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Title **Systematic Lithostratigraphy of the Neogene succession exposed in central parts of Hawke's Bay Basin, eastern North Island, New Zealand**

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Summary This report presents a systematic lithostratigraphy for the Neogene (Miocene–Recent) sedimentary succession in central parts of Hawke's Bay Basin in eastern North Island, New Zealand. It has been built up chiefly from strata exposed in outcrop, but petroleum exploration drill hole data have also been incorporated to produce this stratigraphic synthesis. Most of the strata exposed in this part of the basin are of Late Miocene (Tongaporutuan, local New Zealand Stage) to Recent age, and the majority of this report focuses on these starta, with brief description of Middle and Early Miocene formations. A companion PR report (Kamp et al. 2007) contains stratigraphic columns for sections through the Neogene succession described in this report.

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Systematic Lithostratigraphy of the Neogene succession exposed in central parts of Hawke's Bay Basin, eastern North Island, New Zealand

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EXECUTIVE SUMMARY

This report presents a systematic lithostratigraphy for the Neogene (Miocene–Recent) sedimentary succession in central parts of Hawke's Bay Basin in eastern North Island, New Zealand. It has been built up chiefly from strata exposed in outcrop, but petroleum exploration drill hole data have also been incorporated to produce this stratigraphic synthesis. Most of the strata exposed in this part of the basin are of Late Miocene (Tongaporutuan, local New Zealand Stage) to Recent age, and the majority of this report focuses on these starta, with brief description of Middle and Early Miocene formations.

Early to Middle Miocene beds are encompassed in the **Tolaga Group**. Constituting the Tolaga Group are the **Whakamarino**, **Poamoko, Te Haroto**, **Waitere**, **Mokonui Sandstone,** and **Blowhard Formations**. The Poamoko Formation includes the **Ngatapa Sandstone, Arapaepae Alternating** and **Kingma Peak Mudstone Members.** The Waitere Formation includes the **Tarawera Limestone, Te Ipuohape Sandstone, Auroa Alternating,** and **Rakaita Siltstone Members.** Uppermost Miocene to Late Pliocene beds are largely encompassed in the **Mangaheia Group**. Beds constituting the Mangaheia Group include the **Mangatoro Mudstone, Pakaututu (including Hukanui Limestone Member), Puketitiri, Omahaki, Titiokura (including Naumai, Te Rangi, Taraponui, Bellbird Bush**, and **Opouahi Members), Te Waka**, **Pohue, Matahorua (including Deep Stream, Trelinnoe, Papakiri** and **Grassy Knoll Conglomerate Members), Waipunga, Esk Mudstone, Petane (including Tutira, Aropaoanui Mudstone, Darkys Spur, Park Island Limestone, Mairau Mudstone, Tangoio Limestone, Flag Range Conglomerate, Te Ngaru Mudstone, Waipatiki Limestone,** and **Devils Elbow Mudstone Members), Kaiwaka (including Puketautahi Limestone Member), Taradale Mudstone, Scinde Island, Makaretu Mudstone, Mason Ridge (including Mahana Limestone, Maharakeke Mudstone, Torran Limestone, Whakapirau Mudstone,** and **Pakihirua Limestone Members), Sentry Box, Mount Mary Pebbly Limestone, Kereru, Okauawa (including Kikowhero** and **Whakamarumaru Members)**, and **Poutaki Formations.**

The stratigraphically highest (and youngest) group in the study area is the **Kidnappers Group,** which comprises the **Salisbury Gravel** together with undifferentiated greywacke gravel with minor sandstone and pumiceous beds of Castlecliffian (Middle Pleistocene) age.

A companion PR report (Kamp *et al.* 2007) contains stratigraphic columns for sections through the Neogene succession described in this report. Also, as part of this study, new 1: 50,000 scale geological maps showing the distribution of the stratigraphic units described here have been prepared for the basin, and these will be published in a separate report under preparation. Readers interested in these maps can contact Professor Peter Kamp at the University of Waikato.

INTRODUCTION

In central parts of Hawke's Bay Basin the Neogene succession is folded into a broad syncline that is sympathetic with the modern topography. Jurassic basement that underlies western parts of the basin is exposed along its northwestern faulted margin, and parts of a Neogene accretionary prism are exposed along its southeastern margin. Strata involved in this prism are exposed in coastal hills south of Cape Kidnappers, but farther to the north the prism lies beneath the large coastal embayment of Hawke Bay (Fig. 1A). The Hawke's Bay Basin can be classified as a principal forearc basin. Numerous reports and papers have been written on the stratigraphy of the exposed basin fill, and details of the subsurface stratigraphy have been revealed through several phases of petroleum exploration, including drilling. These prior investigations have tended to be limited to particular, although different parts of the basin, and combined with the stratigraphic diversity highlighted, has resulted in a plethora of stratigraphic names. The first objective of the basin analysis we have undertaken, of which this report is one output, has been to completely geologically map the basin fill at fine scale (reproduced at 1: 50,000) using modern digital methods, including GIS. These studies have highlighted the need for rationalization of the prior stratigraphic nomenclature because close mapping has demonstrated that many named units, each in different parts of the basin, are direct correlatives of each other, and are better given a common name. In this context, the purpose of this report is to describe in detail each of the Neogene geological units cropping out in the basin and their relationship to previously named units. Because of the systematic lithostratigraphic approach we have taken, the report can be heavy reading; a contribution emphasising the stratigraphic patterns and signals in the basin emerging from this detailed work will be written in due course. While this PR report covers the Late Pliocene (Nukumaruan) Mason Ridge Formation, it does not describe the Early Pliocene limestone and associated siliciclastic units exposed in the Havelock North to Waimarama area and involved in the accretionary prism. Readers are referred to Beu (1995) and Caron *et al.* (2004) for details about those units.

Two enclosures are included in this report. One (Enclosure 1) shows geographic place names referred to in the report. The second (Enclosure 2) comprises a correlation panel of the stratigraphic units exposed in 47 key sections/localities throughout the basin. It covers chiefly the late Neogene Mangaheia Group, where most of the lithostratigraphic diversity lies, and the units that are most extensive in the basin. The vertical scale is necessarily compressed, and stratigraphic thickness is limited by the relief at the various localities. This panel is useful to show how units correlate across the basin. New Zealand Neogene stage names are used in the report and we refer readers to Copper *et al.* (2004) (Chapters 12 & 13) for the related Miocene, Pliocene and Pleistocene timescales. Figure 1 (B & C) shows the distribution at a large scale of the geological units mapped in the central part of Hawke's Bay Basin and the location of the stratigraphic columns reported in the companion PR report (Kamp *et al.* 2007).

ACKNOWLEDGEMENTS

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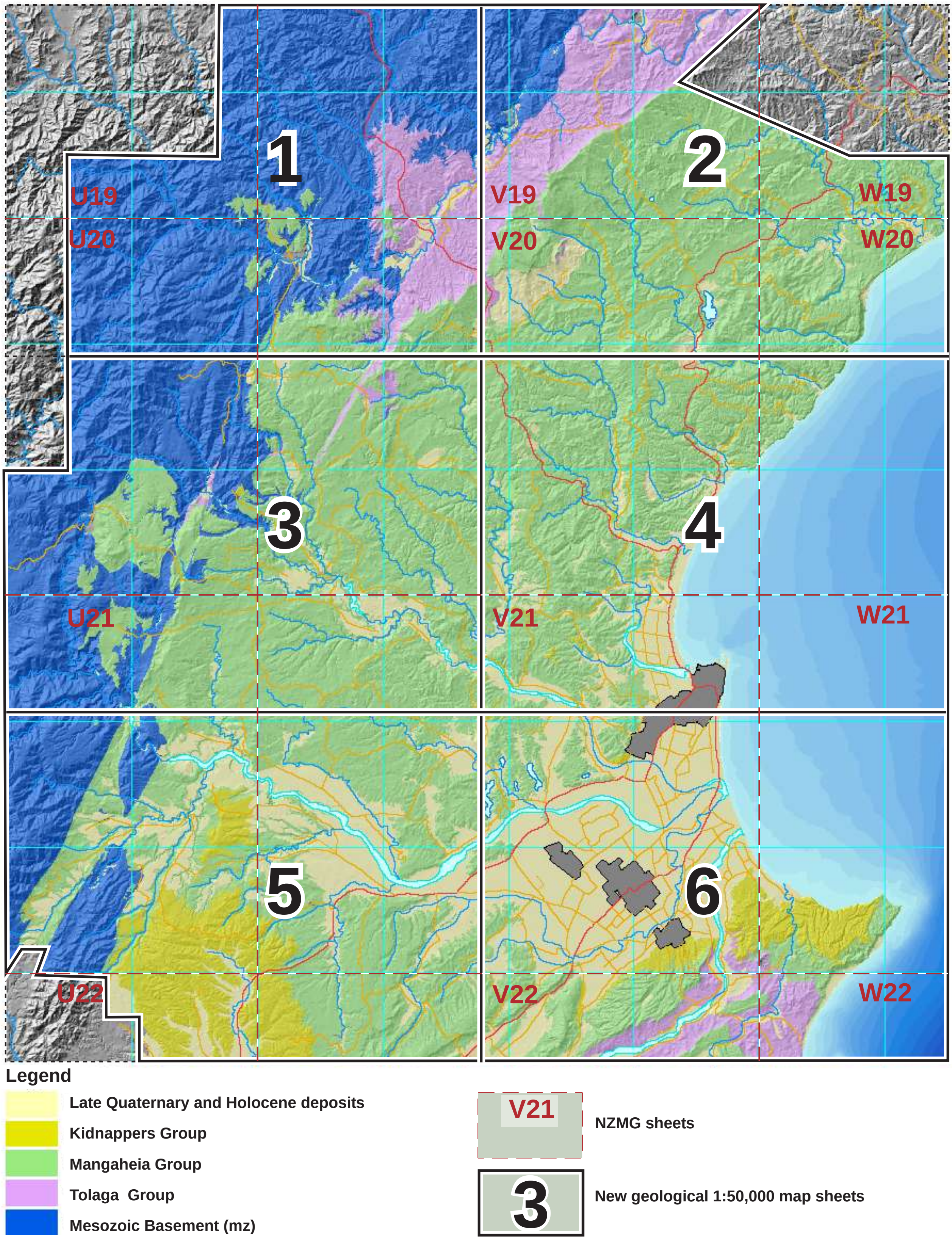


Fig. 1A. Distribution of major rock units (groups) mapped in central Hawke's Bay superimposed on a hillshade relief model. Blue lines are 10 km NZMS 260 series gridlines. State highways (red lines), main roads (orange lines), significant water bodies (blue lines and light-blue polygons) are shown. Grey polygons are (from north to south) the major residential areas of Napier-Taradale, Flaxmere, Hastings and Havelock North. Topographic data are derived from the LINZ NZMS 260 dataset, supplied to The University of Waikato by Eagle Technology. The extent of the six new 1:50,000 geological maps produced as part of this report are indicated in black.

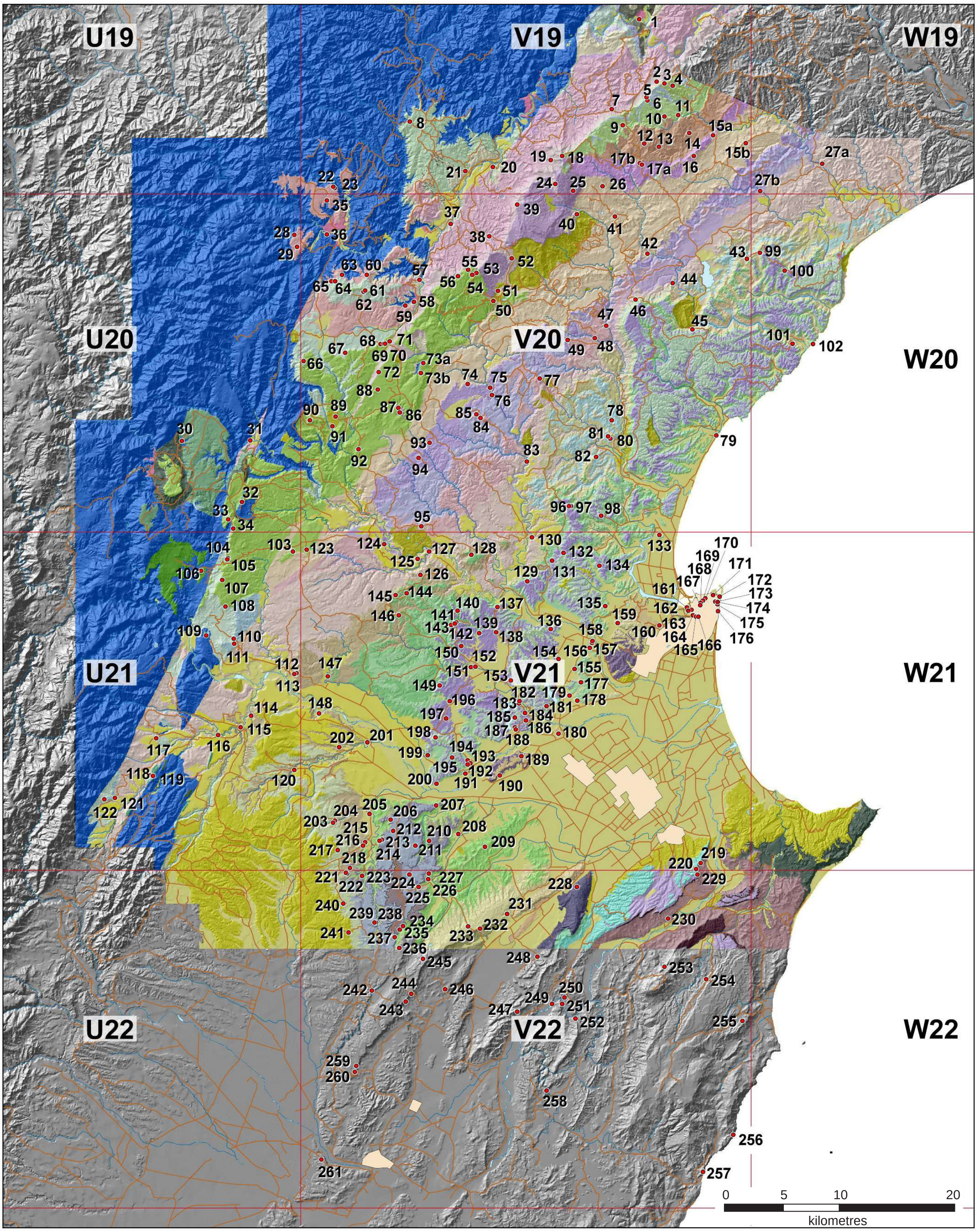


Fig. 1B. Geological map showing the distribution of units mapped through central parts of Hawke's Bay and the location of stratigraphic columns reported in Kamp *et al.* (2007). See Fig. 1C for the map legend.

LEGEND

Units in the north and west

- Kaiwaka Formation
- Petane Formation
- Esk Mudstone
- Waipunga Formation
- Matahorua Formation
- Pohue Formation
- Te Waka Formation
- Puketitiri Formation
- Pakaututu Formation
- Mangatoro Formation
- Blowhard Formation
- Titiokura Formation
- Mokonui Sandstone
- Waitere Formation
- Te Haroto Formation
- Poamoko Formation
- Whakamarino Formation
- Torlesse composite Terrane

Units in the south and east

- Late Quaternary deposits
- Taupo Pumice
- Kidnappers Group
- Poutaki Formation
- Okauawa Formation
- Kereru Formation
- Mount Mary Pebbly Limestone
- Sentry Box Formation
- Mason Ridge Formation
- Makaretu Mudstone
- Pakipkai Limestone
- Black Reef Calcareous Sandstone
- Taradale Mudstone
- Undiff. “Te Aute” limestone and mudstone beds
- Undiff. Early Pliocene-Cretaceous

Fig. 1C. Legend for geological units for which the distribution in central parts of Hawke’s Bay Basin is shown on Fig 1B.

MESOZOIC BASEMENT ROCKS

UNDIFFERENTIATED TORLESSE COMPOSITE TERRANE (mz)

Name and definition

Mesozoic basement rocks are restricted to western parts of the Hawke's Bay where they form the main axial ranges (Fig. 1). The surface distribution of basement rocks in this area was mapped by Grindley (1960) who subdivided them into two major stratigraphic units, the Kaweka Greywacke and Urewera Greywacke. Kaweka Greywacke was mapped to the west of the Kaweka Fault and the Urewera Greywacke to the east of the Kaweka Fault. Urewera Greywacke was inferred by Grindley (1960) to be of Jurassic age, and the Kaweka Greywacke of Jurassic-Triassic age. Subsequent new analysis of basement rock stratigraphy means that basement rocks underlying the East Coast region are assigned to the Torlesse composite terrane (e.g. Lee and Begg 2002). This is one of several Late Paleozoic to Early Cretaceous fault-bounded tectonostratigraphic units of low grade metasedimentary rocks that constitute the Eastern Province of New Zealand (Mazengarb and Speden 2000). Basement rocks of the East Coast region consist mainly of Triassic to Early Cretaceous indurated sandstone and mudstone (greywacke and argillite).

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

Upper contact

Basement exposed in the Pakaututu area comprises alternating greywacke-argillite beds of up to 0.3 m thick. These units are well indurated and moderately to strongly weathered. No fossils have been found in outcrops of this unit during this study. Where the upper surface is exposed, metre-scale relief is typically visible. Stacks up to 2 m in height may protrude into overlying units, and small caves and overhangs in the basement units are commonly infilled with overlying Cenozoic siliciclastic sediments and less commonly bioclastic deposits. Exposures through basement rocks are often several hundred metres in height, especially in areas close to the Kaweka Range (such as along Mangatutu Hot Springs Road).

Distribution

Mesozoic basement rocks are widespread is western parts of the study area, forming the Ruahine, Wakarara, Kaweka, and Ahimanawa Ranges among others. With the exception of an outlier near Patoka, and the Wakarara Range at Kereru, these beds do not crop out west of the Mohaka Fault. Their distribution is illustrated in Fig. 1.

Description

Basement rocks are greywacke-dominated although argillite, chipwacke, flysch, conglomerate and minor chert facies are also present.

Flysch facies are common in the Pakaututu and Puketitiri areas where they are moderately to highly deformed. In close proximity to major faults these beds may be highly sheared and fractured, with varying degrees of folding.

Environment of deposition

The generally monotonous sequence of indurated, interbedded greywacke and argillite typical of the Torlesse composite terrane is inferred to have accumulated mainly in deep marine environments within an accretionary prism (Mortimer 2004).

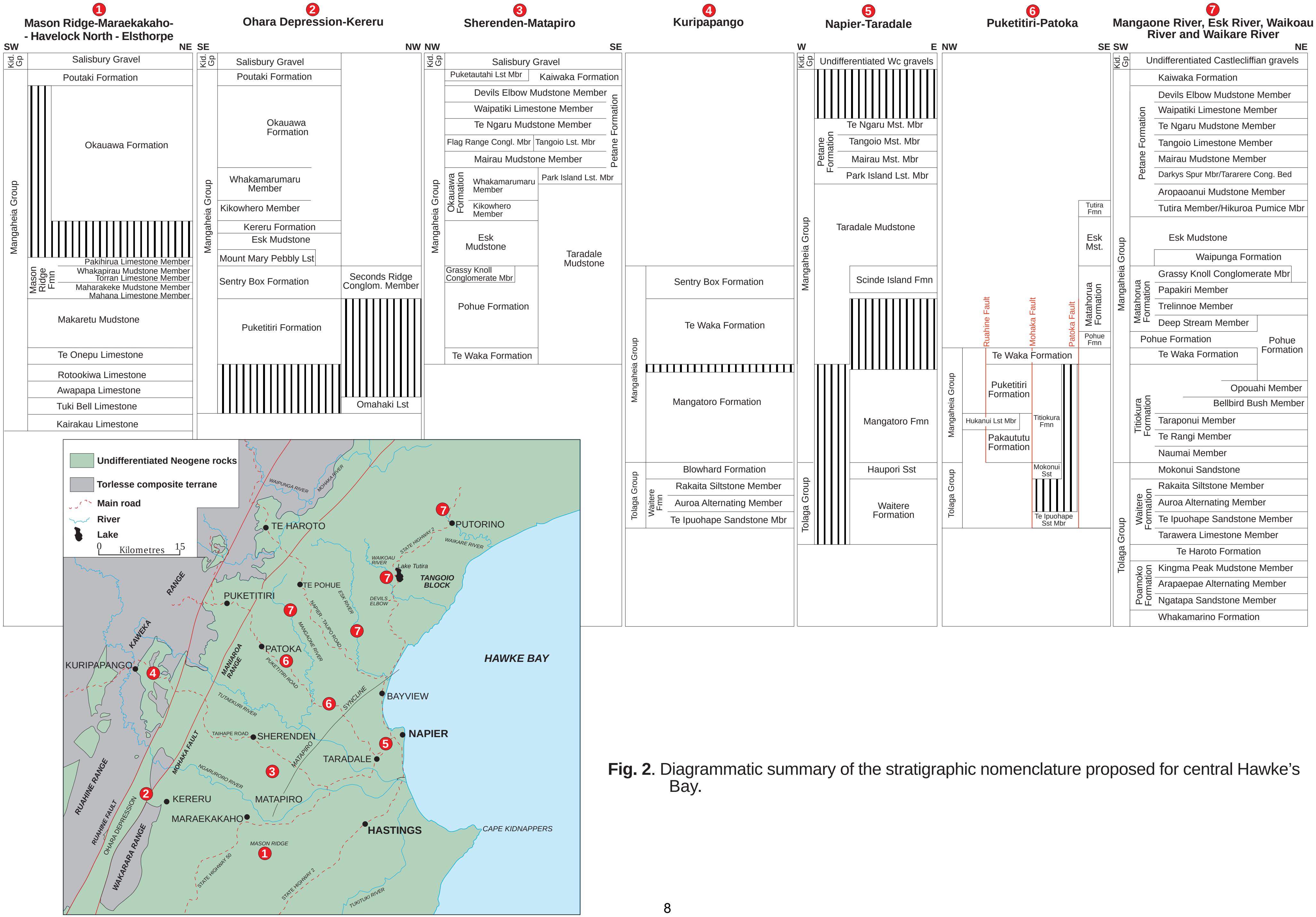


Fig. 2. Diagrammatic summary of the stratigraphic nomenclature proposed for central Hawke's Bay.

