

http://researchcommons.waikato.ac.nz/

Research Commons at the University of Waikato

Copyright Statement:

The digital copy of this thesis is protected by the Copyright Act 1994 (New Zealand).

The thesis may be consulted by you, provided you comply with the provisions of the Act and the following conditions of use:

- Any use you make of these documents or images must be for research or private study purposes only, and you may not make them available to any other person.
- Authors control the copyright of their thesis. You will recognise the author's right to be identified as the author of the thesis, and due acknowledgement will be made to the author where appropriate.
- You will obtain the author's permission before publishing any material from the thesis.

A Geological Map of Te Kuiti Sheet BF33 at 1:50 000 scale, King Country Basin, New Zealand

A thesis

submitted in partial fulfilment

of the requirements for the degree

of

Master of Science in Earth Sciences

at

The University of Waikato

by

Benjamin David Whiteman



THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

University of Waikato

2017

Abstract

The principal research objective of this thesis has been to produce a new 1:50 000 scale geological map of topographic map BF33 (Te Kuiti Sheet), one of the new Topo 50 topographic map sheets covering New Zealand. The geological map was produced through a conventional field mapping approach coupled with structure contouring using ArcGIS software. Hence the physical map printed at a 1:50 000 scale is backed-up by a database in ArcGIS, which is scaleless. The map illustrates the distribution and extent of Cenozoic stratigraphic units (Te Kuiti Group, Mahoenui Group, Mokau Group, Otunui Formation and Pakaumanu Group ignimbrites) and Jurassic basement in the field area. The map represents significant revision of the distribution of units and occurrence of faults compared with previous geological maps of the area, including the 1:50 000 field sheet prepared for the production of the new 1:250 000 Waikato QMAP sheet (Edbrooke, 2005). Several new normal faults east of Te Kuiti have been identified and mapped, as well as minor changes in the location of Waipa Fault. A west-east trending syncline has also been identified and mapped in the southern part of the field area.

Stratigraphic columns through Te Kuiti, Mahoenui and Mokau groups, and Otunui Formation, have been drawn for numerous sites, appealing in some cases to previously produced columns. Facies descriptions of these successions have also been made and environments of deposition interpreted from them. The Oligocene to Earliest Miocene (Whaingaroan-Waitakian stages) Te Kuiti Group is comprised of basal coal measures, calcareous sandstone, calcareous siltstone and limestone facies, which accumulated in fluvial environments (coal measures) and mainly in shelf environments. The Early Miocene (Otaian Stage) Mahoenui Group is comprised mainly of mudstone facies (Taumatamaire Formation) with some interbedded occurrences of turbidites. Limestone facies (Cherry Tree Limestone Member), occurs near the base of Taumatamaire Formation in the close vicinity of Te Kuiti, comprising redeposited beds. The Mahoenui succession accumulated in upper bathyal environments as the basin rapidly subsided. Bexley Sandstone (Mokau Group) comprises mainly sandstone facies with interbedded mudstone-sandstone within Mangarino Member, which occurs in the lower part of the formation north of Te Kuiti. Bexley Sandstone accumulated in shallow marine and marginal marine (Mangarino Member) environments within a transgressive systems

tract. Otunui Formation comprises mainly silty sandstone facies. A shellbed at the base of the formation, known as Mangarara Formation, accumulated as a transgressive shoreface to innermost shelf deposit; it is conformably overlain by thick bioturbated silty fine sandstone facies that accumulated in shelf and upper bathyal environments. From its degree of induration, a 2 km thick succession accumulated above Otunui Formation (e.g. Mt Messenger Formation to Matemateaonga Formation), but it was eroded prior to emplacement of Early Pleistocene Pakaumanu Group ignimbrites sourced from Taupo Volcanic Zone. Individual ignimbrite eruptives have not been differentiated on the geological map. A landscape with considerable relief has developed upon the ignimbrite units and Holocene alluvium has accumulated in valley floors.

Acknowledgements

Firstly, I would like to extend my thanks and appreciation to my supervisor Professor Peter Kamp for providing tremendous help throughout every stage of this thesis project. His open-door policy, willingness to help and his expertise in all areas are the things I have appreciated immensely. The support and continuous encouragement he provided was instrumental and will always be remembered and valued.

I also offer my thanks to Yu-shen Liu for his assistance in tutoring me in many aspects of the use of ArcGIS and its applications to geological mapping in the early stages of my research project. His field assistance is also gratefully appreciated.

I wish to acknowledge access to a field sheet of the BF33 map area provided by GNS Science via their website. Funding to enable this project to be undertaken was provided by MBIE via a contract to Professor Peter Kamp.

I extend my gratitude to my family and friends who have been nothing but supportive and understanding throughout this period. A special thanks must go to my parents for their unfaltering love and encouragement throughout my University studies. Their everlasting support is something I have always valued and for which I cannot be thankful enough; my University achievements are a testament to them both.

I also wish to extend my thanks to both past and present Earth and Ocean Sciences staff and students. They have offered me endless advice and provided me with a knowledge platform to complete this research project and for this I will always be thankful.

Table of Contents

1 Introduction 1

1.1 Overview 1

1.2 Thesis objectives 2

1.3 Study area 2

1.4 Thesis structure 3

1.4.1 Chapter 2: Geological and tectonic setting 3

1.4.2 Chapter 3: Methodology 3

1.4.3 Chapter 4: Te Kuiti BF33 geological map, stratigraphy & structure 3

1.4.4 Chapter 5: Sedimentology 3

1.4.5 Chapter 6: Synthesis of the geological history of the Cenozoic succession in the map area 4

1.4.6 Chapter 7: Summary and conclusions 4

1.4.7 Appendix 4

1.4.8 Enclosure I 4

2 Geological Setting 5

2.1 Introduction 5

2.2 Stratigraphic Units 6

2.2.1 2.1 Basement Geology 6

2.2.2 2.2 Cenozoic Stratigraphy 7

2.2.3 Quaternary Units 10

2.3 Structural Overview 11

2.4 Uplift of North Island in Late Cenozoic 13

3 Methodology 15

3.1 Introduction 15

3.2 Geological Map & Mapping Procedure 15

3.2.1 Field area 15

3.2.2 Topography of the area 16
3.2.3 ArcGIS database and base map 17
3.2.4 Field methods 17
3.2.5 Aerial Photography 19
3.2.6 Methods of geological mapping using GIS 20
4 Te Kuiti BF33 Geological Map, Stratigraphy and Structure 23
4.1 Introduction 23
4.2 Basement Geology 25
4.3 Te Kuiti Group 27
4.3.1 Okoko Subgroup 28
4.3.2 Castle Craig Subgroup 31
4.4 Mahoenui Group 35
4.5 Mokau Group 38
4.6 Whangamomona Group: (*Otunui Formation*) 40
4.7 Quaternary Deposits 41
4.8 Cross-sections 43
4.9 Stratigraphy and structure of important areas 45
5 Sedimentology 63
5.1 Introduction 63
5.2 Te Kuiti Group Facies 63
5.2.1 Limestone Facies 63
5.2.2 Sandstone Facies 69
5.2.3 Siltstone Facies 70
5.3 Mahoenui Group Facies 71
5.3.1 Mudstone Facies 71
5.3.2 Sandstone Facies 73
5.3.3 Interbedded Sandstone-Mudstone Facies 74

5.3.4 Limestone Facies 77
5.4 Mokau Group Facies 78
5.4.1 Sandstone Facies 78
5.4.2 Interbedded Sandstone-Mudstone Facies 79
5.4.3 Conglomerate Facies 80
5.5 Otunui Formation Facies 82
5.5.1 Sandstone Facies 82
5.5.2 Shellbed Facies 83
5.6 Facies summary tables 85
6 Synthesis of the geological history of the Cenozoic succession in the Map Area 97
6.1 Introduction 97
6.2 Paleogeograhic Interpretation 98
7 Summary and conclusions 117
7.1 Introduction 117
7.2 Objectives 117
7.3 Geological and tectonic setting 118
7.4 Geological map and stratigraphy 118
7.5 Sedimentology 118
7.6 Synthesis of the geological history of the Te Kuiti map area 119
7.7 Future work 121
8 References 123
9 Appendix I: Stratigraphic Columns within BF33 Map Area 131
10 Appendix II: Geodetic Database 169

List of Figures

Fig. 2.1. Pre-Cenozoic basement rocks of New Zealand 6
Fig. 2.2. Simplified geological map of the western North Island. 8
Fig. 2.3. Major Neogene stratigraphic units in each of Taranaki, King Country and Wanganui Basins..... 10
Fig. 2.4. Geological structure map of the western North Island showing the main structures and the distribution of basement..... 12
Fig. 2.5. Map of western North Island, showing magnitude of erosion during Pliocene-Pleistocene..... 14
Fig. 3.1. Location of Te Kuiti Sheet BF33. 16
Fig. 3.2. Geomorphology of the Tertiary stratigraphic groups 18
Fig. 3.3. Aerial photography, contact between Mahoenui Group and Mokau Group.. 19
Fig. 3.4. Steps for structure contouring 20
Fig. 4.1. Te Kuiti BF33 map area showing locations of stratigraphic columns by their associated column number. 24
Fig. 4.2. Manaia Hill Group of the Waipapa Composite Terrane outcrop exposed at a road cutting along Otewa Road. 26
Fig. 4.3. Te Kuiti Group cropping out along Walker Road..... 27
Fig. 4.4. Waikato Coal Measures of the Te Kuiti Group, outcropping in a road cutting along Ngapeke Road 29
Fig. 4.5. Schematic cross section of Aotea Formation 31
Fig. 4.6. Waitanguru Limestone and Piopio Limestone Members of the Te Kuiti Group overlain by Mahoenui Group at Oparure Quarry 34
Fig. 4.7. Taumatamaire Formation exposed at a road cutting along State Highway 4 36
Fig. 4.8. Taumarunui Formation exposed at Herlihy Bluff, River Road, south of the field area. 37
Fig. 4.9. Bexley Sandstone outcropping along State Highway 3, south of the turn off west towards Waitomo 39
Fig. 4.10. Fallen ignimbrite 42
Fig. 4.11. Mangaokewa North Road. Alluvial deposits, Mahoenui Group and Otunui Formation overlain by undifferentiated ignimbrite. 42
Fig. 4.12. Orientation and location of cross sections A-A' and A-B. 44

Fig. 4.13. Map section of location 1 in the northeastern region of the field area. 47
Fig. 4.14. View south along Ngapeke Road, with Ngapeke Fault. 48
Fig. 4.15. Te Kuiti Group, Mahoenui Group and Mokau Group located along Ngapeke Road. 49
Fig. 4.16. Tahaia Road at private quarry where Mokau Group unconformably overlies Manaia Hill Group 49
Fig. 4.17. Map at location 2 in the northwestern part of the field area. 50
Fig. 4.18. View north towards Waitomo from Fullerton Road 51
Fig. 4.19. View north along Fullerton Road with the location of Waipa Fault shown. 52
Fig. 4.20. View south from Fullerton Road towards the ramp structure 52
Fig. 4.21. Map of Location 3, in the central part of the field area. 53
Fig. 4.22. View west across Te Kuiti from Walker Road 54
Fig. 4.23. (A.) View south from Walker Road towards Beros Quarry. (B.) View north from Walker Road towards the old quarry east of the town. 55
Fig. 4.24. Map section of location 4, in the central southern region of the field area. . 56
Fig. 4.25. Anticline and syncline structural trends. 57
Fig. 4.26. Map section of location 5, in the southeastern part of the field area. 58
Fig. 4.27. View south along Mangaokewa Road. Geological boundaries between Cenozoic units shown 59
Fig. 4.28. Map section of location 6, in the southwestern part of the field area. 60
Fig. 5.1. Limestone quarry oucrop along Waitomo Valley Road, north of the field area 65
Fig. 5.2. Oparure limestone quarry outcrop 66
Fig. 5.3. Kihi Sandstone and Orahiri Formation outcropping in Honikiwi, north of the field area. 66
Fig. 5.4. Kihi Sandstone and Orahiri Formation outcropping in Honikiwi, north of the field area. 67
Fig. 5.5. Massive glauconitic muddy sandstone (S1), Waitomo Sandstone 70
Fig. 5.6. Massive mudstone facies (M1), Taumatamaire Formation 72
Fig. 5.7. Channelized sandstone sequence (S3), Taumatamaire Formation 74
Fig. 5.8. Interbedded graded sandstone-mudstone sequence (I2), Taumatamaire Formation. 76
Fig. 5.9. Bouma (1962) turbidite divisions. 76
Fig. 5.10. Massive sandstone (S4) and Conglomerate facies (C1), Bexley Sandstone 79

Fig. 5.11. Thick bedded sandstone-mudstone (I3), Mangarino Member 80
Fig. 5.12. Conglomerate layer (C1), Bexley Sandstone 81
Fig. 5.13. Otunui Formation at a road cutting along Mangaokewa Road.. 83
Fig. 6.1. Chronostratigraphic panel 97
Fig. 6.2. Map of western North Island, showing magnitude of erosion during Pliocene-Pleistocene..... 115

1 Introduction

1.1 Overview

King Country Basin is a back-arc basin that is located west of the Taupo Volcanic Zone (TVZ). The Taranaki, King Country and Wanganui Basins are located in central-western North Island (New Zealand). Taranaki Basin has a lower stratigraphic section of Late Cretaceous (Haumarian Stage) sediments, which is overlain by Cenozoic sedimentary units with Miocene to Pleistocene volcanics in northern Taranaki Basin and on land in Taranaki Peninsula. King Country Basin includes sedimentary units that accumulated in the Waikato region. This sedimentary section of Late Eocene and Oligocene age (Te Kuiti Group) is separate from sediments of equivalent age in the adjacent Taranaki Basin, although Herangi High, lying between these basins shed Late Oligocene carbonate sediments into both basins. During the Miocene, Taranaki and King Country basins had linked depositional systems and hence stratigraphies, reflecting Early Miocene subsidence and burial of Herangi High. Wanganui Basin originated during the Pliocene through downwarping of the southern part of King Country Basin and hence there was a linked depositional system until Late Pliocene uplift of the King Country region. There was probably shortening across Taranaki Fault, the main structure between Taranaki and King Country basins from the Middle Oligocene (early Whaingaroan), which was accentuated during the Early Miocene (Nelson et al. 2004; Stagpool and Nicol 2008; Kamp et al. 2014). However from the late-Early Miocene (Altonian Stage), shortening ceased north of Taranaki Peninsula and Taranaki and King Country basins became united as depocentres.

The occurrence of five key 2nd order Late Paleocene and Neogene sequences of tectonic origin throughout the Wanganui, King country and eastern Taranaki basin are suggested (Kamp et al., 2004). These include the Late Eocene-Oligocene Te Kuiti Sequence (King Country Basin), the Early Miocene (Otaian) Mahoenui Group/Sequence (King Country Basin), the late-Early Miocene (Altonian) Mokau Group/Sequence (King Country Basin), the Middle Miocene to Early Pliocene Whangamomona Group/Sequence, and the Middle Pliocene-Pleistocene Rangitikei Supergroup/Sequence.

Using conventional geological mapping techniques as well as GIS-based methods, a 1:50 000 scale geological map has been constructed for part of King Country Basin. The map area investigated here is known as the Te Kuiti Sheet, covering the area surrounding Te Kuiti Township in the King Country region. This map is based on the new topographic map series (Topo 50) and covers map BF33. This represents the production of the first geological map at this scale for the area, although a field sheet was prepared by GNS Science as part of the production of the 1: 250 000 geological map known as QMAP Waikato (Edbrooke 2005). The geological units include Jurassic basement, Te Kuiti Group (Late Eocene-Oligocene), Mahoenui Group (early-Early Miocene), Mokau Group (late-Early Miocene), Otunui Formation (Middle Miocene), Pleistocene ignimbrite units and Late Quaternary fluvial sediments. Besides the mapping of geological units, this thesis also involves stratigraphic column descriptions of sections and facies analysis as a means of interpreting the depositional paleoenvironments of the sedimentary formations. Paleogeographic interpretations for the map area and wider basin have also been established.

The key outcome of this thesis is the production of a new 1:50 000 geological map of the Te Kuiti area. The map covers an area of 890 km^2.

1.2 Thesis objectives

1. To complete the production of a 1:50 000 scale geological map of the Te Kuiti sheet (BF33).
2. To produce descriptions of stratigraphic sections through each of the formations and implement these together with analysis of sedimentary facies to interpret the related depositional environments.
3. To develop understanding about the stratigraphic and structural development of the Te Kuiti map area (BF33) in the context of the wider King Country Basin.

1.3 Study area

Located within King Country, the geological map covers an area of 890 km^2 in and around Te Kuiti Township. The only township of any size in the map area is Te Kuiti. It is located approximately 70 km inland from the West Coast. Waipa River runs through the eastern part of the field area, with many of its tributaries being located throughout the region. The main land use in the field area is dry stock and

dairy farming. Waitomo Caves, which supports a large tourism enterprise, is located in Otorohanga Limestone of Te Kuiti Group. These caves lie in the northwestern part of the field area.

1.4 Thesis structure

To address the thesis objectives and allow for a continuous flow of geological evidence the thesis has been structured to contain the following chapters:

1.4.1 Chapter 2: Geological and tectonic setting

The purpose of this chapter is to describe the geological setting of the field area with respect to earlier literature. The chapter defines the area in relation to its structural and tectonic setting as well as identifying the key geological units that appear throughout the field area as identified in previous studies.

1.4.2 Chapter 3: Methodology

This chapter describes in detail the approach and methods used to produce the 1:50 000 geological map. This involves field methods and the use of ArcGIS and its associated database.

1.4.3 Chapter 4: Te Kuiti BF33 geological map, stratigraphy and structure

This chapter describes geological units within the field area in relation to geomorphology, distribution, age, lithological features, outcrop appearance and other stratigraphic information. The details of stratigraphy and structure are given by reference to six key areas within the overall map area.

1.4.4 Chapter 5: Sedimentology

This chapter describes and interprets sedimentary facies that occur within the stratigraphic units mapped. This analysis is supported by a series of stratigraphic columns produced for different sections through the Cenozoic units mapped (Appendix I) and by tables summarising the description of sedimentary facies.

1.4.5 Chapter 6: Synthesis of the geological history of the Cenozoic succession in the map area

The purpose of this chapter is to establish the paleogeographic development of the sedimentary succession in the field area. This includes assessing depositional trends and proposing an interpretation of the geological history of the field area and wider geological development of King Country Basin.

1.4.6 Chapter 7: Summary and conclusions

This chapter provides an overview of the main findings from this study. The summary largely focuses on the stratigraphy and structure of the field area and presents recommendations for future research.

1.4.7 Appendix

The appendix includes the 25 stratigraphic columns as well as an overview of the coordinate system used for mapping in ArcGIS.

1.4.8 Enclosure I

Enclosure 1 is a 1:50 000 scale geological map of the Te Kuiti area (Topographic Sheet BF33) with two 1:1 cross-sections and a geological legend.

2 Geological Setting

2.1 Introduction

The map area is located in and around Te Kuiti Township, within King Country Basin. It covers topographic map BF33, one of the new Topo 50 topographic map sheets. The Cenozoic sedimentary units present in the map area include the Late Eocene-Oligocene Te Kuiti Group, Early Miocene Mahoenui and Mokau Groups, and middle-Late Miocene Whangamomona Group. Map BF33, hereafter referred to as the Te Kuiti sheet, has some geological significance as it contains a reasonably large area of Te Kuiti Group strata. South of this map area this group of rocks occurs only in the subsurface. Other significant features of the map area are the extent of Mokau Group, particularly in eastern areas where it rests upon basement. Mokau Group is also mapped for the first time in Mangaokewa Valley, which is a location significantly farther east than in areas to the south of the map area such as Ohura where the group has great thickness and includes coal measures. The Te Kuiti sheet also includes the northernmost extent of Otunui Formation. Farther north this formation has been eroded. There is also extensive coverage of Quaternary ignimbrite in the map area, sourced from the Taupo Volcanic Zone (Mangakino Volcanic Centre). These ignimbrites units unconformably overlie Cenozoic formations, and in turn have themselves been significantly eroded in places.

King Country Basin, which has in the past also been titled the North Wanganui Basin, is located to the east of northern Taranaki Basin. The Cenozoic units in the Te Kuiti map sheet rest unconformably on basement of both the Murihuku and Waipapa terranes, and have low dips of a few degrees, mainly to the west but also north and southwest. King Country Basin lies north of the Wanganui Monocline where successive formations progressively onlap basement (Nelson & Kamp, 2013; Kamp et al., 2004). According to Kamp et al. (2004), the southern margin of King Country Basin has no obvious stratigraphic or structural divide to differentiate it from Wanganui Basin. It is explained that the base of Matemateaonga Formation can be utilized as a stratigraphic boundary between the two basins. King Country Basin lies west of the active Taupo Volcanic Zone and east of Taranaki Fault.

2.2 Stratigraphic Units

2.2.1 2.1 Basement Geology

The basement rocks underlying Cenozoic sequences in the field area are commonly referred to as "greywacke" and in this region have been assigned to the Murihiku Terrane and Waipapa Terrane, which are separated by the Waipa Fault. The broad area of interest of this thesis is shown in Fig. 2.1, which displays the Pre-Cenozoic basement rocks of New Zealand.

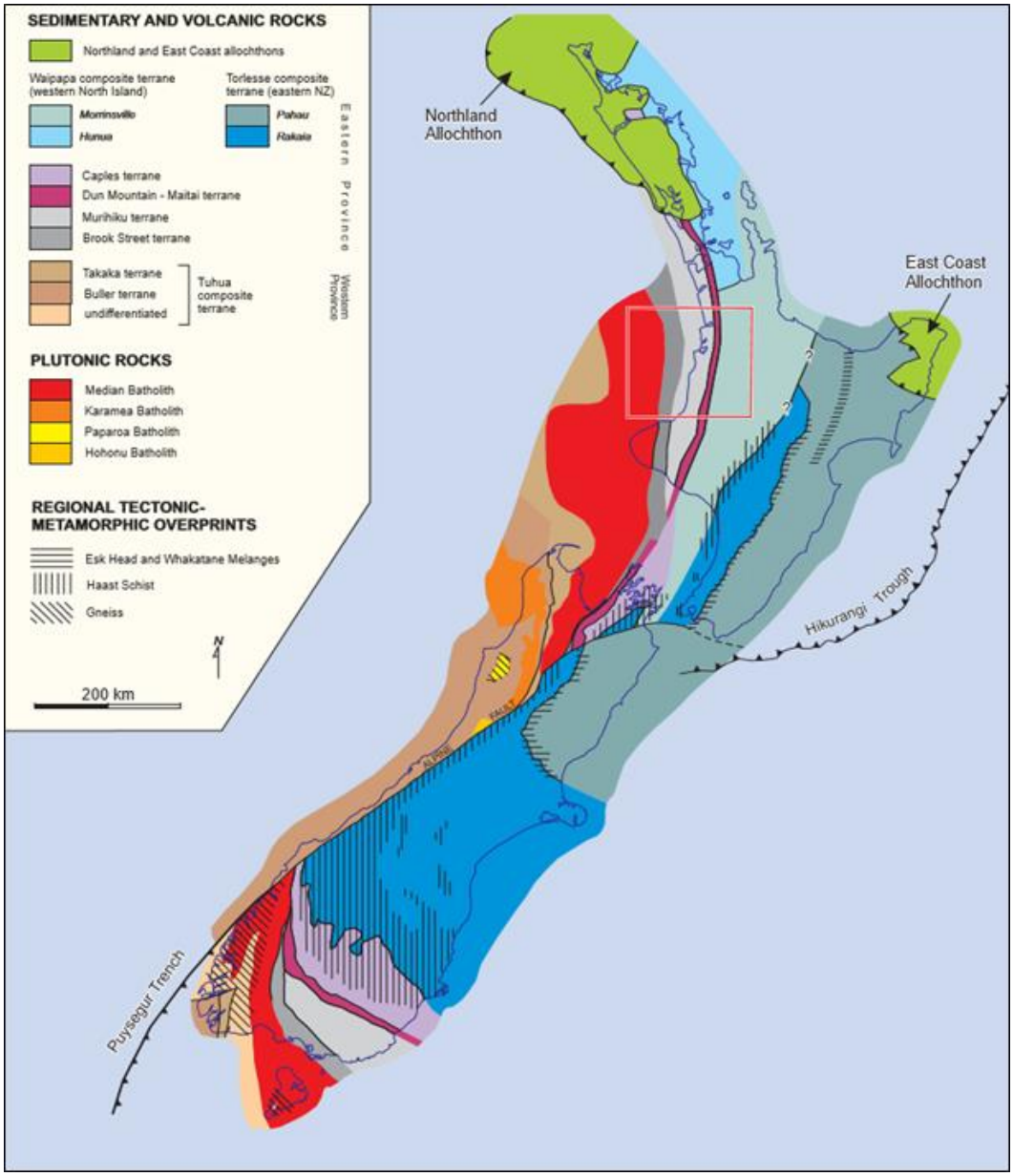


Fig. 2.1. Pre-Cenozoic basement rocks of New Zealand, subdivided into tectonostratigraphic terranes and batholiths (Edbrooke, 2005).

The Late Triassic to Late Jurassic Murihiku Terrane forms the main basement unit west of Waipa Fault (Fig. 2.1). Waipa Fault lies along the western part of the Te Kuiti map sheet. Murihiku Terrane comprises indurated sandstone, mudstone and conglomerate partly of volcaniclastic composition and variably fossiliferous. Edbrooke (2005), following earlier writers, infers Murihiku Terrane as representing a forearc basin succession.

The Jurassic Waipapa Terrane lies east of Waipa Fault and is composed of highly deformed volcaniclastic sandstone (Edbrooke 2005). Waipapa rocks in the King Country region belong to the Manaia Hill Group. Kear (1955) and Edbrooke (2005) describe Manaia Hill Group as dominated by well-indurated, massive or poorly bedded, volcaniclastic sandstone with some interbedded argillite. Edbrooke (2005) and Black (1994) also infer that during the Late Jurassic and through to the Early Cretaceous before the break up of Gondwana, Manaia Hill Group accumulated in an accretionary wedge as slope deposits.

A thin band of serpentinite is located between the Murihiku and Waipapa terranes along a short section of Waipa Fault near Piopio, immediately southwest of the southern boundary of the Te Kuiti map sheet. These rocks are regarded by many authors to be part of the Dun Mountain Ophiolite Belt (Kamp et al., 2008; Kear, 1971). Edbrooke (2005), following earlier authors, describes these ultramafic rocks as being of Early Permian age and associated with a linear positive magnetic anomaly known as the Junction Magnetic Anomaly. Because this anomaly lies along most of western North Island, it is inferred that Dun Mountain-Maitai Terrane rocks are present at depth, separating the Murihiku and Waipapa terranes along the whole of western North Island. (Fig. 2.1).

2.2.2 2.2 Cenozoic Stratigraphy

Nelson and Kamp (2013) note that outcrop patterns throughout the northern King Country Basin are characterised by west-east strike of formations. The stratigraphic units observed in this area are Late Eocene-Oligocene Te Kuiti Group, Early Miocene Mahoenui and Mokau groups, and middle-Late Miocene Whangamomona Group, which are all shown and represented in Fig. 2.2 and Fig. 2.3. As suggested in Fig. 2.3, these units are present in both Taranaki and King Country basins, which indicate a closely interrelated sedimentation history. These units have shallow to

negligible dip, which is locally influenced by the Herangi Range and by the orientation of faults (Nelson & Kamp, 2013).

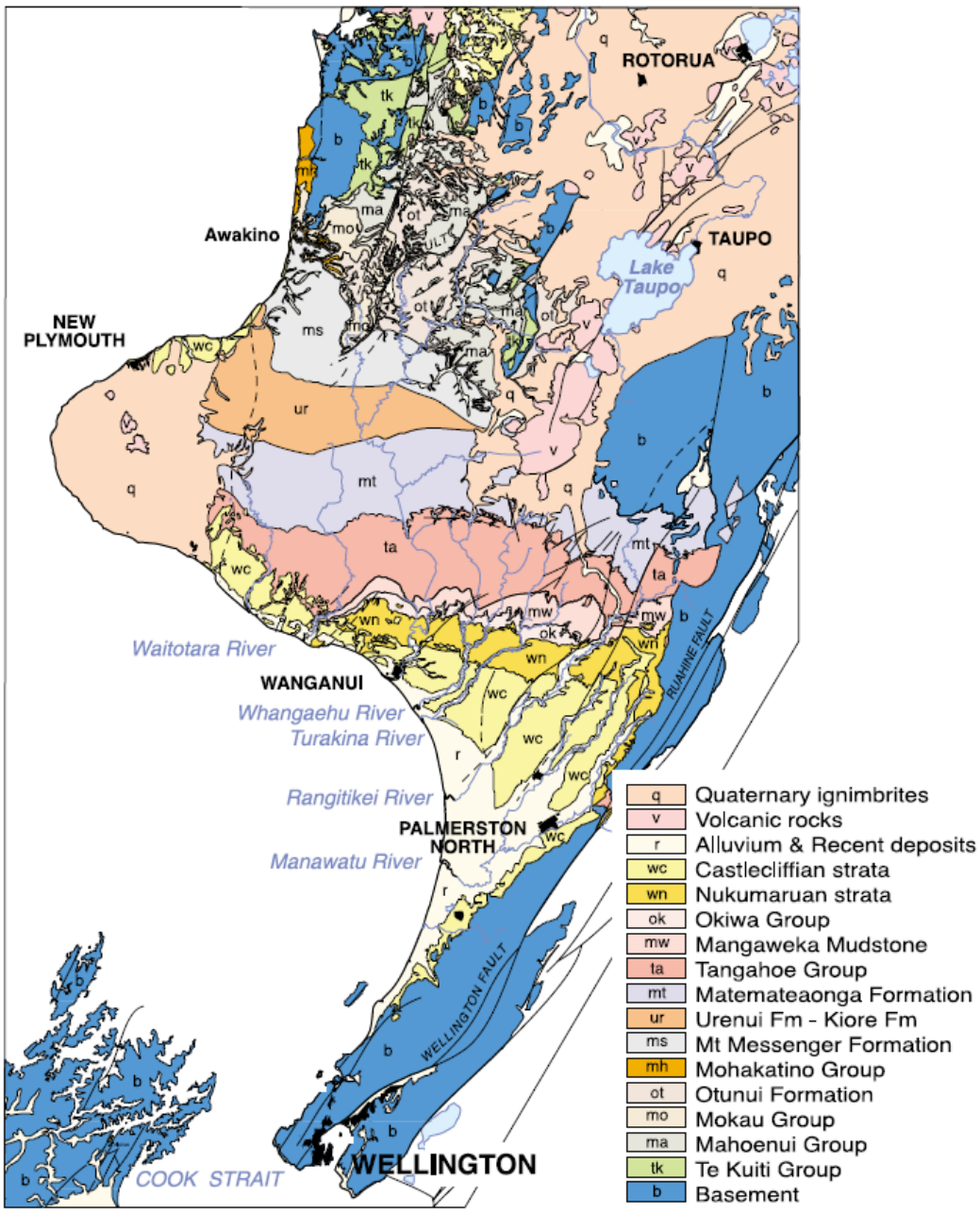


Fig. 2.2. Simplified geological map of the western North Island showing the main stratigraphic units in the eastern basins (Kamp et al., 2004).

Kear and Schofield (1959), Nelson (1978) and White and Waterhouse (1993) showed that Te Kuiti Group comprises a transgressive sequence of coal measures and shelf calcareous mudstone, sandstone and limestone. During the Late Eocene and Oligocene this sedimentary succession is estimated to have accumulated several hundred meters thick above basement (White & Waterhouse, 1993). The

group started accumulating during a time of continental extension that affected western parts of New Zealand.

Mahoenui Group consists of two formations in the field area, the Taumatamaire and Taumarunui Formations, which are Early Miocene (Otaian) in age. (Simms 1999) and Townsend et al. (2008) describes the Taumatamaire Formation as accumulating in mainly outer shelf to mid-bathyal settings and as being mostly a massive to weakly bedded, blue greyish, calcareous mudstone to fine sandy mudstone. Topping (1978) and Simms (1999) relate Taumarunui Formation, which is characterized by the occurrence of flysch, to the accumulation of classic turbidite deposits. The turbidites were probably sourced from the south from basement that was at the time exposed beneath what is now part of the Wanganui Basin area (Kamp et al., 2004).

Mokau Group is mainly exposed in King Country Basin west of Ohura Fault and consists of Bexley Sandstone, Maryville Coal Measures and Tangarakau Formation, which all accumulated during the Early Miocene (Altonian) (Vonk, 1999). In the Te Kuiti sheet area, Mokau Group is exposed across parts of the whole of the northern part of the region. The lowermost unit within this group west of Ohura Fault is a 60 m-thick transgressive shoreface sandstone unit known as Bexley Sandstone. Overlying Bexley Sandstone is the 120 m-thick Maryville Coal Measures, composed of coal measures, conglomerate and shoreface sandstone (Vonk, 1999). Vonk, (1999) and Kamp et al., (2004) highlighted that there is an unconformity between Taumatamaire Formation and Bexley Sandstone, This unconformity is well exposed east of Ohura Township in road cuttings of the Ohura-Tongaporutu Road, where a turbidite succession is overlain with a mild angular unconformity by Bexley Sandstone. This unconformity is also exposed immediately south of Te Kuiti on State Highway 34, where Taumatamaire Formation bathyal mudstone is overlain by a thin shell bed at the base of Bexley Sandstone. Over most areas in the Te Kuiti sheet, this unconformity is poorly exposed due to the contact being covered by modern slope deposits. An important point made by Kamp et al. (2004) is that Bexley Sandstone is not a regressive shelf facies of Mahoenui Group. Rather, it is a transgressive shoreface deposit at the base of Mokau Group that accumulated following inversion of the Mahoenui Basin and

erosion of a regressive shelfal succession that must have accumulated above the slope deposits during and after the basin inversion.

Whangamomona Group in the field area consists of Otunui Formation, which accumulated during the middle-Late Miocene and forms the lowermost unit of this group. Otunui Formation is a 100-200 m-thick sandstone to calcareous sandy siltstone, which comprises a variety of facies characteristic of an on lapping shoreline through shelf and upper slope succession (Cartwright, 2003). Kamp et al., (2004) also describe this formation as a massive to weakly bedded silty fine sandstone and sandy siltstone with shelly conglomerate channels.

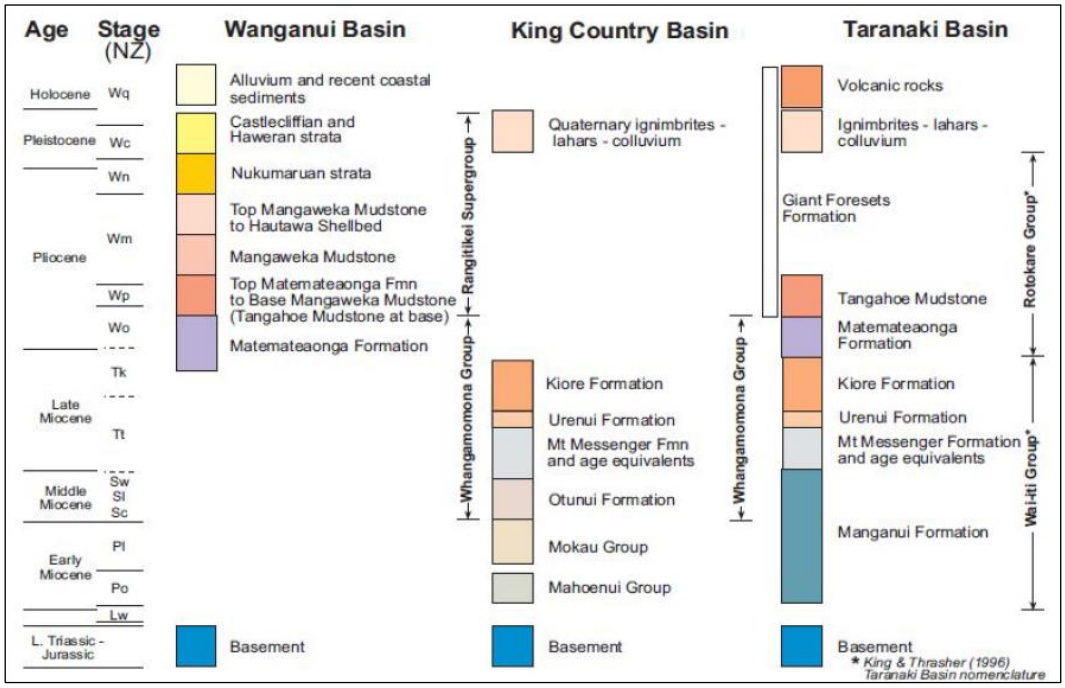


Fig. 2.3. Major Neogene stratigraphic units in each of Taranaki, King Country and Wanganui Basins and their ages (Kamp et al., 2004).

2.2.3 Quaternary Units

Edbrooke (2005) explains that pumice-rich pyroclastic flows from Taupo Volcanic Zone (TVZ) have deposited thick ignimbrites throughout the region. These Quaternary units extensively cover the underlying formations in the map area. The various ignimbrite units have been emplaced from density flows that infilled pre-existing and highly irregular pre-ignimbrite topography. The ignimbrite units belong to Pakaumanu Group and include the Mangaokewa, Ongatiti, Ngaroma and

Raepahu ignimbrites. Pakaumanu Group units were sourced from Mangakino Volcanic Centre (Early Pleistocene) within the Taupo Volcanic Zone. The eastern boundary of the basin and the field area consists of Quaternary ignimbrites (Pakaumanu Group) above basement. Alluvium has been deposited along river and stream valleys from deposition of weathered and reworked materials.

2.3 Structural Overview

The study area is currently located in a back-arc setting behind the Taupo Volcanic Zone as shown in Fig. 2.4, where oceanic Pacific Plate subducts beneath Australian Plate creating a convergent margin setting. Hansen and Kamp (2004) suggest that this area is influenced by a set of strongly developed NE-SW striking normal faults, which reflects the effects of extension in the back-arc zone. Townsend et al. (2008) describe that during the Oligocene, the tectonic origin of King Country Basin was potentially extensional and subsided in an epicontinental sea way, but these occurrences are still relatively uncertain. The Late Oligocene and Early Miocene formation of King Country Basin is associated with basement overthrusting on Taranaki and Manganui Faults and accentuation of the Patea-Tongaporutu-Herangi High (Stagpoole & Nicol, 2008). Stagpoole and Nicol, (2008) state that the Taranaki Fault is approximately 400 km long and is one the longest contractional structures within New Zealand. King and Thrasher (1996) suggest that Taranaki Fault is a reverse fault with an approximate throw of 6 km and that it has had a large effect on the sedimentary architecture of Taranaki Basin. Stagpoole and Nicol (2008) demonstrate that the northern end of the fault became progressively inactive between the Late Oligocene through to Early Pliocene. This fault marks the eastern boundary of Taranaki Basin and the western margin of the Murihiku Terrane. This basement block forms the Patea-Tongaporutu High in the subsurface, which helps define the boundary between the eastern Taranaki Basin margin and the King Country Basin (Stagpoole & Nicol, 2008).

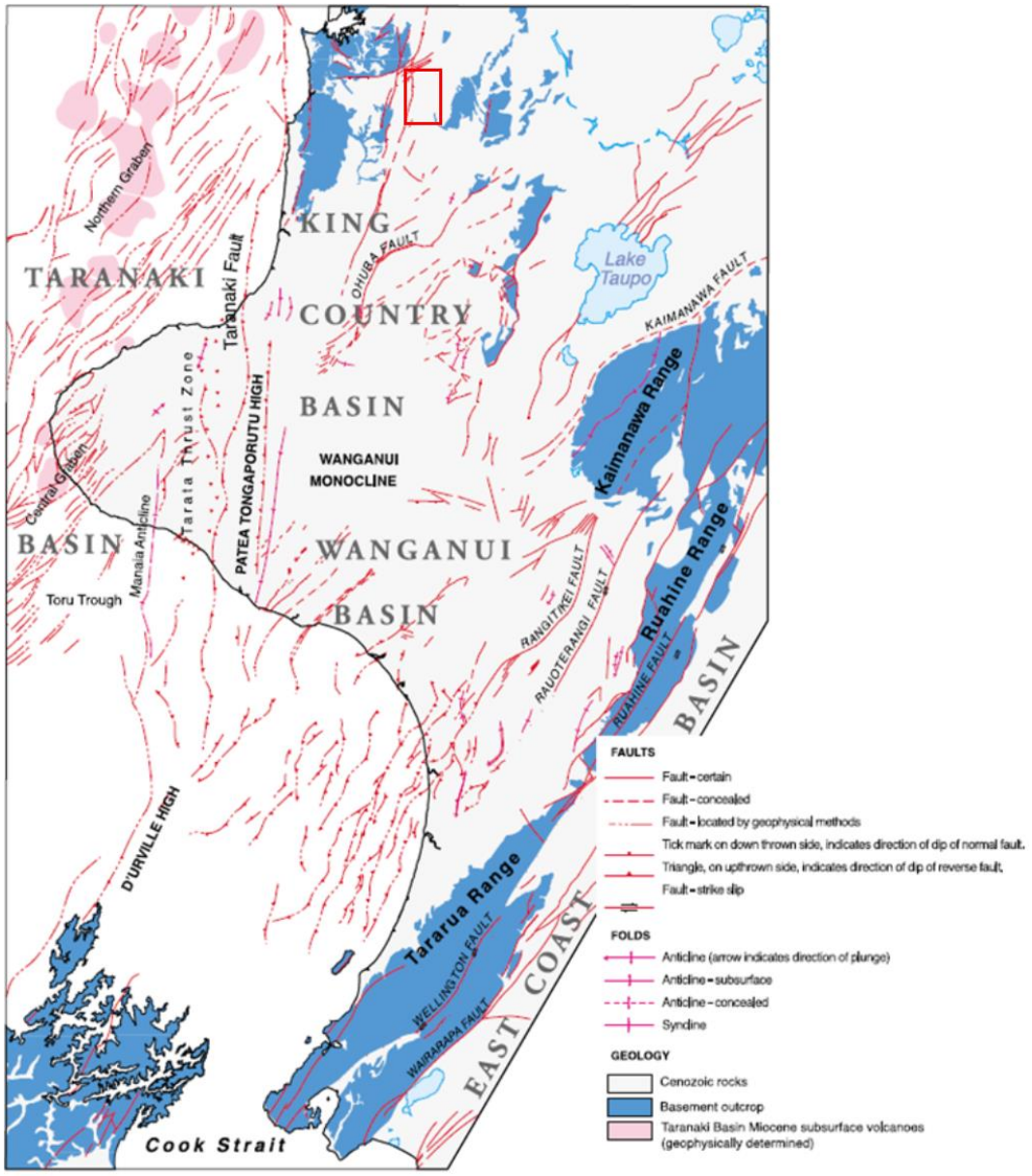


Fig. 2.4. Geological structure map of the western North Island showing the main structures and the distribution of basement. BF33 map area shown by red outline (Kamp et al., 2004).

Waipa Fault is a major fault in the northern part of King Country Basin and strikes NNW to NNE parallel to the underlying basement terranes (Edbrooke, 2005). The amount of Mesozoic offset on Waipa Fault as a terrane boundary is unknown. Late Miocene to Pleistocene offset on Waipa Fault is of the order of tens to hundreds of meters, which is probably linked to extension in its back-arc position (Nelson & Kamp, 2013).

Ohura Fault has a NE-SW orientation in the north and an N-S orientation south of Ohura. Kamp and Vonk (2006) describe Ohura Fault as having a vertical throw of

c. 400 m, having a large effect on sedimentation patterns and distribution of Neogene sedimentary units within the region (Kamp & Vonk, 2006).

2.4 Uplift of North Island in Late Cenozoic

Kamp et al. (2004) described how the outcrop pattern of Neogene formations in central-western North Island relates to Late Pliocene and Pleistocene up-doming of the central North Island area and the subsequent erosion of weakly lithified Neogene sediments. The magnitude and extent of this erosion is shown in Fig. 2.5. As a result of this uplift, progressively older formations are exposed to the north along central-western North Island. In the eastern parts of the Waikato and King Country regions, the Cenozoic succession has been almost completely removed by erosion, and exhumed basement is covered by mainly Quaternary ignimbrites derived from Taupo Volcanic Zone (Kamp et al., 2004). The uplift appears to be centered on the Taupo Volcanic Zone, possibly related to thermal upwelling and crustal extension. The extent of erosion differs systematically with increasing erosion northward from Wanganui Basin into King Country Basin and eastward from eastern Taranaki Basin into King Country Basin (Kamp et al., 2004).

