	
	Fissidentalium sp.	
	Panopea sp.	Articulated, in situ

Additional Remarks

WP 628 (Puketitiri Formation): Highly fossiliferous shellbed sharply overlies sandy siltstone, and is in turn overlain by fine sandstone. Lowermost sandy siltstone is non fossiliferous. Shellbed notably contains a concentration of *Crassostrea* and *Maoricardium*. Many *Crassostrea* are attached to each other, and may have grown on a firm-ground developed on top of the underlying sandy siltstone. Fauna suggests a Wm age, though very close to the Wm-Wn boundary as many species show transitional features between other species. The presence of *Maoricardium spatiosum* confirms an age no younger than Wm for this unit.

Sample site(s) information:

Location description
Puketitiri Road near mountain view lookout
Mount Cameron on western face
Puketitiri Road near Brooklands Station

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 631	2826982	6193981	236
WP 639	2824070	6188291	224
WP 643	2837023	6185469	42

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 631	LOWER SHELLBED	
	Austrovenus stutchburyi	
	Paphies australis	
	Ostrea chilensis	
	MIDDLE SHELLBED	
	Ostrea chilensis	
	Patro undatus	
	UPPER SHELLBED	
	Ostrea chilensis	Almost all juvenille specimens
	Talochlamys gemmulata	
	Austrovenus stutchburyi	
	Patro undatus/Anomia trigonopsis	
	SILTY SANDSTONE	
	Amalda sp.	
	Pratulum pulchellum	
	Maoricolpus roseus	
	Pleuromeris sp.	
WP 639	*Ostrea chilensis*	Common, dominantly juvenille specimens
	Talochlamys gemmulata	Common
	Crepidula radiata	Some
	Maoricolpus roseus	
	Stiracolpus/Zeacolpus	
	Austrovenus stutchburyi	
	Dosina sp.	
	Xenostrobus huttoni	
	Crepidula radiata	
	Trochus sp.?	
	Tawera sp.	
	Pleuromeris sp.	
	Sheet bryozoans	
WP 643	*Tawera subsulcata*	
	Sigapatella novaezelandiae	
	Talochlamys gemmulata	
	?Turbo sp.	
	Purpurocardia purpurata	
	Eumarcia sp.	
	Paphies australis	
	Crepidula radiata	
	Patro undatus	
	Maoricolpus roseus	
	Penion sulcatus	

Additional Remarks

WP 631 (Top Matahorua Formation, Grassy Knoll Conglomerate Member): Top of greywacke conglomerate bed with three fossil-rich zones, overlain by a slightly to sparsely fossiliferous sandy siltstone. Fossiliferous conglomerate beds (TST) total approx. 1.7 m thick and themselves overlie non fossiliferous greywacke conglomerate (LST). The fossil content in the sandy siltstone decreases upsection.
WP 639 (Okauawa Formation): Shellbed in sandy siltstone approx. 1.5 m above non fossiliferous greywacke conglomerate.
WP 643 (Tangoio Limestone Member): Sandy shelly limestone with scattered bivalves and gastropods.

Sample site(s) information:

Location description
Waihau Road face of Mount Cameron
Track up Waihau Rd side of Mount Cameron
Hilltops above Dartmoor Road
Ruawai Station above Tutaekuri River
Ruawai Station in small valley
Ruawai Station overlooking Rissington

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 645	2825180	6188123	321
WP 646	2825159	6188088	331
WP 659	2830596	6183475	123
WP 662	2829308	6185114	180
WP 667	2829931	6184827	140
WP 673	2830120	6185737	205

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 645	*Zethalia zelandica*	Common, often concentrated into lenses
	Paphies australis	
	Bivalvia indet gen. spp.	
	Patro undatus	Scattered
	Ostrea chilensis	Scattered
WP 646	*Ostrea chilensis*	Common
	Patro undatus	Some encrusted with barnacles
	Oxyperis/Eucrassatella	Rare
	Lutraria solida	Uncommon
	Tawera subsulcata	Some
	Cirripedea indet. gen.	Some to abundant
	Bivalvia indet. gen. spp.	Common, present as biomoulds
	Gastropoda indet. gen. spp.	Some, present as biomoulds
WP 659	*Ostrea chilensis*	Some, caps top of limestone
	Bivalvia indet gen. spp.	Abundant, dissolved and recrystallised
WP 662	*Ostrea chilensis*	Common, caps top of limestone
	Bivalvia indet gen. spp.	Abundant, dissolved and recrystallised
WP 667	*Zethalia zelandica*	Common
	Austrovenus stutchburyi	Common
	Patro undatus	Some
	Mactra sp.	Some
	Zeacumantus/Pervericacia	Uncommon
	Myadora sp.	Some
WP 673	PEBBLY LIMESTONE	
	Ostrea chilensis	Common, *Ostrea* beds almost monspecific
	Bivalvia indet gen. spp.	Abundant, dissolved and recrystallised
	SHELLY SANDSTONE	
	Tawera subsulcata	Common, dominant
	Paphies australis	
	Perna canaliculis	
	Lutraria	
	Zethalis zelandica	
	Atrina pectinata zelandica	Rare
	Cirripedea indet. gen.	
	?Mactra sp.	
	?Eumarcia sp.	

Additional Remarks

WP 645 (Flag Range Conglomerate Member): Bioturbated fine sandstone with discrete event-concentrated shell-lenses and scattered oyster valves. Overlies siltstone, overlain by very pebbly limestone.
WP 646 (Flag Range Conglomerate Member): Interbedded pebbly limestone, sandstone and conglomerate. Package sharply overlies non to slightly fossiliferous sandstone. Fossiliferous throughout, with greywacke clasts common in all facies. In places the basal conglomerate bed of the package contains tightly packed beds of barnacles, with common *Ostrea* interbedded. Abundant biomoulds through the unit from dissolved aragonitic bivalves and lesser gastropods.
WP 659 (Waipatiki Limestone Member): *Ostrea* present in thin shellbed that caps biomould-rich limestone.
WP 662 (Waipatiki Limestone Member): *Ostrea* present in thin shellbed that caps biomould-rich limestone.
WP 667 (Flag Range Conglomerate Member): Non fossiliferous conglomerate (LST) capped by a highly fossiliferous pebbly shellbed (TST) that grades into fine-grained sandstone with ripple-laminated and flaser bedded siltstone stringers.
WP 673 (Waipatiki Limestone Member): Pebbly limestone overlying calcareous sandstone and shelly sandstone. Fauna in limestone dominated by aragonitic bivalves that are largely dissolved. Common biomoulds present. Fauna in shelly sandstone indicate nearshore to inner shelf environments.

Sample site(s) information:

Location description	Waypoint Name/No.	Eastings	Northings	Altitude (m)
Farm Track on Butchers Farm, Flag Range	WP 678	2819130	6184269	317
Butchers Farm near woolshed, Flag Range	WP 679	2819505	6184452	299
Flag Range near Butchers Farm woolshed	WP 680	2819653	6184413	302
Flag Range SE of Butchers Farm woolshed	WP 683	2820060	6183885	252
Flag Range SE of Butchers Farm woolshed	WP 684	2820291	6183658	244
Tuna-nui Station below Flag Range	WP 699	2817652	6184216	284

GPS Waypoint information:

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 678	*Ostrea chilensis*	Abundant, dominant
	Patro undatus	Uncommon
	Purpurocardia purpurata	Some
	Encrusting bryozoans	
WP 679	*Ostrea chilensis*	Abundant, dominant
	Purpurocardia purpurata	Uncommon
	Patro undatus	Uncommon
WP 680	*Dosina sp.*	Common
	Purpurocardia	Common
	Tawera subsulcata	Common
WP 683	*Ostrea chilensis*	Abundant, dominant
	Purpurocardia purpurata	Common
	Alcithoe sp.	Some
	Branching and encrusting bryozoans	Many
	Crepidula radiata	Some
	?Eumarcia sp.	Rare
WP 684	*Xenostrobus huttoni*	
	Paphies australis/Gari sp.	
	Tawera subsulcata	
	Purpurocardia purpurata	
	Sigapatella novaezelandiae	
	Ostrea chilensis	Common to abundant
	Eumarcia sp.	
	Dosinia sp. (small size)	
	Patro undatus/Anomia trigonopsis	
	Crepidula radiata	
	Tucetona laticostata	
	Serpulids	Rare
WP 699	*Talochlamys gemmulata*	Common, dominant
	Ostrea chilensis	Some
	Atrina pectinata zelandica	Some
	Patro undatus	Some
	Amalda mucronata	Some

Additional Remarks

WP 678 (Flag Range Conglomerate Member): Pebbly shelly limestone. Virtually monospecific faunal composition to this unit.
WP 679 (Flag Range Conglomerate Member): Pebbly shelly limestone. Almost monospecific composition to limestone. *Ostrea* valves largely disarticulated, though some articulated specimens are present. Bioerosion is common, many valves show borings. *Ostrea* are largely adult, some smaller juvenilles are present.
WP 680 (Te Ngaru Mudstone Member): Pebbly siltstone that overlies pebbly *Ostrea*-dominated limestone.
WP 683 (Flag Range Conglomerate Member): Highly fossiliferous pebbly limestone, packed with *Ostrea* valves.
WP 684 (Flag Range Conglomerate Member): Greywacke-rich shellbeds overlying pebbly limestone. Fauna changes up through the shellbed with *Ostrea* becoming more common. *Xenostrobus* and *Paphies/Gari* are present at the base of the shellbed. Possible deepening-upward trend through shellbed.
WP 699 (Okauawa Formation): Slightly fossiliferous sandy siltstone. Both *Talochlamys* and *Ostrea* are present in a range of sizes.

Sample site(s) information:

Location description	Waypoint Name/No.	Eastings	Northings	Altitude (m)
Flag Range crest near Poplar trees	WP 700	2819493	6184873	318
Flag Range on driveway to Bilby's house	WP 731	2820567	6186188	238
Waikonini Stream below Bilby's, Flag Range	WP 736	2820739	6186988	115
Waikonini Stream below Bilby's, Flag Range	WP 737	2820568	6187055	83
Waikonini Stream below Bilby's, Flag Range	WP 739	2821045	6187299	105
Tutaekuri River below Waikonini Stream	WP 745	2822006	6188550	115

GPS Waypoint information:

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 700	*Ostrea chilensis*	Some to abundant
	Bivalvia indet gen. spp.	Abundant, largely dissovled, some recrystallised
	Tucetona laticostata	Some
	Perna canaliculis	Rare
	Rhodoliths	Common at top of limestone
	Encrusting bryozoans	Present, typically on *Ostrea* valves
WP 731	*Talochlamys gemmulata*	Common, dominant
	Ostrea chilensis	Some
	Tawera subsulcata	Some
	Crepidula radiata	Some
	Pteromyrtea dispar	Some
	Sigapatella novazelandiae	Some
	?Trochus sp.	Rare
	Zeacolpus sp.	Some
WP 736	*Pratulum pulchellum*	Common, dominant
WP 737	*Ostrea chilensis*	Common, co-dominant
	Paphies australis	Common, co-dominant
	Tawera subsulcata	Some
	Dosinia sp.	Some
WP 739	*Ostrea chilensis*	Common, dominant
	Talochlamys gemmulata	Uncommon
	Tawera subsulcata	Common
	Crepidula radiata	Some
	Eumarcia sp.	Some
	Encrusting bryozoans	
WP 745	CONGLOMERATE	
	Paphies australis	Common, dominant
	Ostrea chilensis	Scattered
	?Mactra sp.	Uncommon
	Eumarcia sp.	Uncommon
	SHELLBED	
	Tawera subsulcata	Abundant, dominant
	Ostrea chilensis	Abundant
	Purpurocardia purpurata	Common
	Dosinia sp.	Common
	Patro undatus	Common
	SILTSTONE	
	Pratulum pulchellum	Some
	Talochlamys gemmulata	Some
	Alcithoe sp.	Single internal spire observed

Additional Remarks

WP 700 (Flag Range Conglomerate Member): Most bivalves are disarticulated, fauna dominated by aragonitic bivalves. *Ostrea* valves commonly display evidence of bio-erosion. Upper surface of the limestone notably contains common large bryozoan clusters up to 7-8 cm across. Fossil content varies through the unit with difference concentrations of taxa in different levels.
WP 731 (Okauawa Formation): Bioturbated sandstone with siltstone stringers sharply overlain by shellbed and siltstone. Valves are partially dissolved and grouped into two discrete layers 10-15 cm thick.
WP 736 (Esk Mudstone): Siltstone. with *Pratulum* present in tightly packed clusters.
WP 737 (Top Matahorua Formation, Grassy Knoll Conglomerate Member): Non fossiliferous greywacke conglomerate (LST) overlain by thin shellbed (TST) and siltstone (HST). Many *Paphies* are articulated.
WP 739 (Top Matahorua Formation, Grassy Knoll Conglomerate Member): Shellbed capping non fossiliferous greywacke conglomerate, gradationally overlain by siltstone. *Ostrea* valves, present in a large range of sizes, have many irregular shapes and are disarticulated.
WP 745 (Top Matahorua Formation, Grassy Knoll Conglomerate Member): Fossiliferous conglomerate, capped by a more highly fossiliferous shellbed, in turn abruptly although gradationally overlain by siltstone.

Sample site(s) information:

Location description
Flag Range, face above Waikonini Stream
Flag Range, face above Waikonini Stream
Devils Elbow Section
Devils Elbow Section

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 746	2820441	6186532	192
WP 747	2820273	6186470	197
WP 750	2844776	6208068	150
WP 751	2844965	6208038	168

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 746	*Atrina pectinata zelandica*	Single specimen, in situ
	Talochlamys gemmulata	Uncommon
	Pratulum pulchellum	Uncommon
WP 747	*Ostrea chilensis*	Scattered small clusters
	Talochlamys gemmulata	Some
	Atrina pectinata zelandica	Some
WP 749	*Ostrea chilensis*	Common
	Purpurocardia purpurata	Common
	Cirripidea indet gen.	Some
WP 750	A) BASE SANDSTONE	
	Gonimyrtea sp.	
	Fellaster	Dominant
	Calliostoma sp.	
	Sigapatella	
	Tanea	
	Gari lineolata	
	Atrina pectinata zelandica	
	Neilo sp.	
	Maorimactra ordinaria	
	Stiracolpus sp.	
	B) SANDSTONE approx 4 m upsection	Dominant
	Fellaster	
	Sigapatella	
	C) SANDSTONE approx 1 m upsection	
	Oxyperis	
WP 751	A) BASE SILTSTONE	
(cont. over)	*Ostrea chilensis*	Adult and juvenille valves
	Talochlamys gemmulata	Common, dominant
	Penion sulcatus	
	Pelicaria convexa	
	Maoricolpus roseus	
	Austrofusus sp.	
	Zeacolpus vittatus	
	Dosinia greyi	
	Alcithoe brevis	
	Alcithoe arabica	
	Bassina sp.	
	Amalda mucronata	
	Panis zealandica (Isognomon)	
	Neothyris sp.	
	Brachiopoda indet gen.	
	Caryocorbula sp.	
	Aneator marshalli marshalli	
	Flabellidae indet. gen.	

Additional Remarks

WP 746 (Esk Mudstone): Siltstone contains a strongly burrowed tephra bed.
WP 747 (Esk Mudstone)
WP 749 (Flag Range Conglomerate Member): Top of moderately to highly fossiliferous greywacke conglomerate.
WP 750 (Darkys Spur Member): A) Massive to concretionary fine sandstone. B) *Fellaster* is no longer dominant, *Sigapatella* is. C) Bioclastic-rich sandstone, major change in fauna.
WP 751 (near base Mairau Mudstone Member): A) Moderately fossiliferous siltstone. Some *Ostrea* valves are bioeroded, many are thick-shelled. Lower 2 m of unit more fossilifeorus than upper parts. Fossil content rapidly drops upsection.

Sample site(s) information:

Location description
Devils Elbow Section
Devils Elbow Section
Devils Elbow Section

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 751	2844965	6208038	168
WP 752	2845053	6208056	172
WP 753	2845266	6208052	180

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 751	B) SILTSTONE approx 2 m upsection	
(cont)	*Lucinoma* sp.	
	Antalis nana	
	Myadora sp.	
	Talochlamys gemmulata	
	Ostrea chilensis	
	Neilo australis	
	Zeacolpus sp.	
	Amalda depressa	
	Pratulum pulchellum	
	Cadulis delicatulis	
	Notocallista multistriata	
	Mucula nitidula	
	Pelicaria convexa	
	Iradelula sp.	
	A) SILTSTONE	
WP 752	*Pelicaria convexa*	
	Antalis nana	
	Amalda mucronata	
	Amalda novaezelandiae	
	Ostrea chilensis	
	Cadulis sp.	
	Maoricolpus roseus	
	Stiracolpus sp.	
	Neilo sp.	
	Myadora sp.	
	Notocallista sp.	
	Taniella tanisutralis	
	?Goinomyrtea sp.	
	B) SILTSTONE approx 4 m upsection	
	Stiracolpus spp., numerous fine ribs	Dominant, 2 species present
	Ostrea chilensis	
	Neilo sp.	
	Amalda novaezelandiae	
	Taniella sp.	
	Maoricolpus roseus	
	Dosinia greyi	
	Austrofusus ?chathamensis	
	Notocallista notostriata	
WP 753	*Pelicaria convexa*	
	Ostrea chilensis	
	Amalda novaezelandiae	
	Talochlamys gemmulata	
	Frignatcia sp.	
	Zenatia sp.	
	Penion sulcatus	
	Maoricolpus roseus	
	Pratulum pulchellum	
	Taniella sp.	
	Notocallista multistriata	
	Stiracolpus sp.	
	Pleuromeris sp.	

Additional Remarks

WP 751 (Mairau Mudstone Member): B) At least 10 m of such section present. *Iradelula* is biostratigraphic, and indicative of offshore environments.
WP 752 (Mairau Mudstone Member): A) Slightly fossiliferous siltstone. B) Slightly fossiliferous siltstone with *Stiracolpus* now dominant.
WP 753 (upper Mairau Mudstone Member): Non cemented, slightly fossiliferous siltstone. *Pelicaria convexa* showing a deeper suture than specimens in lower units. Becoming more like *P. convex*a form *fossa*.

Sample site(s) information:

Location description
Devils Elbow Section
Devils Elbow Section
Devils Elbow Section

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 754	2845402	6208015	182
WP 755	2845750	6208057	222
WP 756	2845850	6207959	229

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 754	*Tawera subsulcata*	
	Maorimactra ordinaria	
	Oxyperis sp.	Fragments present
	Serratina sp.	
	Calliostoma sp.	
	Cirripidea indet gen.	
WP 755	A) SILTSTONE	
	Pelicaria convexa form *fossa*	
	Taniella sp.	
	Ostrea chilensis	
	Talochlamys gemmulata	
	Austrofusus taitae	
	Pratulum pulchellum	
	B) SILTSTONE approx 1.5 m upsection	
	Pelicaria convexa form *fossa*	
	Ostrea chilensis	
	Maoricolpus roseus	
	Alcithoe brevis	
	Talochlamys gemmulata	
	Dosinia greyi	
	Dosinia lambata	
	Penion sulcatuc	
	Perna canaliculis	
	Austrofusus sp.	
	Amalda depressa	
	Zenatia sp.	
	C) SILTSTONE approx 1 m upsection	
	Talochlamys gemmulata	
	Ostrea chilensis	
WP 756	A) SHELLBED approx 0.7 m thick	
(cont over)	*Tawera subsulcata*	Common, dominant
	Purpurocardia purpurata	Common
	Ostrea chilensis	Common
	Cirripedea indet. gen.	Some
	Talochlamys gemmulata	Present in topmost part of shellbed
	Neothyris sp.	Present in topmost part of shellbed
	Atrina pectinata zelandica	Present in topmost part of shellbed
	B) SILTY SANDSTONE-SHELLBEDS approx 2m thick	
	Tawera subsulcata	
	C) SHELLBED approx 2 m thick	
	Tawera subsulcata	
	Perna canaliculis	
	Cirripedea indet. gen.	
	Ostrea chilensis	

Additional Remarks

WP 754 (Tangoio Limestone Member): Slightly fossiliferous, strongly cross-bedded sandstone with a high bioclastic-component. Macrofossils typically concentrated into occasional lenses.
WP 755 (Te Ngaru Mudstone Member): A) Non cemented slightly fossiliferous siltstone. B) Unit is more *Pelicaria convexa* form *fossa*-rich. C) *Talochlamys* becomes more dominant, with *Ostrea* interbedded with clusters of shellhash. Rapidly passes into firm sandstone.
WP 756 (Waipatiki Limestone Member): A) Massive to laminated fine sandstone capped by shellbed. Shellbed capped by a 0.15-0.2 m-thick layer of *Ostrea*, *Atrina, Talochlamys* and *Neothyris*. B) Alternating beds of silty sandstone and *Tawera*-dominated shellbeds. C) Slightly cemented *Tawera*-dominated shellbed rich in dissolved articulated and disarticulated valves.

Sample site(s) information:

Location description
Devils Elbow Section
Devils Elbow Section
Devils Elbow Section

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 756	2845850	6207959	229
WP 757	2846028	6207938	236
WP 758	2846137	6207946	253

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 756	Bivalvia indet gen. spp.	Abundant, dominant
	Tawera subsulcata	
	Ostrea chilensis	
WP 757	A) BASE SILTSTONE	
	Poirireria sp.	
	Austrofusus taitae	
	Pelicaria convexa form *fossa*	
	Amalda depressa	
	Amalda mucronata	
	Amalda novaezelaniae	
	Talochlamys gemmulata	
	Pratulum pulchellum	
	Ostrea chilensis	
	Waltonia inconspicua	
	?Amygdalum striatum	
	?Neilo sp.	
	B) SILTSTONE several metres upsection	
	Talochlamys gemmulata	Common, dominant
	Ostrea chilensis	Common
	Atrina pectinata zelandica	Some
	Alcithoe brevis	Some
	Pratulum pulchellum	
	Antalis nana	
	Stiracolpus sp.	
	Cominella sp.	
	Pelicaria convexa form *fossa*	Some
	Poirireria sp.	Uncommon
WP 758	SHELLBED	
	Talochlamys gemmulata	
	Tegulorhychia nigricans	
	Bivalvia indet gen. spp.	Fragments
	SILTSTONE	
	Talochlamys gemmulata	
	Tegulorhychia nigricans	
	Pleuromeris sp.	Rare specimens are articulated
	Dosinia greyi	
	Zeacolpus (very fine ribs)	
	Maorimactra ordinaria	
	?Eumarcia plana	
	Tanea sp.	
	Struthiolaria sp. *?papulosa*	
	Amalda novaezelandiae	
	Austrofusus taitae	
	Turrids spp.	

Additional Remarks

WP 756 (Waipatiki Limestone Member): Shelly limestone dominated by dissolved and partially recrystallised aragonitic bivalves. Limestone comprises two parts comprising a basal bioclastic sand-dominated layer sharply overlain by a bioclastic gravel-dominated layer.
WP 757 (Devils Elbow Mudstone Member): A) Siltstone sharply overlying limestone. Assemblage characteristic of middle-to outer-shelf environments in Hawke's Bay Wn mudstones. B) Upsection unit becomes less fossiliferous with *Talochlamys* more common with *Ostrea*. Macrofossils are scattered up through the section.
WP 758 (Devils Elbow Mudstone Member): Thin *Talochlamys*-brachiopod shellbed overlain by fossiliferous siltstone. Further upsection the faunal content drops as the background sediment coarsens.

Sample site(s) information:

Location description
Top of Devils Elbow Section
SH2 at turnoff to Aropaoanui Beach
Crownthorpe Settlement Road
Taihape Road near Willowford Road intersection

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 759	2846139	6207878	259
WP 760	2845821	6207035	341
WP 761	2822686	6177676	305
WP 762	2809650	6190400	298

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 759	A) SILTY SANDSTONE	
	Bassina yatei	
	Maorimactra ordinaria	
	Dosinia lambata	
	Serratina sp.	
	Dosinia greyi	Specimens in situ
	Myadora stephaniae	
	B) SILTY SANDSTONE approx 3 m upsection	
	Tawera subsulcata	Some, articulated
	Fellaster zelanidae	Relatively intact
	Ostrea chilensis	
	Bassina ?yatei	
	Cirripedea indet. gen.	Present as plates
	C) SILTY SANDSTONE approx 2 m upsection	
	Tawera subsulcata	Abundant, dominant
	Cirripedea indet gen.	Intact and as plates
	D) SHELLY LIMESTONE approx 3 m upsection	
	Tawera subsulcata	Common, valves and as fragments
WP 760	*Ostrea chilensis*	Common, dominant
	Purpurocardia purpurata	
	Talochlamys gemmulata	
	Limatula sp.	
	Dosina sp.	
	Polinices sp.	
	Neothyris sp.	
	Branching bryozoans	Fragments
WP 761	Ostrea chilensis	
	Purpurocardia purpurata	
WP 762	*Mygdolum striatum*	
	Maorimactra ordinaria	
	Atrina pectinata zelandica	Some, occasionally in situ
	Dosinia greyi	
	Pratulum pulchellum	
	Talochlamys gemmulata	
	Taniella sp.	
	Pelicaria sp. (*?convexa*)	Rare, single highly fragmented specimen
	Austrofusus taitae	
	Sigapatella novaezelandiae	
	Crab carapace	
	Offadesma angasai	

Additional Remarks

WP 759 (Devils Elbow Mudstone Member): Fauna and grainsize show a shallowing-upwards pattern with *Tawera* becoming more common up section. A) Silty sandstone with sandy siltstone bioturbated interbeds. B) Change in fauna from below with common articulated *Tawera*. Fauna is relatively sparse through this interval with background sediment coarse-grained. C) Sediment much richer in *Tawera*, moderately to tightly packed, many articulated. Sharply overlain by coarse-grained shelly limestone with broad amplitude erosional relief on the contact. D) Top of coarse-grained shelly limestone. Top of limestone marked by a concentration of *Tawera* valves and fragments set in a shellhash matrix. Mud lenses present that display flaser bedding.
WP 760 (Kaiwaka Formation): Coarse-grained pebbly shelly limestone, fauna dominated by *Ostrea*.
WP 761 (Flag Range Conglomerate Member): Non fossiliferous greywacke conglomerate (LST) capped by thin pebbly shellbed (TST).
WP 762 (?Pohue Formation): *Pelicaria* species uncertain. Whorls look like *P. convexa*, although the fragmented nature of specimen makes identification difficult. Has important implications for age of unit.

Sample site(s) information:

Location description	Waypoint	Name/No.	Eastings	Northings	Altitude (m)
Puketitiri Road just past Misty Valley	WP 764		2817075	6206795	567
Hilltop above Baldy Quarry, Whittle Road	WP 765		2809000	6207579	805
Waldon Road on slope down to ford	WP 766		2815898	6191691	190
Waldon Road on slope down to ford	WP 767		2815651	6191997	234
Mangatutu Stream near bridge	WP 768		2815713	6191572	142
Jumped Up Stream above Mangleton Rd	WP 769		2793370	6166562	454

GPS Waypoint information:

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 764	**REFER TO RECORD FOR WP 628**	
WP 765	*Crassostrea ingens*	Sparse
	Bivalvia indet gen. spp.	Abundant, fragments
	Cirripedea indet gen.	Abundant, fragments
WP 766	*Pratulum pulchellum*	Present in packed clusters
	Dosinia greyi	
	Taniella sp.	
	Notocallista sp.	
	Atrina pectinata zelandica	
	Ostrea chilensis	
	Talochlamys gemmulata	
	Penion sulcatus	Rare, immature specimen
	Stiracolpus sp.	
	Alcithoe hawaerensis	
	Austrofusus pliocenica	
	Myadora sp.	
	Sigapatella sp.	
	Zenatia acinaces	
	Pelicaria acuminata	
	Austrofusus c.f. *taitae*	
WP 767	*Atrina pectinata zelandica*	
	Dosinia greyi	
	Pratulum pulchellum	Dominant
	Ostrea chilensis	
	Taniella sp.	
	Talochlamys gemmulata	
	Stiracolpus sp.	
	Alcithoe hawaerensis	
	Alcithoe c.f. *fusus*	
	Austrofusus c.f. *taitae*	
	Zenatia acinaces	
WP 768	*Atrina pectinata zelandica*	Some, dominant
	Pelicaria acuminata	Uncommon
	Zeacolpus sp.	Some
	Zethalia sp.	Uncommon
WP 769	*Neilo* sp.	Dominant
	Notocallista sp.	
	Calliostoma sp.	
	Talochlamys gemmulata	
	Pleuromeris sp.	
	Nuculanid sp.	

Additional Remarks

WP 765 (?Te Waka Formation): Blocks of coarse-grained sandy limestone as part of mass movement deposits. Sparse intact fauna present, dominated by fragments of bivalves and barnacles.
WP 766 (Pohue Formation): Blue-grey siltstone. Fauna suggest a late Wm-Wn age. Both *Atrina* and *Pratulum*-dominated communities are present.
WP 767 (Pohue Formation): Blue-grey siltstone. Taxa suggest a late Wm-Wn age.
WP 768 (Pohue Formation): Massive siltstone. *Zethalia* are probably derived from wash from coarser-grained, shallower-water units above.
WP 769 (Upper Kaumatua Formation): Non cemented, massive to weakly laminated siltstone. Shells largely dissolved, biomoulds remain. *Neilo* dominated.

Sample site(s) information:

Location description
Jumped Up Stream 20 m above Mangleton Road bridge
Jumped Up Stream 30 m below Mangleton Road bridge

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 770	2793431	6166536	460
WP 771	2793509	6166513	455

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 770	*Austromegabalnus dicorus*	Abundant, co-dominant
	Fosterella dubulatus	Abundant, co-dominant
	Tucetona (?not *laticostata*)	
	Aulacomya ater maoirana	
	Modiolus sp.	
	Talochlamys gemmulata	Common
	Mesopeplum convexum	Common
	Phialopecten triphooki	Some
	Zygochlamys patagonica delicatula	Rare to some
	Crassostrea ingens	
	Limatula sp.	
	?Ostrea chilensis	
	Cadita aoteana	
	Purpurocardia purpurata	
	Marshallena sp.	
	Aneator (Ellieca) sp.	
	Aneator marshalli marshalli	
	Pteromyrtea dispar	
	Maoricardium spatiosum	
	Marama murdochi	
	?Eumarica plana	
	Oxyperis komkoensis	
	Cadulis sp.	
	Talabrica sp.	
	Galeodia sp.	
	Acmaeid sp.	
	Thracia magna	
	Pelicaria acuminata	
	Calliostoma sp.	
	Alcithoe (Alcithoe) sp.	
	Alcithoe (Leporemax) fusus	
	Zeacolpus sp.	
	Sigapatella novaezelandiae	
	Taniella sp.	
	Amalda depressa	
	Phemotma sp.	
	Lamprodominea neozelandica	
	Cominella sp.	
	Austrofusus c.f. *glans*	
	Hartungia typica	
	?Tonui actom	
	Serpulids	
WP 771	TOP OF LIMESTONE	
(cont over)	*Tawera spissa*	Some
	Notocallista multistriata	
	Purpurocardia purpurata	
	Phialopecten triphooki	

Additional Remarks

WP 770 (Base Sentry Box Formation): Interbedded shelly pebbly mudstone overlain by limestone. Barnacle dominated, many intact but largely present as plates. Section marks the base of the Wn stage. The co-occurence of *Crassostrea, Phialopecten triphooki, Zygochlamys delicatula* and *Maoricardium spatiosum* indicates a very basal Wn age. Some fauna (e.g. *Aulacomya* and *Zygochlamys*) also indicate a change to colder water than present in underlying beds. Many *Mesopeplum* valves have growth ridges, suggesting a high-energy stressful environment. Similar *Mesopeplum* valves are found in lowermost Wn shellbeds capping conglomerates in the Matahorua Formation (e.g. top Grassy Knoll Conglomerate Member in Deep Stream and the Esk River).
WP 771 (Top Sentry Box Formation rapidly grading into Esk Mudstone): Top of coarse-grained muddy barnacle plate-dominated limestone. Fauna in Esk Mudstone observed approximately 20 m above top of limestone. Bathyal faunas have been collected from just above the limestone-siltstone contact (Beu 1995).

Sample site(s) information:

Location description	Waypoint Name/No.	Eastings	Northings	Altitude (m)
Jumped Up Stream 30 m below Mangleton Road bridge	WP 771	2793509	6166513	455
Ohara Stream below Big Hill Road bridge	WP 772	2804589	6172622	208
Ohara Stream below Big Hill Road bridge	WP 773	2804692	6172626	208
Aropaoanui Road, Tangoio Block	WP 774	2848827	6206300	279

GPS Waypoint information:

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 771	SILTSTONE approx 20 m upsection	
(cont)	*Tawera subsulcata*	
	Pratulum pulchellum	
	Zenatia acinaces	
	Atrina pectinata zelandica	
	Austrofusus sp.	
WP 772	LOWER FINE-GRAINED SANDSTONE	
	Dosinia c.f. *lambata*	
	Dosinia sp.	
	Offadesma ?angasai	
	Amalda mucronata	
	Panopea sp.	
	Zeacolpus sp.	In situ
	Austrofusus sp.	
	Talochlamys gemmulata	
	Maorimactra ordinaria	
	Neilo sp.	
	Alcithoe sp.	
	Sacella sp.	
	Pelicaria ?convexa	
	Zethalia zelandica	
	UPPER COARSER-GRAINED SANDSTONE	
	Zethalia zelandica	Common
	Bassina yatei	
WP 773	*Tawera subsulcata*	Common, dominant
	Patro undatus	
	Ostrea chilensis	
	Talochlamys gemmulata	
	Nucula nitidula	
WP 774	*Tawera subsulcata*	Common, dominant
	Bivalvia indet gen. spp.	Abundant, largely dissolved
	Ostrea chilensis	
	Patro undatus	
	Dosinia sp. (prob *nukumaruensis*)	
	Talochlamys gemmulata	
	Paphies australis	
	Lutraria solida	
	Perna canaliculis	
	Austromegabalanus	
	Myadora stephaniae	
	Crepidula radiata	
	Maorimactra ordinaria	
	Scalpomactra scalpalum	

Additional Remarks

WP 771 (Top Sentry Box Formation rapidly grading into Esk Mudstone): Top of coarse-grained muddy barnacle plate-dominated limestone. Fauna in Esk Mudstone observed approximately 20 m above top of limestone. Bathyal faunas have been collected from just above the limestone-siltstone contact (Beu 1995).
WP 772 (Okauawa Formation): Bbioturbated very fine sandstone coarsening rapidly upsection into slightly coarser-grained sandstone. Fauna and facies suggest falling water depth from lower to upper parts of the section. Clusters and small lensoidal concentrations of shells are common. Unit is barren at base and becomes increasingly fossiliferous upsection. Upper sandstone is massive to weakly-laminated with cluster of loosely to tightly packed lenses of *Zethalia*. Becomes more pebbly upsection and is erosionally overlain by a non fossiliferous greywacke conglomerate bed.
WP 773 (Okauawa Formation): Many *Tawera subsulcata* are articulated and in life position.
WP 774 (Kaiwaka Formation): Very pebbly limestone overlain by imbricated conglomerate/pebbly limestone. Lower parts are richer in bioclastic materials, becoming more siliciclastic upsection. Valves are largely dissolved, some are calcite-replaced. Abundant biomoulds are present.