NEOGENE STRATIGRAPHY

The Neogene sedimentary succession in Hawke's Bay Basin can be usefully classified into three lithostratigraphic groups: the Tolaga Group; the Mangaheia Group; and the Kidnappers Group (Fig. 2). While the stratigraphic focus has been on the Late Miocene-Early Pleistocene (Kapitean to Nukumaruan) deposits, in northwestern parts of the study area Early to Late Miocene sedimentary beds crop out. These older rocks, assigned to the Tolaga Group, are mostly restricted to the region of Waitere Station and the Mohaka-Te Hoe River confluence. Their distribution was documented in a series of maps produced to identify either potential hydro electric dam sites (e.g. Cutten 1988), hydrocarbon exploration wells (e.g. Moore 1987, 1991; Francis *et al.* 1990) or as summary geological reports (e.g. Grindley 1960; Scott *et al.* 1990; Cutten 1994). The Tolaga Group is overlain by the Mangaheia Group, the interval we have given most attention. The Mangaheia Group is in turn overlain by the Kidnappers Group.

The following sections describe in detail the nature of the Neogene sedimentary succession in central Hawke's Bay. They define stratigraphic units mapped out on the new geological maps, and document their thickness, character, age and inferred depositional environments.

TOLAGA GROUP

(Mazengarb *et al.* 1991)

Name and definition

Tolaga Group was introduced and defined by Mazengarb *et al.* (1991) for sedimentary rocks of Waitakian to Upper Tongaporutuan age in the Tauwhareparae area inland from Tolaga Bay, from where the name is derived. In the original definition of the Tolaga Group, a mainly offshore, moderate to deep-water (outer shelf to ?upper slope) environment of deposition was inferred (Mazengarb *et al.* 1991, p. 33). Only a limited extent and volume of shallow-water beds are present in the Tauwhareparae area and this suggests that shallow conditions only existed in localised areas for temporary periods.

Mazengarb and Speden (2000) extended the definition of the Tolaga Group to include all rocks of Early to Late Miocene age cropping out in the area of the Raukumara QMAP sheet. Beds of similar age, lithology and inferred depositional environments crop out widely through northern parts of central Hawke's Bay and have previously not been included in any stratigraphic group.

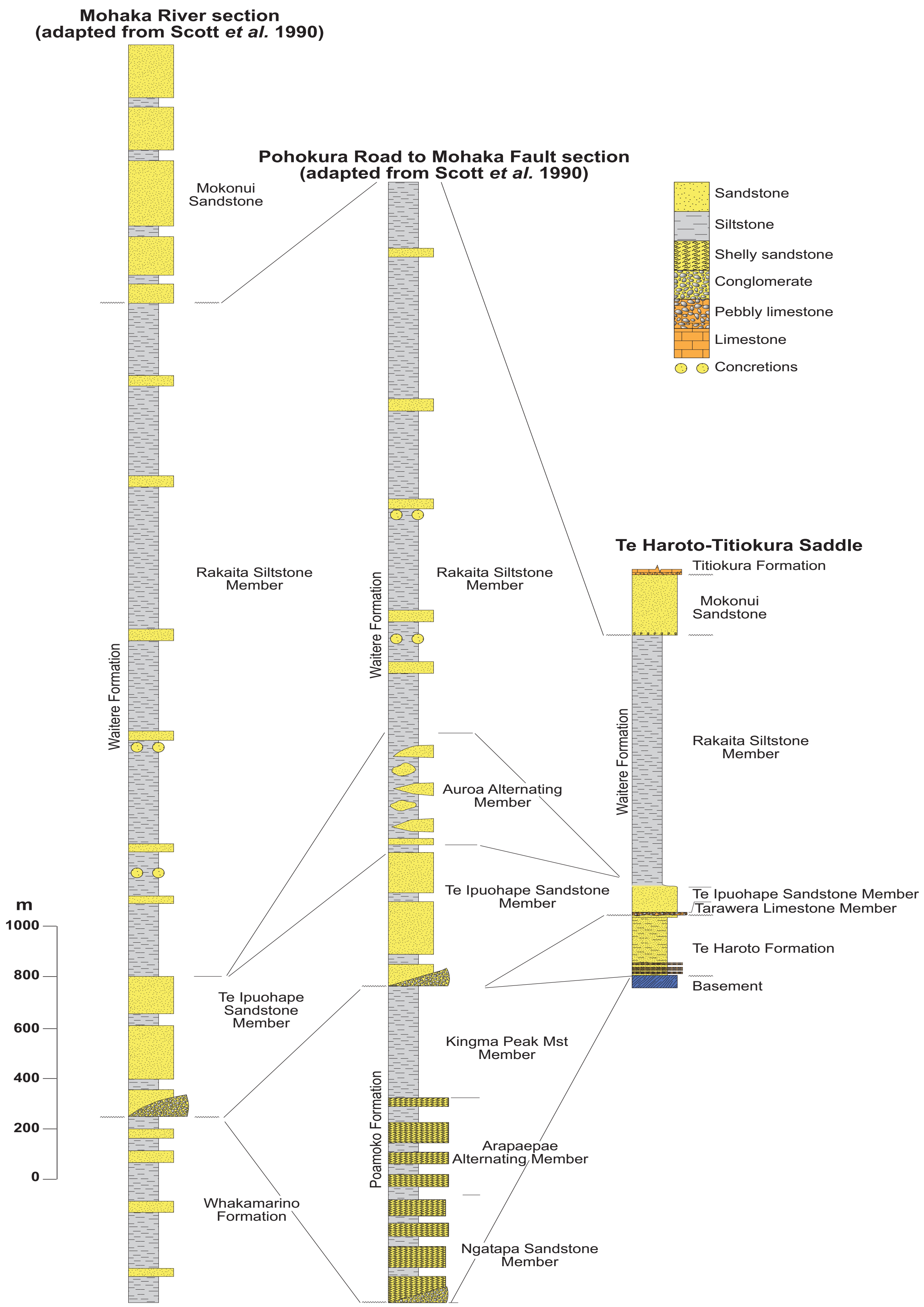


Fig. 3: Schematic stratigraphic columns of the Tolaga Group succession cropping out in the area from the Mohaka River at Waitere Station to the Napier-Taupo Road. Evident is the dominance of siltstone and mudstone facies in the group, and the limited volume of shallower water facies such as shelfal sandstone and limestone. Also evident is how not all formations occur in all areas.

As in the Tolaga Group of Mazengarb *et al.* (1991), shallow-water beds of Early to Late Miocene age are limited in extent in central Hawke's Bay, and the succession is dominated by massive deep-water mudstones and redeposited sandstones. The Late Miocene-Pliocene aged Mangaheia Group of Mazengarb *et al.* (1991) was extended into the Wairoa region by Mazengarb and Speden (2000), and from there into the current study area where it is defined to unconformably overlie the Early to Late Miocene succession prominent from the Napier-Taupo Road to Waitere Station. The Mangaheia Group *sensu stricto* by definition overlies the Tolaga Group. It is viewed as appropriate that the Tolaga Group therefore be extended into the study area (Fig. 1). Formations included here in the Tolaga Group are the Whakamarino, Poamoko, Te Haroto, Waitere, Mokonui and Blowhard Formations.

WHAKAMARINO FORMATION

(Cutten 1988; formally defined by Cutten 1994)

Name and definition

Whakamarino Formation is the oldest Cenozoic unit in the study area and is the basal unit of the Tolaga Group (Fig. 3). The name Whakamarino siltstone lithofacies was introduced by Cutten (1988). The unit was formally defined and named Whakamarino Siltstone Formation by Cutten (1994). As the formation contains a significant thickness of sandstone the unit is renamed Whakamarino Formation in this report, though the general definition of Cutten (1994) is retained. The name is derived from Whakamarino Stream, a tributary of the Te Hoe River.

Type locality and reference sections

The type section established by Cutten (1994) is retained in this report. This section crops out in the banks of the Te Hoe River from the confluence with the Mohaka River upstream to the contact with the Poamoko Formation (V19/406350 to 406386). The basal part of the formation is not exposed in this section but occurs in a small tributary of the Mangahouanga Stream (Moore 1987) at V19/440483 to the north of the study area (Cutten 1994).

Lower and upper contacts

The lower contact of the Whakamarino Formation is not exposed in the study area. North of the study area the unit is reported to unconformably overlie Wanstead Formation (Moore 1987).

The Whakamarino Formation is conformably overlain by the Ngatapa Member of the Poamoko Formation (Cutten 1994).

Distribution and thickness

Whakamarino Formation forms the core of the Pohokura Anticline exposed around the Mohaka-Te Hoe River confluence. The formation is also present west of Te Kooti's Lookout, north to the Hautapu River, and along Ngatapa Road east of the upper Te Hoe River (Cutten 1994).

In the study area, exposure of the Whakamarino Formation is restricted to the area around the Mohaka-Te Hoe River confluence. Excellent exposures are present in the banks of the Mohaka River, especially near the new forest road bridge at Waitere Station (V19/400356; Fig. 4A). Whakamarino Formation is up to 350 m thick in the study area, and reported to be up to 750 m thick north of the Mohaka River (Cutten 1994).

Description

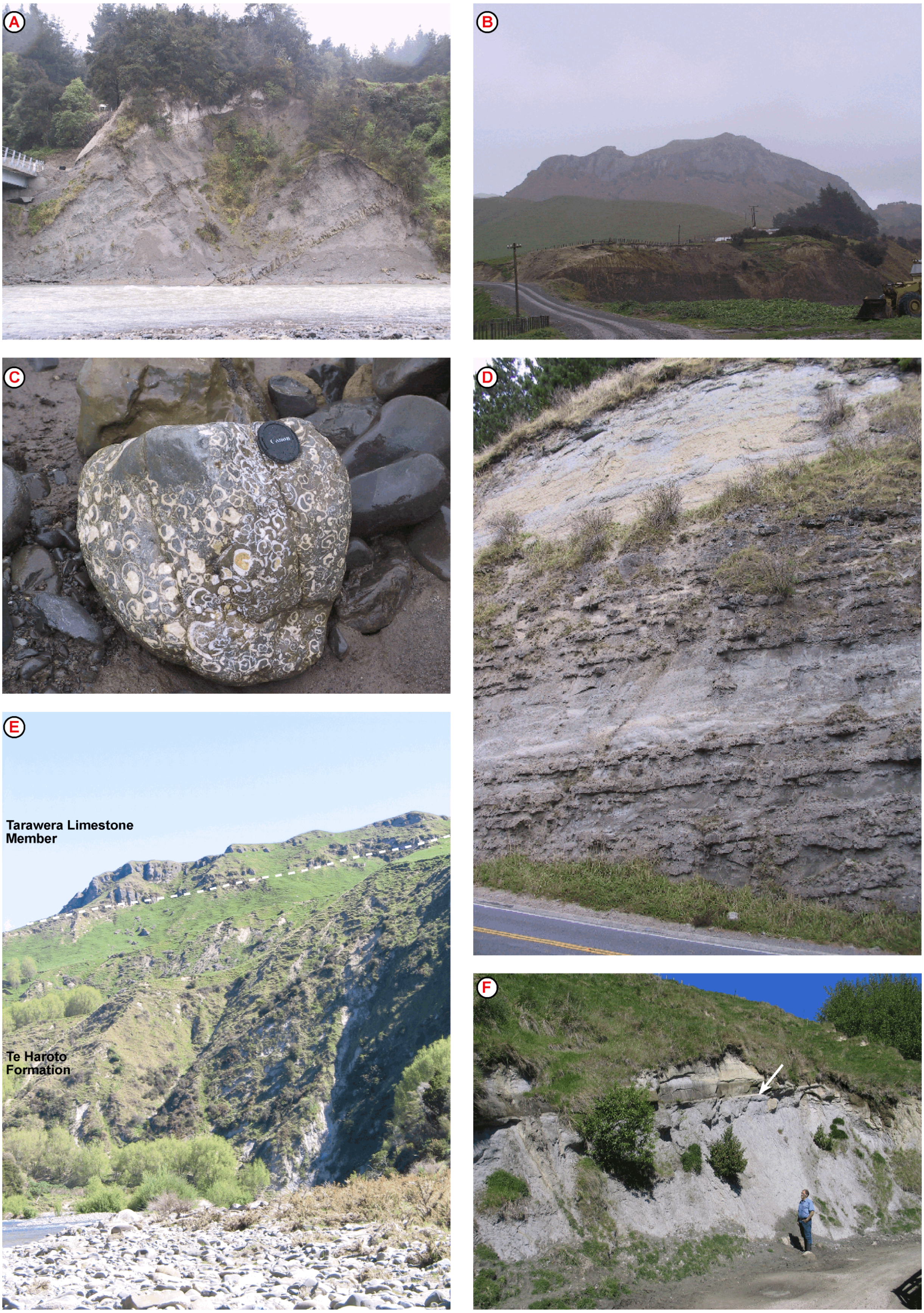
Whakamarino Formation comprises blue-grey frittery very fine siltstone with sandstone interbeds up to 0.5 m thick (Fig. 4A). Beds are commonly offset by small-scale (<1 m throw) reverse and normal faults. The Whakamarino Formation can be distinguished from the overlying Kingma Peak Mudstone Member of the Poamoko Formation by the absence of sandstone beds in the Kingma Peak Mudstone Member (Cutten 1994).

Paleontology and age

Foraminifera from the Whakamarino Formation include *Globoconella incognita, Haeuslerella hectori* (Upper Otaian) and *Globoconella zelandica* (Middle Altonian). Scott *et al.* (1990) suggest that deposition of the Whakamarino Formation may have continued into the Upper Altonian, although there is no conclusive evidence for this (Cutten 1994).

Based on foraminifera an Upper Otaian to Altonian age is assigned to the Whakamarino Formation (Scott *et al.* 1990; Cutten 1994).

Fig. 4 (facing page): Early to Late Miocene Tolaga Group rocks cropping out in the study area (Whakamarino, Poamoko and Te Haroto Formations). **A)** Alternating siliciclastic siltstone-sandstone beds of the Whakamarino Formation in the Mohaka River at Waitere Station. A series of small reverse and normal faults offset several beds in this photograph. Photo location: Mohaka River at new forest bridge, Waitere Station (V19/400356). **B)** Typical high bluffs and hills of Ngatapa Sandstone Member (Poamoko Formation) on Waitere Station. Photograph is taken from Pohokura Road looking south (V19/404350). **C)** Highly fossiliferous boulder of Ngatapa Sandstone Member from the Mohaka River, Waitere Station (V19/400355). This boulder contains abundant *Struthiolaria (Callusaria) spinifera* with *Cucullaea* cf. *ponderosa* and *Tropicolpus milleri*. **D)** Slightly to highly fossiliferous concretionary beds of the basal Te Haroto Formation beside the Napier-Taupo Road near Te Haroto (V19/196265). These beds mark the first Neogene sedimentary rocks encountered on the Napier-Taupo Road above Mesozoic basement. **E)** High bluff in Te Haroto Formation to the overlying Tarawera Limestone Member in the Mohaka River section downstream of Glenfalls Reserve. Immediately upstream of the photo location (V19/274243) Te Haroto Formation unconformably overlies Torlesse basement.



F) Sharp contact between siltstone and an overlying sandstone bed in the Te Haroto Formation (contact arrowed). This sandstone is in turn unconformably overlain several metres above by the Tarawera Limestone Member (Waitere Formation). Photo location: Tarawera Station (V19/246221).

Environment of deposition

Microfauna from near the base of the formation (*Robulus* spp. dominant and rare *Karreriella cushmani*) indicate deposition at upper bathyal water depths. Deepening may have occurred upsection though some Lower Altonian assemblages include outer shelf to upper bathyal taxa (Cutten 1994). Sandstone beds are probably turbidites.

POAMOKO FORMATION (pa)

(Cutten 1994)

Name and definition

Poamoko Formation (Fig. 3) is named after Poamoko Stream, a tributary of the Mohaka River whose confluence is at V19/327331. Poamoko Formation was originally named Narrows Formation in Cutten (1988a, 1988b) and Scott *et al.* (1990). Poamoko Formation comprises three members: Ngatapa Sandstone Member, Arapaepae Alternating Member, and Kingma Peak Mudstone Member.

The three members of the Poamoko Formation thin and pinch out towards the east on the western limb of the Pohokura Anticline. Each successive member wedges out further to the east than the previous member (Cutten 1994).

Ngatapa Sandstone Member (pan)

(Cutten 1994)

Name and definition

Ngatapa Sandstone Member (Fig. 3) is named after Ngatapa Station, and was formally defined by Cutten (1994). The member was referred to as Narrows sandstone lithofacies in Cutten (1988a, 1988b), Latimer (1990) and Scott *et al.* (1990). The definition of Cutten (1994) is retained in this report. Ngatapa Sandstone Member comprises the basal fossiliferous sandstone-dominated portion of the Poamoko Formation that conformably overlies the Whakamarino Formation.

Type locality and reference sections

The type section nominated by Cutten (1994) has been retained. The section is located from the base of the bluff at V19/385358 south of the Mohaka River to the top of the bluff at V19/384357.

Lower and upper contacts

The Ngatapa Sandstone Member conformably overlies the Whakamarino Formation (Cutten 1994). The base is well exposed at V19/398349.

Ngatapa Sandstone Member is overlain by two different stratigraphic units. In the Waitere Station area the member is conformably overlain by the Arapaepae Alternating Member. South of Waitere Station the Ngatapa Sandstone Member is unconformably overlain by the Te Ipuohape Sandstone Member (Waitere Formation). The upper contact is well exposed at the type section at V19/384357 (Cutten 1994). In places the Ngatapa Sandstone Member is in fault contact with basement across the Mohaka Fault.

Distribution and thickness

Ngatapa Sandstone Member crops out in a restricted area in the immediate area of Waitere Station and the Mohaka-Te Hoe River confluence area. On Waitere Station the Ngatapa Sandstone Member forms prominent bluffs (Fig. 4B). The member is up to 150 m thick (Cutten 1994).

Description

The Ngatapa Sandstone Member comprises moderately to well indurated very fine to fine sandstone with occasional medium and rare coarse sandstone. Grain size coarsens towards the top of the member. Minor siltstone and mudstone interbeds are present (Francis 1994). The member is typically a pale yellowish-brown colour, though is blue-grey when fresh. A distinguishing feature of the Ngatapa Sandstone Member is the richly fossiliferous limestone beds present throughout that may comprise up to 95% shell material (Cutten 1994) (Fig. 4C). These shellbeds are well cemented. Scattered greywacke pebbles may be present, where they directly overlie basement (Francis 1994a, b).

Paleontology and age

Molluscs are common in hard, well cemented beds of the Ngatapa Sandstone Member. These include the gastropods *Polinices huttoni*, *Tropicolpus milleri* and *Struthiolaria* (*Callusaria*) *spinifera,* and the bivalve *Cucullaea* cf. *ponderosa* (Fig. 4C). Flabellid corals are also common components of the macrofauna. A Clifdenian (lower-Middle Miocene) age is assigned to the Ngatapa Sandstone Member based chiefly on the occurrence of the foraminifera *Textularia gladizea* and *Praeorbulina glomerosa* (Cutten 1994).

Environment of deposition

Ngatapa Sandstone Member was deposited in a deepening-upward environment from outer shelf to uppermost bathyal depths (supported by the presence of *Notorotalia waiauensis*) in a neritic water mass (Cutten 1994).

Arapaepae Alternating Member (paa)

(Cutten 1994)

Name and definition

Arapaepae Alternating Member (Fig. 3) was introduced and formally defined by Cutten (1994). The name replaced the informal Narrows alternating lithofacies introduced by Cutten (1988), and used in Scott *et al*. (1990) and Latimer (1990). The definition of Cutten (1994) is retained here. Arapaepae Alternating Member represents a transitional lithological unit between the Ngatapa Sandstone Member and the overlying Kingma Peak Mudstone Member.

Type locality and reference sections

The type section nominated by Cutten (1994) is retained. This section is located on the south side of the Mohaka River from V19/360347 to 358346.

Distribution and thickness

The Arapaepae Alternating Member is confined to an area within 2-3 km of the Mohaka River between its confluence with the Te Hoe River and the Mohaka Fault. North of the study area and the Mohaka River, where the member forms the core of the Ngatapa Syncline, the Arapaepae Alternating Member is 240 m thick (Cutten 1994). The member wedges out towards the south and east and is truncated by the Waitere Unconformity (Cutten 1994).

Description

The Arapaepae Alternating Member is distinguished from the younger Auroa Alternating Member (of the Waitere Formation), and parts of the older Whakamarino Formation, by the presence of abundant shells in the sandstone beds of the unit. The alternating mudstone and sandstone beds that comprise the member are individually 0.5-5 m thick. Beds are blue-grey in colour when fresh, weathering to pale yellowish-brown (Cutten 1994).

Paleontology and age

A Lillburnian age was assigned to the Arapaepae Alternating Member by Cutten (1994) on the basis of microfossil assemblages as reported in Scott *et al.* (1990).

Environment of deposition

Sandstone beds contain the same macrofossils as the underlying Ngatapa Sandstone Member. Higher strata contain middle bathyal taxa and indicate a period of significant deepening (Cutten 1994). These beds also contain an increased abundance of planktonic foraminiferal assemblages from underlying beds, and indicate improved paleo-oceanographic access to oceanic water toward the Lillburnian-Waiauan boundary.

Kingma Peak Mudstone Member (pak)

(Cutten 1994)

Name and definition

Kingma Peak Mudstone Member (Fig. 3) of Cutten (1994) was named Narrows mudstone lithofacies in Cutten (1988) and Scott *et al.* (1990). The name is derived from Kingma Peak, a hill located at V19/388344. Kingma Peak Mudstone Member was formally defined by Cutten (1994). His definition is retained in this report.