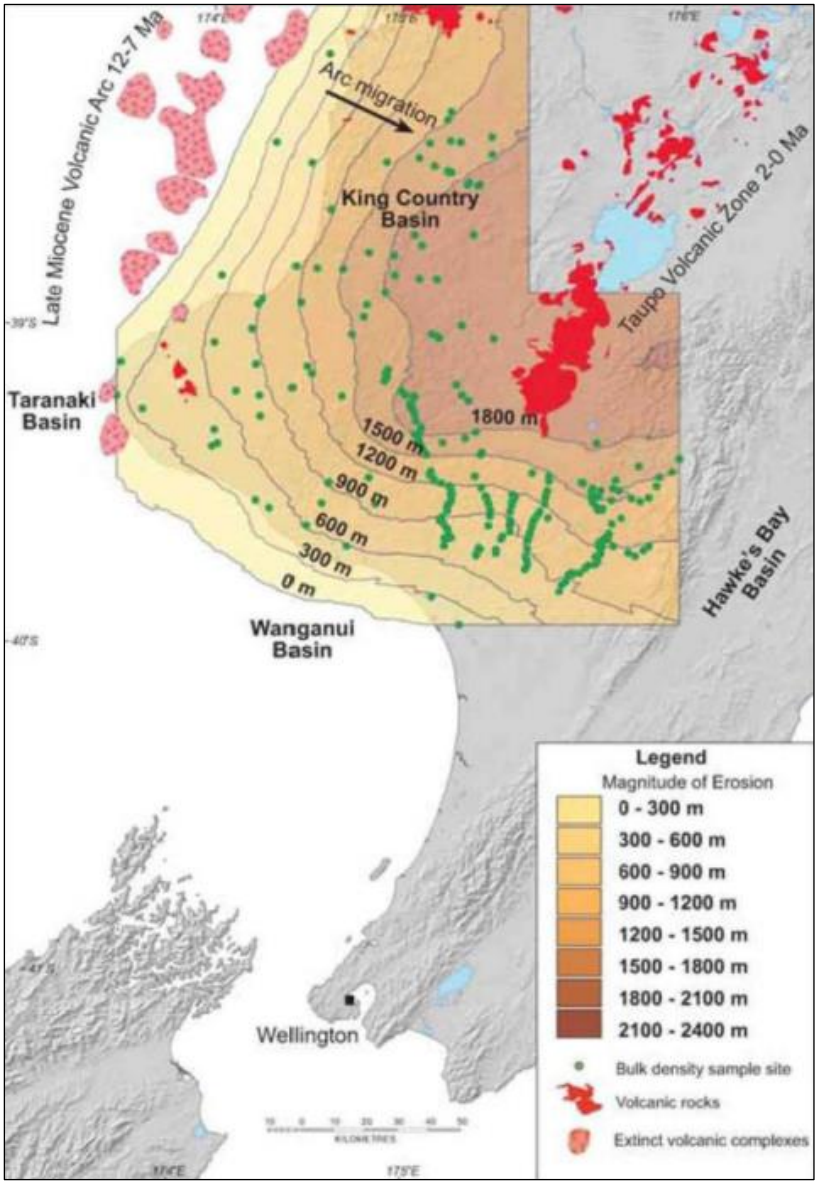


Fig. 2.5. Map of western North Island, showing magnitude in 300 m contours and pattern of Pliocene-Pleistocene erosion over central North Island derived from mudstone bulk density data (Kamp et al., 2004)

It has been suggested by Kamp et al. (2004) that the level of erosion was substantial and the main units that were eroded significantly in this region were Mokau Group and Mahoenui Group and the Middle Miocene through Pliocene stratigraphic units related to the Wanganui Monocline. It has also been inferred from bulk density analysis of exhumed mudstone beds that King Country Basin was a prolonged marine sedimentary depocentre and relates to its depositional continuity with the northern part of Wanganui Basin.

3 Methodology

3.1 Introduction

A wide variety of methods were implemented in order to produce a 1:50 000 geological map of the Te Kuiti area, which features as the main product of this thesis. A 1:50 000 GNS Science field sheet, amongst others, was developed as part of the production of the 1:250 000 Waikato QMAP geological map sheet (Edbrooke, 2005) and was available as a resource in this thesis study. However the thesis map is aligned with the new topographic map series (Topo 50) and covers map BF33. There is currently no geological map of this scale for the Te Kuiti area other than the GNS field sheet described above. Field mapping was undertaken over a 16 week period. The field work included collecting structural and stratigraphic information for formations and groups in the map area. Field data was digitised in a GIS application (ArcGIS) for which the University has a site license.

The purpose of this chapter is to outline the methods used to map the Cenozoic units within the field area and to produce the 1:50 000 scale geological map. The different rock units mapped were the ones that had previously been described, as summarized in Edbrooke (2005). Some units in the field area were mapped as undifferentiated.

3.2 Geological Map & Mapping Procedure

3.2.1 Field area

The field area is located within the King Country region of central-western North Island (New Zealand), covering an area of 890 km^2 (Fig. 3.1). The southern part of the map area forms a seamless border with Liu (2016). The northern boundary lies approximately 15 km north of Te Kuiti and 4 km south of Otorohanga. The eastern boundary is marked by the Rangitoto Range and extensive volcanic high-ground. The northwestern boundary of the map area is approximately 5 km west of Waitomo and approximately 5 km east of Piopio in the south. The southern boundary is located 35 km north of Taumarunui and 25 km south of Te Kuiti. The field area includes two settlements being Waitomo in the north and Te Kuiti in the center of the map sheet. There are many other small settlements throughout the region such as Rangitoto and Mapiu. The main use of land in the field area is dairy and drystock farming, and forestry, with dairy being predominant in the northern region where

the country is less steep. Drystock farming and forestry are more common on the steeper land in the south.

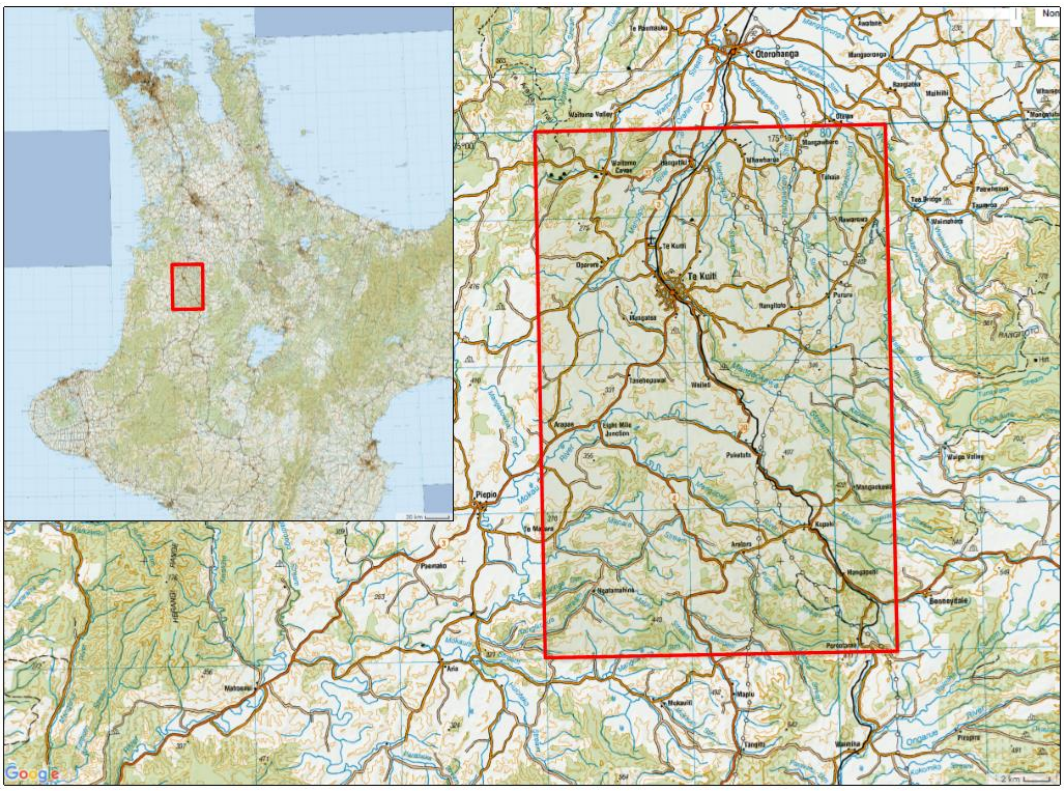


Fig. 3.1. Location of Te Kuiti Sheet BF33, Topo 50 map area in the King Country region, North Island, New Zealand (Modified from LINZ data service & Google Maps).

3.2.2 Topography of the area

The field area consists of wide valleys, which extend south of Te Kuiti. The region includes many valley systems formed by the Mangapu River, lower reaches of the Waipa River and the Mangaokewa Stream, and their tributaries. The northern zone of the field area is dominated by rolling hills formed on Early Quaternary, volcaniclastic-rich alluvium with higher hills formed on basement greywacke and wide valley systems separating them. In the southern region of the field area, narrower valleys are separated by steeper hills and ridges formed on Tertiary units, which are commonly overlain by welded ignimbrites. Karst landscapes are common in the Waitomo area, which are characterised by sinkholes, disappearing streams, caves and fluted rock outcrops. These features relate to the limestone units present within Te Kuiti Group and are produced by chemical solution of the limestone by natural waters.

3.2.3 ArcGIS database and base map

The map production was undertaken in the computer program ArcGIS which is a computer system designed to manipulate and display geographically referenced information for interpretation and presentation purposes. The digital production of the map enables future modifications of the database to be made and also allows for more modern mapping techniques to be utilised, including structure contouring and aerial photography. The ArcGIS database also provided the attributes required to produce a base map with contours, road maps, stream and river locations and other cultural features. These base maps provided a starting point on which geological and structural observations could be plotted. The maps with topography, streams and cultural features were obtained from the Land Information New Zealand (LINZ) data service, which supply the most up to date 1:50 000 topographic maps available for New Zealand.

Prior to the start of field mapping, the GNS 1: 50 000 field sheets (NZMS S16 & S17) covering BF33 were scanned, georeferenced and digitized into a GIS format. GIS files were generated and saved using the projected coordinate system in the New Zealand National Grid known as Transverse Mercator (see Appendix II).

3.2.4 Field methods

A few days were initially spent determining the various formations present within the field area, the general lithology of these units and their structural orientation. The majority of the field work was centered on the roads throughout the area as they provided the main access points to outcrops and into valleys. The main roads that were utilized included State Highways 3, 4, 30 and 37. Rivers and streams in these valleys were also key outcrop locations as they provided rock exposures.

Field mapping involved mapping the contact between units onto field sheets. This included taking GPS coordinates and elevation readings for specific well exposed contacts and subsequently importing this information into the GIS database. Where possible, strike and dip data were also measured, although the low dip of units made this difficult and regional dip was often established from the elevation and distribution of unit boundaries within the Tertiary succession.

Unit boundaries could also be mapped from the different geomorphology of Tertiary units. This is termed “feature mapping” by Lisle et al (2011) and allows boundary mapping to be achieved without direct exposure of the boundary contact. Tertiary units throughout the field clearly display a relationship between landscape features and the underlying geology.

Examples of geomorphological indicators in the field were the undulating hills of Mahoenui Group, which were prone to slips. Steeper slopes and the occurrence of bluffs are associated with Otunui Formation. Rough steep topography with some bluffs is associated with Mokau Group. Cliff outcrops and karst landscapes are linked to Te Kuiti Group. Cliff faces with fallen boulders are an indicator of Quaternary ignimbrite units. Examples for some of these geomorphologies evident in the northern region of the map area are illustrated in Fig. 3.2. These geomorphological features were key in mapping the area but due to the change in lithology and facies in some units throughout the region these factors had to be taken into careful consideration.

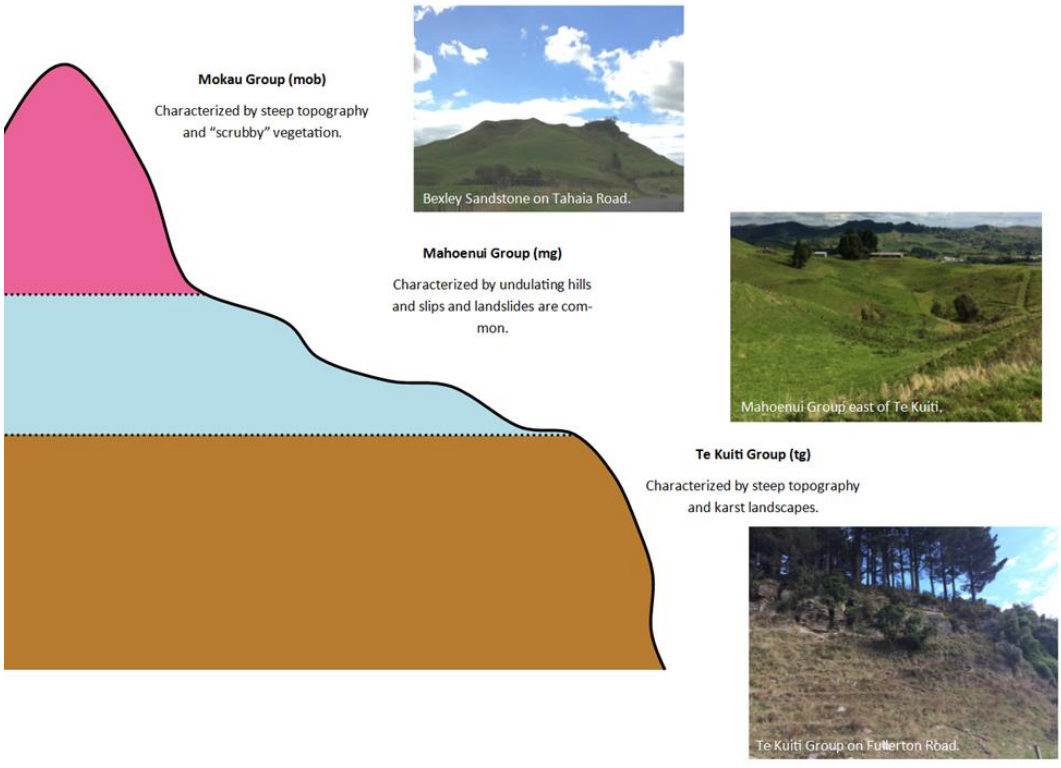


Fig. 3.2. Geomorphology of some of the Tertiary stratigraphic groups present in the northern region of the field area.

Special attention needed to be taken when mapping these unit boundaries due to the presence of faults throughout the field area. This was observed through drastic or sudden changes in lithology and/or repetition of units. The occurrence of fault offset of units in the field area can be rather easily identified, but the specifics relating to amount of fault offset and fault dip were often difficult to determine where units were partially eroded. Hence there is some uncertainty in the precise location and details around the faults as mapped in Enclosure 1, and this data should not be used for any purpose without further work being undertaken.

3.2.5 Aerial Photography

For areas that were inaccessible or unexposed, aerial photography became extremely useful. To produce the best results the most up-to-date and high definition aerial photography was used. This aerial imagery data was also accessed through the ArcGIS database, Waikato Regional Council and Land Information New Zealand (LINZ). Aerial imagery enables a different perspective of geomorphology to be established. Fig. 3.3 shows the effectiveness of aerial imagery in the field area to decipher the boundary between Mahoenui Group and Mokau Group. The boundary can be easily identified through the distinctive properties of each unit, with Mahoenui Group displaying slump geomorphology and Mokau Group displaying bluff and cliff face geomorphology.

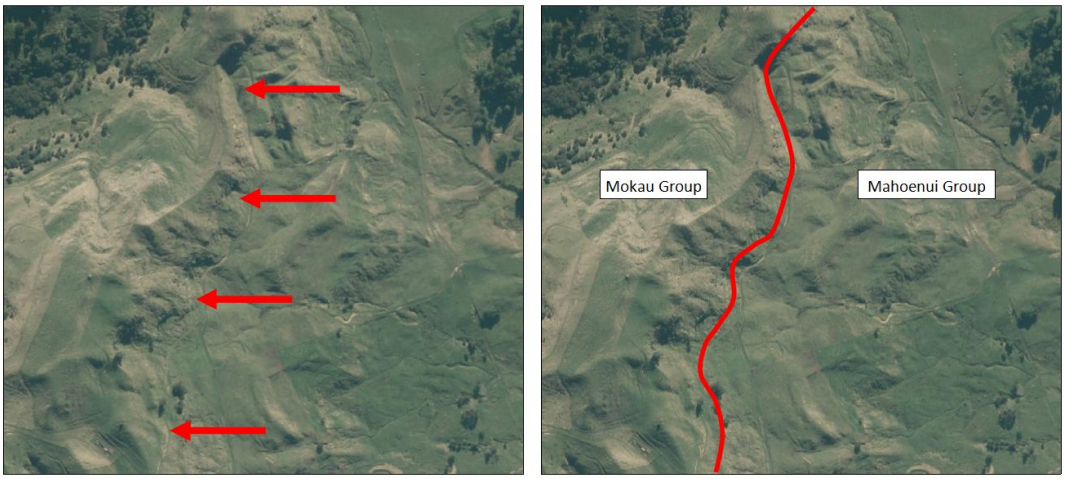


Fig. 3.3. Aerial photography utilized to identify the contact between Mahoenui Group and Mokau Group. The red arrows show the location of the base of bluffs of the Mokau Group (Bexley Formation) (N 5749500 E 1790500).

3.2.6 Methods of geological mapping using GIS

The computer software ArcGIS enables structure contouring of specific unit boundaries to be easily completed under certain circumstances. Fig. 3.4 (from Lisle et al., 2011) gives an example of how this technique can be applied to a regional strike and dip.

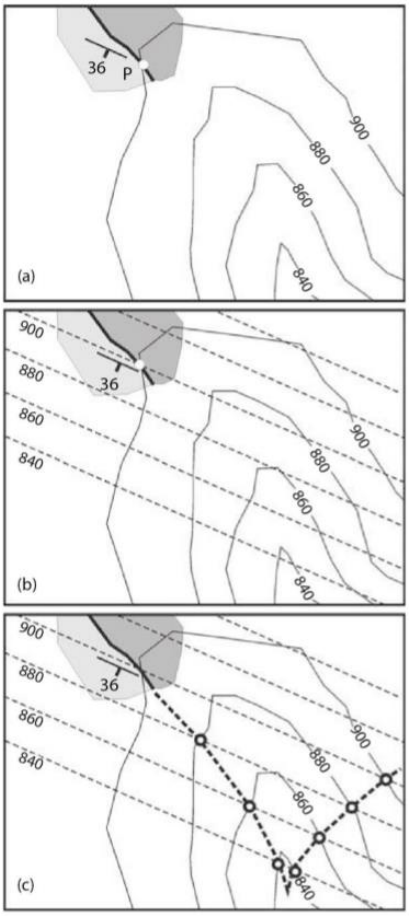


Fig. 3.4. Steps for structure contouring (from Lisle et al., 2011). a) Closest exposure of unit used as starting point. b) Strike and dip information from this exposure used to produce strike lines. c) Geological boundary is constructed using the crossing of strike lines correlating with contours.

The use of structure contours to map a contact relies on knowledge about the strike and dip of two superimposed units and the correct placement of strike lines. Each strike line has an associated elevation and can therefore be referred to as a structure contour. The predicted geological boundary is then inferred to be located at the intersection of the calculated strike line or structure contour and the topographic contours with the same elevation. The following equation was used to calculate the strike line distance or spacing between the strike lines on the map.

Equation:

$$Horizontal\ distance\ between\ strikelines = \text{Vertical height / tan (angle of dip)}$$

The horizontal distance/spacing between strike lines can be measured using the scale on the base map (1:50 000) and the vertical height refers to the elevation change between contours (in this case 20 m). As stated above, the dip can be taken from the nearest exposure or a regional dip can be used. By utilizing this modern mapping method the geological boundary can be predicted across unexposed or inaccessible ground by assuming that the strike and dip of the formation is constant throughout the field area and is not disrupted by other structural effects such as faults. The application of this method worked well for the field area because the Tertiary succession is essentially conformable; that is, the strike and dip of Te Kuiti Group, Mahoenui Group, Mokau Group, and Otunui Formation are the same, even though some of the boundaries are unconformable (with little relief on those contacts). This occurs because of the deformation giving rise to the dip of the beds post-dates accumulation of Otunui Formation and is of Pliocene and Pleistocene age. It was not possible using the methodology described above to structure contour the boundary between the Tertiary units and the Quaternary ignimbrites. This is because there was substantial erosion of the Tertiary succession prior to emplacement of the ignimbrites, giving rise to substantial topography on this contact, and the ignimbrites were not deposited horizontally. They in-filled pre-existing topography and overflowed ridges in places. Hence the base of the ignimbrite unit was mapped traditionally by field traverses across the map area. It is also important to note here that the geological map (Enclosure 1) does not show any differentiation of specific eruptives as this is beyond the scope of this study. While the mapping of particular units is possible and has been undertaken within the Te Kuiti map sheet by others (Edbrooke, 2005; Brink, 2012), mapping of individual units across the whole area of the undifferentiated map unit shown here would be frustrated by the lack of outcrop over significant areas.

4 Te Kuiti BF33 Geological Map, Stratigraphy and Structure

4.1 Introduction

The purpose of this chapter is to describe the different stratigraphic units mapped throughout the field area. The focus is on distribution, thickness and lithology of the different units occurring in the map area. Lateral unit and facies distributions have been illustrated in the stratigraphic columns (Appendix I) and there locations within the field area are shown in Fig. 4.1. The formal stratigraphy has been modified through time. Te Kuiti Group stratigraphy was essentially developed by Kear and Schofield (1959) and subsequently modified by Nelson (1978). Kamp et al. (2008) usefully rationationalised and unified Te Kuiti Group stratigraphy between Port Waikato and Awakino throughout the whole outcrop belt. Mahoenui Group stratigraphy was established by Nelson and Hume (1977) and later modified by Simms (1999). Mokau Group stratigraphy was established by Henderson and Ongley (1923) and later revised by Vonk (1999), using the results of Coal Resources Surveys undertaken during the late 1970s and early 1980s by Doug Phelps. The name Otunui Formation was established by Kamp et al (2004) for Middle Miocene beds in the King Country region and supplanted the name Mohakatino Group of Hay (1968, 1: 250 000 map). Mohakatino Formation is still recognized and attributed to volcaniclastic beds in the Mohakatino Valley, at Mokau River mouth, Awakino River mouth and in exposures along and inland of the coast north of Awakino River (Nodder et al., 1990). Otunui Formation is now recognized as a unit of Whangamomona Group. The naming of ignimbrite units follows usage in Edbrooke (2005).

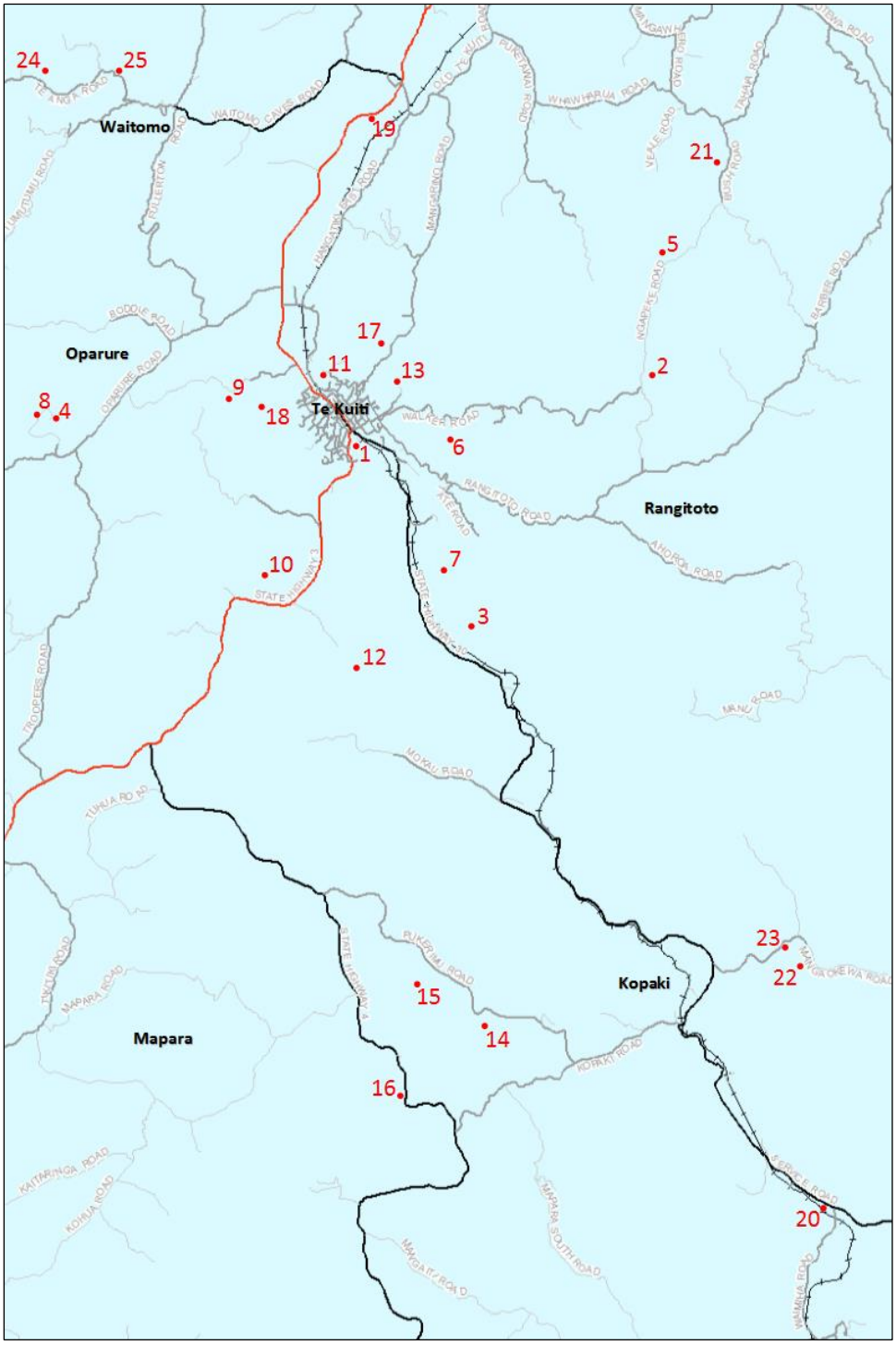


Fig. 4.1. Te Kuiti BF33 map area showing locations of stratigraphic columns by their associated column number as recorded in Appendix I.

4.2 Basement Geology

Basement rocks underlying Cenozoic sedimentary sequences in New Zealand are commonly known as “greywacke” and in the field area have been attributed to Waipapa and Murihiku terranes, which are separated by the Waipa Fault. Along the fault boundary, a section of serpentinite outcrops in a small area southwest of the Te Kuiti map sheet and has been associated with the Dun Mountain-Maitai Terrane. These basement geologic units are described here.

Waipapa Composite Terrane

The basement unit cropping out in the field area is Waipapa Composite Terrane, more specifically the Manaia Hill Group (Edbrooke, 2005). The Manaia Hill Group is considered to be Late Jurassic to Early Cretaceous in age and crops out extensively in the northeastern part of the field area and farther east, forming the Rangitoto Range (Fig. 4.2). It extends west to the Waipa Fault. Murihiku Terrane lies west of Waipa Fault but it is not exposed in the Te Kuiti map sheet. Manaia Hill Group extends well to the north of the map area, north of Auckland and as far south as Wellington. This basement unit has been brought to the surface by uplift and erosion during two deformation periods, one during the Early Miocene following accumulation of Mahoenui Group and during the Late Pliocene and Pleistocene. Manaia Hill Group can be easily accessed and observed along the eastern side of Ngapeke Road and it extensively crops out along the extent of Rangitoto Road.



Fig. 4.2. Manaia Hill Group of the Waipapa Composite Terrane outcrop exposed at a road cutting along Otewa Road in the eastern region of the field area (N 5763700 E 1803700).

This unit can be described as a well-indurated, massive to weakly bedded volcaniclastic sandstone, with interbedded or fault bounded siltstone/argillite and minor conglomerate. Where Manaia Hill Group is present in the field area, it is commonly unconformably overlain by Te Kuiti Group, Mahoenui Group or Mokau Group (e.g. Column 21, Appendix I).

Murihiku Terrane

Murihiku Terrane is mainly of Middle Triassic to Middle Jurassic age in the South Island (Southland Syncline) where it crops out and of Late Triassic to Late Jurassic age in Kawhia Syncline in central-western North Island. This sedimentary succession is arc-derived and considered to have accumulated in a forearc basin (Briggs et al. 2004). Murihiku Terrane forms basement in the Te Kuiti map sheet west of Waipa Fault. It comprises fossiliferous sandstone and mudstone predominantly with distinctive conglomerate units as well (Kamp et al., 2008). This unit unconformably underlies Te Kuiti Group.

Dun Mountain-Maitai Terrane

The Dun Mountain-Maitai Terrane is Early Permian in age. The Dun Mountain belt in South Island and at Piopio comprises an ultramafic assemblage of rocks associated with a linear positive magnetic anomaly known as the Junction Magnetic

Anomaly. At Piopio there is a mined occurrence of serpinitinite considered to be a diapiric and altered component of the Dun Mountain belt lying within the Waipa Fault zone. This outcrop is known as Wairere Serpentinite Group and is the only division of the Dun Mountain-Maitai Terrane and consists of dark blue and green lenses of massive sheared serpentinite with a xenolith abundance relating to metasomatised gabbro (Edbrooke 2005). Because of this outcrop and the associated areo-magnetic anomaly, the Dun Mountain-Maitai Terrane is considered to be present at depth, perhaps excised by the Waipa Fault (Kear, 1993).

4.3 Te Kuiti Group

Te Kuiti Group is of Oligocene age and is exposed extensively throughout the field area, especially east of Waipa Fault, but also around Te Kuiti Township and immediately to the east of it (Fig. 4.3).

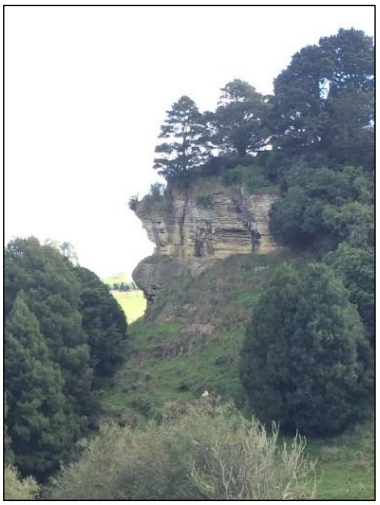


Fig. 4.3. Te Kuiti Group cropping out along Walker Road, east of Te Kuiti (N 5755200 E 1794100).

Te Kuiti Group is predominately comprised of a transgressive sequence of basal coal measures overlain by marginal marine to outer shelf limestone, calcareous sandstone and calcareous mudstone (Nelson, 1978; Edbrooke, 2005). These units have also been identified and illustrated in stratigraphic columns that have been produced and modified from Kamp et al. (2008) (see Appendix I). Te Kuiti Group accumulated during a time of slow regional subsidence and inundation of pre-existing topography. An increase in the rate of subsidence and introduction of copious amounts of mudstone led to the development of a drowning sharply gradational contact with overlying Mahoenui Group (Kamp et al., 2004).

Te Kuiti Group can be subdivided into two subgroups known as Okoko Subgroup and Castle Craig Subgroup. Within the field area, more specifically the Waitomo region, Nelson (1978) established that the average calcium carbonate content of the Okoko Subgroup is 48% and for the Castle Craig Subgroup is 65-98%. Okoko Subgroup is represented in the field area by three formations, including Waikato Coal Measures, Whaingaroa Formation and Aotea Formation. Castle Craig Subgroup is represented in the field area by two formations, which are the Orahiri Formation and Otorohanga Limestone.

4.3.1 Okoko Subgroup

Waikato Coal Measures

The term Waikato Coal Measures is used to describe the Late Eocene to Oligocene coal measures, which form the lowest stratigraphic unit within Te Kuiti Group. It is widely distributed throughout King Country Basin and unconformably overlies Mesozoic basement, either having onlapped or been preserved in faulted depressions (Nelson, 1978). Within the field area, it is generally very thin or absent and displays a very discontinuous placement within basement depressions. A thin section has been identified in a road cutting along Ngapeke Road (Fig. 4.4) and it is displayed in column 5 of the stratigraphic columns (see Appendix I). It is dominated by fine grain sizes such as massive mudstone and less common sandstone, coal and conglomerate beds. Horizontal bedding is common with occasional low-angle cross bedding within sandstone beds. Nelson and Hume (1987) established that clay content in the coal measures is predominantly crystalline kaolinite (80-85%) with illite (<10%) and chlorite (<5%).

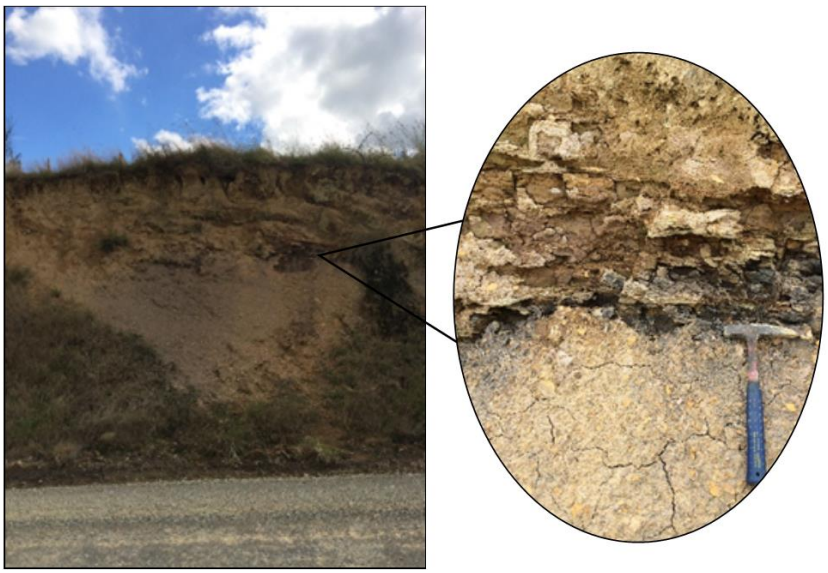


Fig. 4.4. Waikato Coal Measures of the Te Kuiti Group, outcropping in a road cutting along Ngapeke Road, northeast of Te Kuiti (N 5760200 E 1798100).

Waikato Coal Measures were deposited in paleovalleys and faulted sub basins. The lithofacies associations are related in the southern and central regions to terrestrial sub-basins that opened eastward into a coastal plain, which is indicated by an increase in the degree of marine influence. The northern region had less marine influence and sediment accumulation is related to swamp and overbank deposition on an alluvial flood plain. Edbrooke et al. (1994) suggests that the depocentres were separated by linear ridges, bounded by buried fault scarps with steep dips.

Whaingaroa Formation

Whaingaroa Formation is of upper Whaingaroan age. Tripathi's (2008) review supported this correlation as *Rotaliatina sulcigera* and *Notorotalia stachei* were located in samples of Whaingaroa Formation from Raglan Harbour, suggesting an upper Whaingaroan age. In areas outside the Te Kuiti (BF33) map area where Glen Massey Formation is evident, it can be difficult to lithologically differentiate the Whaingaroa Formation from siltstone facies in underlying Glen Massey Formation. In some cases, depending on locality, Whaingaroa Formation can be described as or included in Glen Massey Formation, but it can be distinguished as it is of lower Whaingaroan age. Kear and Schofield (1978) demonstrated that the thickest sections of this formation occur in regions north of the field area in former main coal measure depocentres, having a total thickness of approximately 250 m. This contrasts with the limited observations of Whaingaroa Formation in the field area

where it is distributed sporadically and is either very thin or absent. This was evident in field observations as this unit was only identified in one outcrop displayed in stratigraphic column 5 (see Appendix I), being only approximately 25 m-thick through this section. The Te Kuiti area was more predominantly a site of sand and muddy sand deposition during upper Whaingaroan times and are referred to as Aotea Formation (Nelson, 1978). Whaingaroa Formation is lithologically a siltstone in the field area with thin limestone at its base and sandstone present in the south. Whaingaroa Formation in the Te Kuiti (BF33) map area is a massive, variably sandy siltstone unit.

Waterhouse and White (1994) inferred that Whaingaroa Formation was likely deposited at mid to outer shelf or upper bathyal depths, which is supported by the large numbers of planktic foraminifera (*Globigerina euapertura* and *G. labiacrassata*) present.

Aotea Formation

The Aotea Formation is dominated by a bioturbated muddy sandstone with interbedded siltstone facies (Kihi Sandstone Member) and some localised development of basal carbonate facies (Waimai Limestone Member) in the field area. The limestone member is more evident directly north of the field area becoming most dominant along Waitomo Valley Road and farther north into the Honikiwi region, where it is inferred to progressively onlap basement highs to the east. Foraminiferal content suggest that it ranges in age from upper Whaingaroan to Duntroonian (Kear & Schofield, 1959; Waterhouse & White, 1994).

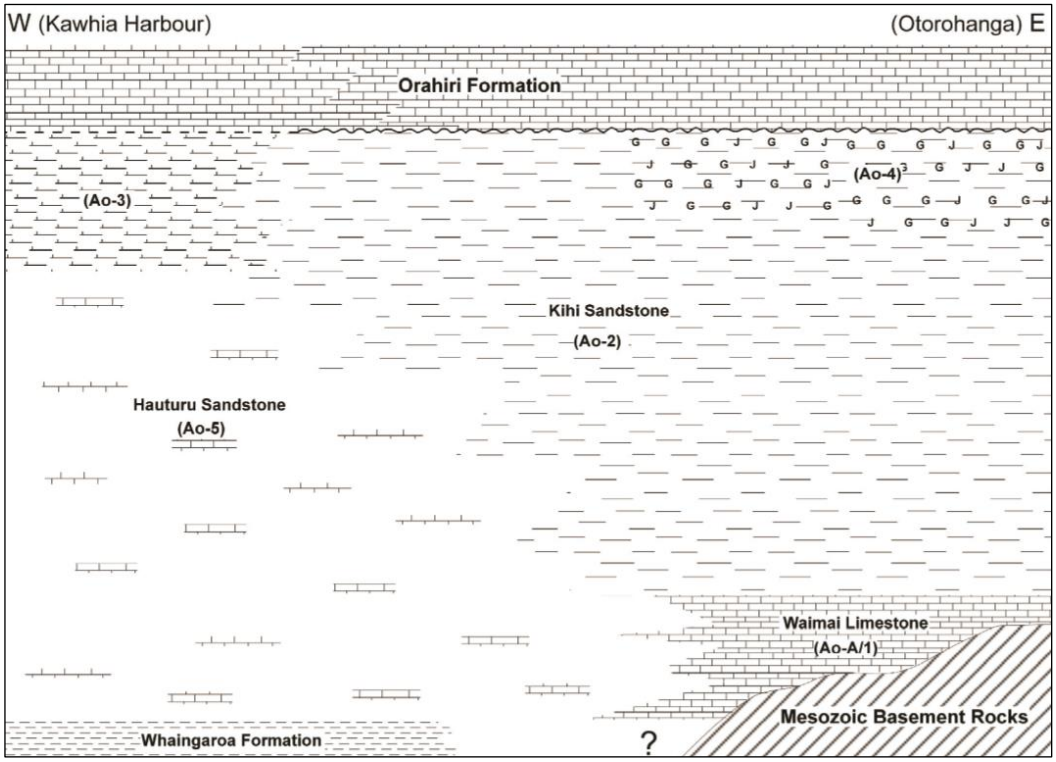


Fig. 4.5. Schematic cross section from Kawhia (west of the field area) to Otorohanga (northeast of the field area) demonstrating the relationship between members in Aotea Formation and also between other formations (Tripathi, 2008).

Hauturu Sandstone Member, which is present west of the field area, is linked to the Kihi Sandstone Member in terms of depositional environments (Fig. 4.5). The pattern in this relationship suggests that the sandstone is sourced from the south, accumulating as a shore-connected wedge along the eastern side of Herangi High, forming a ridge structure. Kihi Sandstone Member accumulated farther east in deeper parts of the continental shelf environment, which is supported by the occurrence of mudstone and siltstone interbeds. Waimai Limestone Member accumulated in a high-energy shallow marine environment and is also shown on Fig. 4.5. It was deposited during a time of developing shelf to upper bathyal water depths, which led to the transgressive onlap of the limestone formation.

4.3.2 Castle Craig Subgroup

Orahiri Formation

Orahiri Formation is the lowermost formation of Castle Craig Subgroup and is inferred to be of Duntroonian aged based on the occurrence of the oyster *Flemingostrea wollastoni* in its upper sections. Within the field area, Orahiri

Formation includes two members, which are Waitomo Sandstone and Orahiri Limestone. Orahiri Limestone has been subdivided by Nelson (1978) into two members. Mangaotaki Limestone Member (OrA) was assigned to the lower limestone unit, often being impure due to appreciable terrigenous sandstone content and is illustrated in stratigraphic column number 7 (see Appendix I) south of Te Kuiti, along Mangaokewa Stream. The upper unit, named Te Anga Limestone Member (OrB), is a more pure limestone including common large oyster beds which is illustrated in stratigraphic columns 6 and 7 (see Appendix I) located east of Te Kuiti, along Walker Road and south of Te Kuiti, along Mangaokewa Stream. The Mangaotaki Limestone is a massive sandy limestone unit with a terrigenous sandstone component. Outcrops in the field area illustrate poor flag development with incipient sandstone seams. Te Anga Limestone Member can be identified in the field by its distinctive oyster shells averaging 15 cm diameter, which show varying trends of discontinuous scattered and continuous clusters and in some sections form entire beds. The Te Anga region and the area west of the field area show the most developed oyster beds being up to 6 m-thick. Morgans et al. (2004) considered the oysters to be *Flemingostrea wollastoni* with large bivalve shell hash and pebbles present. The oyster beds have been described by Nelson et al. (1983) to have a high carbonate mud content which is likely to originate from shell borers. These lithofacies form the basis of the subdivision into a (lower) Mangaotaki Limestone Member and a (upper) Te Anga Limestone Member (Nelson, 1978). Tripathi (2008) suggests that in the east of the field area Orahiri Formation onlaps basement, whereas in central regions around Te Kuiti, a 15-20 m-thick sandy limestone unit has been linked to Orahiri Formation, as discovered in coal exploration drill holes.

In the field area, Orahiri Formation overlies Aotea Formation and is marked by a sharp erosion surface and consequently a landward shift in lithofacies. It also overlies Whaingaroa Formation in the northeast where Aotea Formation was eroded. To the southeast of Te Kuiti, Orahiri Formation commonly onlaps basement, and can be present as a basal gritty to pebbly limestone with abundant shell material. Orahiri Formation also includes subangular greywacke pebbles and grit in some sections. The upper boundary of Orahiri Formation is a gradational contact between Waitomo Sandstone Member and Otorohanga Limestone.

Waitomo Sandstone has been used in the Waitomo region to separate Orahiri Formation and Otorohanga Limestone. In areas farther west where Waitomo Sandstone Member is absent, the shell rich top of Orahiri Limestone has been used to identify the contact.

In the field area, Waitomo Sandstone Member is described as a 15 m-thick unit of massive fine sandstone, particularly evident in the Waitomo region. This member is characteristically massive in appearance due to bioturbation and because of its moderate (18-40%) calcium carbonate and mudstone content this sandstone is usually poorly consolidated. In exposures close to Te Kuiti the sandstone is variably calcareous, glauconitic and often highly fossiliferous, as illustrated in stratigraphic column 6 (see Appendix I). In this region it commonly grades laterally into Orahiri Limestone units or it thins out, ultimately portraying a disconformity between Orahiri Formation and Otorohanga Limestone (Nelson, 1978). Within the field area it can commonly be observed as a smooth sloping topographical surface between upper and lower limestone bluffs.