Sample site(s) information:

Location description
Darkys Spur Road, Tangoio Block
Darkys Spur Road, Tangoio Block

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 775	2839726	6210752	356
WP 776	2840320	6210738	389

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 775	*Talochlamys gemmulata*	Abundant
	Atrina pectinata zelandica	
	Ostrea chilensis	
	Notocallista ?multistriata	
	Jupiteraia sp.	Very sparse
WP 776	A) VERY FINE-GRAINED SILTSTONE	
(cont over)	*Jupiteria* sp.	Very sparse
	Pratulum pulchellum	Abundant (packed), dominant
	Talochlamys gemmulata	Common
	Ostera chilensis	Common
	Nucula nitidula	Some
	Pelicaria ?accuminata	Sparse
	Dosinia greyi	
	Myadora sp.	
	Pleuromeris sp.	
	Stiracolpus sp.	
	B) SANDY SILTSTONE approx 3 m upsection	
	Pelicaria convexa	
	Talochlamys gemmulata	
	Dosinia lambata	Dominant
	Austrofusus sp.	
	Penion sulcatus	Immature specimen
	Atrina pectinata zelandica	
	Modiolaca sp.	
	Zenatia sp.	
	Panopea sp.	
	Xymene plebius	
	Amalda novaezelandiae	
	Sacella sp.	
	Gonimyrtea sp.	
	Dosina sp.	
	C) FINE-GRAINED SANDSTONE approx 14 m upsection	
	Dosinia anus	
	Austromegabalnus dicorus	
	Rexithaerus spenceri	
	Tellinota edgari	
	Perinidiea gaimardi	
	D) FINE-GRAINED SILTY SANDSTONE approx 14 m upsection	
	Maorimactra ordinaria	
	Panopea sp.	
	Nucula sp.	
	Serratina sp.	

Additional Remarks

WP 775 (upper Esk Mudstone): Slightly fossiliferous siltstone with occasional shelly, moderately fossiliferous layers. *Jupiteraia* sp. indicates deep-water, outer shelf depositional environments, and is present in lower parts of the section.

WP 776 (lower Aropaoanui Mudstone Member): A) Fauna suggests a deep-water depostional environment, perhaps towards the edge of the continental shelf. B) Unit coarsens up from the previous sample site with a matching change in fauna. C) Fine to medium sandstone with concretionary bodies , moderately packed shell lenses and scattered macrofossils. Shell lenses get less prominent upsection, and are dominated by disarticulated, concave-down shallow-water bivalves. This interval is approx. 4-5 m thick. D) Blue-grey silty sandstone sharply overlying non fossiliferous siltstone with scattered fine pumice lapilli. *Maorimactra*-dominated. Fauna concentrated in lower 0.3 m, faunal content lessens though *Maorimactra* remains dominant. Passes up into highly fossiliferous sandstone dominanted by abundant shallow-water taxa.

Sample site(s) information:

Location description
Darkys Spur Road
SH5 on Napier side of Titiokura Saddle
SH5 on Napier side of Titiokura Saddle
SH5 across road from Titiokura Station gate
Glengarry Hill road cutting
Mangatutu Stream beside Hawkston-Little Bush track
Seaview Station west of Hawkston Road

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 776	2840320	6210738	389
WP 777	2828954	6214200	654
WP 778	2828945	6214286	659
WP 779	2828727	6214418	681
WP 781	2830999	6203801	370
WP 784	2814163	6200502	344
WP 796	2813073	6200358	428

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 776 (cont)	E) HIGHLY FOSSILIFEROUS SANDSTONE	
	Fellaster zelandiae	Some
	Struthiolaria frazeri	Some
	Panopea sp.	Some
	Dosinia anus	Rare
	Dosina subrosea	Rare
	Sigapatella novaezelandiae	Some
	Amalda depressa	Some
	Amalda mucronata	Some
	Amalda novaezelandiae	
	Maorimactra ordinaria	
	Bassina yatei	
	Divaricella huttoniana	
	Tawera subsulcata	
WP 777	*Talochlamys gemmulata*	Dominant
	Purpurocardia purpurata	
	Ostrea chilensis	
WP 778	*Atrina pectinata zelandica*	
	Talochlamys gemmulata	Abundant
	Ostrea chilensis	
	Brachiopoda indet gen.	
	Bryozoa indet. gen.	
	Mesopeplum sp.	
	?Purpurocardia purpurata	
WP 779	*Tawera* sp.	
	?Mactra sp.	
	Talochlamys gemmulata	
	Cirripedea indet gen.	Abundant, fragments and plates
WP 781	**REFER RECORD FOR WP 23**	
WP 784	*Atrina pectinata zelandica*	Common
WP 796	*Crassostrea ingens*	Common
	Phialopecten triphooki	Common
	?Trachycardium rossi	Rare
	Neothyris sp.	Some
	Cirripedea indet. gen.	Abundant, dominant

Additional Remarks

WP 776 (Top Darkys Spur Member): E) This unit contains a very diverse taxa with many shallow water fauna. *Struthiolaria* supports a confident Wn age.
WP 777 (Te Waka Formation): Moderately- to highly-fossilifeorus sandstone, abundant shellhash in the matrix.
WP 778 (Contact Te Waka Formation-Titiokura Formation): Mixed siliciclastic-bioclastic sandstone gradationally (although rapidly) underlain by sandy limestone.
WP 779 (Titiokura Formation): Stacked alternating bioclastic-siliciclastic dominated bodies with scattered macrofossils. Abundant greywacke pebbles present. Faunal content dominated by barnacle plates and fragment.s
WP 784 (Puketitiri Formation): Fine-grained, slightly fossiliferous sandstone.
WP 796 (Te Waka Formation): Very pebbly limestone with common macrofauna. Fauna dominated by barnacles, many of which are intact though plates and fragments are more typical. Bivalve fauna dominated by intact, disarticulated valves of *Crassostrea ingens*.

Sample site(s) information:

Location description
Mangatutu Station Road at bridge end
Willowford Road before bridge
Summit Road, Te Kowhai Forest
Tutaekuri River upstream of Dartmoor
Tutaekuri River downstream of Waldon Rd
Tutaekuri River downstream of Waldon Rd
Taihape Road at Waikonini Stream

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 803	2815167	6191954	253
WP 804	2809748	6191932	360
WP 808	2810150	6200704	636
WP 813	2827047	6184253	43
WP 814	2816924	6190929	136
WP 816	2817412	6189043	129
WP 825	2810532	6188531	297

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 803	*Dosinia greyi*	Very common
	Talochlamys gemmulata	Very common
	Ostrea chilensis	Some
	Calliostoma sp.	Rare
	Austrofusus sp.	Some
WP 804	*Ostrea chilensis*	Common, present in thin capping shellbed
	Bivalvia indet. gen. spp.	Abundant, dominant. Largely dissolved
WP 808	Cirripedea indet. gen	Abundant, dominant
	Crassostrea ingens	Abundant
WP 813	SHELLBED	
	Tawera subsulcata	Abundant, dominant
	Patro undatus	
	Bassina sp.	
	Penion sulcatus	
	Cominella kereruensis	
	Amalda sp.	
	Xenostrobus huttoni	
	Gari sp.	
	Dosina sp.	
	SILTSTONE	
	Maoricolpus roseus	
WP 814	*Pratulum pulchellum*	Common, dominant
	Dosinia greyi	Some
WP 816	*Pratulum pulchellum*	Common
WP 825	*?Eumarcia* sp.	Dominant
	Ostrea chilensis	
	Talochlamys gemmulata	
	Tawera subsulcata	
	?Maoricardium spatiosum	Rare

Additional Remarks

WP 803 (Pohue Formation): Moderately fossiliferous fine sandstone.
WP 804 (Te Waka Formation): Top of shelly limestone comprising stacked mixed bioclastic-siliciclastic beds. Fauna dominated by dissolved and recrystallised aragonitic bivalves, identification of which is difficult. *Ostrea* present in thin (20 cm thick) shellbed capping the limestone.
WP 808 (Te Waka Formation): Pebbly limestone. Dominated by barnacle fragments with many *Crassostrea* valves. No pectinids present.
WP 813 (Okauawa Formation): Laminated fine sandstone with siltstone stringers capped by highly fossiliferous shellbed. Shellbed is overlain by siltstone. Detached mud lenses are present at the base of the shellbed which itself is dominated by *Tawera subsulcata*. Fauna present in the shellbed suggest a shallow-water, nearshore to inner shelf depositional environment.
WP 814 (Pohue Formation): Slightly to moderately fossiliferous siltstone. Dominanted by *Pratulum pulchellum*.
WP 816 (Pohue Formation): Fine-grained siltstone.
WP 825 (Te Waka Formation): Fauna present in very hard shellbed capping sandy limestone. If *Maoricardium* is present then important implication for age as unit cannot be younger than Wm.

Sample site(s) information:

Location description
Whanawhana Road above Otamauri Stream
Farm track on Whakamarumaru Station
Kikowhero Stm on Whakamarumaru Station

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 830	2808630	6177788	186
WP 836	2812637	6179279	217
WP 838	2812410	6177310	180

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 830	*Talochlamys gemmulata*	Common
	Ostrea chilensis	Common, some articulated
	Pelicaria convexa	
	Stiracolpus sp.	
	Maoricolpus roseus	
	Crepidula radiata	
	Dosina sp. (thick shelled, prominent ribs)	
	Large gastropoda indet. gen. (*Alcithoe/Penion*)	Uncommon
	Atrina pectinata zelandica	
WP 836	*Pratulum pulchellum*	Common, present in clusters
	Talochlamys gemmulata	Common
	Ostrea chilensis	Common
	Atrina pectinata zelandica	Common
	Pleuromeris sp.	Some
	Austrofusus sp.	Some
	?Pelicaria sp.	Poorly preserved specimen
WP 838	A) SANDSTONE	
(cont over)	*Dosinia* sp.	
	Tawera subsulcata	
	Austrofusus sp.	
	B) SHELLY CONGLOMERATE approx 2 m upsection	
	Purpurocardia purpurata	Common, very large specimens
	Tawera subsulcata	
	Dosinia sp.	
	Ostrea chilensis	
	Modiolus sp.	
	Xenostrobus huttoni	
	Tucetona laticostata	Articulated specimens present
	Glycymeris shrimptoni	
	Eumarcia sp.	
	Panopea sp.	
	C) SHELLY CONGLOMERATE approx 2 m upsection	
	Purpurocardia purpurata	Common, dominant
	Tawera subsulcata	Some
	Ostrea chilensis	Some
	D) GREYWACKE GRIT	
	Tawera subsulcata	Scattered specimens through interval

Additional Remarks

WP 830 (Esk Mudstone): Moderately fossiliferous sandy siltstone with common concentrated shell layers and shellhash. Scattered molluscs present throughout the outcrop. Fauna dominated by *Talochlamys* and *Ostrea*.

WP 836 (Okauawa Formation): Slightly fossiliferous siltstone. Fauna similar to that present in Upper Wn mudstones in the Tangoio Block.

WP 838 (Okauawa Formation): Interbedded conglomerate, sandstone and siltstone facies, fossiliferous throughout.
A) Non cemented slightly fossiliferous fine sandstone. Passes rapidly up into highly fossiliferous conglomerate.
B) Highly fossiliferous conglomerate, fauna dominanted by relatively robust, high-energy-dwelling bivalve species.
C) Shelly conglomerate layer 0.4 m thick overlies greywacke grit. Fauna dominated by *Purpurocardia purpurata*.
D) 1.2 m-thick interval of greywacke grit with scattered *Tawera* valves. Gradationally overlain by slightly fossiliferous siltstone, thin layer (0.2 m thick) of reworked greywacke pebbles at base.

Sample site(s) information:

Location description	Waypoint Name/No.	Eastings	Northings	Altitude (m)
Kikowhero Stm on Whakamarumaru Station	WP 838	2812410	6177310	180
Whakamarumaru Station at homestead	WP 840	2811963	6176525	198
Crownthorpe Settlement Road	WP 841	2815507	6178291	235
Gravel pit on Muritai Station	WP 842	2815602	6178600	238
Kikowhero Stream on Muritai Station	WP 843	2813884	6179170	185
Ringarua Station near house and road	WP 855	2815988	6179754	283

GPS Waypoint information:

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 838	E) SILTSTONE	
(cont)	*Talochlamys gemmulata*	
	Ostrea chilensis	
	Atrina pectinata zelandica	
	F) FINE SANDSTONE	
	Talochlamys gemmulata	
	Ostrea chilensis	
	Bivalvia indet. gen. spp.	
WP 840	*Tawera subsulcata*	Abundant, dominant
	Patro undatus	
	Amalda mucronata	
	Ostrea chilensis	
WP 841	*Tawera subsulcata*	Abundant, dominant
	Ostrea chilensis	Some
WP 842	*Tawera subsulcata*	Common, co-dominant
	Tucetona laticostata	Common, co-dominant
	Modiolus sp.	Some
	Ostrea chilensis	Common
	Glycymeris shrimptoni	Some
	Alcithoe ?arabica	Uncommon
	Panopea sp.	Uncommon
	Patro undatus	Some
	Dosina sp.	Uncommon
WP 843	*Pratulum pulchellum*	Common, dominant
	Ostrea chilensis	
	Talochlamys gemmulata	
	Atrina pectinata zelandica	
	Maoricolpus roseus	
	Stiracolpus sp.	
WP 855	*Tawera subsulcata*	Very common, dominant
	Ostrea chilensis	Rare, scattered
	Tucetona laticostata	Common
	Austrovenus stutchburyi	Rare, highly abraded
	Patro undatus	Some
	Paphies australis	Some
	Purpurocardia purpurata	Some

Additional Remarks

WP 838 (Okauawa Formation): E) Slightly fossiliferous siltstone gradationally overlying conglomerate. Grades upsection into fine sandstone with scattered macrofossils. F) Fine sandstone. Passes up into sandstone with siltstone stringers and greywacke conglomerate.
WP 840 (Okauawa Formation): Highly fossiliferous shellbed. Inferred to overlie non fossiliferous greywacke conglomerate although the conglomerate is not exposed. Dominated by *Tawera*. Rapidly though gradationally overlain by less fossilferous siltstone.
WP 841 (Top Flag Range Conglomerate Member): Highly fossiliferous greywacke conglomerate inferred to overlie non fossiliferous greywacke conglomerate.
WP 842 (Top Flag Range Conglomerate Member): Non fossiliferous conglomerate overlain by highly fossiliferous pebbly shellbed. Fauna typical for that of Wm-Wn fossiliferous conglomerate facies through the basin comprising robust shallow-water dwelling bivalves. Fauna here very similar to pebbly conglomerates exposed on Taihape and Crownthorpe Settlement Roads.
WP 843 (Okauawa Formation): Siltstone.
WP 855 (Top Flag Range Conglomerate Member): Non fossiliferous conglomerate overlain by a highly fossiliferous pebbly shellbed. *Tawera* dominanted. *Tawera* and *Tucetona* are commonly articulated and in some silty interbeds appear *in situ*. *Austrovenus* present are highly abraded, suggesting reworking and transport from an estuarine environment to a more open-marine setting.

Sample site(s) information:

Location description	Waypoint	Name/No.	Eastings	Northings	Altitude (m)
Kikowhero Stream above Crownthorpe Rd	WP 856		2816018	6175496	136
Taihape Road on Napier side of Black Bridge	WP 857		2825156	6178546	63
The Lizard, Kaweka Forest	WP 862		2803477	6191166	818
Black Bridge above old Taihape Road course	WP 866		2822921	6179452	180
Ohara Stream below Big Hill Bridge	WP 868		2804656	6172771	184

GPS Waypoint information:

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 856	*Pratulum pulchellum*	
	Alcithoe brevis	
	Austrofusus sp.	Dominant
	Dosinia greyi	
	?Cirsotrema sp.	
	Calliostoma sp.	
	Stiracolpus sp.	
	Maoricolpus roseus	
	Pelicaria convexa	
	Zeacolpus sp.	
WP 857	*Talochlamys gemmulata*	
	Ostrea chilensis	
	Brachiopoda indet gen.	
	Stiracolpus sp.	
	?Serratina sp. (very thin shell, fine ribs)	
	Bivalvia indet. gen. spp.	
WP 862	CONCRETIONARY SANDSTONE	
	Tawera sp.	Dominant
	Perna sp.	Some to common
	?Modiolus sp.	Some to common
	SHELLHASH LIMESTONE	
	Crassostrea ingens	Some
	Phialopecten thomsoni	Uncommon
	Encrusting bryozoans	Some
	Cirripedea indet. gen.	Abundant, plates and fragments
WP 866	*Tawera subsulcata*	Common, dominant in shellbed.
	Ostrea chilensis	
	Bivalvia indet. gen. spp.	Abundant, dominant largely dissolved
WP 868	SHELLY CONGLOMERATE	
	Ostrea chilensis	Common, dominant
	Purpurocardia purpurata	Common
	Dosina sp.	Some
	FINE-GRAINED SANDSTONE	
	Ostrea chilensis	Common, dominant
	Purpurocardia purpurata	
	Lutraria solida	In situ
	Dosina sp.	
	Pelicaria convexa	
	Austrofusus sp.	
	Atrina pectinata zelandica	

Additional Remarks

WP 856 (Okauawa Formation): Slightly fossiliferous siltstone. Gastropod-dominated fauna. *Pelicaria convexa* confirms an Upper Wn age for this unit.
WP 857 (Te Ngaru Mudstone Member): Non cemented, moderately fossiliferous sandy siltstone. *Ostrea* valves are typically quite small, although larger ones are present.
WP 862 (Te Waka Formation): Approx 2/3rds up The Lizard. Non to moderately fossiliferous concretions in sandstone. *Tawera* dominated. Concretions become more common upsection and unit passes into shelly sandy limestone. Underlain by discontinuous sparsely fossiliferous shellhash-dominated limestone beds, intact fauna dominated by *Crassostrea*, many of which are attached to each other.
WP 866 (Waipatiki Limestone Member): Slightly pebbly shellhash limestone with abundant biomoulds. Capped by a pebbly *Tawera* (dominant)-*Ostrea* shellbed.
WP 868 (Base Okauawa Formation): Slightly-pebbly sandstone grading into shelly conglomerate with a burrowed base. Fauna dominated by *Ostrea*. Overlain by sandstone with scattered macrofossils, *Ostrea* most common. Many valves are articulated. Passes into siltstone to sandy siltstone that in turn grades into fine to medium sandstone which is overlain by a non fossiliferous greywacke conglomerate.

Sample site(s) information:

GPS Waypoint information:

Location description	Waypoint Name/No.	Eastings	Northings	Altitude (m)
Ohara Stream below Big Hill Road bridge	WP 869	2805048	6173138	163
Ohara-Big Hill Stream confluence	WP 877	2802643	6172062	205
Awapai Station in small stream	WP 882	2802364	6183120	364
Lizard Road, Kaweka Forest	WP 890	2804013	6190395	796
Luke Road off Lizard Road, Kaweka Forest	WP 891	2804331	6189557	696
Tutaekuri River upstream of Lawrence Road	WP 895	2805519	6198220	363

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 869	*Pelicaria convexa*	Common to abundant
	Tawera subsulcata	Abundant, dominant
	Ostrea chilensis	Common
	Talochalmys gemmulata	Many articulated
	Zethalia zelanica	Common
	Panopea sp.	Rare
WP 877	*Tawera subsulcata*	Abundant
	Ostrea chilensis	Common
	Patro undatus	Common
	Purpurocardia purpurata	Some to common
	Dosina sp.	Some
WP 882	*?Cominella* sp.	Some
	Taniella sp.	Some
	Dosinia greyi	Some
	Gastropoda indet. gen. spp.	Some
WP 890	*Crassostrea ingens*	Some
	?Eumarcia sp.	Some
	Alcithoe sp.	Uncommon
	Austrovenus stutchburyi	Uncommon
	Tucetona laticostata	Uncommon
	Cirripedea indet. gen.	Abundant
WP 891	Bivalvia indet. gen. spp.	Abundant, dominant, largely dissolved
	Crassostrea ingens	Some
	Ostrea chilensis	Some
	?Eumarcia sp.	Some
	Tawera subsulcata	Some
	Perna sp.	Some
	?Xenostrobus huttoni	Some
	Mactra sp.	Some
	Gari sp.	Some
	Zethalia coronata	Some
	?Tellinota sp.	Uncommon
	Panopea sp.	Uncommon
WP 895	*Struthiolaria (Callusaria)* sp.	Dominant
	Crepidula radiata	Abundant
	Sectipecten grangei	Common
	Dosinia sp.	
	?Tellinota sp.	
	Alcithoe sp.	
	Glycymeridae indet. gen.	

Additional Remarks

WP 869 (Okauawa Formation): Sandy siltstone to sandstone with concentrated lenses of bivalve and gastropods. Fauna reworked and concentrated into lenses. Tightly-packed layers rich in *Pelicaria* present, as well as *Tawera*-rich and *Zethalia*-rich zones.
WP 877 (Top Kereru Formation-Base Okauawa Formation): As limestone coarsens upwards *Purpurocardia* becomes more common.
WP 882 (Puketitiri/Kaumatua Formation): Sparsely to slightly fossiliferous siltstone, gastropod-dominated
WP 890 (Te Waka Formation): Concretionary sandstone to very pebbly limestone. Fauna dominated by barnacle fragments and plates.
WP 891 (Te Waka Formation): Fauna dominated by aragonitic bivalves in a shellhash medium sand matrix. Fauna dominated by aragonitic bivalves that are largely dissolved.
WP 895 (Waitere Formation): Concretionary fine sandstone erosionally overlain by strongly laminated channelised alternating sandstone-siltstone beds. The presence of common *Sectipecten grangei* confirms a Tt age for this unit. A single *S. grangei* was also identified in one redeposited sandstone bed.

Sample site(s) information:

Location description	Waypoint	Name/No.	Eastings	Northings	Altitude (m)
Puketitiri Road near Glengarry Road	WP 904		2833524	6188230	211
Side Road off Link Road, Kaweka Forest	WP 908		2809136	6194197	533
Bluffs above Link Road, Kaweka Forest	WP 909		2809132	6194305	527
Sandy Ridge, Kaweka Forest	WP 916		2804786	6192787	819
Kohurau Station near airstrip	WP 933		2803265	6186656	668
Kohurau Station between airstrip and Awapai	WP 937		2802538	6185088	666
Southern Glenross Range near Omahaki Road	WP 939		2803475	6187674	575
Puketitiri Road near Glengarry Road	WP 951		2833177	6188250	190

GPS Waypoint information:

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 904	*Paphies australis*	
	Tawera subsulcata	
	Dosinia anus	
	Patro undatus	
	Panopea sp.	
	Mactra sp. (very steep sides, ~60 mm high)	Dominant
WP 908	Bivalvia indet gen. spp.	Chalky largely dissolved aragonitic bivalves
	Eumarcia benhami	
	Tawera subsulcata	
	Dosinia anus	
	Talochlamys gemmulata	
	Ostrea chilensis	Common
	Purpurocardia purpurata	
	Gari sp.	
	Panopea sp.	
WP 909	*Tawera subsulcata*	
	Ostrea chilensis	
	Zethalia ?coronata	Relatively common
	Dosinia sp.	
	Eumarcia sp. (prob. *E. benhami*)	Common, dominant
WP 916	*Crassostrea ingens*	Abundant
	Tucetona laticostata	
	Phialopecten thomsoni	
	Panopea sp.	
	Cirripedea indet gen.	
WP 933	*Phialopecten thomsoni*	
	Crassostrea ingens	
WP 937	*Crassostrea ingens*	Uncommon, scattered.
WP 939	*Zeacolpus sp.*	
	Zenatia sp.	
	Cirripedea indet gen.	
WP 951	*Tawera subsulcata*	
	Gari sp.	
	Crepidula radiata	
	Zeacolpus sp.	
	Panopea sp.	
	Talochlamys gemmulata	
	Atrina pectinata zelandica	
	Ostrea chilensis	
	Purpurocardia purpurata	
	Sigapetella novaezelandiae	

Additional Remarks

WP 904 (Devils Elbow Mudstone Member): Fine sandstone. Fauna disarticulated although largely intact.

WP 908 (Te Waka Formation): Coarse-grained shelly limestone with abundant chalky, largely dissolved bivalves. Valves are dominantly disarticulated although intact.

WP 909 (Te Waka Formation): Abundant biomoulds, dominated by chalky dissolved aragonitic bivalves. *Ostrea* more common at top of bed.

WP 916 (Base Te Waka Formation): Unit unconformably overlies Torlesse basement, rocky substrate at the time of deposition. *Crassostrea* only occurs in vicinity of greywacke onlap. The presence of *Phialopecten thomsoni* confirms a Mangapanian age.

WP 933 (Te Waka Formation): Stacked mixed siliciclastic-bioclastic bodies. Few intact macrofossils visible. One bed contains identifiable *P. thomsoni* and *Crassostrea*. The presence of *P. thomsoni* confirms a Wm age.

WP 937 (Te Waka Formation): Sandy shellhash limestone. Few intact macrofossils visible, occasional *Crassostrea*.

WP 939 (Te Waka Formation): Well sorted fine sandstone. Passes up into sandy limestone.

WP 951 (Te Ngaru Mudstone Member): Massive to laminated muddy sandstone with bioclastic-rich sheets that increase in number and thickness upsection. *Maorimactra ordinaria* and *Pleuromeris* sp. are present in underlying siltstone unit.

Sample site(s) information:

Location description
Greywacke quarry on Hawkston Station
Limestone ridges above track, Hawkston Stn
Bluffs above Hawkston Lake, Hawkston Stn
Kaweka Range near Kaweka Forest H.Q.
Below Taihape Rd near Kaweka Forest H.Q.
Ford over Otamauri Stream, Hildreths Farm
Otamauri Road

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 952	2813122	6197532	405
WP 954	2813605	6198260	370
WP 956	2812814	6199510	333
WP 960	2808554	6190481	382
WP 962	2809104	6190566	345
WP 976	2807150	6184971	259
WP 982	2808869	6181022	290

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 952	*Crassostrea ingens*	Common
WP 954	*Crassostrea ingens*	Common
	Cirripedea indet. gen.	Abundant, dominant, plates and fragments
WP 956	*Crassostrea ingens*	Common
	Phialopecten triphooki	Common
	Patro undatus	Abundant
	Cirripedea indet. gen.	Abundant, dominant, plates and fragments
WP 960	Bivalvia indet. gen. spp.	Common, largely dissolved aragonitic bivalves
	Zethalia sp. (size looks like *Z. coronata*)	
	Tawera sp.	Difficult to identify, largely dissolved
	Ostrea chilensis	Present capping limestone
	?Eumarica sp. (small shell size)	Difficult to identify, largely dissolved
WP 962	*Zethalia* sp. Small size, tall spire (*Z. coronata*?)	Common
	Bivalvia indet. gen. spp.	Common, largely dissolved aragonitic bivalves
WP 976	*Talochlamys gemmulata*	Rare
	Dosinia greyi	Rare
	Pratulum pulchellum	Common, often in cluster and thin bands
WP 982	*Ostrea chilensis*	Very common
	Talochlamys gemmulata	Abundant, dominant
	Amalda mucronata	Some
	?Pelicaria convexa	Rare. Poorly preserved specimen
	Sigapatella novaezelandiae	Some
	?Amygdolum striatum	Uncommon
	?Aulacomya ater maoriana	Uncommon
	Zeacolpus sp.	Some
	Atrina pectinata zelandica	Uncommon
	Maoricolpus roseus	
	Crepidula radiata	
	Cirripedea indet. gen.	
	Purpurocardia purpurata	Some

Additional Remarks

WP 952 (Base Te Waka Formation): Pebbly shellhash limestone overlying greywacke. Fall blocks of limestone display common *Crassostrea*, typical of onlap facies in area.
WP 954 (Base Te Waka Formation): Shellhash limestone. Few intact macrofossils present. Unit largely dominated by barnacle plates and fragments.
WP 956 (Te Waka Formation): Coarse-grained pebbly shelly limestone dominated by barnacle plates and fragments. Intact barnacles present, commonly attached to shells and more rarely greywacke pebbles. The presence of *Phialopecten thomsoni* confirms a Wm age for this unit.
WP 960 (Top Te Waka Formation): Sandy limestone capped by *Ostrea*-rich shellbed. Fauna dominated by dissolved unidentified aragonitic bivalves. If *Zethalia* sp. is *Z. coronata* then the unit has a likely Wm age.
WP 962 (Top Te Waka Formation): Sandy limestone with common shellhash filled lenses. Extensively bioturbated, shellhash-filled burrows common. Intact fauna dominated by *Z. ?coronata*. Most taxa are dissolved with common biomoulds present, especially in upper parts of the limestone.
WP 976 (Esk Mudstone): Sparse macrofauna in siltstone. Dominated by *Pratulum*.
WP 982 (Esk Mudstone): Sandy siltstone grading into silty sandstone. Many *Talochlamys* quite large, virtually all disarticulated though valves are intact.

Sample site(s) information:

Location description
Ohiti Road near Matapiro Road intersection

GPS Waypoint information:

Waypoint Name/No.	Eastings	Northings	Altitude (m)
WP 983	2822063	6172393	120

Faunal List

Waypoint Number	Taxonomic Name	Comment
WP 983	LOWER 2 m	
	Tawera subsulcata	Very common
	Zeacolpus sp.	
	Amalda sp.	
	Mactra sp.	
	UPPER 3 m	
	Tawera subsulcata	Very common
	Ostrea chilensis	Some
	Atrina pectinata zelandica	Uncommon

Additional Remarks

WP 983 (Kaiwaka Formation): Interbedded highly fossiliferous shellbeds and strongly cross-bedded sandstones passing upsection into a more highly fossiliferous sandstone with a higher shell content. Fauna *Tawera*-dominated with a very high shellhash content throughout.

Sample: V20/f442: FORAMINIFERA
Indentifier*:* M.P.CRUNDWELL
Date: 18/06/200
Age: Tt
Comments: Tongaporutuan, constrained by planktics and benthics (*Globoconella miotumida, Neogloboquadrina pachyderma,* and *Bolivinita pohana*). The relative abundance of *Globigerinoides* and the apparent absence of *Globoquadrina dehiscens* suggest an age of 8.8-8.0 Ma.

F36893

KJB-31, Kyle Bland (UOW): Well-preserved predominantly calcareous assemblage. Upper-slope (300-400 m water depth) based on *Cibicides molestus*. 6% planktics, largely crust-free specimens (inner-neritic water mass). Normal marine conditions. Misc: few shell (gastropod and bivalve) fragments, ostracods, echinoid spines, fish teeth, and otoliths. Sediment volcanogenic (abundant glass shards, quartz and mica).

Haeuslerella morgani
Textularia miozea
Siphotextularia sp.
Saracenaria italica
Lenticulina calcar
Lenticulina sp.
Nodosaria longiscata
Dentalina spp.
Marginulina subbullata
Vaginulina sp.
Stilostomella sp.
Amphicoryna hirsuta
Amphicoryna sp.
Plectofrondicularia pohana
Proxifrons wairarapa
Lagena spp.
Bulimina striata
Bulimina vellai
Virgulopsis petiae
Bolivina spathulata
Bolivina lapsus
Trifarina cf. bradyi
Euuvigerina cf. *tutamoea*
Bolivinita pohana
Dyocibicides sp.
Cibicides cf. *neoperforatus*
Cibicides deliquatus
Cibicides molestus
Nonionella novozealandica
Elphidium advenum
Notorotalia cf. *hurupiensis*
Gyroidinoides zelandicus
Anomalinoides parvumbilius
Anomalinoides subnonionoides
Astrononion parki
Gyroidina danvillensis
Sphaeroidina bulloides
Evolvocassidulina orientalis

Cassidulina neocarinata
Laticarinina altocamerata
Hoeglundina elegans
Globoconella miotumida (24S:0D) largely crust-free specimens
Neogloboquadrina pachyderma (6S:0D)
Globigerinita glutinata (rare)
Globigerina cf. *bulloides* (common)
Zeaglobigerina woodi (common)
Globigerinoides quadrilobatus (common)
Orbulina universa (rare)

Sample: V20/f443: FORAMINIFERA
Identifier: M.P.CRUNDWELL
Date: 18/06/2004
Age: Wn
Comments: Nukumaruan, constrained by planktics and benthics (*Truncorotalia crassula, Globoconella inflata triangula*, and *Notorotalia zelandica*).

F36893

Mangatutu, Kyle Bland (UOW): Well-preserved predominantly calcareous assemblage. Outer shelf (100-200 m water depth). 2% planktics (sheltered inner-neritic water mass). Normal marine conditions. Misc: common shell (bivalve and gastropod) fragments and ostracods, few echinoid spines, rare fish teeth and otoliths.

Haeuslerella cf. *finlayi*
Siphonaperta macbethi
Quinqueloculina spp.
Lenticulina sp.
Marginulina subbullata
Fissurina sp.
Oolina squamosa
Lagena hexagona
Lagena distoma
Lagena striata
Bulimina aff. *aculeata*
Globobulimina pacifica
Virgulopsis wanganuiensis
Virgulopsis pustulata
Bolivina spathulata
Rectobolivina striatula
Euuvigerina cf. *rodleyi*
Bolivinita cf. *quadrilatera*
Dyocibicides sp.
Cibicides sp.
Discorbinella bertheloti
Gavelinopsis sp.
Nonionella flemingi
Elphidium crispum
Elphidium charlottensis
Notorotalia cf. *finlayi*
Notorotalia zelandica
Anomalina spherica
Anomalinoides parvumbilius

Astrononion kickinskii
Evolvocassidulina orientalis
Sphaeroidina bulloides
Cassidulina neocarinata
Pullenia subcarinata
Laticarinina pauperata
Globoconella inflata (5S:0D)
Globoconella inflata triangula (33S:0D)
*Truncorotalia crassula**(7S:0D)*
Neogloboquadrina pachyderma (2S:2D)
*Globigerinita glutinata (*rare)
Globigerina bulloides
Globigerina sp. (common)
Zeaglobigerina woodi (few)
Globigerinoides ruber (rare)
Orbulina universa (rare)

Sample: V20/f444: FORAMINIFERA
Identifier: M.P.CRUNDWELL
Date: 19/06/2004
Age: No age obtained
Comments: No foraminifera, but contains radiolarians.

F36895

WP-764, Kyle Bland (UOW): Weathered, no calcareous material. Marine. Misc: common sponge spicules, common radiolarians, rare fish teeth. Common devitrified volcanic glass and a few glauconite grains.

Sample: V20/f445: FORAMINIFERA
Age: M.P.CRUNDWELL*
Date: 20/06/2004
Age: Wp
Comments: Waipipian, constrained by planktics (*Truncorotalia crassaformis, Globoconella inflata, Gc. inflata triangula, Gc. puncticulata, Gc. subconomiozea, Gc. pliozea*).

F36897

WP-784, Kyle Bland (UOW): Preservation highly variable (poor to very good), predominantly calcareous assemblage. Inner shelf (0-50 m water depth) with significant reworking of taxa indicate of an upper slope environment. 50% planktics (intermediate water mass). Misc: abundant shell (bivalve and gastropod) fragments, common ostracods and echinoid spines, a few bryozoan fragments, rare fish teeth. Normal marine conditions.