Type locality and reference sections

The type section designated by Cutten (1994) has been retained. It is located on the south bank of the Mohaka River from V19/370341 to 372341.

Lower and upper contacts

Kingma Peak Mudstone Member conformably overlies, and is considered to be a partial lateral equivalent of, the Arapaepae Alternating Member (Cutten 1994).

The Kingma Peak Mudstone Member is unconformably overlain by the Waitere Formation (Fig. 5).

Distribution and thickness

Kingma Peak Mudstone Member has only limited exposure in the study area, almost entirely restricted to the south bank of the Mohaka River below the ridge west of Kingma Peak. The Member is up to 120 m thick, and wedges out against the Pohokura Anticline (Cutten 1994). To the west the member is truncated by the Mohaka Fault.

Description

Kingma Peak Mudstone Member consists entirely of dark to medium blue-grey poorly indurated mudstone (Cutten 1994).

Paleontology and age

An Upper Lillburnian age is assigned to the Kingma Peak Mudstone Member on the basis of microfauna. Scott *et al.* (1990) and Cutten (1994) suggest that the member was deposited concurrently with the upper beds of the Arapaepae Alternating Member.

Environment of deposition

Kingma Peak Mudstone Member was inferred by Cutten (1994) to have been deposited in an environment similar to that of the upper beds of the Arapaepae Alternating Member. Foraminiferal assemblages including *Sigmoilopsis schlumbergi, Tritaxia instar* and *Triaxilina zelandica* are similar to those contained in the Arapaepae Alternating Member (Scott *et al.* 1990; Cutten 1994). The occurrence of the foraminifera *Haeuslerella pukeuriensis* and *Vaginulinopsis recta* suggest upper bathyal rather than middle bathyal depositional water depths (Scott *et al.* 1990).

TE HAROTO FORMATION (th)

(Francis 1994b)

Name and definition

Te Haroto Formation (Fig. 3) is named after the small village of Te Haroto, located at the summit of the Napier-Taupo Road. The formation name was introduced by Francis (1994b) to encompass a basal highly fossiliferous concretionary sandstone and overlying silty sandstone to sandy siltstone that unconformably overlies basement, and underlies the Tarawera Limestone Member (Waitere Formation).

Type locality and reference sections

No type locality was nominated by Francis (1994b). The type locality for the Te Haroto Formation is designated as the part of the cliff along the Mohaka River from the unconformable contact with greywacke (V19/274243) upstream to section on the true left bank near Glenfalls Reserve (V19/276223), where it is overlain by the Waitere Formation. A reference section is designated along the Napier-Taupo Road in a road cutting from V19/196265 to 213219 (Fig. 4D). Although discontinuously exposed, most of the formation is visible along this section. Another reference section on Tarawera Station displays the uppermost 20 m of the formation, incorporating very good exposures of the upper contact (V19/246221 to 247220) (Fig. 4E). Several good exposures of the formation occur along the northeastern end of the Tarawera Station farm track above the Mohaka River from V19/273243 to 275234 (Fig. 4F).

Lower and upper contacts

The lower contact is everywhere unconformable on basement. The contact is well exposed in the eastern bank of the Mohaka River downstream of Glenfalls Reserve (V19/274243). On the Napier-Taupo Road the lower contact is mostly obscured, though can be located in places in overgrown road cuts (e.g. V19/193264).

The Te Haroto Formation is unconformably overlain by the Tarawera Limestone Member (Waitere Formation) on Tarawera Station. The contact is erosional with decimetre-scale relief. This contact is exposed in a cutting along a farm track on Tarawera Station at V19/247220, in a nearby hill section at V19/249227, in the Mohaka River where the main Tarawera Station track first meets the Mohaka River bank (V19/251221) and at Glenfalls Reserve above the Mohaka River (V19/276223) (Fig. 4E).

Distribution and thickness

The Te Haroto Formation is restricted in outcrop to the Te Haroto and Tarawera areas near the Napier-Taupo Road (Fig. 4D) to Mohaka River cliffs near Glenfalls Reserve (Fig. 4E). The formation thins out rapidly to the south of the Napier-Taupo Road and is not present in Mohaka River cliffs near the State Highway 5 road bridge. The formation crops out extensively along the Mohaka River from Glenfalls Reserve to Tarawera Station, and along the Napier-Taupo Road in the Te Haroto area.

Te Haroto Formation is about 200 m thick.

Description

Te Haroto Formation comprises a lower highly concretionary zone of fossiliferous sandstone (Fig. 4D), passing upsection into weakly bedded fine sandstone to sandy siltstone. Occasional redeposited sandstone beds are present, although they tend to be minor components of the unit.

Paleontology and age

Basal parts of the Te Haroto Formation contain an abundant macrofauna, as displayed in cuttings on the Napier-Taupo Road (V19/196265; Fig. 4D). Macrofauna identified at this locality include *Zeacolpus* sp., *Zenatia* sp., *Struthiolaria* sp., *Dosinia* sp. and *Glycymeris modesta.*

Microfossil samples from lower parts of the Te Haroto Formation reported in the fossil record file for sites along the Napier-Taupo Road are reported as having a Waiauan-Lower Tongaporutuan age (V19/f258; V19/f259). Samples V19/f8644, V19/f8521, V19/f8644 and V19/f6491, from middle and upper parts of the formation, have been assigned a Tongaporutuan age. On the basis of stratigraphic position, microfossil content, and the abundance of *Struthiolaria (Callusaria)* the Te Haroto Formation is assigned a Lower Tongaporutuan age.

Environment of deposition

Te Haroto Formation accumulated in a progressively deepening-upward environment. Macrofauna in the basal concretionary interval indicate an inner shelf depositional setting.

WAITERE FORMATION (wa)

(Cutten 1988 (informal); formally defined by Cutten 1994)

Name and definition

Waitere Formation (Fig. 3) was informally introduced by Cutten (1988), the name being derived from Waitere Station (V19/388334) at the end of Pohokura Road on the south bank of the Mohaka River. The formation was formally defined by Cutten (1994). The Waitere Formation is the stratigraphically highest formation of the Tolaga Group. Waitere Formation comprises four members: Tarawera Limestone Member (new); Te Ipuohape Sandstone Member; Auroa Alternating Member; and Rakaita Siltstone Member. Waitere Formation has been mapped as its constituent members in our maps, and by Cutten (1994).

Lower and upper contacts

Waitere Formation overlies several stratigraphic units. On Tarawera Station the formation unconformably overlies the Te Haroto Formation (Fig. 4E). At Waitere Station region Waitere Formation unconformably overlies the Whakamarino Formation, Ngatapa Sandstone Member, Arapaepae Alternating Member and Kingma Peak Mudstone Member of the Poamoko Formation.

Throughout much of the outcrop area Waitere Formation appears to be conformably overlain by the Mokonui Sandstone The contact is exposed at Titiokura Saddle on the Napier-Taupo Road, where it is a condensed contact. In Opau Stream the formation is unconformably overlain by the Te Waka Formation. In the Tutaekuri River section the Waitere Formation is inferred to be unconformably overlain by the Waikarokaro Sandstone Member of the Blowhard Formation.

In Hukarere-1 exploration well the Waitere Formation unconformably overlies the Oligocene-aged Weber Formation (Westech Energy Ltd 2001).

Distribution and thickness

Waitere Formation is widespread, although discontinuously exposed, through western portions of the map area from Te Hoe Station in the north to the Tutaekuri River in Kaweka Forest Park to the south. The most widespread occurrence of the formation is from the McVicars Road bridge over the Mohaka River north to the Te Hoe-Mohaka River confluence. South of Crohane Forest outcrops become restricted to small localised areas.

A 380 m-thick interval named Waitere Formation was identified in Hukarere-1 exploration well at the Napier Breakwater. This may suggest that Waitere Formation underlies much of the study area at depth (Westech Energy NZ Ltd 2001).

Description

The Waitere Formation effectively represents a Late Miocene deepening-upward succession.

Tarawera Limestone Member (wat) (new)

Name and definition

Tarawera Limestone Member is named after Tarawera Station on and around which the member crops out. The member represents the stratigraphically lowest member of the Waitere Formation.

Type locality and reference sections

The type locality for the Tarawera Limestone Member is located on Tarawera Station where both lower and upper contacts are well exposed (V19/247220) (Fig. 5A). An easily accessible reference section is nominated beside Waitara Road near Glenfalls Reserve, where most of the member is visible. The base of the member is well exposed in a reference section on Tarawera Station on the true left bank of the Mohaka River (V19/276223: Fig. 4E), and at V19/249227 (Fig. 5B). The member is also well exposed in a reference section in Crohane Forest beside Church Bush Road (V20/209133; Fig. 5C). At this site the member has a more concretionary appearance than in the Tarawera Station area (Fig. 5A).

Lower and upper contacts

The Tarawera Limestone Member unconformably overlies two stratigraphic units. In the region of Tarawera Station the member overlies the Te Haroto Formation with a sharp erosion surface. In the Mohaka River section above the Napier-Taupo Road bridge, and at Crohane Forest and Tutaekuri River (Kaweka Forest Park), the member overlies basement by way of an angular unconformity. In Hukarere-1 well an inferred lateral equivalent of the Tarawera Limestone Member unconformably overlies the (Oligocene-aged) Weber Formation.

The member is conformably and gradationally overlain by sandstone facies of the Te Ipuohape Sandstone Member.

Distribution and thickness

The Tarawera Limestone Member is restricted to the Te Haroto and Tarawera Station areas. The member becomes less well developed towards the southwest of Tarawera Station and Crohane Forest and cannot be differentiated in the Tutaekuri River section where the Te Ipuohape Sandstone Member directly overlies basement. The Tarawera Limestone Member is also absent in many localities in Crohane Forest although it is widespread and well developed on and around Tarawera Station. The member is also sporadically present through the map area of Cutten (1994), although he did not differentiate it from basal beds of the Te Ipuohape Sandstone Member. It is not present on Waitere Station.

A 35 m-thick limestone interval was reported at the base of Waitere Formation in Hukarere-1 well (Westech Energy NZ Ltd 2001). On the basis of stratigraphic position this interval is included in the Tarawera Limestone Member.

Description

The Tarawera Limestone Member comprises either a pebbly, moderately to highly fossiliferous limestone (Fig. 5A, B), or a series of well cemented, non to highly fossiliferous concretionary beds (Fig. 5C, D).

Greywacke clasts are a common component throughout the Tarawera Limestone Member in the Tarawera Station area. Large mudstone and sandstone clasts of pebble to boulder size are common in basal parts of the member in this area (Fig. 5B).

South of the Napier-Taupo Road, greywacke clasts generally become less conspicuous components of the member, although where the member directly overlies basement they are present in basal greywacke conglomerate beds.

Limestone at the base of the Waitere Formation in Hukarere-1 well comprises light greenish-grey very sandy limestone with abundant well sorted angular to subrounded quartz, rare lithics, and rare glauconite, cemented by calcite spar. Subordinate beds of grainstone are present and are dominated by bryozoans with sparse siliciclastic sandstone (Westech Energy NZ Ltd 2001).

Paleontology and age

In the Tarawera Station and Waitara Road areas the Tarawera Limestone Member contains a sparse intact macrofauna, with a high shellhash content. Fossiliferous beds cropping out through southern parts of Crohane Forest and in Opau Stream contain a macrofauna rich in *Struthiolaria* (*Callusaria*) *?calcar* (Fig. 5D) and *Zenatia acinaces.* Macrofossils are more commonly intact here than in the Tarawera Station area.

The presence of *Struthiolaria* (*Callusaria*) *?calcar* strongly suggests an age not older than Tongaporutuan, and not younger than Opoitian. On the basis of macrofossil content and stratigraphic position the Tarawera Limestone Member is assigned a “middle” Tongaporutuan (Late Miocene) age.

Environment of deposition

The Tarawera Limestone Member was deposited as the basal unit in a broadly deepening-upward shelf setting from shoreface to outer shelf depths.

Te Ipuohape Sandstone Member (wai)

(Cutten 1994)

Name and definition

Te Ipuohape Sandstone Member (Fig. 3) was introduced by Cutten (1994). The name is derived from Te Ipuohape peak located at V19/422371. The unit was informally referred to as the Waitere sandstone lithofacies in Cutten (1988a, 1988b), Scott *et al.* (1990) and Latimer (1990). The formal definition of Cutten (1994) is emended in this report, with removal from it of the basal concretionary, fossiliferous portions of the member and their assignment to the Tarawera Limestone Member (new; see above).

A
Tarawera Limestone Member
Te Haroto Formation
B
C
D
E
TOYOTA
F
G

Type locality and reference sections

The type section nominated by Cutten (1994) is retained. It is located in a gorge of the Mohaka River just downstream of the confluence with the Te Hoe River. This section is through the nearly vertically-dipping eastern limb of the Pohokura Anticline and extends downstream from V19/407350 where Te Ipuohape Sandstone Member rests unconformably on the Whakamarino Formation to V19/408348 at the conformable upper contact with the Rakaita Siltstone Member (Fig. 3). Excellent reference sections are located in the Mohaka River banks in several localities around the Napier-Taupo Road and on Tarawera Station.

Lower and upper contacts

Throughout most of its outcrop area the Te Ipuohape Sandstone Member conformably and gradationally overlies the Tarawera Limestone Member. In localities in the Crohane Forest area where the Tarawera Limestone Member is absent, Te Ipuohape Sandstone Member directly overlies Torlesse basement, such as at V19/251217 and V19/276233, on Tarawera Station at V19/247220 and V20/192127 (Fig. 5E), in Crohane Forest, and U20/055982 in the Tutaekuri River.

Fig. 5 (facing page): Field examples of the Tarawera Limestone and Te Ipuohape Sandstone Members of the Waitere Formation, Tolaga Group. **A)** Tarawera Limestone Member unconformably overlying uppermost sandstone beds of the Te Haroto Formation (contact arrowed). Photo location Tarawera Station (V19/247220). **B)** Basal beds of the Tarawera Limestone Member. Large sandstone (arrowed) and greywacke clasts are present in this unit. The member unconformably overlies the Te Haroto Formation across a contact that displays decimetre-scale relief. Photo location Tarawera Station (V19/249227). **C)** Non to highly fossiliferous concretionary sandstone beds of the Tarawera Limestone Member in close proximity to an unconformable contact with basement. Photo location Church Bush Road, Crohane Forest near Inangatahi Stream (V20/209133). **D)** Highly fossiliferous concretionary beds, lowermost parts of the Te Ipuohape Sandstone Member (Waitere Formation). At this locality the Tarawera Limestone Member is not developed and the Te Ipuohape Sandstone Member directly overlies Torlesse basement. Macrofauna in the concretionary beds here are virtually exclusively *Struthiolaria (Callusaria) callosa.* Photo location Crohane Forest (V20/205140). **E)** Te Ipuohape Sandstone Member (Waitere Formation) unconformably overlying Torlesse basement in Crohane Forest (contact arrowed). The Tarawera Limestone Member is not developed at this locality. Greywacke conglomerate interbeds and lenses are common in the lower few metres of the Te Ipuohape Sandstone Member around this area (V20/198138). **F)** Bluffs of Te Ipuohape Sandstone Member (Waitere Formation) cropping out beside Pohokura Road (V19/385336). **G)** Te Ipuohape Sandstone Member (Waitere Formation) cropping out in the Tutaekuri River above the Lawrence Road swingbridge (U20/057982). The small sets of rapids in the middle right of the photograph mark the confluence of the Tutaekuri and Donald Rivers. The sandstone bluffs display prominent concretionary sandstone beds rich in macrofauna including *Crepidula radiata, Struthiolaria (Callusaria) calcar, Crassostrea ingens* and *Sectipecten grangei.* The Ruahine Fault cuts across the river approximately 250 m upstream of this locality.

North of Auroa Road (V19/305267) the Te Ipuohape Sandstone Member is conformably and gradationally overlain by the Auroa Alternating Member. South of Auroa Road the Te Ipuohape Sandstone Member is conformably and rapidly overlain by the Rakaita Siltstone Member. The basal contact is well exposed on the Napier-Taupo Road immediately south of the Mohaka River bridge where the Te Ipuohape Sandstone Member is gradationally although rapidly overlain (over 0.5 m) by siltstone of the Rakaita Siltstone Member (V20/241185). In Opau Stream (V20/207049) and Waipunga Streams the Te Ipuohape Sandstone Member is overlain by the Te Waka Formation across a spectacular angular unconformity

Distribution and thickness

Te Ipuohape Sandstone Member crops out widely through northern and western parts of the study area, in particular as a series of high bluffs along Pohokura Road on the descent to Waitere Station (Fig. 5F). Steeply-dipping Tongaporutuan sandstone exposed in Opau and Waipunga Streams (V20/208048) is referred to the Te Ipuohape Sandstone Member. The member crops out in the Mohaka River from Glenfalls Reserve downstream to the McVicars Road bridge.

Highly fossiliferous concretionary sandstone in Crohane Forest is referred to the Te Ipuohape Sandstone Member on the basis of lithology and stratigraphic position. The member also crops out in Gorge Stream at the entrance to Te Kowhai Forest (V20/118011).

A fault-bounded Tongaporutuan aged fine sandstone unit exposed in the upper reaches of the Tutaekuri River (Fig. 5G) contains common, highly fossiliferous concretionary and shell horizons with common *Sectipecten grangei*. This suggests that either Waitere Formation was much more widespread than its present distribution would indicate, or that there was a complicated paleogeography during the Tongaporutuan. With the exception of the fault-bounded Tutaekuri River block, the Te Ipuohape Sandstone Member is not present west of the Mohaka Fault, and it is likely that erosion associated with or following post-Pliocene movement along this fault has truncated the unit.

The Te Ipuohape Sandstone Member thins through its outcrop extent. Downstream of the confluence between the Mohaka and Te Hoe Rivers the Te Ipuohape Sandstone Member is 300 m thick. To the north it reaches a thickness of 600 m. South of Waitere Station the thickness decreases to approximately 100 m at the Napier-Taupo Road, to at least 60 m in Opau Stream, and 30-50 m in the Tutaekuri River section.

Description

Prominent sandstone bluffs of Te Ipuohape Sandstone Member up to 50 m high crop out along Pohokura Road (Fig. 5F). The member in this region comprises discrete sandstone and siltstone bodies. At V19/385336 grey-green sparsely fossiliferous siltstone to sandy siltstone is abruptly overlain by yellowish-brown, clean, non cemented non fossiliferous fine sandstone. At V19/ 385335 firm yellow-brown moderately well sorted sandstone is abruptly overlain by sparsely fossiliferous siltstone. Fauna in the siltstone consists of gastropods and large flabellid corals. The 3 m-thick siltstone grades up-section into a fine sandstone.

Where Te Ipuohape Sandstone Member crops out along Auroa Road in Mohaka Forest (e.g. V19/ 305267) the member comprises blue-grey to yellowish-brown, thickly-bedded, firm, non calcareous massive fine sandstone with no obvious macrofossils.

The uppermost parts of the Te Ipuohape Sandstone Member crop out on the Napier-Taupo Road immediately on the south side of the Mohaka River bridge (V20/241185). Medium sandstone with scattered shellhash grades over 50 cm into blue-grey siltstone (Rakaita Siltstone Member). The Auroa Alternating Member is absent from this locality. This contact represents the uppermost part of a section well exposed in the Mohaka River from near the McVicars Road bridge (V20/216167) to Glenfalls Reserve (V20/276233). Immediately upstream of the McVicars Road bridge Te Ipuohape Sandstone Member is in fault contact with basement (V20/219171). Several hundred metres above the McVicars Road bridge the Te Ipuohape Sandstone Member rapidly overlies concretionary macrofossil-rich (largely *Struthiolaria*) beds of the Tarawera Limestone Member (V20/216167). The Te Ipuohape Sandstone Member in this section is quite concretionary and poorly to moderately well bedded. Macrofossils are very sparse throughout.

The most macrofossil-rich expression of the member crops out in the Tutaekuri River, Kaweka State Forest Park, above the Lawrence Road swingbridge (Fig. 5G). The Tarawera Limestone Member appears to be absent at this site, with the Te Ipuohape Sandstone Member directly overlying, or in fault contact with basement. The member here comprises blue-grey, non cemented massive fine sandstone to silty sandstone with common concretionary bands up to 0.3 m thick every few metres (U20/057982). Macrofauna are abundant in concretionary layers, and relatively sparse in the non cemented intervals. The member is abruptly overlain by strongly bedded channelised deposits assigned to the Auroa Alternating Member. These channelised deposits have eroded up to 20 m into the underlying Te Ipuohape Sandstone Member (Fig. 6B, C).

At Opau Stream near Patoka (V20/208048) steeply dipping Te Ipuohape Sandstone Member is overlain by Te Waka Formation across a spectacular angular unconformity. The Te Ipuohape

Sandstone Member dips at 45° and unconformably overlies basement, and wedges out to the south of the section.

The Te Ipuohape Sandstone Member is generally coarser-grained than the Ngatapa Sandstone Member (Poamoko Formation). Macrofossils are generally absent, except at the base of the formation in the vicinity of the gradational contact with the underlying Tarawera Limestone Member.

Paleontology and age

Macrofossils are dominated by *Struthiolaria* spp.*, Zeacolpus,* and *Zenatia,* although they are almost entirely restricted to basal parts of the member. Only in the Tutaekuri River section are macrofauna abundant. Fauna at that section are dominated by *Crassostrea ingens, Struthiolaria* (*Callusaria*) *callosa* and *Crepidula radiata.* The Tongaporutuan pectinid *Sectipecten grangei* is common, together with *Alcithoe, Dosinia, Anomia, Patro* and *Glycymerita.* Other fauna present include *Talochlamys gemmulata, Zeacolpus*, *Eumarcia ?benhami, Maoricardium spatiosum* and *Panopea worthingtoni*. *Crepidula* are typically present in the form of "fornicating stacks"; one such stack observed to comprise 24 individuals.