Otorohanga Limestone

Otorohanga Limestone represents the uppermost unit of Te Kuiti Group and is Waitakian in age. The presence of *Athlopecten athleta* and the planktic foraminifera *Globoquadrina dehiscens* indicates accumulation during the Waitakian Stage (Nelson, 1978). Within the field area, this formation has been subdivided by Nelson (1978) into three members from distinctive weathering patterns. These members include a lower flaggy limestone facies named Pakeho Limestone Member (OtA); a knobbly limestone named Waitanguru Limestone Member (OtB); and an upper flaggy limestone named Piopio Limestone Member (OtC). The Te Kuiti and Waitomo regions have the thickest development of Otorohanga Limestone Formation, where it is up to 80 m-thick. It commonly forms cliffs and karst topography throughout the field area.

Otorohanga Limestone appears in the field area as a light grey to white, flaggy to knobbly, pure limestone with a low terrigenous content, but in areas east of Te Kuiti where it onlaps basement, a lag deposit is present containing glauconitised granule or conglomerate beds and large bivalve shell fragments at its base. Pakeho Limestone Member (OtA) is the most widely occurring member and consists of

well developed flaggy limestone which is well exposed at the Mcdonald's Lime quarry along Oparure Road (Column 4, Appendix I). Waitanguru Limestone Member (OtB) has a high calcium carbonate (98%) and can be identified by its distinctive pure whiteness and its blocky and knobbly weathering appearance as indicated in Fig. 4.6 and stratigraphic column 4 (see Appendix I). In some sections this member has high quantities of bryozoan causing unusual weathering bands which have sharp contacts with flaggy sections. These sharp contacts are most likely due to an abrupt change in bioclastic composition (Tripathi, 2008). Piopio Limestone Member (OtC) is a flaggy well developed limestone with a high calcium carbonate content. The very top of the formation comprises a meter or so of massive or thickly flagged silty limestone alternating with thin mudstone interbeds that rapidly thicken upward over a few meters into massive Mahoenui Group (Taumatamaire Formation) as demonstrated in Fig. 4.6 and stratigraphic column 4 (see Appendix I).

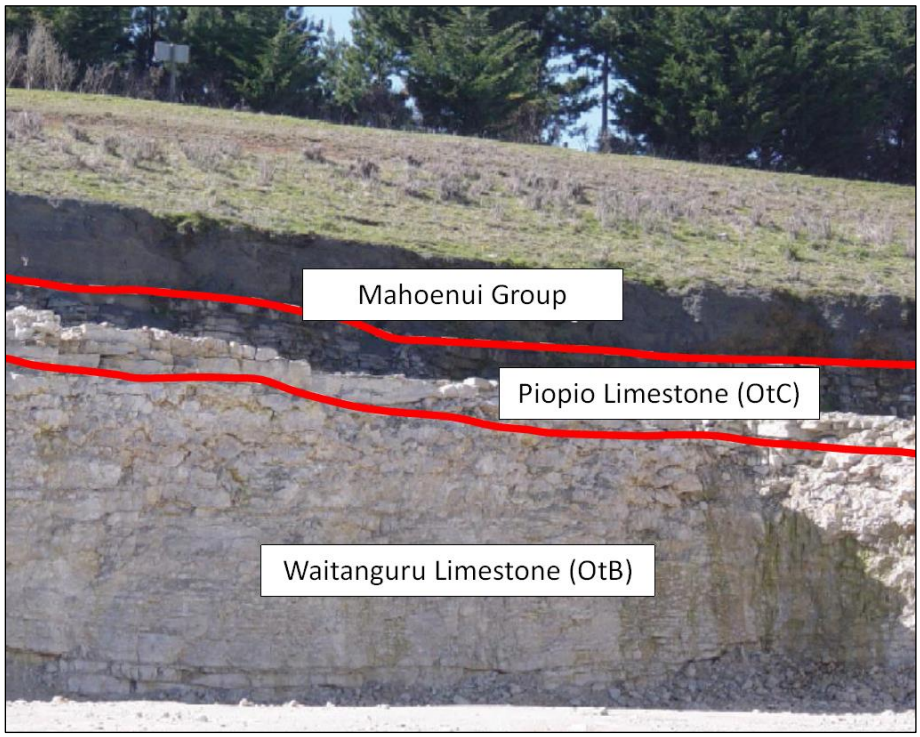


Fig. 4.6. Waitanguru Limestone and Piopio Limestone Members of Te Kuiti Group overlain by Mahoenui Group at Oparure Quarry, directly west of Te Kuiti (Column 4, Appendix I). Modified from Tripathi (2008). (N 5754500 E 1781100).

4.4 Mahoenui Group

Mahoenui Group is of Early Miocene age within Waitakian to lower Altonian stages and is the most extensive single stratigraphic unit present in the Te Kuiti (BF33) field area. In a wider context it extends and outcrops from Otorohanga in the north to Taumarunui in the south, bounded by Herangi Range in the west and Rangitoto Range in the east. The transition from high carbonate accumulation in Te Kuiti Group to terrigenous mudstone accumulation in Mahoenui Group was caused by rapid subsidence in the King Country, probably associated with crustal shortening. It coincided with westward overthrusting of basement on the Taranaki Fault (Kamp & Vonk, 2006).

Mahoenui Group units in the field area include Taumatamaire Formation and Taumarunui Formation. Taumatamaire Formation is the most extensive of these formations, extending from Mangaotaki, north of Otorohanga, to Taumarunui. Taumarunui Formation is limited in occurrence mainly to the southern parts of King Country Basin. Taumatamaire Formation includes three limestone members in the Awakino Gorge area. In the map area the only limestone member that occurs is the Cherry Tree Limestone (Simms, 1999). In the 1:50 000 geological map presented here (Enclosure 1), both of the constituent formations in Mahoenui Group have been grouped as undifferentiated Mahoenui Group, which mainly comprises Taumatamaire Formation (Fig. 4.7). There are few well-exposed outcrops of Mahoenui Group in the map area. Both of these formations have also been identified and illustrated in stratigraphic columns that have been produced and modified from Simms (1999) (see Appendix I).

Taumatamaire Formation

This unit comprises the bulk of Mahoenui Group in its northern outcrop area and accumulated mainly in mid-bathyal environments. The sediment comprising slightly calcareous mudstone (Fig. 4.7) accumulated by hemipelagic/pelagic suspension sedimentation and deposition out of mud plumes and/or turbidites at bathyal depths. A turbidite sequence within this formation has been identified in a road cutting along Pukerimu Road, south of Te Kuiti and is illustrated in stratigraphic column 14 (see Appendix I). The calcareous mudstone is massive and variably indurated, weathering to a frittery texture. Within the field area, the lower

contact with Te Kuiti Group is sharp. The overlying 1 m of mudstone containing upward thinning carbonate layers 1 to several cm-thick before sedimentation was overwhelmed by mudstone accumulation. This transition from Te Kuiti Group to Mahoenui Group reflects a marked increase in subsidence rate and a concurrent increase in siliciclastic mud supply. The upper boundary is an unconformable contact with Bexley Sandstone in northern areas (Column 19, SH3, Appendix I) and with Otunui Formation in southern areas. Simms (1999) notes that there has been uncertainty about the nature of the contact between Taumatamaire Formation and Mangarino Member (Bexley Sandstone) in the Te Kuiti and Waitomo areas (Column 24, Te Anga Road, Appendix I) and east of Te Kuiti (Column 17, Mangarino Road, Appendix I). Because Mangarino Member is interpreted to have a back barrier (paralic) depositional environment and Taumatamaire Formation represents a bathyal hemipelagic mudstone, there must be an erosional contact at which regressive shelf deposits have been eroded prior to accumulation of Bexley Sandstone (Simms, 1999).



Fig. 4.7. Taumatamaire Formation of Mahoenui Group exposed at a road cutting along State Highway 4, just south of Pukerimu Road (N 5740500 E 1789100).

Just west of Te Kuiti a limestone unit is interbedded within Taumatamaire Formation. This is known as the Cherry Tree Limestone Member and has been interpreted as an instance of mass emplacement of carbonate sediment into bathyal mudstone. Cherry Tree Limestone Member is a light grey, coarse grained, well cemented limestone with “pinch and swell” flags approximately 20-80 cm-thick separated by silty mudstone layers. Both the lower and upper boundaries of this limestone can be described as sharp conformable contacts with Taumatamaire

Formation. In some areas, such as directly west of Te Kuiti, this member is unconformably overlain by Bexley Sandstone of Mokau Group. The thickness of this member is 20-25 m and is illustrated in stratigraphic columns 9 and 18, south of Gadsby Road (see Appendix I).

Taumarunui Formation

Taumaranui Formation is a flysch sequence that crops out in a few locations in the southern part of the Te Kuiti (BF33) map area. This flysch sequence consists of alternating sandstone and mudstone (Fig. 4.8). This flysch sequence was deposited out of turbidites in a bathyal environment. Simms (1999) inferred that this formation accumulated with a fan-like geometry in a submarine trough produced through shortening of Mesozoic basement caused by plate boundary development. The shortening could have caused the subsidence via loading across reverse faults concurrent with the generation of siliciclastic sediment.

The graded beds (turbidites) contain small rip-up mud clasts and comply with classic Bouma Divisions (Ta, Tb, Tc, Te) (Bouma, 1962). Thick sandstone beds (1-8 m) are probably also turbidites, representing the lower Ta, Tb divisions, but these beds have also been inferred to have been deposited out of sandy debris flows.



Fig. 4.8. High section of Taumarunui Formation exposed at Herlihy Bluff, River Road, south of the field area. (Kamp & Vonk, 2006).

4.5 Mokau Group

Mokau Group is Late Miocene in age and is synchronous with the uplift and erosion of the Mahoenui Group (Kamp & Vonk, 2006). Mokau Group is exposed in the northern half of the map area and is attributed to Bexley Sandstone and its Mangarino Member. It unconformably overlies Mahoenui Group throughout this area and is a shallow marine sandstone with interbedded mudstone in some localities. These Mokau Group units display minor dips, with most structural tilting being associated within Pliocene-Pleistocene normal faulting. These units have also been identified and illustrated in stratigraphic columns that have been produced and modified from Vonk (1999) (see Appendix I).

Bexley Sandstone

Bexley Sandstone represents the most extensive Mokau Group unit within the Te Kuiti (BF33) field area and represents a transgressive shoreface deposit. Vonk (1999) describes this formation as being poorly fossiliferous limiting biostratigraphic age determination. Topping (1978) demonstrated that lower age limits can be indicated by the age of the uppermost units of Mahoenui Group. Topping (1978) determined uppermost Mahoenui Group to be of upper Otaian to lower Altonian age within the field area. Upper age limits have been established by King et al. (1993) outside the field area in the Awakino Valley. It was suggested that the upper age limit can be obtained from the age of the lowermost part of Ladies Mile Mudstone. This mudstone unit has an age no younger than lower Altonian due to the presence of *Haeuslerella pukeuriensis* and *Globorotalia incognitia*. From these observations it can be implied that Bexley Sandstone has a lower Altonian age.

Bexley Sandstone is an orangey-brown, well-sorted, massive to thickly-bedded, weakly-indurated, fine sandstone with carbonaceous mudstone beds and rare coal seams (Fig. 4.9). The formation also contains local rare shellbeds, concretionary horizons and exhibits weakly developed low-angle cross-bedding, faint lineations and fossil clasts (Kamp & Vonk, 2006). Bexley Sandstone's colour is due to weathering processes causing the dissolution of iron bearing minerals forming ferruginous limonite layers within the sandstone (Wilson, 1994). Pebble conglomerate layers occur at the base of the formation throughout the field area

(Fig. 4.9) (Column 19, SH3; Column 17, Mangarino Road; Column 21, Tahaia Road). These layers consist of well-sorted, rounded greywacke pebbles (1-5 cm diameter) supported in a fine grained, well-sorted, sandstone matrix. Overall, Bexley Sandstone has a maximum thickness of 60 m within the field area, with much thicker sequences present farther south toward the Ohura Fault, where it thins markedly east of this fault.

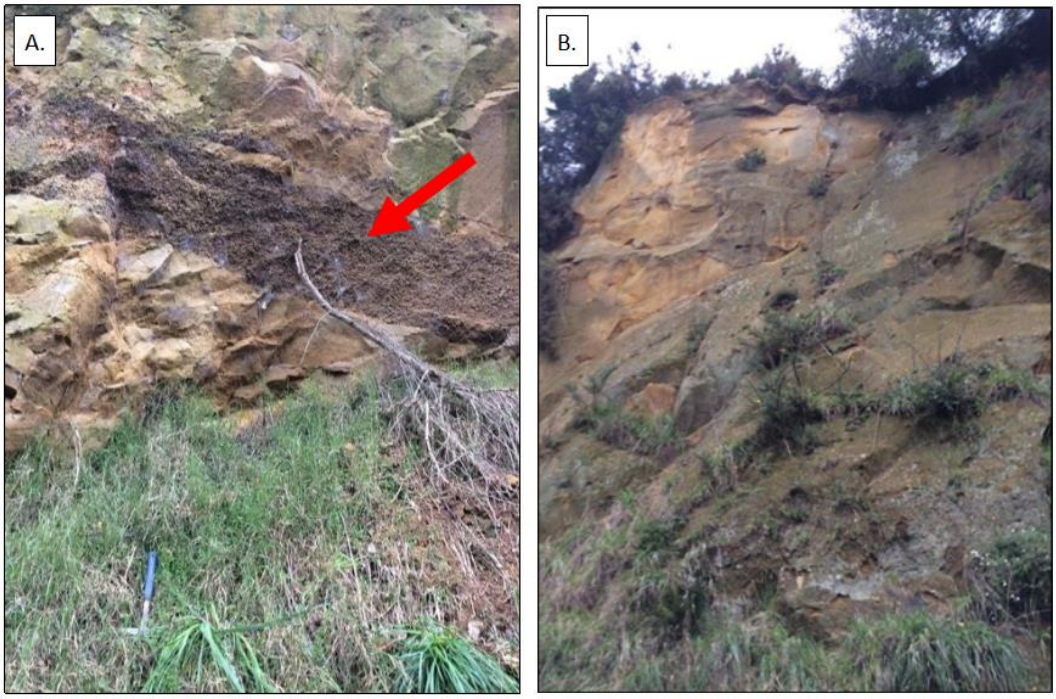


Fig. 4.9. Bexley Sandstone outcropping along State Highway 3, south of the turn off west towards Waitomo (Column 19, Appendix I) (N 5763000 E 1790100). (A.) Pebble conglomerate layer at the base of Bexley Sandstone. (B.) Massive (faintly bedded) sandstone unit of Bexley Sandstone.

Mangarino Member

Mangarino Member was introduced as a new unit in Bexley Sandstone by Vonk (1999). The type section occurs on Mangarino Road northeast of Te Kuiti (Column 17, Appendix I). This member commonly occurs in basal sections of Bexley Sandstone but it has not been individually mapped on BF33. The age of this member is the same as Bexley Sandstone, namely lower Altonian and it represents deposition in a back-barrier environment. The lower contact is with Mahoenui Group (Taumatamaire Formation) in the field area and its extent is limited to northern localities east of Te Kuiti and north of Waitomo (Mangarino Road, Column 17 & Te Anga Road, Column 24). The upper contact is gradational with ferruginous sandstone of Bexley Sandstone. In the field area, it reaches a maximum

thickness of about 20 m, which is evident in sequences along Te Anga Road, northwest of Waitomo.

Mangarino Member, in the field area, comprises thick-bedded (1-4 m) alternating sandstone and mudstone. The slightly argillaceous sandstone beds are orange to brown, predominantly massive with some fine parallel and wavy laminations, fine grained and well sorted. Laminations are accentuated in some sections by the presence of limonite staining and liesegang weathering. Mudstone beds within this member are dark grey, parallel-laminated, moderately carbonaceous, slightly sandy and fine grained. The beds are moderately bioturbated with very fine silt and sand infilling burrows (Vonk, 1999).

4.6 Whangamomona Group: (*Otunui Formation*)

Whangamomona Group is represented by Otunui Formation in the field area and accumulated during the upper Lillburnian to Waiauan stages. It is defined as a transgressive sequence at the base of Whangamomona Group. Otunui Formation mainly overlies Mahoenui Group throughout the field area and its extent is limited to regions south of Te Kuiti Township. It occurs on the tops of ridges and cliffs, reaching maximum thicknesses of 30-40 m. Otunui Formation is dominantly displayed as a silty fine sandstone and sandy siltstone with channelized conglomerate facies present in a few places. It can evidently be described as a blue-grey, massive to thickly-bedded, indurated, bioturbated, argillaceous, fine to medium sandstone to calcareous sandy siltstone. A key diagnostic characteristic of Otunui Formation is its orangey brown limonite mottling brought out by weathering at the outcrop surface as a result of syn-sedimentary bioturbation and burrowing. These units have also been identified and illustrated in stratigraphic columns that have been produced and modified from Vonk (1999) (see Appendix I).

Near Benneydale (Column 20, Appendix I), and in Mangaokewa Valley, (Column 22, Appendix I) a shelly limestone layer is present at the base of Otunui Formation and is recognised as Mangarara Formation. This formation is isolated to these areas in BF33. It is of mid-Lillburnian age and is characterised by the occurrence of bivalve and echinoderm fragments, bryozoans, calcareous red algae and large sedimentary rock fragments. King et al. (1993) and Wilson (1994) describe that micro-faunal assemblages indicate a Waiauan age, but this is in the Mohakatino

Valley well to the west of the BF33 field area where the formations occurs in slope deposits rather than as a transgressive shellbed in inner shelf environments.

4.7 Quaternary Deposits

Quaternary deposits occur throughout the field area, unconformably overlying the Tertiary stratigraphic units described above. These deposits include alluvial sediments, volcanic ash beds and ignimbrites all occurring extensively throughout the Te Kuiti (BF33) field area.

Alluvial Deposits

Alluvium has been deposited on valley floors along rivers and streams from aggradation of weathered and reworked materials shed into the valleys. The alluvium onlaps a range of different units throughout the study area. Volcanic ash beds also cover the Tertiary units in some areas. They were sourced from Central North Island volcanic centers and are predominantly described as Taupo Ash. These ash beds mantle the surface and form the parent material for most modern soils of the region.

Ignimbrites

Within the field area, Early Quaternary ignimbrite surfaces form flat-topped hills up to approximately 700 m high with eroding bluffs along their margins. These units have been mapped in Enclosure 1 as undifferentiated ignimbrite, but a summary of the various eruptive units are presented in Table 4.1. Because of erosion and failure of weaker underlying Tertiary sedimentary rocks, rock falls are common leaving talus deposits on the lower slopes of many hills throughout the field area (Fig. 4.10). Brink (2012) explains that the present ignimbrites, more specifically, Ongatiti Ignimbrite, covers a highly irregular pre-ignimbrite topography in the central-eastern King Country region. Edbrooke (2005) describes that mapping the outer limits of ignimbrites is difficult, as they become intercalated with reworked material. Some ignimbrite units also continue to cover the landscape beyond the level of where they are thick enough to be mappable units. The

ignimbrite units and topography are most common in eastern and southern areas of BF33.



Fig. 4.10. Fallen ignimbrite (undifferentiated) located east of Ngapeke Road. Red arrows indicating the outcrop source of the boulders (N 5759100 E 1797400).

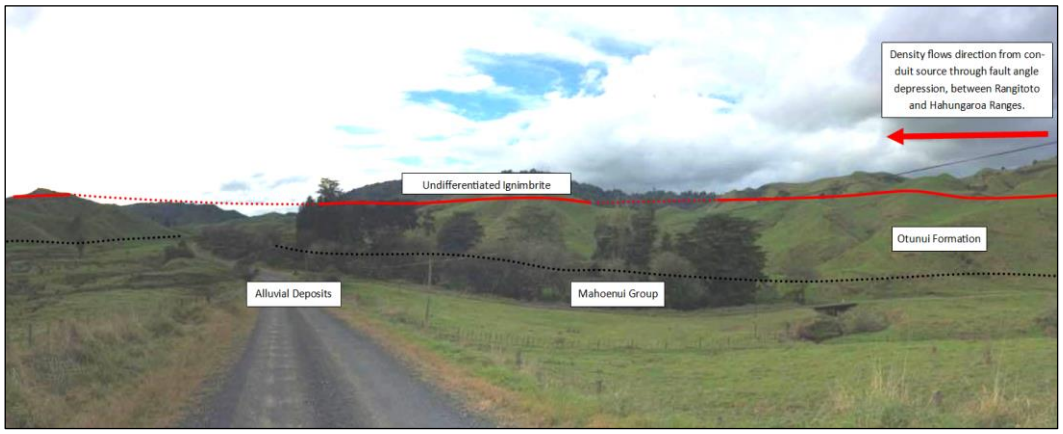


Fig. 4.11. Looking north along Mangaokewa North Road in the Mangaokewa Valley. Alluvial deposits, Mahoenui Group and Otunui Formation overlain by an undulating undifferentiated ignimbrite. Red arrow indicates the direction of ignimbrite emplacement (N 5742500 E 1801000).

Fig. 4.11 shows Mangaokewa stream, in the eastern part of the field area, which flows through a valley and cuts into ignimbrite units of Pakaumanu Group. The eastern valley side represents the eastern volcanic uplands where Ongatiti Formation is overlain by Mangaokewa and Raepahu Formations. The Otunui Formation and Mahoenui Group underlie these volcanic units. Many of the ignimbrite units present throughout the map area are sourced from the interaction

of pyroclastic density flows flowing over and around the high standing Rangitoto Range located just east of the field area. This range acts as a physical barrier, having a significant impact on the depositional patterns of ignimbrites throughout the region. The pyroclastic flows were predominantly directed westwards through a fault angle depression between two ridges, acting as a conduit (Brink, 2012).

Table 4.1. Summary of ignimbrite formations and associated ages (Ma) determined by Brink (2012) and Edbrooke (2005) to be evident within the field area.

Group	**Formation**	**Age (Ma)**
Pakaumanu Group	Raepahu Formation	1.00±0.05
	Mangaokewa Formation	1.20±0.04
	Ongatiti Formation	1.21±0.04
	Ngaroma Formation	1.55±0.05

4.8 Cross-sections

In addition to the production of the geological map, two 1:1 geological cross-sections were produced and included on the geological map (Enclosure 1). The orientation of the cross-sections through the field area are also shown on Fig. 4.12. Cross-sections are useful in helping to understand subsurface stratigraphic trends.

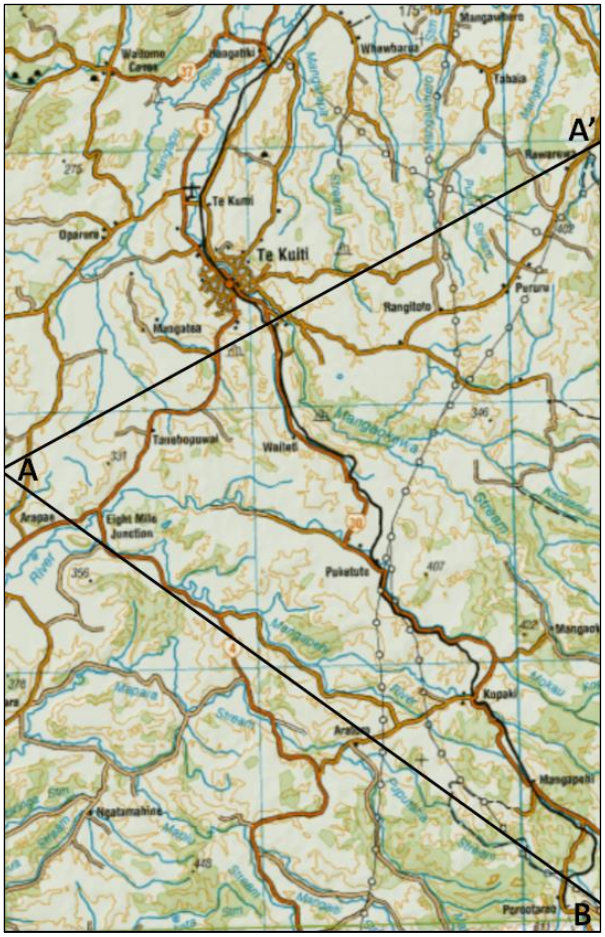


Fig. 4.12. Orientation and location of cross sections A-A' and A-B.

Line A-A'

Line A-A' represents a cross-section from a point located centrally along the western margin of the field area, trending northeast towards the eastern margin (Fig. 4.12). This cross-section passes through the Waipa Fault in the west and illustrates the offset it produces within the field area (approx. 200 m). On the western side of the fault, the subsurface is underlain by Newcastle Group of the Murihiku Terrane, overlain by Te Kuiti Group, which is approximately 100 m-thick. The Newcastle Group is not exposed in the field area. To the east of Waipa Fault, Manaia Hill Group of the Waipapa Composite Terrane represents the basement unit and is overlain by Te Kuiti Group, ranging from 100 m-thick in the vicinity of the fault to 200 m-thick east of Te Kuiti. Mahoenui Group is also present at a thickness of approximately 90-100 m west of Te Kuiti, whereas east of Te Kuiti it has been eroded in most areas and is only evident on some hilltops. Mokau Group is only present in the steep hill country west of Te Kuiti, at a maximum thickness of

approximately 80 m. The Manaia Hill Group basement unit is dominant east of Ngapeke Fault, suggesting all Tertiary units have been removed from this area.

Line A-B

Line A-B represents a cross section from the same point located centrally along the western margin of the field area, but trends southeast directly north of the southeastern corner (Fig. 4.12). To the east of the Waipa Fault in this section, Te Kuiti Group is also present in the subsurface at approximately 100 m-thick. Farther east, its thickness decreases gradually as reported by Nelson (1978). Nelson (1978) described the variations in thickness to be a result of basement paleorelief and areas of tectonic subsidence during the accumulation of Te Kuiti Group. Mahoenui Group is present in the subsurface and crops out frequently at the surface along this section. This unit also ranges in thickness (approx. 100-200 m) and is probably thickest at the syncline axis. Topographic highs are dominated by Otunui Formation and commonly overlying undulating ignimbrite units. The subsurface characteristics of the syncline structure, present through the southern part of the field area is also illustrated. It displays very shallow and gradual dips on both sides of the structure involving all units.

4.9 Stratigraphy and structure of important areas

Previous mapping in the field area was undertaken at 1:250 000 (e.g. Hay, 1967; Edbrooke, 2005) and/or of particular areas at smaller scales for the mapping of coal or limestone resources. The earliest geological mapping was completed by Henderson and Ongley (1923). Their work defined the nature and distribution of the sedimentary units present in Te Kuiti, Mahoenui and Mokau groups across an area much broader than the Te Kuiti map (BF33). Subsequently, Marwick (1946) and Grange (1972) produced maps of the Te Kuiti Subdivision, also at a large scale. This early mapping and stratigraphic investigation attracted the interest of petroleum explorers, including Shell, B.P., and Todd Oil Services, who undertook petroleum exploration surveys during the 1960s including well drilling. Their results are contained in petroleum reports. These reports and subsequent work has developed the current stratigraphic understanding within the map area (Kear and Schofield, 1959; Nelson, 1978; Tripathi, 2008). The most recent large scale mapping is represented in the 1:250 000 QMAP Waikato map by Edbrooke (2005).

Six key areas are now described in some detail to highlight the stratigraphy and structure of the Cenozoic units in BF33. This will also show where significant improvements have been made in the new map (Enclosure I) versus the field sheet for BF33 (NZMS 260 S16 & S17) used in compiling related parts of the Waikato QMAP by Edbrooke (2005). Many of these changes affect the location of formation boundaries and formation thicknesses.

LOCATION 1: NGAPEKE ROAD

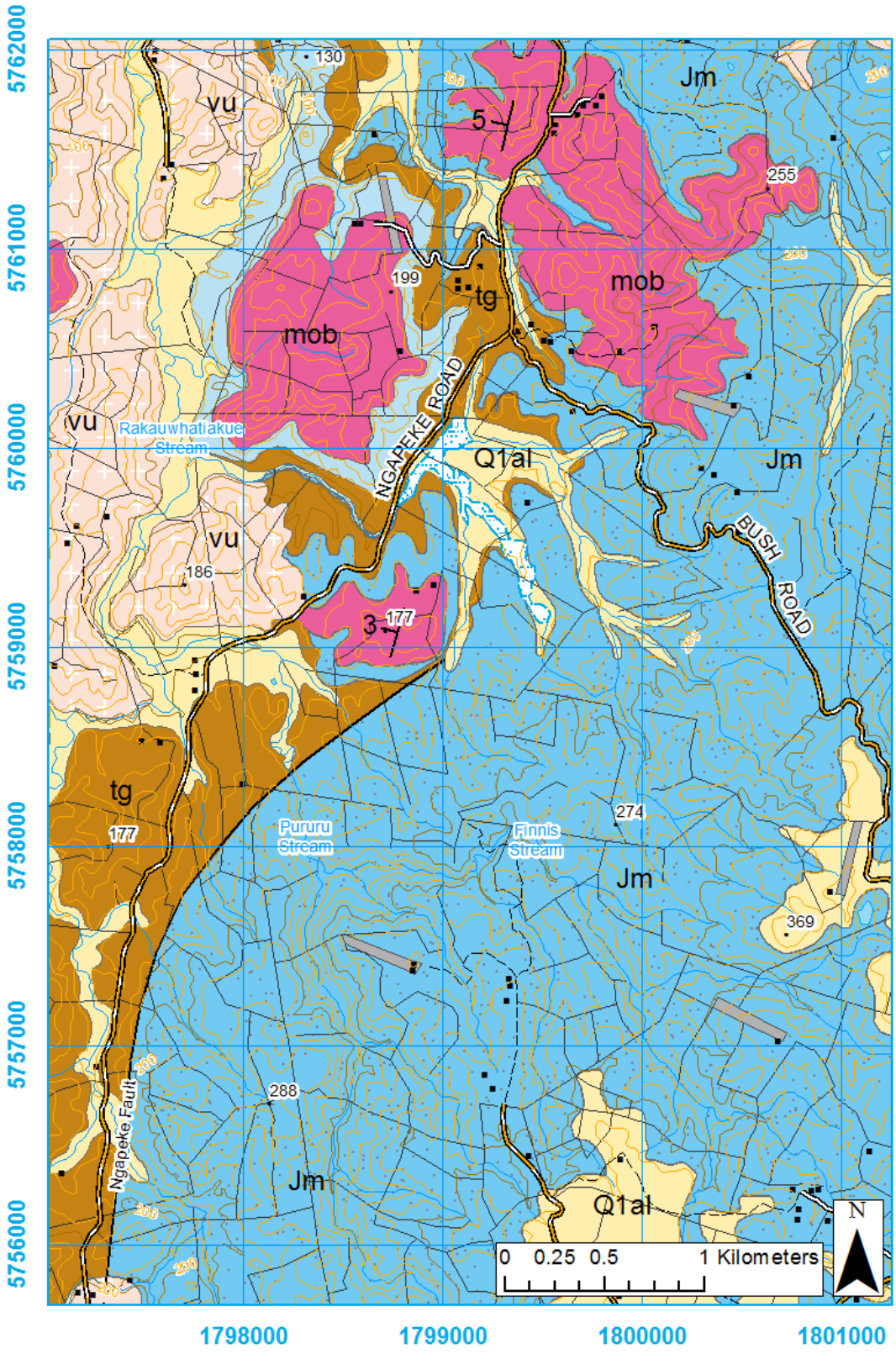


Fig. 4.13. Map section of location 1 in the northeastern region of the field area.

Stratigraphy and structure

Location 1, Ngapeke Road (Fig. 4.13), is located in the northeastern part of the field area. This area is characterised by basement (Manaia Hill Group Terrane) in the east and onlapping Cenozoic units. Previous mapping by Edbrooke (2005) described that along Ngapeke Road, Te Kuiti Group overlies basement directly, but closer observation shows that there is a fault that has uplifted basement relative to Te Kuiti Group. This is supported in Fig. 4.14 where it is evident that basement and Te Kuiti Group occur at the same elevation. This explains why there is an abrupt disappearance of Tertiary units to the east of Ngapeke Road. Kamp et al. (2004) and Nelson (1978) have previously noted that the occurrence of Te Kuiti Group can be commonly preserved in fault depressions within King Country Basin. Another factor that could have caused this structural high in the east is the presence of an anticline structure. At this basement high, all Tertiary sediments have been removed through erosion.

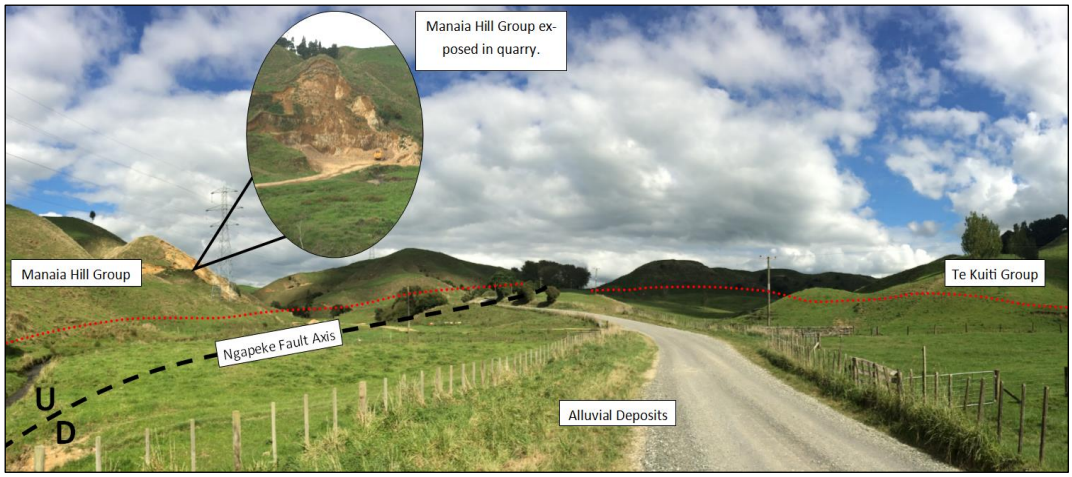


Fig. 4.14. View south along Ngapeke Road, with Ngapeke Fault strike illustrated. The offset of Te Kuiti Group and Manaia Hill Group are shown (N 5756500 E 1797300).

In the northern part of location 1, Te Kuiti Group, Mahoenui Group and Mokau Group are exposed along Ngapeke Road (Fig. 4.15). All units are relatively thin but definitely evident at this location with Mokau Group exposed on steep hilltops, Mahoenui Group present through the undulating hill section and Te Kuiti Group present along the road as Waikato Coal Measures.

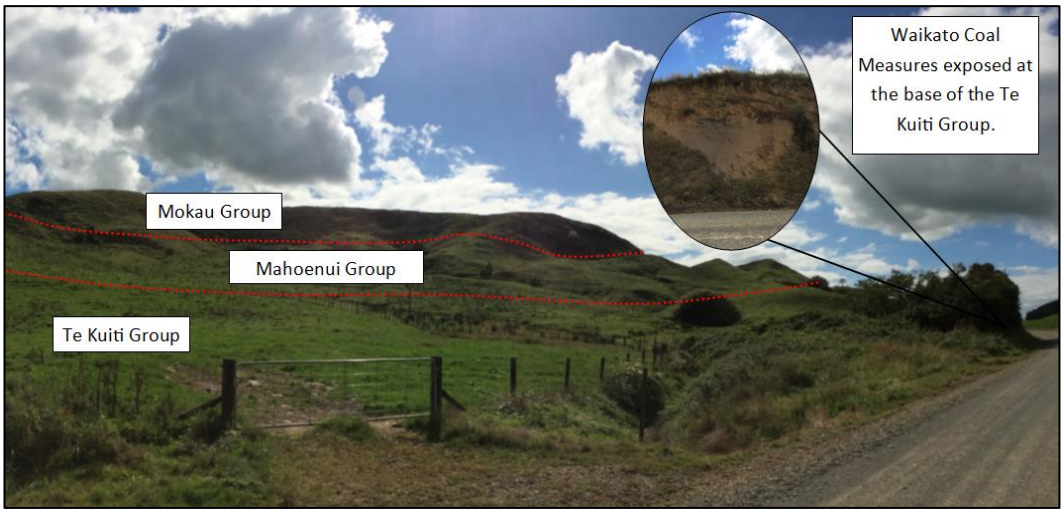


Fig. 4.15. Te Kuiti Group, Mahoenui Group and Mokau Group located along Ngapeke Road, north of the Ngapeke Fault (N 5760100 E 1799000).

Farther north in location 1, Mokau Group, as Bexley Sandstone, lies unconformably on Manaia Hill Group (Jurassic Basement) which is also illustrated in stratigraphic column 20 (see Appendix I) and in Fig. 4.16. This implies that the whole of Te Kuiti Group and Mahoenui Group have been removed prior to accumulation of Mokau Group.

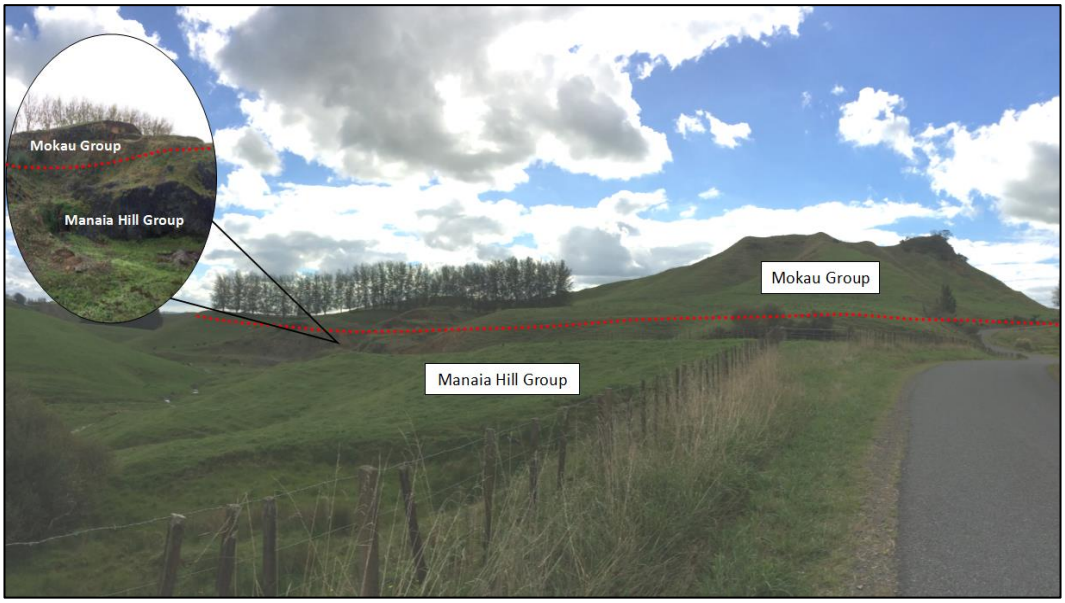


Fig. 4.16. View north along Tahaia Road at private quarry where Mokau Group unconformably overlies Manaia Hill Group (N 5761400 E 1799300).

LOCATION 2: FULLERTON ROAD

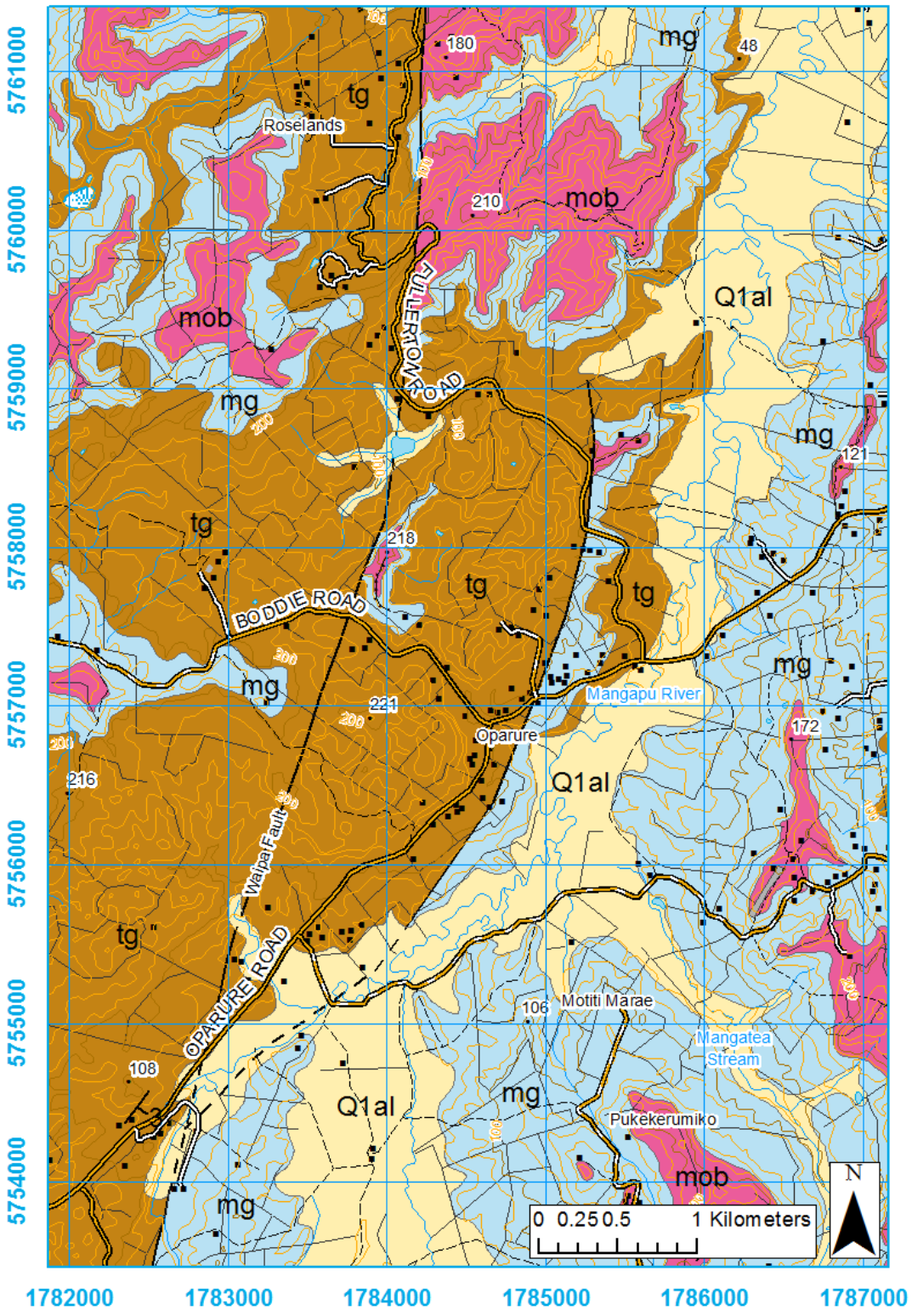


Fig. 4.17. Map at location 2 in the northwestern part of the field area.

Stratigraphy and structure

Location 2, Fullerton Road (Fig. 4.17), is located in the northwestern part of the field area, south of Waitomo. This area has been highly impacted by the large fault structure extending through this region known as Waipa Fault (Fig. 4.18). Waipa Fault passes through the northwestern part of the field area and has a vertical offset of approximately 200 m. The block west of the fault has been uplifted relative to the eastern side, such that Te Kuiti Group occurs at high elevations. This fault also acts as a boundary between Murihiku Terrane in the west and Manaia Hill Group in the east, which is displayed clearly in the cross sections (Enclosure 1).

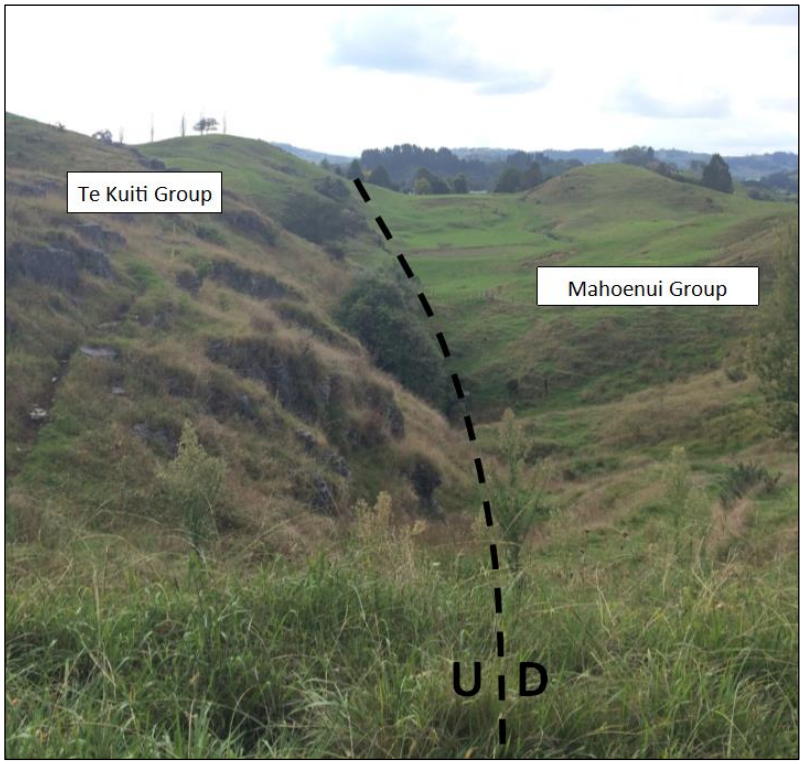


Fig. 4.18. View north towards Waitomo from Fullerton Road where Waipa Fault is illustrated. Mahoenui Group on the east is downthrown relative to Te Kuiti Group on the west (N 5761800 E 1784200).