Gaudryina cf. *kingi*
Haeuslerella morgani
Karreriella cylindrica
*Textulari*a sp.
Siphotextularia sp.
Siphonaperta macbethi
Quinqueloculina spp.
Lenticulina spp.
Nodosaria longiscata

Dentalina spp.
Stilostomella sp.
Sigmoidella sp.
Amphicoryna hirsuta
Amphicoryna scalaris
Oolina squamosa
Virgulopsis pustulata
Virgulopsis wanganuiensis
Rectobolivina striatula
Trifarina bradyi
Euuvigerina cf. *rodleyi*
Euuvigerina cf. *miozea*
Bolivinita pohana
Bolivinita cf. *finlayi*
Dyocibicides sp.
Cibicides cf. *deliquatus*
Cibicides neoperforatus
Cibicides spp.
Cibicides molestus
Rosalina cf. *bradyi*
Rosalina sp.
Pileolina radiata
Patellinella inconspicua
Nonionella flemingi
Zeaflorilus parri
Elphidium charlottensis
Haynesina depressula
Elphidium crispum
Ammonia beccarii
Amphistegina sp.
Elphidium novozealandicum
Elphidium sp.
Notorotalia sp.
Notorotalia finlayi
Gyroidinoides zelandicus
Anomalina spherica
Anomalinoides subnonionoides
Anomalinoides parvumbilius
Pullenia bulloides
Pullenia subcarinata
Astrononion parki
Astrononion kicinskii
Ehrenbergina sp.
Evolvocassidulina orientalis
Globocassidulina subglobosa
Sphaeroidina bulloides
Discorbinella sp.
Discorbinella bertheloti
Oridorsalis tenera
Hoeglundina elegans
Globoconella puncticulata (few)
Globoconella inflata (abundant)
Globoconella inflata triangula (common)
Globoconella subconomiozea (common)
Globoconella pliozea (few)

Truncorotalia crassaformis (4S:1D)
Neogloboquadrina pachyderma (2S:6D)
Globigerinita glutinata (few)
Globigerina sp. (common)
Globigerina bulloides
Zeaglobigerina sp. (common)
Zeaglobigerina woodi
Globigerinoides trilobus (few)
Globigerinoides quadrilobatus (rare)
Globigerinoides ruber (rare)
Orbulina sp.
Orbulina universa (few)

Sample: V21/f443: FORAMINIFERA
Identifier: M.P.CRUNDWELL
Date: 21/06/2004
Age: Wn
Comments: Nukumaruan, constrained by planktics (*Globoconella inflata, Globoconella inflata triangula, Truncorotalia crassaformis, Truncorotalia truncatulinoides, Truncorotalia* cf. *crassula*).

F36898

WP-825, Kyle Bland (UOW): Well-preserved almost entirely calcareous assemblage. Inner shelf (0-50 m water depth), rare taxa presumably reworked from a deeper-slope environment. 19% planktics (outer-neritic water mass). Misc: common shell (bivalve) fragments, ostracods, few echinoid spines and plate fragments, rare fish teeth and radiolarians. Marine, with slight brackish influence.

Karreriella sp.
Siphotextularia mestayerae
Spirillina sp.
Quinqueloculina sp.
Lenticulina sp.
Plectofrondicularia pohana
Fissurina spp.
Oolina squamosa
Lagena spp.
Bulimina cf. *elongata*
Bolivina cf. *barnwelli*
Bolivina affiliata
Rectobolivina striatula
Virgulopsis sp.
Trifarina angulosa
Siphouvigerina sp.
Euuvigerina cf. *rodleyi*
Dyocibicides sp.
Cibicides cf. *corticatus*
Cibicides molestus
Discorbinella bertheloti
Discorbinella sp.
Calcareous sp.
Patellinella
Ammonia beccarii
Ammonia sp.

Zeaflorilus parri
Nonionella flemingi
Haynesina depressula
Elphidium advenum
Elphidium charlottensis
Elphidium novozealandicum
Notorotalia finlayi
Notorotalia cf. *depressa*
Gyroidinoides zelandicus
Anomalina spherica
Anomalinoides parvumbilius
Astrononion parki
Pullenia bulloides
Pullenia subcarinata
Sphaeroidina bulloides
Evolvocassidulina orientalis
Cassidulina neocarinata
Globocassidulina subglobosa
Cassidulina sp.
Ehrenbergina mestayeri
Hoeglundina elegans
Globoconella inflata (common)
Globoconella inflata triangula (common)
Truncorotalia truncatulinoides (0S:1D)
Truncorotalia cf. *crassula* (2S:0D)
Truncorotalia cf. *crassaformis* (2S:2D)
Globoconella cf. *puncticuloides* (1S:0D)
Obandyella cf. *scitula* (3S:0D)
Neogloboquadrina pachyderma (16S:21D)
Globigerinita glutinata (few)
Globigerina spp. (common)
Zeaglobigerina sp. (common)
Zeaglobigerina woodi
Orbulina sp. (rare)

Sample: U20/f149: FORAMINIFERA
Identifier: M.P.CRUNDWELL*
Date: 20/06/2004
Age: Wn
Comments: Nukumaruan, constrained by planktics and benthics (*Truncorotalia crassula* and *Notorotalia zelandica*).

F36894

WP-764, Kyle Bland (UOW): Well preserved almost exclusively calcareous assemblage. inner to middle shelf (0-100 m water depth). 1% planktics (sheltered inner-neritic water mass). Misc: common shell (bivalve and gastropod) fragments, echinoid spines, ostracods, and fish teeth. Marine, with a slight brackish influence.

Siphotextularia cf. *wairoana* (rare)
Quinqueloculina spp.
Amphicoryna sp.
Stilostomella sp.
Marginulina sp.

Fissurina sp.
Oolina squamosa
Lagena spp.
Bulimina cf. *aculeata*
Bolivina spathulata
Bolivina sp.
Bolivina affiliata
Virgulopsis wanganuiensis
Virgulopsis pustulata
Rectobolivina striatula
Siphouvigerina sp.
Euuvigerina rodleyi
Bolivinita cf. *finlayi*
Cibicides sp.
Discorbinella bertheloti
Gavelinopsis sp.
Ammonia beccarii
Elphidium excavatum
Elphidium sp.
Elphidium crispum
Zeaflorilus parri
Nonionella flemingi
Elphidium charlottensis
Notorotalia cf. *finlayi*
Notorotalia zelandica
Anomalina spherica
Anomalinoides parvumbilius
Gyroidinoides zelandicus
Astrononion parki
Evolvocassidulina orientalis
Cassidulina laevigata
Cassidulina neocarinata
Globocassidulina subglobosa
Sphaeroidina bulloide
Laticarinina pauperata
Globoconella inflata (20S:2D)
Globoconella inflata triangula (18S:10D)
Truncorotalia sp. (2S:1D) keeled
Truncorotalia crassula (1S:0D)
Obandyella cf. *scitula* (0S:1D)
Neogloboquadrina pachyderma (14S:18D)
Globigerinita glutinata (few)
Globigerina cf. *quinqueloba* (rare)
Globigerina spp. (common)
Globigerina bulloides
Zeaglobigerina sp. (few)
Zeaglobigerina woodi
Orbulina sp. (juvenile specimen)

Sample: U20/f150: FORAMINIFERA
Identifier: M.P.CRUNDWELL
Date: 22/06/2004
Age: Tt
Comments: Tongaporutuan, constrained by planktics and benthics (*Globoconella miotumida*, *Neogloboquadrina pachyderma*, and *Bolivinita* cf. *pliobliqua*).

F36899

WP-920, Kyle Bland (UOW): Sparse, moderately well preserved, predominantly calcareous assemblage. Middle shelf (50-100 m water depth). 9% planktics (inner-neritic water mass). Misc: few shell (bivalve) fragments, echinoid spines, ostracods, bryozoan fragments. Common glauconite. Normal marine conditions.

Haeuslerella morgani
Lenticulina sp.
Amphicoryna hirsuta
Oolina squamosa
Lagena sp.
Bulimina cf. *aculeata*
Bolivina spathulata
Bolivina sp.
Bolivina lapsus
Rectobolivina striatula
Trifarina bradyi
Siphouvigerina sp.
Euuvigerina cf. *rodleyi*
Bolivinita cf. *pliobliqua*
Cibicides sp.
Cibicides deliquatus
Cibicides cf. *perforatus*
Gavelinopsis sp.
Discorbinella bertheloti
Haynesina depressula
Zeaflorilus parri
Nonionella flemingi
Elphidium novozealandicum
Elphidium charlottensis
Elphidium excavatum
Notorotalia cf. *hurupiensis*
Notorotalia sp.
Gyroidinoides zelandicus
Gyroidina pseudorbicularis
Anomalina spherica
Anomalinoides subnonionoides
Astrononion kicinskii
Evolvocassidulina orientalis
Cassidulina sp.
Globocassidulina subglobosa
Epistominella sp.
Globoconella miotumida (7S:0D)
Neogloboquadrina pachyderma (1S:0D)
Globigerinita glutinata (rare)
Globigerina sp. (common)
Zeaglobigerina woodi (few)

Orbulina universa (few)

Sample: U21/f87:FORAMINIFERA
Identifier: M.P.CRUNDWELL
Date: 22/06/2004
Age: Wo
Comments: Opoitian, constrained by planktics (*Globoconella puncticulata, Globoconella pliozea, Truncorotalia juanai*).

F36900

WP-922, Kyle Bland (UOW): Very sparse, moderately well preserved, predominantly calcareous assemblage. Uppermost slope (300-400 m), with a significant shelf component. 29% planktics (outer-neritic water mass). Misc: few shell (bivalve) fragments, echinoid spines, ostracods, bryozoan fragments, rare pteropods and fish teeth. Marine, with a slight brackish influence. Deposited in an environment where there was a rapid rate of deposition.

Haeuslerella morgani
Siphotextularia dawesi
Quinqueloculina sp.
Lenticulina calcar
Amphicoryna sp.
Oolina squamosa
Bolivina affiliata
Virgulopsis sp.
Rectobolivina striatula
Trifarina bradyi
Euuvigerina rodleyi
Euuvigerina cf. *miozea*
Bolivinita finlayi
Dyocibicides sp.
Cibicides deliquatus
Cibicides molestus
Cibicides spp.
Gavelinopsis sp.
Ammonia beccarii
Zeaflorilus parri
Elphidium cf. excavatum
Elphidium charlottensis
Notorotalia sp.
Gyroidina pseudorbicularis
Gyroidinoides zelandicus
Anomalinoides parvumbilius
Sphaeroidina bulloides
Astrononion parki
Globocassidulina subglobosa
Globoconella puncticulata
Globoconella pliozea
Truncorotalia juanai
Neogloboquadrina pachyderma
Neogloboquadrina dutertrei
Globigerina sp.
Globigerina bulloides
*Zeaglobigeri*na sp.
Orbulina universa

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The early Pliocene Titiokura Formation: stratigraphy of a thick, mixed carbonate-siliciclastic shelf succession in Hawke's Bay Basin, New Zealand

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Abstract This paper presents a systematic stratigraphic description of the architecture of the early Pliocene **Titiokura Formation** (emended) in the Te Waka and Maungaharuru Ranges of western Hawke's Bay, and presents a facies, sequence stratigraphic, and paleoenvironmental analysis of the sedimentary succession. The Titiokura Formation is of early Pliocene (Opoitian–Waipipian) age, and unconformably overlies Mokonui Formation, which is a regressive late Miocene and early Pliocene (Kapitean to early Opoitian) succession. In the Te Waka Range and the southern parts of the Maungaharuru Range, the Titiokura Formation comprises a single limestone sheet 20–50 m thick, with calcareous sandstone parts. In the vicinity of Taraponui Trig, and to the northeast, the results of 1:50 000 mapping show that the limestone gradually partitions into five members, which thicken markedly to the northeast to total thicknesses of c. 730 m, and concomitantly become dominated by siliciclastic sandstone. The members (all new) from lower to upper are: **Naumai Member**, **Te Rangi Member**, **Taraponui Member**, **Bellbird Bush Member**, **and Opouahi Member**. The lower four members are inferred to each comprise an obliquity-controlled 41 000 yr 6th order sequence, and the Opouahi Member at least two such sequences. The sequences typically have the following architectural elements from bottom to top: disconformable sequence boundary that formed as a transgressive surface of erosion; thin transgressive systems tracts (TSTs) with onlap and backlap shellbeds, or alternatively, a single compound shellbed; downlap surface; and very thick (70–200 m) highstand (HST) and regressive systems tracts (RST) composed of fine sandstone. The sequences in the Opouahi Member have cryptic TSTs, sandy siltstone to silty sandstone HSTs, and cross-bedded, differentially cemented, fine sandstone RSTs; a separate variant is an 11 m thick bioclastic limestone (grainstone and packstone) at the top of the member that crops out in the vicinity of Lake Opouahi. Lithostratigraphic correlations along the crest of the ranges suggest that the Titiokura Formation, and its correlatives to the south around Puketitiri, represent a shoreline-to-shelf linked depositional system. Carbonate production was focused around a rocky seascape as the system onlapped basement in the south, with dispersal and deposition of the comminuted carbonate on an inner shelf to the north, which was devoid of siliciclastic sediment input. The rates of both subsidence and siliciclastic sediment flux increased rapidly to the northeast of the carbonate "platform", with active progradation and offlap of the depositional system into more axial parts of Hawke's Bay Basin.

Keywords Pliocene; Opoitian; Waipipian; Hawke's Bay Basin; Te Aute limestone lithofacies; sequence stratigraphy; Titiokura Formation; Naumai Member; Te Rangi Member; Taraponui Member; Bellbird Bush Member; Opouahi Member; new stratigraphic names

INTRODUCTION

The Titiokura Formation is a mixed carbonate-siliciclastic succession of early Pliocene age forming prominent bluffs and dip-slopes in the Te Waka and Maungaharuru Ranges along the western margin of Hawke's Bay Basin (Fig. 1). This formation is part of the Te Aute lithofacies limestone of Beu (1995), which is a descriptive term for the numerous Pliocene barnacle-dominated yellow-coloured limestone units of eastern North Island. In the synthesis volume of the Pliocene limestones and their scallops, Beu (1995) restricted the Titiokura Limestone to a unit of Waipipian age exposed along the northwestern side of the Te Waka Range south of State Highway 5 (SH5; Napier-Taupo Road) (Fig. 1). The much thicker succession of interbedded limestone and sandstone forming the crest of the Maungaharuru Range north of SH5 was referred to the Maungaharuru Formation (Cutten 1994), and on balance attributed an Opoitian age, although a Waipipian age could not be ruled out for the upper part of the formation (Beu 1995). Subsequent regional mapping by Francis (1991), Graafhuis (2001), and Bland (2001) suggests that the Titiokura Limestone and the limestone-bearing parts of the Maungaharuru Formation are probably part of the same depositional system; consequently, understandings about the origin of these units can usefully be advanced by associating them stratigraphically. As this and related work (K. Bland, PhD thesis in prep. "Analysis of the Late Miocene–Early Pleistocene Hawke's Bay Basin") shows, the limestone-bearing succession is cyclothemic, onlaps to the south in the Te Waka Range, and, in parts of the Maungaharuru Range, has been disrupted by large scale slumping. We infer that the Titiokura Limestone mapped and described by Beu (1995) is an upper sequence(s) within a stack of sequences that are thicker and mostly older in the more northerly sited Maungaharuru Range.

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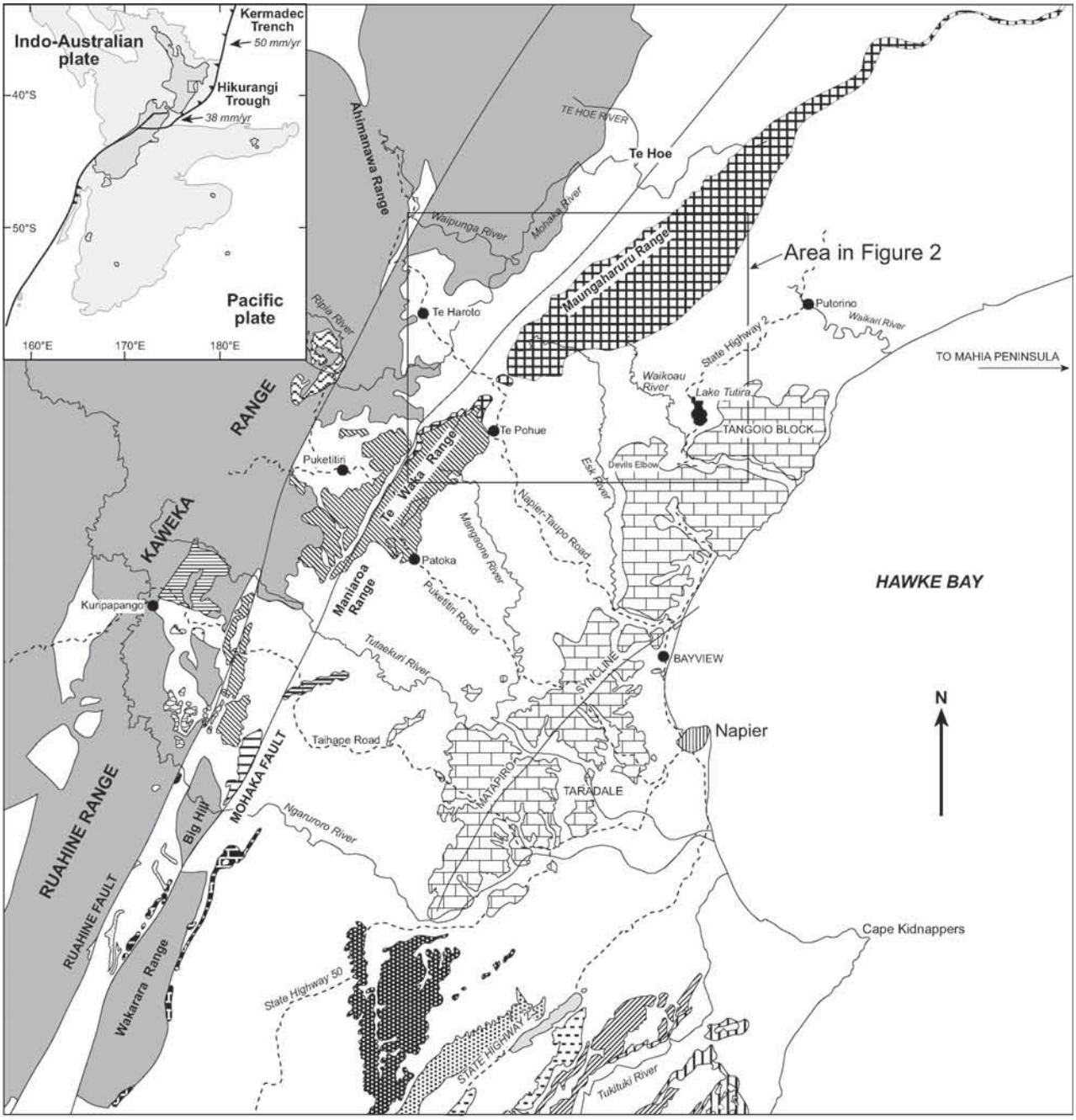


Fig. 1 Generalised distribution of Pliocene–Pleistocene limestone formations in Hawke's Bay Basin (after Beu (1995), with modifications from Bland (2001, in prep.), Graafhuis (2001), and Caron (2002)). New Zealand biostratigraphic stage abbreviations: Tk, Kapitean; Wo, Opoitian; Wp, Waipipian; Wm, Mangapanian; Wn, Nukumaruan. Note the nomenclature for stratigraphic units that crop out along the western versus eastern margins of the basin. *Inset*: The tectonic setting of the New Zealand region.

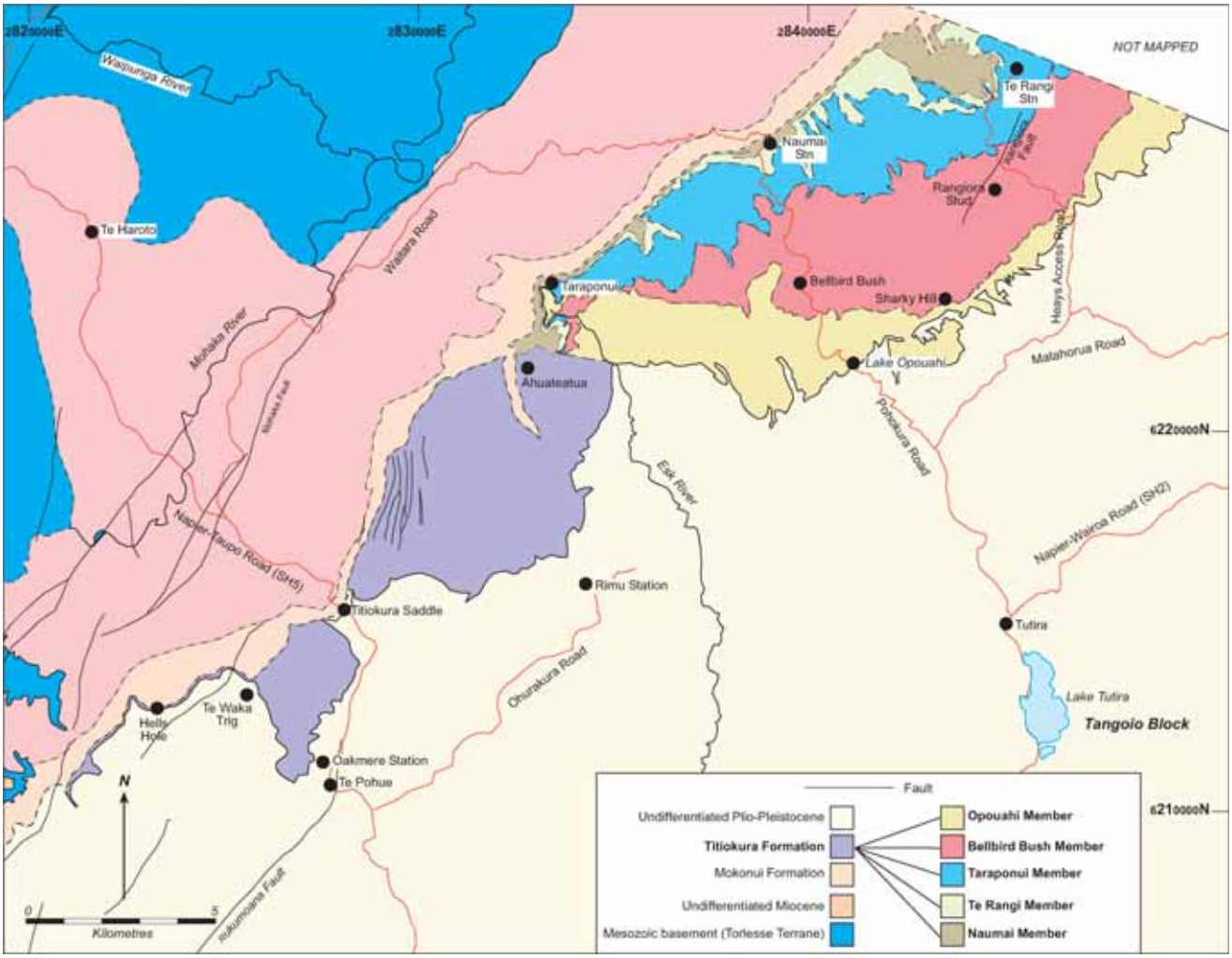


Fig. 2 Simplified geological map of part of western Hawke's Bay (outlined in Fig. 1), highlighting the distribution of the Titiokura Formation and its differentiation into five members. Map has been adapted from Grindley (1960), Bland (2001), and Graafhuis (2001), with modifications from Bland (in prep.).

This paper provides new information on the stratigraphy, facies, sequence stratigraphy, and depositional paleoenvironments of the Titiokura Formation. The formation marks an important change in the character and evolution of the central Hawke's Bay part of the basin, as these and younger sediments, despite their considerable thicknesses, accumulated in diversified shelf environments, compared with the underlying (Tongaporutuan) bathyal mudstone and regressive Mokonui Formation (Cutten 1994). The move to more detailed investigation of the internal characteristics of the Te Aute lithofacies, supported by mapping, is a natural follow-on from the comprehensive synthesis of the occurrence, biostratigraphy, and distribution of these lithofacies completed by Beu et al. (1980) and Beu (1995). The results of the work reported here on the Titiokura Formation on the northwestern margin of the basin complement detailed work on the Te Aute lithofacies on the southeastern margin of the basin (Caron 2002; Caron & Nelson 2003; Caron et al. 2004, this issue).

GEOLOGICAL SETTING

Titiokura Formation (Titiokura Limestone of Beu (1995) and the lower part of the Maungaharuru Formation of Cutten (1994)) occurs about midway within a 5–7 km thick late Miocene to late Pliocene succession dominated by siliciclastic sediments, representing the Tongaporutuan–Nukumaruan development and infilling of Hawke's Bay Basin (Fig. 2). The deposits underlying the Titiokura Formation chiefly involve Tongaporutuan–Kapitean Waitere Formation (Cutten 1994), which ranges from c. 1 to 4 km thick along the western side of the Maungaharuru Range. The Waitere Formation has a lower transgressive shelf sandstone member (Te Ipuohape Sandstone Member, lower Tongaporutuan) up to several hundred metres thick that onlaps older Neogene units and oversteps on to basement in a southwestward direction along the axial range. It is overlain by a very thick (850–3000 m) bathyal mudstone (Rakaita Siltstone Member) that thickens to the northeast and reflects late Miocene rapid and substantial basin subsidence.

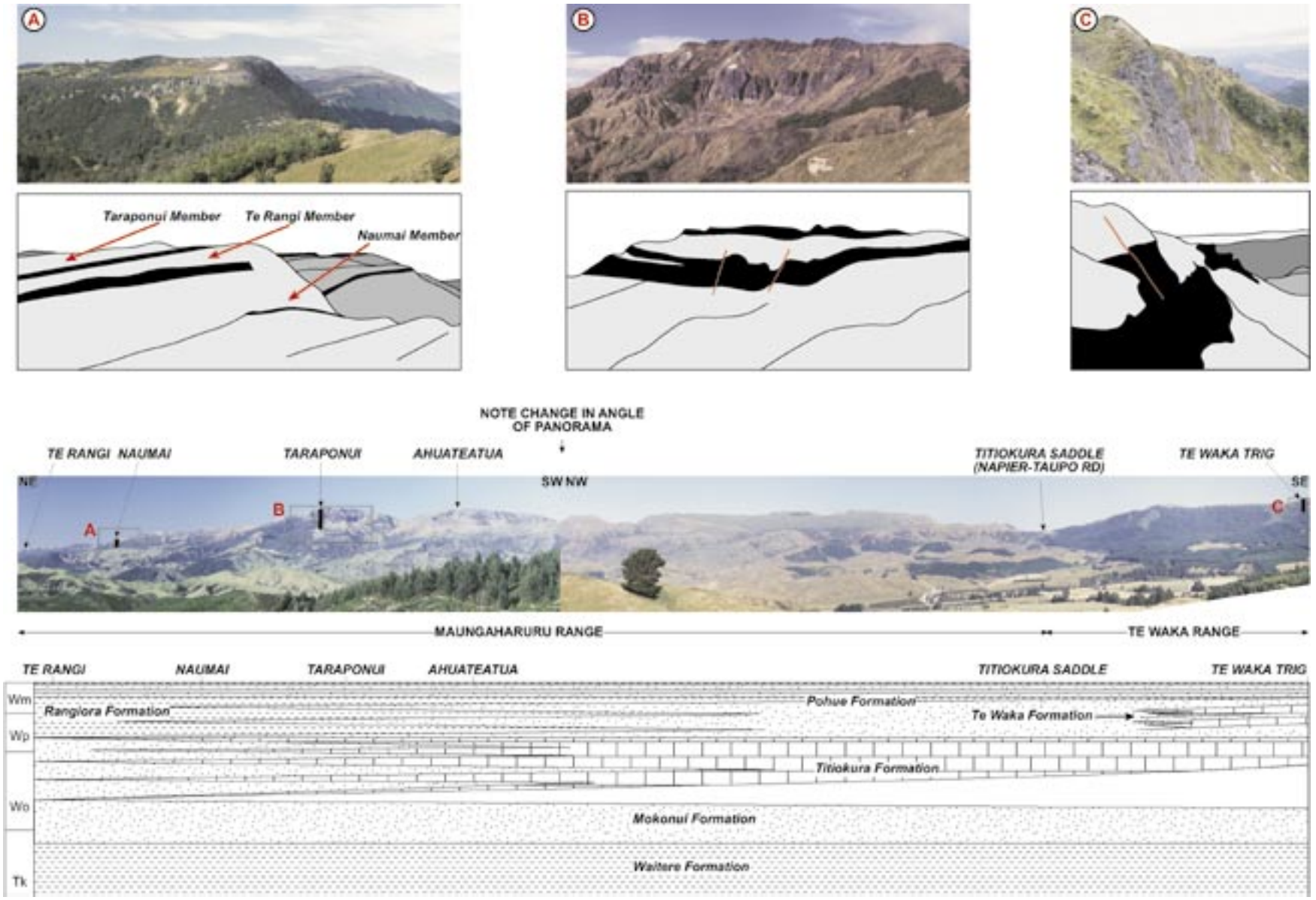


Fig. 3 Panoramic photographs, panel diagrams, and generalised chronostratigraphic panel for Titiokura Formation in the Maungaharuru Range and the Te Waka Range. **A**, View south from Naumai Station. Multiple, thin limestone sheets are present in this area. **B**, Taraponui Trig, viewed from the south below Ahuateatua Trig, where a single limestone unit to the south divides into multiple members. **C**, Te Waka Range west of Te Waka Trig, showing the single limestone unit characteristic of the southern sector. The chronostratigraphic panel schematically illustrates the distribution of the main stratigraphic units and their lithology in the western ranges. Black bands in sketches below photographs illustrate the extent of limestone facies.

The Rakaita Siltstone Member is unconformably overlain by the early Kapitean to early Opoitian Mokonui Formation (Cutten 1994) in a cutting on SH5, but elsewhere to the north along most of the Maungaharuru Range this contact is gradational. Facies analysis indicates that the upper part of the Mokonui Formation accumulated in inner shelf to shoreface paleoenvironments. The Mokonui Formation is unconformably overlain by the Titiokura Formation. This contact may mark a substantial change in the paleogeographic development of the basin, as it is the point at which carbonate beds become an obvious stratigraphic component (Te Aute lithofacies) of the basin succession, the overlying stratigraphy becomes lithologically very diversified, the basin depocentre shifts southeastward towards the axis of the Matapiro Syncline, and the inboard margin of the accretionary prism in the coastal hill country of southern Hawke's Bay starts to emerge above sea level (Beu et al. 1980, Kamp 1982; Pettinga 1982; Beu 1995).

The marked erosion of the Waitere Formation in the modern landscape, reflected in the formation of the Mokaha River valley, has removed any stratigraphic continuity that may have formerly existed between the Titiokura Formation in the Maungaharuru Range (Fig. 3) and the Torlesse greywacke basement in the axial range to the west (Fig. 1, 2). Hence, the relationship of the Titiokura Formation to basement cannot be established immediately west of the Maungaharuru Range. This can, however, be established through mapping of Pliocene units to the south. Opoitian limestone outliers have recently been mapped between the Kaweka and Ruahine Faults just north of Puketitiri, and west of the Mohaka Fault, in the vicinity of the Ripia River (Bland et al. 2003) (Fig. 1). This limestone unit is named Pakaututu Formation (Fig. 1) and it is characterised by abundant robust bivalves, especially *Tucetona laticostata* and common *Phialopecten marwicki*, and abundant greywacke breccia and conglomerate at its base, which has marked relief suggestive of a rocky paleo-coastline with sea stacks. The most continuous outcrop and contact with basement can be observed above and southeast of the Ripia River (e.g., NZMS 260 metric grid reference V19/128209–V20/134195), where the limestone is overlain by sandy siltstone with up to 50 m of section preserved. East of the Ruahine Fault, a lithologically similar limestone containing *Phialopecten marwicki* is considered to be a correlative unit. The contact with basement is located near the bottom of valleys (e.g., V20/120117), but is not obviously exposed, although the basement contact can be shown to be c. 50 m lower in elevation, being overlain by a marine sandstone and conglomerate, which reach their greatest thickness (50 m) adjacent to the Ruahine Fault. The Pakaututu Formation in this area is overlain by 120 m of poorly exposed siltstone, which coarsens upward to sandy siltstone, in turn unconformably overlain by the Te Waka Formation. Another calcareous formation of probable Opoitian age (Beu 1995), known as the Omahaki Formation, has been described from the Omahaki Depression (Kingma 1957) west of Ruahine Fault and well to the south of Puketitiri (Fig. 1). This unit is 5–20 m thick and comprises a carbonate cemented, sparsely fossiliferous conglomerate with sandstone interbeds that accumulated over greywacke basement (Beu 1995). Caron (2002) reported a 20 m thick calcareous sandstone with large scale trough cross-beds at the southern end of the Glenross Range (U21/032867), which is probably part of the Omahaki Formation. The Omahaki Formation accumulated through marine onlap over an indurated rocky surface.