Foraminiferal assemblages are poorly preserved and diversity is low. Diagnostic taxa are rare and biostratigraphic resolution is usually poor (Scott *et al.* 1990). The limited microfossil data available for the Te Ipuohape Sandstone Member indicate that deposition of the member commenced during the Lower Tongaporutuan and continued into the Upper Tongaporutuan. There is no definite evidence of Waiauan deposition (Scott *et al.* 1990). The occurrence of *Struthiolaria* (*Callusaria*) *callosa* strongly suggests an age not younger than Tongaporutuan. The presence of common *Sectipecten grangei* in the Tutaekuri River section also indicates a Tongaporutuan age.

In samples from the Napier-Taupo Road section (V19/f228, V20/f384 and V20/f386) the presence of *Globoconella miotumida* and absence of *G. dehiscens* suggests an Upper Tongaporutuan age.

On the basis of stratigraphic position, macrofossil and microfossil content an Upper Tongaporutuan age is assigned to the Te Ipuohape Sandstone Member.

Environment of deposition

The Te Ipuohape Sandstone Member is inferred to have been deposited in a variety of progressively deepening environments, from shallow-water settings with a rocky coastline (Fig. 5E), to possible outer shelf water depths. Shallower water environments are more prominent south of the Napier-Taupo Road. Highly fossiliferous concretionary beds in Crohane Forest are rich in *Struthiolaria (Callusaria)* and *Zenatia acinaces*, suggesting a relatively nearshore depositional setting with a sandy bottom substrate. These beds occur in very close proximity to basement. The rarity of planktonic taxa suggests that deposition of much of the unit occurred in a neritic water mass (Cutten 1994).

Auroa Alternating Member (waa)

(Cutten 1994)

Name and definition

Auroa Alternating Member (Fig. 3) is named after Auroa Road near The Organs, Mohaka Forest. The unit was informally referred to as the Waitere alternating lithofacies in Cutten (1988) and Scott *et al*. (1990). Cutten (1994) formally defined the unit as the Auroa Alternating Member. The member represents a transitional zone between the Te Ipuohape Sandstone and the Rakaita Siltstone Members.

Type locality and reference sections

The type section designated by Cutten (1994) has been retained. It is located in Anticline Creek from V19/401313 to V19/396311. A reference section is designated in the Tutaekuri River from the Lawrence Road swing bridge upstream to the confluence with the Donald River (U20/062980 to U20/060980; Fig. 6B-D).

Lower and upper contacts

In almost all localities Auroa Alternating Member conformably and gradationally overlies the Te Ipuohape Sandstone Member, and is conformably overlain by the Rakaita Siltstone Member. An exception to this is in the Tutaekuri River where channelised facies of the Auroa Alternating Member unconformably and erosionally overlie sandstone of the Te Ipuohape Sandstone Member (Fig. 6B-D).

The Auroa Alternating Member passes conformably upsection into the Rakaita Siltstone Member.

Distribution and thickness

The Auroa Member is up to 240 m thick in the type section and is reported to wedge out against the eastern limb of the Pohokura Anticline (Cutten 1994). Auroa Alternating Member is mostly restricted in outcrop to the map area of Cutten (1994) (NZMS260 V19 Te Haroto). Strongly bedded fine-scale alternating siltstone-sandstone couplets cropping out in the Tutaekuri River (Kaweka Forest Park) have been assigned to the Auroa Alternating Member, and represent the only known occurrence of the unit south of the Napier-Taupo Road. In this section the member is estimated to be 30-50 m thick.

Description

Auroa Alternating Member comprises an alternating sequence of an approximately equal number of 5 cm to 5 m-thick sandstone and siltstone beds. Sandstone units are similar to the underlying Te Ipuohape Sandstone Member, whereas siltstone beds are similar to the overlying Rakaita Siltstone Member. Sandstones are well indurated, fine to medium-grained, yellow-brown in colour and generally massive. Siltstones are massive to finely laminated, poorly indurated and blue-grey in colour (Cutten 1994).

The Auroa Alternating Member sporadically crops out along parts of Coppermine Road in Mohaka Forest. At V19/339298, in the boundary zone with the underlying Te Ipuohape Sandstone Member, Auroa Alternating Member comprises grey to yellowish-brown, non cemented, firm, very fine siltstone with a prominent blocky conchoidal fracture weathering pattern. Some well cemented sandstone beds up to 0.2 m thick are present at this site. No obvious macrofossils are present.

Auroa Alternating Member cropping out in the Tutaekuri River differs from outcrops in the Mohaka-Te Hoe River area in its fine-scale bedding.

Paleontology and age

Macrofossils are very rare in the Auroa Alternating Member. One fragmented valve of *Sectipecten grangei* and scattered shell fragments have been observed in the Tutaekuri River section.

Based on foraminifera a Tongaporutuan age was assigned to the Auroa Alternating Member by Scott *et al.* (1990). The absence of *Globoquadrina dehiscens* suggests deposition after the Lower Tongaporutuan, but whether this foraminifer is restricted to the Upper Tongaporutuan, or extended into the Lower Kapitean, has not been resolved (Cutten 1994). Changes in the morphology of *Bolivinita* spp. suggest close proximity to the Tongaporutuan-Kapitean boundary.

Fig. 6: Waitere Formation cropping out in Tutaekuri River cliffs, above Lawrence Road end, Kaweka Forest Park. These units represent the southernmost outcrops of Waitere Formation and Tongaporutuan beds in the study area. **A)** Highly fossiliferous concretionary sandstone of the lower Te Ipuohape Sandstone Member (U20/061980). The pectinid valves visible are *Sectipecten grangei* which confirms a Tongaporutuan age for this unit. The sample is dominated by the gastropod *Crepidula radiata.* **B)** Strongly channelised alternating sandstone-siltstone couplets of the Auroa Alternating Member unconformably overlying Te Ipuohape Sandstone Member (U20/060980). Incision of channelised beds into the Te Ipuohape Sandstone Member is as much as 30 m. **C)** Close-up view of channelised beds in B (U20/060980). **D)** Finely laminated sandstone-siltstone couplets of the Auroa Alternating Member. This interval conformably overlies similar channelised facies, and is inferred to pass conformably upsection into massive to weakly laminated Rakaita Siltstone Member. A microfossil sample (U20/f150) collected from near the hammer (circled) yielded a confident Tongaporutuan age, and an outer shelf to upper bathyal depositional environment (U20/061980).

Microfossil sample U20/f150 contained a sparse, moderately well preserved predominantly calcareous assemblage. A Tongaporutuan age was assigned on the basis of planktic and benthic content (*Globoconella miotumida, Neogloboquadrina pachyderma* and *Bolivinita* cf. *plioliqua*). Glauconite is common in this sample.

Based on foraminifera (Scott *et al.* 1990; Cutten 1994) an Upper Tongaporutuan age is assigned to Auroa Alternating Member.

Environment of deposition

Throughout its outcrop extent microfossil evidence suggests that the Auroa Alternating Member was deposited at upper to middle bathyal water depths (Scott *et al*. 1990; Cutten 1994). Greater abundances of planktic foraminifera in the Auroa Alternating Member than the underlying Te Ipuohape Sandstone Member suggest a higher degree of exposure to oceanic water and that the focus of deposition may have been located further offshore.

The composition of microfossil sample U20/f150 from the Tutaekuri River section indicates deposition at middle shelf water depths (50-100 m) under normal marine conditions for beds in the Kuripapango region. The presence of 9% planktics in this sample (U20/f150) suggests an inner neritic water mass.

Rakaita Siltstone Member (war)

(Cutten 1994)

Name and definition

Rakaita Siltstone Member (Fig. 3) is named after Rakaita peak, located at V19/437345. Cutten (1988) introduced the informal name Waitere siltstone lithofacies for this member, with Cutten (1994) formally defining the unit as the Rakaita Siltstone Member of the Waitere Formation. The definition of Cutten (1994) is extended to include the thick siltstone unit exposed in road cuttings along State Highway 5, immediately below Titiokura Saddle on the southern side of the Mohaka River bridge at the base of the Maungaharuru Range.

Type locality and reference sections

The type section nominated by Cutten (1994) has been retained in this report. Rakaita Siltstone Member is best exposed in road cuttings on the western side of the Te Waka Range as the Napier-Taupo Road climbs from the Mohaka River bridge to Titiokura Saddle. Waitara Road between Glenfalls Reserve and Pohokura Road provides numerous outcrop windows into the member.

Lower and upper contacts

The Rakaita Siltstone Member overlies three stratigraphic units. Where the Auroa Alternating Member is present the Rakaita Siltstone Member gradationally overlies it. This transition is poorly exposed in the study area, but crops out on Auroa Road, Mohaka Forest. Where the Auroa Alternating Member wedges out against the Pohokura Anticline the Rakaita Siltstone Member overlies the Te Ipuohape Sandstone Member (Cutten 1994). A cutting immediately south of the Mohaka River bridge on the Napier-Taupo Road shows a fine sandstone rapidly grading over 0.5 m into siltstone. This is inferred to represent the lower contact of the Rakaita Siltstone Member.

The upper contact is only confidently identified in one locality, that being in a cutting on the Napier-Taupo Road immediately on the Taupo side of Titiokura Saddle (V20/278152). At this location the Rakaita Siltstone Member is sharply overlain by a strongly cemented concretionary layer up to 50 cm thick, capped by a 10-15 cm-thick interval rich in phosphate nodules, glauconite and shark teeth.

It was suggested by Cutten (1994) that the upper contact was exposed on Pohokura Road near the Woodstock Road intersection. Exposure is poor in this area and the location of the contact has not been confidently resolved.

Distribution and thickness

The unit is exposed in many slips along the western face of the Maungaharuru Range. A fault-bounded Tongaporutuan aged fine-grained thinly-bedded unit (Fig. 6D) exposed in the upper reaches of the Tutaekuri River is included in the Waitere Formation based on age and lithological similarities. This section marks the southernmost outcrop known in the study area of the Waitere Formation.

A foraminiferal sample (V20/f442) collected from sandy siltstone in Gorge Stream near Te Kowhai forest yielded a Tongaporutuan age. On the basis of age and lithological similarities this unit is assigned to the Rakaita Siltstone Member.

The occurrence of the member south of the Napier-Taupo Road is strongly controlled by displacement on faults of the North Island Shear Belt and associated erosion. The member erosionally wedges out rapidly south of the Napier-Taupo Road, a reflection of post-depositional displacement on the Mohaka Fault.

In the section below Taraponui Trig the Rakaita Siltstone Member is approximately 850 m thick, increasing to 3000 m in the Willowflat area to the north (Cutten 1994). Over 1100 m of section is exposed on State Highway 5 from the Mohaka River bridge to Titiokura Saddle (V20/241185-V20/278152). The Mohaka Fault passes through this section (V20/245176) making an accurate estimate of thickness difficult.

Description

In the vicinity of State Highway 5 the Rakaita Siltstone Member comprises blue-grey, massive, non to slightly cemented, non to slightly fossiliferous sandy siltstone that is relatively consistent in grainsize through its thickness. Scattered concretions of variable size are present through the member.

Paleontology and age

Only very sparse macrofossils have been observed in the Rakaita Siltstone Member. An Upper Tongaporutuan to Lower Kapitean age has been inferred for this member in the north of the study area (Scott *et al.* 1990). The assemblage in sample V19/f100, taken from a site along the Mohaka River, includes *Bolivinita pohana* and *Globoquadrina dehiscens* (Scott *et al.* 1990). The appearance of *Bolivinita pliozea* in sample V19/f4 (V19/414329) suggests proximity to the Tongaporutuan-Kapitean boundary (Cutten 1994).

A suite of samples reported in the fossil record file from sites along the Napier-Taupo Road from the Mohaka River bridge to Titiokura Saddle are consistently dated as Upper Tongaporutuan to Lower Kapitean. The microfossil content in the stratigraphically highest of these samples (V20/f399), while dated as Upper Tongaporutuan-Kapitean is more suggestive of a Kapitean age.

A Tongaporutuan age for foraminiferal sample V20/f442 in Gorge Stream is constrained by both planktic and benthic taxa, including *Globoconella miotumida, Neogloboquadrina pachyderma* and *Bolivinita pohana.* The relative abundance of *Globigerinoides* and the apparent lack of *Globoquadrina dehiscens* suggest an age of 8.8-8.0 Ma (Upper Tongaporutuan) (M. Crundwell IGNS pers. comm. 2004).

The overlying Mokonui Sandstone is assigned a “lower to middle” Kapitean to Opoitian age, helping to constrain the age of the Rakaita Siltstone Member. On the basis of microfossil content and stratigraphic position, the Rakaita Siltstone Member is assigned an Upper Tongaporutuan to Lower Kapitean age.

Environment of deposition

Foraminiferal collections V19/f163-f53 from the Mohaka River include some bathyal taxa such as *Karreriella cylindrica* and *Sigmoilopsis schlumbergeri* which also occur in the underlying Auroa Alternating Member. Other depth diagnostic species such as *Vulvulina pennatula,* however, are absent. As in the Auroa Alternating Member, *Cibicides molestus* and *Haeuslerella morgani* are well represented in the Rakaita Siltstone Member. A continuation of depositional conditions initiated during the latest phase of Te Ipuohape Sandstone Member deposition is inferred (Scott *et al.* 1990). Deposition in the Waitere region at upper to middle bathyal water depths is inferred for the Rakaita Member, an environment similar to that inferred for the Auroa Alternating Member (Cutten 1994). 20% planktics were present in sample V19/f53 from the Mohaka River site indicating a neritic water mass (Scott *et al.* 1990), but taxa could have been reworked into deeper water.

Foraminiferal sample V20/f442 from Gorge stream contained approximately 6% planktics that were largely crust-free specimens, and indicates an inner neritic water mass. An upper slope (300-400 m) depositional setting under normal marine conditions is inferred for this area based on the presence of *Cibicides molestus* (M. Crundwell GNS pers. comm. 2004).

MOKONUI SANDSTONE (mk)

(Cutten 1988; formally defined by Cutten 1994)

Name and definition

Cutten (1988) introduced the informal name Mokonui sandstone lithofacies, in reference to a massive sandstone unit prominent on the northern face of the Maungaharuru Range. McKay (1886) had earlier referred to this unit as the Maungaharuru Range sandstone. (informal) The name is taken from a peak located at V21/432330. This peak was named Mokonui on NZMS 1 Tutira N114 (1975 3rd edition), but the name was dropped on NZMS 260 V19 Te Haroto (Edition 1, 1988). Cutten (1994) retained Mokonui as a name for consistency with earlier reports published on the area. The unit is named here Mokonui Sandstone in reference to the dominant lithology of the formation. The formation is defined as a sandstone unit that conformably to unconformably underlies the Titiokura Formation in a region from the northern parts of the Maungaharuru Range to the Maniaroa Range in the south. The formation is the uppermost unit of the Tolaga Group for much of the study area east of the Mohaka Fault, north of Puketitiri Road.

Type locality and reference sections

The type section nominated by Cutten (1994) along Pohokura Road on the western face of the Maungaharuru Range has been retained (Fig. 7A), although the base of the formation here remains poorly resolved. The basal and upper contacts of the formation are exposed in a reference section along the Napier-Taupo Road from V20/278152 to V20/287144. Much of the formation is visible in scrappy outcrops along this section, which is one of the very few localities where the basal contact has been confidently identified. The unit is well exposed in the upper parts of Jeph Everett Road north of Pohokura Saddle.

Lower and upper contacts

The lower contact is highly variable through the study area and is very poorly exposed. The contact has only been confidently identified at Titiokura Saddle on the Napier-Taupo Road (V20/ 278152) where a pronounced glauconite layer up to 50 cm thick is present immediately above a very sharp contact with the underlying Waitere Formation. This layer contains abundant phosphate nodules, as well as very high numbers of shark teeth and less common phosphatised gastropods, solitary corals, and bivalves.

The upper contact of the Mokonui Sandstone is marked throughout the field area by the presence of a conglomerate bed at the base of the overlying Titiokura Formation. The upper contact is exposed on Pohokura Road near the intersection with Jeph Everett Road, on the Napier-Taupo Road at V20/287144, in Titiokura Quarry at the northern end of the Maungaharuru Range, at two locations on Oakmere Station near the boundary with Rock Station, Te Pohue, and in numerous localities on the north face of the Te Waka Range (e.g. V20/270115; V20/239128).

Although partially obscured by vegetation, the upper contact can also be located on the Napier-Taupo Road near Titiokura Saddle (V20/287144). A prominent feature of the upper contact is the increasing level of erosion on the upper contact southward along the Maungaharuru and Te Waka Ranges, especially south of the Napier-Taupo Road. At Pohokura Saddle relief on the upper contact is up to 6 m (Fig. 7D). Approximately 21 km to the southwest erosional relief on the upper surface of the Mokonui Sandstone is in the order of 30 m on the western face of the Te Waka Range (V20/235127) (Fig. 7F).

Distribution and thickness

Mokonui Sandstone is widespread through the high hill country in northern parts of the study area, and is particularly well exposed in the Maungaharuru and Te Waka Ranges. The unit steadily decreases in thickness from 300 m at Pohokura Road to 240 m at Titiokura Saddle on the Napier-

Taupo Road (V20/280152). South of the highway, the unit thins slightly to 180 m in the Hell's Hole area (V20/233126) southwest of Te Waka Trig. North of the study area, Mokonui Sandstone increases in thickness to over 1000 m (Cutten 1994).

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Mokonui Sandstone has been mapped as far south as the southern Maniaroa Range. As the outcrop strike of the Mokonui Sandstone is oblique to that of the North Island Shear Belt (in particular the Mohaka Fault), it is truncated by the Mohaka Fault near Hawkston Station and does not crop out south of this point. The Blowhard Formation in the Kuripapango area is a correlative of Mokonui Sandstone (Fig.2).

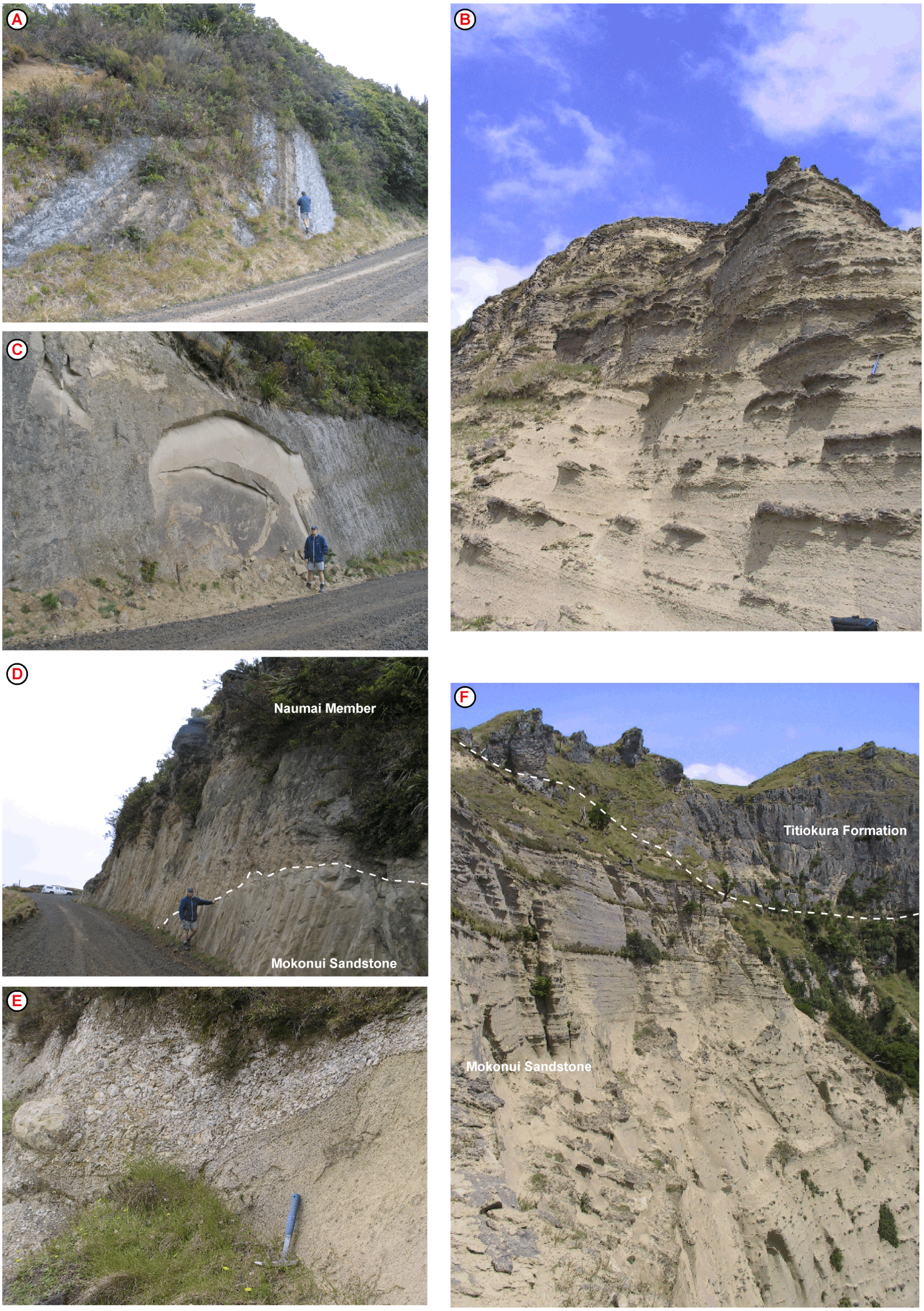
A siliciclastic sandstone unit 180 m thick was intercepted in Hukarere-1 and dated as Upper Opoitian to possibly uppermost Kapitean age. Although named Haupori Sandstone it was acknowledged that it may be possible that this 180 m-thick sandstone is correlative with the Mokonui Sandstone (Westech Energy NZ Ltd 2001).