Previous mapping by Edbrooke (2005) suggested that Mahoenui Group was much more extensive east of Waipa Fault in this area. A north-dipping ramp structure has been identified, offsetting Te Kuiti Group on a second (unnamed) fault east of the Waipa Fault trace. This ramp structure is shown in Fig. 4.19 and Fig. 4.20., extending from the Waipa Fault (south of Oparure) to just north of the intersection with Boddie Road and Fullerton Road. This ramp structure explains why Te Kuiti

Group occurs at higher elevations than Mahoenui and Mokau groups along Fullerton Road (Fig. 4.19 & 4.20) and Boddies Road.



Fig. 4.19. View north along Fullerton Road with the location of Waipa Fault shown. Te Kuiti Group crops out in the steep country to the west of Waipa Fault (N 5758400 E 1785300).

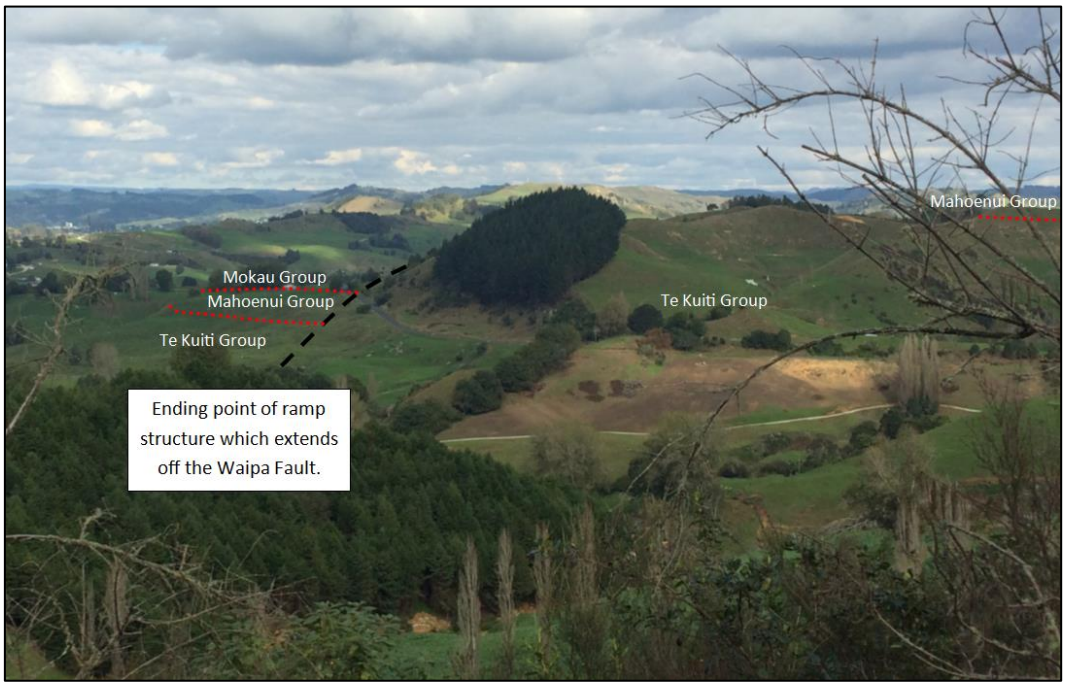


Fig. 4.20. View south from Fullerton Road towards the ramp structure (N 5759600 E 1784100).

LOCATION 3: TE KUITI

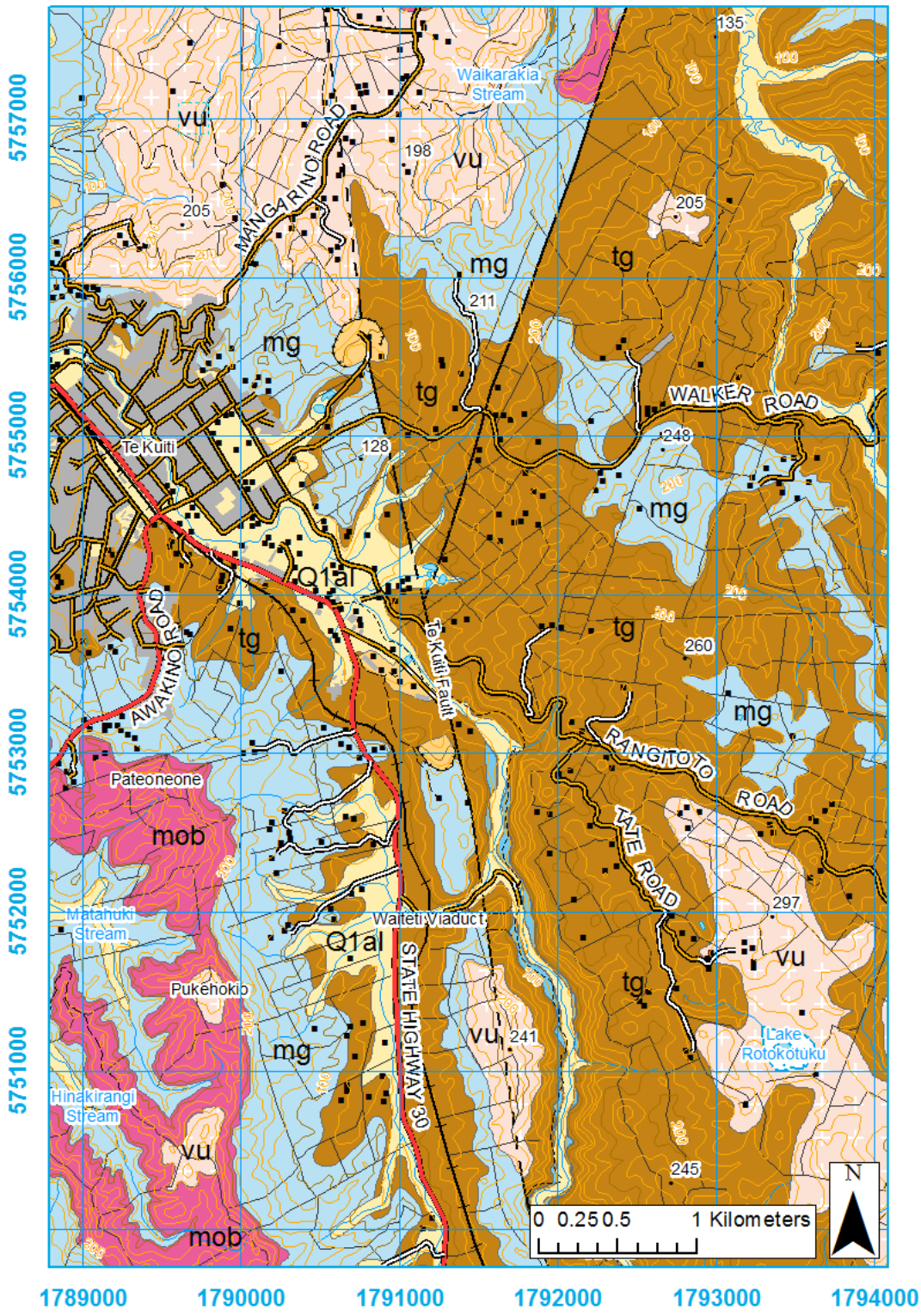


Fig. 4.21. Map of Location 3, in the central part of the field area.

Stratigraphy and structure

Location 3, occurs in the central part of the field area (Fig. 4.21). Te Kuiti Township is predominantly situated on Quaternary alluvial sediments and Te Kuiti Group occurs at higher elevations to the west. Above Te Kuiti Group in this area, Mahoenui Group is evident as Taumatamaire Formation and discontinuous occurrences of Cherry Tree Limestone Member (Columns 9 & 18, South of Gadsby Road; Column 1, east of Te Kuiti; Column 6 & 7, south of Te Kuiti). At higher elevations, Mokau Group is present in the form of Bexley Sandstone, with the unconformable contact with Mahoenui Group represented by an abrupt steepening in topography (Fig. 4.22). Previous mapping by Edbrooke (2005), showed a very roughly located boundary between units, especially between Mokau and Mahoenui Groups in this area. With the mapping methods described above, this formation boundary has been mapped with more precision, tested by structure contouring enabling the geological boundary to be predicted across areas where the contact is not exposed.



Fig. 4.22. View west across Te Kuiti from Walker Road (N 5755100 E 1790900). The geological boundaries between Te Kuiti, Mahoenui and Mokau groups are indicated by the red dotted lines.

The eastern part of location 3, is dominated by Te Kuiti Group and small areas of Mahoenui Group at higher elevations. A new fault, named Te Kuiti Fault, has been mapped in this area. Te Kuiti Fault strikes north-south, with the fault trace located east of Beros Quarry and the old quarry east of the town, which is now a landfill

(Fig. 4.23). This fault offsets Te Kuiti and Mahoenui groups and accounts for presence of Te Kuiti Group at higher elevations, in the eastern hill country.

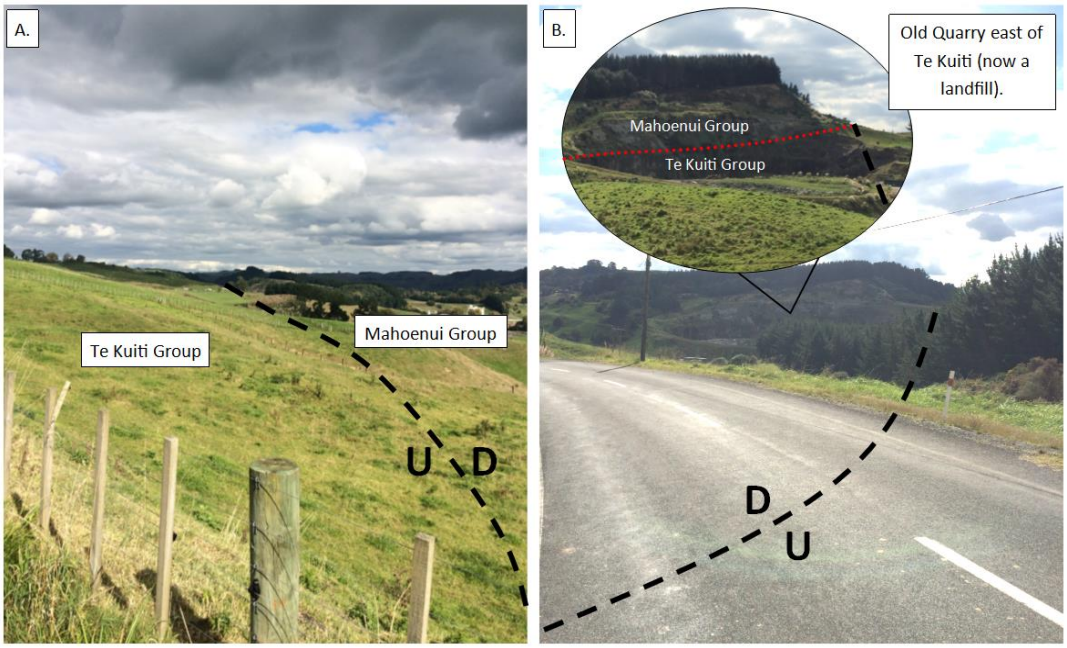


Fig. 4.23. (A.) View south from Walker Road towards Beros Quarry. (B.) View north from Walker Road towards the old quarry east of the town. (N 5755100 E 1790900).

LOCATION 4: SH4/PUKERIMU ROAD

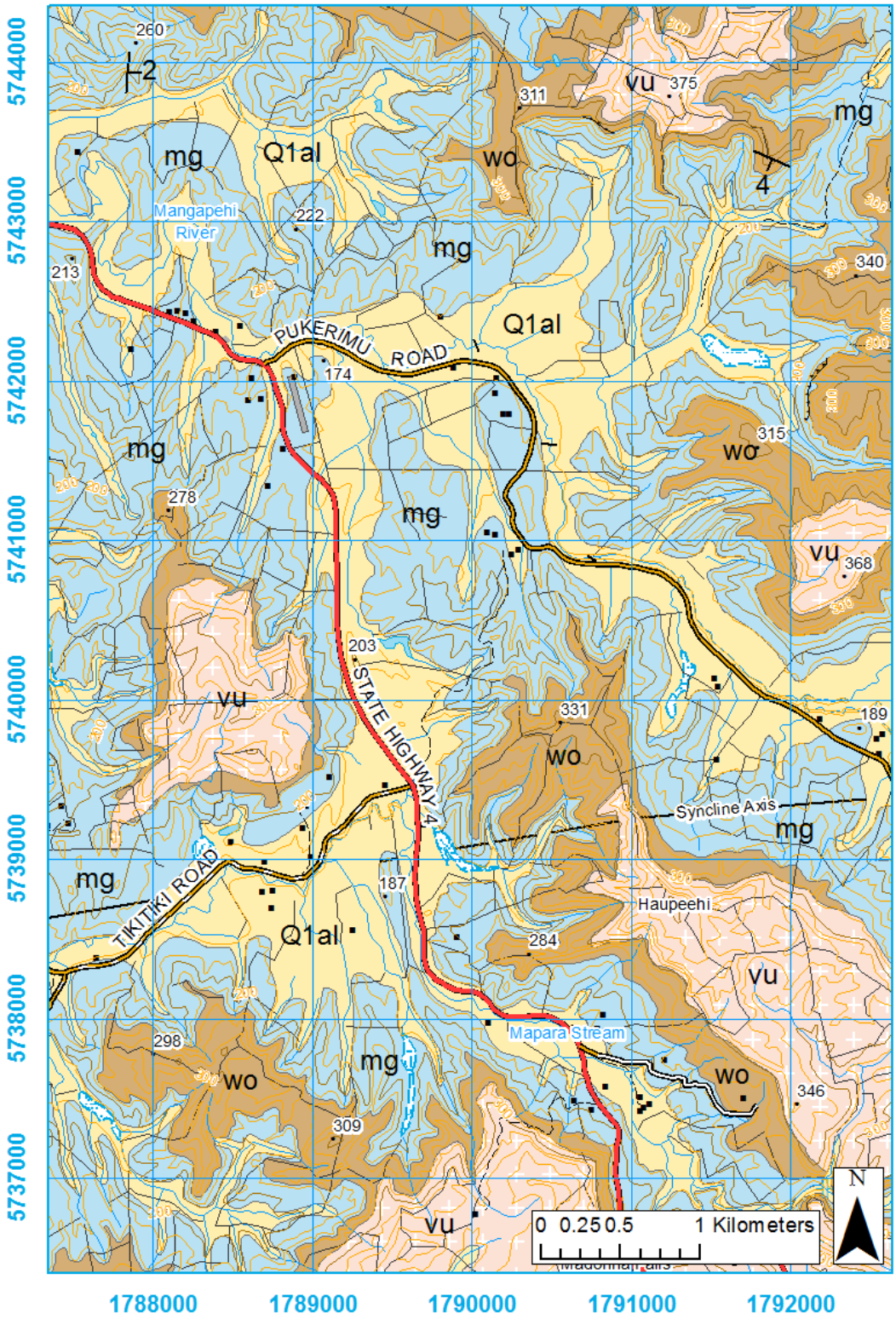


Fig. 4.24. Map section of location 4, in the central southern region of the field area.

Stratigraphy and structure

Location 4, SH4/Pukerimu Road (Fig. 4.24), occurs just south of Te Kuiti Township in the map area. This area comprises mainly Mahoenui Group in the low lands made up of undulating hill country. Otunui Formation occurs at higher elevations and commonly forms large bluffs. Ignimbrites are also present throughout this area. The dominant structural feature is a syncline and it extends east-west across the southern part of the map area, effecting Cenozoic units. See also Enclosure 1 and cross-section A-B. A syncline is a downward fold of stratified rock in which the strata slopes towards a fold axis, as illustrated in Fig. 4.26. The syncline is a shallow open fold with a horizontal fold axis.

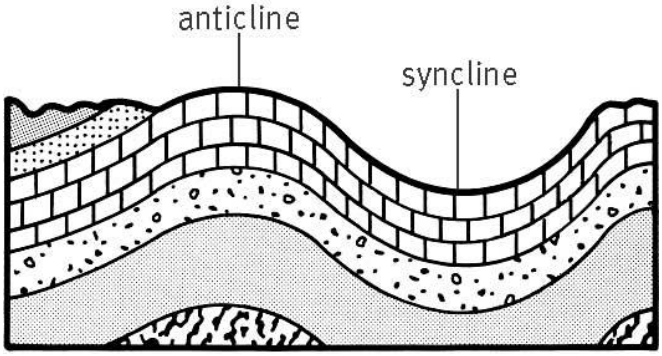


Fig. 4.25. Anticline and syncline structural trends (Science Dictionary, 2002).

LOCATION 5: MANGAOKEWA VALLEY

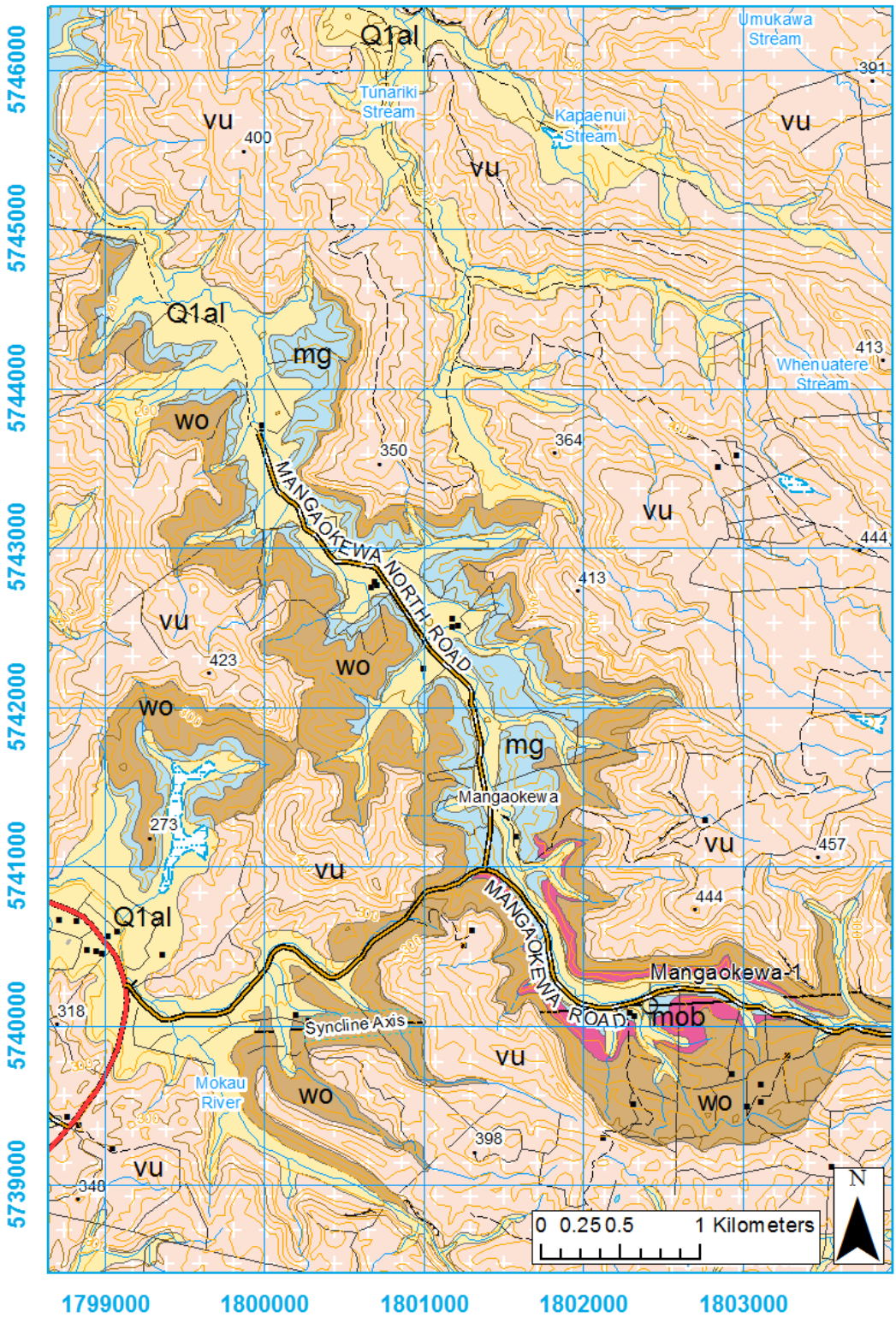


Fig. 4.26. Map section of location 5, in the southeastern part of the field area.

Stratigraphy and structure

Location 5, Mangaokewa Valley (Fig. 4.26), is located in the southeastern part of the map area. As demonstrated in Fig. 4.27, the highlands are dominated by volcanic ignimbrite surfaces, which overlie Otunui Formation and Bexley Sandstone in some areas. Mahoenui Group occurs in undulating lowland areas. Both Otunui Formation and undifferentiated ignimbrite unit boundaries were largely remapped in this area compared with earlier maps. Along the western end of Mangaokewa Road, outcrops of Bexley Sandstone are evident, representing the eastern extent of Mokau Group in the map area. At a more regional scale, this Mokau Group occurrence represents the southeastern most outcrop occurrence of Bexley Sandstone.



Fig. 4.27. View south along Mangaokewa Road. Geological boundaries between Mahoenui Group, Mokau Group, Otunui Formation and undifferentiated ignimbrite are indicated by the red dotted lines. (N 5740900 E 1801000).

LOCATION 6: KOHUA ROAD

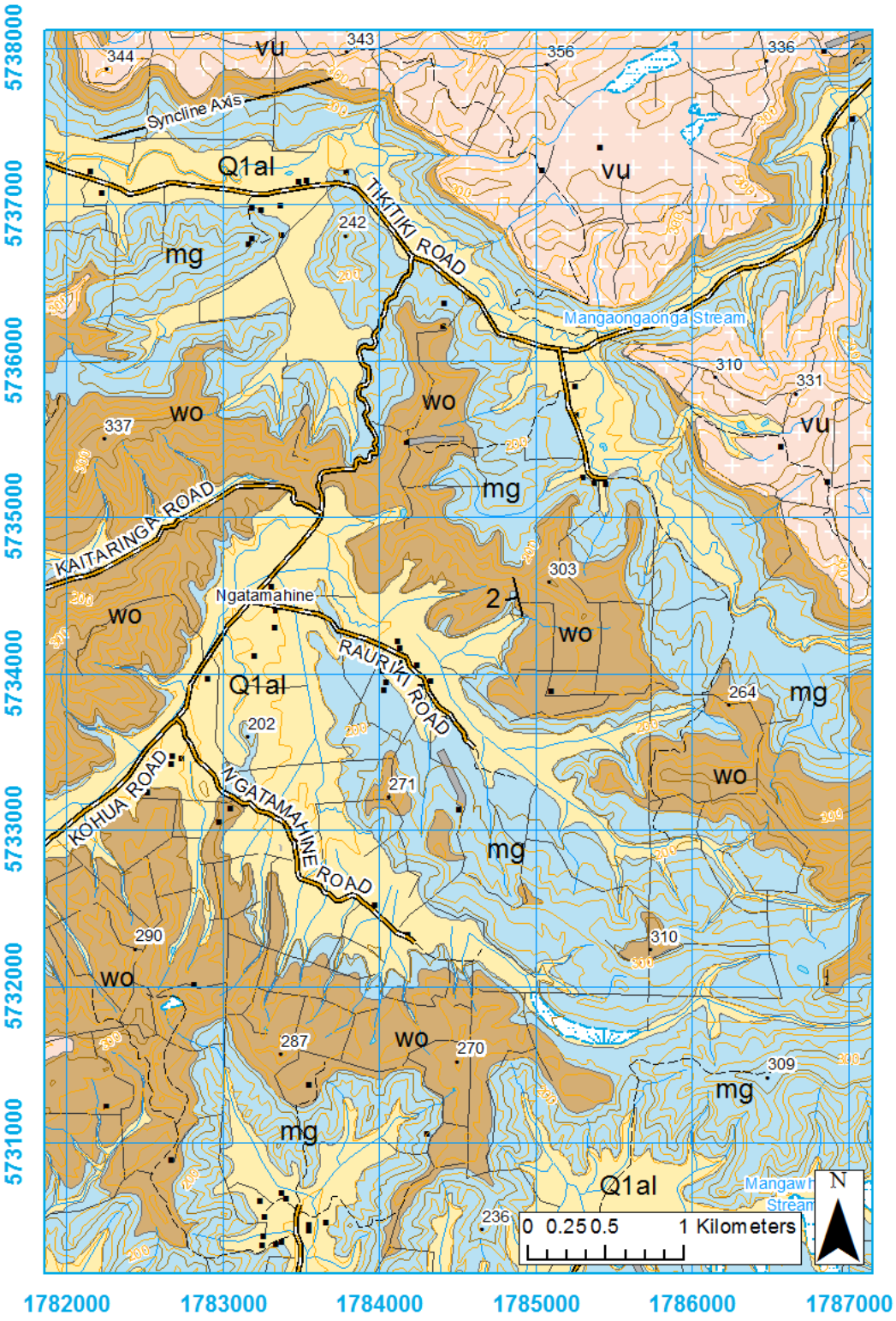


Fig. 4.28. Map section of location 6, in the southwestern part of the field area.

Stratigraphy and structure

Location 6, Kohua Road (Fig. 4.28), occurs in the southern part of the map area. This area is dominated by low lying Mahoenui Group, with higher elevations and cliff faces representing Otunui Formation. Otunui Formation and Mahoenui Group geological boundary in this part of the field area has been modified and updated from the maps produced by Cartwright (2003), Evans (2003) and Edbrooke (2005). Areas that are covered have been remapped using structure contour techniques from new and old data. Previous geological maps illustrated a fault striking northwest-southeast from just north of Kaitaringa Road to 4 km east of Ngatamahine Road. This was an unusual strike for a fault in this area as they normally strike north-south or northeast-southwest. Mahoenui Group was dominant north of this fault and in the south the geology was limited to Otunui Formation. During field mapping for the preparation of the thesis map, no evidence was found for this fault as no offset occurs there between Mahoenui Group and Otunui Formation. The geological boundary between Mahoenui Group and Otunui Formation were remapped from field observations and structure contouring.

5 Sedimentology

5.1 Introduction

In this chapter, the main sedimentological properties of the geological units present in the Te Kuiti (BF33) mapping area are described and summarized in tables and figures. Stratigraphic columns have been constructed from my own observations during fieldwork and have also been modified from previous work by Vonk (1999), Simms (1999), Tripathi (2008) and Kamp et al. (2008). Where possible, the column sites were revisited and re-logged.

Variations in lithologies amongst the different units have been recognized by developing facies associations from facies analysis. Facies have been defined based on lithology, geometry, sedimentary structures, faunal content and mineralogy. Interpretations about environment of deposition and processes of sedimentation have been made from this facies analysis for the Tertiary stratigraphic units mapped in the field area. It must be noted that much of the facies information in this chapter has been adapted and field checked from previous research by Vonk (1999), Simms (1999), Tripathi (2008) and Kamp et al. (2008). Facies codes are shown on the stratigraphic columns (see Appendix I) to illustrate the vertical distribution of the facies identified for successive beds and formations.

5.2 Te Kuiti Group Facies

5.2.1 Limestone Facies

Te Kuiti Group in the map area is dominated by limestone facies, particularly in Otorohanga Limestone and Orahiri Formation. The limestone facies can be broadly described as medium to coarse, poorly to moderately sorted, flaggy limestone. This section describes the nature of each facies based dominantly on field observations and some laboratory analysis. Depositional mechanisms and paleoenvironments are also briefly discussed.

Pebbly Grainstone-Packstone (L1)

The pebbly grainstone-packstone facies ranges from 0.5-1.5 m in thickness and is limited to where Orahiri Formation/Otorohanga Limestone laps onto basement. It is well exposed in the map area along Mangaokewa Stream at the base of the Orahiri

Formation where it unconformably overlies basement (Column 3, Appendix I). It is lithologically described as containing common to abundant sub-rounded pebbles and cobbles, which may occur as pebble bands, or fabric supported by bioclastic silty fine sandstone and is usually massive in appearance. It is a medium to coarse grainstone-rudstone, containing occasional large shell fragments, poorly to moderately sorted; very abraded. Some sections contain fragmented pectinids, oysters, echinoderm, clasts occasionally encrusted by calcareous red algae, including rhodoliths (Tripathi, 2008). The carbonate content can be described as moderate, being around 50-60%. Due to the texture and fossiliferous content it can be indicated that the depositional environment is near shore to inner shelf, adjacent to a rocky shoreline. It is inferred to have formed as a transgressive lag deposited during marine encroachment onto basement, which is suggested by its stratigraphic position and the abundance of basement derived clasts.

Cross Stratified Grainstone (L2)

This cross stratified grainstone facies is confined to Mangaotaki Limestone Member (Orahiri Formation) and Otorohanga Limestone, being approximately 0.3-4.5 m-thick, usually interbedded with horizontally bedded and/or sandy grainstone. It can be described as having sigmoidal to tabular cross-beds which are low (< 100) to moderate angle (100-250), occurring as 0.3-4.5 m-thick cross-sets traceable laterally for a few tens of meters; base and tops of sets are sharp and discordant (cross-beds are generally 2-15 cm-thick). It is a medium to very coarse grainstone with rare small pebbles and granules. Siliciclastic particles are present in bedding planes and are generally of fine sandstone to siltstone and are moderately abraded and poorly to moderately sorted. Bryozoans, echinoderms, benthic foraminifers, occasional bivalves, coralline red algae and rare planktic foraminifers are also abundant in some sections (Tripathi, 2008). The carbonate content can be described as high, being around 91-96%. The depositional environment is a high energy inner to mid-shelf zone dominated by strong offshore-directed storm and or tidal induced currents (Kamp et al., 2008). The presence of unidirectional cross stratification implies that it was produced by long subaqueous sand waves migrating within a

seaway between basement highs. These were produced by strong tidal and bottom currents that were likely generated by irregular and rugged topography.

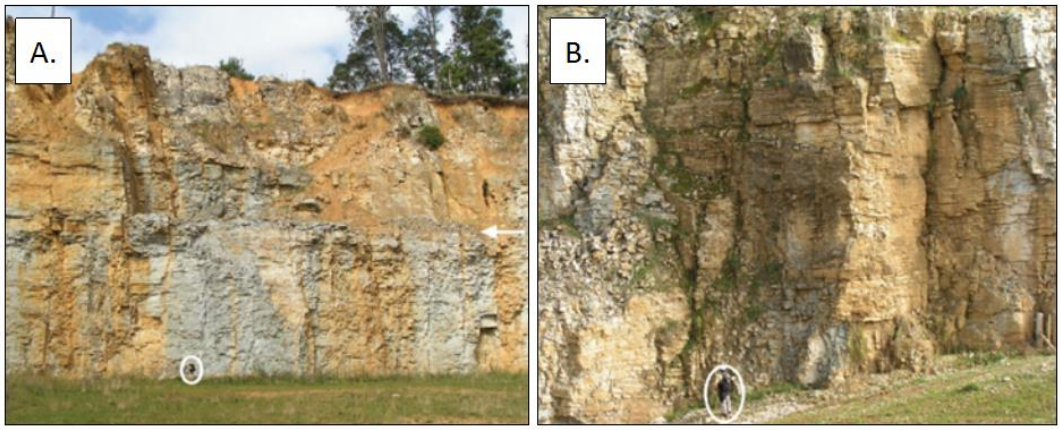


Fig. 5.1. (A.) Cross-bedded grainstone (L2) overlain by horizontally bedded grainstone (L3). Person for scale. Limestone quarry at Waitomo Valley Road, just north of the field area (Tripathi, 2008). (B.) Tabular cross-bed sets of grainstone (L2). Person for scale. Limestone quarry at Waitomo Valley Road, just north of the field area (Tripathi, 2008).

Horizontally Bedded Grainstone (L3)

The horizontally bedded grainstone facies forms units up to tens of meters in thickness and represents much of the upper part of the Orahiri Formation and most of Otorohanga Limestone, being well exposed at the McDonald's Lime, Oparure quarry west of Te Kuiti (Fig. 5.2.) (Column 4, Appendix I). It is also well exposed in Honikiwi, directly north of the map area, overlying a sandstone facies (Kihi Sandstone) (Fig. 5.3). It is described as having well developed beds, averaging 2-10 cm (well developed flagginess is characteristic). It is a medium to very coarse grainstone, abraded and poorly to moderately sorted. Bryozoans, echinoderms, benthic foraminifers, and occasional bivalves and calcareous red algae (rare planktic foraminifers) are present throughout many sections (Tripathi, 2008). The carbonate content can be described as high, being around 81-99%. The depositional environment is a high energy inner to mid, wave dominated shelf zone (similar environment to the cross stratified facies L2) (Kamp et al., 2008). Interrelations with the cross-bedded limestone facies (L2) implies a lateral variation

demonstrating that conditions fluctuated from a wave to current dominated shelf with these settings changing locally due to complex topography.



Fig. 5.2. Cavernous weathering (arrow) characterizes an "Irregularly bedded rudstone-grainstone" (L5) unit overlying prominent "Flaggy grainstone" (L3). Oparure Limestone quarry (Column 4, Appendix I) (Modified from Tripathi, 2008) (N 5754500 E 1781100).

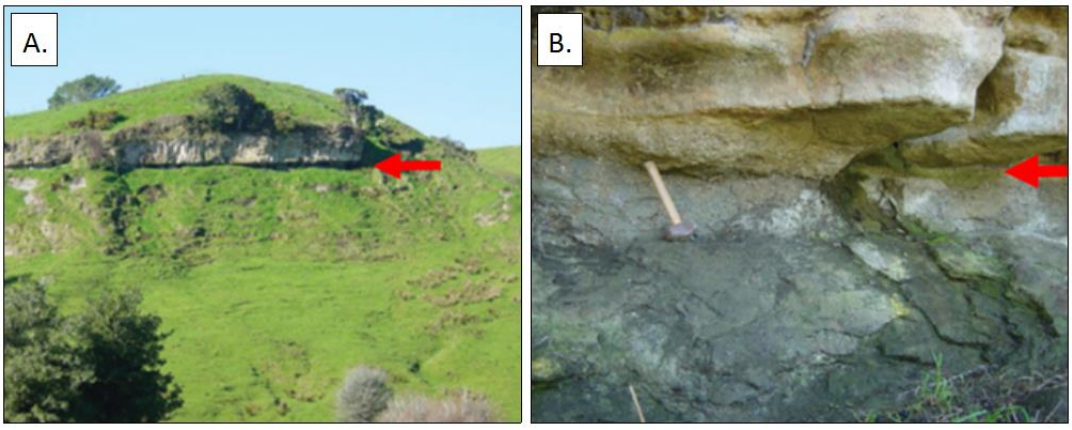


Fig. 5.3. (A.) Sharp and broadly undulating contact (arrow) between bioturbated muddy sandstone (Kihi Sandstone Member) and overlying low-angle cross-bedded grainstone (Orahiri Formation). Outcrop is approximately 20 m high. Honikiwi, just north of the field area (Modified from Tripathi, 2008). (B.) A bioturbated glauconitic sandstone unit (Kihi Sandstone Member) is truncated at the top by a wave planed surface (arrow), overlain by slightly sandy grainstone (Orahiri Formation) with a thin basal pebble grit and containing abundant skeletal fragments(transgressive lag deposit). Waitomo Valley Road, just north of the field area (Modified from Tripathi, 2008).

Sandy Grainstone-Packstone (L4)

The sandy grainstone-packstone facies occurs in the lower section of Orahiri Formation and comprise the dominant part of Mangaotaki Limestone Member (Fig. 5.4). It commonly varies from massive to tabular bedded units with a bedding plane (0.1-1.5 cm) rich in siliciclastic material obvious in places. It is a coarse to very coarse grainstone with medium to coarse quartz sand grains common and is poorly to moderately sorted. It contains echinoderm, large benthic foraminifers (*Amphistegina*), bryozoans, and occasional bivalves and calcareous red algae (rare planktic foraminifers) (Tripathi, 2008). The carbonate content can be described as moderate to high, being around 42-87%. The depositional environment for this facies is also suggested to be very similar to the cross stratified and horizontally bedded facies which is an inner to mid-shelf, high energy environment. The high quantity of quartz and sand along with the presence of calcareous red algae and *Amphistegina* support the near shore shallow depositional setting (Tripathi, 2008). The activity of intense bioturbation destroyed a large quantity of the original depositional structures causing the rocks to appear massive.

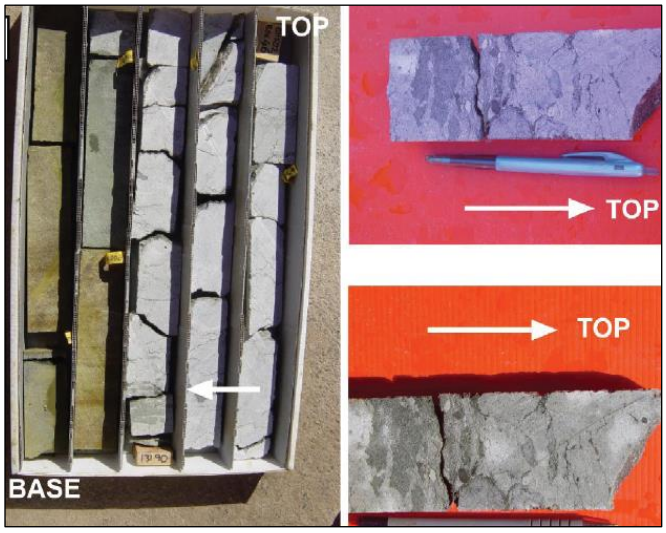


Fig. 5.4. Slightly irregular scoured contact (arrow) between dark greenish-grey muddy glauconitic sandstone (Kihi Sandstone Member) and overlying sandy grainstone-packstone (L4) (Orahiri Formation). Two insets show close-ups of this contact. Note the glaucontic, burrowed mottled texture of the sandstone below the contact and rounded pebbles in the overlying glauconitic grainstone-packstone unit. Photograph of core from BH-502, Oparure Limestone Quarry (Column 4, Appendix I) (Tripathi, 2008).

Massive to Irregularly Bedded Fossiliferous Rudstone-Grainstone (L5)

The massive to irregularly bedded fossiliferous rudstone-grainstone facies forms isolated 0.2-12 m-thick units and comprises much of the Waitanguru Limestone Member. It is well exposed west of Waipa Fault in outcrops and is evident in cuttings within the Oparure quarry (Column 4, Appendix I). It can be described as massive to irregularly bedded (occasionally well bedded 20-100 cm-thick beds) and commonly develops a "knobbly" to "blocky" weathering feature. It is a medium to coarse grainstone with common large skeletal fragments and is poorly to moderately sorted. It contains bryozoans (up to 80 %), echinoderms, benthic foraminifers, common bivalves and gastropod moulds and occasional calcareous red algae. The carbonate content can be described as high, being around 98-100%. The depositional environment for this facies is also suggested to be similar to the ones stated above, which is at high energy inner mid-shelf depths. This is also reinforced by the presence of bryozoan mound build up in some sections and the occurrence of calcareous red algae and *Amphistegina*, similar to facies L4 (Tripathi, 2008). The presence of isopachous sea floor cements implies a high-energy setting and a depositional mechanism relating to substantial wave and/or current agitation.

Massive to Horizontally Bedded Skeletal Packstone-Wackestone (L6)

The massive horizontally bedded skeletal packstone-wackestone facies occurs predominantly at the top of the Otorohanga Limestone and rapidly passes upwards into deep-water planktic foraminiferal rich siliciclastic beds (Mahoenui Group, Taumatamaire Formation). It is generally very thin throughout the field area and represents a gradational contact between the Te Kuiti and Mahoenui Group as depositional environment changed to deeper water. It is lithologically a massive to well bedded (2-25 cm) packstone with prominent sub-horizontal to bifurcating thin (0.5-1.5 cm) silty interbeds. There is moderate to abundant planktic foraminifera with subequal proportions of echinoderms, benthic foraminifers, bivalve fragments and occasional whole well preserved echinoderms. Bryozoans and calcareous red algae are also absent or present in traces (Tripathi, 2008). The carbonate content can be described as moderate to high, being around 59-89%. The depositional environment is outer shelf to slope. The bioturbated siliciclastic interbeds represent sediment that most likely accumulated during low energy periods (post-storm), and

they alternate with relatively higher energy fine-grained packstone-wackestone beds, likely deposited during storm events (Tripathi, 2008).

5.2.2 Sandstone Facies

Te Kuiti Group sandstone facies in Te Kuiti (BF33) mapping area are very limited and are only present within small sections of Orahiri Formation, more specifically recognized as the Waitomo Sandstone Member. This section describes the nature of each facies based dominantly on field observations and some laboratory analysis. Depositional mechanisms and paleoenvironments are also briefly discussed when applicable.

Massive Glauconitic Muddy Sandstone (S1)

The massive glauconitic muddy sandstone facies occurs mainly within the vicinity of Waitomo (Column 7, Appendix I) but also forms isolated lensoidal bodies within the Orahiri Formation/Otorohanga Limestone east of Te Kuiti (Column 6, Appendix I). This facies is effectively the "Waitomo Sandstone Member" described by Nelson (1978) from the type Waitomo location outcrop shown in Fig. 5.5. It is typically massive with a smooth weathering profile and is poorly to moderately cemented. It is a fine to very fine bioturbated, poorly sorted sandstone. Echinoderms, bryozoans and benthic foraminifers are abundant in sections and the presence of calcareous red algae and bivalves is rare (Tripathi, 2008). The carbonate content can be described as low to moderate, being around 20-60%. The depositional environment of this facies is suggested to be moderate energy, mid to outer shelf setting. The rate of bioturbation is suggested to be uniform with the slow rate of sediment accumulation causing its massive appearance. The limited deposition of this facies, suggested by Tripathi (2008), could be caused by an increase in terrigenous sediment supply associated with the active faulting and/or subsidence in this region.



Fig. 5.5. Massive glauconitic muddy sandstone (S1) comprise Waitomo Sandstone Member of the Orahiri Formation. The moderately cemented fine sandstone is variably glauconitic and displays extensive bioturbation in places (Tripathi, 2008).

5.2.3 Siltstone Facies

Te Kuiti Group siltstone facies in map BF33 (Enclosure 1) are also very limited and are only present within limited parts of Whaingaroa Formation and is more specifically recognized as the Whaingaroa Siltstone Member. This section describes the nature of each facies based dominantly on field observations and some laboratory analysis. Depositional mechanisms and paleoenvironments are also briefly discussed when applicable.

Massive Calcareous Siltstone (Z1)

The massive calcareous siltstone facies is evident in the field area as the Whaingaroa Siltstone and is distributed sporadically in thin sections. This facies is limited due to more mud and sand dominated deposition during the Whaingaroan stage. It can be described as a massive blue-grey, cemented siltstone with no obvious structures. There is occasional concretionary bands with ellipsoidal shaped concretions up to 10 cm in size. It is fine grained and has occasional traces of, moderately sorted fine to very fine sandstone. Planktic and benthic foraminifera are also present with sparse macrofossils (Tripathi, 2008). The carbonate content can be described as moderate to high, being around 33-79%. The depositional environment of this facies is suggested to be around outer shelf to upper bathyal setting due to the abundance of *Zoophycus* ichnofacies implying marine, quiet-

water, muddy substrates (Tripathi, 2008). Deposition was likely dominated by hemipelagic settling of background sedimentation.

Table 5.1. Summary of the facies present in each member of the Otorohanga Limestone, Orahiri Formation and Whaingaroa Formation within Te Kuiti Group.