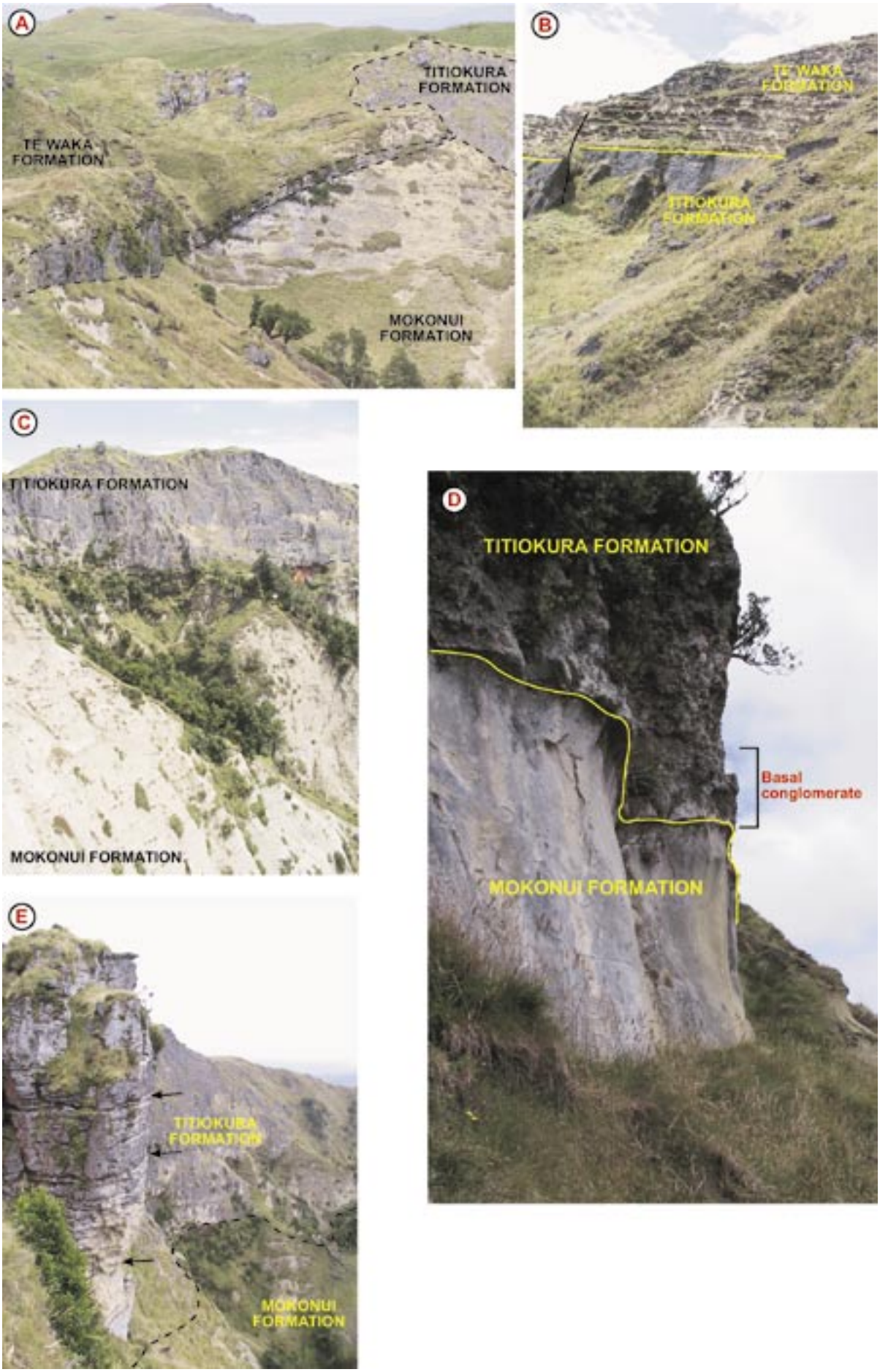
The Opoitian age of the Pakaututu Formation and Omahaki Formation implies that they are correlatives of the lower part of the Titiokura Formation in the Maungaharuru Range, but slightly older than Beu's (1995) Titiokura Limestone at Te Waka Trig. These differences in the stratigraphy along the range front can be attributed to differences in early Pliocene paleogeography. The Pakaututu Formation and Omahaki Formation accumulated on basement as transgressive onlap facies, while the Titiokura Formation formed as part of a linked depositional system farther north in the basin involving the dispersion of sediments on a subsiding shelf, the carbonate sediment having been sourced from the contemporary carbonate factories at or near the more southern rocky shorelines, and being transported offshore to the north by strong tidal currents. There is no direct evidence that the Titiokura Formation onlapped basement immediately west of the Maungaharuru Range. The strike-slip fault zones between the Pakaututu Formation and Titiokura Formation probably formed during the Nukumaruan (Erdman & Kelsey 1992; Bland et al. 2003), and associated uplift and erosion have removed the original stratigraphic continuity between them. Consequently, we refer to the Titiokura Formation as an example of a continent-attached mixed carbonate-siliciclastic depositional system. It provides a new perspective on the Te Aute lithofacies because it reveals a highly oblique section from a shoreline across the early Pliocene paleo-shelf, enabling some insights to be gained into the cross-shelf profile of these lithofacies. This contrasts with similar aged Te Aute lithofacies units exposed along the southeastern margin of the inland seaway, such as the Opoitian Kairakau Limestone and Waipipian Awapapa Limestone, which show limited down-dip exposure (Kamp et al. 1988; Caron 2002).

The Maungaharuru Formation as defined by Cutten (1994) is a very thick and lithologically diverse unit, which includes beds ranging in age from Opoitian to early Nukumaruan. Mapping by Bland (2001, in prep.) and Graafhuis (2001) has subdivided this unit into numerous formations and members. In their stratigraphic rationalisation, the name Maungaharuru Formation has been abandoned, and we adopt the name **Titiokura Formation** for the Opoitian–Waipipian limestone-bearing succession in the Maungaharuru Range and the Te Waka Range, thereby expanding the usage of Titiokura Limestone of Beu (1995), but changing the name to substitute the term "Formation" for "Limestone" in recognition of the siliciclastic content of correlative beds in the Maungaharuru Range.

STRATIGRAPHY

TITIOKURA FORMATION (emended)

NAME AND DEFINITION: The Titiokura Limestone was formally defined by Beu (1995) for a 50 m thick Waipipian limestone at Titiokura Summit in the Te Waka Range near Te Pohue, immediately south of SH5 (Napier-Taupo Road), where it underlies brown sandstone traditionally included in the Te Waka Formation (Fig. 4). Here, we formally emend the name Titiokura Limestone (Beu 1995) to Titiokura Formation, to accommodate the lithological variation evident in the beds in the Manugaharuru Range that we now include in the one depositional system, which ranges in age from Opoitian to Waipipian.


A
TITIOKURA FORMATION
TE WAKA FORMATION
MOKONUI FORMATION
B
TE WAKA FORMATION
TITIOKURA FORMATION
C
TITIOKURA FORMATION
MOKONUI FORMATION
D
TITIOKURA FORMATION
Basal conglomerate
MOKONUI FORMATION
E
TITIOKURA FORMATION
MOKONUI FORMATION

We retain the name "Titiokura" in Titiokura Formation for several reasons. In Beu et al. (1980) the Titiokura Limestone was mapped along the eastern side of Maungaharuru Range, where it was applied to a clear limestone facies considered at the time to be Waipipian in age. Subsequently, Beu (1995) raised uncertainty about the Waipipian age of northern occurrences of this limestone unit near Lake Opouahi (V19/403227; Fig. 2), and chose to restrict Titiokura Limestone *sensu stricto* to the Te Waka Range. All of the limestone units in the Maungaharuru Range were then included by Beu (1995) in the Maungaharuru Formation, a unit that had been redefined by Cutten (1994) to include all strata above the Mokonui Formation through to the Mangapanian conglomerate units on Matahorua Road near Lake Tutira (Fig. 2). Mapping by Graafhuis (2001) showed that the Maungaharuru Formation within Cutten's map area, and farther to the east, can very usefully be subdivided into multiple units, some of them being discrete sequences. As the new map units will require new names, we will raise the Maungaharuru Formation to subgroup rank (e.g., Bland in prep.). This leaves open the need for a name for the limestone and associated lithofacies of Opoitian–Waipipian age in the Maungaharuru and Te Waka Ranges, for which we apply the name Titiokura Formation.

A previously unknown limestone at the base of a section in Wai-iti Stream near Patoka (Gorges Section, V20/188007) was interpreted by Caron (2002) to be Titiokura Formation, thereby extending its known occurrence significantly to the south of Te Pohue (Fig. 1).

TYPE AND REFERENCE SECTIONS: Beu (1995) established a type locality (V20/278148) for the Titiokura Formation at the northern end of Te Waka Range. The base of the formation is not well exposed at that locality, and therefore we establish a new type section for the formation 3 km along the ridge crest to the south at V20/248133, where there is complete exposure of the formation from bottom to top (Fig. 4A, 5). Good accessible exposures of the formation occur along SH5 at V20/289142–287144. A good reference section along the down-dip eastern side of the Te Waka Range is located on Oakmere Station above Te Pohue village (Caron 2002, column 38, V20/275115). Another useful reference section characterising the stratigraphy of Titiokura Formation in the central part of the Maungaharuru Range occurs on the western side of Taraponui Trig (V19/331228) (Fig. 5). A reference section in the northern part of the Maungaharuru Range (V19/387273–408218) is located along Pohokura Road, east of the intersection with Jeph Everett Road to Lake Opouahi.

DISTRIBUTION AND BOUNDARIES: The distribution of the Titiokura Formation within the Maungaharuru and Te Waka Ranges has been mapped at 1:50 000 (Bland 2001, in prep.; Graafhuis 2001). The generalised distribution is illustrated in Fig. 2. The Titiokura Formation occurs exclusively east of Mohaka Fault, and everywhere overlies the Mokonui Formation (Fig. 3). It has an erosional contact with Mokonui Formation for c. 30 km along the western face of the Te Waka (Fig. 4) and Maungaharuru Ranges, but this contact becomes conformable in the northernmost parts of Maungaharuru Range, where the paleogeography allowed for continuous sedimentation.

The upper contact of the Titiokura Formation south and west of SH5 has been mapped around a prominent dip-slope and along the western face of Te Waka Range (Fig. 2). Beu (1995) suggested that the contact in this area is unconformable, but our observations are that the upper contact is sharp but conformable at Oakmere Station near Te Pohue, or gradational and conformable along the western face of the Te Waka Range (Fig. 4A,B). In the Maungaharuru Range, the upper contact of the Titiokura Formation occurs in catchments facing east off the range. Invariably, the mapped position of this contact is inferred, as good exposures have not been located due to the occurrence of extensive slump deposits. The contact is inferred to be conformable and overlain by siliciclastic siltstone and sandstone of the Rangiora Formation (Fig. 3) (Graafhuis 2001).

THICKNESS: The Titiokura Formation varies from a few metres thick to composited thicknesses of c. 730 m (Fig. 5, 6). These measurements have been made along the northeast–southwest-trending western faces of the Te Waka and Maungaharuru Ranges; it is expected that correlative beds will increase in thickness eastward into subsurface parts of Hawke's Bay Basin. This is suggested by a systematic decrease in dip upwards within the members of the Titiokura Formation in the vicinity of Naumai and Te Rangi Stations, such that beds will diverge and thicken southeastward into the basin. An outlier of Titiokura Formation at Patoka has a thickness of 20 m, but this is likely to be only the uppermost part of the formation. Along the western face of the Te Waka Range, Titiokura Formation overlies and infills a spectacular paleo-relief carved into underlying Mokonui Formation (Fig. 4). Relief on this surface may locally be as much as 20–30 m. As a result, the Titiokura Formation shows prominent local thickness changes ranging from 2 to 75 m.

LITHOLOGY: In the southern part of the Maungaharuru Range, south of Ahuateatua Trig and extending into Te

◄ **Fig. 4** Photographs of parts of Titiokura Formation at various localities along the western face of the Te Waka Range, southwest of Te Waka Trig. **A**, Titiokura Formation unconformably over Mokonui Formation, showing marked relief on the contact. The dark grey limestone on the left side of the photo view is c. 15 m thick, thins to 1 m over the Mokonui Formation high in the centre, and then thickens to the right to >50 m thick. The overlying grey limestone is part of the Te Waka Formation. Location: V20/242130, view looking southwest. **B**, Titiokura Formation limestone gradationally overlain by concretionary sandstone facies of the Te Waka Formation. Location: V20/239128, looking north. **C**, Sandy limestone facies of the Titiokura Formation unconformably overlying concretionary, non-fossiliferous sandstone facies of the Mokonui Formation at Hells Hole, Te Waka Range. The limestone sheet is c. 50 m thick. Location: V20/235127, looking south. **D**, Contact between Titiokura Formation and Mokonui Formation. The 0.5 m thick bed above the contact comprises a conglomerate consisting of Tertiary sandstone and mudstone clasts. Relief on the contact is up to 0.3 m. Location: V20/239128. **E**, Approximately 20 m thick outcrop of Titiokura Formation in foreground, above buff-coloured Mokonui Formation. Arrows denote surfaces defining broad "packages" within an otherwise single limestone sheet. Location: V20/241129, looking southwest.

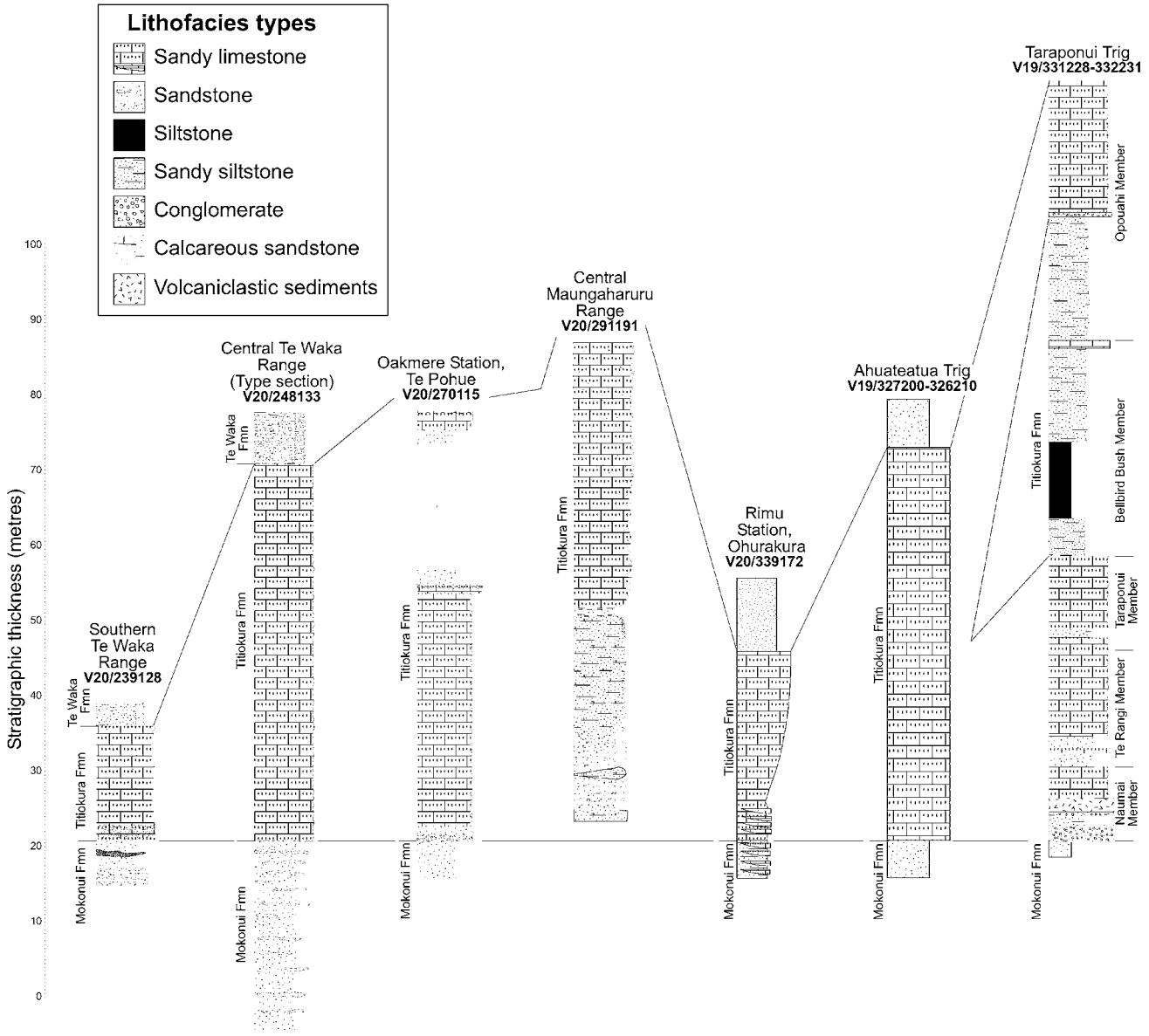


Fig. 5 Stratigraphic columns of the Titiokura Formation at localities within the Te Waka Range and southern part of the Maungaharuru Range. Note the differentiation from a principal limestone unit into more diversified lithologies at Taraponui Trig.

Waka Range, the Titiokura Formation consists chiefly of limestone that unconformably overlies sandstone facies of the Mokonui Formation (Fig. 2, 4, 5). The limestone comprises alternating coarsening-upward skeletal grainstone and mixed carbonate-siliciclastic packstone in tabular sets up to 30 cm thick. Cementation is more pronounced in the skeletal beds compared with siliciclastic beds (Caron 2002). Lower parts of the limestone are dominated by bivalve fragments and barnacle plates, passing up into bryozoan-rich facies (Caron 2002).

North of Ahuateatua Trig, the lithology of the Titiokura Formation becomes more diversified, with multiple limestone beds separated by silty sandstone and siltstone (Fig. 3, 5, 6, 7). Limestone units consist primarily of barnacle-bryozoan packstone to grainstone beds. Basal parts of the limestone beds consist largely of barnacle plates, and branching and encrusting bryozoans, with an increase in bryozoan content up-section. These beds are separated by fossiliferous sandstone and siltstone units that become thicker to the northeast. Also, with increasing distance to the north, particularly in the vicinity of Naumai and Te Rangi Stations (Fig. 2), the limestone units pass into cross-bedded fossiliferous sandstone (Graafhuis 2001).

PALEONTOLOGY AND AGE: The limestone sheet in the southern extent of the Titiokura Formation is composed of barnacle plates, fragmented bryozoans (robust-branching and encrusting types), and bivalve and echinoderm fragments. Macrofossils include *Talochlamys gemmulata*, *Ostrea chilensis*, *Neothyris* aff. *obtusa* (locally forming brachiopod beds), *Amalda* (*Baryspira*) *mucronata*, and rare *Atrina pectinata zelandica*. At Pohokura Saddle, the basal conglomerate contains rare *Penion* sp., *Alcithoe* sp., solitary corals, and shark teeth.

The occurrence of large *Phialopecten marwicki* and rare *Mesopeplum crawfordi* in the uppermost parts of Titiokura Formation in the Te Waka Range suggest a Waipipian age for

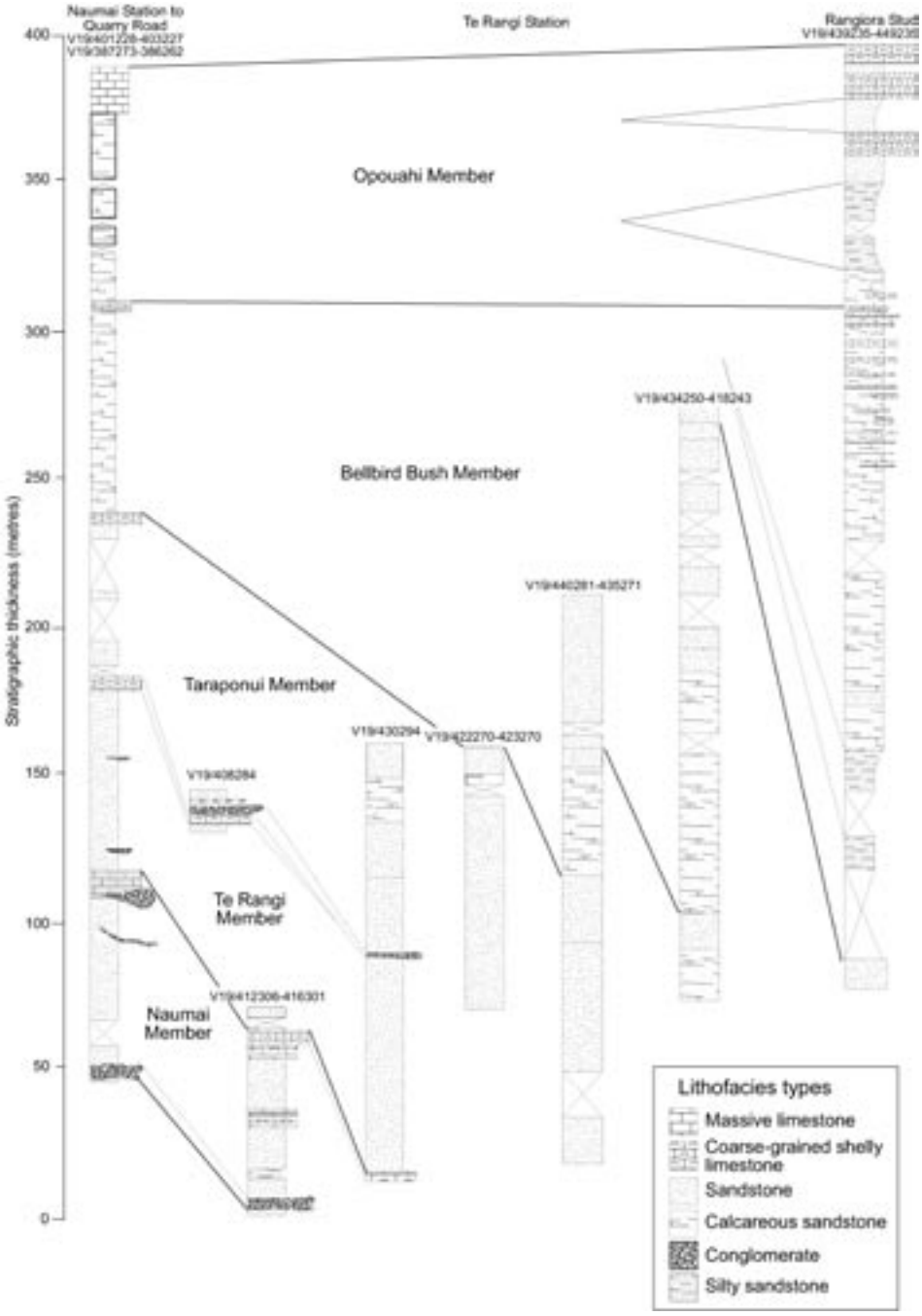


Fig. 6 Stratigraphic columns of the Titiokura Formation in the Maungaharuru Range from Taraponui Trig north to Te Rangi Station, showing the differentiation into lithostratigraphic members.

the beds (Beu 1995; Bland 2001). In the northern parts of the Maungaharuru Range, shellbed correlatives of the limestone units at Taraponui Trig (Fig. 5, 6) contain *Crassostrea ingens* and Opoitian forms of *Phialopecten marwicki*, suggesting an Opoitian age for this part of the formation. The underlying Mokonui Formation has been reported by Cutten (1994) to be of late Kapitian to early Opoitian age. The uppermost limestone unit (Opouahi Member) in Titiokura Formation corresponds to the beds reported by Beu (1995) to contain rare *Mesopeplum crawfordi*, suggesting an Opoitian or earliest Waipipian age.

The early Pliocene ages inferred from the relatively sparse age-diagnostic macrofossils identified by prior workers and ourselves, together with the thickness distribution of the formation and its members, suggest that the strata onlap to the south and offlap to the north and east.

In the following sections we establish five new members within Titiokura Formation. These include **Naumai**, **Te Rangi**, **Taraponui**, **Bellbird Bush**, and **Opouahi Members** (Fig. 6).

Naumai Member (new)

NAME AND DEFINITION: Naumai Member is named after Naumai Station at the crest of the Maungaharuru Range on Pohokura Road (Fig. 2), and is the lowest member in the Titiokura Formation. The member comprises a stratigraphic succession of conglomerate, calcareous sandstone or limestone, silty sandstone, and sandy limestone.


A
B
C
E
Bellbird Bush Member
Taraponui Member
Te Rangi Member
F
D
G

TYPE LOCALITY: The type section is designated on Pohokura Road at the crest of the range and within adjacent parts of Naumai Station (Fig. 8). The base of the member is very well exposed on Pohokura Road at V19/387273, being the roadcuts on the southern side of the intersection with Jeph Everett Road (Fig. 9B). The majority of the stratigraphic extent of the member is exposed in natural outcrops in the paddock on the northern side of Pohokura Road at this intersection, the top of the section being located at V19/386265. Reference sections have been drawn for Taraponui Trig (V19/331228) and on Te Rangi Station (V19/412306–416301) (Fig. 6) (Graafhuis 2001).

DISTRIBUTION AND BOUNDARIES: Naumai Member has been mapped (1:50 000 scale) from the section below Ahuateatua Trig along the western face of the Maungaharuru Range to Te Rangi Station (Graafhuis 2001; Bland in prep.) (Fig. 2). The member also crops out east of the range crest in the sides of incised stream valleys, the broadest extent being at the end of Heayes Access Road on Te Rangi Station.

The base of Naumai Member, as identified north of Ahuateatua Trig, coincides with the base of the Titiokura Formation. Throughout the map area (Fig. 2), the lower contact is an erosional unconformity, possibly angular, most of the apparent discordance being due to channelisation and large scale cross-bedding, rather than to tectonic tilting. This contact varies from being sharp and planar to having a local relief up to 6 m over 10 m length of outcrop (Fig. 6, 8) Northwards from Te Rangi Station, which corresponds to a direction into the depocentre, the lower contact appears to become conformable. The upper contact of Naumai Member is considered to be a disconformity and is a sharp planar surface with minor local relief on it.

THICKNESS: At Taraponui Trig, Naumai Member is 15 m thick, which increases to c. 60 m in sections at Te Rangi Station. Most of the northeastward increase in thickness is due to thickening of sandstone facies comprising the middle to upper parts of the member. Basal conglomerate facies, by contrast, are thickest (up to 6 m) in the southwest, reducing to c. 4 m in the northeast, although depending on the degree of channelisation, may not be present at any point along the outcrop extent. The limestone facies at the top of the member are also thickest in the southwest, being 9 m at Taraponui Trig.

LITHOLOGY: The basal beds of Naumai Member comprise various types of conglomerate and breccia. At the type section, basal channelised conglomerate comprises well-rounded and angular pebble to boulder size mudstone (90%) and sandstone clasts (10%) in a shelly sandstone matrix, which pass upwards into differentially cemented, bipolar cross-bedded, sandy limestone and calcareous sandstone, with rare mudstone clasts; this succession is repeated two or three times in the lower 6 m of the member at the type section (Fig. 7A, 9A,B). Greywacke pebbles are not prominent in the type section, but occur at localities above the contact to the south near Taraponui Trig, where pumice and charcoal fragments are locally conspicuous components of the conglomerate facies.

Sandstone beds comprise the bulk of Naumai Member in the type section and localities to the northeast (Fig. 6, 8). Lower parts are fine-grained sandstone to silty sandstone (Fig. 7F), with thin beds of sandy siltstone; upper parts are variably cemented, moderately calcareous and concretionary fine sandstone, with a few discontinuous and thin fine pebbly beds. The sandstone facies grade southward into limestone facies of the undifferentiated Titiokura Formation.

AGE: The Mokonui Formation underlying Naumai Member has an early Kapitean–Opoitian age in the Mohaka River section, and an early Opoitian age at Pohokura Road (Cutten 1994). Small size specimens of *Phialopecten marwicki* occur in the limestone facies of the Naumai Member, suggestive of an Opoitian age.

Te Rangi Member (new)

NAME AND DEFINITION: The name Te Rangi Member is derived from Te Rangi Station at the end of Heays Access Road (Fig. 2). This member has similar content and facies succession to Naumai Member, as described above.

TYPE LOCALITY: The type section is designated on Naumai Station at V19/387273–386262, being the succession immediately above the Naumai Member, and located immediately to the east and at higher elevation, involving natural outcrops in the same paddock (Fig. 6, 8). Reference sections have been logged for localities at Taraponui Trig (V19/331228), on Naumai Station (V19/392274, 407287) and on Te Rangi Station (V19/430297, 407287) (Graafhuis 2001).

DISTRIBUTION AND BOUNDARIES: Te Rangi Member immediately overlies Naumai Member and is distributed in a belt to the east of it, forming prominent dip-slopes on the flanks above deeply incised stream valleys (Fig. 2).

The lower boundary of the Te Rangi Member is sharp and erosional at Naumai Station, forming a disconformity. To the north at Te Rangi Station it is sharp, but possibly conformable. The upper boundary has similar character, locally showing relief of up to 60 cm.

THICKNESS: The member is 20 m thick at Taraponui Trig (Fig. 5), thickening to c. 70 m in the vicinity of Naumai

◄ **Fig. 7** Photographs of parts of the constituent members of the Titiokura Formation in northern parts of the Maungaharuru Range. **A**, Conglomeratic limestone with large mudstone clast at the base of the Naumai Member (facies MX_2), Naumai Station (V19/394277). **B**, Cross-bedded pumiceous sandstone (facies S_7) in upper parts of Te Rangi Member, Naumai Station (V19/392272). **C**, Calcareous sandstone (facies MX_1) interbedded with thin siliciclastic siltstone beds, Bellbird Bush Member, Heays Access Road (V19/469253). **D**, Alternating grainstone and packstone beds (facies BC_1), Opouahi Member, Lake Opouahi (V19/408218). Note the sharp lower contact (arrowed) with underlying siltstone. **E**, View of Taraponui Member overlying Te Rangi Member in the western face of the Maungaharuru Range south of Naumai Station. Location: V19/370265, looking south. **F**, Alternating beds of siltstone and sandstone (facies S_6), Naumai Member, Naumai Station (V19/394273). **G**, Bioturbated, fine sandy packstone (facies MX_1) of Taraponui Member, Boundary Stream Reserve (V19/446270).

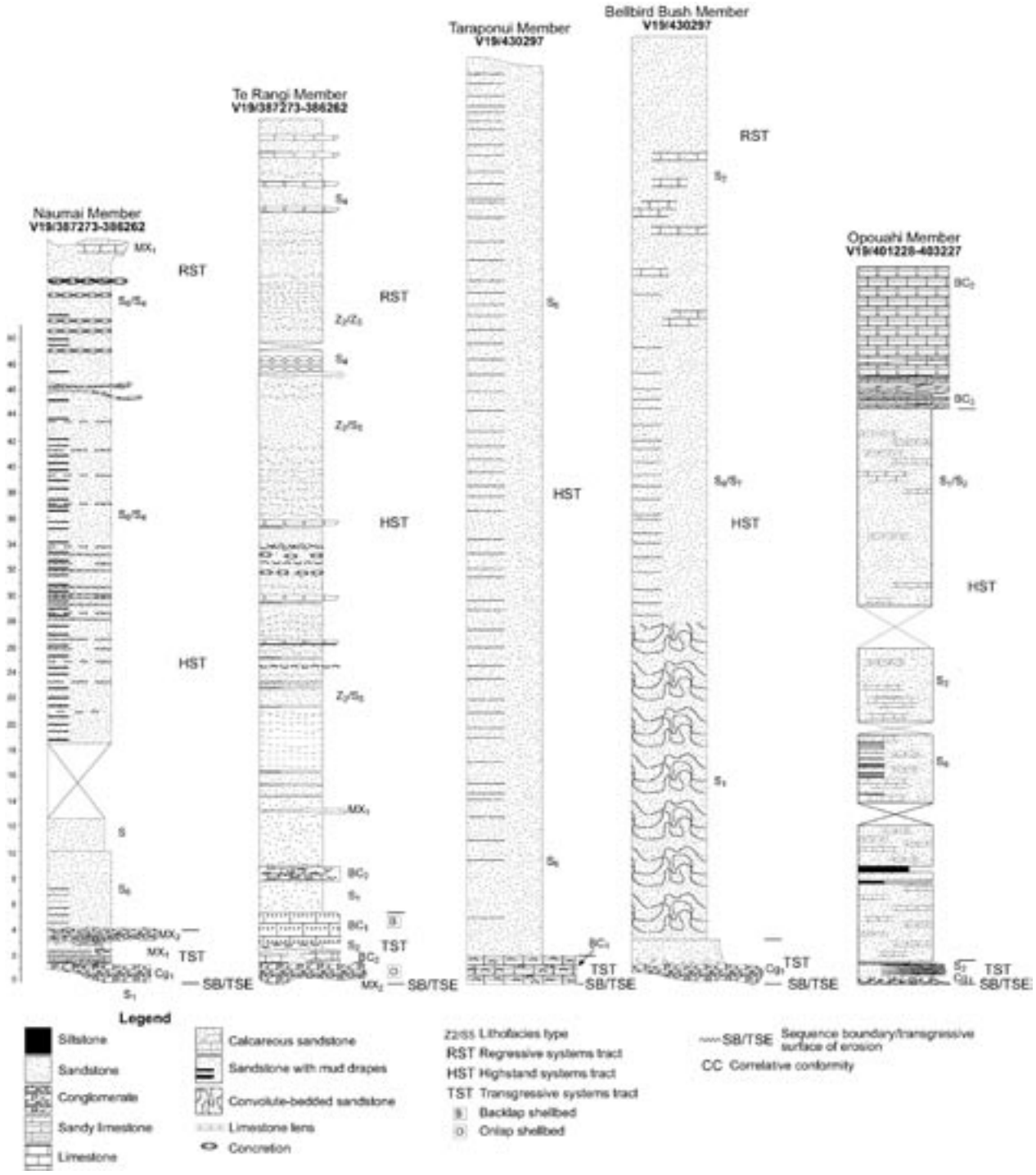
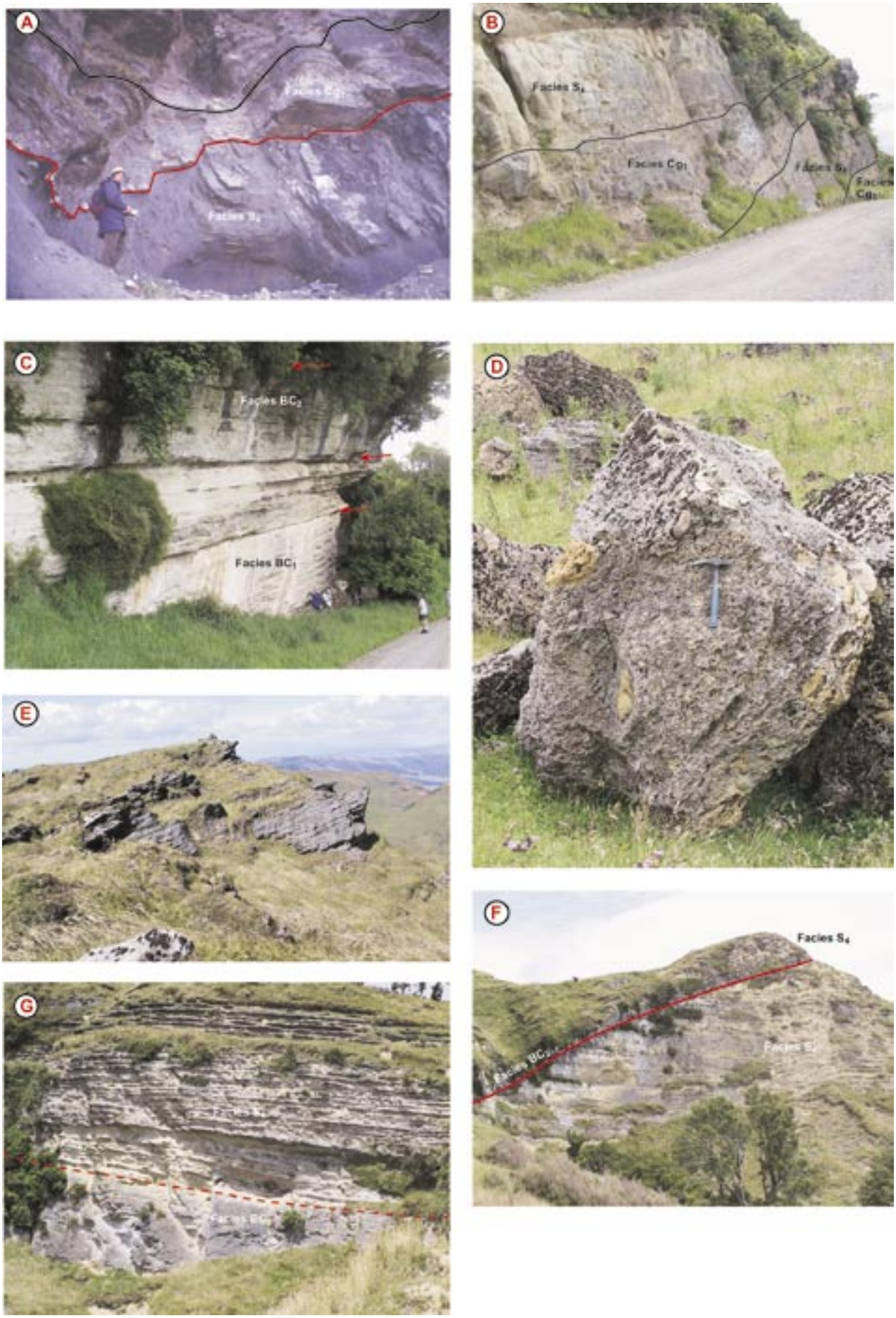


Fig. 8 Detailed stratigraphic logs for the type sections of the members in the Titiokura Formation in northern parts of the Maungaharuru Range, showing the vertical distribution of facies. Also shown are the positions of key sequence stratigraphic surfaces defining TST deposits and the stratigraphic extents of systems tracts.