Description

The Mokonui Sandstone comprises blue-grey weathering to light brown, non to slightly cemented, slightly concretionary, non to sparsely fossiliferous, very well sorted fine to medium sandstone as observed at the type section (Fig. 7A). Weathering of exposures has tended to obscure primary sedimentary structures. Scattered brachiopods are the only macrofossils observed at this locality. Faint channelised beds, large-scale and low-angle tabular cross-beds are evident in sections along Pohokura Road (Fig. 7C). At the type section the Mokonui Sandstone is unconformably and erosionally overlain by basal conglomerate facies of the Naumai Member, Titiokura Formation (Fig. 7D).

At Titiokura Quarry in southern parts of the Maungaharuru Range (V20/293159) the Mokonui Sandstone comprises slightly cemented, moderately weathered medium sandstone that displays faint laminar bedding and small-scale tabular cross-stratification. Concretions up to 6 cm thick are present and frequently contain common *Talochlamys gemmulata*. At this locality the Mokonui Sandstone is sharply overlain by basal conglomeratic facies of the Titiokura Formation.

The Mokonui Sandstone is exposed in road cuttings near Titiokura Saddle on State Highway 5 from the disconformable lower contact with the Rakaita Siltstone Member (Waitere Formation) described above, to the upper sharp contact with the Titiokura Formation. In this section the formation comprises blue-grey weathering yellow-brown, non cemented, massive to planar laminated, fine sandstone.


A
B
C
D
Naumai Member
Mokonui Sandstone
E
F
Titiokura Formation
Mokonui Sandstone

Macrofossil content increases upsection at this locality, from slightly to moderately fossiliferous, and largely consists of the bivalves *Tawera, Mactra* and *Talochlamys,* with some shellhash and occasional burrows.

Mokonui Sandstone often becomes relatively concretionary in upper parts south of Titiokura Saddle. Bedding in the form of planar laminations and cross-stratification is prominent (Fig. 7B, F). Near Hell's Hole, central Te Waka Range (V20/235127) (Fig. 7B, E), the unit contains channels filled with siltstone rip-up clasts up to 0.1 m in size. The channels are typically 2-5 m below the upper surface of the unit, and are continuous over several metres (Fig. 7E).

At Hell's Hole well sorted, fine to medium sandstone crops out in a steep cliff-face exposure over 200 m high (Fig. 7F). Concretionary beds (Fig. 7B) become more common upsection, as do well-developed small to moderate-scale, low- to moderate-angle tabular and trough cross-beds. A spectacular paleo-relief of up to 30 m has been carved into the top of the Mokonui Sandstone, which is overlain by Titiokura Formation (Fig. 7F).

Paleontology and age

Very few macrofossils have been observed in the Mokonui Sandstone. Most fauna collected have come from Titiokura Saddle (V20/278152), and are dominated by shark teeth. Scattered, unidentified, brachiopod fossils have been observed at the base of the type section along Pohokura Road near the Woodstock Road intersection. Common *Talochlamys gemmulata* have been observed in thin concretions in upper beds of the formation at Titiokura Quarry. Based on foraminifera, Cutten (1994) assigned a Lower Kapitean to Opoitian age to this formation. A collection taken 100 m above the base of the unit near Pohokura Road by Cutten (1994) (sample V19/f160) included *Truncorotalia crassaformis, Globoconella pliozea,* and *Globoconella. puncticulata*, indicating a Lower to "Middle" Opoitian age. Collections near the base of the unit (also by Cutten) in the Mohaka River (sample V19/f46) contain *Globoconella miotumida* (with *conomiozea* morphotypes) and are dated Lower Kapitean, possibly near Upper Kapitean boundary. Mokonui Sandstone is assigned a Kapitean to Upper Opoitian (Late Miocene to Early Pliocene) age.

Fig. 7 (facing page): Mokonui Sandstone. **A)** Basal moderately steeply-dipping and possibly slumped beds of the Mokonui Sandstone cropping out at the base of the type section (V19/375276) on Pohokura Road, near the Woodstock Road intersection **B)** Highly concretionary sandstone of the upper Mokonui Sandstone at Hell's Hole on the north face of the Te Waka Range (V20/235127). **C)** Mokonui Sandstone cropping out beside Pohokura Road at the top of the type section on Pohokura Road near the Jeph Everett Road intersection (V19/389273). **D)** Mokonui Sandstone unconformably overlain by basal conglomerate beds of the Naumai Member (Titiokura Formation) on Pohokura Road (V19/390273). Metre-scale relief is present on this erosional contact. **E)** Mokonui Sandstone overlain by Titiokura Formation at Hell's Hole (V20/235127), central Te Waka Range. Up to 30 m of relief is present on the contact between the two formations at this site. **F)** Siltstone clast-filled conglomerate bed in the Mokonui Formation immediately below the sharp erosional upper contact with the Titiokura Formation, north face Te Waka Range (V20/239128).

Mokonui Sandstone is in part a chronostratigraphic equivalent of the Blowhard, Omahaki, Mangatoro, and (possibly) the lower Pakaututu Formations cropping out west of the Mohaka Fault.

Environment of deposition

Mokonui Sandstone was deposited in a progressively shallowing environment from upper bathyal to inner shelf water depths. A broadly shore-perpendicular shelf to upper bathyal depositional gradient is evident from the Te Waka Range to the northern Maungaharuru Range. Upper bathyal deposition is suggested in lower parts of the unit near Pohokura Road (V19/f160) based on the presence of *Cibicides deliquatus, C. neoperforatus, Haeuslerella pliocenica, Karreriella cylindrical, Notorotalia* sp. and common *Robuslus* spp. (Cutten, 1994). Cutten (1994) also suggests that exposure to oceanic water is indicated by the presence of c. 40-50% planktic specimens in foraminiferal assemblages. Mokonui Sandstone cropping out in the Te Waka Range was deposited at much shallower water depths than equivalent horizons in the Maungaharuru Range. This is supported by the abundance of shallow-water bedforms (Fig. 7B, E) and the spectacular paleo-relief carved into the formation at Hell's Hole.

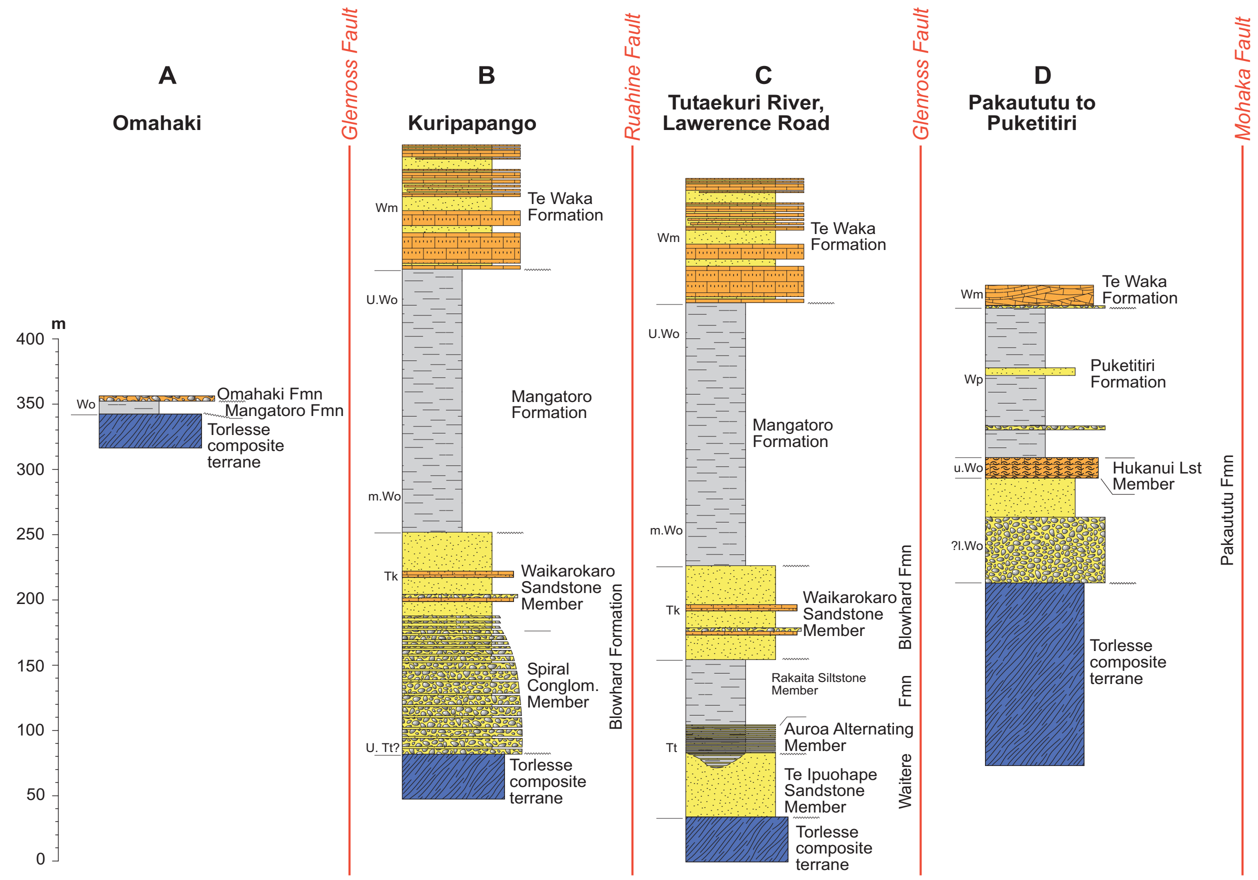


Fig. 8: Schematic stratigraphic columns illustrating the relationships between lower formations in the Mangaheia Group along the western side of the study area in the North Island Shear Belt. Omahaki is in the southwest, Pakaututu-Puketitiri is to the northeast. Note how the Te Waka Formation is common across several fault blocks, indicating its importance in determining displacement histories of faults in the North Island Shear Belt.

BLOWHARD FORMATION (bh)

(Browne 1981; formally defined by Browne 2004a)

Name and definition

In his geological map of the Kuripapango region, Browne (1981) introduced the Blowhard Formation in reference to beds unconformably overlying basement on the Blowhard and Castle Rock Plateaus. Included were two members, namely the Spiral Conglomerate Member and the Waikarokaro Sandstone Member. The Blowhard Formation and its constituent members were formally defined by Browne (2004a).

Beu (1995) introduced the informal name Owhaoko limestone (informal) for beds of the Blowhard Formation. In reality, "limestone" beds are uncommon, thin and discontinuous in this unit. Beu's definition of the Owhaoko limestone excluded the prominent thick greywacke conglomerate beds that comprise lower parts of the Blowhard Formation in many parts of the Kuripapango region. For these reasons Browne's (2004) formal definition of the Blowhard Formation is used in this report. The name is derived from Blowhard Plateau on the foothills of the Kaweka Range, east of Kuripapango. Although Blowhard Formation comprises two distinctive members, the unit has been mapped as undifferentiated Blowhard Formation. These members are the Spiral Conglomerate and Waikarokaro Sandstone Members.

Blowhard Formation represents the stratigraphically highest unit of the Tologa Group west of the Mohaka Fault (Fig. 8B, C).

Type locality and reference sections

This report nominates type sections for each of the two members of the Blowhard Formation (see below) as at no one locality is the entire formation exposed in a clear manner.

Distribution and thickness

Blowhard Formation is restricted in distribution to the Kuripapango area. In this study area Blowhard Formation is not known west of the Kaweka Fault or east of the Glenross Fault. North of the Tutaekuri River the correlative, although younger, unit is the Mokonui Snadstone. Browne (2004a, b) describes similar lithologies west of Kuripapango on Ngamatea and Timahanga Stations which are probable equivalents of the Blowhard Formation. Further correlatives are probably present in other regions of isolated Tongaporutuan-Kapitean rocks in the Mangaohane Plateau-southern Kaimanawa Range area. The Matemateaonga Formation of Wanganui Basin and eastern Taranaki Basin is correlative with the Blowhard Formation. Blowhard Formation has a maximum exposed thickness of up to 170 m. in the Kuripapango area.

Spiral Conglomerate Member (bas)

(Browne 1981; formally defined by Browne 2004a)

Name and definition

Spiral Conglomerate Member (Fig. 8B) is named after "The Spiral", a local name for a now realigned part of Taihape Road near Kuripapango.

Type locality and reference sections

The type section nominated by Browne (2004a) is retained in this report and occurs along "The Spiral" (now part of the Kaweka Forest road system) near the modern path of Taihape Road and the hillsides immediately above (U20/996958-U20/001956: Fig. 9A).

Lower and upper contacts

The Spiral Conglomerate Member always unconformably overlies greywacke basement.

The member is conformably and gradationally overlain by the Waikarokaro Sandstone Member.

Distribution and thickness

Spiral Conglomerate Member crops out in a very small part of the Kuripapango area and is best development adjacent to the Napier-Taihape Road and in the Waikarokaro Stream catchment (Fig. 9A) (Browne 2004a). The member is thickest adjacent to faults, which may indicate contemporaneous fault displacement.

Spiral Conglomerate Member is present infilling localised (?fault) depressions in basement rocks in the Waikarokaro Stream catchment, and is not known away from this region. In this area the member is over 100 m thick (Browne 2003).

Description

The Spiral Conglomerate Member consists of poorly sorted, clast-supported greywacke conglomerate comprising angular to well rounded clasts of greywacke with thin interbeds of pale-grey, non calcareous, moderately well sorted, fine to medium sandstone and minor siltstone.

The basal portion of the member comprises poorly sorted, poorly stratified greywacke conglomerate to breccia (Fig. 9A). Clasts in this basal zone are coarser-grained than further up-section. Clasts in this interval are angular, and beds have scoured bases. Sandstone interbeds are rare, although typically very thin (Browne 2004a).

Paleontology and age

No macrofossils have been collected from Spiral Conglomerate Member. Browne (1981, 2004) reports a palynological sample (U20/f129) collected from the member that contains species indicating a Tongaporutuan or younger age, although these could not be refined any further. The overlying Waikarokaro Sandstone Member contains the pectinid *Sectipecten wollastoni*, which places a Kapitean age on the Spiral Conglomerate Member.

Environment of deposition

Pollen from the uncommon mudstone intervals within the member indicates a kauri swamp forest with podocarps, broadleaf trees, and a cool climate (Browne 2003). These areas were likely part of alluvial fans that were probably not very extensive and largely restricted to the outcrop area.

Waikarokaro Sandstone Member (baw)

(Browne 1981; formally defined by Browne 2004a)

Name and definition

Waikarokaro Sandstone Member (Fig. 8) was introduced by Browne (1981) and formally defined by Browne (2004a). It is the stratigraphically highest member of the Blowhard Formation. The unit is named after Waikarokaro Stream, a small waterway in the Kuripapango region near Taihape Road. The spelling of the name is taken from NZMS 1 map series, rather than the "Waikarekare" spelling that occurs on the NZMS 260 map series (Browne 2004a).

Type locality and reference sections

Browne (2004a) nominated a quarry exposure at U20/99498 (Fig. 9B) as the type section. This section is retained in this report and shows well-developed greywacke stacks unconformably overlain by a slightly concretionary, well sorted sandstone. A reference section is nominated below Mount Miroroa (U20/008927) above an old forest road past the abandoned Miroroa Road greywacke quarry.

Lower and upper contacts

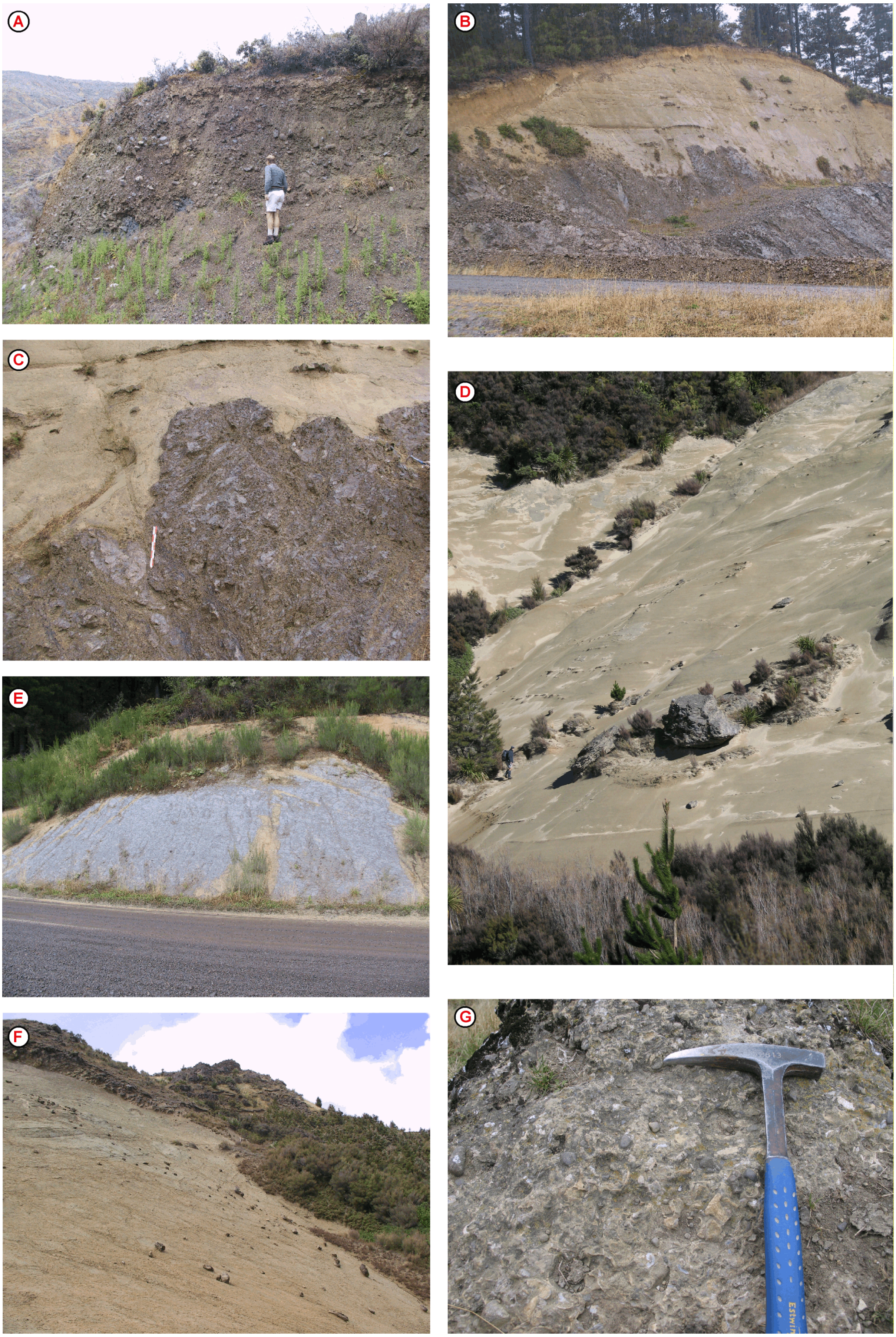
The Waikarokaro Sandstone Member conformably overlies the Spiral Conglomerate Member. Where the Spiral Conglomerate Member is not present Waikarokaro Sandstone Member rests directly on basement (Fig. 9B, C). The member is inferred to unconformably underlie the Mangatoro Mudstone, although this contact is not exposed in the study area. In almost all localities the Waikarokaro Sandstone Member is in fault contact with the Mangatoro Mudstone.

Throughout much of the Kuripapango area, the top of the Waikarokaro Sandstone Member is marked by the modern eroded land surface. In isolated areas it is probable that the member is unconformably overlain by the Mangatoro Mudstone. At Mount Miroroa (Fig. 9D) the member is inferred to be unconformably overlain by limestone facies of the Lower Nukumaruan Sentry Box Formation, the Mangatoro Mudstone having been eroded during the Late Pliocene.

Distribution and thickness

Waikarokaro Sandstone Member is widely distributed across the Blowhard and Castle Rocks Plateaus in the Kaweka Forest area, although it forms mainly isolated, thin outcrops. The member does not crop out north of the Tutaekuri River, west of the Kaweka Fault or east of the Glenross Fault. Browne (1981, 1986, 2003, 2004) displayed on geological maps Blowhard Formation capping the MacIntosh Plateau. Although the MacIntosh Plateau (located north of the Tutaekuri River) has a geomorphology indicative of being capped by the Waikarokaro Sandstone Member, recent field investigations have failed to locate any Cenozoic sediments overlying basement (Greg Browne, GNS Science pers. comm. 2004). The Waikarokaro Sandstone Member is a maximum of 70 m thick in the Kuripapango region.

Fig. 9 (facing page): Blowhard Formation, Mangatoro Formation and Omahaki Formation cropping out in western parts of the study area. **A)** Very poorly sorted basal beds of the Spiral Conglomerate Member (Blowhard Formation) cropping out beside "The Spiral", Kaweka Forest. **B)** Basal beds of the Waikarokaro Sandstone Member (Blowhard Formation) overlying highly shattered basement. Metre-scale relief is clearly visible on this basal contact. The sporadic concretions and concretionary lenses visible in the sandstone are non to moderately fossiliferous. Rare valves of *Sectipecten wollastoni* have been observed at this locality. Uncommon *Crassostrea ingens* valves are present immediately above the basal contact. Quarry beside Kuripapango Road, Kaweka Forest (U20/994981). **C)** Close-up of the basal contact of the Waikarokaro Sandstone Member at Kuripapango Road quarry (U20/994981). **D)** Bluffs of Waikarokaro Sandstone Member cropping out below Mount Miroroa, Kaweka Forest (U20/008927). **E)** Mangatoro Formation beside Taihape Road, Kaweka Forest. **F)** Mangatoro Formation on the north face of Mount Kohinga (U20/980938). The formation is unconformably overlain by limestone beds of the Te Waka Formation at this locality. **G)** Well cemented pebbly limestone to shelly conglomerate of the upper part of the Omahaki Formation at Omahaki Station (U21/013867).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Description

The Waikarokaro Sandstone Member comprises sandstone, conglomerate, pebbly limestone and calcareous sandstone, of which massive to trough cross-bedded, slightly concretionary and fossiliferous, very well sorted medium sandstone is the dominant lithology (e.g. Fig. 9B). Sandstones are generally fine to medium-grained and moderately to well sorted. The two best exposed sections through the member are at the type section (U20/994981) and below Mount Miroroa (U20/008927). At the type section it unconformably overlies strongly fractured greywacke through a surface displaying decimetre to metre-scale relief (Fig. 9B, C). The sandstone is massive to weakly laminated with scattered 10-20 cm thick oval-shaped concretions that are typically concentrated into bands up to 3 m long. Macrofossils are sparse through the sandstone, though slightly more common in the concretions. Scattered valves of *Crassostrea ingens* may be present encrusting hollows in the basal contact. Uncommon *Sectipecten wollastoni* are present in this section.