Group	Formation	Member	Facies
Te Kuiti Group	Otorohanga Limestone	Piopio Limestone (OtC)	L1, L3, L4, L6, Z1
		Waitanguru Limestone (OtB)	L5
		Pakeho Limestone (OtA)	L1, L4
	Orahiri	Waitomo Sandstone	S1
		Te Anga Limestone (OrB)	L1, L3, L5
		Mangaotaki Limestone (OrA)	L1, L4
	Whaingaroa	Whaingaroa Siltstone	Z1

5.3 Mahoenui Group Facies

5.3.1 Mudstone Facies

Mahoenui Group is dominated by mudstone facies in the BF33 map area and is represented by Taumatamaire Formation. The Taumaranui Formation flysch sequence, which is not distinguished in the field area as a separate map unit, also contains thin layers of this facies deposited between turbidite beds (Simms, 1999). The mudstone facies is a grey, frittery, slightly fossiliferous, calcareous mudstone varying in sand content. Concretionary layers, shell fragments and Mesozoic basement granules are also common. This section describes the nature of each facies based dominantly on field observations and some laboratory analysis. Depositional mechanisms and paleoenvironments are also briefly discussed.

Massive Mudstone (M1)

Massive mudstone is the dominant facies in Taumatamaire Formation, forming as massive dark grey, frittery, slightly fossiliferous, bioturbated, calcareous mudstone with ≤10% sand content (Fig. 5.6). This facies is widespread throughout the field area, with the Taumatamaire Formation being the most evident formation, in all groups, throughout the region. This facies contains a flaggy and mass-emplaced limestone unit. This facies was probably deposited at outer shelf to upper bathyal depths- see the results of foraminiferal analyses reported in Simms (1999). The depositional mechanism is probably one out of sediment suspension through hemipelagic sedimentation.



Fig. 5.6. Massive mudstone facies (M1) in Taumatamaire Formation along State Highway 4 (N 5740500 E 1789100).

Cryptically Bedded Mudstone (M2)

This cryptically bedded mudstone facies is a weakly planar-bedded, frittery, slightly fossiliferous mudstone. It is defined by the presence of poorly developed planar bedding and is randomly distributed in thin sequences throughout the field (>15 m-thick) and commonly directly underlies Cherry Tree Limestone Member as illustrated by stratigraphic column 9 (see Appendix I). This facies suggests the same depositional depth range as the massive mudstone unit described above, which was around outer shelf to upper bathyal depths. Simms (1999) proposes that the most likely depositional mechanism for this facies is mud plumes or mud turbidites, which are also influenced by background mud sedimentation. This is reinforced by

Piper (1987), who describes that deep depositional environments expressing massive and sandy silts are of turbidite origin.

Sandy Mudstone (M3)

The sandy mudstone facies is described as a massive, dark grey, non-frittery, fossiliferous (shell fragments), calcareous sandy mudstone and is commonly located at the base of Taumatamaire Formation, directly overlying Te Kuiti Group as demonstrated in stratigraphic column 8 (see Appendix I). This facies most likely formed at mid to outer shelf depths and represents a gradational contact transitioning between Te Kuiti Group and Mahoenui Group. The most likely depositional mechanism that was present for this facies, supported by Piper (1978), is from coarse-grained sediment suspension. Simms (1999) also proposes that some of the sand fraction could have been supplied by sand-rich mass emplaced deposits.

5.3.2 Sandstone Facies

Mahoenui Group sandstone facies in map BF33 are predominantly restricted to the Taumarunui Formation, but some thick sandstone units occur within Taumatamaire Formation. The sandstone facies can generally be described as grey (fresh) to orange (weathered), well-sorted, fine sandstone. The mechanism of deposition is mass-emplacement at mid-bathyal depths. This section describes the nature of each facies based dominantly on field observations. Depositional mechanisms and paleoenvironments are also briefly discussed.

Massive Sandstone (S2)

The massive sandstone facies is described as a massive grey (fresh) to orange (weathered), well-sorted, fine sandstone, which ranges in thickness from 1-8 m. Within this facies there is variation, as exposed at the Pukerimu Road (Column 14, Appendix I) relating to massive clast-bearing sandstone unit (S2a). Simms (1999) describes them as mud rip-up clasts that were influenced by underlying mudstone beds when deposition occurred. Because this sandstone unit occurs in both Mahoenui Group formations, the environment of deposition relates to the depth range of these units. This suggests an outer shelf, to bathyal depth. It is likely that this facies was deposited from large magnitude debris flows, which are supported

by matrix strength, dispersive pressure and buoyancy allowing transport of sediment of all sizes.

Channelized Sandstone (S3)

The channelized sandstone facies is described as a massive grey (fresh) to orange (weathered), well-sorted, fine sandstone, which ranges in thickness from 1-8 m and displays major variations in thickness laterally. This channelized sandstone is located around the Te Kuiti, Pukerimu and Mapara areas (Fig. 5.7). The depositional environment of this facies is similar to the massive sandstone facies (around outer shelf to mid-bathyal). This facies was also likely deposited as large-scale debris flows due to its structureless nature and the presence of rip-up clasts.

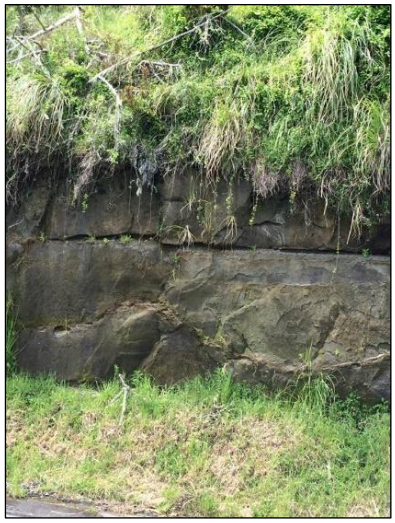


Fig. 5.7. Channelized sandstone sequence (S3) outcropping along Pukerimu Road (N 5739200 E 1793500).

5.3.3 Interbedded Sandstone-Mudstone Facies

Mahoenui Group interbedded sandstone-mudstone facies are also predominantly restricted to Taumarunui Formation but do occur within Taumatamaire Formation. This facies can be described as grey, poorly to well-sorted, massive/graded sandstone interbedded with massive, dark grey, frittery, slightly fossiliferous, calcareous mudstone with variable sand content. This section describes the nature of each facies based dominantly on field observations. Depositional mechanisms and paleoenvironments are also briefly discussed.

Interbedded Massive Sandstone-Mudstone (I1)

The interbedded massive sandstone-mudstone facies is dominantly in Taumarunui Formation, which is only present in limited locations within the southern region of the field area. It is lithologically described as a grey (fresh) to orange (weathered), well sorted, massive sandstone, which range in thickness from 1 cm to 1 m, interbedded with massive, dark grey, frittery, slightly fossiliferous, calcareous mudstone. The depositional environment of this facies in the Taumarunui Formation is between upper to mid-bathyal and in the Taumatamaire Formation it is suggested to be as shallow as inner to mid-shelf. The method of deposition is most likely a sandy debris flows forming the sandstone units and turbidity currents forming the mudstone units.

Graded Sandstone-Mudstone (I2)

The graded sandstone-mudstone facies is present in some isolated parts of Taumatamaire Formation and are characterized as a grey (fresh) to orange (weathered), graded sandstone-mudstone, which ranges in thickness from 1 cm to 1 m, interbedded with massive, dark grey, frittery, slightly fossiliferous, calcareous mudstone. Units that display this facies are well exposed along Pukerimu Road, south of Te Kuiti (Column 14, Appendix I) and demonstrate a turbidite sequence (Fig. 5.8). Because of the large variation in sand to mud ratios throughout this facies there have been three variations allocated; interbedded graded sandstone-mudstone facies with a low sand:mud ratio (I2a) (<30% sandstone beds in the total sediment contained in the sequence), interbedded graded sandstone-mudstone facies with an intermediate sand:mud ratio (I2b) (30-70% sandstone beds in the total sediment contained in the sequence), interbedded graded sandstone-mudstone facies with a high sand:mud ratio (I2c) (>70% sandstone beds in the total sediment contained in the sequence) (Simms, 1999). The depositional environment of this facies is the same as the massive facies within Taumarunui Formation, being between upper to mid-bathyal. The depositional mechanism for this facies has been defined by Bouma (1962) as a turbidity current. Fig. 5.9 illustrates the divisions present in a turbidite, which are comprised of a normally graded deposit.



Fig. 5.8. Interbedded graded sandstone – mudstone sequence (I2) (turbidite sequence) on road section along Pukerimu Road (Column 14, Appendix I) (N 5739200 E 1793500).

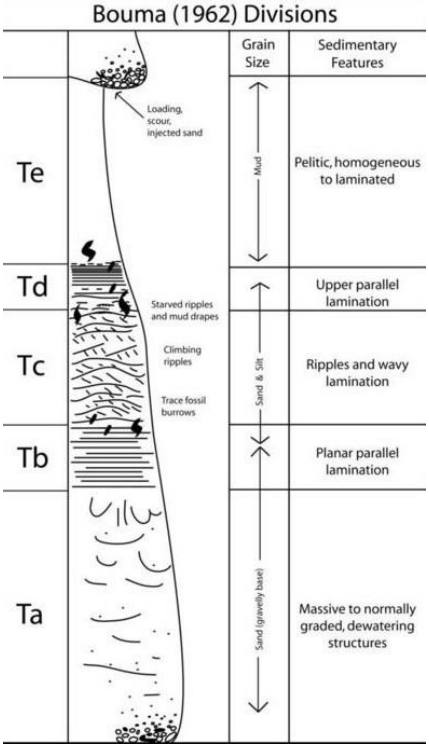


Fig. 5.9. Bouma (1962) turbidite divisions.

Interbedded Slumped Sandstone-Mudstone (I3)

The interbedded slumped sandstone-mudstone facies is present within the Taumarunui Formation flysch sequence and can be described as a grey (fresh) to orange (weathered), graded or massive sandstone, which range in thickness 1-5 m, interbedded with massive, dark grey, frittery, slightly fossiliferous, calcareous

mudstone. This facies is only present at the Madonna Falls location within the map area (Column 16, Appendix I) and contains large intraformational asymmetric folds within the slump unit. The depositional environment of this facies is the same as the massive and graded beds within Taumarunui Formation, being between upper to mid-bathyal. The method of deposition is by slump deposition.

5.3.4 Limestone Facies

Mahoenui Group limestone facies are limited to the Cherry Tree Limestone Member within Taumatamaire Formation and is localized around the northwestern part of Te Kuiti and east of Te Kuiti, along Walker Road (Column 9 & Column 6, Appendix I). Thin sections have also been recognized south of Te Kuiti, along the Mangaokewa Stream (Column 7, Appendix I). The limestone facies is broadly characterized as a light grey/white, flaggy, moderately to well indurated, poorly to well-sorted limestone with variable content of terrigenous material. This section describes the nature of each facies based dominantly on field observations. Depositional mechanisms and paleoenvironments are also briefly discussed.

Flaggy Amalgamated Limestone (L7)

The flaggy amalgamated limestone facies is characterized as a light grey, coarse grained, well indurated, amalgamated flaggy limestone with incipient pinch and swell (20-80 cm-thick) flags separated by silty mudstone layers (1-5 cm-thick). It is described in this field area more specifically as the Cherry Tree Limestone Member. Based on benthic foraminifera, Taumatamaire Formation (Simms, 1999) is inferred to have been deposited at upper bathyal depths. The depositional mechanism is most likely to be related to redeposition in sporadic mass flow events due to the presence of small mud rip-up clasts within the limestone.

Massive Limestone (L8)

The massive limestone facies is also recognized within the Cherry Tree Limestone Member and is characterized as a grey (fresh), moderately to well indurated, moderately to well-sorted, massive limestone with variable sand and mud content. It is most evident in thin sections within the Taumatamaire Formation at the old quarry east of Te Kuiti (Column 13, Appendix I), near the margin of the newly recognised Te Kuiti Fault. This facies is a lateral equivalent of the flaggy

amalgamated limestone facies. The environment of deposition is likely to be similar, being upper bathyal depth. The depositional mechanism is also most likely to be related to redeposition in sporadic mass flow events.

Table 5.2. Summary of the facies present in each member of the Taumatamaire Mudstone and Taumaranui Flysch within the Mahoenui Group.

Group	Formation	Member	Facies
Mahoenui Group	Taumatamaire		M1, M2, M3, I2
		Cherry Tree Limestone	L7, L8
	Taumarunui		M2, I1, I3

5.4 Mokau Group Facies

5.4.1 Sandstone Facies

Mokau Group in the map area is represented by the Bexley Sandstone and the accompanying Mangarino Member in some areas. The Bexley Sandstone is comprised of a sandstone facies and a conglomerate facies. The Mangarino Member is described in its entirety as a thick interbedded sandstone-mudstone. This section describes the nature of each facies based mainly on field observations. Depositional mechanisms and paleoenvironments are also briefly discussed.

Massive (faintly bedded) Sandstone (S4)

The massive sandstone facies is the dominant facies representing the Bexley Sandstone and can be described as a massive to slightly bedded lightly grey (fresh) to orange brown (weathered), well sorted, fine grained, moderately calcareous, poorly fossiliferous, slightly argillaceous sandstone (Fig. 5.10). Vonk (1999) describes the depositional environment as being shoreface to foreshore and that it relates to transgression over earlier sequences producing a ravinement surface, which is a product of shoreline advance.

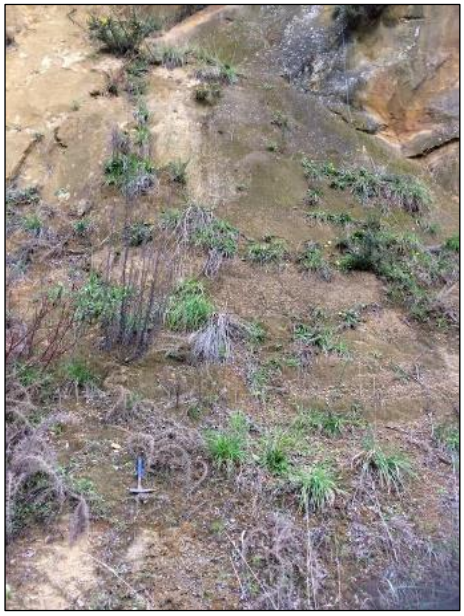


Fig. 5.10. Massive sandstone (S4) at the base of the Bexley Sandstone at a road cutting along SH3 just north of Te Kuiti (Column 19, Appendix I) (N 5763000 E 1790100). Conglomerate facies (C1) also evident below the massive sequence.

Cross Bedded Sandstone (S5)

The cross bedded sandstone facies is also a common facies within Bexley Sandstone and can be described as a small to large scale, hummocky, trough, tabular or swally cross-stratified (low angle), and medium to fine sandstone. It may also include mud-draped current and wave ripples in some sections. The depositional environment is similar to the massive sandstone facies, which is shoreface to foreshore, but it relates more to megaripples and sand wave migration offshore in response to unidirectional storm currents on a storm dominated shoreface.

5.4.2 Interbedded Sandstone-Mudstone Facies

The interbedded sandstone-mudstone facies are limited to a small section of Mokau Group in Te Kuiti (BF33) mapping area. This facies relates to Mangarino Member, which is present in the central and northwestern parts of the field area (Mangarino Road, Te Kuiti - Column 17, and Te Anga Road, Waitomo - Column 24). This section describes the nature of each facies based dominantly on field observations. Depositional mechanisms and paleoenvironments are also briefly discussed.

Thick Bedded Sandstone-Mudstone (I4)

The thick-bedded sandstone-mudstone facies ultimately relates to the Mangarino Member and is only present in isolated areas within the map area (east of Te Kuiti and Waitomo regions). It can be described as a thickly bedded (0.2-4 m) alternating carbonaceous sandstone and mudstone succession (Fig. 5.11). Sandstone beds appear massive but the presence of carbonaceous material and limonite staining reveals thin parallel and wavy laminations. Mudstone beds are slight to moderately carbonaceous, dark grey, slightly sandy, fissile and bioturbated with fine sand or silt infilling burrows. The depositional environment is described as alternating between channel to mud flat, and intertidal mud flat. It can be implied that the parallel and wavy lamination in sandstone beds developed from variable tidal current speeds. Mudstone beds accumulated in intertidal mudflats where sediment movement was limited with moderate bioturbation.



Fig. 5.11. Thick bedded sandstone – mudstone of the Mangarino Member outcropping on a section along Te Anga Road, just north of Waitomo (Column 24, Appendix I) (N 5763900 E 1780800).

5.4.3 Conglomerate Facies

The conglomerate facies are limited to small sections of Mokau Group in Te Kuiti (BF33) mapping area. This facies relates to conglomerate beds within the Bexley Sandstone. This section describes the nature of each facies based dominantly on

field observations. Depositional mechanisms and paleoenvironments are also briefly discussed.

Greywacke and Quartzose Conglomerate (C1)

The greywacke and quartzose conglomerate facies is displayed as thin layers near the base of the Bexley Sandstone throughout the field area. It can be described as a massive to poorly bedded, both normally and reverse graded, clast-supported conglomerate. Clasts are equant, subangular to well rounded, and pebble to cobble sized (4-25 cm diameter) with no significant imbrication. Composition of the clasts is predominantly greywacke with some argillite, vein quartz and rare chert. Larger clasts exhibit shear planes and jointing and the matrix is composed of poorly sorted, medium to coarse carbonaceous sandstone. Vonk (1999) describes the depositional environment for this facies as being either a fan delta or a braid plain delta. Fan conglomerates accumulate in fluvial systems that project out from a point source into a fan shaped depositional lobe. Braid plain delta conglomerates accumulate due to coalescing fluvial channels from multiple sources.



Fig. 5.12. Conglomerate layer (C1) present in the Bexley Sandstone outcrop along Mangarino Road, Te Kuiti (Column 17, Appendix I) (N 5758500 E 1791100).

Table 5.3. Summary of the facies present in the Bexley Sandstone within the Mokau Group

Group	Formation	Member	Facies
Mokau Group	Bexley Sandstone		S4, S5, C1
		Mangarino Member	I4

5.5 Otunui Formation Facies

5.5.1 Sandstone Facies

Otunui Formation is comprised of a sandstone facies and in some sections a shellbed facies, which is more specifically known as Mangarara Formation. This section describes the nature of each facies based dominantly on field observations. Depositional mechanisms and paleoenvironments are also briefly discussed.

Tuffaceous Sandstone (S6)

The sandstone facies represents the Otunui Formation throughout the field area and can be described as a blue grey (fresh) to yellow brown (weathered), fine to medium grained, moderately sorted, argillaceous, bioturbated sandstone. This facies is only present in the southern part of the field area, south of Te Kuiti, and outcrops extensively along Mangaokewa Road (Column 23, Appendix I). Tuffaceous material occurs in lenses and is yellowish brown in outcrop. The depositional environment is suggested to be outer shelf to upper slope and related to hemipelagic suspension sedimentation and low energy turbidity currents. Tuffaceous lenses are remains of tephra beds derived from offshore Taranaki andesitic volcanism.

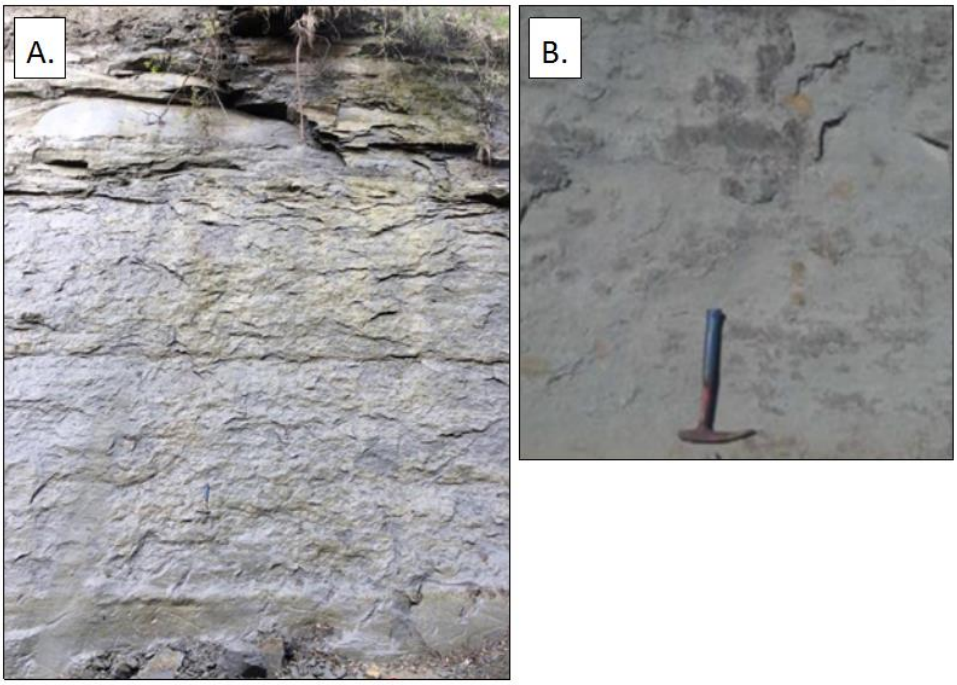


Fig. 5.13. (A.) Tuffaceous sandstone (wet) (S5) at an outcrop of Otunui Formation at a road cutting along Mangaokewa Road (Column 23, Appendix I) (N 5740900 E 1801000). (B.) Tuffaceous sandstone (dry) (S5) at an outcrop of Otunui Formation at a road cutting along Mangaokewa Road (N 5740900 E 1801000). Mottling of Otunui Formation from weathering and burrowing.

5.5.2 Shellbed Facies

This shellbed facies is limited to Mangarara Formation in Te Kuiti (BF33) map area. It is present in the southeastern regions of the field area and is also associated with Otunui Formation. This section describes the nature of each facies based dominantly on field observations. Depositional mechanisms and paleoenvironments are also briefly discussed.

Shellbed (L9)

The shellbed facies embodies the Mangarara Formation, which is found only in the southeastern region of the field area as a basal shellbed within Otunui Formation (Column 20 & Column 22, Appendix I). It can be described as a light yellow to brown, glauconitic shellbed. Pebble layers (20 cm-thick) contain dark grey, rounded to subangular, pebbles (<5 mm diameter) supported in a matrix of fine sandstone and shell fragments. Skeletal material is dominated by bivalves, with minor echinoderms and calcareous red algae (Vonk, 1999). The depositional environment is inner shelf to high energy transgressive shoreline.

Table 5.4. Summary of the facies present in each member of the Otunui Formation and Mangarara Formation within Whangamomona Group.

Group	Formation	Member	Facies
Whangamomona Group	Otunui		S6
	Mangarara		L9

5.6 Facies summary tables

Table 5.5. Lithofacies description and depositional interpretation of Te Kuiti Group sediments in the Te Kuiti area (Topographic Sheet BF33). Modified from Kamp et al. (2008).

Limestone Facies.		
Lithofacies and code name.	Description	Depositional Environment & Mechanism.
Pebbly Grainstone - Packstone (L1)	Common to abundant sub-rounded pebbles occurring as pebble bands, or fabric supported by bioclastic silty fine sandstone. Massive, medium to coarse grainstone-rudstone, occasional large shell fragments, poorly to moderately sorted; very abraded. Fragmented pectinids, oysters, echinoderm, calcareous red algae. Carbonate content – moderate (50-60%).	Environment – near shore to inner shelf adjacent to rocky shoreline. Mechanism – transgressive lag deposited during marine encroachment.
Cross Stratified Grainstone (L2)	Sigmoidal to tabular cross- beds are low (< 100) to moderate angle (100-250); cross-beds are generally 2-15 cm-thick. Medium to very coarse grainstone, rare small pebbles and granules. Siliciclastic particles in bedding planes are fine sandstone to siltstone, moderately abraded, poorly to moderately sorted. Bryozoans, echinoderms, benthic foraminifers, occasional bivalves, coralline red algae, rare planktic foraminifers. Carbonate content – high (91-96%).	Environment – high energy inner to mid-shelf dominated by strong offshore directed storm and or tidal induced currents. Mechanism – migration of (1-5 km) long subaqueous megadunes to sand waves within a sea way between basement highs.

Horizontally Bedded Grainstone (L3)	Beds typically well developed, averaging 2- 10 cm; well developed flags. Medium to very coarse grainstone, abraded, poorly to moderately sorted. Bryozoans, echinoderms, benthic foraminifers, and occasional bivalves and calcareous red algae; planktic foraminifers rare or absent. Carbonate content – high (81-99%).	Environment – inner to mid wave dominated shelf. Mechanism – fluctuation from a wave to current dominated shelf with lateral variation into subfacies L2 indicating settings varied locally due to complex topography
Sandy Grainstone – Packstone (L4)	Massive to tabular bedded units, bedding plane (0.1 - 1.5 cm) rich in siliciclastic material in places. Coarse to very coarse grainstone, common medium to coarse quartz sand grains, abraded, and poorly to moderately sorted. Echinoderm, large benthic foraminifers (*Amphistegina*), bryozoans, and occasional bivalves and calcareous red algae; planktic foraminifers rare or absent. Carbonate content – moderate to high (42-87%).	Environment – inner to mid shelf. Mechanism – reworking of sediments by intense bioturbation destroyed most of the primary depositional structures giving the rocks a massive appearance.
Massive to Irregularly Bedded Fossiliferous Rudstone – Grainstone (L5)	Massive to irregularly bedded, occasionally well bedded (20-100 cm-thick beds), commonly develops blocky weathering feature, frequently cavernously weathered. Medium to coarse grainstone, common large skeletal fragments, abraded, poorly to moderately sorted. Bryozoans (up to 80 %), echinoderms, benthic foraminifers, common bivalves and gastropod moulds and calcareous red algae. Carbonate content – high (98-100%).	Environment – bryozoan mound buildup indicating high energy inner mid-shelf depths. Mechanism – substantial wave and/or current agitation indicated by the presence of isopachous sea floor cements.
Massive to Horizontally Bedded Skeletal Packstone – Wackestone (L6)	Massive to well bedded (2-25 cm) with sub-horizontal to bifurcating thin (0.5 -1.5 cm) silty interbeds. Micritic with fragmented bivalves (pectinids) and echinoderms, poorly to moderately sorted. Moderate to abundant planktic foraminifera with subequal proportions of echinoderms, benthic foraminifers and bivalve fragments. Bryozoans and calcareous red algae are absent or present in traces. Carbonate content – moderate to high (59-89%).	Environment – outer shelf to slope. Mechanism – alternating low energy periods (before or after storms) and high energy periods (storm events).

Sandstone Facies.		
Lithofacies and code name.	Description	Depositional Environment & Mechanism.
Massive Glauconitic Muddy Sandstone (S1)	Massive with smooth weathering profile, poorly to moderately cemented, and bioturbated. Fine to very fine sandstone, poorly sorted. Echinoderms, bryozoans and benthic foraminifers with rare presence of calcareous red algae and bivalves. Carbonate content – low to moderate (20-60%). are absent or present in traces. Carbonate content – moderate to high (59-89%).	Environment – mid to outer shelf. Mechanism – bioturbation and sediment deposition rates uniform causing massive appearance. Limited deposition caused by increase in terrigenous sediment supply.
Siltstone Facies.		
Lithofacies and code name.	Description	Depositional Environment & Mechanism.
Massive Calcareous Siltstone (Z1)	Massive blue-grey siltstone, well cemented. No obvious structures. Occasional concretionary bands with ellipsoidal shaped concretions (10 cm in size). Fine siltstone with traces of very fine to fine sandstone, moderately sorted. Planktic and benthic foraminifera, sparse macrofossils. Carbonate content – moderate to high (33-79%).	Environment – outer shelf to upper bathyal. Mechanism – hemipelagic settling of background sedimentation.

Table 5.6. Lithofacies description and depositional interpretation of Mahoenui Group, sediments in the Te Kuiti area (Topographic Sheet BF33) (Modified from Simms, 1999).

Mudstone Facies.		
Lithofacies and code name.	Description	Depositional Environment & Mechanism.
Massive Mudstone (M1)	Massive dark grey, frittery, slightly fossiliferous, calcareous mudstone with variable sand content.	Environment – between outer shelf to mid-bathyal. Mechanism – sediment suspension through hemipelagic sedimentation.
Cryptically Bedded Mudstone (M2)	Dark grey, frittery, slightly fossiliferous, calcareous mudstone with poorly developed planar bedding, sometimes visible only at a distance from the outcrop.	Environment – between an outer shelf to mid-bathyal. Mechanism – sediment suspension through hemipelagic sedimentation interrupted by mud plumes or turbidites.
Sandy Mudstone (M3)	Massive dark grey, frittery, slightly fossiliferous, calcareous mudstone with variable sand content.	Environment – outer shelf Mechanism – sediment suspension through hemipelagic sedimentation with the sand fraction being supplied by sand rich mass-emplaced deposits.

Sandstone Facies.		
Lithofacies and code name.	Description	Depositional Environment & Mechanism.
Massive Sandstone (S2), Clast Bearing (S2a)	Massive grey (fresh) to orange (weathered), well sorted, fine grained, sandstone which ranges in thickness from 1-8 m.	Environment – wide depth range from around outer shelf to mid-bathyal. Mechanism – deposited by large scale debris flows.
Channelised Sandstone (S3)	Massive grey (fresh) to orange (weathered), well sorted, fine grained sandstone which ranges in thickness from 1-8 m and displays major variations in thickness in the horizontal direction.	Environment – upper most to mid-bathyal. Mechanism – deposited by large scale debris flows.

Interbedded Sandstone – Mudstone Facies.		
Lithofacies and code name.	Description	Depositional Environment & Mechanism.
Interbedded Massive Sandstone - Mudstone (I1)	Grey (fresh) to orange (weathered), well sorted, massive sandstones which range in thickness 1 cm to 1 m, interbedded with massive, dark grey, frittery, slightly fossiliferous, calcareous mudstone.	Environment – outer shelf to mid-bathyal depths. Mechanism – sandy debris flows with the continuation of background sediment suspension through hemipelagic sedimentation.
Interbedded Graded Sandstone - Mudstone (I2), Low Sand:Mud Ratio (I2a), Intermediate Sand:Mud Ratio (I2b), High Sand:Mud Ratio (I2c)	Grey (fresh) to orange (weathered), graded sandstones which range in thickness 1 cm to 1 m, interbedded with massive, dark grey, frittery, slightly fossiliferous, calcareous mudstone.	Environment – outer shelf to mid-bathyal depths. Mechanism – turbidites with the continuation of background sediment suspension through hemipelagic sedimentation.
Interbedded Slumped Sandstone-Mudstone (I3)	Grey (fresh) to orange (weathered), graded or massive sandstones which range in thickness 1 cm to 1 m, interbedded with massive, dark grey, frittery, slightly fossiliferous, calcareous mudstone.	Environment – outer shelf Mechanism – turbidites or sandy debris flows with the continuation of background sediment suspension through hemipelagic sedimentation

Limestone Facies.		
Lithofacies and code name.	Description	Depositional Environment & Mechanism.
Flaggy Amalgamated Limestone (L7)	Light grey, coarse grained, well indurated, amalgamated flaggy limestone with incipient pinch and swell (20-80 cm-thick) flags separated by silty mudstone layers (1-5 cm-thick).	Environment – uppermost bathyal depths Mechanism – most likely redeposited in sporadic mass flow events.
Massive Limestone (L8)	Grey (fresh), moderately to well indurated, moderately to well sorted, massive limestone with variable mud and sand components.	Environment – between mid-shelf to uppermost bathyal depths. Mechanism – most likely redeposited in sporadic mass flow events.

Table 5.7. Lithofacies description and depositional interpretation of Mokau Group sediments in the Te Kuiti area (Topographic Sheet BF33) (Modified from Vonk, 1999).

Sandstone Facies.		
Lithofacies and code name.	Description	Depositional Environment & Mechanism.
Massive Sandstone (S4)	Massive lightly grey (fresh) to orange brown (weathered), well sorted, fine grained, moderately calcareous, poorly fossiliferous, slightly argillaceous sandstone.	Environment – shoreface to foreshore. Mechanism – transgression over earlier sequences produces a source diastem or ravinement surface which is a product of shoreline retreat.
Cross Bedded Sandstone (S5)	Small to large scale, hummocky, trough, tabular or swaly cross stratified (low angle), medium to fine grained sandstone. May include mud draped current and wave ripples.	Environment – shoreface to foreshore. Mechanism – megaripples and sand waves migrating offshore in response to unidirectional storm currents on a storm dominated shoreface.

Interbedded Sandstone – Mudstone Facies.		
Lithofacies and code name.	Description	Depositional Environment & Mechanism.
Thick Bedded Sandstone - Mudstone (I4)	Thickly bedded (0.2-4 m) alternating carbonaceous sandstones and mudstones. Sandstones appear massive but the presence of carbonaceous material, limonite staining reveal thin parallel and wavy laminations. Mudstones are slight to moderately carbonaceous, dark grey, slightly sandy, fissile, bioturbated with fine grained sand or silt infilling burrows.	Environment – alternating tidal channel to mud flat, intertidal mud flat. Mechanism – parallel and wavy lamination in sandstones developed from variable tidal current speeds. Mudstones accumulated in intertidal mudflats where sediment movement was limited with moderate bioturbation.
Conglomerate Facies.		
Lithofacies and code name.	Description	Depositional Environment & Mechanism.
Greywacke Quartzose Conglomerate (C1)	Massive to poorly bedded, both normally and reverse graded, clast supported conglomerates. Clasts are equant, subangular to well rounded, and pebble to cobble sized (4-25cm diameter) with no significant imbrication. Composition of the clasts is predominantly greywacke with some argillite, vein quartz and rare bed chert. Larger clasts exhibit shear planes and jointing. Matrix is composed of poorly sorted, medium to coarse grained, carbonaceous sandstone.	Environment – fan delta or braid plain delta deposition. Mechanism – fan conglomerates accumulate in fluvial systems that fan out from a point source into a fan shaped deposition lobe. Braid plain delta conglomerates accumulate due to coalescing fluvial channels from multiple sources.

Table 5.8. Lithofacies description and depositional interpretation of Otunui Formation, sediments in the Te Kuiti area (Topographic Sheet BF33) (Modified from Vonk, 1999).

Sandstone Facies.		
Lithofacies and code name.	Description	Depositional Environment & Mechanism.
Tuffaceous Sandstone (S5)	Sparsely tuffaceous blue grey (fresh) to yellow brown (weathered), fine to medium grained, moderately sorted, argillaceous, bioturbated, sparsely tuffaceous sandstone. Tuffaceous material occurs in lenses and is yellow brown in outcrop.	Environment – outer shelf to upper slope. Mechanism – hemipelagic suspension sedimentation and low energy turbidity currents. Tuffaceous lenses are remains of tephra beds derived from offshore Taranaki andesitic volcanism.

Shellbed Facies.		
Lithofacies and code name.	Description	Depositional Environment & Mechanism.
Shellbed (L9)	Light yellow to brown, coarse grained, slightly incipient bedded, glauconitic, shelly, pebbly limestone. Pebble layers (20cm) contain dark grey, rounded to subangular, pebbles <5mm diameter, supported in a matrix of medium grained sandstone and shell fragments. Skeletal material is dominated by bryozoans and bivalves, with minor echinoderms and calcareous red algae. Large sedimentary rock fragments are common throughout the limestone.	Environment – inner shelf Mechanism – bryozoan rich limestones are common on high energy open shelves around NZ. A low terrigenous sediment supply is required for these suspension feeders to dominate.

6 Synthesis of the geological history of the Cenozoic succession in the Map Area

6.1 Introduction

The stratigraphy and sedimentology of Te Kuiti Group, Mahoenui Group, Mokau Group and Otunui Formation within the Te Kuiti (BF33) map area have been outlined in previous chapters. The objective of this chapter is to establish the paleogeographic development of the sedimentary succession in the field area. This includes assessing depositional trends and proposing an interpretation of the geological history of the field area and wider geological development of the basin. Fig. 6.1 summarises relationships in time between Cenozoic formations for a cross-section through eastern Taranaki Basin and part of King Country Basin.

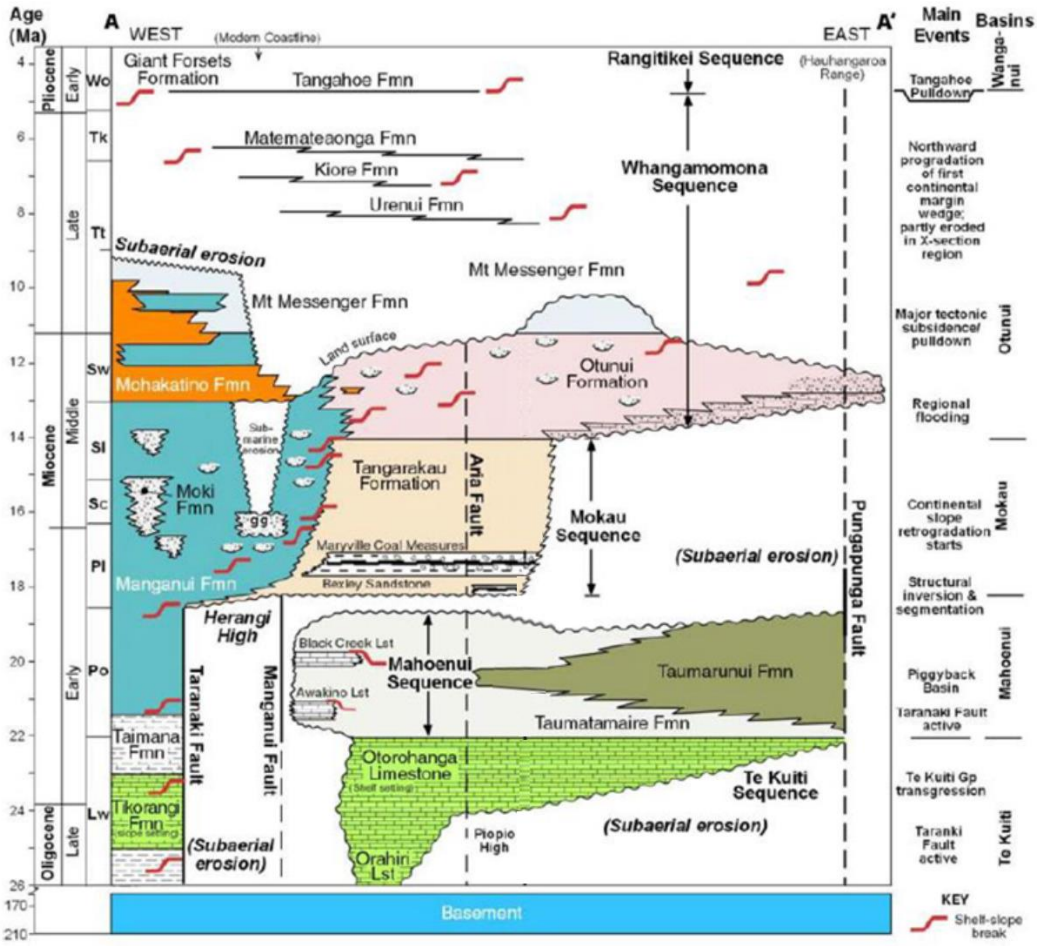
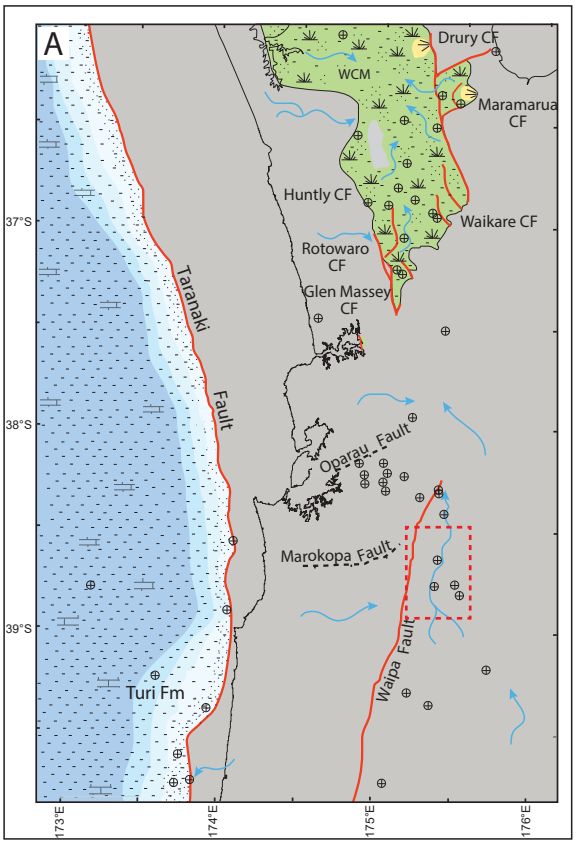


Fig. 6.1. Chronostratigraphic panel illustrating relationship between formations and 2nd order sequences of Cenozoic age cropping out between Awakino Heads (south west of the field area) and the eastern margin of King Country Basin (east of the field area) (Modified from Vonk & Kamp, 2006).

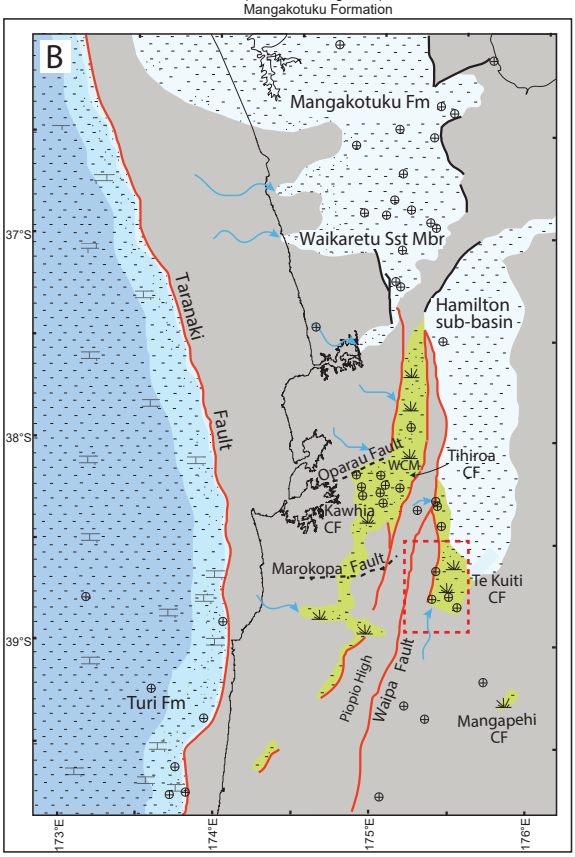
6.2 Paleogeograhic Interpretation

Paleogeographic reconstructions for Te Kuiti Group, Mahoenui Group, Mokau Group and Otunui Formation in the Waikato-King Country Basin between Port Waikato and Awakino are presented for 18 intervals (Maps A-R) during the Late Eocene to Middle Miocene. Intervals 1 to 13 within the BF33 map area have been modified from Kamp et al. (2014), who drew interpretations for Te Kuiti Group from new information about its lithostratigraphy, biostratigraphy, chronostratigraphy, facies descriptions and paleoenvironment interpretations.