Fig. 9 Examples of lithofacies in the Titiokura Formation. **A**, Concretionary sandstone (lithofacies S_4) of the Mokonui Formation unconformably beneath basal conglomerate bed (lithofacies Cg_1) of the Titiokura Formation. Location: cliff section below Taraponui Trig (V19/331236). **B**, Conglomerate lithofacies (lithofacies Cg_1) at the base of the Naumai Member, Pohokura Road/Jeph Everett Road intersection, interbedded with concretionary sandstone (lithofacies S_4) (V19/387273). **C**, Alternating packstone-grainstone beds (lithofacies BC_1), passing up into more siliciclastic rich beds (lithofacies BC_2), Opouahi Member, Pohokura Road (V19/403222). Note the prominent surfaces (arrowed) in this outcrop. **D**, Coarse-grained mixed bioclastic-siliciclastic lithofacies (lithofacies MX_1) in fall blocks, southern Maungaharuru Range (V20/219191). **E**, Moderately dipping (c. 22°), well-cemented, alternating packstone-grainstone beds (facies BC_1), Ahuateatua Trig, central Maungaharuru Range (V19/327216). **F**, Skeletal limestone (lithofacies BC_2) laterally passing into concretionary sandstone (facies S_4), Te Waka Range south of Te Waka Trig (V20/235126). The Titiokura Formation unconformably overlies concretionary sandstone of the Mokonui Formation (also lithofacies S_4). **G**, Skeletal-terrigenous limestone (lithofacies BC_2) of the Titiokura Formation underlying concretionary sandstone (lithofacies S_4) of the Te Waka Formation (V20/235126). ➤


A
B
Facies S_4
Facies C_{D1}
C
Facies BC_2
Facies BC_1
D
E
F
Facies S_4
G

and Te Rangi Stations (Fig. 8). The northward increase in member thickness is due exclusively to substantial increases in the amount of siliciclastic sandstone within the bulk of the member.

LITHOLOGY: The base of Te Rangi Member at Naumai Station comprises a 0.5 m thick fossiliferous pebble to cobble greywacke conglomerate with disarticulated and fragmented bivalves, including *Crassostrea ingens* (Fig. 8, 9D). It is overlain by 1–2 m of cross-bedded, well-sorted calcareous sandstone, and then c. 1 m of moderately to well cemented, medium to coarse grained skeletal grainstone and packstone. This limestone is sharply overlain by 10 m of massive, non-cemented, well-sorted fine sandstone, with occasional thin interbeds of cemented skeletal grainstone. The overlying 30 m of section is comprised of thin to medium bedded, non-cemented fine sandstone, sometimes with internal ripple bedding, convolute bedding, thin skeletal grainstone beds, and concretionary horizons. Bioturbation is obvious. The upper 30 m of the member is comprised of differentially cemented, medium to coarse grained, calcareous sandstone, displaying sets of megaripple to sand wave-scale trough and tabular cross-bedding, with convolute bedding and disrupted mud drapes (Fig. 7B). Sandstone beds and sets become more thickly bedded and cross-bedded upwards to the top of the member. Pumice is a conspicuous component of some cross-beds.

At Taraponui Trig the Te Rangi Member is 18 m thick, the lower 2 m comprising a grey calcareous fine sandstone, and the upper 16 m comprising cross-bedded fossiliferous grainstone with greywacke pebbles throughout, together with scattered, large sandstone rip-up clasts. In the vicinity of Rangiora and Te Rangi Station, the member comprises chiefly massive, bioturbated fine sandstone with mudstone drapes.

AGE: No age-diagnostic macrofossils have been identified in the member, which is inferred to be of Opoitian age, based on stratigraphic position.

Taraponui Member (new)

NAME AND DEFINITION: The name Taraponui Member is derived from Taraponui Trig on the crest of the Maungaharuru Range, where it is well exposed as a limestone unit. Northwards away from Taraponui Trig, the member is characterised by the occurrence of thick sandstone, with a limestone unit at its base (Fig. 6, 8).

TYPE LOCALITY: The type section is designated on Te Rangi Station at V19/430297, being the most accessible section where the whole of the member is exposed, including its lower contact (Fig. 8). Reference sections have been logged for localities at Taraponui Trig (V19/331228–332231), Naumai Station (V19/408284), Boundary Stream Walkway (V19/440281–435271), and Rangiora Stud (19/422270–423270) (Graafhuis 2001).

DISTRIBUTION AND BOUNDARIES: Taraponui Member overlies Te Rangi Member and has a similar distribution to it (Fig. 2). The top of the member forms a prominent dip-slope that runs out to bluffs above deeply incised streams.

The lower boundary of the Taraponui Member is sharp and disconformable at localities between Taraponui Trig and Te Rangi Station. The upper boundary is also a disconformity, showing relief of a few decimetres, but it is also rarely well exposed.

THICKNESS: The member is 10 m thick at Taraponui Trig, thickening to c. 75 m in the vicinity of Te Rangi and Rangiora Stations (Fig. 6, 8). As with the two underlying members, the northward increase in member thickness is due exclusively to substantial increases in the amount of siliciclastic sandstone within the bulk of the member.

LITHOLOGY: Taraponui Member comprises two main lithologies: a limestone or shellbed facies, which forms within the basal few metres of the member north of Taraponui Trig (Fig. 8), thickening up to comprise the bulk of the member (10 m) in the vicinity of Taraponui Trig (Fig. 5) and to the south of it; and sandstone facies, which form the bulk of the member in the vicinity of Naumai, Rangiora, and Te Rangi Stations. At Taraponui Trig the base of the member is a 0.5 m thick silty sandstone, overlain by moderately cemented, cross-bedded, glauconitic grainstone (10 m), with mudstone rip-up clasts, rare pumice, and greywacke pebbles. Bioclasts are comprised of barnacle and echinoderm plates, and bryozoan and pecten fragments.

At V19/408284 on Naumai Station, Taraponui Member has at its base a fossiliferous and cemented conglomerate, containing sandstone and mudstone clasts, and greywacke pebbles. This is overlain by 1–2 m of cross-bedded sandstone, and then a 0.5 m thick shellbed with rip-up clasts and flame structures at its base. At V19/386262 on the same property, the basal unit is a cross-bedded sandy limestone (grainstone) with mudstone and pumice clasts at its base. A similar single shellbed at the base of the member occurs on Te Rangi Station at V19/430297, but without the pumice and greywacke clasts. The lowermost beds appear to become amalgamated into one shellbed in a northeast direction, corresponding to a direction farther out into the basin.

Sandstone facies in Taraponui Member are 70–80 m thick, forming most of the member thickness (Fig. 8). Generally, lowermost parts are clean, fine sandstone with low-angle megaripple cross-beds, passing up into massive and ripple-bedded, bioturbated fine sandstone with mud drapes, reactivation surfaces, and differentially cemented concretionary horizons, and further upwards into amalgamated, well sorted, cross-bedded, fossiliferous fine sandstone (Fig. 7G).

AGE: No age-diagnostic macrofossils have been identified in Taraponui Member, which is inferred to be of Opoitian age, based on stratigraphic position.

Bellbird Bush Member (new)

NAME AND DEFINITION: Bellbird Bush Member is named after Bellbird Bush, a nature reserve near Naumai Station on the Maungaharuru Range (Fig. 2). The member is characterised by very thick accumulations of sandstone facies.

TYPE LOCALITY: The type section is designated on Te Rangi Station at V19/430297, where the member directly overlies the Taraponui Member, and the middle and lower parts of Bellbird Bush Member, including its lower contact, are exposed (Fig. 8). A reference section is located at V19/440281–435271 on Boundary Stream Walkway, where c. 110 m of the member is well exposed. Other good exposed

sections occur at Taraponui Trig (V19/332231), on Quarry Road (V19/401228–4032270), on the steep-sided ridge on Rangiora Stud known to local residents as "Sharky Hill" (V19/439235–449235, 220 m of section exposed; V19434250–418243; V19/445255), and on Maori Gully Track (V19/405246) (Graafhuis 2001).

DISTRIBUTION AND BOUNDARIES: Bellbird Bush Member is extensively distributed in outcrop on the eastern flanks of the Maungaharuru Range (Fig. 2). It disconformably overlies Taraponui Member at Taraponui Trig and in the type section at Te Rangi Station, but appears to have a gradational contact in sections on Rangiora Stud to the east, which are located farther into the paleo-basin. The upper boundary is disconformable at Taraponui Trig, but conformable in other accessible sections located to the northeast.

THICKNESS: The Bellbird Bush Member is 25 m thick at Taraponui Trig, 70 m thick in the Waikoau River catchment, and 240 m thick to the northeast in the Waikari River catchment (Rangiora Stud) (Fig. 6). The dramatic increase in thickness into the paleo-basin is associated with the accumulation of sandstone facies.

LITHOLOGY: At the type section, a conglomerate containing subangular sandstone pebbles/clasts and numerous gastropods rests on a surface cut across Taraponui Member with 0.6 m of local relief (Fig. 8). This is overlain by fine clean sandstone with low-angle cross-beds. The lower 20 m of this sandstone section displays numerous zones of intricate convolutedly deformed beds, probably having a syn-sedimentary dewatering origin. This is overlain by 20 m of fine sandstone with megaripples, mud drapes (c. 2 cm thick), and internal cross-lamination. The mud drapes and sandstone beds are heavily bioturbated. This section passes into a 50 m thick section of cross-bedded fine sandstone with differentially cemented calcareous sandstone horizons.

The reference section on Boundary Stream Walkway is characteristic of other sections on Rangiora Stud. It appears to show a conformable base without a lower conglomerate bed or shellbeds, and comprises sandstone facies throughout. From bottom to top, the sandstone is parallel-laminated to cross-bedded (lower 25 m), heavily bioturbated and cross-bedded sandstone with mud drapes and concretionary horizons (middle 40 m), and massive to parallel-laminated sandstone, with rare mudstone stringers and concretionary horizons (upper 45 m) (Fig. 7C). In general, the upper third of the thickness of the member has common cemented horizons, reflecting a cleaner sandstone and higher carbonate content originating from finely comminuted shell hash. At Taraponui Trig, the Bellbird Bush Member comprises 23 m of thin-bedded, fossiliferous sandy siltstone. This member may include part of the underlying limestone, included above in the Taraponui Member, as the position of the lower boundary is uncertain.

AGE: No age-diagnostic macrofossils have been identified in Bellbird Bush Member, which is inferred to be of Opoitian age, based on stratigraphic position.

Opouahi Member (new)

NAME AND DEFINITION: Opouahi Member is named after Lake Opouahi on the eastern flank of the Maungaharuru Range (Fig. 2, 7D). The member is characterised by diversified lithologies, including silty sandstone, sandstone, and limestone, possibly forming cyclothems.

TYPE LOCALITY: The type section is designated on Quarry Road at V19/401228–403227 (Fig. 8). In this section, the base of the member is well exposed above 14 m of the upper part of Bellbird Bush Member. A reference section is located at V19/439235–449235 north of Matahorua Road, where it forms the topographically highest beds of "Sharky Hill".

DISTRIBUTION AND BOUNDARIES: Opouahi Member is distributed on the eastern flank of Maungaharuru Range, south and east of Bellbird Bush Member, where it forms the uppermost member of the Titiokura Formation (Fig. 2). East and south of the outcrop area of Opouahi Member, the elevation of the surface drops rapidly into the catchments of the Waikoau, Matahorua, and Waikari Streams. The member has a sharp disconformable base at the type section. At the reference section, the base is conformable with a transition from clean cross-bedded sandstone to silty sandstone. The upper contact of Opouahi Member has not been observed. The overlying unit is a massive fossiliferous siltstone (Rangiora Formation), and the contact is probably gradational.

THICKNESS: The Opouahi Member is 45 m thick at the type section where it has an eroded top. At the reference section it is 75 m thick, also with an eroded top.

LITHOLOGY: At the type section the base of the member comprises two beds of trough cross-bedded limestone (grainstone) 0.5 m thick, separated by laminated siltstone containing ripples (Fig. 8). The limestone beds contain c. 5% greywacke granules, and sandstone and mudstone rip-up clasts. They are overlain by 1 m of cross-bedded fossiliferous sandstone, which passes upward into 43 m of weathered calcareous sandstone with abundant concretionary horizons. This sandstone is sharply overlain, probably disconformably, by 12 m of cross-bedded fossiliferous limestone containing greywacke granules (Fig. 9C). At the reference section there are two upward-coarsening cyclothems, in which 20 m of massive, bioturbated silty sandstone passes gradationally upward into bipolar cross-bedded, fossiliferous, concretionary sandstone containing greywacke granules. At Taraponui Trig there are also two sedimentary cycles represented in Opouahi Member. The lower one comprises a 1–2 m thick basal cross-bedded shelly limestone lens with a disconformable base that grades sharply into a thin-bedded fossiliferous sandy siltstone. The upper one comprises a 9 m thick cross-bedded fossiliferous limestone with greywacke granules. It has a disconformable base.

AGE: The Opouahi Member may be of Opoitian or Waipipian age, based on the occurrence of *Mesopeplum crawfordi* within limestone facies (Beu 1995).

LITHOFACIES AND DEPOSITIONAL PALEOENVIRONMENTS

A first-order lithofacies analysis has been undertaken of the Titiokura Formation to help interpret the depositional setting and paleoenvironments in which the formation and its constituent members accumulated. Lithology and sedimentary

structures are the two facies parameters emphasised in the descriptions; information about the paleoecology of the faunal components is difficult to assemble and interpret due to the fragmental nature of the macrofossils, and the degree of their sedimentary transportation and dispersal. The diagnostic characteristics of each facies are summarised in Table 1, the descriptive details not being repeated in the text. The vertical stratigraphic distribution of the various

Table 1 Lithofacies and inferred depositional paleoenvironments, Titiokura Formation.

Code	Description	Relative abundance		Depositional environment
	BIOCLASTIC LITHOFACIES	**South**	**North**	
BC_1	ALTERNATING PACKSTONE/GRAINSTONE SHEETS; Moderately to well-cemented medium to coarse-grained stacked skeletal grainstone/packstone sheets 0.1-0.3 m thick. Skeletal grains of barnacle, bryozoan, and epifaunal bivalve material dominate the composition of the facies.	**C**	**S/C**	Inner to middle shelf
BC_2	ALTERNATING MIXED SKELETAL-TERRIGENOUS SHEETS; Slightly to well-cemented alternating skeletal grainstone and mixed carbonate-siliciclastic packstone sheets to 0.3 m thick. Skeletal grainstone beds are generally better cemented than layers with a higher terrigenous component.	**C**	**S/C**	Middle shelf
BC_3	PEBBLY LIMESTONE; Moderately to well-cemented medium to coarse-grained bioclastic-dominated beds with common pebble to cobble-sized clasts of siliciclastic sandstone and mudstone and Torlesse greywacke comprising less than 50% of the volume of the facies. Contains *Phialopecten marwicki, Mesopeplum crawfordi,* and *Neothyris* aff. *obtusa*.	**S**	**R/S**	Inner shelf adjacent to siliciclastic sediment input
	SILICICLASTIC LITHOFACIES			
Cg_1	CONGLOMERATE; Moderately to poorly-sorted non to moderately-fossiliferous conglomerate. Clasts are sub-angular to well-rounded and comprise a mixture of granule to boulder sizes, pebble to cobble-sized clasts predominate. Clasts are dominated by Tertiary sandstone and mudstone lithologies, with rare to common scattered basement material, and locally important pumice and carbonised logs. The matrix of this facies is siliciclastic sand, with rare to abundant shellhash in lenses through the unit.	**S**	**S**	Inner to middle shelf
S_1	BARREN SANDSTONE; Massive to cross-bedded, non-cemented very well-sorted non to slightly-fossiliferous fine to medium-grained sandstone. Foresets are of medium to large-scale, bedding is dominated by tabular and planar bedforms.	**Ab**	**C**	Inner shelf
S_2	CALCAREOUS SANDSTONE; Massive to cross-bedded, non-cemented very well-sorted moderately calcareous fine to medium-grained sandstone. Foresets are of medium to large-scale, bedding is dominated by tabular and planar bedforms.	**Ab**	**S**	Inner shelf
S_3	THIN-BEDDED SANDSTONE; Well-sorted, non-cemented fine-grained sandstone to sandy siltstone.	**Ab**	**S**	Inner to middle shelf
S_4	CONCRETIONARY SANDSTONE; Non to well-cemented fine-grained slightly to moderately–calcareous sandstone with prominent concretions and cemented horizons. Non to slightly-fossiliferous and massive to thin-bedded.	**Ab**	**C**	Inner to middle shelf
S_5	SANDSTONE WITH RIP-UP CLASTS; Non to well-cemented, fine-grained sandstone to sandy siltstone with common concretionary horizons and prominent sandstone and mudstone rip-up clasts. Occasional channelised structures occur. Rip-up clasts are composed of sandstone and mudstone lithologies.	**Ab**	**S**	Inner to middle shelf
S_6	SANDSTONE WITH MUDSTONE STRINGERS; Non to well-cemented, fine-grained sandstone to sandy siltstone with common mudstone stringers up to 0.1 m thick that may extend laterally for many metres.	**Ab**	**S**	Innermost shelf
S_7	RIPPLE-BEDDED SANDSTONE; Non to slightly fossiliferous fine to medium-grained sandstone with ripple-bedded units, flaser bedding, cross-stratification, and common siltstone interbeds. Occasional channelised interbeds and calcareous lenses and horizons are present as are sandstone and siltstone rip-up clasts of pebble to cobble-size.	**Ab**	**S**	Middle to outer shelf
Z_1	MASSIVE SILTSTONE; Non-fossiliferous, massive to laminated siltstone, with rare, low-angle cross-bedding in sandstone interbeds.	**Ab**	**S**	Middle to outer shelf
Z_2	RIPPLE-BEDDED SILTSTONE; Non fossiliferous massive siltstone to fine sandstone with ripple bedding and mud drapes; disrupted mud clasts.	**Ab**	**S**	Shoreface to inner shelf, submarine channels
	MIXED BIOCLASTIC-SILICICLASTIC LITHOFACIES			
MX_1	MIXED TERRIGENOUS-SKELETAL SANDSTONE; Non to slightly-cemented medium-grained mixed siliciclastic-carbonate sandstone, commonly cross-bedded with common mudstone lenses and stringers to 0.3 m thick.	**Ab**	**S**	Inner to middle shelf
MX_2	FOSSILIFEROUS CONGLOMERATE; Pebble to cobble-dominated conglomerate with common valves of robust epifaunal and infaunal bivalves set in a matrix of mixed siliciclastic and bioclastic sediments. *Crassostrea ingens* is common, with scattered fragments of *Phialopecten marwicki* and some flabellid corals.	**R**	**S**	Inner shelf adjacent to siliciclastic sediment input

Abbreviations for relative abundance: Ab, absent; R, rare; S, some; C, common. South refers to locations south of Taraponui Trig; North refers to locations north of Taraponui Trig.

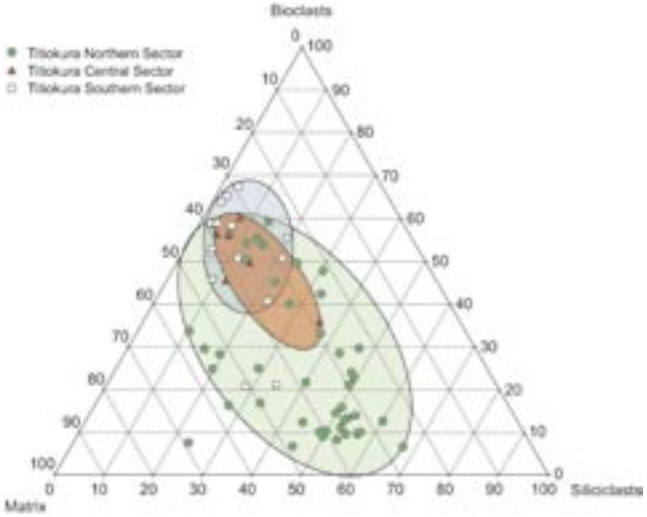


Fig. 10 Ternary plot of siliciclasts, bioclasts, and matrix/cement content of the Titiokura Formation derived from modal analysis of thin sections, separated into samples derived from southern, central, and northern parts of the Te Waka and Maungaharuru Ranges. Note the variability present in samples from the northern sector, reflecting the higher proportion of siliciclastic sediment, and the general trend from bioclastic-dominated to more mixed lithologies from south to north (cf. Fig. 3).

lithofacies, particularly within the lower three members, is shown in Fig. 5, 6, and 8. The lithofacies have been grouped into three associations, based on the proportion of siliciclastic and bioclastic components. Bioclastic lithofacies dominate southern areas of the Titiokura Formation, while siliciclastic lithofacies dominate in northern areas where the formation is mapped as five members. In the following text we outline some petrographic information about the sediments from thin-section derived point-count data of Titiokura Formation (Fig. 10), and interpret the depositional paleoenvironments from the field-based lithofacies descriptions.

Bioclastic lithofacies

In the southern parts of Titiokura Formation where limestone lithofacies predominate (Fig. 5), limestone beds are skeletal grainstones and packstones, with fragmented and abraded barnacle plates and bryozoan branches, as well as bivalve shells. Microborings are common, together with intraskeletal and detrital glauconite, supportive of prolonged seafloor residence for the deposits in this area. The matrix in skeletal packstones consists of a mixture of detrital carbonate mud, argillaceous material, and crypto/microcrystalline calcite cement. Skeletal grainstones are often impure, and their matrix-free biomoulds and interparticle pore space are cemented by equant calcite spar, typically exhibiting a drusy fabric.

Bioclastic lithofacies accumulated on a carbonate-dominated shelf subjected to strong tidal currents at inner–middle shelf water depths (Kamp et al. 1988). The presence of dispersed greywacke clasts implies an emergent basement hinterland and substrate, probably in the southwest, to which bryozoans, bivalves, and brachiopods could attach. These lithofacies are inferred to have accumulated in water depths of 20–50 m. The composition and discontinuous nature of individual sheets of lithofacies BC_3 indicate a wave-dominated environment on an open shelf. The skeletal grainstone beds represent storm-emplaced sheets mobilised from carbonate factories and dispersed across a shelf. Lithofacies BC_1 is thought to also represent sedimentation in a current-swept environment with individual skeletal grainstone and packstone sheets being products of sediment remobilisation off carbonate factories during storm events. The occurrence of burrows extending from overlying into underlying sheets, and sharp bases to beds in lithofacies BC_1 and BC_2, indicate that deposition of the sheets occurred as discrete sedimentation events.

Siliciclastic lithofacies

In the central and northern sectors, siliciclastic lithofacies become more common (Fig. 8, 10), comprising mixed skeletal-terrigenous packstones to wackestones and siliciclastic sandstone and siltstone. Skeletal grainstones are rare. The bioclastic component is dominated by strongly fragmented and abraded barnacle fragments and minor contributions from bivalves and bryozoans, and also benthic foraminifera and echinoderms. The observable siliciclastic component is made up of quartz, feldspar, and rock fragments, with occasional flakes of mica. Reduced average grain sizes result in an overall irresolvable matrix, which is most likely a mixture of detrital carbonate, argillaceous material, and cryptocrystalline calcite cement.

Deposition occurred on a shelf environment that at times was satiated with siliciclastic sediments, chiefly sandstone. The deposition of sandstone lithofacies (lithofacies S_1–S_7) took place on an inner–mid-shelf environment, with the accumulation of siltstone at middle shelf depths. The accumulation of conglomerate lithofacies represents high-energy deposition of clasts in beach to fan-delta settings. The presence of Tertiary sandstone and mudstone clasts in lithofacies Cg_1, S_5, and Z_2 is suggestive of emergent areas of older basin fill in the hinterland. A tidal influence is inferred for the deposition of lithofacies S_7 based on the occurrence of flaser bedding, ripple-laminations, and bipolar cross-stratification. The thickness of sandstone within the members of the Titiokura Formation implies that sand was able to be dispersed well out on to the shelf, possibly to mid-shelf water depths.

SEQUENCE STRATIGRAPHY

The Titiokura Formation accumulated during a period of known 41 000 yr 6th order global sea-level oscillations of c. 75 m magnitude (Kamp et al. 2002, 2004; Vonk et al. 2002), as established from correlative strata in Wanganui Basin. We anticipate, therefore, the occurrence of 6th order cyclothems or sequences in Titiokura Formation. The constituent members of the Opoitian Titiokura Formation exhibit many of the characteristics of the siliciclastic-dominated sequences evident in the late Miocene and early Pliocene (Kapitean to early Opoitian) Matemateaonga Formation of Wanganui Basin (Vonk et al. 2002; Hendy & Kamp 2004), and hence we suggest that they may also have a 41 000 yr periodicity, although specific age control is not available.

In the following text we outline the characteristics of the sequences, suggesting that Naumai, Te Rangi, Taraponui, and Bellbird Bush Members are individual sequences, and that there are at least two sequences in the Opouahi Member. These members become amalgamated south of Taraponui Trig

and pass into the main limestone unit of Titiokura Formation (Fig. 3, 5). The next phase of our research will be to identify discrete sequences within this amalgamated limestone, using the sedimentological and diagenetic approaches and techniques developed by Caron & Nelson (2003) for subdivision of the Opoitian Kairakau and Waipipian Awapapa Limestone units in the southeastern parts of Hawke's Bay Basin.

Key surfaces

The location of successive sequence boundaries is required to enable subdivision of a succession into sequences. On Naumai and Te Rangi Stations we can confidently identify sharp disconformable lower sequence boundaries for the base of each of Naumai, Te Rangi, Taraponui, and Bellbird Bush Members, as described above. The geomorphic expression of these boundaries is sufficiently well marked to enable these members or sequences to be mapped over considerable areas (Fig. 2). These sequence boundaries may initially have formed as subaerial erosion surfaces, but they are not associated with non-marine sediments nor paleosols; the surfaces have probably been modified by wave erosion during marine transgression and consequently they are ravinement surfaces, otherwise known as transgressive surfaces of erosion (TSEs) (e.g., Naish & Kamp 1997; Kamp & McIntyre 1998). Away from the type section, the base of Opouahi Member is a gradational boundary and is best described as a correlative conformity, having formed as a result of a sea-level lowering without subaerial exposure or impingement of the wave-base of erosion upon the contemporary seafloor.

The other key surface that can be identified within the Titiokura sequences is the downlap surface, which approximates the stratigraphic position of the maximum flooding surface (Naish & Kamp 1997). This lies only up to a few metres above the sequence boundary, as described in the following text, and marks the progradation of facies belts in response to the development of relative highstand sea-level conditions, or the start of relative sea-level fall, the details of this timing depending upon the sediment flux and distance across the shelf-slope profile from the highstand shoreline. The usefulness of identifying the downlap surface is that it enables the transgressive systems tracts (TST) to be separated from the highstand (HST) and regressive systems tracts (RST). Other flooding surfaces besides the sequence boundary, or surfaces of regression, have not been identified in the Titiokura sequences.

Systems tracts

The lower four members of Titiokura Formation have clearly distinguishable thin TSTs that are comparable to the types of TSTs forming the lower parts of sequences in the Matemateaonga Formation in King Country Basin (Vonk et al. 2002). HSTs and RSTs form the majority of the thickness of the members and are dominated by sandstone facies. It is not possible to place a definitive boundary in these sequences between the HST and RST deposits.

The beds at the base of Naumai Member at Pohokura Saddle comprise several sets of channels infilled with large mudstone and sandstone clasts and a calcareous sandstone matrix (Fig. 7A, 9B). These channels reflect active marine erosion of underlying beds, and contemporary deposition, probably in a subtidal setting under rising sea-level conditions. The channelised conglomerate facies pass into c. 6 m of differentially cemented, clean calcareous sandstone, which we infer to be the upper part of the TST; overlying beds are uncemented, slightly silty sandstone with mud layers, reflecting quieter energy levels and accumulation in inner to mid-shelf conditions as HST deposits. The carbonate content of the sandstone facies increases upward, expressed in the development of concretionary horizons and cleaner sandstone, which we associate with higher wave energy in inner shelf to shoreface environments, more active progradation, and falling sea-level conditions consistent with classification as RST deposits.

The Te Rangi Member on Naumai Station shows a typical Wanganui-type TST (Naish & Kamp 1997): a 1–2 m thick lower calcareous sandy conglomerate represents an onlap deposit akin to an onlap shellbed and is separated from a 2 m thick backlap shellbed composed of a sandy limestone by a 3 m thick fossiliferous sandstone. The downlap surface rests upon the top of the backlap shellbed. The HST comprises well-sorted, non-cemented fine sandstone, with convoluted deformation structures and thin mudstone layers, which passes up into a RST characterised by wavy and trough cross-bedded calcareous sandstone, with abundant convolute deformation structures, a few concretionary horizons, and differential cementation. The coarseness of the sand is due to the finely comminuted shell hash content. The paleobathymetry probably shallows from just above the downlap surface up to the sequence boundary, and the syn-sedimentary deformation structures, arising from rapid loading and catastrophic water escape, are an expression of the very rapid sediment accumulation rates associated with infilling of the paleobathymetric "hole" created by the eustatic sea-level rise during a transgression, combined with minimal TST thickness (e.g., Kamp & Naish 1998). This sequence, as with the Naumai sequence, is highly asymmetric, with a thin TST and very thick HST and RST.

The sequence mapped as the Taraponui Member also has a thin TST. In one locality on Naumai Station (V19/408284) it has the same architecture as the Naumai sequence, with a 1 m thick conglomeratic onlap shellbed, a thin siliciclastic wedge, and a 0.5 m thick backlap shellbed. At the type section on Te Rangi Station and at another locality on Naumai Station (V19/386262), the TST comprises a single shellbed up to 3 m thick, which shows the characteristics of a compound shellbed (Naish & Kamp 1997). The onlap and backlap components are collapsed together without an intervening nearshore siliciclastic wedge. The HST and RST components of the sequence are composed of bioturbated fine sandstone with disrupted mudstone drapes, grading into calcareous, cross-bedded fine sandstone with concretionary horizons, suggestive of gradually decreasing water depths within strongly progradational (regressive) inner shelf to shoreface deposits.

At the type section of the Bellbird Bush Member (V19/430297), the TST comprises a single shellbed and conglomerate (Fig. 8), which is probably a compound shellbed. The base of the sequence is infrequently exposed at other accessible sections. The HST/RST components of the sequence on Naumai and Te Rangi Stations are composed of sandstone with identical facies characteristics to the HST/RST of Taraponui sequence. However, at easternmost outcrop sections (e.g., Sharky Hill, V19/439235–449235) the lower half of the HST/RST is a massive sandy siltstone, which grades up into a massive sandstone, and then into a cross-bedded, calcareous sandstone with abundant cemented horizons.

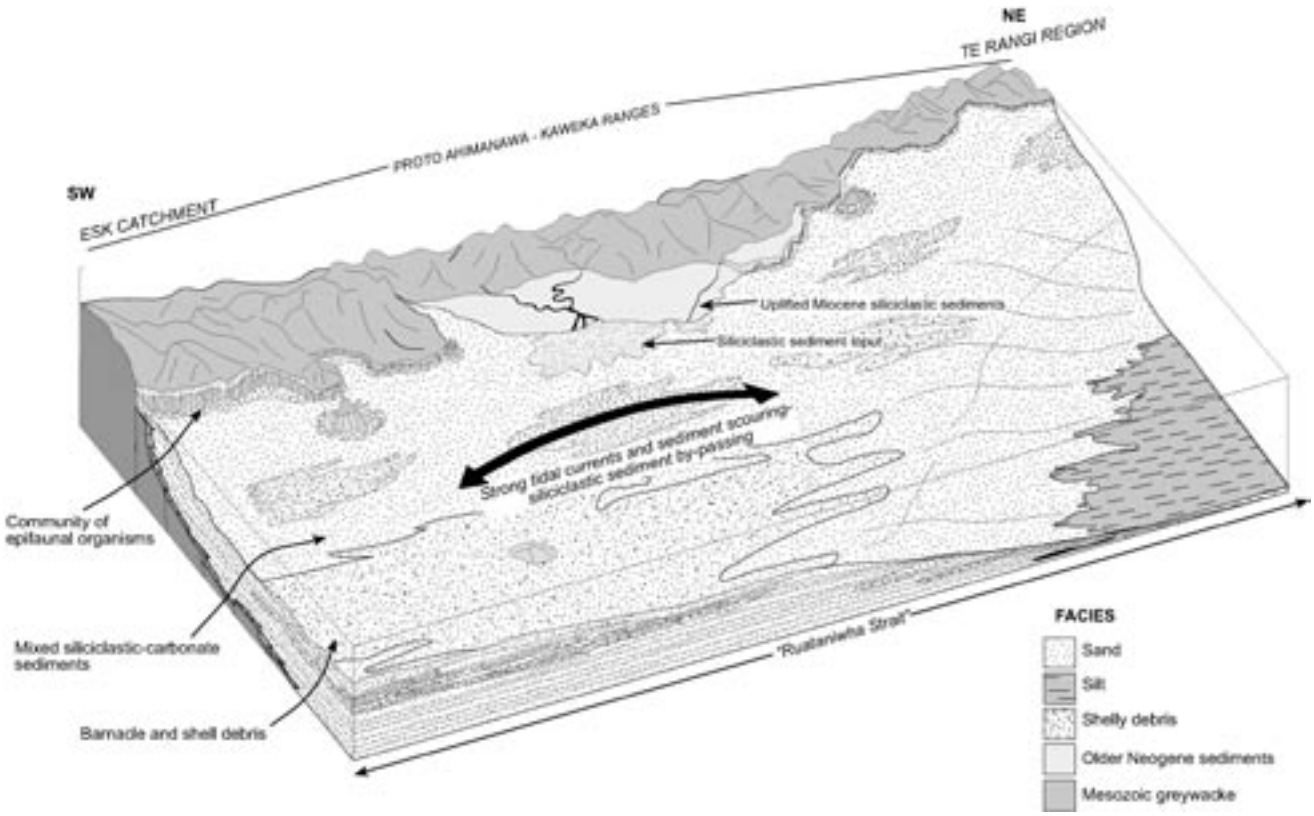


Fig. 11 Paleogeographic reconstruction of the inferred depositional setting for the Titiokura Formation in the early Pliocene.

The Opouahi Member is composed of two or more sequences, each inferred to be of 41 000 yr duration. At the type section on Quarry Road, the lower sequence has two thin shellbeds separated by a thin siltstone, and we interpret this package as the TST. This is overlain by 43 m of typical HST/RST sandstone. The overlying succession is an 11 m thick limestone (Fig. 7D) adjacent to Pohokura Road (Fig. 9C). In it there are three prominent stratigraphic breaks. We are uncertain about the sequence stratigraphic significance of these surfaces. The degree of limestone development in Opouahi Member in the vicinity of Pohokura Road is atypical in this part of the basin, and contrasts with the siliciclastic dominance of lower members of Titiokura Formation. Its occurrence at the top of the Titiokura Formation heralds a change in the basin development, and a dramatic decrease in the rate of siliciclastic sediment supply with the transition into the Rangiora Formation (Graafhuis 2001). On Sharky Hill, which lies farther to the east, the Opouahi Member contains two thin siliciclastic sequences that comprise lower sandy siltstone units (HST) that grade upward into cross-bedded calcareous sandstone units (RST). TSTs are cryptic as the sequence boundaries are probably correlative conformities.