Blowhard Formation cropping out across the Castle Rocks Plateau is dominated by sandstone facies with lenses and stringers of greywacke pebbles typical near the basal contact with basement. At U20/023974 fine-grained massive sandstone crops out in a road cutting with greywacke pebble stringers up to 0.1-0.15 m thick. Pebbles are well rounded. A prominent block of Waikarokaro Sandstone Member crops out beside Castle Rocks Road at U20/029994. This block consists of grey weathering to cream, hard, very well cemented, fine to medium sandstone.

A section below Mount Miroroa (U20/008927) (Fig. 9D) displays at least 30 m of sandstone very similar to that in the type section. The Waikarokaro Sandstone Member consists of brown, non cemented, slightly micaceous fine to medium sandstone. Scattered concretions and concretionary horizons are present. The concretionary bodies are largely composed of cemented sandstone though some consist of coarse sand to gravel-sized shellhash. The main sandstone body is massive although occasional sigmoidal and tabular cross-beds are present. Thin pebble stringers of sandstone and mudstone clasts are also occasionally present. The base of the member is not exposed at this locality.

Paleontology and age

The Waikarokaro Sandstone Member contains a sparse to moderate macrofauna. *Crassostrea ingens* occurs just above the basement contact. Occasional barnacle plates and fragments have been observed in the type section in Kaweka Forest. Waikarokaro Sandstone Member contains the pectinid *Sectipecten wollastoni* (Kapitean index fossil). Based on the presence of *Sectipecten wollastoni* a Kapitean age is assigned to the Waikarokaro Sandstone Member.

Environment of deposition

The Waikarokaro Sandstone Member was deposited in a nearshore setting on and adjacent to exposed basement

MANGAHEIA GROUP

(Steineke 1934; formally defined by Mazengarb *et al.* 1991)

Name and definition

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

Pallentin and Nelson (2001) and Pallentin (in prep.) recognised similarities between rocks of the Mangaheia Group in the Wairoa-Mahia area, and strata in the Maungaharuru-Willowflat-Putere Lakes area further south. Bland (2001) and Graafhuis (2001) had included rocks of this area in a new group they named the Maungaharuru Group (a redefinition of the Maungaharuru Formation of Cutten (1994)). Given Mangaheia Group is an accepted and established stratigraphic name, and there are lithological and paleoenvironmental similarities between rocks in these two areas, it seems appropriate to extend the use of Mangaheia Group south into the present study area. Mangaheia Group includes rocks of Opoitian (Late Miocene) to Upper Nukumaruan (Early Pleistocene) age cropping out widely through western and northern parts of the study area. It unconformably overlies deep-water-dominated beds of the Tolaga Group and is overlain by non- to marginal-marine-dominated beds of the Kidnappers Group.

The Mangaheia Group includes rocks assigned to the Maungaharuru Subgroup of Bland *et al.* (2004) and the Petane Group by Haywick *et al*. (1991), Beu (1995), Bland (2001), Graafhuis (2001), Baggs (2004) and Dyer (2005). Mangaheia is preferred over Petane as a group name as it has a more widespread and accepted usage, and the base of the group can be confidently defined (see “Petane Formation”). There are no broad lithological differences between rocks of the Mangaheia Group and Petane Group, and there seems little sense in maintaining beds in two separate groups.

Type locality

Mazengarb *et al.* (1991) nominated the type locality of Steineke’s (1934) Mangaheia Formation, and the section on the Tolaga Bay-Tauwhareparae Road as the type locality for the Mangaheia Group. This section has its base at Y17/597076, with its top near the headwaters of Ramanui Stream at Y16/559108. This locality is retained in this report. Reference sections are nominated in the study area. An easily accessible reference section is nominated across the Maungaharuru Range to the Tangoio Block along Pohokura Road and State Highway 2 to the Tangoio Block. It has its base at Pohokura Saddle (V19/389273), and its top at Ridgemount Road (W20/537133). Another reference section extends from the Mohaka River near Riverlands (V20/236180), along the Napier-Taupo Road to Petane Corner (V20/437937).

Distribution

Rocks of the Mangaheia Group crop out widely through western and central parts of the study area (Fig. 1), and appear to be part of an almost continuous outcrop belt extending from the Ohara Depression northeast through the Maungaharuru Range, towards Willowflat, the Putere Lakes (inland from Raupunga), Tiniroto Lakes (inland from Gisborne), and toward Tolaga Bay and Tauwhareparae.

Lower and upper contacts

The base of the Mangaheia Group is unconformable through all of the study area. At Titiokura Saddle and along the western face of the Maungaharuru Range the group unconformably overlies Mokonui Sandstone (Tolaga Group). In southwestern parts of the study area Mangaheia Group unconformably overlies basement, such as at Kuripapango, Pakaututu and in the Ohara Depression.

The group is unconformably overlain by Kidnappers Group (Middle to Upper Castlecliffian, Late Pleistocene).

Age

Mangaheia Group is of Lower Opoitian to Upper Nukumaruan age (Late Miocene to Early Pleistocene).

Environment of deposition

Rocks of the Mangaheia Group accumulated in a variety of shelfal depositional paleoenvironments. Limited incursions into upper bathyal water depths are recorded in some Lower Nukumaruan (Late Pliocene) rocks. Non-marine beds, although volumetrically uncommon, are geographically widespread in upper beds of the group.

MANGATORO FORMATION (ma)

(Lillie 1953)

Name and definition

Mangatoro Formation (Fig. 8) was introduced by Lillie (1953) in reference to Early Pliocene mudstones in the Dannevirke Subdivision. The name is derived from the Mangatoro River. Lillie (1953) did not define a type section for the Mangatoro Formation, and the formation was emended by Harmsen (1985).

Browne (1981, 1986, 2004) applied the name Mangatoro Formation to Early Pliocene (Opoitian) siltstone cropping out in the Kuripapango area. This extension is retained in this report.

Type locality and reference sections

The type section designated by Harmsen (1985) is retained in this report. This section is located along part of Mangahei Road from V23/926057 to 920062. As the type section is well south of the study area, reference sections are nominated along Taihape Road (U20/993982; Fig. 9E) and on Mount Kohinga (U20/979937; Fig. 9F).

Lower and upper contacts

Except for in the Omahaki Depression, the lower contact of the Mangatoro Formation in the study area is not exposed and is almost always in fault contact with older units. In the Omahaki Depression Mangatoro Formation unconformably overlies Torlesse basement. The contact has been observed beside a farm track near the end of Glenross Road (U21/011866). Although not positively identified elsewhere, the lower contact with basement can be located to within a few metres to tens of centimetres at other locations in the Omahaki Depression. In the Kuripapango area it is inferred that Mangatoro Formation unconformably overlies the Blowhard Formation (Browne 2004a). In the Cape Kidnappers and Maraetotara areas Mangatoro Formation unconformably overlies undifferentiated Miocene rocks.

Mangatoro Formation unconformably underlies Mangapanian (Late Pliocene) limestone of the Te Waka Formation, although this contact is not exposed. A Waipipian unconformity is inferred in the Kuripapango area from the Opoitian age of the Mangatoro Formation (see below) and the Mangapanian age of the Te Waka Formation in this area. In the Omahaki Depression, Mangatoro Formation is inferred to be unconformably overlain by coarse-grained shelly conglomerate and pebbly limestone of the Omahaki Formation. In the Kidnappers Section Mangatoro Formation grades conformably into the Black Reef Calcareous Sandstone (Kingma 1971; Francis 1993).

Distribution and thickness

Mangatoro Formation is widespread through the wider East Coast Basin, from at least as far north as Kuripapango, south to the Dannevirke region. The formation crops out more commonly away from the study area than in it.

In no place in the study area is the entire thickness of the Mangatoro Formation exposed. Most outcrops of Mangatoro Formation are contained in the Kuripapango region. The formation crops out in several cuttings beside Taihape Road and around Mount Kohinga, and is well exposed on the northern slopes (U20/994981;3 Fig. 9F). It is also well exposed in the Kidnappers Section from Cape Kidnappers to Black Reef.

A Mangatoro Formation equivalent unit 990 m thick was reported in the hydrocarbon exploration hole Hukarere-1 by Westech Energy NZ Ltd. This well was sited on a wharf in the Port of Napier (Westech Energy NZ Ltd 2001). The formation is likely to be thicker here than in outcrop as all Te Aute lithofacies are absent at this site.

In the Dannevirke Subdivision (Lillie 1953) Mangatoro Formation averages 300 m thick and is best developed in western parts of that area (Harmsen 1985). In the Te Aute subdivision (Kingma 1971) Mangatoro Formation is 530 m thick and only occurs between Cape Kidnappers and the Maraetotara River. This marks the region of greatest outcrop thickness for the formation.

Browne (1981) undertook a gravity profile across part of the Kuripapango area to determine the thickness of the Mangatoro Formation. From his modelling he estimated the depth to basement at 1 km. On the basis of geological mapping, Browne (1981) estimates the Mangatoro Formation in the study area may be as much as 1500 m thick (Browne 2003, 2004a). This thickness estimate is vastly greater than any other Opoitian succession present in the study area and Hawke's Bay Basin. It is very probable that Browne (2004a) has significantly overestimated the thickness of this unit. Geological cross sections suggest that Mangatoro Formation in the Kuripapango area is more likely to be 200-500 m thick.

Description

Mangatoro Formation comprises muddy very fine to fine sandstone and sandy mudstone (Fig. 9E, F). The sediments in the formation are massive, but laminated silty sandstone beds up to 0.4 m-thick are present (Browne 2003). Macrofossils are rare although foraminifera are abundant (Browne 2004a).

Paleontology and age

No macrofossils have been collected from the Mangatoro Formation, although Browne (2004a) records abundant well-preserved foraminifera, with ostracods, molluscs, echinoid spines, bone fragments and fish teeth.

Foraminiferal sample (FRF U21/f87) from Omahaki Stream taken from near the base of the Mangatoro Formation yielded an Opoitian age. The age of this sample was constrained by planktics (*Globoconella puncticulata, Globoconella pliozea* and *Truncorotalia juanai*). On the basis of foraminifera, Mangatoro Formation in the study area is assigned a late Lower to Upper Opoitian age (Kingma 1957; Browne 2003).

Environment of deposition

Mangatoro Formation appears to record a marked period of subsidence in the Kuripapango region (Browne 2004a). Foraminifera collected from the Mangatoro Formation in the Kuripapango area indicate a middle shelf environment of deposition (Browne 2004a). Foraminifera from near the base of the formation in the Omahaki Depression (U21/f87) indicate deposition at upper bathyal (300-400 m) water depths.

OMAHAKI FORMATION (om)

(Beu 1995)

Name and definition

Omahaki Formation (Fig. 8) was introduced by Beu (1995) for a very pebbly limestone to shelly conglomerate occurring in close proximity to basement in the Omahaki Depression (Omahaki Station), from which the name is derived. Beu (1995) suggested that the pebbly limestone of his original definition directly overlay basement rocks. In reality the limestone is separated from basement by several metres of siliciclastic siltstone and sandstone, assigned to the Mangatoro Formation.

Type locality and reference sections

The type locality designated by Beu (1995) is retained, although access is now somewhat difficult and exposure poor due to recent planting of *Pinus radiata*. A reference section in Omahaki Stream provides an easily accessible section through the basal siltstone-sandstone elements of the formation (U21/008858).

Lower and upper contacts

Throughout the Omahaki Depression the Omahaki Formation is inferred to unconformably overlie basement.

The upper contact has not been observed in outcrop. On the northern end of the Ruahine Range at Seconds Ridge (informal local name) the formation is inferred to unconformably overlie greywacke and underlie Sentry Box Formation (U21/973802) (Beu 1995).

Distribution and thickness

The Omahaki Formation is not known east of the Glenross Fault. Outcrop is mostly restricted to the Omahaki Depression although one small outlier occurs on the northern end of the Ruahine Range at Seconds Ridge (U21/973802) (Beu 1995). The Omahaki Formation was mapped as Blowhard Formation in Browne (1986, 2003, 2004), and therefore by implication assigned a Kapitean (Late Miocene) age. This extended the distribution of the Blowhard Formation significantly south of Kuripapango. However, microfossil analysis of a sample from the Omahaki Formation gives an Opoitian (Early Pliocene) age. This, and the different lithology of the unit, separates it as a distinct unit from the Blowhard Formation.

Description

Basal beds of the Omahaki Formation comprise thin-bedded sandstone and siltstone units. Coarse-grained upper facies of the formation vary from a pebbly limestone to a shelly greywacke conglomerate to non fossiliferous greywacke conglomerate (Fig. 9G).

The Pakaututu Formation, which includes a limestone unit also stratigraphically near basement, can easily be differentiated from the Omahaki Formation by its much more diverse faunal content, and the abundant *Tucetona laticostata* valves it contains. Valves of *Phialopecten marwicki* are also common in the Pakaututu Formation, with none being identified in the Omahaki Formation.

Paleontology and age

The sole age diagnostic fossil identified in the Omahaki Formation is *Struthiolaria* (*Callusaria*) *obesa* which has an age range of Tongaporutuan to Opoitian (Beu 1995). On the basis of macrofaunal and stratigraphic position the Omahaki Formation is assigned an Opoitian (Early Pliocene) age. The Omahaki Formation is age equivalent to the Pakaututu Formation cropping out widely in the Puketitiri and Pakaututu areas.

Environment of deposition

The lithology of the coarse-grained beds of the Omahaki Formation suggests a source from a high-energy nearshore setting, proximal to an emergent basement hinterland. The presence of *Struthiolaria (Callusaria) obesa, Crassostrea ingens* and *Ostrea chilensis* further suggest that the upper facies of the formation were derived from a relatively high-energy shelf setting. The presence of Opoitian Omahaki Formation above upper bathyal Opoitian Mangatoro Formation infers a rapid redeposition of the upper pebbly limestone facies.

PAKAUTUTU FORMATION (pk) (new)

(Including Hukanui Limestone Member (pkh) (new))

Name and definition

The name Pakaututu Formation (Fig. 8) is derived from Pakaututu Road in western Hawke's Bay northwest of Puketitiri. It is applied to previously undescribed Neogene rocks that unconformably overlie basement above the Ripia River/Mohaka River confluence at the end of Pakaututu Road (V20/136160), Hot Springs Road (V20/119126), and the Balls Clearing Scenic Reserve area (V20/120090).

The name Hukanui Limestone Member is introduced to encompass the distinctive shelly limestone interval that characterises the Pakaututu Formation. In many areas the Hukanui Limestone Member represents the entire formation. The name is derived from Hukanui Station (V20/153109) where the member is widespread (Fig. 10A).

Type locality and reference sections

The type locality for the Pakaututu Formation is designated at Ripia Station above the Ripia River, on what is locally referred to as the "Ripia Face" (V20/128207). The type section for the formation is also designated as the type section for the Hukanui Limestone Member (Fig. 10A). Reference sections, where the base of the formation is exposed, are located above Pakaututu Road (V20/127123) and in the Mohaka River downstream of the Makahu River confluence (V20/123000-165000). These sections are all located west of the Ruahine Fault. A reference section is nominated east of the Ruahine Fault (V20/127123). This section is located on Hukanui Station and displays a thick basal greywacke conglomerate, overlain by concretionary sandstone and the Hukanui Limestone Member.

The lower contact in the Ripia area is an angular unconformity between the Hukanui Limestone Member and greywacke (Fig. 10C, D). No encrusting faunas were observed on the upper surface of the greywacke, although the facies immediately above the greywacke are highly variable, with sandstone, shellbed and conglomerate all present. This contact displays metre-scale relief, with common greywacke stacks protruding into the overlying limestone. Small caves in the greywacke have been infilled with calcareous sediments, as have many fissures. Valves of the large oyster *Crassostrea ingens* are often present near the basement onlap.

The upper contact is poorly exposed through the study area and has been observed only on Hukanui Station (Fig. 10A).

Above Hot Springs Road near the Ruahine Fault the Hukanui Limestone Member is separated from the underlying basement rocks by at least 50 m of mainly thick greywacke conglomerate beds (Fig. 10A). The contact between the conglomerate facies and basement has not been observed, though it has been located within a few metres of WP128 (V20/120117) and WP476 (V20/136129).

Fig. 10 (facing page): Pakaututu Formation and Puketitiri Formation. These two units comprise the basal beds of the Maungaharuru Subgroup (Mangaheia Group) in the Puketitiri and Pakaututu areas. **A)** Panorama of part of Hukanui Station illustrating the stratigraphic relationship between basement, the Pakaututu Formation, Puketitiri Formation and Te Waka Formation. Photo taken from V20/132128 looking southeast. **B)** Hukanui Limestone Member (Pakaututu Formation) unconformably overlies basement at the type section, Ripia Station (V20/134198). **C)** Unconformable contact between basement and the Hukanui Limestone Member (V20134198). Decimetre- to metre-scale relief is present on this contact. **D)** Fragmented valves of *Crassostrea ingens* (arrowed) overlying basement at the base of the Hukanui Limestone Member, Ripia Station (V20/128207). **E)** Abundant large intact valves of *Tucetona laticostata* in the Hukanui Limestone Member in a section above Pakaututu Road (V20/122117). **F)** Interbedded siltstone and sandstone beds of the Puketitiri Formation cropping out beside Puketitiri Road at the type section (V20/170067).


A
Te Waka Formation
Puketitiri Siltstone
Hukanui Limestone Member
Pakaututu Formation
Torlesse basement
B
C
D
Canon
E
F

Lower and upper contacts

Pakaututu Formation overlies Torlesse basement (Fig. 10A-D). Significant decimetre-scale relief is common on this contact (Fig. 10C). The top of the unit has not been observed, and it is inferred that Pakaututu Formation conformably underlies Puketitiri Formation (Fig. 10A). West of the Ruahine Fault, where only the Hukanui Limestone Member crops out, the Pakaututu Formation is up to 15 m thick, and averages 8-10 m thick. East of the Ruahine Fault the Pakaututu Formation is up to 90 m thick. The increase in thickness reflects the increased prominence of basal siliciclastic beds. The basal conglomerate facies are 0 m to over 50 m thick, concretionary sandstone up to 20 m thick and the Hukanui Member 8-15 m thick. The increased thickness between sections east and west of the Ruahine Fault reflects the occurrence of prominent greywacke conglomerate and concretionary sandstone facies that underlie the limestone unit in this area.

Distribution and thickness

Pakaututu Formation is widespread on farms above the Ripia and Mohaka Rivers at the end of Pakaututu Road, and on farms above Hot Springs Road near "the switchback" (V20/119126). Small outcrops are also present beside Puketitiri Road near Rocky Hill and Anawhenua Stations (V20/133074, V20/118075), and on the northern side of Hukanui Station above Hot Springs Road (e.g. V20/122117). Units mapped by Grindley (1960) in Awahohonu Forest inland from State Highway 5 are also likely to be Pakaututu Formation. These areas display the same flat hilltop geomorphology known to be associated with Pakaututu Formation outcrops (e.g. at V19/139216 and V19/128234). A conglomeratic sandstone bed present near Makahu Road (U20/096134) is inferred to be a correlative of the Pakaututu Formation. Pakaututu Formation does not crop out east of the Mohaka Fault.

Description

The Pakaututu Formation is one of the most distinctive units in the study area, containing a shelly limestone bed (defined here as the Hukanui Limestone Member) dominated by the large semi-infaunal bivalve *Tucetona laticostata* (Fig. 10E), many valves of which are commonly articulated. West of the Ruahine Fault only the Hukanui Limestone Member is present and it unconformably overlies basement; east of the fault the member is underlain by greywacke conglomerate and sandstone facies that vary in thickness with proximity to the Ruahine Fault trace.

The Hukanui Limestone Member is moderately to highly fossiliferous, moderately to well cemented with a matrix of medium siliciclastic sandstone and granule-sized greywacke grains, and in places is whole shell dominated (Fig. 10E). While valves are typically disarticulated they are otherwise intact.

Beds of very well sorted coarse sandstone to granule sized greywacke grains are common, especially at the base of the limestone. Greywacke detritus comprises a larger part of the Hukanui Limestone Member west of the Ruahine Fault, reflecting the proximity of the unit here to basement. In many places west of the Ruahine Fault (e.g. V20/128207 and V20/123195) the Hukanui Limestone Member comprises two shelly limestone beds separated by up to 5 m of non cemented, very well sorted greywacke granules, shellhash and coarse sand.

Thick non fossiliferous greywacke conglomerate facies in the Pakaututu Formation have been identified only east of the Ruahine Fault. The conglomeratic interval comprises metre-scale alternating intervals of poorly to very poorly sorted massive to imbricated conglomerate interbedded with massive to trough cross-stratified gritty coarse sandstone containing scattered greywacke pebbles and thin pebble stringers. The gritty sandstone is composed entirely of coarse sandstone to granule greywacke clasts. Clasts in the poorly sorted greywacke conglomerate beds range from 0.5-20 cm across, although average about 2.5 cm across. All beds are clast supported. Conglomerate facies are well exposed in a high cutting at the head of a stream above Hot Springs Road at V20/127123 (face shown in Fig. 10A). Above the conglomeratic interval at this site is an 8 m-thick interval of non-exposure, above which is a 10 m thick interval of clean, well sorted non cemented sandstone with common concretionary lenses and horizons up to 60 cm thick and averaging 30 cm thick. These concretions contain any of, or a combination of, well rounded greywacke pebbles up to 3 cm across, bivalve, and gastropod fossils. *Stiracolpus, Zeacolpus* and *Struthiolaria (Callusaria) obesa/dolorosea* are common in these concretions. A further 1.5 m is not exposed, followed by 8 m of moderately cemented fossiliferous Hukanui Limestone Member rich in *Tucetona laticostata* with a few scattered greywacke grains.