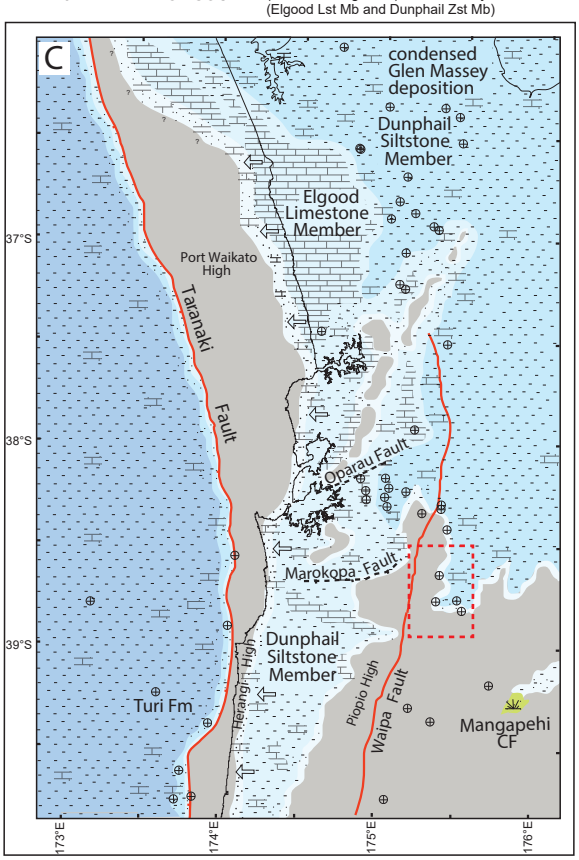
MAP 1 LATE EOCENE (Runangan) Waikato Coal Measures



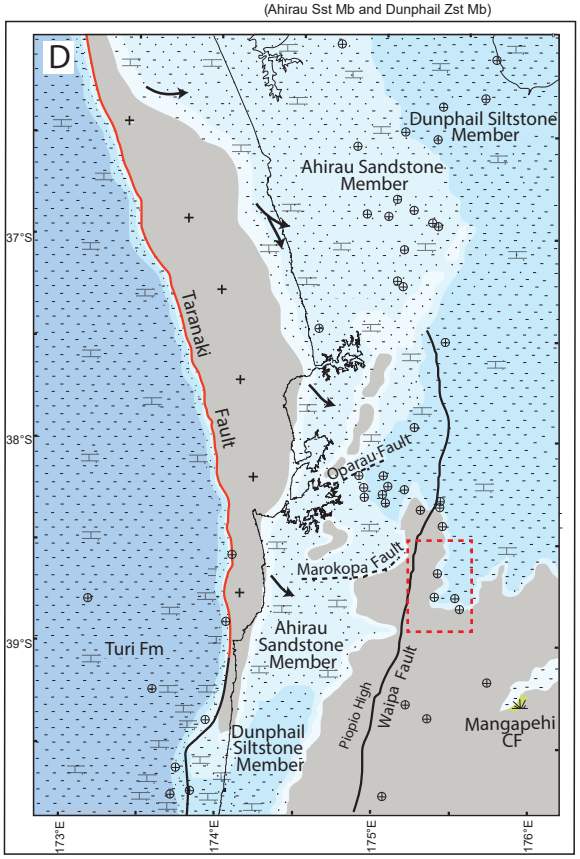
MAP 2 LATEST EOCENE (earliest Whaingaroan) Waikato Coal Measures and Mangakotuku Formation



MAP 3 EARLY OLIGOCENE (Lower Whaingaroan) Glen Massey Fm (Elgood Lst Mb and Dunphail Zst Mb)



MAP 4 EARLY OLIGOCENE (Lower Whaingaroan) Glen Massey Fm (Ahirau Sst Mb and Dunphail Zst Mb)



Map 1: Late Eocene (Runangan)

The Runangan Stage represents a period of no Cenozoic sedimentation in the BF33 map area, which at that time was a landscape with probably mild erosion. Waikato Coal Measures were accumulating farther north in a meandering river and floodplain environment, with accumulation above Triassic and Jurassic basement. In the interpretation of Kamp et al. (2014), Taranaki Fault was taken as being active at this time. Waipa Fault is also assumed to have been active at this time, but there is no evidence for this in the BF33 map area, mainly because the fault offset as observed today is normal displacement of Late Pliocene and Pleistocene age.

Map 2: Latest Eocene (earliest Whaingaroan)

During the earliest Whaingaroan, Te Kuiti Group accumulated as a consequence of regional subsidence and regional onlap. Waikato Coal Measures was deposited in narrow valleys between basement highs, thinning eastward, onlapping the Rangitoto Range. The Piopio High was present throughout this time, segmenting the areas of coal measure deposition to the west and east of it. Waipa-Aria Fault and related faults to the west probably controlled the location of coal measure accumulation. North of the BF33 map area, Mangakotuku Formation accumulated conformably above Waikato Coal Measures, meaning that coal measure lithofacies are time-transgressive on basement towards the south.

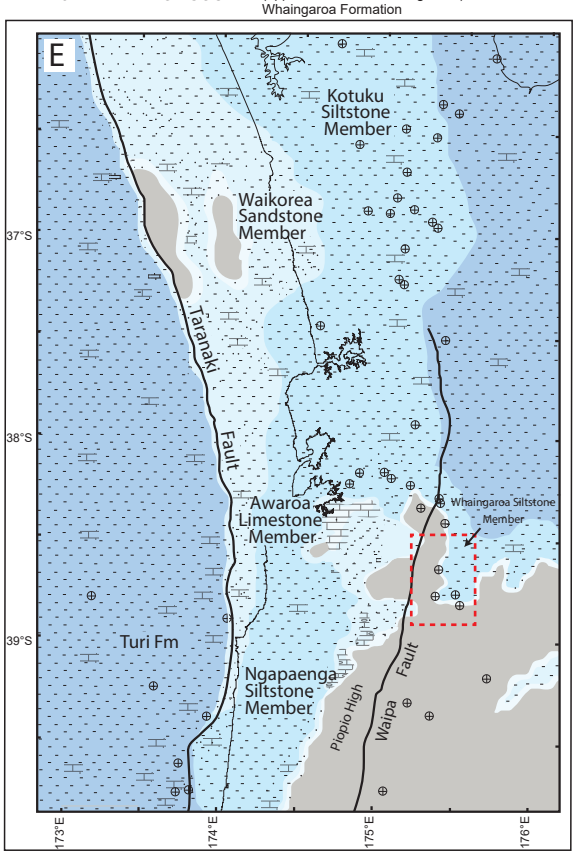
Map 3: Early Oligocene (lower Whaingaroan)

The majority of the Waikato and King Country basins were shallow marine areas during the lower Whaingaroan. Coastal onlap occurred along the eastern margin of Herangi High and either side of the Piopio High. These areas formed rocky shorelines and zones of high carbonate productivity, particularly north of Raglan harbour (Elgood Limestone). Calcareous sandstone was dispersed across shelf environments between the basement highs and around their margins. Dunphail Siltstone, being a calcareous silty sandstone to calcareous sandy siltstone, accumulated in mid to outer shelf environments in central parts of Waikato Basin, including in the map area east of Piopio High.

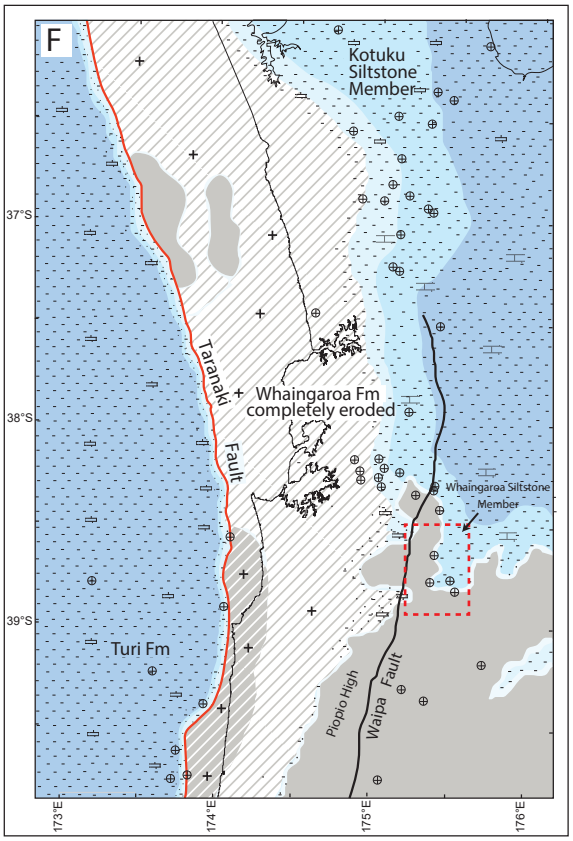
Map 4: Early Oligocene (lower Whaingaroan)

Ahirau Sandstone accumulated widely across the Waikato and King Country basins during the lower Whaingaroan, including within the eastern part of the BF33 map area. This reflects a relative sea-level fall, most likely due to a change in the rate of subsidence, possibly related to less faulting along Taranaki Fault. During this stage, Turi Formation accumulated in Taranaki Basin at bathyal depths (Kamp et al., 2014).

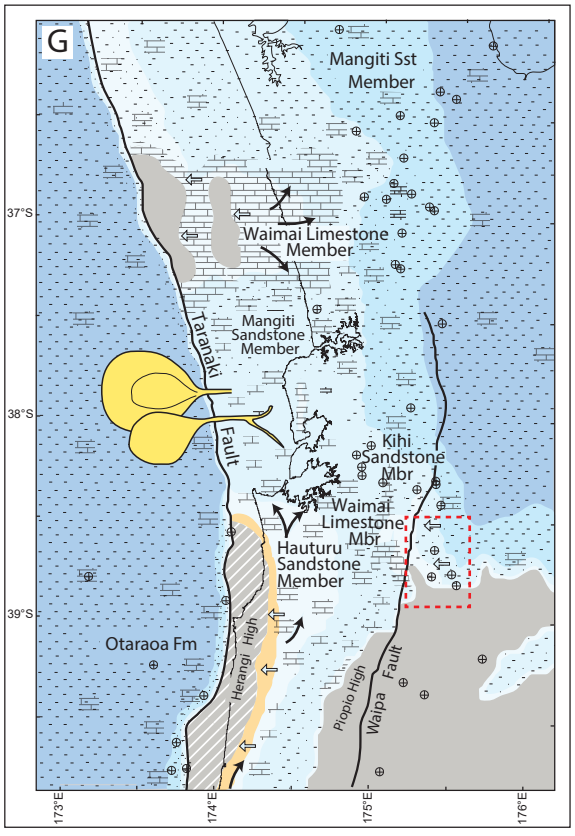
MAP 5 EARLY OLIGOCENE (uppermost-Lower Whaingaroan) Whaingaroa Formation



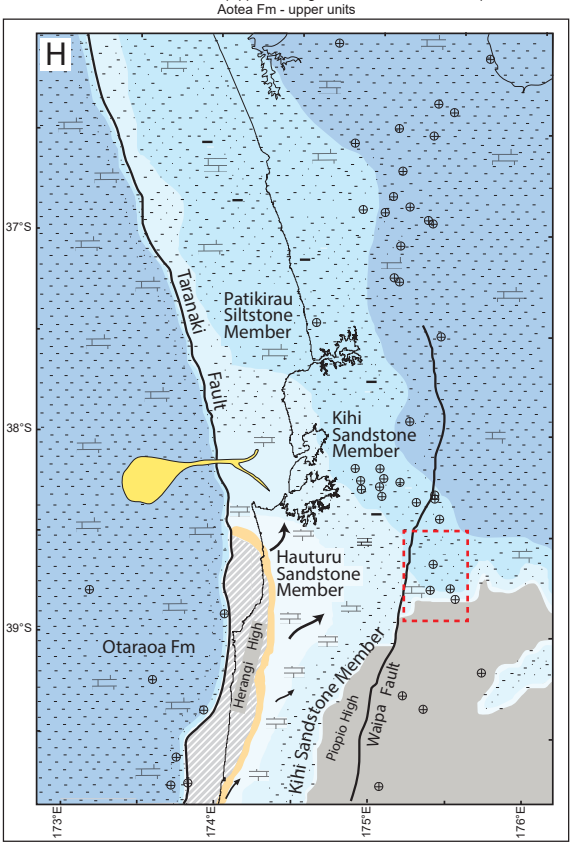
MAP 6 MIDDLE OLIGOCENE (mid-Whaingaroan) Extent of sub-Aotea unconformity



MAP 7 LATE OLIGOCENE (Upper Whaingaroan) Aotea Fm - lower units



MAP 8 LATE OLIGOCENE (Upper Whaingaroan to lower Duntroonian) Aotea Fm - upper units



Map 5: Early Oligocene (uppermost-lower Whaingaroan)

During the upper part of the lower Whaingaroan, relative sea level rise led to accumulation of Whaingaroa Formation calcareous siltstone widely across the basins. Basal facies of limestone (Awaroa Limestone Member) accumulated as a transgressive shellbed in some places, including west of the BF33 map area. Within the BF33 map area and southwest of it, a calcareous fine sandstone was the predominant highstand facies (Whaingaroa Siltstone Member) deposited, whereas to the north of the field area it is known as Kotuku Siltstone Member.

Map 6: Middle Oligocene (mid-Whaingaroan)

During the mid-Whaingaroan, an unconformity developed within the Waikato and King Country basins between Whaingaroa and Aotea formations and it has been inferred that large areas of Whaingaroa Formation were truncated, possibly by subaerial erosion or by wave planation during subsequent accumulation of Aotea Formation (Kamp et al., 2014). The erosion of Whaingaroa Formation is more pronounced along the western basin margin, possibly reflecting activity on Taranaki Fault at this time. This unconformity is not evident in the BF33 field area, where the succession is characterized by Whaingaroa Siltstone Member. An instance of this formation has been observed and illustrated in stratigraphic column 5, in the northeastern region of the field area (Ngapeke Road) (see Appendix I).

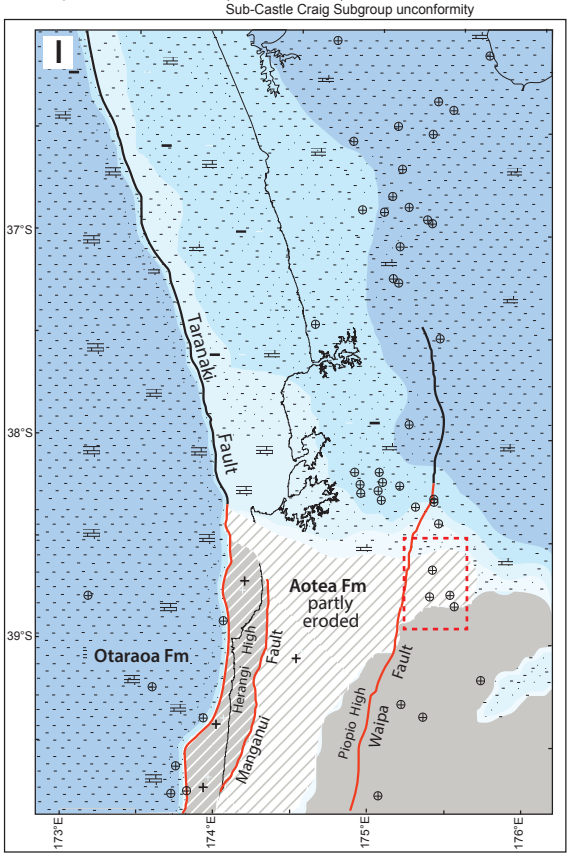
Map 7: Late Oligocene (upper Whaingaroan)

During the upper Whaingaroan, Aotea Formation accumulated across the Waikato and King Country basins. It is characterized by diversified facies, particularly those that onlap underlying Te Kuiti Group formations and members. West of the BF33 map area, Hauturu Sandstone Member accumulated as shoreline facies that fed north into mid to outer shelf environments as Mangiti Sandstone Member and east as Kihi Sandstone Member. In the field area east of Piopio High, Kihi Sandstone Member accumulated. Waimai Limestone Member accumulated in a high-energy shallow marine environment east of the field area. It was deposited during a time of developing shelf to upper bathyal water depths. Carbonate sedimentation within the Aotea Formation was a lot more predominant in the north, with the development of a carbonate shelf (Waimai Limestone Member) (Kamp et al., 2014).

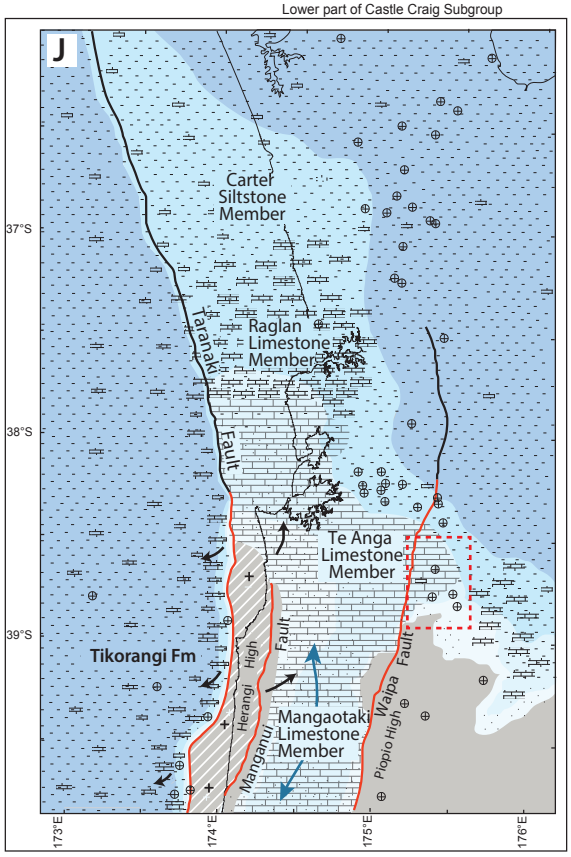
Map 8: Late Oligocene (upper Whaingaroan to lower Duntroonian)

During the upper Whaingaroan to lower Duntroonian, Patikirau Siltstone Member accumulated in Waikato Basin, north of Raglan Harbour (Kamp et al., 2014). This is a calcareous glauconitic siltstone and its accumulation reflects deeper water conditions (outer shelf) due to subsidence, possibly related to decreasing displacement on Taranaki Fault. Farther south, accumulation of Aotea Formation members (Hauturu Sandstone and Kihi Sandstone) continued. In the map area, silty sandstone accumulated indicating a deepening of the basin in this region. This silty sandstone is described as a deep water facies of the Kihi Sandstone Member.

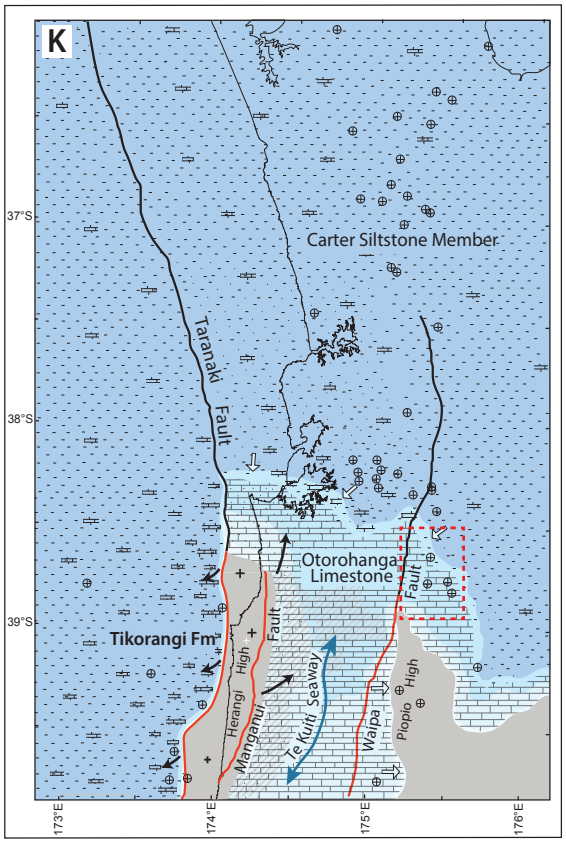
MAP 9 LATE OLIGOCENE (lower Duntroonian)
Sub-Castle Craig Subgroup unconformity



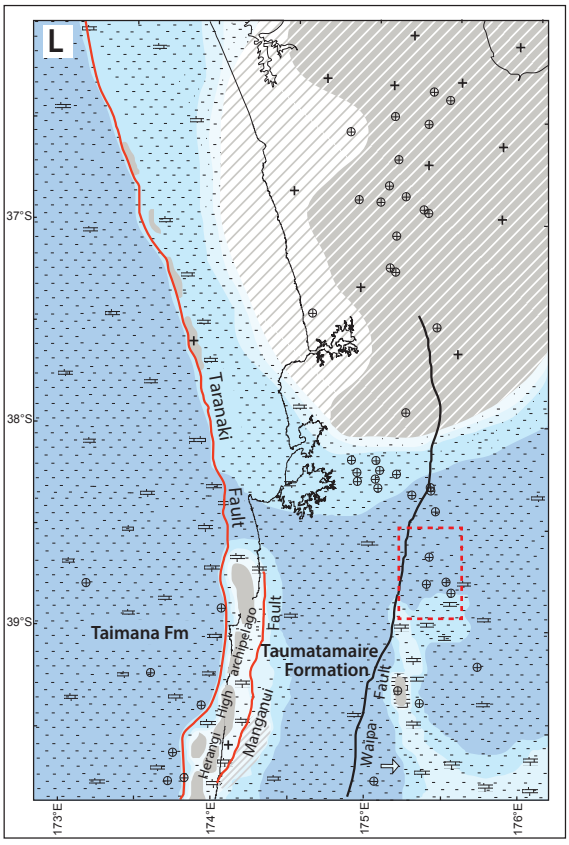
MAP 10 LATE OLIGOCENE (Duntroonian)
Lower part of Castle Craig Subgroup



MAP 11 LATE OLIGOCENE to earliest Miocene (Waitakian)
Upper part of Castle Craig Subgroup



MAP 12 EARLY MIOCENE (uppermost Waitakian)
Extent of sub-Waitemata - Mahoenui Gp unconformity



Map 9: Late Oligocene (lower Duntroonian)

During the lower Duntroonian, large-scale erosion of Aotea Formation occurred in the south between Herangi High and Piopio High. Reverse displacement on Manganui Fault is thought to be linked to uplift and erosion developing this unconformity. In the field area, this unconformity is evident south of Waitomo with the majority of the Aotea Formation succession being eroded during this phase. North of Waitomo in the map area, the contact is proposed to be gradational as demonstrated in stratigraphic columns by Kamp et al. (2008) in Honikiwi, just north of the field area, where the Aotea Formation is present in much thicker successions. In the north, a paraconformity marks the contact between Aotea Formation and Te Akatea Formation, indicating continuing regional subsidence, which contrasts with the uplift and erosion in the south.

Map 10: Late Oligocene (mid to upper Duntroonian)

During the middle to upper Duntroonian, marine conditions were re-established across the basin due to subsidence allowing for accumulation of Castle Craig Subgroup. This point marked a shift in deposition from quartzofeldspathic Hauturu Sandstone, to a more marked carbonate phase of deposition (Orahiri Formation), with possible reworking of Hauturu Sandstone, especially into the base of Orahiri Formation. This is supported by the sandy limestone lithology of the Mangaotaki Limestone Member at the base of the Orahiri Formation, which is illustrated in stratigraphic column 7, located along Mangaokewa Stream, south of Te Kuiti (see Appendix I). Rocky shorelines around the Herangi and Piopio basement highs, were the areas where most of the carbonate formed and became fragmented through wave action. The carbonate sand and gravel produced along shorelines was reworked across the shelf away from the structural highs during storm events. (Nelson et al., 1994). A seaway with strong currents was known to be present in the basin. In the north, Carter Siltstone Member accumulated in outer shelf to upper slope depths. The carbonate is sourced from pelagic foraminifera and from the physical breakdown of skeletal carbonate sand and gravel to carbonate mud, which was carried northward and eastward. Tikorangi Formation accumulated in Taranaki Basin to the west, being redeposited form a narrow shelf along the Herangi High (Hood et al. 1990). In the map area, Te Anga Limestone Member and Mangaotaki

Limestone Member were deposited in thick succession in the vicinity of Te Kuiti Township, as indicated by stratigraphic columns 5, 6 and 7 (see Appendix I).

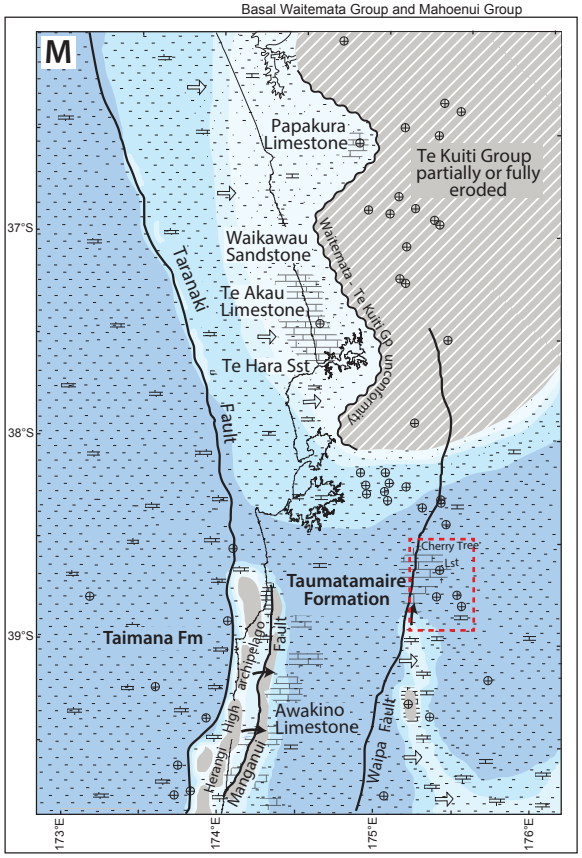
Map 11: Late Oligocene to Earliest Miocene (Waitakian)

During the Waitakian, Otorohanga Limestone accumulated at shelf depths in King Country Basin south of Kawhia Harbour, the main lithology being carbonate grainstone. This facies also accumulated across the Piopio High, marking its subsidence below sea level. In areas west of the map area, Otorohanga Limestone and Orahiri Formation are separated by an unconformity but within the map area, the contact is most commonly observed as gradational. This was observed in the field and its gradational nature is recognised on stratigraphic columns 1, 2, 3, 6 and 7 (see Appendix I). In the areas north of Raglan Harbour, Carter Siltstone continued to accumulate at upper bathyal depths (Kamp et al., 2014).

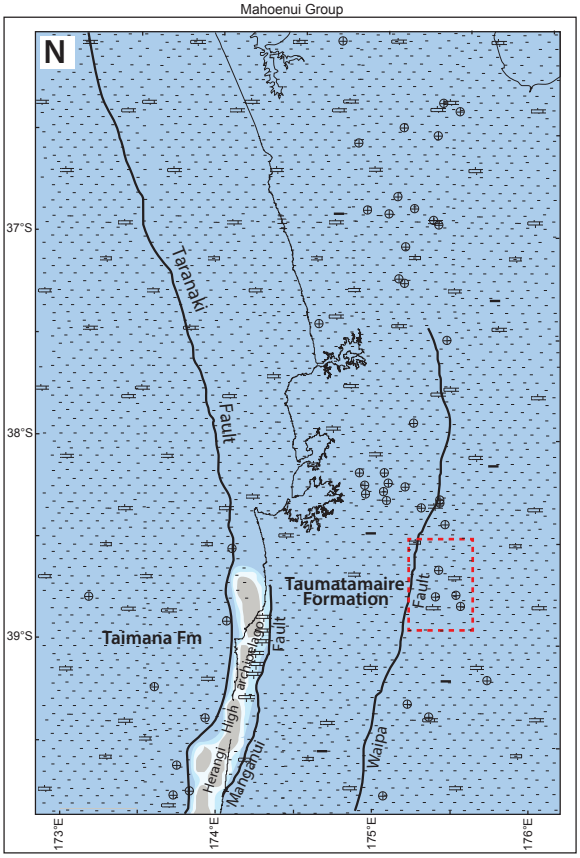
Map 12: Early Miocene (uppermost Waitakian)

During the uppermost Waitakian, there was dramatic subsidence in King Country Basin with accumulation of Mahoenui Group. The Piopio High also subsided markedly and, particularly in quarry sections (Column 1, Old Beros quarry, & Column 6, McDonalds Lime quarry), one can observe that underlying Otorohanga Limestone deposition was rapidly supplanted by mudstone accumulation. In Waikato Basin, Carter Siltstone started to be uplifted from upper bathyal depth to inner shelf depths where it was wave planed.

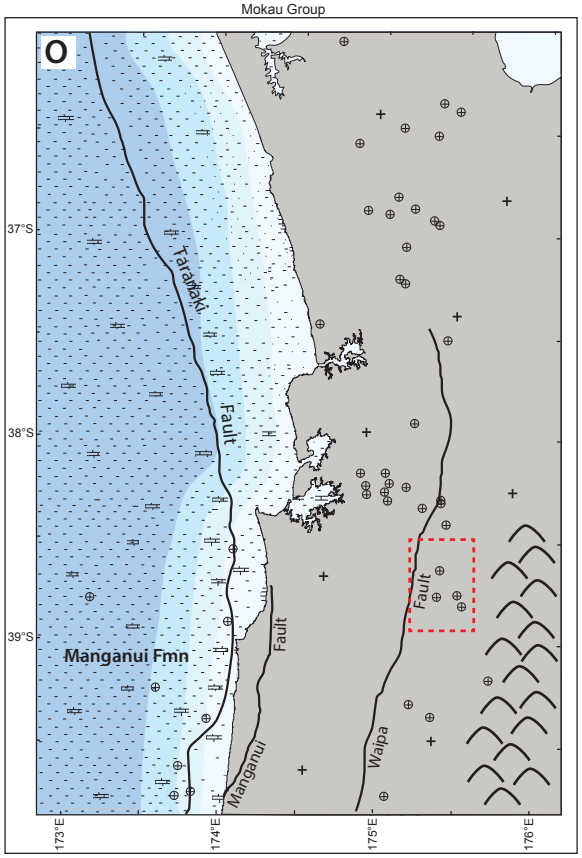
MAP 13 EARLY MIOCENE (uppermost Waitakian to Otaian)
Basal Waitemata Group and Mahoenui Group



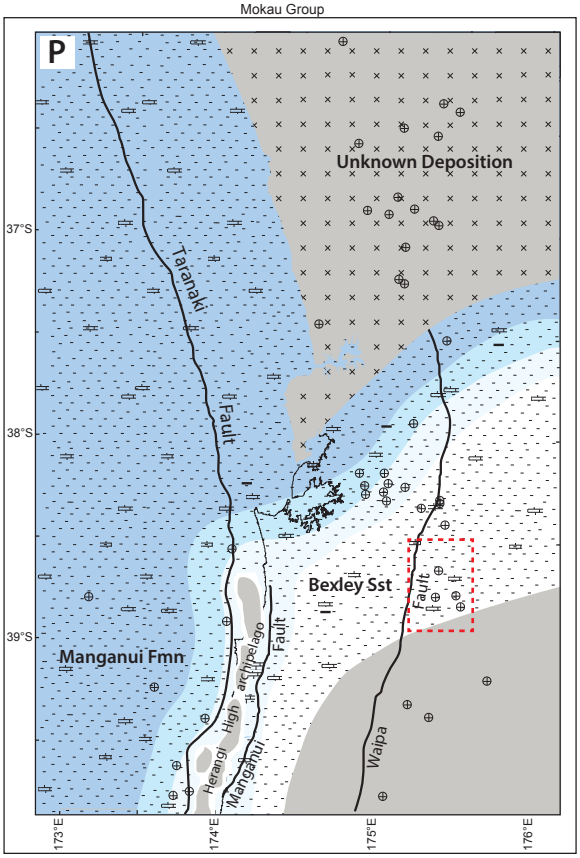
MAP 14 EARLY MIOCENE (mid to upper Otaian)
Mahoenui Group



MAP 15 EARLY MIOCENE (lower to mid Altonian)
Mokau Group



MAP 16 EARLY MIOCENE (upper Altonian)
Mokau Group



Map 13: Early Miocene (uppermost Waitakian to Otaian)

During the uppermost Waitakian to Otaian, most of Waikato Basin, north of Raglan Harbour was uplifted and Te Kuiti Group was subjected to subaerial erosion. The degree of erosion was more marked in the northeast, reflected in Waitemata Group unconformably overlying successively lower Te Kuiti Group formations in that direction. The source of the uplift was focused in the northeast rather than along Taranaki Fault (Kamp et al., 2014). South of Awakino there was however significant overthrusting of Murihiku basement by Taranaki Fault, leading to offset of Tikorangi Limestone at the tip of the fault. Simms (1999) describes that Taumatamaire Formation, the most dominant Mahoenui Group formation in the field area, was deposited between mid-shelf to mid-bathyal depths via hemipelagic sedimentation. The base of this formation is represented by a glauconitic mudstone facies in places (facies code M1), reflecting condensed sedimentation when the rate of basin subsidence exceeded sediment supply and sediment accumulation. Carbonate shelf facies also accumulated along the Herangi High and are present interfingering with Taumatamaire Formation as Awakino Limestone and Black Creek Limestone members (Kamp et al., 2014). Carbonate material was also being fed into the basin, specifically in the map area, forming Cherry Tree Limestone Member. The accumulation of Cherry Tree Limestone indicates that rocky shorelines capable of producing carbonate in high-energy clear water were present to the south of its outcrop area. Basement may have been exposed for a while after rapid subsidence started in the region south of the map area.

Map 14: Early Miocene (mid to upper Otaian)

During the mid to upper Otaian, large scale regional subsidence of the Waikato and King Country basins had occurred with Taumatamaire Formation mudstone facies accumulating widely across the area south of Kawhia Harbour. North of Raglan Harbour, Waitemata Group accumulated in bathyal environments. In southern parts of King Country Basin, not shown in Map 14, Taumarunui Formation flysch facies accumulated, with the source of sediment probably being farther south and part of the Patea-Tongaporutu-Herangi High being uplifted as a result of thrust displacement on Taranaki Fault south of Awakino. Taimana Formation, which is a

marl (calcareous siltstone), accumulated in Taranaki Basin during this time where it overlies Tikorangi Formation.

Map 15: Early Miocene (lower to mid-Altonian)

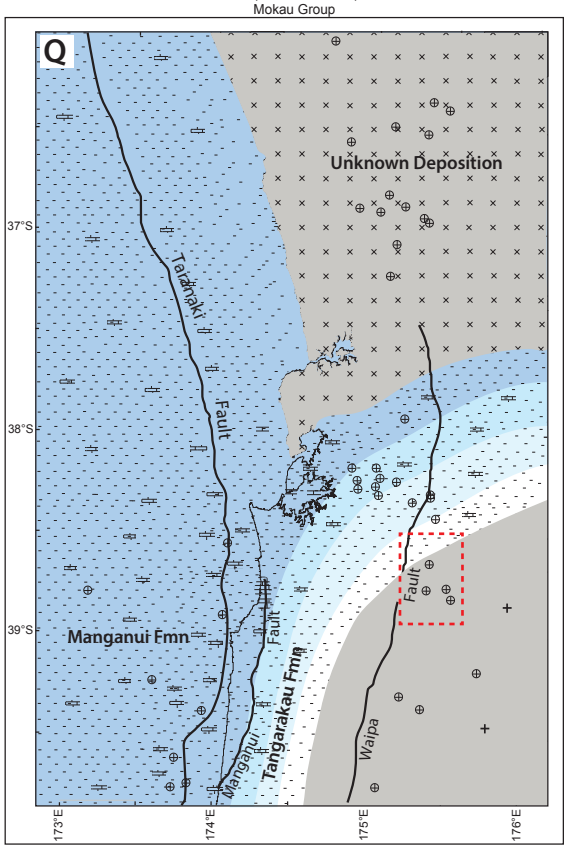
From upper Otaian to lowermost Altonian, a phase of crustal shortening caused inversion of King Country Basin leading to subaerial erosion of Mahoenui Group and Waitemata Group throughout the entire region. Kamp et al. (2002) showed that there are no regressive shelf facies in the upper part of Mahoenui Group. On the upthrown side of Ohura Fault, Taumarunui Formation flysch facies have shallow dip and are unconformably overlain by Bexley Sandstone, indicating that there was erosion of regressive shelf facies that must have accumulated prior to Mahoenui Group being uplifted above sea level. There was also erosion of Mahoenui Group in the eastern part of the map area as Bexley Sandstone directly overlies basement, yet it is reasonable to assume that bathyal Taumatamaire Formation once overlay it. Manganui Formation accumulated in northern Taranaki Basin during this time. Waitemata Group probably continued to accumulate across Waikato Basin north of Raglan Harbour, but subsequent erosion of these sediments make it difficult to be definitive of this.

Map 16: Early Miocene (upper Altonian)

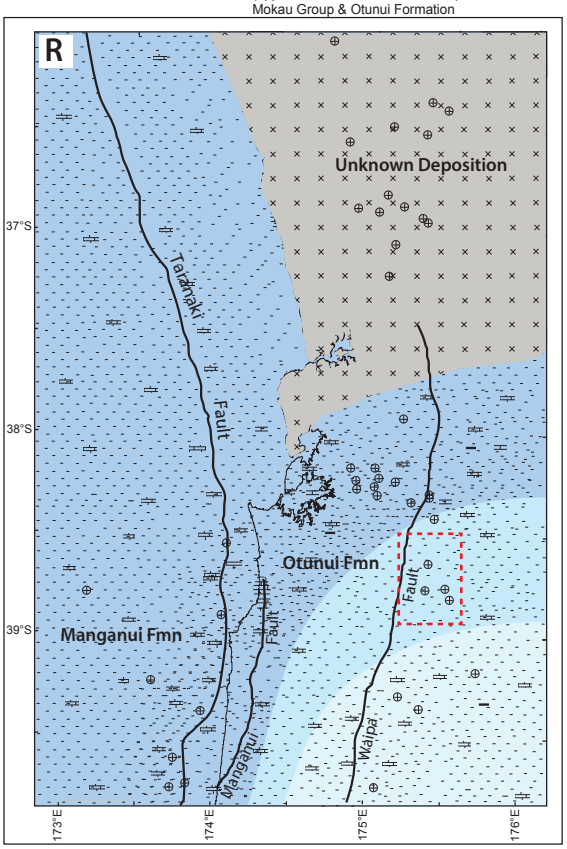
Mokau Group accumulated within King Country Basin initially as shoreface and fluvial sediments (Bexley Sandstone) followed by coal measure accumulation (Maryville Coal Measures) and then shallow marine sandstone (Tangarakau Formation). This full succession is developed west of Ohura Fault and chiefly in the southern part of King Country Basin, south of the extent of Map 16. In the map area, Bexley sandstone has been shown to rest directly upon basement (Location 1) (Column 21, Appendix I). This most probably indicates that after accumulation of Mahoenui Group there was extensive uplift and erosion, which removed Mahoenui Group and any underlying Te Kuiti Group. This probably occurred during the lower Altonian uplift and erosion phase described previously (Map 15). The Mokau Group was sourced from erosion of the Murihiku Terrane underlying the Herangi High, and erosion of Waipapa Composite Terrane further east. Bexley Sandstone was deposited within a transgressive systems tract. Mangarino Member is related to thickly bedded carbonaceous sandstone and mudstone, representing

accumulation in back barrier tidally-influenced environments. In the north, sediment accumulation trends were unknown.

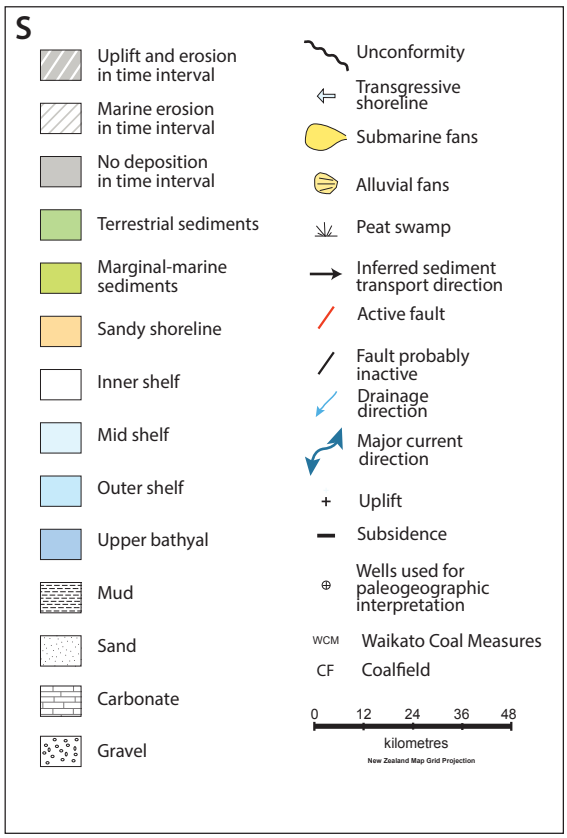
MAP 17 MIDDLE MIOCENE (lower Clifdenian)
Mokau Group



MAP 18 MIDDLE MIOCENE (uppermost Lilburnian to Waiauan)
Mokau Group & Otunui Formation



LEGEND



Map 17: Middle Miocene (lower Clifdenian)

During the lower Clifdenian, Tangarakau Formation accumulated in a shelf setting that probably extended to the northwest of Kawhia Harbour. The map area was probably mainly land surface where there was erosion of underlying units. Some areas of Bexley Sandstone may have been eroded at this time, although we know that it remained in the area of Mangaokewa Road (Location 5) (Column 22, Appendix I).

Map 18: Middle Miocene (uppermost Lillburnian to Waiauan)

During the uppermost Lillburnian to Waiauan, the eastern margin of Taranaki Basin subsided. This led to widespread accumulation of Otunui Formation across King Country Basin, including the map area. Otunui Formation accumulated in shelf environments across most of the area east of Ohura, but probably accumulated at upper bathyal depths across the Herangi High south of Awakino and in eastern Taranaki Basin (Kamp et al., 2004). Manganui Formation accumulated in Taranaki Basin generally at this time, although distinguishing it from Otunui Formation equivalent facies could be difficult.

Late Neogene

Following deposition of Otunui Formation, considerable burial of other sedimentary units must have been evident due to its hard lithology and consolidated nature. This burial must have consisted of at least 2 km of overburden but less than 3 km as Otunui Formation is not quartz cemented. Kamp et al., (2004) illustrated the distribution of erosion, as reproduced in Fig. 6.2. The map area lies where the erosion contours indicate about 2 km of erosion, measured from analysis of the bulk density of mudstone by reference to calibration wells in Taranaki Basin where there has been no erosion. This erosion probably occurred during the middle to Late Pliocene and predated the first emplacement of ignimbrite derived from Taupo Volcanic Zone. The material eroded likely comprised part of Otunui Formation and the formations that overlie it in southern King Country (Mt Messenger, Urenui and Matemateaonga Formations).

The uplift accompanying the Pliocene erosion phase exhumed successively older formations to the north in King Country Basin. In eastern parts of the King Country region, the Cenozoic succession has been almost completely removed by erosion, and exhumed basement is covered by mainly Quaternary ignimbrites derived from Taupo Volcanic Zone (Kamp et al., 2004). The uplift appears to have been centered on the Taupo Volcanic Zone, possibly related to thermal upwelling and crustal extension. The extent of erosion differs systematically with increasing erosion northward from Wanganui Basin into King Country Basin and eastward from eastern Taranaki Basin into King Country Basin (Kamp et al., 2004). The earliest emplacement of ignimbrite occurred at 1.6 Ma during the early Pleistocene. The ignimbrites present in the BF33 map area unconformably overlie Cenozoic units with an undulating surface. This surface represents the topography prior to ignimbrite deposition. Following the last of the major ignimbrite eruptions (Raepahu Formation, 1.00±0.05 Ma) there has been another phase of erosion, which has resulted in the present topography.

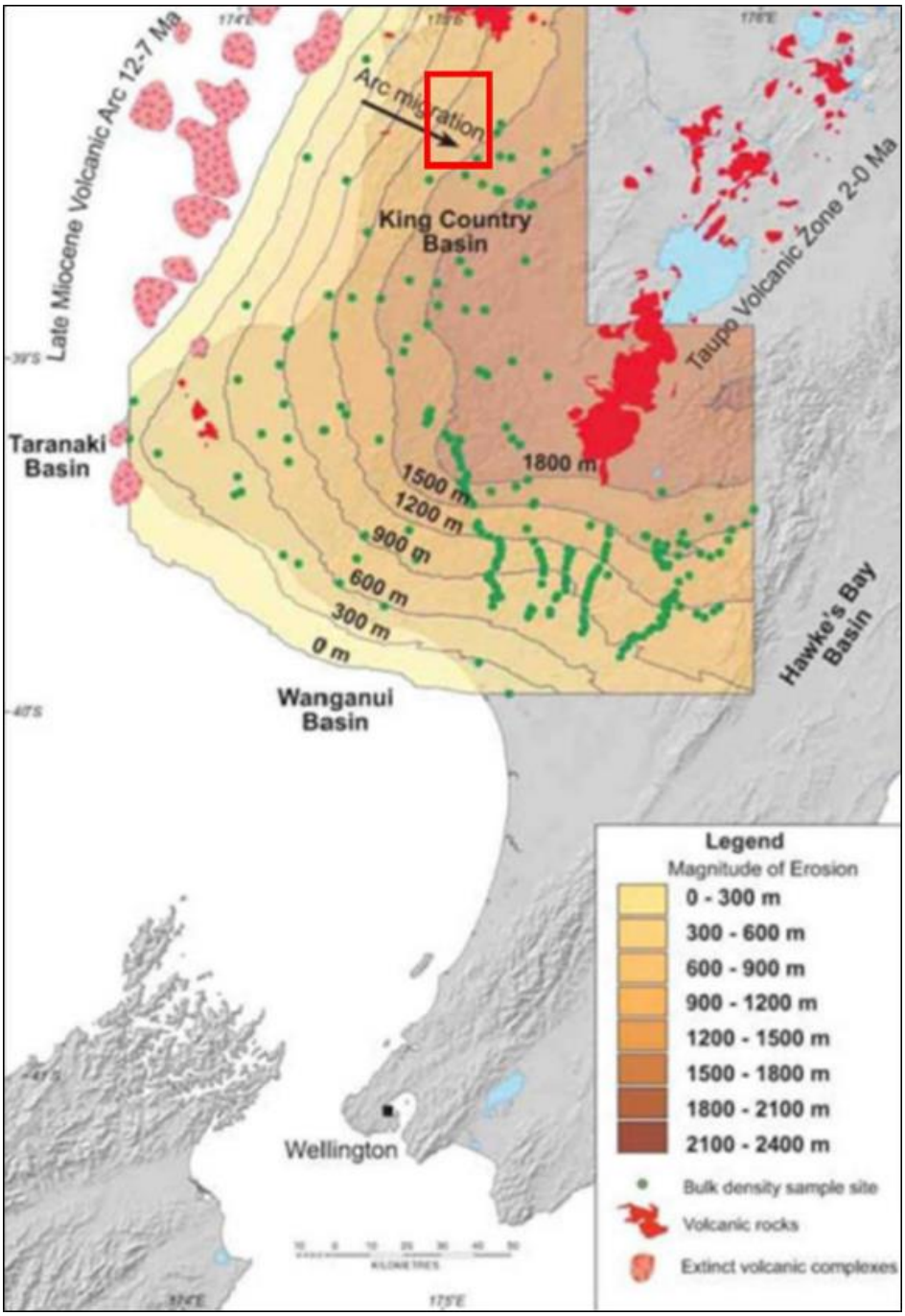


Fig. 6.2. Map showing the magnitude in 300 m contours and pattern of Pliocene – Pleistocene erosion over central North Island derived from mudstone bulk density. Red box indicates Te Kuiti BF33 map area location (Kamp et al., 2004).