PALEOGEOGRAPHY

The formation of the Mohaka River valley has removed the contemporary stratigraphic relationships between the Titiokura Formation and the basement now exposed in the ranges to the west. It is not clear, therefore, whether or not there was a western basin margin during sediment accumulation, and the extent to which basement was exposed, if at all, at that time. The onlap of Opoitian Pakaututu Formation and Omahaki Formation on to basement in the vicinity of Puketitiri, near the southern outcrop extent of the Titiokura Formation (Fig. 1), indicates that a rocky shoreline was present in the south during accumulation of Titiokura Formation. We infer therefore that the Titiokura Formation, as mapped in outcrop (Fig. 2), represents an oblique northeast–southwest cross-section through a depositional system on a paleoshelf that was attached to a basement shoreline in the south, and downlapped into a basin depocentre to the northeast and east (Fig. 11).

The limestone-dominated parts of the Titiokura Formation developed seaward of a rocky shoreline, probably in inner shelf water depths. Strong tidal currents, coupled with adequate nutrient supply, promoted the growth of epifaunal organisms such as barnacles, bryozoans, pectinids, and oysters (Kamp et al. 1988). Carbonate factories were probably located around shoreline to inner shelf rocky (basement) substrates. Locally, greywacke pebbles can be important components of the limestone beds, as in Opau Stream near Patoka (Kingma 1958; Katz 1973), supporting the concept of a seascape with numerous rocky islands. The carbonate sediment was comminuted by wave and strong tidal action and dispersed on to the shelf where it accumulated. The rocky shorelines were not supplied with high siliciclastic sediment load. The origin of the siliciclastic sand and the direction of its transport on to the shelf have not been resolved in this study, but may have been sourced from the northwest to have avoided the rocky shoreline in the south. The paleobathymetry in northern parts of the study area was greater than that to the south, allowing for increased accommodation of the large volumes

of siliciclastic sediment that accumulated as the constituent members of the Titiokura Formation (Fig. 11).

DISCUSSION

The Te Waka and Maungaharuru Ranges are very prominent landforms in western parts of Hawke's Bay, rising to over 1000 m above sea level. This paper presents for the first time a systematic stratigraphic description of the architecture of the early Pliocene sedimentary succession that underlies these ranges, and aspects of its sedimentology and sequence stratigraphy.

In the Te Waka Range and the southern part of the Maungaharuru Range, the Titiokura Formation comprises a single limestone sheet with calcareous sandstone parts. In the vicinity of Taraponui Trig and to the northeast, our 1:50 000 mapping (Bland 2001; Graafhuis 2001) (Fig. 2) shows that the limestone partitions into five members, which thicken markedly to the northeast, and concomitantly become dominated by siliciclastic sandstone (Fig. 3).

The Titiokura Formation is of early Pliocene age, based on macrofossil content, which is consistent with a Kapitean to early Opoitian age for the underlying Mokonui Formation (Cutten 1994). The occurrence of *Phialopecten marwicki* and *Mesopeplum crawfordi* within limestone facies of the Titiokura Formation suggests an Opoitian–Waipipian age for the formation (Austin Hendy pers. comm. 2003). All of the sediment accumulation could have occurred within 250 000 yr if the six sequences we have identified accumulated during successive obliquity-controlled 41 000 yr sea-level oscillations, which are known to have been a major control on sedimentation at that time. If so, the Titiokura Formation could either be of early Opoitian age, which would emphasise a major reduction in siliciclastic sedimentation in the basin during the late Opoitian and Waipipian, or be of late Opoitian–Waipipian age, which would emphasise the amount of time missing in the unconformity between the Mokonui Formation and Titiokura Formation. Further efforts at dating the sediments will resolve these alternatives.

Given the age control available at present, and our lithostratigraphic correlations along the crest of the ranges, we suggest that the Titiokura Formation, and its correlatives to the south around Puketitiri, represent a shoreline-to-shelf linked depositional system. Carbonate production was focused around a rocky seascape as the system onlapped basement in the south, with dispersal and deposition of this carbonate debris on an inner shelf to the north, surprisingly devoid of siliciclastic sediment. The gradual differentiation into thick siliciclastic members farther to the northeast, which nevertheless maintained inner to mid-shelf paleo–environments, indicates that the rates of both subsidence and sediment flux increased rapidly in that direction, with active progradation and offlap of the depositional system into more axial parts of Hawke's Bay Basin. Future work will detail the internal sedimentological and diagenetic features that accompany the lithological changes within this oblique shoreline-to-shelf depositional system, which we have reconstructed over a length of 50 km, a rare geological situation in Hawke's Bay Basin.

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ENCLOSURE 1, SHEET 1
MOHAKA

Topographic Legend

ROADS

Road surface: sealed; metalled; unmetalled
Vehicle track
Foot track
National State Highway 4

WATER FEATURES

River, stream
Riverbody

RELIEF FEATURES

Index contour 400
Intermediate contour
Trig station beaconed; unbeaconed ▲ △
Elevation in metres 130 △130 m
Cliff, terrace

MISCELLANEOUS

Large buildings
Residential area
Building
Homestead Ararawa
Airstrip Airstrip
Mine; underground, opencast

CULTURAL FEATURES

Localities (over 200)
Localities (under 200)
Homesteads
Miscellaneous features and descriptive notes
Airstrip
ROAD AND RAILWAY NAMES
TRACK NAMES
Trig identification numbers and names

Grid North
Magnetic North
G-M Angle

MAGNETIC NORTH on this map is 23.5° (418mils) EAST of GRID NORTH during 1997 increasing at a rate of approx 1/2° (9 mils) every 8 years.

This map is drawn on the New Zeland Map Grid Projection, a minimum-error conformal projection. The grid is the New Zeland map grid, showing coordinates in metres in terms of the Geodetic Datum 1949, based on the International (Hayford) Spheroid.

TO GIVE A GRID REFERENCE ON THIS MAP
(To nearest 100 metres)
Disregard the smaller figures of corner grid numbers.
They are for finding full coordinates.

SAMPLE POINT: *Papahaua*

East		West	
Locate first VERTICAL grid line to LEFT of point and read figures labelling the line on either the bottom margin or across the centre of the map	04	Locate first HORIZONTAL grid line to BELOW of point and read figures labelling the line on either the left or right margin or up the centre of the map	85
Estimate tenths eastward from grid line to point.	3	Estimate tenths northward from grid line to point.	2

SAMPLE REFERENCE (Quote sheet number first): V20 043852

The topography on this map is taken from the LINZ CD Rom 1:50 000 Topographic Vector Data Set. Note that this map covers all or part of topographic sheets NZMS 260 U21 Kereru and V21 Napier.

THE VERTICAL INTERVAL BETWEEN THE CONTOURS IS 20 METRES
HEIGHTS ARE ABOVE MEAN SEA LEVEL

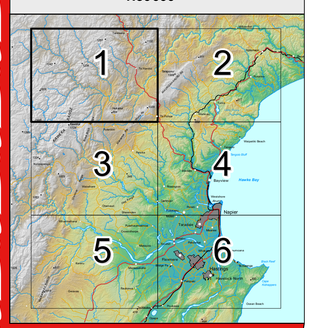
BLAND, K.J. (2006) - ENCLOSURE 1 - SHEET 1 - MOHAKA

Geological Map

Enclosure 1 **Sheet 1**

Mohaka

1:50000



Kyle J. Bland

2006

PhD Thesis

Analysis of the central Hawke's Bay sector of the Late Neogene forearc basin, Hikurangi margin, New Zealand

Department of Earth and Ocean Sciences
The University of Waikato

SCALE 1:50 000

1 .5 0 1 2 3 4 5 KILOMETRES

BIBLIOGRAPHIC REFERENCE
Bland, K.J., 2006: Enclosure 1: 1:50 000 geological map of central Hawke's Bay. Sheet 1, Mohaka.
Analysis of the central Hawke's Bay sector of the Late Neogene forearc basin, Hikurangi Margin, New Zealand.
Unpublished PhD thesis, The University of Waikato, Hamilton, New Zealand.

Enclosure 1, Sheet 1 - Mohaka
K.J. Bland 2006

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ENCLOSURE 1, SHEET 2
MAUNGAHARURU

Topographic Legend

ROADS

Road surface: sealed; metalled; unmetalled

Vehicle track

Foot track

National State Highway 6

WATER FEATURES

River, stream

Riverbody

RELIEF FEATURES

Index contour 400

Intermediate contour

Trig station beaconed; unbeaconed

Elevation in metres 130 △130 m

Cliff, terrace

MISCELLANEOUS

Large buildings

Residential area

Building

Homestead Ararawa

Airstrip Aerodrome

Mine; underground, opencast

CULTURAL FEATURES

Localities (over 200)

Localities (under 200)

Homesteads

Miscellaneous features and descriptive notes

Aerodrome

ROAD AND RAILWAY NAMES

TRACK NAMES

Trig identification numbers and names

Grid North

Magnetic North

G-M Angle

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TO GIVE A GRID REFERENCE ON THIS MAP
(To nearest 100 metres)
Disregard the smaller figures of corner grid numbers. They are for finding full coordinates.

SAMPLE POINT: *Pakehaua*

East		West	
Locate first VERTICAL grid line to LEFT of point and read figures labelling the line in either the top or bottom margin or across the centre of the map.	04	Locate first HORIZONTAL grid line to BELOW of point and read figures labelling the line in either the left or right margin or up the centre of the map.	85
Estimate tenths eastward from grid line to point.	3	Estimate tenths northward from grid line to point.	2

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THE VERTICAL INTERVAL BETWEEN THE CONTOURS IS 20 METRES HEIGHTS ARE ABOVE MEAN SEA LEVEL

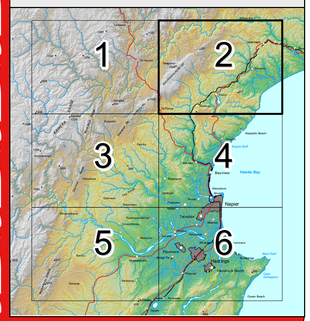
BLAND, K.J. (2006) - ENCLOSURE 1 - SHEET 2 - MAUNGAHARURU

Geological Map

Enclosure 1 **Sheet 2**

Maungaharuru

1:50000



Kyle J. Bland

2006

PhD Thesis

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Department of Earth and Ocean Sciences

The University of Waikato

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

SCALE 1:50 000

1 .5 0 1 2 3 4 5 KILOMETRES

BIBLIOGRAPHIC REFERENCE
Bland, K.J., 2006: Enclosure 1: 1:50 000 geological map of central Hawke's Bay. Sheet 2, Maungaharuru. Analysis of the central Hawke's Bay sector of the Late Neogene forearc basin, Hikurani margin, New Zealand. Unpublished PhD thesis, The University of Waikato, Hamilton, New Zealand

Enclosure 1, Sheet 2 - Maungaharuru
K.J. Bland 2006
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ENCLOSURE 1, SHEET 3
KURIPAPANGO

Topographic Legend

ROADS

- Road surface: sealed
- Road surface: metalled
- Road surface: unmetalled
- Vehicle track
- Foot track
- National State Highway 4

WATER FEATURES

- River, stream
- Riverbody

RELIEF FEATURES

- Index contour 600
- Intermediate contour
- Trig station beacond; unbeaconed ▲ △
- Elevation in metres 130 △130 m
- Cliff, terrace

MISCELLANEOUS

- Large buildings
- Residential area
- Building
- Homestead • Karamea
- Airstrip Airstrip
- Mine; underground, opencast

CULTURAL FEATURES

Localities (over 200)

Localities (under 200)

Homesteads

Miscellaneous features and descriptive notes

Airstrip

ROAD AND RAILWAY NAMES

TRACK NAMES

Trig identification numbers and names

Grid North

Magnetic North

G-M Angle

MAGNETIC NORTH on this map is 23.5° (418mils) EAST of GRID NORTH during 1997 increasing at a rate of approx 1/2° (9 mils) every 8 years.

This map is drawn on the New Zeland Map Grid Projection, a minimum-error conformal projection. The grid is the New Zeland map grid, showing coordinates in metres in terms of the Geodetic Datum 1949, based on the International (Hayford) Spheroid.

TO GIVE A GRID REFERENCE ON THIS MAP
(To nearest 100 metres)
Disregard the smaller figures of coordinate numbers. They are for finding full coordinates.

SAMPLE POINT: Pohatuhaul

East		West	
Locate first VERTICAL grid line to LEFT of point and read figures labelling the line in either the top or bottom margin or across the centre of the map.	04	Locate first HORIZONTAL grid line to BELOW of point and read figures labelling the line in either the left or right margin or up the centre of the map.	85
Estimate tenths eastward from grid line to point.	3	Estimate tenths northward from grid line to point.	2

SAMPLE REFERENCE (Quote sheet number first): V20 043852

The topography on this map is taken from the LINZ CD Rom 1:50 000 Topographic Vector Data Set. Note that this map covers all or part of topographic sheets NZMS 260 U21 Kereru and V21 Napier.

THE VERTICAL INTERVAL BETWEEN THE CONTOURS IS 20 METRES HEIGHTS ARE ABOVE MEAN SEA LEVEL

BLAND, K.J. (2006) - ENCLOSURE 1 - SHEET 3 - KURIPAPANGO

Geological Map

Enclosure 1 **Sheet 3**

Kuripapango

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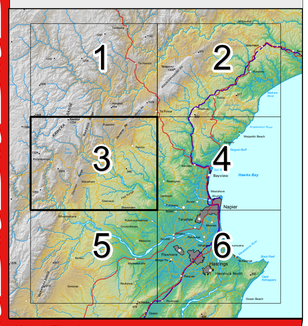


Kyle J. Bland

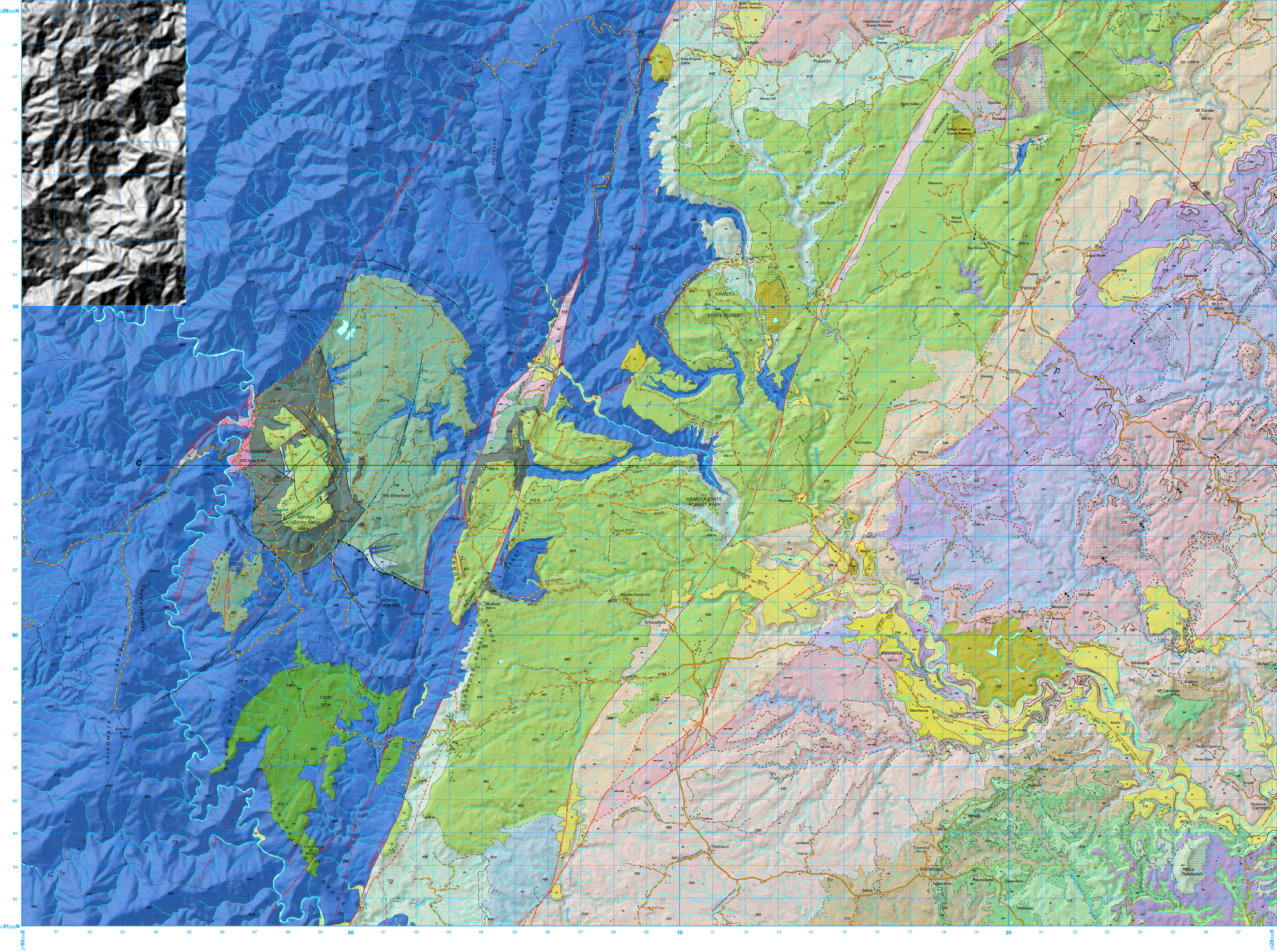
2006

PhD Thesis

Analysis of the central Hawke's Bay sector of the Late Neogene forearc basin, Hikurangi margin, New Zealand

Department of Earth and Ocean Sciences

The University of Waikato



SCALE 1:50 000

1 .5 0 1 2 3 4 5 KILOMETRES

BIBLIOGRAPHIC REFERENCE

Bland, K.J., 2006: Enclosure 1: 1:50 000 geological map of central Hawke's Bay. Sheet 3, Kuripapango. Analysis of the central Hawke's Bay sector of the Late Neogene forearc basin, Hikurangi margin, New Zealand. Unpublished PhD thesis. The University of Waikato, Hamilton, New Zealand.

Enclosure 1, Sheet 3 - Kuripapango
K.J. Bland 2006
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ENCLOSURE 1, SHEET 4
ESK

Topographic Legend

ROADS

- Road surface: sealed
- Road surface: metalled
- Road surface: unmetalled
- Vehicle track
- Foot track
- National State Highway 6

WATER FEATURES

- River, stream
- Riverbody

RELIEF FEATURES

- Index contour 400
- Intermediate contour
- Trig station beaconed; unbeaconed
- Elevation in metres 130 △130 m
- Cliff, terrace

MISCELLANEOUS

- Large buildings
- Residential area
- Building
- Homestead • Ararawa
- Airstrip Aramp
- Mine; underground, opencast

CULTURAL FEATURES

Localities (over 200)

Localities (under 200)

Homesteads

Miscellaneous features and descriptive notes

Aramp

ROAD AND RAILWAY NAMES

TRACK NAMES

Trig Identification numbers and names

Grid North

Magnetic North

G-M Angle

MAGNETIC NORTH on this map is 23.5° (418mils) EAST of GRID NORTH during 1997 increasing at a rate of approx 1/2° (9 mils) every 6 years.

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TO GIVE A GRID REFERENCE ON THIS MAP
(To nearest 100 metres)
Disregard the smaller figures of corner grid numbers.
They are for finding full coordinates.

SAMPLE POINT: *Taperhaua*

East		West	
Locate first VERTICAL grid line to LEFT of point and read figures labelling the line in either the top or bottom margin or across the centre of the map.	04	Locate first HORIZONTAL grid line to BELOW of point and read figures labelling the line in either the left or right margin or up the centre of the map.	85
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THE VERTICAL INTERVAL BETWEEN THE CONTOURS IS 20 METRES
HEIGHTS ARE ABOVE MEAN SEA LEVEL

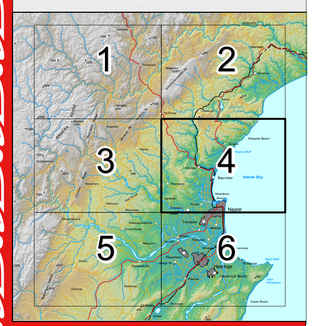
BLAND, K.J. (2006) - ENCLOSURE 1 - SHEET 4 - ESK

Geological Map

Enclosure 1 **Sheet 4**

Esk

1:50000



Kyle J. Bland 2006

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Department of Earth and Ocean Sciences

The University of Waikato

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

SCALE 1:50 000

1 .5 0 1 2 3 4 5 KILOMETRES

BIBLIOGRAPHIC REFERENCE
Bland, K.J., 2006: Enclosure 1: 1:50 000 geological map of central Hawke's Bay. Sheet 4, Esk.
Analysis of the central Hawke's Bay sector of the Late Neogene forearc basin, Hikurangi margin, New Zealand.
Unpublished PhD thesis, The University of Waikato, Hamilton, New Zealand

Enclosure 1, Sheet 4 - Esk
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ENCLOSURE 1, SHEET 5
KERERU

Topographic Legend

ROADS

Road surface: sealed; metalled; unmetalled

Vehicle track

Foot track

National State Highway 6

WATER FEATURES

River, stream

Riverbody

RELIEF FEATURES

Index contour 400

Intermediate contour

Trig station beaconed; unbeaconed

Elevation in metres 130 △130 m

Cliff, terrace

MISCELLANEOUS

Large buildings

Residential area

Building

Homestead Aoraiwa

Airstrip Airstrip

Mine; underground, opencast

CULTURAL FEATURES

Localities (over 200)

Localities (under 200)

Homesteads

Miscellaneous features and descriptive notes

Airstrip

ROAD AND RAILWAY NAMES

TRACK NAMES

Trig Identification numbers and names

Grid North

Magnetic North

G-M Angle

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TO GIVE A GRID REFERENCE ON THIS MAP
(To nearest 100 metres)
Disregard the smaller figures of corner grid numbers. They are for finding full coordinates.

SAMPLE POINT: Papahaua

East		West	
Locate first VERTICAL grid line to LEFT of point and read figures labelling the line in either the top or bottom margin or across the centre of the map.	04	Locate first HORIZONTAL grid line to BELOW of point and read figures labelling the line in either the left or right margin or up the centre of the map.	85
Estimate tenths eastward from grid line to point.	3	Estimate tenths northward from grid line to point.	2

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THE VERTICAL INTERVAL BETWEEN THE CONTOURS IS 20 METRES HEIGHTS ARE ABOVE MEAN SEA LEVEL

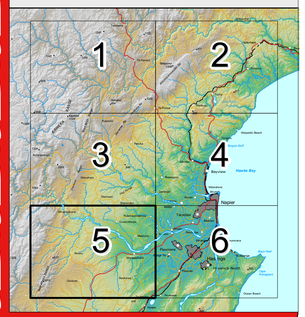
BLAND, K.J. (2006) - ENCLOSURE 1 - SHEET 5 - KERERU

Geological Map

Enclosure 1 **Sheet 5**

Kereru

1:50000



Kyle J. Bland

2006

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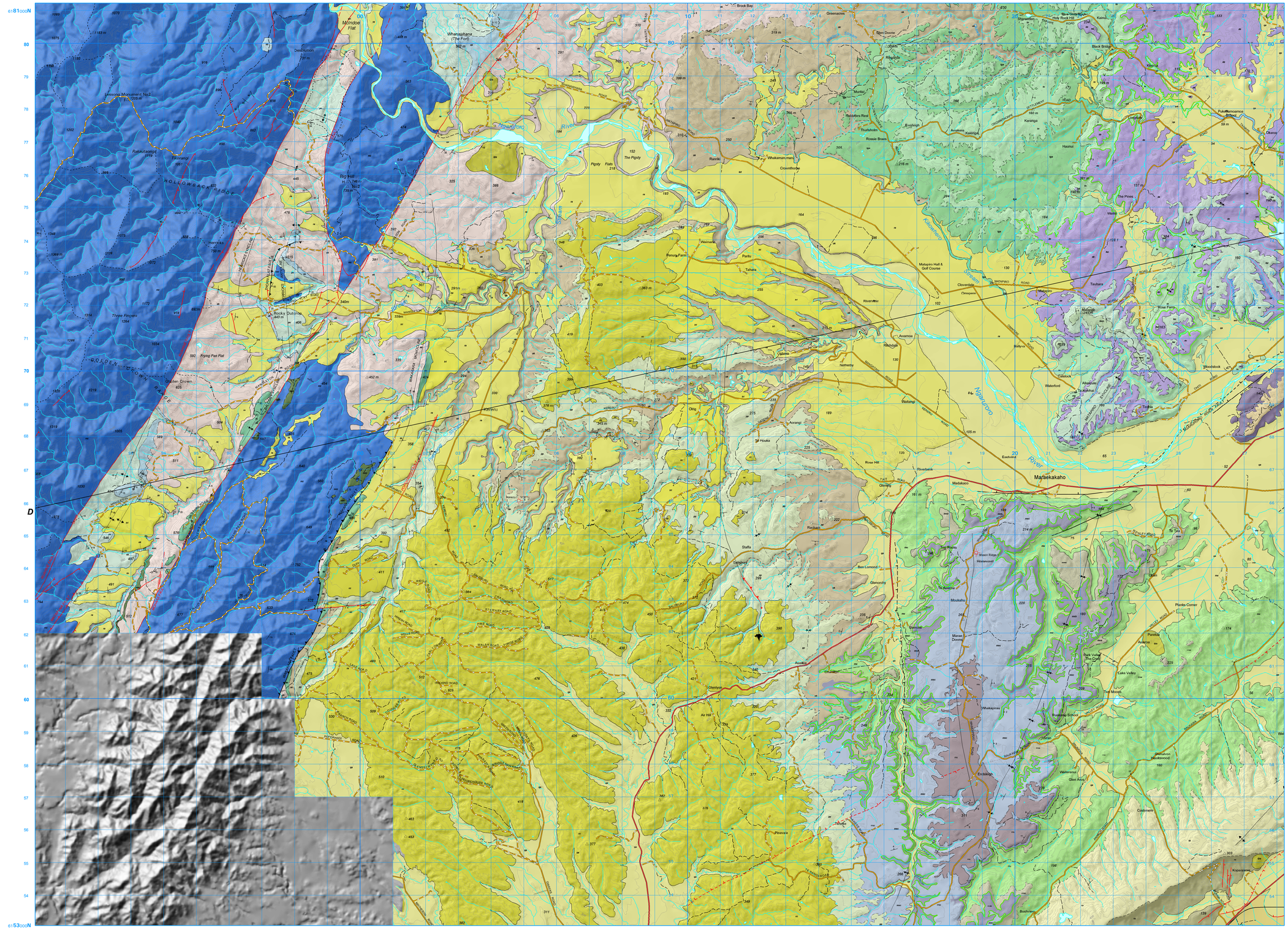
Department of Earth and Ocean Sciences

The University of Waikato


6181000N
6153000E
2790000E
3028000E
Mondale Flat
Desbulson
Lessons Monument No2
Rakauroa
Kahuranga
HOLLOWBACK RIDGE
Big Hill
Herricks
Rocky Dutchos
These Fecals
GOLDEN CROWN RANGE
Golden Crown
Frying Pan Flat
Whanaruhana (The Fort)
Brock Bay
Greenacres
Ben Doone
Mangatuna
Murrays
Rebbetts Rest
Thurlsholm
Rossie Braes
Evelough
Auskere
Kairanga
Haumui
Pukehamoamoa
Rawiki
Whakamarumaru
Crownthorpe
Pigsty Flats
The Pigsty
Womens
Penny Farm
Puritu
Tahuna
Matapiro Hall & Golf Course
Clovardale
Omaweva
Rivervale
Awamoa
Rahdale
Hethenby
Waitangi
Houka
Rose Hill
Riverbank
Madakaro
Maraekakaho
Black Bridge
Kaimai
Holy Rock Hill
Shoreston
Kereru
Waiohiki
The Pines
Tauhara
Rose Ford
Mataroa
Oruawhata
Woodstock
Oakaoka
Waterford
Te Aohiku
Ngaruroro River
Tutaekuri River
Tuki Tuki River
Tomoana
Bellvue
Eskdale
Top Rocks
Mason Ridge
Hinewoosel
Ben Lomond
Glenorchy
Te Awaroa
Moukahu
Planks Corner
Puketapu
Arataua
Rock Valley
The Cutts
Lake Valley
Two Mooses
Whakapirau
Ruahapia School
Glenfalloch
Mawlawood
Glen Ross
Waiterenga
Eskdale
Cashmere
Kopuaranga
Bushmere
Glenfalloch
Stalfa
Awatoto
Pleasant
Ohuia
Korirriru
Ruahapia
Ngaruroro River
Tutaekuri River
Tuki Tuki River
Waipawa River
Makaroro River
Mangaone Stream
Mangaone Road
Kahuranga Road
Wills Road
Pipe Road
Stewart Road
Walsall Road
Young Road
Lake Road
Dalton Road
Gwavas Road
Kereru Road
Ohuia Road
Waitangi Road
Matapiro Road
Omahu Road
Maraekakaho Road
Te Mahoe Road
Te Awaroa Road
Mission Road
Gwavas Road
Ngaruroro Road
Tutaekuri Road
Puketapu Road
Kopuaranga Road
Bushmere Road
Glenfalloch Road
Mawlawood Road
Waipawa Road
Makaroro Road
Omahu Road
Maraekakaho Road
Te Mahoe Road
Te Awaroa Road
Mission Road
Gwavas Road
Ngaruroro Road
Tutaekuri Road
Puketapu Road
Kopuaranga Road
Bushmere Road
Glenfalloch Road
Mawlawood Road
Waipawa River
Makaroro River
Mangaone Stream
Mangaone Road
Kahuranga Road
Wills Road
Pipe Road
Stewart Road
Walsall Road
Young Road
Lake Road
Dalton Road
Gwavas Road
Kereru Road
Ohuia Road
Waitangi Road
Matapi

ENCLOSURE 1, SHEET 6
HERETAUNGA

Topographic Legend

ROADS

Road surface
- sealed
- metalled
- unmetalled

Vehicle track
Foot track
National State Highway

WATER FEATURES

River, stream
Riverbody

RELIEF FEATURES

Index contour
Intermediate contour
Trig station beaconed; unbeaconed
Elevation in metres
Cliff, terrace

MISCELLANEOUS

Large buildings
Residential area
Building
Homestead
Airstrip
Mine; underground, opencast

CULTURAL FEATURES

Localities (over 200)
Localities (under 200)
Homesteads
Miscellaneous features and descriptive notes
Airstrip
ROAD AND RAILWAY NAMES
TRACK NAMES
Trig identification numbers and names

Grid North
Magnetic North
G-M Angle

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SAMPLE POINT: *Papahaua*

East		West	
Locate first VERTICAL grid line to LEFT of point and read figures labelling the line in either the top or bottom margin or across the centre of the map.	04	Locate first HORIZONTAL grid line to BELOW of point and read figures labelling the line in either the left or right margin or up the centre of the map.	85
Estimate tenths eastward from grid line to point.	3	Estimate tenths northward from grid line to point.	2

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THE VERTICAL INTERVAL BETWEEN THE CONTOURS IS 20 METRES
HEIGHTS ARE ABOVE MEAN SEA LEVEL

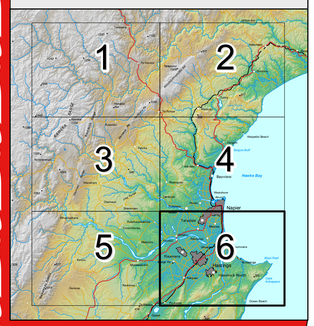
BLAND, K.J. (2006) - ENCLOSURE 1 - SHEET 6 - HERETAUNGA

Geological Map

Enclosure 1 **Sheet 6**

Heretaunga

1:50000



Kyle J. Bland 2006
PhD Thesis

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Department of Earth and Ocean Sciences
The University of Waikato



SCALE 1:50 000

1 .5 0 1 2 3 4 5 KILOMETRES

BIBLIOGRAPHIC REFERENCE
Bland, K.J., 2006: Enclosure 1, Sheet 6, Heretaunga.
Analysis of the central Hawke's Bay sector of the Late Neogene forearc basin, Hikurangi margin, New Zealand.
Unpublished PhD thesis, The University of Waikato, Hamilton, New Zealand

Enclosure 1, Sheet 6 - Heretaunga
K.J. Bland 2006
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Enclosure 2: Legends for 1:50 000 Geological Maps

Analysis of the Late Neogene Forearc Basin, Central Hawke's Bay

GEOLOGICAL LEGEND

AGE

QUATERNARY

RECENT

HAWERIAN

0.0 Ka

sn — UNCONSOLIDATED-RECENT ALLUVIUM (qa): Non-cemented, poorly sorted clast-supported gravels, sand and silt (Holocene).

1.8 Ka

tp — TALUS PLANTS (qc): Unreferentiated deposits of Taupo tephrafalls and Taupo Pumice Alluvium. Non-cemented pale to pale grey, massive to cross-stratified sand and gravel, with common carbonised branches and logs. Restricted in occurrence to banks in the base of the map sheet. 0.0 to 4 Ka.

10.0 Ka

ra — INFILL ALLUVIUM (qa): Poorly to well rounded, poorly sorted greywacke gravel and sandstone beds forming terraces up to 10 m above base level. This unit has been mapped as the terrace alluvium inside river levels.

s1 — HIGH LEVEL TERRACES 1 (q1): Poorly to well rounded, poorly sorted greywacke gravel and minor sandstone beds forming terraces up to 10 m above base level. This unit has been mapped as the terrace alluvium inside the modern river levels.

s2 — HIGH LEVEL TERRACES 2 (q2): Poorly to well rounded, poorly sorted greywacke gravel and minor sandstone beds forming terraces up to 10 m above base level. This unit has been mapped as the terrace alluvium inside the modern river levels.

Qls — MASS MOVEMENT DEPOSITS (Qls): Poorly sorted mud-matrix deposits resulting from mass movement events. Historical, displaced blocks, 10m to 50 m, with landslide scarps, many of which are muddy, very subangular.

PLEISTOCENE

LATE

EARLY

CASTLECLIFFIAN

1.63

PLEISTOCENE

NUKUMARUAN

2.15

MANGAPANIAN

3.0

WAIPIPIAN

3.60

PLIOCENE

TERTIARY

MIOCENE

TONGAPORUTUAN

5.28

KAPITEAN

6.5

10.92

WAIAUAN

12.7

LILLBURNIAN

15.1

CLIFDENIAN

15.9

ALTONIAN

19.0

OTAIAN

21.7

JURASSIC

Millions of years

NORTHERN AND CENTRAL AREAS (TE HAROTO-TE POHUE-MAUNGAHUKURU-TANGOO-TARAGALE)

REGIONAL UNCONFORMITY

NE — SW

KAIMANGA GROUP

cc — UNDIFFERENTIATED CASTLECLIFFIAN SEDIMENTS (cc): Poorly sorted non-cemented greywacke gravel, minor sandstone and siltstone. Basal marker to Kidnappers Tilpinia.