An outcrop near Makahu Road of pebbly sandstone to greywacke conglomerate is thought to be a lateral equivalent of the limestone facies of Pakaututu Formation (U20/096154). This outcrop is characterised by the occurrence of distinctive, angular pebble and cobble-sized clasts set in a matrix often filled with shellhash. Fauna are typically sparse and highly fragmented, and only the thick shelled oyster *Crassostrea ingens* is commonly present intact.

Paleontology and age

A moderate range of fauna have been collected from this formation, although mostly from the Hukanui Limestone Member. *Tucetona laticostata* conspicuously dominates the taxa present

(Fig. 10E), with *Phialopecten marwicki, Dosinia* sp., *Purpurocardia purpurata, Glycymeris* sp., and *Eucrassatella* sp., also common. Other fauna observed include *Crassostrea ingens* (Fig. 10D), *Oxyperis ?komakoensis*, *Eumarcia benhami., Talochlamys gemmulata, Zeacolpus* sp., *Stiracolpus* sp., *Panopea* sp., *Mesopeplum* sp., and sparse *Tawera* sp.

Pakaututu Formation is inferred to be of Opoitian age based on the occurrence of *Phialopecten marwicki* (Wo form). *Phialopecten* has not previously been known from Lower Opoitian rocks in eastern North Island (Beu 1995, p. 59). The accurate identification of specimens of the gastropod genus *Struthiolaria* fossils in the formation has been problematic. Specimens collected resemble Opoitian *S. dolorosea,* a species not known away from the Awatere River valley in Marlborough. If these specimens are indeed *S. dolorosea* then it dramatically extends the known range of this form, and helps to support a confident Opoitian age for the Pakaututu Formation. It is possible that the *Struthiolaria* fossils collected are of the more common and widespread species *Struthiolaria (Callusaria) obesa* (Tt-Wo). The upper age limit of this species (Opoitian), when coupled with the presence of *Phialopecten marwicki,* further supports an Opoitian age for the Pakaututu Formation. Lowermost beds of the Pakaututu Formation may be of Kapitean age, although this is very poorly resolved.

The Pakaututu Formation is likely to be age equivalent of parts of the Titiokura Formation cropping out east of the Mohaka Fault.

Environment of deposition

The fauna in the Pakaututu Formation are consistent with the *Tucetona-Ostrea* assemblage described by Hendy and Kamp (2004) for Opoitian rocks of the Matemateaonga Formation in Wanganui and Taranaki basins. *Tucetona* prefers clean water of relatively high-energy, and presently occupies environments such as channels in many Northland harbours. A similar depositional environment is envisaged for the limestone and sandstone facies of the Pakaututu Formation. The presence of strong relief on the lower greywacke surface west of the Ruahine Fault indicates a rugged sea-bottom with sea stacks.

The basal thick conglomerate facies adjacent to the Ruahine Fault probably accumulated as alluvial fans infilling fault depressions.

PUKETITIRI FORMATION (pu) *(new)*

Name and definition

Puketitiri Formation (Fig. 8) is named after the small farming community of Puketitiri (V20/150074) near the northern end of the Kaweka Range, western Hawke's Bay. The name has been applied to "middle" Pliocene siltstone and sandstone with thin locally prominent coarse-grained conglomerate beds overlying either Torlesse basement, Rakaita Siltstone Member (Waitere Formation) or the Hukanui Limestone Member (Pakaututu Formation). The Puketitiri Formation underlies Te Waka Formation limestone facies in the area west of the Mohaka Fault from Puketitiri to Awapai Station, and Sentry Box Formation in the Ohara Depression. Puketitiri Formation is probably a correlative of Mangatoro Formation.

Puketitiri Formation is defined to incorporate the Kaumatua Formation of Erdman and Kelsey (1992). Kaumatua Formation was introduced as a name by Erdman and Kelsey (1992) for Pliocene (Mangapanian) rocks overlying Torlesse basement, and underlying Sentry Box Formation in the Ohara Depression. Beu (1995) included the Kaumatua Formation in the Poporangi Group. This report suggests it is more appropriate to include the formation in the Puketitiri Formation, as it underlies the Te Waka Formation on Awapai Station, and is similar to the Puketitiri Formation in terms of age, lithology and general character. This helps to simplify the stratigraphic nomenclature.

Type locality and reference sections

The type section is designated as the series of road cuttings on Puketitiri Road (V20/170067) near Misty Valley and Potter Road (Fig. 10F).

The type locality established by Erdman and Kelsey (1992) for the Kaumatua Formation is nominated here as a reference section for Puketitiri Formation in the Ohara Depression. This section is located in Kaumatua Stream extending from the unconformable contact with Torlesse basement above Mangleton Road, downstream to the contact with the overlying Sentry Box Formation. Reference sections are nominated in Jumped Up Stream above the Mangleton Road bridge and on Awapai Station.

Lower and upper contacts

The lower contact is poorly exposed in the study area. Through the Puketitiri and Pakaututu areas the Puketitiri Formation is inferred to conformably overlie the *Tucetona*-rich Hukanui Limestone Member (Pakaututu Formation) (Fig. 10A). In the Ohara Depression Puketitiri Formation unconformably overlies or is in fault contact with basement. The lower contact is exposed in

Kaumatua Stream above Mangleton Road (Kelsey *et al.* 1993), although flood debris and vegetation have now mostly obscured this outcrop (U21/920643). On Awapai Station the Puketitiri Formation interdigitates with the massive lower member of the Te Waka Formation (U21/016841). Along the Glenross Range the formation underlies the Te Waka Formation.

The upper contact is exposed in several locations across Hukanui and Rocky Hill Stations. At V20/145117 near Hukanui Trig, 5 m of upper Puketitiri Formation is exposed and coarsens upwards into a 0.7 m-thick unit comprising moderately cemented sandstone beds each up to 1 m long and 0.25 m thick. Above this interval is a 2 m-thick unit of Te Waka Formation comprising bioclastic lenses up to 0.4 m-thick consisting of moderately cemented partially recrystallised sandy limestone. The Puketitiri Formation is unconformably overlain by the Te Waka Formation near the northwestern end of Hukanui Hill (Fig. 130). At this locality (V20/141117) a coarse-grained poorly sorted conglomerate containing common *Crassostrea ingens* of the Te Waka Formation sharply overlies the Puketitiri Formation across an erosional surface. The upper 1.5 m of Puketitiri Formation exposed here comprises non cemented siltstone, the lower half of which is strongly bioturbated, and the upper half weakly to moderately laminated (Column Pu-7). At the southeastern end of Hukanui Hill (V20/155114, Column Pu-2) laminated fine sandstone of the Puketitiri Formation is sharply overlain by concretionary sandstone beds of the Te Waka Formation. On Rocky Hill Station (V20/139059) the Puketitiri Formation coarsens upwards over 20 m from silty sandstone into fine sandstone. This sandstone becomes more concretionary over several metres and is overlain by shellhash sandy limestone of the Te Waka Formation (Column Pu-4). A similar transition is present near Little Bush Road (V20/156061) where at least 50 m of silty sandstone passes up-section through a series of concretionary beds into calcareous sandstone of Te Waka Formation.

The upper contact is well exposed in Jumped Up Stream immediately above the Mangleton Road bridge where it has a gradational contact with the Sentry Box Formation (U21/933665). Pebbly mudstone and mudstone beds of the Puketitiri Formation pass conformably into pebbly limestone to pebbly muddy limestone of the Sentry Box Formation. In northern parts of the Ohara Depression, such as at Rocky Outcrop beside Gull Flat Road the Puketitiri Formation is unconformably overlain by the Sentry Box Formation.

Distribution and thickness

Puketitiri Formation crops out sparsely through the Puketitiri area, on Hukanui Hill (V20/137121, and below V20/155114), Rocky Hill Station (V20/139060), Puketitiri Road (V20/170067; V20/148074), Te Kowhai Forest (V20/119013) and on Anawhenua Station above Lucknow Road, Kaweka Forest Park (U20/099053). It is absent from Kuripapango to the Omahaki Depression, and occurs again from the Glenross Range southwest into the Ohara Depression. Puketitiri Formation is not seen east of the Mohaka Fault.

The formation thins from northern to southern outcrops. At least 40 m of Puketitiri Formation is partially exposed near Hukanui Trig (V20/155114, Column Pu-2). Near Little Bush Road (V20/156061) at least 50 m of Puketitiri Formation is present. The Puketitiri Formation is a minimum of 100 m thick in the Ohara Depression (Erdman and Kelsey 1992). In the Awapai Station area Puketitiri Formation is absent at The Lizard, and thickens southwest along the Glenross Range toward Awapai Station to a minimum thickness of 140 m. The thickness for the formation in the Ohara Depression is a minimum as all along its western edge, except for near the Kaumatua Stream reference section, its outcrop extent is truncated by the Ruahine Fault or the Glenross Fault.

In the Ohara Depression Puketitiri Formation is restricted in outcrop to the Ohara Depression and Awapai Station areas. It is inferred to also underlie areas east of the Mohaka Fault based on rocks intercepted in drill holes (e.g. Kereru-1; Johnston and Francis 1996). Puketitiri Formation is a lateral equivalent, at least in part to the Te Waka and Pohue Formations.

Description

Puketitiri Formation comprises blue-grey to light-brown non to slightly cemented, massive, non to slightly fossiliferous sandy siltstone that coarsens up-section into fine to medium sandstone (Fig. 10F). The formation is typically massive to planar laminated. Localised beds of poorly sorted greywacke conglomerate up to 2 m thick occur on Hukanui Hill (V210/136124; V20/138123) and in the Whittle Road area on Anawhenua Station (V20/110159). Concretions may occur in the upper few metres of the formation, and are scattered elsewhere.

At V20/137121 on Hukanui Station, white, massive, hard fractured and frittered very fine siltstone is sharply overlain by grey, weathering to tan-brown, non cemented, very well sorted, strongly bioturbated massive to weakly laminated sandstone (Column Pu-7). The upper 5-10 cm of the lower siltstone interval is riddled with burrows, suggestive of a period of condensed sedimentation. The upper sandstone interval is at least 2 m thick and passes up-section into laminated fine siltstone to silty sandstone, as exposed at V20/141117.

Macrofossils are rare and have only been observed in fresh road cuttings on Puketitiri Road near Misty Valley (Fig. 13F; V20/170067, Column Pu-9). The lower 3 m of this section comprises non cemented non fossiliferous blue-grey sandy siltstone. This interval is sharply overlain by a highly fossiliferous 0.45 m-thick shellbed with a fine sandstone matrix. The shellbed notably contains common large *Crassostrea ingens* and *Maoricardium spatiosum*, many of which are articulated. Other components of the shellbed include *Trachycardium rossi, Phialopecten* sp., and *Panopea* sp. The shellbed is in turn overlain by over 2.5 m of non cemented slightly to moderately fossiliferous sandstone with a diverse bivalve and gastropod fauna. *Maoricolpus roseus, Atrina pectinata zelandica, Amalda (Baryspira) mucronata, Ostrea chilensis, Talochlamys gemmulata* and *Dosinia greyi* are the most common faunal elements of this interval, although many other species are present. Overlying this shellbed is approximately 9 m of centimetre to metre-scale interbedded silty sandstone/fine sandstone beds. Fauna in the silty sandstone beds are similar to those for the underlying bed, though sandstones are non fossiliferous. The section is capped by nearly 4 m of non cemented, non fossiliferous, well sorted, fine to medium sandstone. Pebbly limestone of the Te Waka Formation crops out in low bluffs 40-50 m above this section. Although there is no exposure between the two intervals it is probable that the contact between the two formations is unconformable. An unconformable contact between the Te Waka Formation and Puketitiri Formation is seen in natural exposures in a farm paddock near Puketitiri Road (V20/ 173068; V20/174068). At these two sites moderately well cemented greywacke gravel-rich calcareous sandstone of the Te Waka Formation very sharply overlies olive-brown, non cemented well sorted fine to medium sandstone of upper parts of the Puketitiri Formation. This sandstone is massive, although faint low-angle, small- to moderate-scale sigmoidal cross beds are present. The contact is erosional with centimetre-scale relief. Greywacke clasts up to 70 mm across are concentrated immediately above the contact as part of a shellbed rich in large chalky aragonitic bivalves such as *?Maoricardium spatiosum*, with *Zethalia coronata,* oyster and other bivalves and gastropods. A prominent feature of this contact is the abundant well-developed burrows that occur for up to 60 cm below the contact in the Puketitiri Formation. These (?*Ophiomorpha*) burrows are up to 20 cm long and 4 cm wide, and are infilled by greywacke granules, pebbles and shellhash (Columns Pu-4, Pu-6).

Uncommon plant fossils (leaf impressions) have been observed in a concretion on Rocky Hill Station (V20/139060, Column Pu-4).

Coarse-grained intervals rich in greywacke clasts occur periodically through the Puketitiri Formation. At V20/136124 the Pakaututu Formation is abruptly overlain by siltstone facies of the Puketitiri Formation. Approximately 10 m above the Pakaututu Formation occurs a moderately cemented greywacke conglomerate to breccia containing clasts of granule to boulder size. This unit is poorly to moderately cemented, massive and contains a sandy matrix. Approximately 12 m above the Pakaututu Formation at V20/138123 on Hukanui Station this interval is represented by a 2.5 m-thick well cemented sandstone containing greywacke clasts of granule to coarse pebble size with occasional cobble-sized clasts. Biomoulds, shellhash and oyster valves are scattered through this chaotically-bedded unit. Approximately 1 m of section is not exposed, followed by a 0.7 m-thick well cemented conglomerate with a 0.2 m-thick basal massive sandstone unit. Small abundant biomoulds are present through the conglomerate, with occasional oyster valves. Greywacke clasts are well sorted, well rounded, of granule to coarse pebble size and average 2 cm across. At V20/110059 on Anawhenua Station a pebbly limestone bed 2.5 m thick crops out sharply overlying well sorted fine to medium sandstone. The sandstone is massive, moderately weathered and passes up into 0.25 m of sandstone similar to below, but containing scattered shellhash and occasional pectinid valves. Above this is a dark-grey, massive to broadly laminated, weathered flaggy pebbly limestone containing abundant greywacke granules and cobbles, although pebble-sized clasts dominate. Shellhash and intact disarticulated bivalves are present, including *Tucetona laticostata* and unidentified pectinids. Biomoulds are abundant in this unit.

In the Ohara Depression Puketitiri Formation comprises sandy mudstone, sandstone, pebbly grainstone lenses, and shelly conglomerate beds that unconformably overlie basement. In Kaumatua Stream, where the basal contact is exposed, basal beds of the formation comprise a slightly cemented granule to pebble-sized grainstone approximately 3 m thick. This grainstone passes up-section into siltstone to sandy siltstone.

Fine sandstone beds are slightly muddy, locally calcareous and blue-grey to olive-green in colour, weathering to tan colour. Mudstone beds are blue-grey and sandy (Erdman and Kelsey 1992). In Jumped Up Stream approximately 100 m above the Mangleton Road bridge (U21/933665) Puketitiri Formation comprises non cemented massive to weakly laminated, slightly fossiliferous siltstone. Macrofossils are largely dissolved and only biomoulds remain. *Neilo* is the main macrofaunal element, with *Notocallista, Calliostoma, Talochlamys, Pleuromeris* and *Nuculanid.* This interval passes up-section into a series of interbedded shelly pebbly mudstone and mudstone beds that are overlain by pebbly limestone to pebbly muddy limestone beds of the Sentry Box Formation. These beds significantly contain the last occurrence of *Crassostrea ingens* and *Phialopecten thomsoni*, and the first occurrence of *Zygochlamys patagonica delicatula* and *Phialopecten triphooki.*

Northeast from Awapai Station the Puketitiri Formation wedges out along the Glenross Range toward The Lizard. At the greywacke quarry beside Lizard Road (U20/038909, northern end of the Glenross Range) Puketitiri Formation is absent and limestone of the Te Waka Formation directly overlies basement. Southwest along the Glenross Range the Puketitiri Formation thickens and at Awapai Station separates Te Waka Formation from basement by at least 140 m. Puketitiri Formation in this area is dominated by massive, slightly to moderately weathered non to slightly fossiliferous siltstone to sandy siltstone. At U21/023831 macrofauna are dominated by the gastropods *?Cominella, Taniella* and especially the bivalve *Dosinia greyi*.

Paleontology and age

The age of the Puketitiri Formation is poorly constrained, with few macrofossils observed. A foraminiferal sample from V20/141005 on the Little Bush-Hawkston Station paper road (V20/f445) contains a Waipipian assemblage constrained by planktics (*Truncorotalia crassaformis, Globoconella inflata, G. inflata triangula, G. puncticulata, G. subconomiozea* and *G. pliozea*). Foraminiferal sample V20/f444 collected from below the shellbed on Puketitiri Road (V20/170067, Column Pu-9) contained no foraminifera, but common radiolarians, sponge spicules and rare fish teeth.

Many fauna in the shellbed on Puketitiri Road display affinities with Nukumaruan species, although the presence of *Crassostrea ingens* and *Maoricardium spatiosum* (with no *Phialopecten triphooki* and/or *Zygochlamys delicatula*) strongly indicates an age no younger than uppermost Mangapanian. At least in this area, middle to upper parts of the Puketitiri Formation appear to be of Upper Mangapanian age. The underlying Pakaututu Formation is assigned a confident Opoitian age, and the overlying Te Waka Formation a confident Mangapanian age.

In the Ohara Depression Puketitiri Formation contains the Mangapanian index scallops *Phialopecten thomsoni* and *Towaipecten katieae* (Beu 1995), and underlies limestone and sandstone containing a basal Nukumaruan fauna including *Phialopecten triphooki* and *Zygochlamys delicatula* in association with *Crassostrea ingens* and *Phialopecten thomsoni.* In this area the Puketitiri Formation is of Mangapanian age, and older ages are known.

On the basis of stratigraphic position and macrofauna, the Puketitiri Formation is assigned a Waipipian to Upper Mangapanian age.

Environment of deposition

Foraminifera from V20/f445 near Hawkston Road indicate an upper bathyal environment of deposition at this location. Significant reworking of formanifera, including the presence of many inner shelf (0-50 m water depth) taxa, suggests an upper bathyal environment with normal marine conditions. The presence of 50% planktics indicates an intermediate water mass (M. Crundwell, GNS Science pers. comm. 2004).

The shellbed and overlying silty sandstone on Puketitiri Road (V20/170067) indicate deposition at shelf water depths on a hard-ground setting, supported by the presence of *Crassostrea ingens* and *Maoricardium spatiosum*. In the Ohara Depression Puketitiri Formation was deposited in a variety of shelfal environments. Macrofauna in Jumped Up Stream indicate a progressively-shallowing marine environment from outer shelf to inner shelf water depths.

Common devitrified volcanic glass was recognised in sample V20/f444, suggesting contemporaneous volcanic activity.

TITIOKURA FORMATION (tk)

(Beu *et al.* 1980; formally defined by Beu 1995)

Name and definition

The stratigraphy of the Titiokura Formation (Fig. 11) has recently been documented by Bland *et al*. (2004). The history of naming and correlating limestone beds in the Te Waka and Maungaharuru Ranges has been complicated. Limestone beds forming the Te Waka Range (V20/257130) above Te Pohue (V20/277105) were included in the Pohui limestone of Hector (1877) and McKay (1886) during early geological surveys through western Hawke's Bay. Subsequent geological study has revealed that the Te Waka Range is actually underlain by two discrete limestone packages, the lowermost of which is now referred to as the Titiokura Formation (the upper package is assigned to the Te Waka Formation).

The Titiokura limestone was first introduced as an informal name by Beu *et. al.* (1980) to describe a Waipipian limestone sheet exposed near the summit of the Napier-Taupo Road at the northern end of the Te Waka Range. In the original application of the name by Beu *et al.* (1980) a limestone of probable Waipipian age cropping out above Lake Opouahi (V19/152214) was also included in the Titiokura Formation. Limestone beds underlying the Titiokura limestone at Lake Opouahi were assigned by Beu *et al.* (1980) to the informal Maungaharuru limestone. Beu (1995) formally defined the Titiokura Limestone and restricted the name to the limestone sheet of Waipipian age cropping out in the Te Waka Range (south of the Napier-Taupo Road) above Te Pohue. Limestone beds immediately north of the Napier-Taupo Road were assigned by Cutten (1994) to the Maungaharuru Formation. Beu (1995) adopted the definition of Cutten (1994). This definition included the limestone cropping out above Lake Opouahi that was originally included in the Titiokura Limestone of Beu *et al.* (1980). The Maungaharuru Formation included over 1500 m of rocks extending from Opoitian to Nukumaruan. The formation inadequately described the varied lithologies and stratigraphic units through the Maungaharuru Range area.

Detailed geological mapping by Bland (2001) and Graafhuis (2001) significantly subdivided the Maungaharuru Formation into a more manageable form, and effectively disbanded it. These two studies revealed that the Titiokura Limestone of Beu (1995) and Maungaharuru limestone (informal) of Beu *et al.* (1980) were in fact part of the same stratigraphic unit, and were best included in the same stratigraphic formation. Bland *et al.* (2004) formally defined and documented the correlations of Bland (2001) and Graafhuis (2001), including these beds in a highly redefined Titiokura Formation. The name Maungaharuru was elevated to subgroup status to incorporate much of the stratigraphy cropping out in western and northern districts of the study area. The Titiokura Formation is defined in this report (as in Bland *et al.* 2004) to include all Upper Opoitian to Waipipian calcareous sediments above a conglomeratic basal bed (overlying the Mokonui Sandstone), and below the Te Waka Formation occurring on the western side of the forearc basin in Hawke's Bay.