7 Summary and conclusions

7.1 Introduction

This thesis project has produced a new 1:50 000 scale geological map of topographic map BF33 (Te Kuiti), one of the new Topo 50 topographic map sheets covering New Zealand. The map area is located within King Country Basin, containing Cenozoic sedimentary units of Late Eocene-Oligocene Te Kuiti Group, Early Miocene Mahoenui and Mokau groups, and middle to Late Miocene Otunui Formation. Quaternary ignimbrite sheets (undifferentiated) and Holocene fluvial deposits have also been mapped within the field area. The thesis chapters describe the stratigraphy and structure of the Cenozoic units and their sedimentology. A synthesis chapter outlines the paleogeographic development of the field area in the context of the western North Island region.

7.2 Objectives

Thesis Objectives:

1. To complete the production of a 1:50 000 scale geological map of the Te Kuiti sheet (BF33).
2. To produce descriptions of stratigraphic sections through each of the formations and implement these together with analysis of sedimentary facies to interpret the related depositional environments.
3. To develop understanding about the stratigraphic and structural development of the Te Kuiti map area (BF33) in the context of the wider King Country Basin.

These objectives have been completed. In particular, a 1:50 000 scale geological map and associated cross sections have been generated through field mapping coupled with structure contouring of formation boundaries on the ArcGIS platform. Stratigraphic descriptions summarised on stratigraphic columns have been made, making good use of those established in earlier thesis projects. Sedimentary facies have been identified for each of the Cenozoic sedimentary formations, in some case with reference to earlier work reported in prior theses. Depositional environments have been interpreted for each of the formations from the facies descriptions.

7.3 Geological and tectonic setting

The field map area is located in and around Te Kuiti Township within King Country Basin. King Country Basin is located in central-western North Island, New Zealand, to the east of North Taranaki Basin. King Country Basin is located in a back-arc setting behind the Taupo Volcanic Zone, which itself arises from oblique extension associated with subduction of oceanic Pacific Plate in the Hikurangi Margin east of the North Island. The Late Oligocene and Early Miocene formation of King Country Basin is associated with basement overthrusting on Taranaki and Manganui faults.

7.4 Geological map and stratigraphy

Geological mapping at a scale of 1:50 000 was undertaken in and around Te Kuiti Township within King Country Basin. The field area covers topographic map BF33, one of the new Topo 50 topographic map sheets. The Cenozoic sedimentary units present in this area include Late Eocene-Oligocene Te Kuiti Group, Early Miocene Mahoenui and Mokau groups, and middle to Late Miocene Otunui Formation. Quaternary alluvium and ignimbrites sheets also occur throughout the map area. The geological map produced in this research project represents significant revision of previous geological maps of the area, including the 1:50 000 field sheet prepared for the production of the new 1:250 000 Waikato QMAP sheet (Edbrooke (2005). The mapping in this project identified new normal faults not previously identified, disproved other faults mapped in the past for which there is no evidence and located a regional syncline structure that trends west-east in the southern part of the field area.

7.5 Sedimentology

Stratigraphic columns and associated facies descriptions were produced for a range of different locations throughout the BF33 map area, or compiled from prior thesis projects undertaken in the area. They provide vertical and to some extent lateral distribution of sedimentary facies in Te Kuiti Group, Mahoenui Group, Mokau Group and Otunui Formation. Te Kuiti Group is dominated by limestone facies, particularly in Orahiri Formation and Otorohanga Limestone, which accumulated in shelf environments. Mahoenui Group is comprised of mudstone facies throughout most of the field area, with interbedded mudstone-sandstone present as

turbidites in some locations, mainly in the southern part of the map area. Limestone facies, mapped as Cherry Tree Limestone Member, occur near the base of Mahoenui Group to the south and northwest of Te Kuiti Township. Cherry Tree Limestone Member comprises redeposited beds that accumulated in upper bathyal environments as the basin rapidly subsided. Shelf facies have not been identified within Mahoenui Group in the map area. Bexley Sandstone (Mokau Group) comprises mainly sandstone facies with interbedded mudstone-sandstone of Mangarino Member, which occurs discontinuously in the lower part of the formation north of Te Kuiti Township. Bexley Sandstone accumulated in shallow marine and fluvial environments. Otunui Formation is represented by silty sandstone facies and, in some sections south of Pukerimu, a basal shellbed facies, which is recognised as Mangarara Formation. The shellbed is a transgressive shoreface to innershelf deposit and it is conformably overlain by thick bioturbated silty sandstone facies that accumulated in shelf and upper bathyal environments.

7.6 Synthesis of the geological history of the Te Kuiti map area

Chapter 6 presents a paleogeographic summary for each of the Cenozoic formations in the BF33 map area, placing it into a regional context derived from Kamp et al. (2014). During the Late Eocene, Te Kuiti Group was deposited in the field area in the form of Waikato Coal Measures, as a consequence of regional subsidence and onlap. It was deposited in valleys between basement highs, thinning eastward, onlapping basement now exposed in the Rangitoto Range. By the earliest Oligocene, the majority of the Waikato Basin and King Country Basin areas were shallow marine environments, with Dunphail Siltstone accumulating in central parts. A period of sea level rise led to accumulation of Whaingaroa Formation widely across the basin represented by calcareous mudstone facies, including in the map area. During the Late Oligocene, Aotea Formation accumulated across the region, characterized by diversified facies, particularly those that onlap underlying Te Kuiti Group formations and members. Kihi Sandstone Member was the dominant unit deposited in the field area during this interval, before it was mostly eroded during the lower Duntroonian. Reverse displacement on Manganui Fault is thought to be linked to uplift and erosion developing this unconformity. During the Duntroonian, marine conditions were re-established across the basin due to subsidence allowing for accumulation of Castle Craig Subgroup. In the map area,

Te Anga Limestone Member and Mangaotaki Limestone Member of Orahiri Formation were deposited as a thick succession in the vicinity of Te Kuiti Township. During Late Oligocene to Earliest Miocene, Otorohanga Limestone accumulated at shelf depths in King Country Basin south of Kawhia Harbour, with the main lithology being carbonate grainstone. In the map area, it is separated from underlying Orahiri Formation by a gradational contact, in contrast to the unconformable nature of the contact in surrounding areas.

The Early Miocene reflected a time of dramatic subsidence of King Country Basin, leading to accumulation of Mahoenui Group. Taumatamaire Formation, the main Mahoenui Group formation in the map area, accumulated at inner to mid-bathyal depths via hemipelagic sedimentation. The base of this formation is represented by a glauconitic mudstone facies in places, reflecting condensed sedimentation when the rate of basin subsidence exceeded sediment supply and sediment accumulation. During this time, carbonate material was also being fed into the field area from the south, represented by the Cherry Tree Limestone Member. From upper Otaian to lowermost Altonian, a phase of crustal shortening caused inversion of King Country Basin leading to subaerial erosion of Mahoenui Group and Waitemata Group throughout the entire region. Mokau Group accumulated within King Country Basin initially as shoreface and fluvial sediments (Bexley Sandstone) followed by coal measure accumulation (Maryville Coal Measures) and then shallow marine sandstone (Tangarakau Formation). Bexley Sandstone was deposited within a transgressive systems tract. Mangarino Member is related to thickly bedded carbonaceous sandstone and mudstone, representing accumulation in back barrier tidally-influenced environments.

During the Middle Miocene, the eastern margin of Taranaki Basin subsided. This led to widespread accumulation of Otunui Formation across King Country Basin, including the map area. Otunui Formation accumulated in shelf environments across most of the area east of Ohura, but probably accumulated at upper bathyal depths across the Herangi High south of Awakino and in eastern Taranaki Basin. Following deposition of Otunui Formation, considerable burial of other sedimentary units must have been evident due to its hard lithology and consolidated nature, consisting of at least 2 km of overburden. Erosion probably occurred during the Middle to Late Pliocene and predated the first emplacement of ignimbrite

derived from Taupo Volcanic Zone. The ignimbrites present in the field area display an undulating contact with the underlying Cenozoic units. This surface represents the topography prior to ignimbrite deposition. The latest ignimbrite emplacement (Raepahu Formation, 1.00±0.05 Ma) demonstrates that recent erosion has occurred to produce the present day topography.

7.7 Future work

This study has produced a new geological map for sheet BF33 (Te Kuiti) and outlined the stratigraphy and sedimentology of Cenozoic sedimentary formations. It may provide a useful basis for more detailed sedimentological or diagenetic studies of the stratigraphic units within this map area. There is also much value to be gained from the mapping of individual ignimbrite units, which have derived from TVZ during the Pleistocene.

8 References

Black, P.M. (1994). The Waipapa Terrane, North Island, New Zealand: Subdivision and correlation. *Geoscience reports of Shizuoka University,* 20, 55-62.

Bouma, A.H. (1962). Sedimentary of some flysch deposits: a graphic approach to facies interpretation. Elesvier Publishing Company, Amsterdam, Netherlands.

Briggs, R.M., Middleton, M.P., & Nelson, C.S. (2004). Provenance history of a Late Triassic-Jurassic Gondwana margin forearc basin, Murihiku Terrane, North Island, New Zealand: petrographic and geochemical constraints. *New Zealand Journal of Geology & Geophysics,* 47 (4), 589-602.

Brink, M. (2012). Emplacement processes of ignimbrites in the Ongatiti Valley, southeast of Te Kuiti. *Unpublished MSc Thesis,* University of Waikato, Hamilton, New Zealand.

Cartwright, S.J. (2003). Cenozoic geological evolution of the central-eastern King Country Basin, North Island. *Unpublished MSc Thesis,* University of Waikato, Hamilton, New Zealand.

Edbrooke, S.W., Sykes, R. & Pocknall, D.T. (1994). Geology of the Waikato Coal Measures, Waikato Coal Region, New Zealand. *Institute of Geological & Nuclear Sciences Monograph 6.*

Edbrooke, S.W. (2005). Geology of the Waikato area – scale 1:50,000. *Institute of Geological and Nuclear Science 1:250,000 geological map 4.* Lower Hutt, New Zealand.

Evans, T.P.H. (2003). Stratigraphy and sedimentology of Early to Middle Miocene strata, western Taumarunui region, King Country Basin. *Unpublished MSc thesis,* University of Waikato, Hamilton, New Zealand.

Furlong, K.P., & Kamp, P.J.J. (2013). Changes in plate boundary kinematics: punctuated or smoothly varying - Evidence from the Mid – Cenozoic transition from lithospheric extension to shortening in New Zealand. *Tectonophysics,* 608.

Hadden, P. (2014). North New Zealand: A natural history of the upper North Island. *Wairau Press.* Auckland, New Zealand.

Hansen, R., & Kamp, P.J.J. (2004). Late Miocene to early Pliocene stratigraphic record in northern Taranaki Basin: condensed sedimentation ahead of Northern Graben extension and progradation of modern continental margin. *New Zealand Journal of Geology and Geophysics,* 645-667.

Hay, R.F. (1968). Sheet 7 - Taranaki. Geological map of New Zealand 1:250 000. Wellington. *Department of Science and Industrial Research*.

Henderson, J., Ongley, M. (1923). The geology of the Mokau Subdivision. *New Zealand Geological Survey Bulletin* 24.

Hollis, C.J., Beu, A.G., Crampton, J.S., Crundwell, M.P., Morgans, H.E.G., Raine, J.I., & Boyes, A.F. (2010). Calibration of the New Zealand Cretaceous-Cenozoic Timescale to GTS2004. *GNS Science Report.* 2010/43, 20p.

Hood, S.D., Nelson, C.S., & Kamp, P.J.J., (2003). Lithostratigraphy and depositional episodes of the Oligocene carbonate-rich Tikorangi Formation, Taranaki Basin, New Zealand. *New Zealand Journal of Geology and Geophysics v.46*, 363-386.

Kamp, P.J.J., Vonk, A.J., Bland, K.J., Griffin, A.G., Hayton, S.H., Hendy, A.J.W., Austin, J.W., McIntyre, A.P., Nelson, C.S., & Naish, T.R. (2002). Megasequence architecture of Taranaki, Wanganui and King Country basins and Neogene progradation of two continental margin wedges across western New Zealand. *2002 New Zealand Petroleum Conference Proceedings.* Wellington, New Zealand Petroleum and Minerals. Pp. 464-481.

Kamp, P.J.J., Vonk, A.J., Bland, K.Y., Hansen, R.J., 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.

Kamp, P.J.J., & Vonk, A. (2006). Eastern Taranaki Basin field guide – linking the onshore and offshore parts of Eastern Taranaki Basin: insights to stratigraphic architecture, sedimentary facies, sequence stratigraphy, paleogeography and hydrocarbon exploration from the on land record. *Ministry of Economic Development,* Hamilton, New Zealand.

Kamp, P.J.J., Tripathi, A.R.P. & Nelson, C.S. (2008). Stratigraphic columns and correlations for the Late Eocene – Oligocene Te Kuiti Group, central-western North Island, New Zealand. *Petroleum Report Series – PR3901*. Ministry of Economic Development, New Zealand.

Kamp, P.J.J., Tripathi, A.R.P., & Nelson C.S. (2014). Paleogeography of Late Eocene to Earliest Miocene Te Kuiti Group, central-western North Island, New Zealand. *New Zealand Journal of Geology and Geophysics, 57 (2),* 128-148.

Kamp, P.J.J. & Bland, K.J. (2014). Structure of the Hawke's Bay Forearc Basin and North Island Shear Belt, eastern North Island, New Zealand. *Ministry of Business, Innovation and Employment, New Zealand,* unpublished Petroleum Report PR4884.

Kear, D. (1960). Sheet 4-Hamilton. Geological map of New Zealand 1: 250 000. *Department of Scientific and Industrial Research*, Wellington, New Zealand.

Kear, D. (1971). Basement rock facies – Northern North Island. *New Zealand Journal of Geology and Geophysics*, 275-283.

Kear, D. (1993). Reflections on major North Island basement rock assemblages and on megafaults. *Journal of the Royal Society of New Zealand,* 23:1, 29-41.

Kear, D., & Schofield, J.C. (1959). Te Kuiti Group. *New Zealand Journal of Geology and Geophysics* 2 (4): 685-717.

Kear, D., & Schofield, J.C. (1978). Geology of the Ngaruawahia subdivision. *New Zealand Geology Survey Bulletin 88*.

King, P.R., Scott, G.H. & Robinson, P.H. (1993). Description, correlation and depositional history of Miocene sediments outcropping along North Taranaki Coast. *Institute of Geological & Nuclear Sciences Monograph 5*.

King, P.R., & Thrasher, G.P. (1999). Cretaceous-Cenozoic geology and petroleum systems of the Taranaki Basin, New Zealand. *Institute of Geological & Nuclear Sciences Limited*, Lower Hutt, New Zealand.

Lisle, R.J., Brabham, P.J. & Barnes, J.W. (2011). *Basic geological mapping.* 5th Edition. John Wiley & Sons Ltd, West Sussex, UK.

Liu, Y. (2016). Pliocene and Pleistocene doming of central North Island: Evidence from sedimentary basins surrounding the Taupo Volcanic Zone. *University of Waikato.* Hamilton, New Zealand. Unpublished MSc Thesis.

Marwick, J. (1946). The geology of the Te Kuiti Subidvison. *New Zealand Geological Survey Bulletin 41*.

Morgans, H.E.G., Beu, A.G., Cooper, R.A., Crouch, E.M., Hollis, C.J., Jones, C.M., Raine, J.I., Strong, C.P., Wilson, G.J. & Wilson, G.S. (2004). In: The New Zealand Geological Timescale (Ed. Cooper RA). *Institute of Geological & Nuclear Sciences Monograph* 22: 284 p.

Nelson, C.S. (1978). Stratigraphy and paleontology of the Te Kuiti Group, Waitomo Country, South Auckland, New Zealand. *New Zealand Journal of Geology and Geophysics,* 21, 223-242.

Nelson, C.S., Burns, D.A. & Rodgers, K.A. (1983). The taxanomic status and isotope evidence for paleoenvironments of giant oysters from the Oligocene Te Kuiti Group. *New Zealand Journal of Geology and Geophysics* 26: 289-299.

Nelson, C.S., & Hume, T.M. (1977). Relative intensity of tectonic events revealed by the Tertiary sedimentary record in the North Wanganui Basin and adjacent areas, New Zealand. *New Zealand Journal of Geology and Geophysics* 20: 369-392.

Nelson, C.S., & Hume, T.M. (1987). Paleoenvironmental controls on mineral assemblages in a shelf sequence: Te Kuiti Group, South Auckland, New Zealand. *New Zealand Journal of Geology and Geophysics* 30: 343-362.

Nelson, C.S., Kamp, P.J.J., & Young, H.R. (1994). Sedimentology and petrography of mass-emplaced limestone (Orahiri Limestone) on a late Oligocene shelf, western North Island, and tectonic implications for eastern margin development of Taranaki Basin. *New Zealand Journal of Geology and Geophysics*. 37 (3), 269-285.

Nelson, C.S., & Kamp, P.J.J. (2013). Field trip guide to the Onland Oligocene-Miocene Sedimentary Record, Eastern Taranaki Basin Margin. Ministry of Economic Development, New Zealand, *Unpublished Petroleum Report PR4065,* 56 pp.

Nodder, S.D., Nelson, C.S., & Kamp, P.J.J. (1990). Mass emplaced siliciclastic-volcaniclastic-carbonate sediments in Middle Miocene shelf-to-slope environments at Waikawau, northern Taranaki and some implications for Taranaki Basin development. *New Zealand Journal of Geology and Geophysics.* 33, 599.

Piper, D.J.W. (1978). Turbidite muds and silts on deepsea fans and abyssal plains. *In* Stanley, D.J., & Kelling, G. (eds) Sedimentation on submarine canyons, fans and trenches. Dowden Hutchinson and Ross Inc., Stroudsburg.

Simms, B. (1999). Stratigraphic architecture and sedimentology of the early Miocene Mahoenui Group, North Wanganui Basin, Western North Island, New Zealand. *Unpublished Msc (Tech) Thesis,* University of Waikato, Hamilton, New Zealand.

Stagpoole, V. & Nicol, A. (2008). Regional structure and kinematic history of a large subduction back thrust: Taranaki Fault, New Zealand. *Journal of Geophysical Research*, 113, B01403,

Topping, R.M. (1978). Foraminifera from the Mahoenui Group, north Wanganui Basin. *Unpublished PhD thesis*, University of Auckland, Auckland, New Zealand.

Townsend, D., Vonk, A., & Kamp, P.J.J. (2008). Geology of the Taranaki area. *Institute of geological & Nuclear Sciences*.

Tripathi, A., Kamp, P.J.J., & Nelson, C.S. (2008). Te Kuiti Lithostratigraphy east of Taranaki Basin in central-western North Island, New Zealand. *Ministry of Economic Development*, Hamilton, New Zealand.

Tripathi, A. (2008). Basin Analysis of the Late Eocene – Oligocene Te Kuiti Group, Western North Island, New Zealand. *Unpublished PhD Thesis.* University of Waikato, Hamilton, New Zealand.

Vonk, A.J. (1999). Stratigraphic architecture and sedimentology of the early Miocene Mokau Group, north Wanganui Basin, western North Island, New Zealand. *Unpublished MSc (Tech) thesis,* University of Waikato, Hamilton, New Zealand.

Waterhouse, B.C., & White, P.J. (1994). Geology of the Raglan-Kawhia area. Scale 1:50 000. *Institute of Geological & Nuclear Sciences geological map 13*. 48 p, 1 sheet. Institute of Geological & Nuclear Sciences Lower Hutt, New Zealand.

White, P. J., & Waterhouse, B. (1993). Lithostratigraphy of the Te Kuiti Group: a revision. *New Zealand Journal of Geology and Geophysics*, 255-266.

Wilson, B.T. (1994). Sedimentology of the Miocene Succession (Coastal Section), Eastern Taranaki Basin Margin: A Sequence Stratigraphic Interpretation. *Unpublished MSc Thesis*, University of Waikato, Hamilton, New Zealand.

9 Appendix I: Stratigraphic Columns within the Te Kuiti Sheet BF33 Map Area

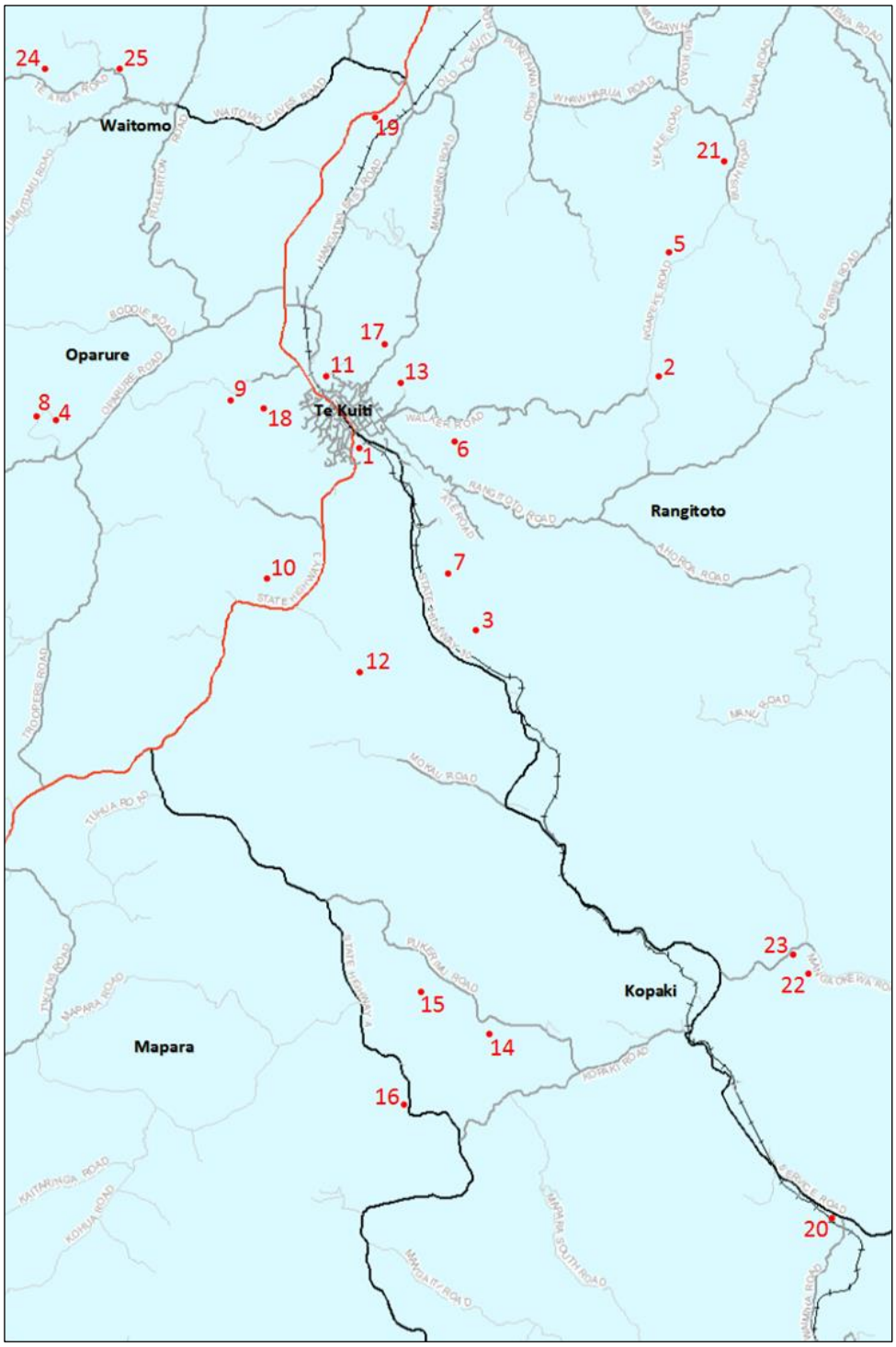


Fig. I.1. Te Kuiti BF33 map area showing locations of stratigraphic columns by their associated column number as recorded.

Stratigraphic Column No: *1* ***Grid Reference:*** **BF33**

Region: Te Kuiti ***E:*** 1791100

Location: Old Beros quarry, Te Kuiti ***N:*** 5753100

NZMS 260 Sheet: S16/014152

Author: A.S. Anastas & A. Tripathi

Modified: B. Whiteman

Stage	Strat Unit	Scale (metres)	Strat Unit (old)	Lithology	Structures	Fossils	Facies	Photo No.	WO No.	Description
Po	Mahoenui	90	Cherry Tree Limestone Mmb			Arenicolites, Scolithos				Vertical burrows containing pellets. Cross-bedded lst. Laminated grey-green shale.
		80					L6			Argillaceous lst./interbedded shale and lst., shale % decreases upwards, beds undulatory, shales 1-1.5 cm, lsts. 7-12 cm.
		70				Large echinoid. frags. Fossiliferous shale	L4-Z1	2		Tempestite, sharp base.
Lw	Otorohanga Limestone	60	Otorohanga Limestone				L2	1		Cross-bedded lst., formset preservation, 7-10 cm beds.
		50								
		40					L3			Horizontally bedded lst., glauconite common.
	-	30								
		20					L4			Massive argillaceous lst.
Ld	Orahiri Formation	10	Otorohanga Limestone				L2	2		Horizontal bedding.
							L3-L4			Massive lst., argillaceous, poorly developed bedding.
		0				Bivalve and bryozoan frags.	L2			Cross-bedded lst., one large set, obscure, north.

mud | fine silt | med silt | coarse silt | fine sand | med sand | coarse sand | gravel

1



2



3



4



Stratigraphic Column No: *2* ***Grid Reference: BF33***

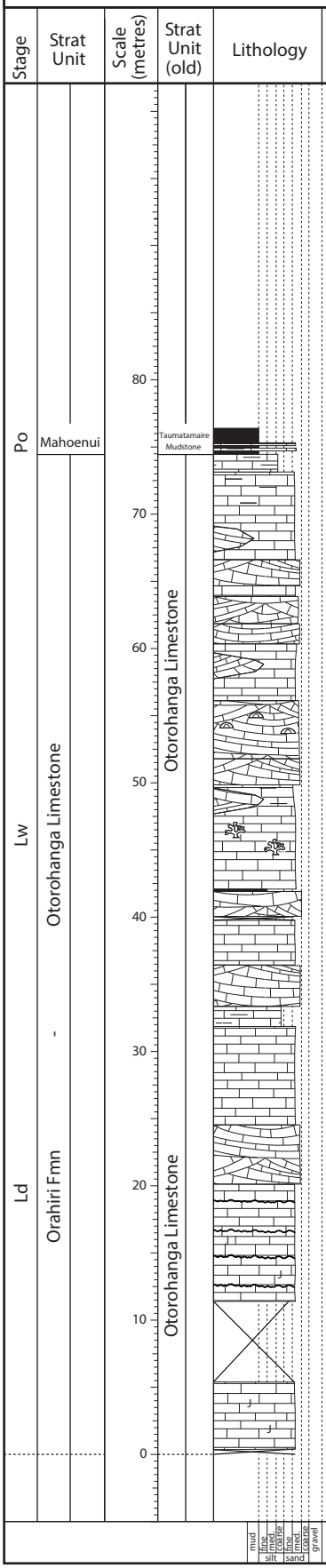
Region: Te Kuiti ***E:*** 1790800

Location: Old Rangitoto quarry, currently landfill. ***N:*** 5755600

NZMS 260 Sheet: S16/008173 *Page* 1 *of* 1

Author: A.S. Anastas & A. Tripathi

Modified: B. Whiteman

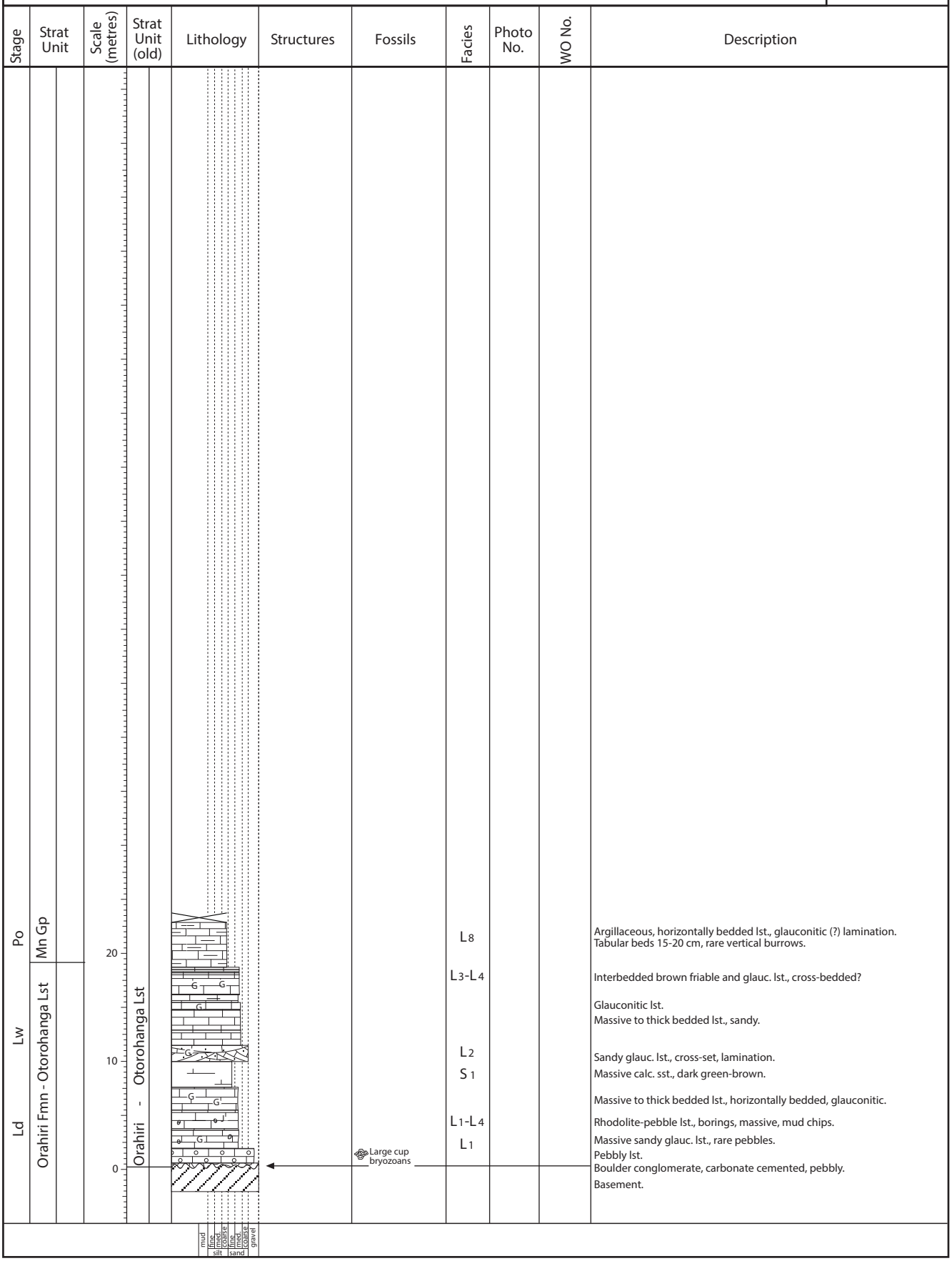


Facies	Description
M1	Mahoenui Mudstone with interbedded planktic foram-rich argillaceous limestone. near base. Argillaceous, horizontally bedded lst.
L6	Horizontally bedded limestone, tabular partings, increases in argill. at top, one laterally discontinuous planar-tabular cross-bed.
L2	Planar-tabular cross-bedding, discordant lamination. Low angle, planar-tabular cross-beds. 5-15 cm flags, tangential bases and tops, sets < 30 cm. Planar-tabular cross-beds, widespread.
L3	Horizontally bedded limestone., darker weathered, passes laterally into small sets.
L2	Low angle, planar-tabular cross-beds, 5-15 cm flags, tangential bases and tops, sets < 30 cm, rare large rounded echinoid frags.
	Cross-bedded limestone. Thin, hor. bedded limestone, weathers darker than unit below , increased argillaceous content, passes laterally into small sets.
L3	Horizontally bedded lst., bryozoan grainstone, transected by reverse fault, 1-2 m tabular partings, tabular flags.
L2	Cross-bedded lsts (poorly exposed, cream colour, thin shale seam at top).
L3	Horizontally bedded lst., green bedding planes, seams 10-15 cm apart, rubbly disconnected outcrop.
L2	3D planar tabular cross-beds, numerous intraset discontinuities, compound set, 220 azimuth. Massive, horizontally bedded limestone, appears argillaceous.
L3	Horizontally bedded limestone, seams 5-10 cm apart, pack-grainstone.
L2	Amalgamated cross-bedded complex, 5-10 cm flags, 3D lee side cross-stratification, 2D planar-tabular at top with ubiquitous troughs in lower 2/3. Horizontally bedded lst., 5-10 cm flags, wavy argillaceous seams, horizontal burrows.
L3-L4	Horizontally bedded lst., packstone, mass. to 15-30 cm 'beds', tabular partings, wavy argillaceous seams, blue and beige-green flecks, homogeneous bioturbation, tempestites.
L3	Horizontally bedded lst., 15-30 cm tabular beds, homogeneous texture, tempestite?, horizontal and vertical burrows, 1-2 m tabular partings, vertical fractures, green insoluble residue at seams.

Stratigraphic Column No: *3*
Region: Te Kuiti
Location: Mangaokewa Stream, south of Te Kuiti.
NZMS 260 Sheet: S16/032112

Grid Reference: BF33
E: 1793100
N: 5749500

Author: A.S. Anastas & A. Tripathi
Modified: B. Whiteman



Stratigraphic Column No: *4* ***Grid Reference:*** **BF33**

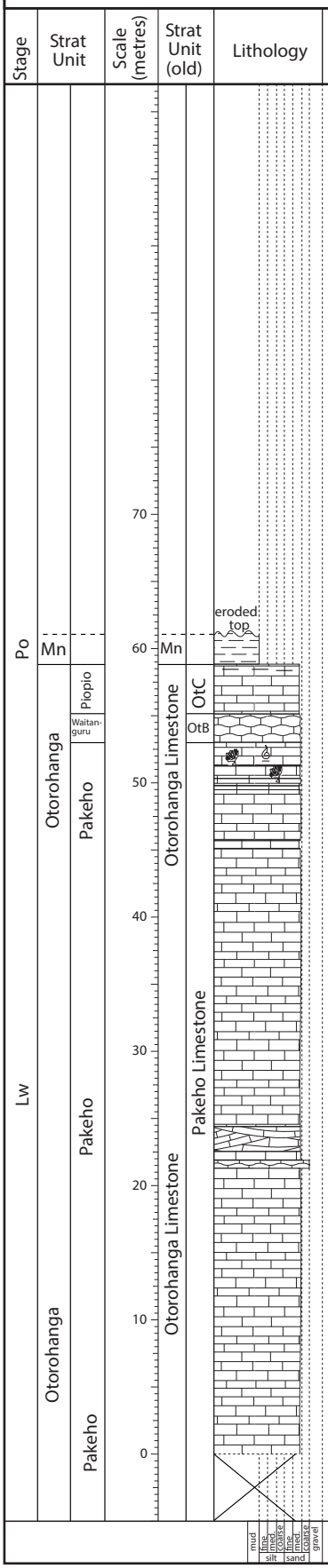
Region: King Country/Waitomo ***E:*** 1781100

Location: McDonald Lime Quarry, Oparure Road. ***N:*** 5754500

NZMS 260 Sheet: S16/916161 *Page* 1 *of* 2

Author: C. Nelson & A. Tripathi

Modified: B. Whiteman



Facies	Photo No.	WO No.	Description
			Blue-grey calc. mst., Mn mst.
L6	5-6		Smooth flags, av. 13 cm, slightly irregular and sandy seams.
L3			Mod.-well developed flaggs, to 30 cm, occ. vertical joints, rough surface, var. flag width.
L5	3-4		Irregular pseudoknobbly lst., cavernous weathering not advanced.
L3-L4			Moderately-well flagged, av. 2.5-7.6 cm, smooth-slightly wavy seams, becomes sandy downwards where mass., slightly frittery, fossiliferous (esp. bryoz.). Above unit repeated 49.4-50.3 m.
			Pure flaggy av. 5 cm lst., slightly wavy seams.
			Frittery sandy lst., similar to above sandy horizons.
L3			Well flagged av. 5-7.6 cm lst., seams occ. slightly wavy.
	1		Occ. veining in 5 cm flagged lst., sl. honeycomb weath. appearance to lst.
L2			Crossbeds, dip 10o to NW, c/gr. lst., variable flag width, comm. large.
			21.3-22 m vert. jointed, slightly knobbly-slabby unit.
L3	2		Well flagged, av. 7.6 cm pure lst. as monotonous sequence down to river.

1



2



3



4



5



6



Stratigraphic Column No: *5* ***Grid Reference: BF33***

Region: King Country/Waitomo ***E:*** 1799000

Location: Ngapeke Road, northwest of Rangitoto ***N:*** 5760100

NZMS 260 Sheet: S16/084215 *Page* 1 *of* 1

Author: C. Nelson & A. Tripathi

Modified: B. Whiteman

Stage	Strat Unit	Scale (metres)	Strat Unit (old)	Lithology	Structures	Fossils	Facies	Photo No.	WO No.	Description
Ld	Orahiri	40	Or Lst?	eroded top						(after Glennie, 1956)
		30	OrB				L_1-L_3			Flaggy slightly pebbly limestone.
	Glen Massey	20	Whaingaroa Slst			Shell bed, molluscs common	Z_1			Blue-grey calcareous siltstone.
e. Lwh	WCM	10	WCM							4.6 m coal seam.
	Dunphail	0								Carbonaceous mudstone.
										Mesozoic basement rocks.

mud | fine silt | med silt | coarse silt | fine sand | med sand | coarse sand | gravel

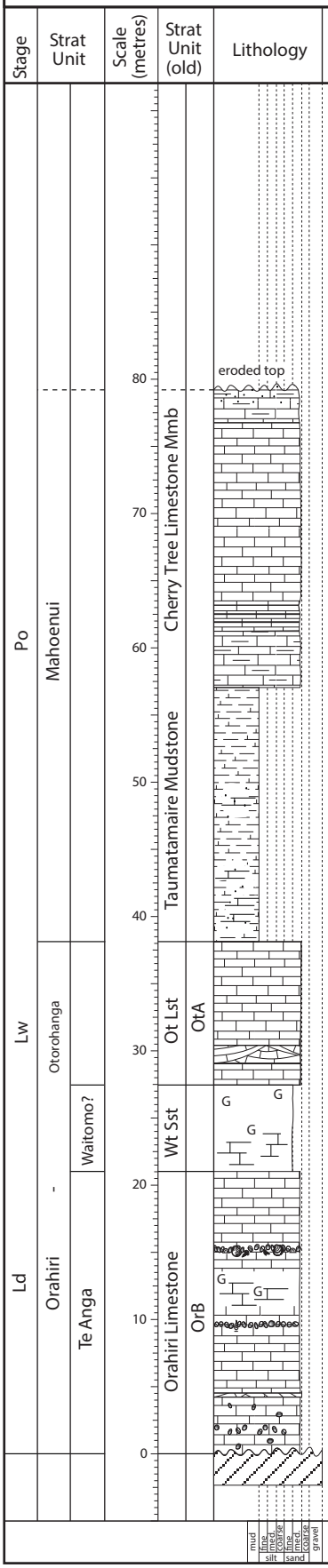
Stratigraphic Column No: *6*
Region: King Country/Waitomo
Location: Walker Road, east of Te Kuiti.

NZMS 260 Sheet: S16/045174

Grid Reference: BF33
E: 1793600
N: 5755500

Page 1 *of* 1

Author: C. Nelson & A. Tripathi
Modified: B. Whiteman



Facies	Photo No.	WO No.	Description
			Top sample muddy limestone. in paddock. Variable sandy-muddy lst., incipient-mod. flags 2.5-20 cm with shaley seams.
L8			Mod.-well flagged, var. 5-23 cm, av. 13 cm thick limestone., seams common, wavy and occ. thick, topog. shelves develop at a no. of heights.
			Flags 5-25 cm thick.
			Prominent sandy mudstone. seams to 2.5 cm thick between var. thickness flags.
			40° connecting slope of sandy muddy lst. and interbedded mst., lst. beds 15-20 cm thick, nearer base mst. beds up to 23 cm thick.
M1			Bl/gr. calc. mst., weaths. brown, very frittery appearance, contains interbedded smooth mass. slightly sandy muddy lst., non-seamed. Msts. burrowed.
L6			
L3			Well flagged 5-15 cm pure lst., seams slightly wavy.
L2			Cross-beds dip 15 °, flags 5-15 cm.
			Reg. seams 5-7.6 cm apart, sl. glauc. at base.
S1			Mass. calc. glauc. fine sst., fluted outcrop.
			Incip. seams 10-20 cm apart nearer base.
			Flaggy lst., 7.6-20 cm flags, av. 15 cm.
			Gritty sandy lst.
			Gritty-pebbly band 10 cm wide, non-seamed, fossiliferous material.
L4			Incip.-mod. flaggy lst., flags av. 7.6 cm, slightly glauc., slightly gritty.
			Ff-gritty base, with pebble band 9.5-9.8 m, pebbs. av. 0.3-1.3 cm, sharp base, grad. top, slightly glauconitic.
			Flaggy 5-10 cm lst., occ. grit.
L1			30.5 cm cross-bedded unit.
			Incip. seams 5-10 cm apart, slightly gritty, pebbs. av. 0.3-0.6 cm, common 1.5-2.1 m, no basal conglom., sharp irregular contact.
			Mesozoic basement rocks.

Stratigraphic Column No: *7* ***Grid Reference: BF33***

Region: King Country/Waitomo

Location: Mangaokewa Stream, SH30, south of Te Kuiti.