PUKEHAMOANA GROUP

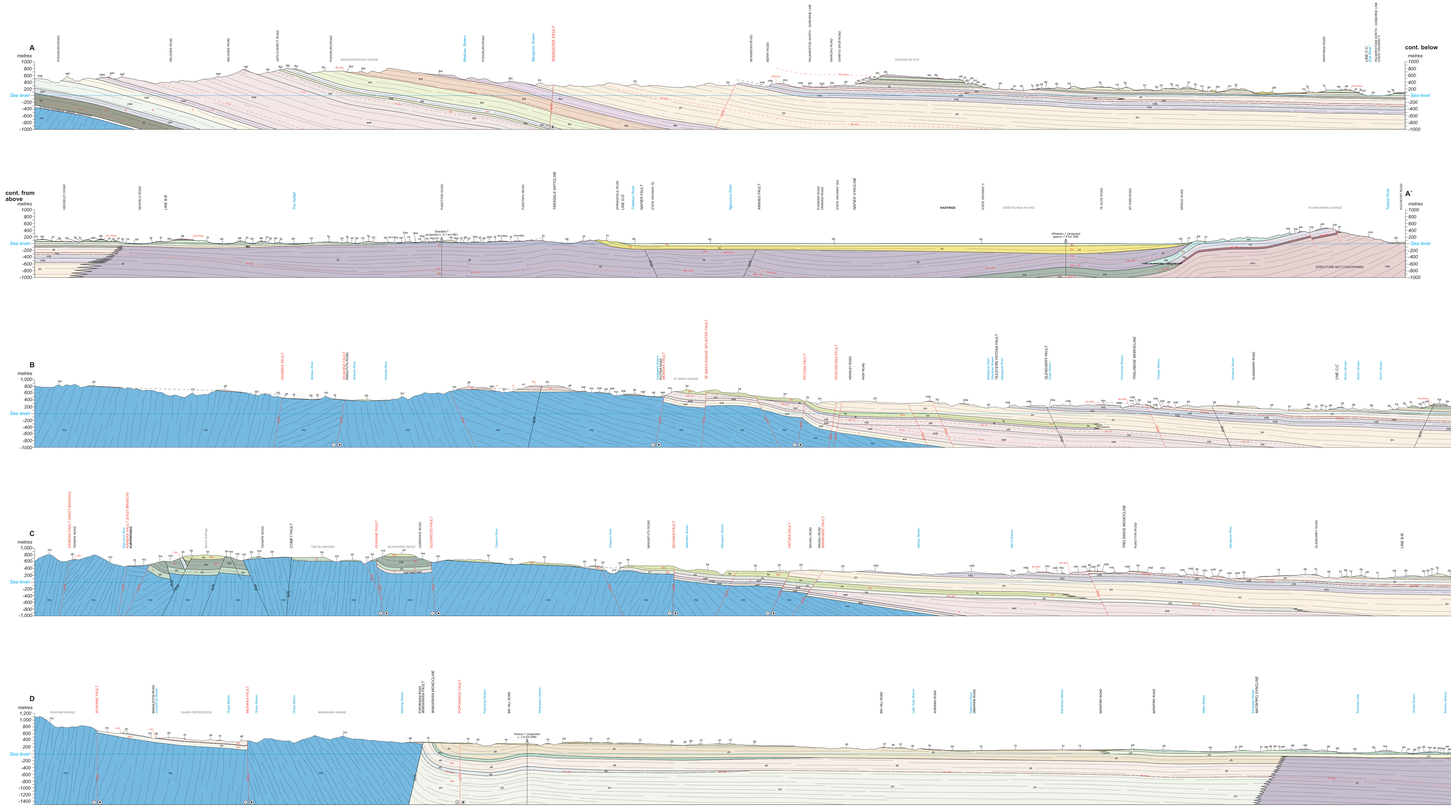
KAIMANGA FORMATION (kai): Cosmo-graded, cross-stratified mixed bioclastic siliciclastic sandstone interbedded with bioclastic limestone, minor conglomerate and siltstone. Restricted to the Kaimanga Syncline. Contains well-preserved to poorly preserved Pectinid, Bivalve, Gastropod, Echinoderm, Bryozoan and Coral fossils. Approximately 600 m.

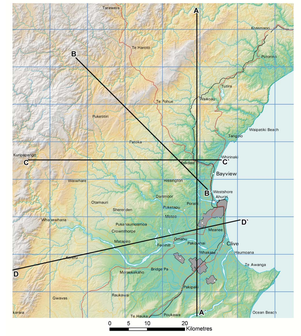
DEVILS ELBOW MUDSTONE MEMBER (dm): Unconsolidated, massive slightly to moderately fossiliferous siltstone and minor sandstone. Contains well-preserved to poorly preserved Pectinid, Bivalve, Gastropod, Echinoderm and Bryozoan fossils. Becomes increasingly coarser-grained away from the Tangoo region. 0-400 m thick.

MARTINS LIMESTONE MEMBER (ma): Bioclastic and carbonate sandstone with common shell bioclast grainy limestone beds. Contains well-preserved to poorly preserved Pectinid, Bivalve, Gastropod and Echinoderm fossils. Becomes micaceous and patchy away from the Tangoo region. 10-60 m thick.

TE HOAPU MUDSTONE MEMBER (tm): Unconsolidated, massive, slightly to moderately fossiliferous bioturbated mud-grey siliciclastic-rich(?) clayey siltstone grading upwards into silty sandstone. Contains 5 to 10 thick(?) tuff beds.

TANGOO LIMESTONE MEMBER (tg): Bioclastic, fine-grained silty sandstone with highly fossiliferous shell bedding. Up to 60 m thick. Contains well-preserved to poorly preserved Pectinid, Bivalve, Gastropod, Echinoderm and Bryozoan fossils. Becomes more massive, muddy and less fossiliferous to the south. Up to 60 m thick





Key to geological unit codes

qa - Late Quaternary alluvium
tpa - Taupo Pumice Alluvium
ra - Ripia Alluvium
cc - Kidnappers Group
pp - Poutaki Formation
ok - Okauawa Formation
ke - Kereru Formation
sb - Sentry Box Formation
kw - Kaiwaka Formation
de - Devils Elbow Mudstone Member
wk - Waipatiki Limestone Member
tn - Te Nguru Mudstone Member
tga - Flag Range Conglomerate Member
tg - Tangoio Limestone Member
mr - Mairau Mudstone Member
dsa - Park Island Limestone Member
ds - Darkys Spur Member
ap - Aropaoanui Mudstone Member
tu - Tutira Member
ek - Esk Mudstone
td - Taradale Mudstone
wp - Waipunga Formation
mtd - Grassy Knoll Conglomerate Member
mtc - Papakiri Member
mtb - Trelinnoe Member
mta - Deep Stream Member
po - Pohue Formation
tw - Te Waka Formation
tk - Tiitokura Formation
tke - Opouahi Member
tkd - Bellbird Bush Member
tkc - Taraponui Member
tkb - Te Rangi Member
tka - Naumai Member
mk - Mokonui Sandstone
pu - Puketitiri Formation
pk - Pakaututu Formation
ma - Mangatoro Formation
bh - Blowhard Formation
war - Rakaita Siltstone Member
waa - Auroa Alternating Member
wai - Te Ipuohape Sandstone Member
wat - Tarawera Limestone Member
paa - Arapaepae Alternating Member
pak - Ngaiapa Sandstone Member
kz - Whakamarino Formation
aw - Awapapa Limestone
mp - Mokopeka Sandstone
kr - Kairakau Limestone
mio - Undifferentiated Late Miocene-Cretaceous
mz - Undifferentiated Torlesse composite terrane

SCALE 1:50 000

1 0 1 2 3 4 5 KILOMETRES

HORIZONTAL SCALE 1:50 000: VERTICAL EXAGGERATION=1X

NOTES

- The detailed locations of cross-section lines are shown on Enclosure 1, Sheets 1-6.
- All cross-sections span multiple map sheets.
- Refer to Enclosure 2 - Legends for 1:50 000 Geological Maps, for description of geological units.
- Well symbols are petroleum exploration holes.
- Red letters are New Zealand stages

WARNING AND DISCLAIMER

These cross-sections show an interpretation of the geology of central and western parts of Hawke's Bay based on both published and unpublished geological information from a variety of sources. These cross-sections should not be used for building site assessment, land-use planning, engineering design, or any other purpose or other work for which detailed site-specific investigations are required. The University of Waikato and its staff and students accept no responsibility for any losses arising from the use of these cross-sections.

DATA SOURCES

Beanland, S., 1995: The North Island Dextral Fault Belt. Unpublished PhD thesis, Victoria University of Wellington, Wellington, New Zealand.

Beanland, S.; Melhuish, A.; Nicol, A..; Ravens, J., 1998: Structure and deformational history of the inner forearc region, Hikurangi subduction margin, New Zealand. New Zealand Journal of Geology and Geophysics 41. 325-342.

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Hukarere-1: Westech Energy New Zealand Ltd 2001: Hukarere-1 well completion report. PEP 38325. Ministry of Economic Development New Zealand. Unpublished Petroleum Report PR 2656.

Kereru-1: Johnston, J.G.; Francis, D.A. 1996: Kereru-1 well completion report. PEP 38328. Ministry of Economic Development New Zealand. Unpublished Petroleum Report PR 2283.

Taradale-1: Darly, J.H.; Kirby, K.F.S. 1969: Taradale-1 well completion report. BP Shell Aquitaine and Todd Petroleum Development Ltd report. Ministry of Economic Development New Zealand. Unpublished Petroleum Report PR 331.

Whakatu-1: Ozolins, V.; Francis, D. 2000: Whakatu-1 well completion report. PEP 38328. Ministry of Economic Development New Zealand. Unpublished Petroleum Report PR 2476.

BIBLIOGRAPHIC REFERENCE

Bland, K.J., (2006): Enclosure 3: Geological Cross Sections. Analysis of the central Hawke's Bay sector of the Late Neogene forearc basin, Hikurangi margin, New Zealand. Unpublished PhD thesis, The University of Waikato, Hamilton, New Zealand.

Enclosure 3
Geological Cross-Sections
Scale 1:50 000 Vertical exaggeration 1x

Kyle J. Bland
PhD Thesis
2006

Analysis of the central Hawke's Bay sector of the Late Neogene forearc basin, Hikurangi margin, New Zealand

Department of Earth and Ocean Sciences

The University of Waikato

Enclosure 3
Geological Cross-Sections
K.J. Bland 2006
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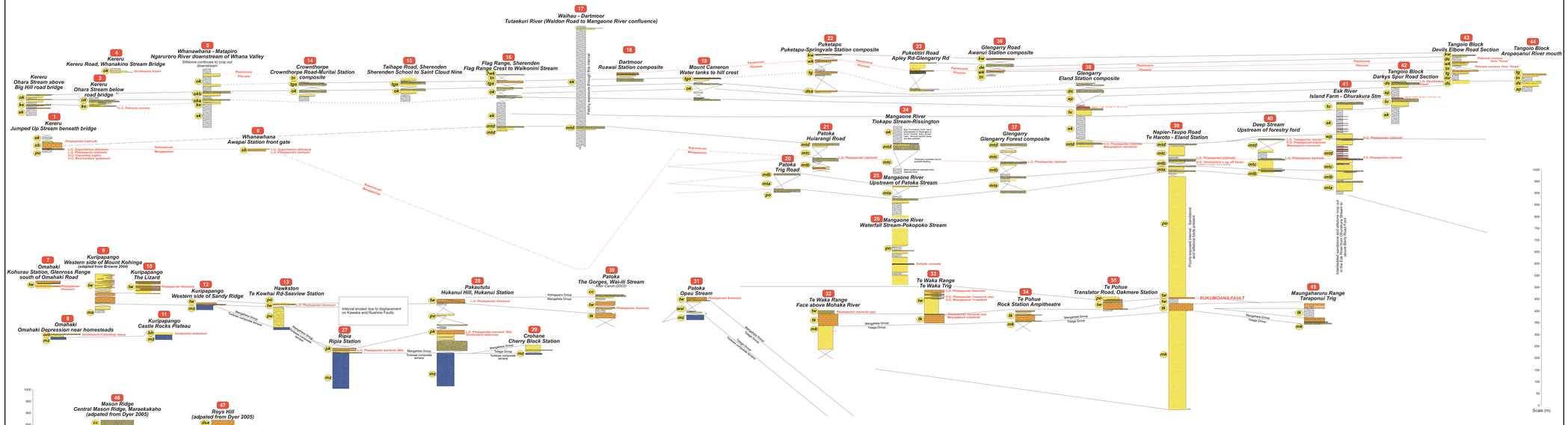
Enclosure 4 - Stratigraphic Correlations

Mangaheia Group simplified composite stratigraphic columns

Analysis of the Late Neogene forearc basin, central Hawke's Bay

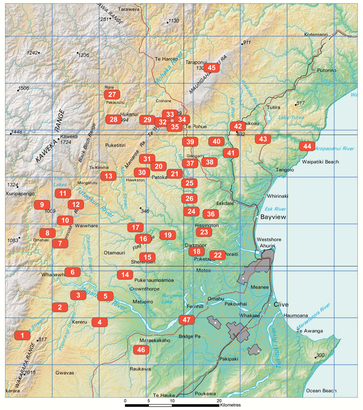


Key to geological unit codes

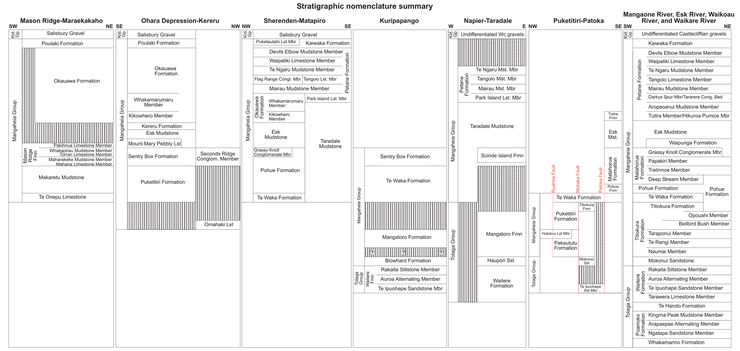
- Kidnappers Group (cc)
- Poutaki Formation (po)
- Okauawa Formation (ok)
- Whakamarumaru Member (okb)
- Kikowhero Member (oka)
- Kereru Formation (ke)
- Sentry Box Formation (sb)
- Kaiwaka Formation (kw)
- Devils Elbow Mudstone Member (de)
- Waipatiki Limestone Member (wk)
- Te Ngaru Mudstone Member (tn)
- Flag Range Conglomerate Member (fgx)
- Tangoio Limestone Member (tg)
- Mairau Mudstone Member (mr)
- Park Island Limestone Member (dha)
- Darleys Spur Member (ds)
- Arapaoanui Mudstone Member (ap)
- Tutira Member (tu)
- Esk Mudstone (ek)
- Taradale Mudstone (td)
- Waipunga Formation (wp)
- Grassy Knoll Conglomerate Member (mtd)
- Papakiri Member (mtc)
- Trelinnoe Member (mtb)
- Deep Stream Member (mta)
- Pohue Formation (po)
- Te Waka Formation (tw)
- Titokura Formation (tk)
- Mokonui Sandstone (mk)
- Pukeitiri Formation (pu)
- Pakaututu Formation (pk)
- Mangatoro Formation (ma)
- Blowhard Formation (bh)
- Rakaita Siltstone Member (war)
- Aurea Alternating Member (wra)
- Te Ipuohape Sandstone Member (wra)
- Tarawera Limestone Member (wrz)
- Mason Ridge Formation (mr)
- Makaretu Mudstone (ku)
- Te Onepu Limestone (te)
- Undifferentiated Torlesse composite terrane (mz)

Lithology

- Basement
- Sandstone
- Silty sandstone
- Siltstone
- Limestone
- Sandy limestone
- Cross-bedded limestone
- Pebbly Limestone
- Shellbed
- Conglomerate
- Shelly conglomerate
- Volcaniclastic bed
- Calcareous sandstone



Stratigraphic nomenclature summary



Enclosure 4
Stratigraphic Correlations
Mangaheia Group simplified composite stratigraphic columns

Kyle J. Bland
2006
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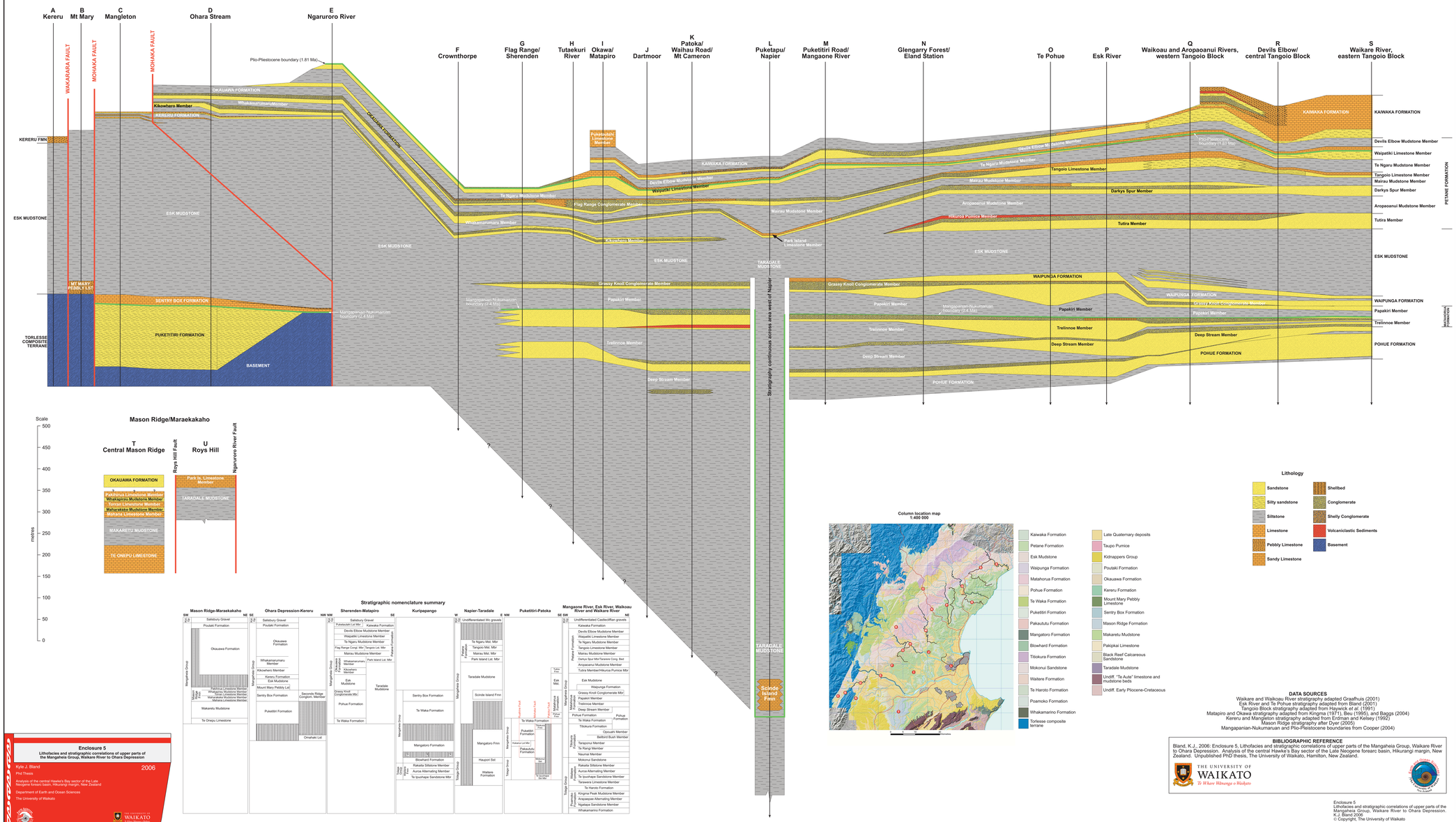
Enclosure 5 - Lithofacies and stratigraphic correlations of upper parts of the Mangaheia Group, Waikare River to Ohara Depression



DATA SOURCES

Waikare and Waikoau River stratigraphy adapted Graafhuis (2001)
Esk River and Te Pohue stratigraphy adapted from Bland (2001)
Tangoio Block stratigraphy adapted from Haywick et al. (1991)
Matapiro and Okawa stratigraphy adapted from Kingma (1971), Beu (1995), and Baggs (2004)
Kereru and Mangleton stratigraphy adapted from Erdman and Kelley (1992)
Mason Ridge stratigraphy after Dyer (2005)
Mangapanian-Nukumaruan and Plio-Pleistocene boundaries from Cooper (2004)

BIBLIOGRAPHIC REFERENCE

Bland, K.J., 2006: Enclosure 5, Lithofacies and stratigraphic correlations of upper parts of the Mangaheia Group, Waikare River to Ohara Depression. Analysis of the central Hawke's Bay sector of the Late Neogene forearc basin, Hikurangi margin, New Zealand. Unpublished PhD thesis, The University of Waikato, Hamilton, New Zealand.

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Enclosure 5
Lithofacies and stratigraphic correlations of upper parts of the Mangaheia Group, Waikare River to Ohara Depression

Kyle J. Bland
Phd Thesis

2006

Analysis of the central Hawke's Bay sector of the Late Neogene forearc basin, Hikurangi margin, New Zealand

Department of Earth and Ocean Sciences
The University of Waikato

Enclosure 5
Lithofacies and stratigraphic correlations of upper parts of the Mangaheia Group, Waikare River to Ohara Depression.
in J. Bland 2006

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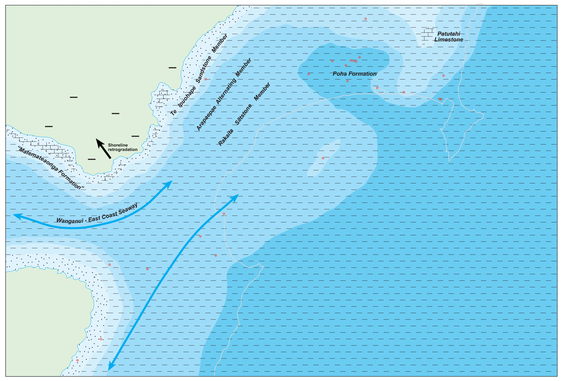
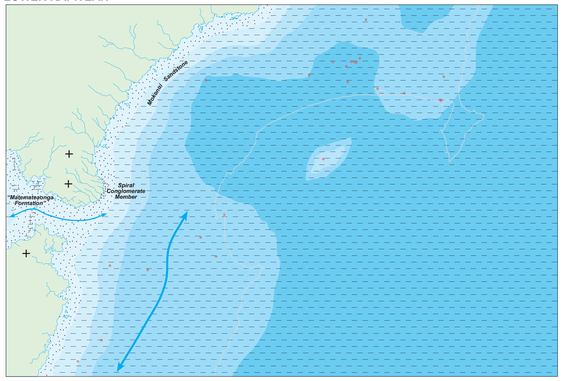
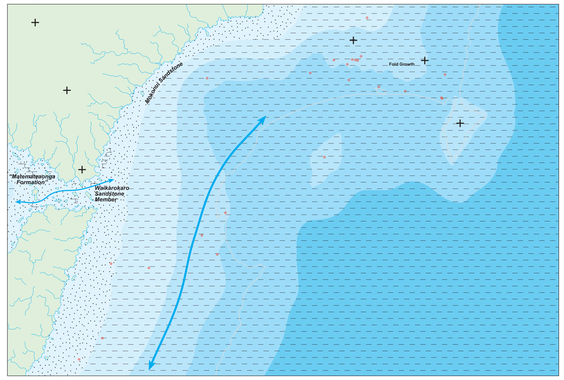
Map 1 c. 8 Ma
UPPER TONGAPORUTUAN



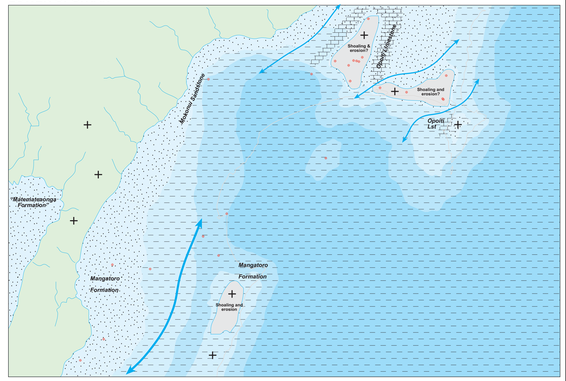
Map 2 c. 6.5 Ma
LOWER KAPITEAN



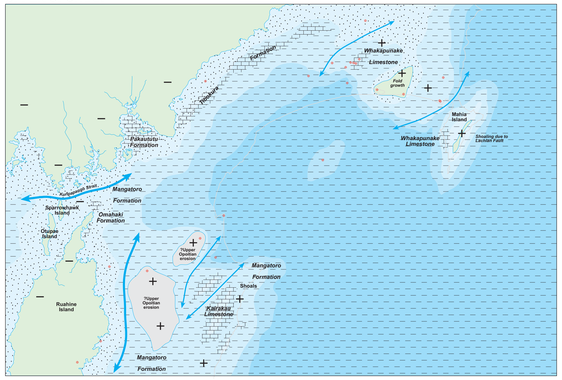
Map 3 c. 5.5 Ma
UPPER KAPITEAN



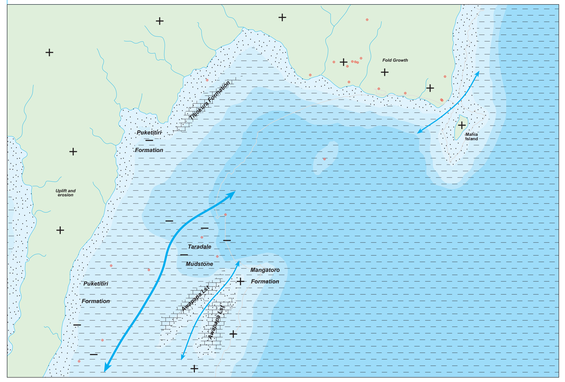
Map 4 c. 5.25 Ma
LOWER OPOITIAN



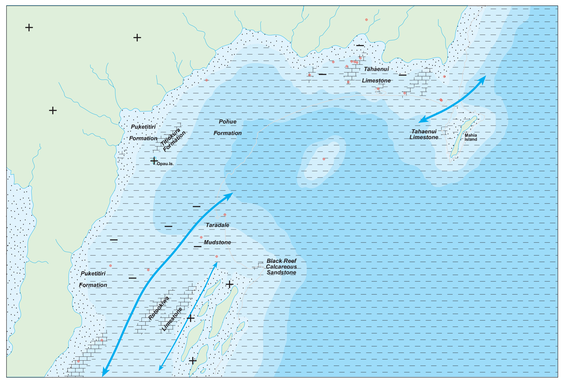
Map 5 c. 4 Ma
UPPER OPOITIAN



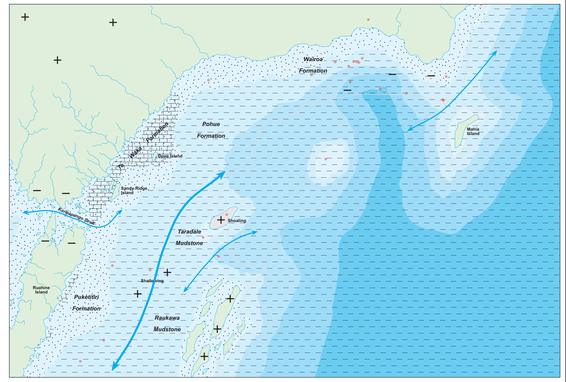
Map 6 c. 3.6 Ma
LOWER WAIPIPIAN



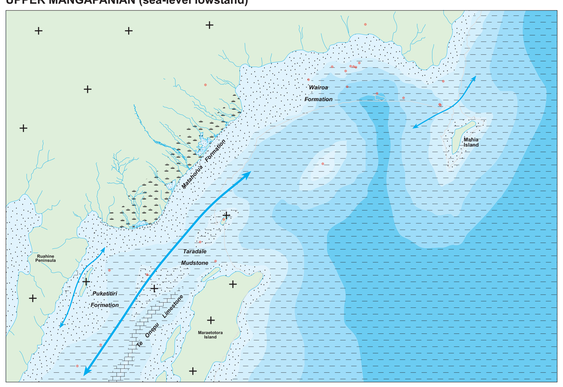
Map 7 c. 3.2 Ma
UPPER WAIPIPIAN



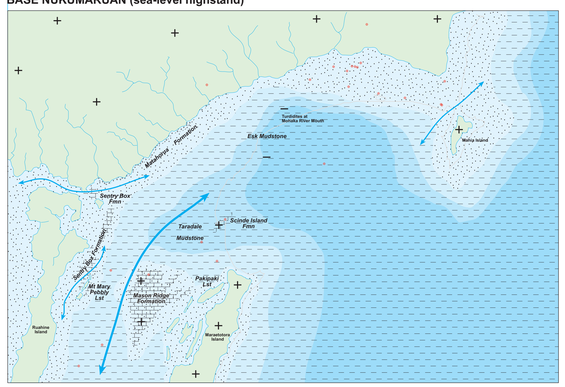
Map 8 c. 3.0 Ma
LOWER MANGAPANIAN



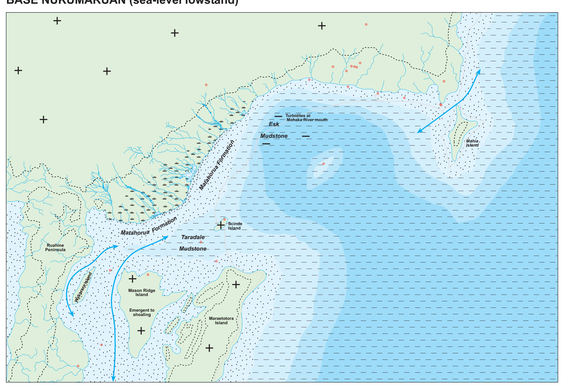
Map 9 c. 2.5 Ma
UPPER MANGAPANIAN (sea-level lowstand)



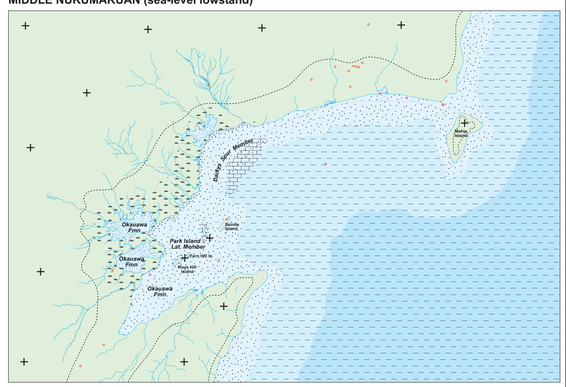
Map 10 c. 2.4 Ma
BASE NUKUMARUAN (sea-level highstand)



Map 11 c. 2.4 Ma
BASE NUKUMARUAN (sea-level lowstand)



Map 12 c. 2 Ma
MIDDLE NUKUMARUAN (sea-level lowstand)



Notes about these paleogeographic maps

Although based on available data, the positions of rivers, estuaries, and harbours on these maps are inferred and are present for illustrative purposes. These maps have been constructed with all areas fixed, and paleogeography is depicted relative to the modern coastline. No allowance has been made for lateral displacment or structural block rotations.

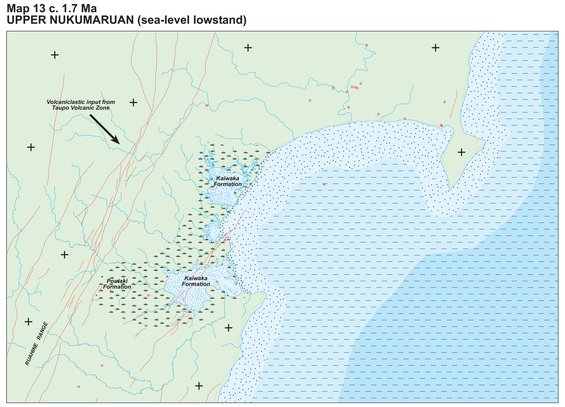
Data sources

Strong (1927): N.Z. Petroleum Development Co Ltd (1939); Watson (1962); NZ Aquitane Petroleum Development Ltd (1967); Darley and Kirby (1969), Leslie (1971a-c); BP Shell Aquitane Todd Petroleum Development Ltd (1976); Beu *et al.* 1980; Dobbie and Carter (1990); Erdman and Kelsey (1992); Beu, A.G. 1995; Johnston and Francis (1996); Field *et al.* (1997); Ian R. Brown and Associates Ltd (1998a-f, 1999a-c), Bland (2001); Graafhuis (2001); Westech Energy New Zealand Ltd (2001); Ozolins and Francis (2000); Bland *et al.* (2004); Browne (2004a, b); Kamp *et al.* in prep. (Creataceous-Cenozoic Geology of Wanganui Basin and its petroleum systems).

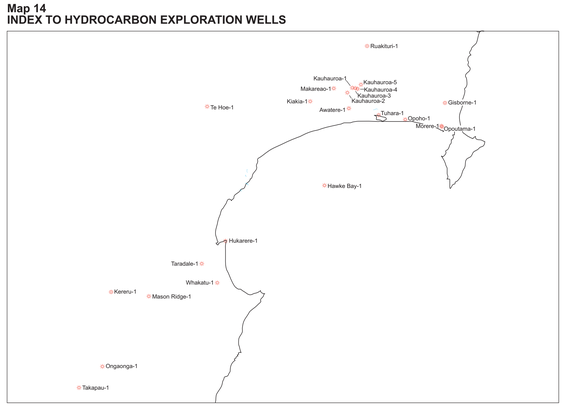
Warning and disclaimer

The paleogeographic maps are interpretations based on both published and unpublished geological information from a variety of sources. The University of Waikato and its staff and students accept no responsibility or liability for any losses arising from the use of these maps. They should not be used for buidling site assessment, land-use planning, engineering projects, quarrying operations, or other work for which site-specific investigations are required.

Map 13 c. 1.7 Ma
UPPER NUKUMARUAN (sea-level lowstand)



Map 14
INDEX TO HYDROCARBON EXPLORATION WELLS



LEGEND

- Land
- Inner shelf c. 0-50 m
- Middle shelf c. 50-100 m
- Outer shelf c. 100-200 m
- Upper bathyal c. 200-400 m
- Middle/lower bathyal c. 400 m+
- Shoals/non-deposition
- Silt
- Sand
- Carbonate banks
- Alluvial deposition
- Conglomerate
- Harbour/estuary
- Highstand shoreline
- River
- Braided river
- Active fault
- Hydrocarbon exploration well
- Uplift
- Subsidence
- Current direction
- Major current direction

Enclosure 6
Paleogeographic Maps

Kyle J. Bland
Phd Thesis
2006

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Enclosure 6
Paleogeographic Maps
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Enclosure 7: Geographic Information System Database Model

Analysis of the Late Neogene Forearc Basin, Central Hawke's Bay

Master Geological Geodatabase model

Master Geological Geodatabase is the primary database for this geological analysis of central and western parts of Hawke's Bay, with a target scale of 1:50 000

Geology

Simplefeatureclass — **GEOL_UNITS** — Geological Units — Geological units mapped as polygon features. — Geometry: Polygon

Fieldname	Datatype	Alias	Allow nulls	Domain	Precision	Length	Description
OBJECTID	OID	OBJECTID			0	4	
SHAPE	Geometry	SHAPE			0	0	
UNIT_CODE	String	Geological Unit Code	Yes		0	10	Geological Unit Code used for differentiating geological units
MAIN_ROCK	String	Main Rock Type	Yes	Rock Names	0	32	Main rock type of the mapping unit
SUB_ROCKS	String	Subordinate Rock Types	Yes	Rock Names	0	64	Subordinate rock type of the mapping unit
STRAT_UNIT	String		Yes		0	32	Stratigraphic unit name
SEQUENCE	String		Yes		0	32	Sequence name
TERRANE	String		Yes		0	32	Terrane name
STRAT_AGE	String		Yes	Age	0	32	International stratigraphic age
NZ_STAGE	String		Yes	Stage	0	32	New Zealand stage
STAGE_POS	String		Yes	Stage_Position	0	32	Position in New Zealand Stage
ABS_MIN	Double		Yes		0	8	Absolute minimum age
ABS_MAX	Double		Yes		0	8	Absolute maximum age
CONFIDENCE	String		Yes		0	64	Confidence of age assignment
DESCRIPTION	String		Yes		0	128	Description of mapping unit
ROCK_GROUP	String		Yes	Rock Group	0	32	Broad rock group name
ROCK_CLASS	String		Yes	Rock Class	0	32	Broad rock class
SUPERGROUP	String	Lithostratigraphic Supergroup	Yes		0	50	Lithostratigraphic supergroup name
GROUP	String	Lithostratigraphic Group	Yes		0	50	Lithostratigraphic Group
SUBGROUP	String	Lithostratigraphic Subgroup	Yes		0	50	Lithostratigraphic subgroup name
FORMATION	String	Lithostratigraphic Formation	Yes		0	50	Lithostratigraphic formation name
MEMBER	String	Lithostratigraphic Member	Yes		0	50	Lithostratigraphic member name
SED_ENV	String	Sedimentary Environment	Yes	Environment	0	50	Depositional sedimentary environment
BED	String		Yes		0	50	Lithostratigraphic bed name
SHAPE_Length	Double		Yes		0	8	
SHAPE_Area	Double		Yes		0	8	

Simplefeatureclass — **Geol_Units_Lines** — Geological Units Lines — Describes geological units as linear features. — Geometry: Polyline

Fieldname	Datatype	Alias	Allow nulls	Domain	Precision	Length	Description
OBJECTID	OID	OBJECTID			0	4	
SHAPE	Geometry	SHAPE	Yes		0	0	
UNIT_CODE	String		Yes		0	6	
MAIN_ROCK	String		Yes	Rock_Names	0	32	
SUB_ROCKS	String		Yes	Rock_Names	0	64	
STRAT_UNIT	String		Yes		0	32	
SEQUENCE	String				0	32	
TERRANE	String				0	32	
STRAT_AGE	String			Age	0	32	
NZ_STAGE	String			Stage	0	32	
STAGE_POS	String			Stage_Position	0	32	
ABS_MIN	Double				0	8	
ABS_MAX	Double				0	8	
CONFIDENCE	String				0	64	
DESCRIPTION	String				0	128	
ROCK_GROUP	String			Rock_Group	0	32	
ROCK_CLASS	String			Rock_Class	0	32	
SUPERGROUP	String				0	50	
GROUP	String				0	50	
SUBGROUP	String				0	50	
FORMATION	String				0	50	
MEMBER	String				0	50	
SED_ENV	String			Environment	0	50	
ACCURACY	String			Accuracy	0	50	
MAX_THICK	Double				0	8	
Bed	String				0	50	
SHAPE_Length	Double				0	8	

Simplefeatureclass — **HORIZONS** — Horizons — Describes geological horizons. — Geometry: Polyline

Fieldname	Datatype	Alias	Allow nulls	Domain	Precision	Length	Description
OBJECTID	OID	OBJECTID			0	4	
SHAPE	Geometry	SHAPE	Yes		0	0	
UNIT_CODE	String		Yes		0	6	
MAIN_ROCK	String		Yes	Rock Names	0	32	
SUB_ROCKS	String		Yes	Rock Names	0	64	
STRAT_UNIT	String				0	32	
STRAT_UNIT	String				0	32	
SEQUENCE	String				0	32	
TERRANE	String				0	32	
STRAT_AGE	String			Age	0	32	
NZ_STAGE	String			Stage	0	32	
STAGE_POS	String			Stage_Position	0	32	
ABS_MIN	Double				0	8	
ABS_MAX	Double				0	8	
CONFIDENCE	String				0	64	
DESCRIPTION	String				0	128	
ROCK_GROUP	String			Rock Group	0	32	
ROCK_CLASS	String			Rock Class	0	32	
SUPERGROUP	String				0	50	
GROUP	String				0	50	
SUBGROUP	String				0	50	
FORMATION	String				0	50	
MEMBER	String				0	50	
SED_ENV	String			Environment	0	50	
ACCURACY	String			Accuracy	0	50	
MAX_THICK	Double				0	8	
Bed	String				0	50	
SHAPE_Length	Double				0	8	

Simplefeatureclass — **Boundaries** — Boundaries — Describes geological boundaries. — Geometry: Polyline

Fieldname	Datatype	Alias	Allow nulls	Domain	Precision	Length	Description
OBJECTID	OID	OBJECTID			0	4	
SHAPE	Geometry	SHAPE	Yes		0	0	
BOUNDARY_TYPE	String		Yes	Boundary_Type	0	50	
ACCURACY	String		Yes	Accuracy	0	50	
DIP	Small Integer		Yes	Dip	0	2	
SHAPE_Length	Double		Yes		0	8	

Simplefeatureclass — **3D_X_Section_Line** — Boundaries — Describes geological boundaries. — Geometry: Polyline

Fieldname	Datatype	Alias	Allow nulls	Domain	Precision	Length	Description
OID	OID	OBJECTID			0	4	
SHAPE	Geometry	SHAPE	Yes		0	0	
Shape_Length	Double		Yes		0	8	
Id	Integer		Yes		0	4	

Simplefeatureclass — **Mass_Movement_Extent** — Mass Movement Extent — Describes the distribution and character of mass movement deposits. — Geometry: Polygon

Fieldname	Datatype	Alias	Allow nulls	Domain	Precision	Length	Description
OBJECTID	OID	OBJECTID			0	4	
SHAPE	Geometry	SHAPE	Yes		0	0	
UNIT_CODE	String	Geological Unit Code	Yes		0	10	Geological Unit Code used for differentiating geological units
MAIN_ROCK	String	Main Rock Type	Yes	Rock Names	0	32	Main rock type of the mapping unit
SUB_ROCKS	String	Subordinate Rock Types	Yes	Rock Names	0	64	Subordinate rock type of the mapping unit
ABS_MIN	Double	Absolute minimum age	Yes		0	8	Absolute minimum age
ABS_MAX	Double	Absolute maximum age	Yes		0	8	Absolute maximum age
CONFIDENCE	String		Yes		0	128	Confidence of age assignment
DESCRIPTION	String		Yes		0	128	Description of mapping unit
MOVEMENT_TYPE	String		Yes		0	50	Type of mass movement deposit
SHAPE_Length	Double		Yes		0	8	
SHAPE_Area	Double		Yes		0	8	

Annotationfeatureclass — **Geological_Unit_Codes** — Geological Unit Codes — Reference scale 50000; Reference scale Units Metres; Annotation version 2; Autoscale Horizontal; Autoscale Rotation; No annotation subclasses; No subtypes — Geometry: Polygon

Fieldname	Datatype	Domain	Precision	Length
OBJECTID	OID		0	4
SHAPE	Geometry		0	0
FeatureID	Integer		0	4
ZOrder	Integer		0	4
AnnotationClassID	Integer		0	4
Element	Blob		0	0
SHAPE_Length	Double		0	8
SHAPE_Area	Double		0	8

Coded value domain — **Rock_Names**
Description: —
Field type: String
Split policy: Duplicate
Merge policy: Default value

Code	Description
agg	agglomerate
alb	albite granite
alg	algal limestone
alk	alkali basalt
ash	shale
and	andesite
ano	anorthosite
apl	aplite
arc	arcosite
arg	argilite
ark	arkose
bas	basalt
basitc	basaltic
basand	basaltic andesite
bdol	basaltic
biocarb	biocarbonate
biocalc	biocalcarenite
biosper	biosparite
bonin	boninite
bound	boundstone
boundst	boundstone
brec	breccia
brok	broken formation
camp	camptonite
carb	carbonate rock
carbroc	carbonate rock
cartite	carbonatite
chalk	chalk
chalk	chalk
cham	chamockite
che	chert
chp	chopwacke
clay	clay
clayst	claystone
clino	clinopyroxenite
coal	coal
congl	conglomerate
coq	coquina
cpx	cpxite
dam	diamictite
diat	diatomite
dior	diorite
dole	dolerite
dolmstn	dolomitic limestone
dolost	dolostone
duni	dunite
dun	dunite
eclo	eclogitic
evap	evaporite
fang	fanglomerate
feni	fenite
fos	fossil
gabbro	gabbro
gabbronr	gabbronorite
gneiss	gneiss
gran	granite
granst	granstone
granod	granodiorite
granul	granulite
granulite	granulite
grape	grapestone
grd	granodiorite
green	greenstone
grsch	green schist
grey	greywacke
grt	grt
gypano	gypsum
harz	harzburgite
hawe	hawaiite
hbgab	hornblende gabbro
hblite	hornblendite
hornf	hornfels
ign	igneous
kim	kimberlite
kers	kerstanite
kerz	kerzantite
kom	komatiite
komite	komatiite
lamp	lamprophyre
lap	lapilli tuff
leaf	leaf beds
lher	lherzolite
lig	lignite
lime	limestone
lime	limestone
loam	loam
lst	limestone
marb	marble
mart	mart
meta	metamorphic
melt	melt
metabch	metabasalt
metacon	metaconglomerate
metap	metapelite
metast	metasandstone
metav	metavolcanics
micr	microfossil
micro	microcrystalline
mig	migmatite
mon	monzonite
monch	monchiquite
monzd	monzodiorite
monzo	monzonite
mud	mud
mudst	mudstone
mvl	mylonite
neph	nepheline syenite
nor	norite
obs	obsidian
oil	oil shale
olbas	olivine basalt
olivneph	olivine nephelinite
ool	oolitic limestone
opal	opal
opth	ophiolite
ortho	orthopyroxenite
peat	peat
peb	pebble
peg	pegmatite
peralky	peralkaline rhyolite
perid	peridotite
phon	phonolite
phos	phosphorite
phy	phyllite
pic	picrite
pillo	pillowlite
porph	porphyry
psamm	psammite
pyro	pyroclastics
qdiorite	quartz diorite
qdolo	quartz dolerite
qtzsye	quartz syenite
rhyl	rhyolite
rhyod	rhyodacite
rhy	rhyolite
rock	rockgolle
sand	sand
sandst	sandstone
samsate	samsatite
sch	schist
sed	sediment
semsch	semischist
shale	shale
shlbed	shell bed
shrgr	shingle
silt	silt
sltst	siltstone
skar	skarn
slate	slate
spes	spessartite
spit	spilite
syen	syenite
syngran	syenogranite
talc	talc
till	till
tillite	tillite
tonal	tonalite
tonalite	tonalite
trachya	trachyandesite
trachb	trachybasalt
trach	trachyte
trachbrec	trachytic breccia
trav	travertine
troc	trocolite
troctuf	trocolithemite
tuff	tuff
turb	turbidites
ultra	ultramafic
vit	vitric tuff
vog	vogesite
vbold	volcanic boulders
vbrec	volcanic breccia
wack	wackestone
vsand	volcanic sandstone
web	websterite
wehr	wehrlite
shlbst	shellbed siltstone
shbdstcong	shellbed siltstone conglomerate

Coded value domain — **Rock_Classes**
Description: —
Field type: String
Split policy: Duplicate
Merge policy: Default value

Code	Description
un	unknown
tec	tectonic
clsed	clastic sediment
clsedim	clastic sediment
ultraex	ultramafic extrusive
mafex	mafic extrusive
intex	intermediate extrusive
felex	felsic extrusive
intplut	intermediate plutonic
mafint	mafic intrusive
intint	intermediate intrusive
felint	felsic intrusive
gneiss	gneiss
schist	schist

Coded value domain — **Stage**
Description: —
Field type: String
Split policy: Duplicate
Merge policy: Default value

Code	Description
Ynq	Haweran
Wc	Castlecliffian
Wn	Nukumaruan
Wm	Mangapanian
Wo	Opoitian
Wq	Opoitian
Tk	Kapitean
Tw	Waiarekauan
Tw	Waiauan
Sl	Lillburnian
Sc	Clifdenian
Pt	Altonian
Pw	Waitakian
Lw	Waitakian
Ld	Duntroonian
Lh	Hutchinsonian
Ar	Runangan
Ak	Kaiatan
Ab	Borhonian
Dp	Porangan
Dn	Dannevirkan
Dw	Mangarangan
Dw	Waipawan
Dt	Teurian

Coded value domain — **Stage_Position**
Description: —
Field type: String
Split policy: Default value
Merge policy: Default value

Code	Description
early	early
middle	middle
late	late

Coded value domain — **Boundary_Type**
Description: —
Field type: String
Split policy: Default value
Merge policy: Default value

Code	Description
conformable	Conformable
fault	Fault
Intrusive	Intrusive
unknown	Unknown
wall	Wall
unconfable	Unconfiable
terrace	Terrace
isotect	Isotect
uncertain	Uncertain
border	Border, indicates map border
offshore	Offshore, indicates contact is below mean sea-level
unconformable	Unconformable
disconformable	Disconformable
gradational	Gradational
paraconform	Paraconformity

Coded value domain — **Accuracy**
Description: —
Field type: String
Split policy: Default value
Merge policy: Default value

Code	Description
app	Approximate
con	Concealed
est	Estimated
flu	Fluvial
acc	Accurate

Coded value domain — **Environment**
Description: —
Field type: String
Split policy: Default value
Merge policy: Default value

Code	Description
nonmar	Non-Marine
fluv	Fluvial
alluvan	Alluvial Fan
bs	Braided Stream
ms	Meandering Stream
lac	Lacustrine
glac	Glacial
marmar	Marginal-Marine
del	Deltaic
deltpl	Delta Plain
delfr	Delta Front
prodel	Prodelta
beachbar	Beach/barrier bar
tidflt	Tidal Flat/Lagoonal
tidflt	Tidal Flat
eol	Eolian Dune System
fsh	Foreshore
fsh	Foreshore
bcsh	Backshore/dune
mar	Marine
slf	Shelf (neritic)
inshf	Inner-Shelf
midsh	Middle-Shelf
oush	Outer-Shelf
slp	Slope
upslp	Upper-Slope
midslp	Middle-Slope
lowslp	Lower-Slope
abf	Abyssal
sfan	Slope Floor Fan
slpchan	Slope Channel

Coded value domain — **Grain_Size**
Description: —
Field type: String
Split policy: Default value
Merge policy: Default value

Code	Description
B	boulder
C	cobble
P	pebble
1	granule
2	very coarse sand
3	coarse sand
4	medium sand
5	fine sand
6	very fine sand
7	silt
8	silt
9	mud

Coded value domain — **Bed_Thickness**
Description: —
Field type: String
Split policy: Default value
Merge policy: Default value

Code	Description
1	non-bedded
2	>120cm
3	30-120cm
4	5-60cm
5	1-5cm
6	<1cm

Structure

Simplefeatureclass — **FAULTS** — Faults — Describes the location and character of fault traces. — Geometry: Polyline

Fieldname	Datatype	Alias	Allow nulls	Domain	Precision	Length	Description
OBJECTID	OID	OBJECTID			0	4	
SHAPE	Geometry	SHAPE	Yes		0	0	
IDENTIFIER	String		Yes		0	16	
ACCURACY	String		Yes	Accuracy	0	16	Accuracy of location of fault trace
DOM_SENSE	String		Yes	Fault Sense	0	11	
SUB_SENSE	String		Yes	Fault Sense	0	11	
ACTIVITY	String		Yes		0	8	
PLOT_RANK	Integer		Yes	Plot Rank	0	4	
NAME	String		Yes		0	32	
ZONE	Small Integer		Yes		0	32	
FAULT_TYP	Small Integer		Yes	Fault Type	0	11	
RSOM_SENSE	String		Yes	Fault Sense	0	11	
RSUB_SENSE	String		Yes	Fault Sense	0	11	
DIP	Small Integer		Yes		0	2	
DIP_DIR	Small Integer		Yes	Dip	0	2	
DIP	Small Integer		Yes	Dip	0	2	
AGE	String		Yes	Age	0	16	
TOTAL_SLIP	String		Yes	Fault Slip	0	8	
STRIKE_QUAD	String		Yes		0	3	
ACCUR_SENSE	String		Yes		0	32	
SHAPE_Length	Double		Yes		0	8	

Coded value domain — **Fault_Sense**
Description: —
Field type: String
Split policy: Default value
Merge policy: Default value

Code	Description
dex	Dextral
dpslp	Dipslip
non	Normal
nrm	Normal
rvs	Reverse
sin	Sinistral
slkslp	Strike-Slip
thr	Thrust
unknown	Unknown

Simplefeatureclass — **FOLDS** — Folds — Describes the location of folds. — Geometry: Polyline

Fieldname	Datatype	Alias	Allow nulls	Domain	Precision	Length	Description
OBJECTID	OID	OBJECTID			0	4	
SHAPE	Geometry	SHAPE	Yes		0	0	
IDENTIFIER	String		Yes		0	4	
NAME	String		Yes		0	50	Name of fold
ACCURACY	String		Yes	Accuracy	0	16	Accuracy of location of fold
TYPE	String		Yes	Fold Type	0	30	Type of fold
VERTICITY	String		Yes		0	16	Verticity of fold
TREND	Small Integer		Yes		0	2	Trend of fold
PLUNGE	Small Integer		Yes		0	2	Plunge of fold
DIP_DIR	Small Integer		Yes		0	2	Dip direction of fold
DIP	Small Integer		Yes		0	2	Dip of fold in degrees
FACING	String		Yes	Fold Facing	0	16	Facing of fold
VERGENCE	String		Yes	Fold Vergence	0	16	Vergence of fold
SURFACE	String		Yes	Fold Surface	0	16	
AGE	String		Yes	Age	0	16	Age of fold
Plot_Rank	Integer		Yes	Plot Rank	0	4	Plot rank
SHAPE_Length	Double		Yes		0	8	

Coded value domain — **Fold_Type**
Description: —
Field type: String
Split policy: Default value
Merge policy: Default value

Code	Description
ant	Anticline
antinv	Anticline Inverted
antiover	Anticline Overturned
antioverinv	Anticline Overturned Inverted
antibed	Anticline Bedding
antiverbed	Anticline Overturned Bedding
antischist	Anticline Overturned Schistosity
antisch	Anticline Schistosity
monbedhoz	Monocline Bedding Limb Horizontal
monbedinv	Monocline Bedding Limb Dipping
monover	Monocline Overturned
monschhoz	Monocline Schistosity Limb Horizontal
monschdip	Monocline Schistosity Limbs Dipping
syn	Syncline
synnv	Syncline Inverted
synover	Syncline Overturned
synoverinv	Syncline Overturned Inverted
synbed	Syncline Bedding
synboverbed	Synform Overturned Bedding
synoverschi	Synform Overturned Schistosity
synsch	Synform Schistosity
plungant	Plunging Anticline
plungsyn	Plunging Syncline
plungmono	Plunging Monocline

Coded value domain — **Fold_Surface**
Description: —
Field type: String
Split policy: Default value
Merge policy: Default value

Code	Description
bedd	Bedding
fault	Fault
fol	Foliation
S1	S1 Foliation
S2	S2 Foliation
S3	S3 Foliation
S4	S4 Foliation
unknown	Unknown

Simplefeatureclass — **LINEAMENTS** — Lineaments — Describes the location of remotely-sensed lineaments. — Geometry: Polyline

Fieldname	Datatype	Alias	Allow nulls	Domain	Precision	Length	Description
OBJECTID	OID	OBJECTID			0	4	
SHAPE	Geometry	SHAPE	Yes		0	0	
IDENTIFIER	String		Yes		0	8	Indentifier of lineament
ACCURACY	String		Yes	Accuracy	0	16	Accuracy of lineament trace
TYPE	String	Lineament type	Yes	Lineark_Type	0	16	Method of lineament identification, type of lineament
SHAPE_Length	Double		Yes		0	8	

Coded value domain — **Lineark_Type**
Description: —
Field type: String
Split policy: Default value
Merge policy: Default value

Code	Description
aspphoto	Air Photograph
aeromagnetic	Aeromagnetic
gravity	Gravity
satelliteimage	Satellite image
DEM	Digital Elevation Model

Simplefeatureclass — **Waypoints** — Waypoints — Describes GPS waypoint records. — Geometry: Point

Fieldname	Datatype	Alias	Allow nulls	Domain	Precision	Length	Description
OBJECTID	OID	OBJECTID			0	4	OBJECTID
Field_Trip_Dates	String	Waypoint Date	Yes		0	50	Actual dates of the field trip when the waypoint was collected
Waypoint_Number	String	Waypoint Number	Yes		0	50	Authors Waypoint Reference
NZMS_260_Map	String	Map Name	Yes		0	50	Name of map sheet the waypoint has been recorded
NZMS_260_Map_Sheets	String	Northings	Yes		0	50	NZMS 260 series topographic map/sheet name and number
Eastings	Long Integer		Yes		0	0	Eastings in New Zealand Map Grid co-ordinates
Northings	Long Integer		Yes		0	0	Northings in New Zealand Map Grid co-ordinates
Elevation	Long Integer		Yes		0	0	Elevation in metres above mean sea level
Description	String		Yes		0	90	Brief summary of features at waypoint
Samples	String		Yes		0	50	Samples taken at that waypoint
Strat_Column	String		Yes		0	50	Stratigraphic column number
Mapped_Orginator	String		Yes		0	50	Author of waypoint description
Notes	String		Yes		0	90	Other information relevant to waypoint
Fossil_Observation_Site	String		Yes		0	50	Records whether fossil data was recorded at this locality
Fossil_Observation_Type	String		Yes		0	50	Type of fossil observation recorded
Faunal_Association_Comments	String		Yes		0	200	Comment on the faunal association present at the locality
NZ_Stratigraphic_Stage	String		Yes		0	50	NZ stage in which the waypoint was taken
Age_Source	String		Yes		0	50	Method by which the NZ stage age was obtained
SHape	Geometry		No		0	0	

Simplefeatureclass — **Dips_and_Strikes** — Dips and Strikes — Describes dip and strike records. — Geometry: Point

Fieldname	Datatype	Alias	Allow nulls	Domain	Precision	Length	Description
OBJECTID	OID	OBJECTID			0	4	
SHAPE	Geometry	SHAPE	Yes		0	0	
Waypoint_Number	String		Yes	Waypoint Number	0	50	
Eastings	Double		Yes	Eastings	0	8	
Northings	Double		Yes	Northings	0	8	
Elevation	Double		Yes		0	8	
Dip_Angle	Double		Yes		0	8	
Azimuth	Double		Yes		0	8	
Strike	Double		Yes		0	8	
Dip	Double		Yes		0	8	
Dip_Direction	String		Yes		0	50	
Geological_Formation	String		Yes		0	50	
Map_Angle	Double		Yes		0	8	
Measurement_type	String		Yes		0	50	
Structural_Domain	String		Yes		0	90	

Simplefeatureclass — **STRUCTURE** — Structure — Describes structural points. — Geometry: Point

Fieldname	Datatype	Alias	Allow nulls	Domain	Precision	Length	Description
OBJECTID	OID	OBJECTID			0	4	
SHAPE	Geometry	SHAPE	Yes		0	0	
NUMBER	Integer		Yes		0	16	
IDENTIFIER	String		Yes		0	50	
TITLE	String		Yes		0	32	
AUTHORS	String		Yes		0	90	
PUBLICATION	String		Yes		0	0	
INSTITUTION	String		Yes		0	7	
SCALE	Integer		Yes		0	2	
YEAR	Integer		Yes		0	4	
SHAPE_Length	Double		Yes		0	8	
SHAPE_Area	Double		Yes		0	8	

Annotationfeatureclass — **Faultlines** — Fault Names — Reference scale 50000; Reference scale Units Metres; Annotation version 2; Autoscale Rotation; No subtypes — Displays geological unit codes assigned to geological units. — Geometry: Polygon

Fieldname	Datatype	Domain	Precision	Length
OBJECTID	OID		0	4
SHAPE	Geometry		0	0
FeatureID	Integer		0	4
ZOrder	Integer		0	4
AnnotationClassID	Integer		0	4
Element	Blob		0	0
SymbolID	Integer	Annotation Status	0	4
Status	Small Integer		0	2
TextString	String		0	255
FormName	String		0	255
FontSize	Double		0	8
Bold	Small Integer: BooleanSymbolValue		0	2
Italic	Small Integer: BooleanSymbolValue		0	2
Underline	Small Integer: BooleanSymbolValue		0	2
VerticalAlignment	Small Integer: VerticalAlignment		0	2
HorizontalAlignment	Small Integer: HorizontalAlignment		0	2
XOffset	Double		0	8
YOffset	Double		0	8
Angle	Double		0	8
LineSpacing	Double		0	8
WordSpacing	Double		0	8
CharacterWidth	Double		0	8
CharacterSpacing	Double		0	8
FlipAngle	Double		0	8
Override	Double		0	8
SHAPE_Length	Double		0	8
SHAPE_Area	Double		0	8

Structure Contours

Simplefeatureclass — **Base_Okaueva_Formation** — Base Okaueva Formation — Structure contour horizon on base Okaueva Formation. — Geometry: Polyline

Fieldname	Datatype	Alias	Allow nulls	Domain	Precision	Length	Description
OBJECTID	OID	OBJECTID			0	4	
SHAPE	Geometry	SHAPE	Yes		0	0	
ELEVATION	Small Integer		Yes		0	2	Elevation on horizon in metres above mean sea level
SHAPE_Length	Double		Yes		0	8	

Simplefeatureclass — **Base_Te_Waka_Formation** — Base Te Waka Formation — Structure contour horizon on base Te Waka Formation. — Geometry: Polyline

Fieldname	Datatype	Alias	Allow nulls	Domain	Precision	Length	Description
OBJECTID	OID	OBJECTID			0	4	
SHAPE	Geometry	SHAPE	Yes		0	0	
ELEVATION	Small Integer		Yes		0	2	Elevation on horizon in metres above mean sea level
SHAPE_Length	Double		Yes		0	8	

Simplefeatureclass — **Top_Basement** — Top Basement — Structure contour horizon on top basement. — Geometry: Polyline

Fieldname	Datatype	Alias	Allow nulls	Domain	Precision	Length	Description
OBJECTID	OID	OBJECTID			0	4	
SHAPE	Geometry	SHAPE	Yes		0	0	
ELEVATION	Small Integer		Yes		0	2	Elevation on horizon in metres above mean sea level
SHAPE_Length	Double		Yes		0	8	

Simplefeatureclass — **Top_Darkys_Spur_Formation** — Top Darkys Spur Formation — Structure contour horizon on top Darkys Spur Formation. — Geometry: Polyline

Fieldname	Datatype	Alias	Allow nulls	Domain	Precision	Length	Description
OBJECTID	OID	OBJECTID			0	4	
SHAPE	Geometry	SHAPE	Yes		0	0	
ELEVATION	Small Integer		Yes		0	2	Elevation on horizon in metres above mean sea level
SHAPE_Length	Double		Yes		0	8	

Simplefeatureclass — **Top_Darkys_Spur_Horizon** — Top Darkys Spur Formation and equivalents — Structure contour horizon on top Darkys Spur Formation and time-equivalent horizon. — Geometry: Polyline

Fieldname	Datatype	Alias	Allow nulls	Domain	Precision	Length	Description
OBJECTID	OID	OBJECTID			0	4	
SHAPE	Geometry	SHAPE	Yes		0	0	
ELEVATION	Small Integer		Yes		0	2	Elevation on horizon in metres above mean sea level
SHAPE_Length	Double		Yes		0	8	

Simplefeatureclass — **Top_Deep_Stream_Member** — Top Deep Stream Member — Structure contour horizon on top Deep Stream Member. — Geometry: Polyline

Fieldname	Datatype	Alias	Allow nulls	Domain	Precision	Length	Description
OBJECTID	OID	OBJECTID			0	4	
SHAPE	Geometry	SHAPE	Yes		0	0	
ELEVATION	Small Integer		Yes		0	2	Elevation on horizon in metres above mean sea level
SHAPE_Length	Double		Yes		0	8	

Simplefeatureclass — **Top_Matahorua_Formation** — Top Matahorua Formation — Structure contour horizon on top Matahorua Formation. — Geometry: Polyline

Fieldname	Datatype	Alias	Allow nulls	Domain	Precision	Length	Description
OBJECTID	OID	OBJECTID			0	4	
SHAPE	Geometry	SHAPE	Yes		0	0	
ELEVATION	Small Integer		Yes		0	2	Elevation on horizon in metres above mean sea level
SHAPE_Length	Double		Yes		0	8	

Simplefeatureclass — **Top_Okaueva_Conglom** — Top Okaueva Conglomerates — Structure contour horizon on top Okaueva conglomerate beds, Okaueva Formation. — Geometry: Polyline

Fieldname	Datatype	Alias	Allow nulls	Domain	Precision	Length	Description
OBJECTID	OID	OBJECTID			0	4	
SHAPE	Geometry	SHAPE	Yes		0	0	
ELEVATION	Small Integer		Yes		0	2	Elevation on horizon in metres above mean sea level
SHAPE_Length	Double		Yes		0	8	

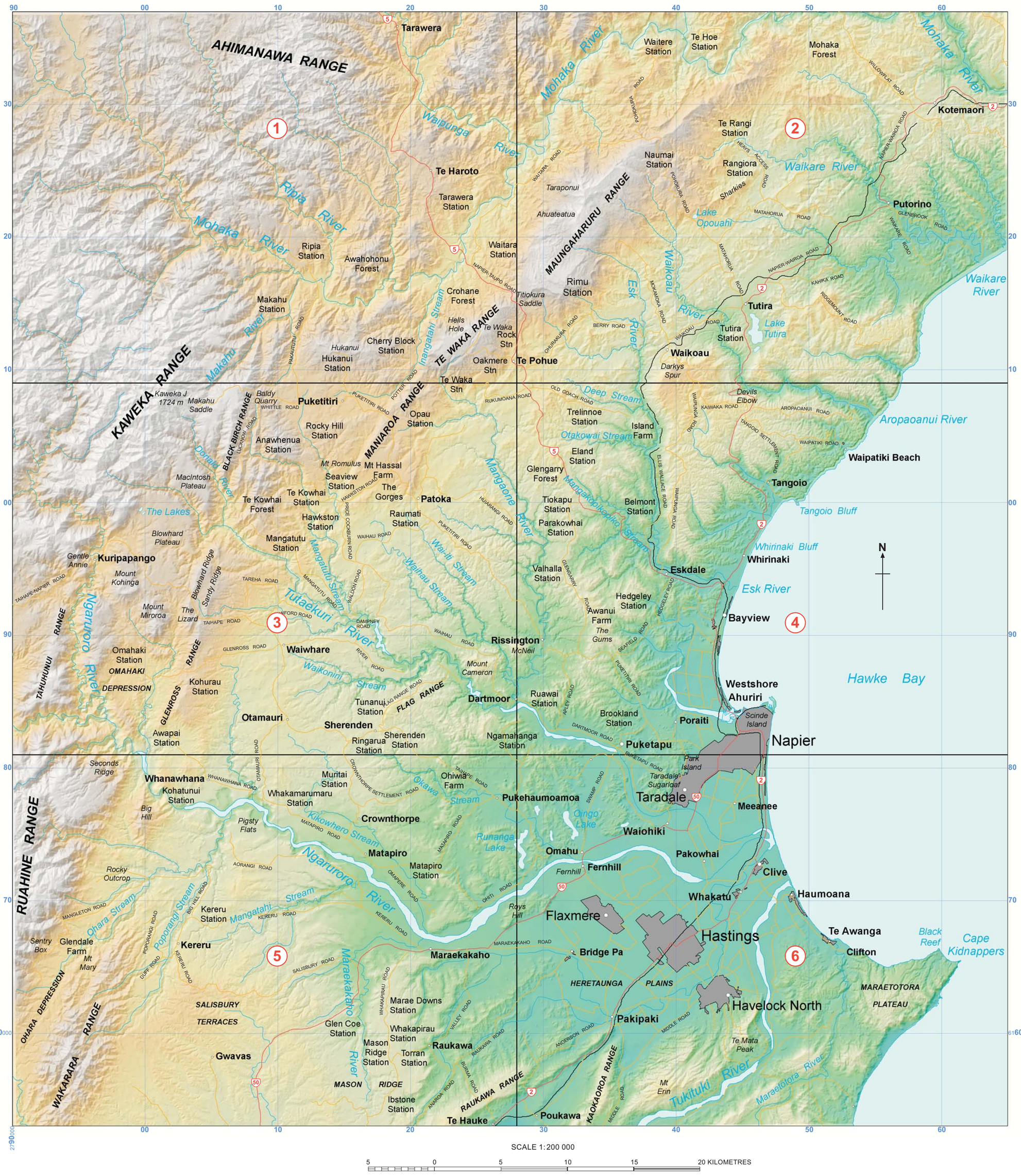
Simplefeatureclass — **Top_Opaoa_Sandstone** — Base Te Ipuohape Sandstone — Structure contour horizon on base Te Ipuohape Sandstone Member. — Geometry: Polyline

Fieldname	Datatype	Alias	Allow nulls	Domain	Precision	Length	Description
OBJECTID	OID	OBJECTID			0	4	
SHAPE	Geometry	SHAPE	Yes		0	0	
ELEVATION	Small Integer		Yes		0	2	Elevation on horizon in metres above mean sea level
SHAPE_Length	Double		Yes		0	8	

Simplefeatureclass — **Base_Te_Waka

Enclosure 8: Locality and Topographic Feature Map

Analysis of the Late Neogene Forearc Basin, Central Hawke's Bay



SCALE 1:200 000

5 0 5 10 15 20 KILOMETRES

TOPOGRAPHIC LEGEND

TOPOGRAPHIC FEATURES

- Major mountain range ..... KAWEKA RANGE
- Mountain range ..... TE WAKA RANGE
- Significant topographic feature ..... HERETAUNGA PLAINS
- Other topographic feature ..... Darkys Spur

WATER FEATURES

- Major river ..... Mohaka River
- Significant river ..... Esk River
- Other rivers, streams, and lakes ..... Deep Stream
- Significant oceanic feature ..... Cape Kidnappers
- Other oceanic features ..... Black Reef
- River .....
- Lake .....

CULTURAL FEATURES

- Residential area .....
- Major settlement ..... Napier
- Significant settlement ..... Taradale
- Other settlements ..... Bayview
- Localities ..... Otamauri
- Farms and stations ..... Sherenden Station

ROAD AND RAIL FEATURES

- State Highway 2
- Other roads .....
- Palmerston North-Gisborne Railway line .....

6 Geological Map Sheet in Enclosure 1

Enclosure 8
Locality and Topographic Feature Map
Scale 1:200 000

Kyle J. Bland

2006

Phd Thesis

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Department of Earth and Ocean Sciences

The University of Waikato

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Enclosure 8
Locality and Topographic Feature Map
K.J. Bland 2006
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