NZMS 260 Sheet: S16/019114

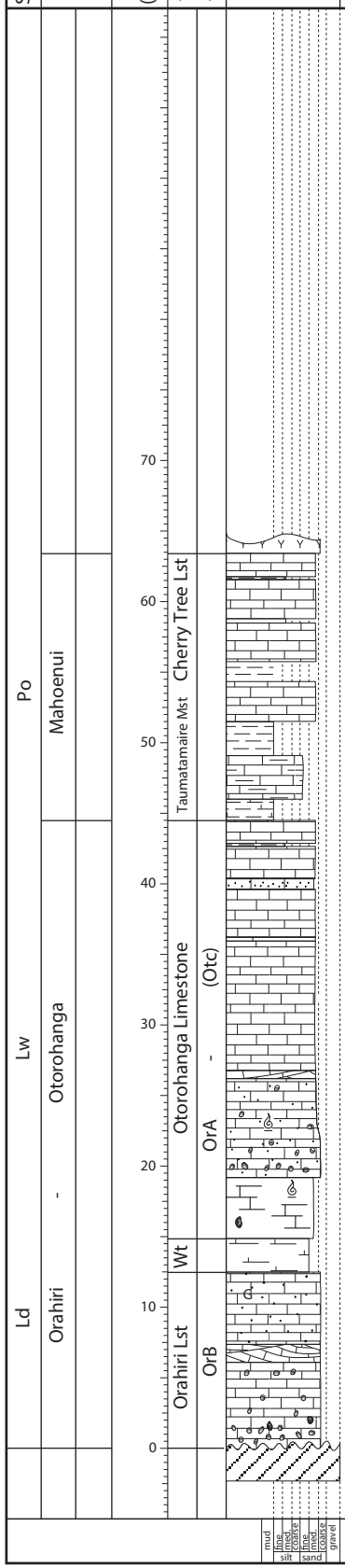
E: 1792500

N: 5749000

Page 1 *of* 1

Author: C. Nelson & A. Tripathi

Modified: B. Whiteman



Stratigraphic Column No: *8* ***Grid Reference: BF33***

Region: King Country/Te Kuiti ***E:*** 1781100

Location: Oparure Limeworks Quarry, West of Te Kuiti. ***N:*** 5754500

NZMS 260 Sheet: S16/914163 *Page* 1 *of* 1 **Author:** B. Simms

Modified: B. Whiteman

Stage	Strat Unit	Scale (metres)	Strat Unit (old)	Lithology	Structures	Fossils	Facies	Photo No.	WO No.	Description
Lw Po	Mahoenui	70 60 50 40 30 20 10 0	Taumatamaire Mudstone				M1 M3 L3			Mudstone contains three sandy layers at 3, 5 and 10 metres Layers - Massive, grey, non-frittery, moderately indurated, slightly fossiliferous, calcreous sandy mudstone. Massive, grey, frittery, well sorted, moderately indurated, slightly fossiliferous calcreous mudstone. Massive, grey, non-frittery, moderately indurated, slightly fossiliferous, calcreous sandy mudstone. Horizontally bedded lst, tabular partings, increases in argill. at top, one laterally discontinuous planar-tabular cross-bed.

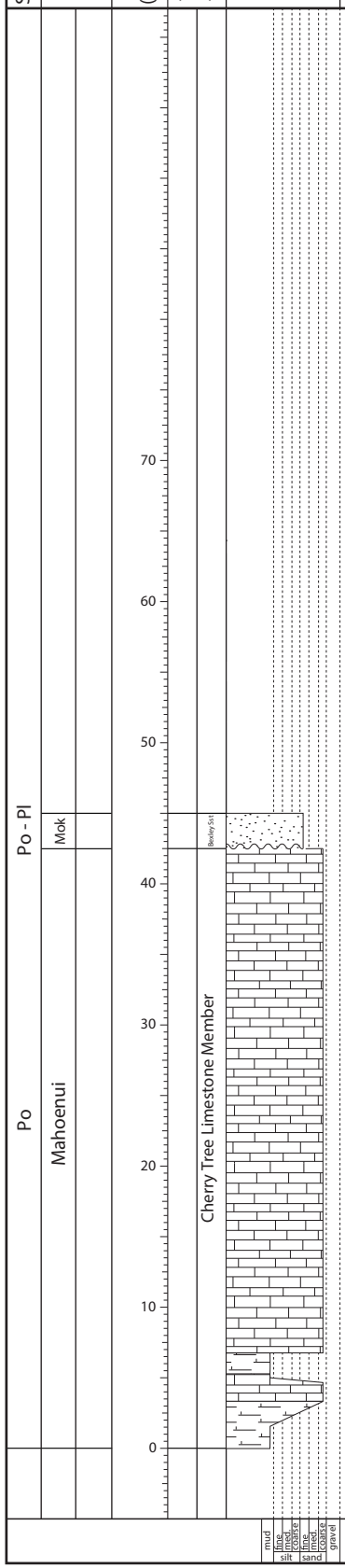
Stratigraphic Column No: *9* ***Grid Reference:*** ***BF33***

Region: King Country/Te Kuiti ***E:*** 1786300

Location: Gadsby Road, North-West of Te Kuiti. ***N:*** 5755500

NZMS 260 Sheet: S16/964172 *Page* 1 *of* 1 **Author:** B. Simms

Modified: B. Whiteman



Facies	Description
S_4	Massive, orange/brown, well sorted, fine grained sandstone. (fine cross beds and fine laminations.
L_7	Light brown, incipient, pinch and swell structures, flags/beds 20-80cm thick, coarse grained, well indurated calcareous limestone. - Flags/beds are caped with silty mudstone of 1 to 5cm thick. - 2-8cm silty mudstone ripup clasts are present within the basal 20cm of some flags.
M_2	Massive, grey, frittery, well sorted, moderately indurated, slightly fossiliferous calcreous sandy mudstone.
M_3	Light brown, incipient, pinch and swell structures, flags/beds 20-80cm thick, coarse grained, well indurated calcareous limestone. - Flags/beds are caped with silty mudstone of 1 to 5cm thick. - 2-8cm silty mudstone ripup clasts are present within the basal 20cm of some flags. Massive, grey, frittery, well sorted, moderately indurated, slightly fossiliferous calcreous mudstone.

Stratigraphic Column No: *10* ***Grid Reference: BF33***

Region: King Country/Te Kuiti ***E:*** 1787800

Location: State Highway 3, South of Te Kuiti. ***N:*** 5750500

NZMS 260 Sheet: S16/976123 *Page* 1 *of* 1 **Author:** B. Simms

Modified: B. Whiteman

Stage	Strat Unit	Scale (metres)	Strat Unit (old)	Lithology	Structures	Fossils	Facies	Photo No.	WO No.	Description
Po	Mahoenui	70 60 50 40 30 20 10 0	Taumatamaire Formation	mud, fine silt, medium silt, coarse silt, fine sand, medium sand, coarse sand, gravel		Fossils (general).	M1 L7 L7 M1			Massive, light blue grey, frittery, well sorted, calcreous mudstone. Light brown, incipient, some pinch and swell structures, flags/beds 5-30cm thick, coarse grained, well indurated calcareous limestone. Light blue grey, frittery, faintly bedded, calcareous mudstone. Faint sandstone interbeds and fossil content both become more apparent towards the base of the limestone. Light brown, incipient, some pinch and swell structures, flags/beds 5-30cm thick, coarse grained, well indurated calcareous limestone. Massive, light blue grey, frittery, well sorted, calcreous mudstone.

Stratigraphic Column No: *11* ***Grid Reference: BF33***

Region: King Country/Te Kuiti ***E:*** 1788500

Location: Mintech Quarry, North of Te Kuiti. ***N:*** 5756400

NZMS 260 Sheet: S16/986179 *Page* 1 *of* 1 **Author:** B. Simms

Modified: B. Whiteman

Stage	Strat Unit	Scale (metres)	Strat Unit (old)	Lithology	Structures	Fossils	Facies	Photo No.	WO No.	Description
Lw Po	Mahoenui	70 60 50 40 30 20 10 0	Taumatamaire Formation			Contact not seen.	M1			Massive, grey, frittery, well sorted, moderately indurated, slightly fossiliferous calcreous mudstone. Contains two calcite veins of 15cm thick at 4 and 6 metres.
	TK		Oto Lst				S3 L3			Massive, light brown/orange, non-frittery, moderately indurated, calcreous muddy sandstone.

mud | fine | med | coarse | silt | fine | med | coarse | sand | gravel

Stratigraphic Column No: *12* ***Grid Reference: BF33***

Region: King Country/Te Kuiti ***E:*** 1789300

Location: Pukenui Road, South of Te Kuiti. ***N:*** 5748700

NZMS 260 Sheet: S16/994103 *Page* 1 *of* 1 **Author:** B. Simms

Modified: B. Whiteman

Stage	Strat Unit	Scale (metres)	Strat Unit (old)	Lithology	Structures	Fossils	Facies	Photo No.	WO No.	Description
Po	Mahoenui	110	Taumatamaire Formation							
		100					S_3			Massive, orange/brown, well sorted, fine grained sandstone.
		90								
		80					M_1			
		70								
		60				Broken shell Material, Shell Bed	S_3			Massive, orange/brown, well sorted, fine grained sandstone. Fossil layer 1m below contact.
		50								
		40								
		30					M_1			
		20								
		10								Massive, light grey, frittery, argillaceous, wavy bedded, calcreous mudstone.
		0								

mud | silt: fine, med, coarse | sand: fine, med, coarse | gravel

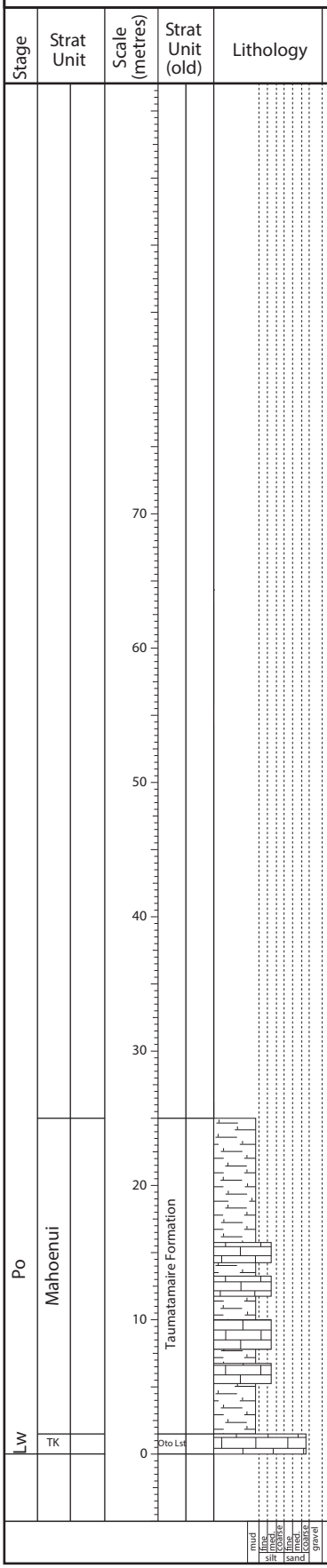
Stratigraphic Column No: *13* ***Grid Reference: BF33***

Region: King Country/Te Kuiti ***E:*** 1790800

Location: Old Limestone Quarry - Currently a Landfill, East of Te Kuiti. ***N:*** 5755600

NZMS 260 Sheet: S16/008173

Page 1 *of* 1 **Author:** B. Simms
Modified: B. Whiteman



Stratigraphic Column No: *14* ***Grid Reference: BF33***

Region: King Country/Pukerimu ***E:*** 1793500

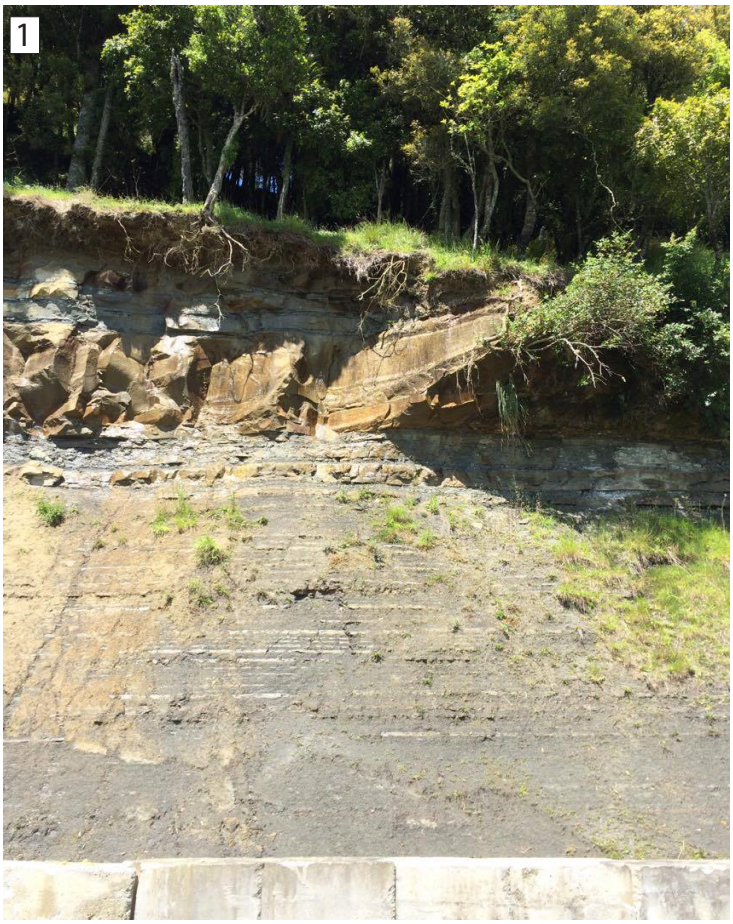
Location: Pukerimu Road, South of Te Kuiti. ***N:*** 5739200

NZMS 260 Sheet: S17/032007

Page 1 *of* 2 **Author:** B. Simms
Modified: B. Whiteman

Stage	Strat Unit	Scale (metres)	Strat Unit (old)	Lithology	Structures	Fossils	Facies	Photo No.	WO No.	Description
Po	Mahoenui	70	Taumatamaire Mudstone							
		60								
		50					I2b			Alternating carbon rich sandstone/mudstone beds - Bouma structures - A, B, C, D, E Sandstone beds 2-10cm Mudstone beds 2-15cm
		40					S2a	2 3		Massive, brown/tan, ferrigenous, moderately indurated, wavy topped sandstone with rip up clasts. Sandstone thickness changes constantly 3-4 metres.
							I2c			Alternating sandstone/mudstone beds: Sandstone - Massive, brown/tan, ferrigenous, moderately indurated sandstone Mudstone - Light grey, frittery, slightly bedded, moderately indurated mudstone.
		30					S2a	1		Massive, brown/tan, ferrigenous, moderately indurated, wavy topped sandstone with rip up clasts. Sandstone thickness changes constantly 2.3-1.5 metres.
		20								Alternating limestone/mudstone beds.
							I2b			Alternating carbon rich sandstone/mudstone beds - Bouma structures - A, B, C, D, E Sandstone beds 2-10cm Mudstone beds 2-15cm
		10								
		0								

mud | silt: fine, medium, coarse | sand: fine, medium, coarse | gravel


1


2


3

Stratigraphic Column No: *15* ***Grid Reference: BF33***

Region: King Country/Pukerimu ***E:*** 1791100

Location: Pukerimu Road, South of Te Kuiti. ***N:*** 5739900

NZMS 260 Sheet: S17/013009 *Page* 1 *of* 1 **Author:** B. Simms

Modified: B. Whiteman

Stage	Strat Unit	Scale (metres)	Strat Unit (old)	Lithology	Structures	Fossils	Facies	Photo No.	WO No.	Description
Sl - Sw	Whangamomona	140	Otunui Formation							
		130								
		120								
		110					S4			Massive, brown/tan, ferrigenous, moderately indurated, well sorted sandstone.
		100								
		90								
		80								
		70					M1			Massive, dark grey, frittery, well sorted, calcareous mudstone with sandstone beds at base.
		60								Alternating sandstone/mudstone beds: Sandstone - Massive, brown/tan, ferrigenous, moderately indurated sandstone Mudstone - Light grey, frittery, slightly bedded, moderately indurated mudstone.
		50								
		40								
		30					S4			Massive, brown/tan, ferrigenous, moderately indurated, well sorted sandstone.
		20								
		10					M1			Mudstone interbed - massive, dark grey, slightly frittery mudstone.
		0					S4			

mud | silt: fine, med, coarse | sand: fine, med, coarse | gravel

Stratigraphic Column No: *16* ***Grid Reference: BF33***

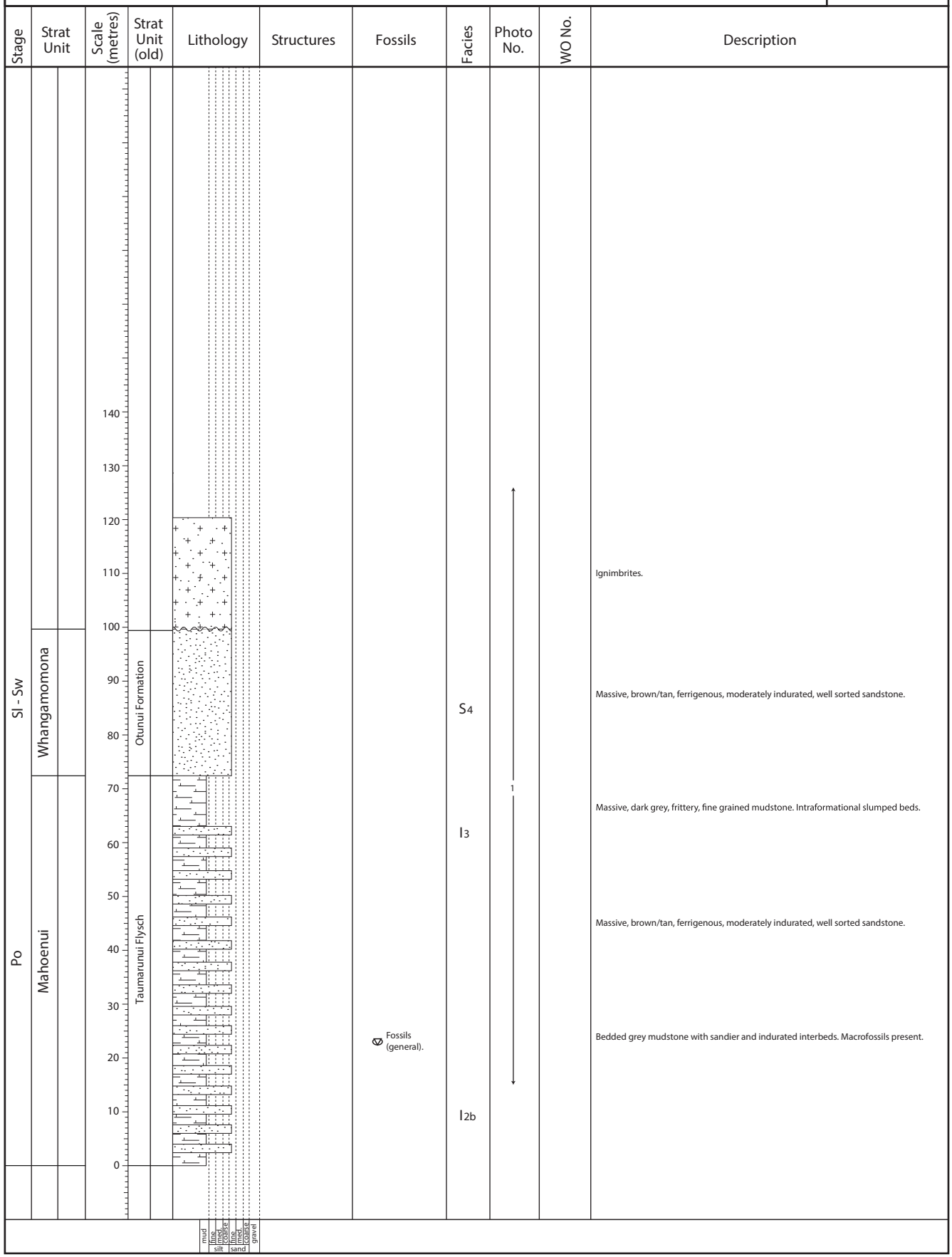
Region: King Country/Mapara ***E:*** 1790900

Location: Madonna Falls (SH4), South-West of Te Kuiti. ***N:*** 5736500

NZMS 260 Sheet: S17/011983

Page 1 *of* 2 **Author:** B. Simms

Modified: B. Whiteman



1



Stratigraphic Column No: *17* ***Grid Reference: BF33***

Region: King Country/Te Kuiti ***E:*** 1791100

Location: Mangarino Road, East of Te Kuiti. ***N:*** 5758500

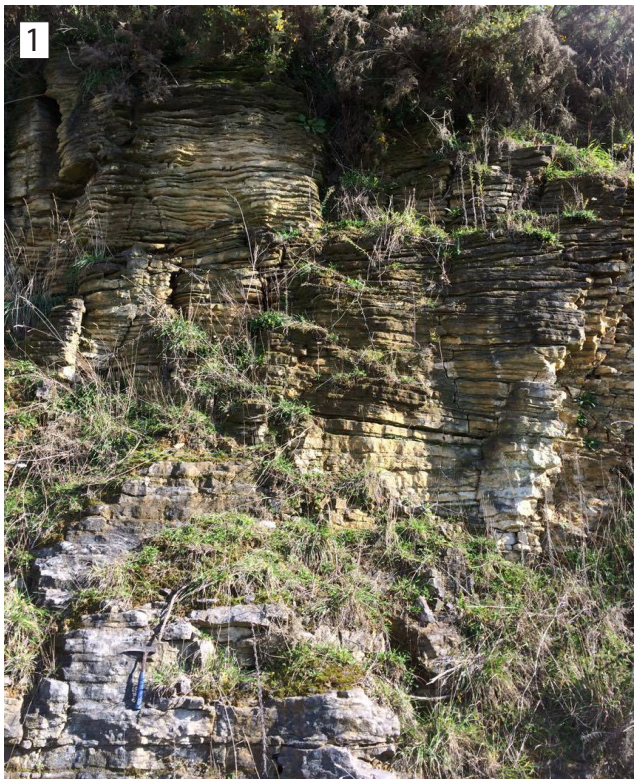
NZMS 260 Sheet: S16/013194

Page 1 *of* 2 **Author:** A. Vonk
Modified: B. Whiteman

Stage	Strat Unit	Scale (metres)	Strat Unit (old)	Lithology	Structures	Fossils	Facies	Photo No.	WO No.	Description
Po - Pl	Mokau	70	Mangarino Member							Brown/grey, frittery, argillaceous, ferrugenously stained, wavy, bedded, carbonaceous, silty mudstone. Weathering horizons of brown mudstone.
		60								Massive to slightly wavy to parallel laminations accentuated by lysegang weathering, orange/brown, well sorted fine grained sandstone.
		50						3		Brown/grey, frittery, argillaceous, ferrugenously stained, wavy, bedded, carbonaceous, silty mudstone. Weathering horizons of brown mudstone.
		40					I4			Massive to slightly wavy to parallel laminations accentuated by lysegang weathering, orange/brown, well sorted fine grained sandstone. Lensoidal conglomerate, 15cm max thickness, well rounded greywacke pebbles.
		30						4		Brown/grey, frittery, argillaceous, ferrugenously stained, wavy, bedded, carbonaceous, silty mudstone. Weathering horizons of brown mudstone.
		20						2		Massive to slightly wavy to parallel laminations accentuated by lysegang weathering, orange/brown, well sorted fine grained sandstone.
Po	Mahoenui	10	Taumatamaire Mudstone			Unconformable contact. Actual contact unseen.				
Lw	Te Kuiti	0	Oto Lst				L3	1		Planar-tabular cross-bedding, discordant Low angle, planar-tabular cross-beds. 5-15 cm flags (bottom sets 15-30 cm).

mud | silt: fine, med, coarse | sand: fine, med, coarse | gravel

1



2



3



4



Stratigraphic Column No: *18* ***Grid Reference: BF33***

Region: King Country/Te Kuiti ***E:*** 1787500

Location: Gadsby Road, West of Te Kuiti. ***N:*** 5755500

NZMS 260 Sheet: S16/972165 *Page* 1 *of* 1 **Author:** A. Vonk

Modified: B. Whiteman

Stage	Strat Unit	Scale (metres)	Strat Unit (old)	Lithology	Structures	Fossils	Facies	Photo No.	WO No.	Description
Po - Pl	Mokau	60	Mangarino Member				S_4			Massive to slightly laminated, orange/brown, well sorted, medium to fine grained, ferrugenously stained sandstone.
		50				Broken shell material.	S_4			Massive to slightly laminated, orange/brown, well sorted, medium to fine grained, ferrugenously stained sandstone. Concretion containing whole and broken bivalve and gastropod macrofossil clasts.
Po	Mahoenui	40	Cherry Tree Limestone		Uncertain contact location.					
		30					L_7			Light brown, incipient, pinch and swell structures, flags/beds 20-80cm thick, coarse grained, well indurated calcareous limestone. - Flags/beds are caped with silty mudstone of 1 to 5cm thick. - 2-8cm silty mudstone ripup clasts are present within the basal 20cm of some flags.
		20								
		10	Taumatamaire Mst		Uncertain contact location.					
		0					M_1			Massive, grey, frittery, well sorted, moderately indurated, slightly fossiliferous calcreous sandy mudstone.

mud | silt: fine, med, coarse | sand: fine, med, coarse | gravel

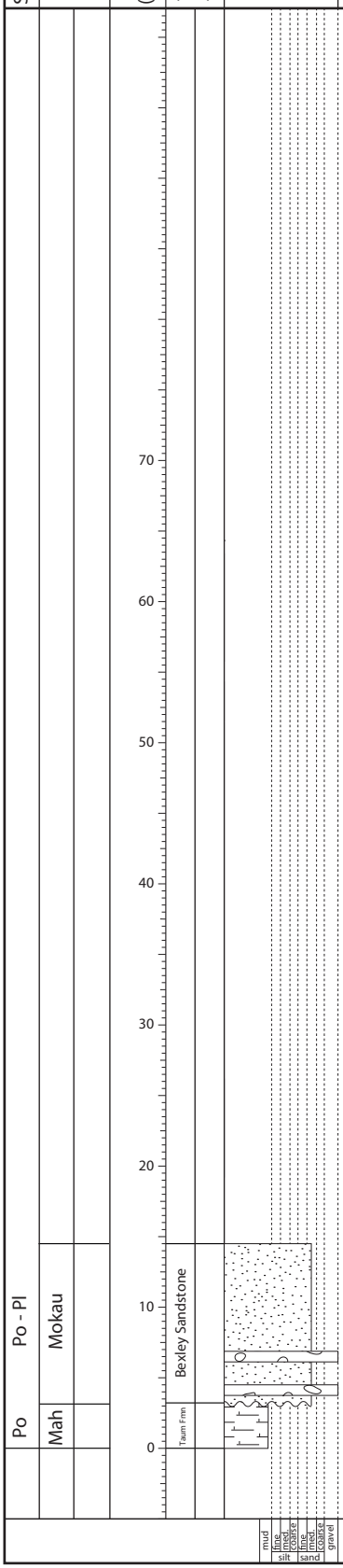
Stratigraphic Column No: *19* ***Grid Reference: BF33***

Region: King Country/Waitomo ***E:*** 1790100

Location: State Highway 3, East of Waitomo. ***N:*** 5763000

NZMS 260 Sheet: S16/005248 *Page* 1 *of* 2 **Author:** A. Vonk

Modified: B. Whiteman



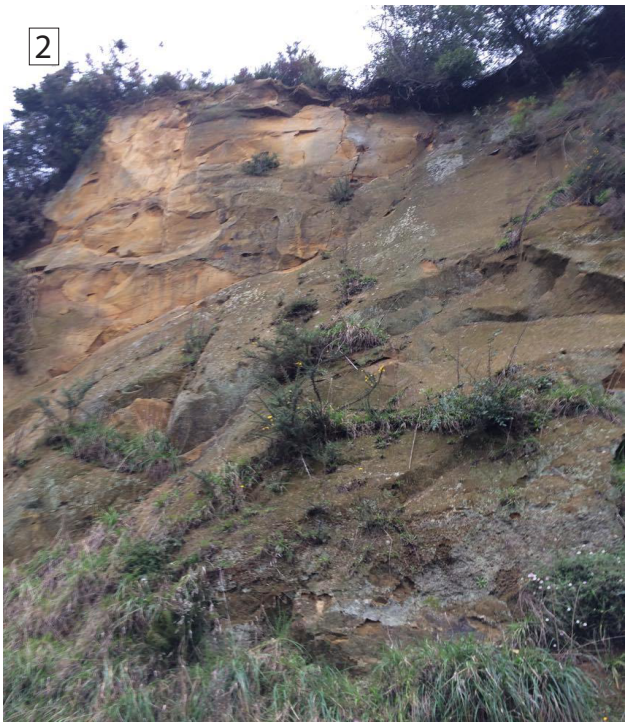
Facies	Photo No.	Description
S_5	1, 2	Massive to faintly parallel bedded, orange/brown, well sorted, medium to fine grained, limonite stained sandstone.
C_1	1, 3	Intraformational bed of matrix supported conglomerate. Pebbles 1-5cm diameter, mainly greywacke, pinches out over short distances (5m horizontally) channelised.
C_1		
M_1		Massive, blue/grey, frittery, moderately indurated, silty mudstone.

Column 19: Photos

1



2



3



Stratigraphic Column No: *20* ***Grid Reference: BF33***

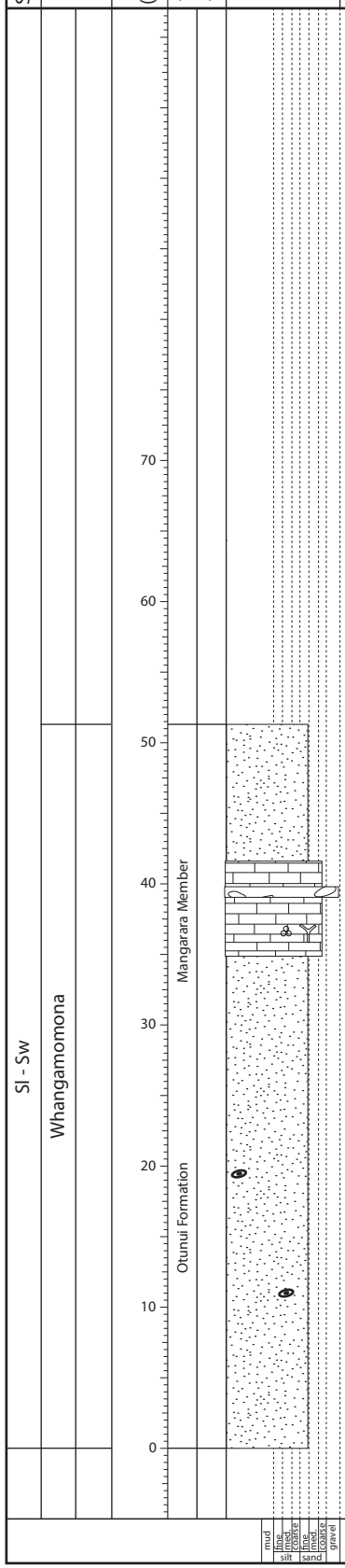
Region: King Country/Benneydale ***E:*** 1802700

Location: State Highway 30, Railway Cutting, West of Benneydale. ***N:*** 5733100

NZMS 260 Sheet: S17/128948

Page 1 *of* 1 **Author:** A. Vonk

Modified: B. Whiteman



Stratigraphic Column No: 21 ***Grid Reference: BF33***

Region: King Country/Otewa ***E:*** 1799300

Location: Tahaia Road Farm Quarry & Hill Section, North-East of Te Kuiti. ***N:*** 5761400

NZMS 260 Sheet: S16/094231 *Page* 1 *of* 2 **Author:** B. Whiteman

Stage	Strat Unit	Scale (metres)	Strat Unit (old)	Lithology	Structures	Fossils	Facies	Photo No.	WO No.	Description
Po - Pl	Mokau	90	Bexley Sandstone				S 4			Massive to faintly parallel bedded, orange/brown, well sorted, medium to fine grained, limonite stained sandstone.
		80								
		70								
		60								
		50								
		40								
		30								
		20								
		10	Bexley Sst				S 4 C 1 S 4	1 2 3		Massive to faintly parallel bedded, orange/brown, well sorted, medium to fine grained, highly weathered, limonite stained sandstone. Intraformational bed of matrix supported conglomerate. Pebbles 1-5cm diameter, mainly greywacke.
Jm	Manaia Hill	0	Basement		Unconformable contact. Actual contact unseen.					Mesozoic basement rocks. (Greywacke).

mud | fine | med | coarse | silt | fine | med | coarse | sand | gravel

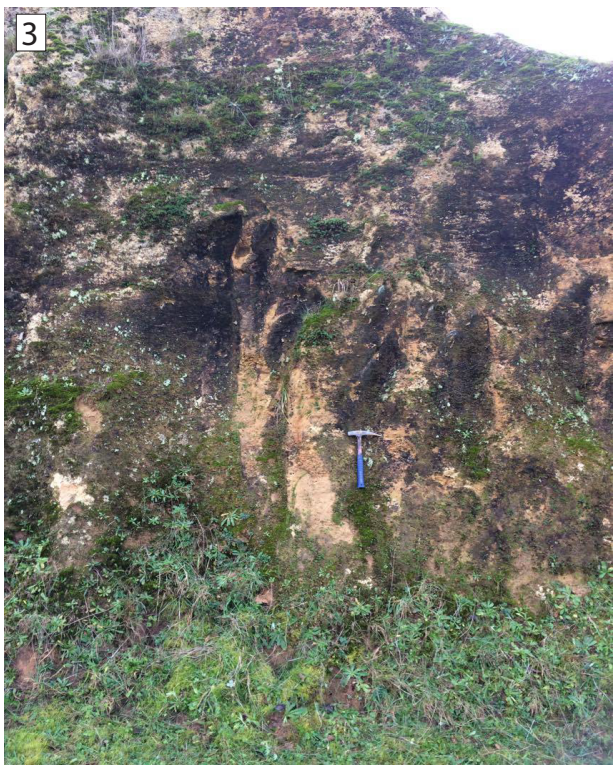
1



2



3



Stratigraphic Column No: *22* ***Grid Reference: BF33***

Region: King Country/Mangaokewa ***E:*** 1801600

Location: Mangaokewa Road, South of Te Kuiti. ***N:*** 5740600

NZMS 260 Sheet: S17/118025 *Page* 1 *of* 2 **Author:** B. Whiteman

Stage	Strat Unit	Scale (metres)	Strat Unit (old)	Lithology	Structures	Fossils	Facies	Photo No.	WO No.	Description
Po - Pl Sl - Sw	Whangamomona	70 60 50 40 30 20 10 0	Otunui Fmn / Mangarara Mmb		Formation extends upwards but is covered in vegetation.	Broken shell material. Shellbed layer	S 6			Light greyish brown, frittery, argillaceous, carbonaceous, fine grained, tuffaceous sandstone.
	Mok		Bexley Sst				L 9 S 4	1 2		Light grey/brown, incipient, coarse grained, poorly sorted, highly indurated, silty limestone. Mostly Massive with 2 thin mudstone laminations, light brown/orange, non-frittery, moderately indurated, calcreous muddy sandstone.

mud | silt: fine, med, coarse | sand: fine, med, coarse | gravel

1



2



Stratigraphic Column No: *23* ***Grid Reference: BF33***

Region: King Country/Mangaokewa ***E:*** 1801000

Location: Mangaokewa Road, South of Te Kuiti. ***N:*** 5740900

NZMS 260 Sheet: S17/113025 *Page* 1 *of* 2 **Author:** B. Whiteman

Stage	Strat Unit	Scale (metres)	Strat Unit (old)	Lithology	Structures	Fossils	Facies	Photo No.	WO No.	Description
Sl - Sw	Whangamomona	70, 60, 50, 40, 30, 20, 10, 0	Otunui Formation	mud, fine silt, med silt, coarse silt, fine sand, med sand, coarse sand, gravel			S 6	1, 2, 3		Light greyish brown, frittery, argillaceous, carbonaceous, fine grained, tuffaceous sandstone. Light grey, argillaceous, carbonaceous, fine grained, tuffaceous sandstone. Thin more well cemented layers present at 1m, 5m, 7m, 11m and 12m which contain concretions (10-40cm)


1


2


3

Stratigraphic Column No: *24* ***Grid Reference: BF33***

Region: King Country/Waitomo ***E:*** 1780800

Location: Te Anga Road, North of Waitomo. ***N:*** 5763900

NZMS 260 Sheet: S16/910255 *Page* 1 *of* 2 **Author:** B. Whiteman

Stage	Strat Unit	Scale (metres)	Strat Unit (old)	Lithology	Structures	Fossils	Facies	Photo No.	WO No.	Description
Po - Pl	Mokau	70, 60, 50, 40, 30, 20, 10, 0	Mangarino Member	mud, fine silt, medium silt, coarse silt, fine sand, medium sand, coarse sand, gravel	Highly eroded and weathered top.		I4	1		Finely laminated, blue grey, furrigenously stained, frittery, moderately indurated siltstone. Massive to slightly parrallel bedded, orange/brown, ferruginously stained, medium to fine grained, well sorted sandstone. Two 3cm medium grainsize siltstone beds are present between the sandstones. (Sandstone dip = 7 degrees.) Finely laminated, blue grey, furrigenously stained, frittery, slightly fossiliferous, moderately indurated siltstone. Concretions present.

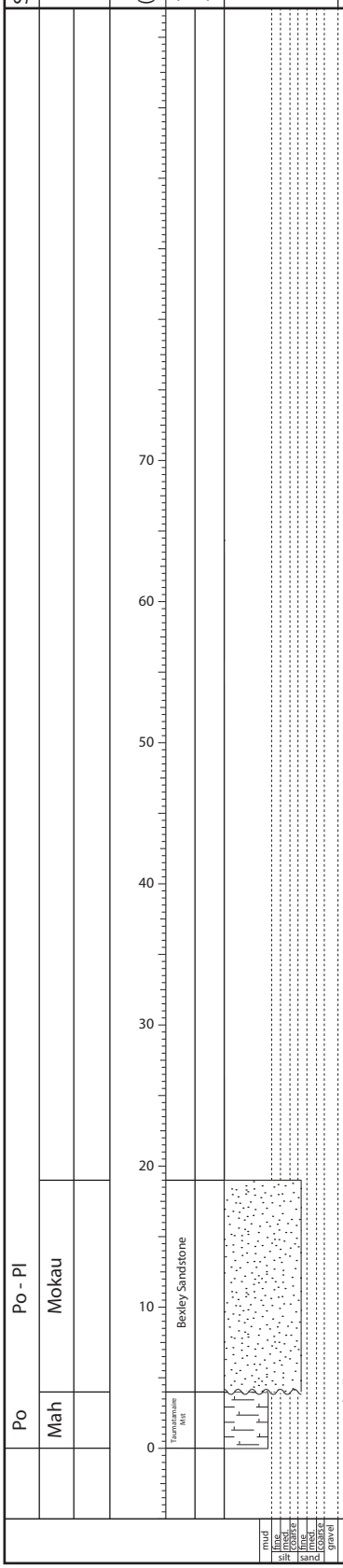

1

Stratigraphic Column No: *25* ***Grid Reference: BF33***

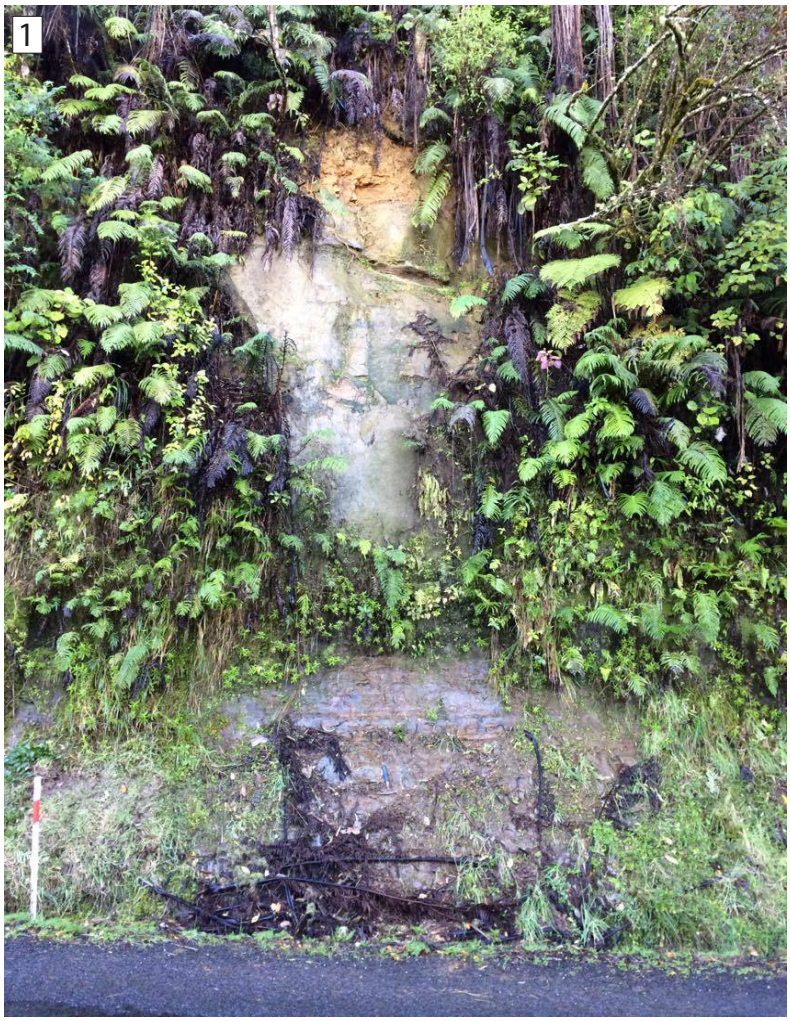
Region: King Country/Waitomo ***E:*** 1783100

Location: Te Anga Road, North of Waitomo. ***N:*** 5764100

NZMS 260 Sheet: S16/934257 *Page* 1 *of* 2 **Author:** B. Whiteman



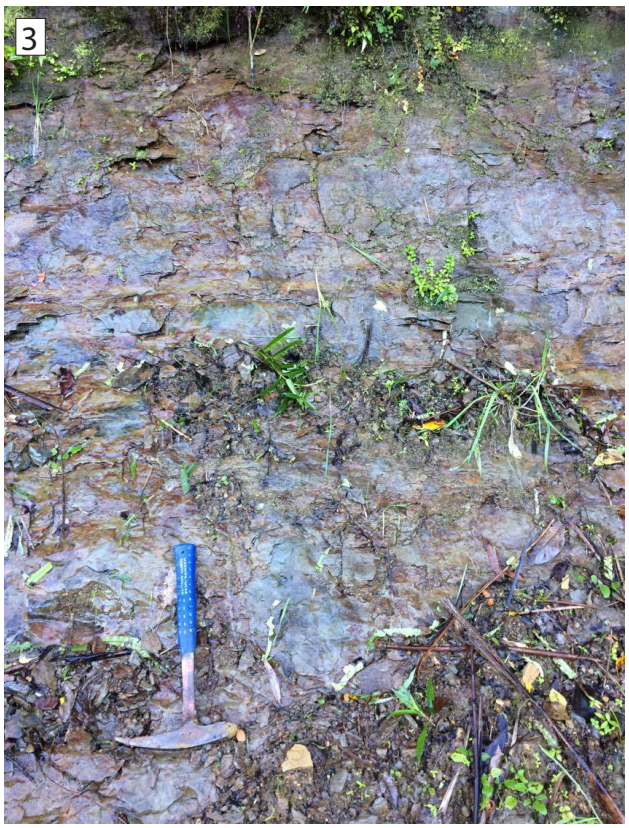
1



2



3



10 Appendix II: Geodetic Database

New Zealand Transverse Mercator 2000 (NZTM2000) is the preferred and used coordinate system in this thesis project. NZTM2000 is a Transverse Mercator projection based on the NZGD2000 datum using the GRS80 reference ellipsoid. The projection is only applicable for the mainland New Zealand (North, South and Steward) with a separate projection defined for New Zealand's offshore islands and continental shelf.

NZTM2000 will be used in New Zealand for further Topo 50 1:50 000 and other small scale mapping. The use of this projection is preferred where a projection is required within mainland New Zealand. For further information regarding the coordinate systems refer to the Land Information New Zealand (LINZ) website.

Name:	New Zealand Transverse Mercator 2000
Abbreviation:	NZTM2000
Projection type:	Transverse Mercator
Reference ellipsoid:	GRS80
Datum:	NZGD2000
Origin latitude:	0° 00' 00" South
Origin longitude / central meridan:	173° 00' 00" East
False Northing:	10,000,000 metres North
False Easting:	1,600,000 metres East
Central meridian scale factor:	0.9996

Enclosure 1 (see back pocket): Geological Map of Te Kuiti Sheet BF33 (Topo 50), Geological Legend and 1:1 cross sections (A-A’ & A-B).