The "Limestone" portion of the name was dropped in favour of the term "Formation" by Bland *et al.* (2004) to reflect the varied facies present in the formation. The Titiokura Formation is defined as a succession unconformably overlying the Mokonui Sandstone that contains prominent limestone beds.

The character of the Titiokura Formation (Fig. 11) can usefully be subdivided into two broad packages. South of Ahuateatua Peak (V19/328216) the Titiokura Formation consists largely of a single limestone package 30-50 m thick (Fig. 12A-F). North of Ahuateatua Peak the formation has been mapped and described as five members. This reflects the greater amounts of subsidence, sediment thickness and diversification of lithofacies within the formation through this area. Each of these five members are described separately. Characteristics of the Titiokura Formation presented below deal dominantly with the southern (Te Waka Range-Ahuateatua Peak) outcrops of the formation where the formation consists essentially of a single limestone unconformably overlying Mokonui Sandstone (Fig. 12B).

Type locality and reference sections

Beu (1995) formally defined the Titiokura [Formation] and established a type section (V20/278148) at the northern end of the Te Waka Range. Neither the base nor the top of the formation is well exposed at this locality and a new type section was designated by Bland *et al.* (2004) 3 km southwest along the range crest at V20/248133 (Fig. 12B; Column Tw-2). At this locality there is complete exposure of the formation from bottom to top.

A good, easily accessible reference section at the northern end of the Te Waka Range occurs along State Highway 5 (V20/289142, Column Ti-2). A useful reference section characterising stratigraphy through central parts of the Maungaharuru Range occurs on the western side of Taraponui Trig (V19/331228). A reference section in the northern part of the Maungaharuru Range is located along Pohokura Road, east of the intersection with Jeph Everett Road to Lake Opouahi (V19/387273-408218).

Lower and upper contacts

The lower contact of the Titiokura Formation is easily recognisable in the form of a conglomeratic bed that sharply and unconformably overlies sandstone facies of the Mokonui Formation (Fig. 12B, C). The internal composition of this bed is variable, but its stratigraphic position and continuity is a distinguishing feature of the Titiokura Formation throughout the study area. Below Taraponui Trig on the Maungaharuru Range (V19/332233) the conglomerate comprises a basal greywacke pebble conglomerate which in turn is overlain by a 1 m thick cross-bedded unit of well rounded pumice and carbonised wood set in a shelly matrix (Cutten 1994; Graafhuis, 2001). Closer to Wakaateo Trig (V20/295169) the conglomerate is composed of sandstone and mudstone pebbles and boulders up to 1.5 m across with common large pebbles and cobbles of greywacke (Fig. 12C). In Titiokura Quarry near State Highway 5 (V20/292159) the bed comprises sandstone and mudstone pebbles set in a sandstone matrix. On Oakmere Station above Te Pohue (V20/270115), the basal conglomerate consists of sandstone and mudstone pebbles interbedded with shell fragments.

The upper contact appears to be conformable through the study area in the form of a gradational contact into sandstone facies of the Te Waka Formation. Beu (1995) suggests that an unconformity is present at this contact, but this is not confirmed in this report.

Titiokura Formation overlies Mokonui Sandstone in the north face of the Te Waka Range where there is spectacular paleorelief of 30 m cut into Mokonui Sandstone.

Distribution and thickness

Titiokura Formation is widespread throughout the high country inland of Lake Tutira and Te Pohue, and crops out in a broadly southwest-northeast belt from Te Pohue to at least as far north as Willowflat (W19/524371) and the Putere Lakes (W19/591433).

In the study area the formation crops out from Pohokura Saddle to Lake Opouahi on the Maungaharuru Range, and underlies the prominent dipslope below Te Waka Trig at the northern end of the Te Waka Range. Caron (2002) suggested that the lowermost limestone bed exposed in the headwaters of Wai-iti Stream (The Gorges Station) near Patoka (V20/186011) was a further southern occurrence of Titiokura Formation, thereby extending its distribution significantly to the south. Titiokura Formation is not known west of the Mohaka Fault, while the immediately overlying Te Waka Formation occurs west of the Mohaka and Ruahine Faults. This situation has implications for timing of movement on faults in the North Island Shear Belt.

The Titiokura Formation varies from as little as two metres thick to composited thicknesses of about 730 m. Graafhuis (2001) estimated a maximum thickness of the Titiokura Formation in the Waikare River catchment of over 800 m.

Description

The Titiokura Formation is a complex mixed bioclastic-siliciclastic sedimentary succession that displays dramatic facies and thickness changes along its outcrop extent (Fig. 11). The stratigraphy of the formation was detailed in Bland *et al.* (2004). The stratigraphy of southern portions of the unit was described by Bland (2001), while northern regions were studied by Graafhuis (2001). In its southern extent (Te Waka Range-southern Maungaharuru Range) Titiokura Formation is limestone dominated with some sandstone and minor conglomerate and rare siltstone facies. In northern sections (north of Ahuateatua Peak, Fig. 12A) the formation becomes more siliciclastic, and by the Waikare River catchment carbonate constitutes only a minor portion of the formation. This trend continues northwards towards Willowflat and the Putere Lakes.

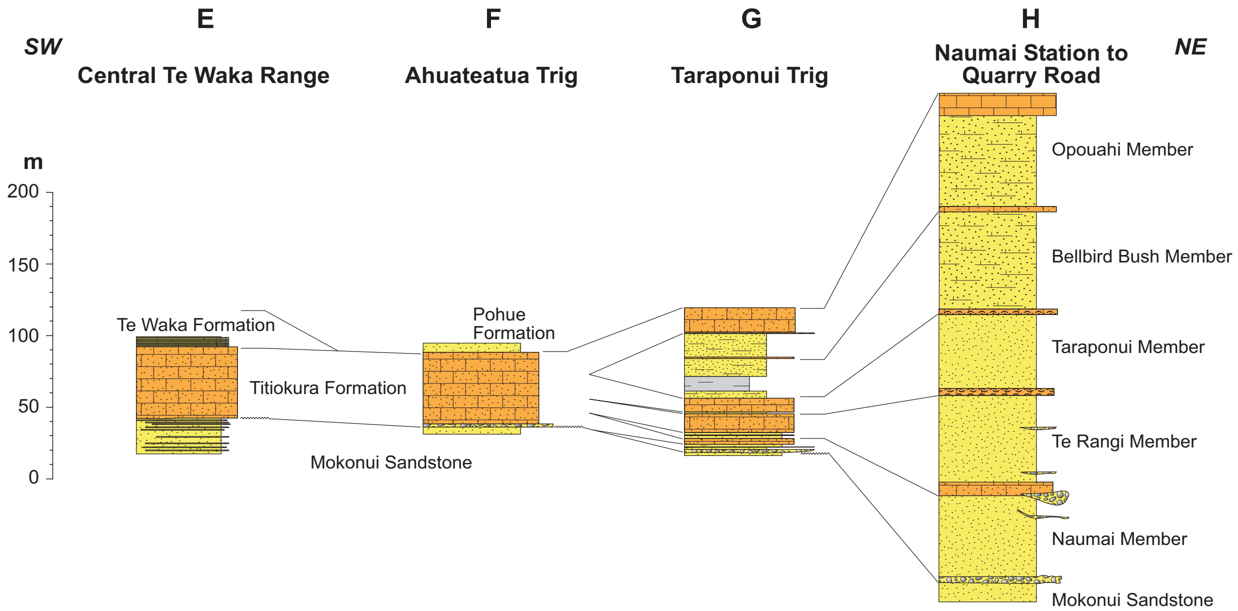


Fig. 11: Schematic stratigraphic columns of the Titiokura Formation from the type section on the Te Waka Range to the northern end of the Maungaharuru Range.

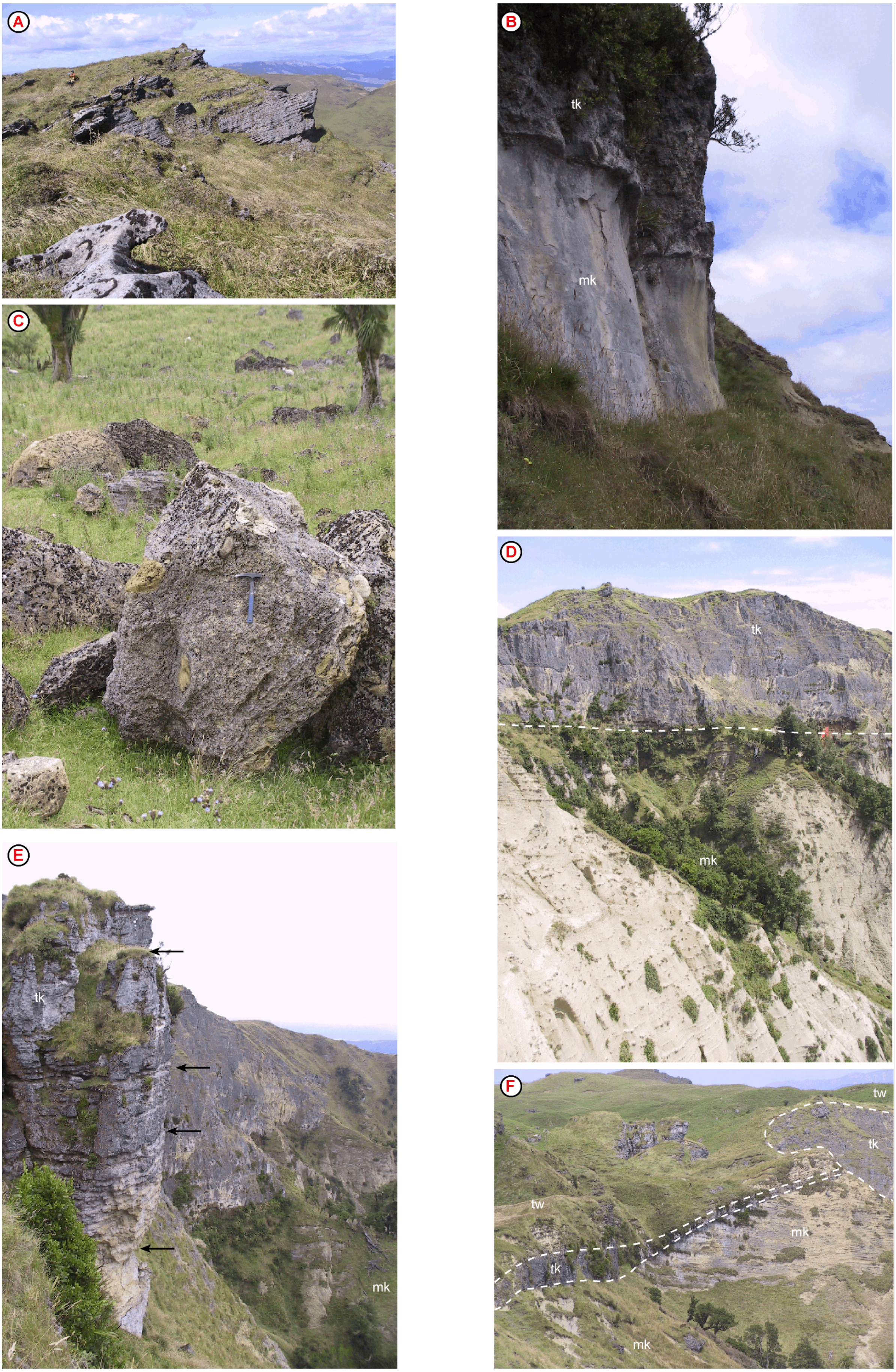
In southern regions Titiokura Formation typically comprises pale-grey to yellow-grey, parallel to cross-bedded, slightly to moderately cemented fine limestone dominated by small molluscan bivalve, barnacle plate and bryozoan fragments. Lower parts of the formation comprise a non to slightly fossiliferous conglomerate bed 0.5-1.5 m thick dominated by clasts of Miocene sandstone and siltstone, with rare greywacke grains (Fig. 12C). Erosional relief on the base of this conglomerate is generally 0.1-0.5 m. The Titiokura Formation comprises discrete stacked bodies of carbonate, sandstone and conglomerate that vary in thickness through the field area. The composition of these lenses is predominantly of mixed bioclastic-siliciclastic composition, though the bioclastic content dominates.

Outcrops of the Titiokura Formation are frequently flaggy, especially in exposures along the Te Waka Range crest, on Oakmere and Rock Stations, and at Ahuateatua Trig (Fig. 12A). The bioclastic beds are typically 0.03-0.2 m thick and continuous over tens of metres. The siliciclastic-beds average less than 0.4 m in thickness. Bioturbation trails and blebs are visible in this part of the formation.

Fragmented barnacle plates and shellhash dominate the composition of the limestone in the area above Te Pohue village. Rare intact bivalves are present, both articulated and disarticulated, and usually these are concentrated into fossiliferous beds. *Ostrea chilensis* valves are common in these beds, as are bryozoans, pectinids and some gastropods. The fossiliferous lenses have a matrix of bioclastic-dominated coarse siltstone to sandstone. These lenses display erosional lower bases with centimetre-scale relief between them and underlying siliciclastic beds. This suggests that the bioclastic layers may have been storm emplaced. Well rounded lensoidal greywacke pebbles up to 15 mm across are scattered through the formation.

Titiokura Formation exposed in the southern Maungaharuru Range (Ahuateatua Trig-Titiokura Quarry) is much coarser-grained than those parts in the dipslope above Te Pohue. The Titiokura Formation becomes coarser-grained from the Te Waka Range to southern Maungaharuru Range. Around Wakaateo Trig the limestone consists of coarse sand to gravel sized barnacle plates. Barnacle plates and fragments are abundant and up to 5 cm across, although few intact barnacles occur. Secondary calcite is common, as are manganese coatings. Small greywacke grains are often present in the lower 8 m of the Titiokura Formation exposed in Titiokura Quarry. These grains make up less than 5% of the matrix of the limestone, and are less than 6 mm across in size, well sorted and well rounded. In some fall blocks, siltstone and sandstone clasts up to 0.6 m across occur. Sandstone clasts in the basal parts of the coquina are frequently bored, with the borings infilled with shellhash sandstone. Some blocks show abundant *Talochlamys gemmulata* valves. A sandy matrix is common, comprising shellhash, with faint primary bedding structures. Bivalve and oyster fragments also occasionally occur. Exposures around Wakaateo Trig contain abundant biomoulds. The limestone at this locality also appears to be relatively uncompacted. Overall grain size in the sediments of the formation decreases further northward toward Ahuateatua Trig, where its clast size is similar to that observed in the Te Waka Range.

Fig. 12 (facing page): Titiokura Formation south of Ahuateatua Trig. **A)** Moderately dipping (c. 22°) flaggy well cemented alternating packstone and grainstone beds of the Titiokura Formation cropping out on the summit ridge of the Maungaharuru Range at Ahuateatua Trig. North of this locality the formation diverges into multiple members. Location: V19/327216, looking south. **B)** Contact between the Titiokura Formation and Mokonui Sandstone. The 0.5 m-thick bed above the contact comprises a conglomerate consisting of Cenozoic sandstone and mudstone clasts. Relief on the contact is up to 0.3 m. Location: V20/239128. **C)** Coarse-grained mixed bioclastic-siliciclastic basal conglomerate of the Titiokura Formation displayed in fall blocks at the end of the Maungaharuru Range track, Waitara Station. Location: V20/219191. **D)** Sandy limestone facies of the Titiokura Formation unconformably overlying concretionary, non fossiliferous sandstone of the Mokonui Sandstone at Hell's Hole, Te Waka Range. The limestone "sheet" is c. 50 m thick. Location: V20/235127 looking south. **E)** Slightly flaggy 20 m high bluffs of Titiokura Formation cropping out near Hell's Hole. Arrows denote surfaces defining broad "packages" within an otherwise single limestone sheet. Western face of the Te Waka Range, V20/241129 looking southwest. **F)** Titiokura Formation unconformably overlying Mokonui Sandstone across a spectacular angular unconformity with at least 30 m of relief. The dark grey limestone on the left side of the photograph is c. 15 m thick, thins to < 1 m over the Mokonui Sandstone high in the centre, and then thickens to the right to > 50 m thick. The overlying grey limestone is part of the Te Waka Formation. Location: western face of the Te Waka Range, V20/242130 looking south. mk, Mokonui Sandstone; tk, Titiokura Formation; tw, Te Waka Formation.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The basal conglomerate in the southern Maungaharuru Range near Wakaateo Trig comprises mudstone clasts with lesser sandstone clasts (Fig. 15C). These clasts are well rounded, of oblate shape, and up to 100 mm long. In places the lower parts of the formation above the basal conglomerate are composed of at least 40% well sorted mudstone clasts that average 20 mm in size.

Some very small-scale but finely-developed cross-bedding can be observed in some parts of the formation (e.g. V20/277149). Well developed cross-bedding is frequently visible in single flags in outcrops. Sediments in these zones are of medium to coarse sand size, with a concentration of heavy minerals at the top of a layer that highlight the bedforms. Above this is a thin layer of well rounded conglomeratic mudstone clasts (<6 mm across). Sediments above are frequently sandier and rich in shell fragments.

Throughout the Te Waka Range, and the dipslope running down to the Napier-Taupo Road and Te Pohue, the top of the Titiokura Formation is marked by a prominent brachiopod bed. A sandstone unit in the dipslope above Te Pohue Village overlies this brachiopod bed. At Te Waka Trig the brachiopod bed forms the top of the Titiokura Formation, and is overlain by the Te Waka Formation. In several locations highly fossiliferous beds dominated by brachiopods are present within the main body of the formation. The capping brachiopod bed is typically 0.3-0.5 m thick and dominated by *Neothyris* aff. *obtusa,* with occasional *Phialopecten marwicki, Mesopeplum convexum* and rare echinoids and echinoid spines. It appears that the brachiopod bed is lensoidal throughout the outcrop area and although widespread, does not crop out continuously.

In bluffs above Te Pohue on Translator Road coarse-grained limestone facies of the Te Waka Formation sharply overlie siltstone facies of the Titiokura Formation (V20/271106). This siltstone contains occasional concretions, many of which have been incorporated into the basal conglomerate facies of the overlying Te Waka Formation at this site. This suggests that concretionary beds in this siltstone probably formed at or very close to the sea floor. Bedding is faint in the siltstone.

Near Hell's Hole (Fig. 12D, E) the formation thins rapidly from 50 to 2 m where it unconformably overlies spectacular paleo-relief carved into the underlying Mokonui Formation (Fig. 7F). Southward, the formation thickens to over 50 m (Fig. 7F). In this region the Titiokura Formation comprises a 1 m-thick basal conglomerate that passes conformably up into shellhash limestone. The conglomerate comprises clasts of well cemented shellhash unit with well rounded greywacke pebbles up to 5 cm across, as well as sandstone and siltstone pebble clasts. Fauna are dominated by brachiopods, with some oysters (?*Ostrea*). The overlying limestone interval comprises stacked beds of medium-grained shellhash. The limestone is conformably overlain by concretionary fossiliferous sandstone (Te Waka Formation) containing large *Phialopecten marwicki* (Wp) (Fig. 12F; Column Tw-3).

Paleontology and age

Beu (1995) described the Titiokura Formation as one of the least satisfactorily dated limestone units in the eastern North Island, despite at least four pectinid collections at GNS Science (Lower Hutt). *Phialopecten marwicki* occurs sporadically through the Titiokura Formation, with *Mesopeplum crawfordi* relatively rare. *Phialopecten* is not known in Lower Opoitian rocks of eastern North Island (Beu 1995, p.59). The Titiokura Formation is assigned an Upper Opoitian to Waipipian age based on the presence of *Phialopecten marwicki* (Opoitian form), co-occurrence of *Phialopecten marwicki* (Waipipian form) and *Mesopeplum crawfordi*, and stratigraphic position. Evidence strongly suggests that the Titiokura Formation is diachronous across the study area. More southern outcrops, such as those in the Te Waka Range and Patoka area, are likely to be of Waipipian age only.

Environment of deposition

The Titiokura Formation is inferred to represent a shoreline to shelfal mixed carbonate-siliciclastic depositional system (Bland *et al.* 2004). Beds cropping out in the Te Waka Range area were deposited at inner to middle shelf water depths in a current-swept seaway (Beu *et al.* 1980; Beu 1995; Bland *et al.* 2004). It is envisaged that carbonate production occurred on parts of the middle shelf or around rocky shorelines, with remobilisation of shell debris by strong tidal sea-floor currents. Fauna are dominated by barnacles, largely as plates and fragments, though rare intact specimens occur. A unique combination of marine conditions must have occurred to allow for this “blooming” of barnacles (Beu *et al.* 1980). *Mesopeplum (Borehamia) crawfordi*, present in the Titiokura Formation, is one of a group of pectinids that lives on current-swept “hard-grounds” where sediment will not clog their gills, as they lack a mantle cleaning mechanism (Beu *et al.* 1990). The presence of reasonably common *M. crawfordi* indicates that such an environment must have occurred during deposition of the Titiokura Formation. Other common fauna in the Titiokura Formation (e.g. *Neothyris*, *Phialopecten* and *Ostrea*) also require similar environments relatively free of siliciclastic sediment. Modern *Ostrea* presently live in areas such as Foveaux Strait. A similar depositional setting is envisaged for the Titiokura Formation. It is probable that there were contemporaneously high inputs of siliciclastic sediment occurring into the basin at this time. It is considered that much of this sediment effectively by-passed the inner and middle shelf and was focused into deeper parts of the basin in the north, such as the Waikare River catchment.

Naumai Member (tka)

(Graafhuis, 2001; formally defined by Bland *et al.* 2004)

Name and definition

Naumai Member (Fig. 11H) was introduced by Graafhuis (2001) and formally defined by Bland *et al.* (2004). The name is derived from Naumai Station at the crest of the Maungaharuru Range on Pohokura Road (V19/388268). The name is applied to the stratigraphically lowest member of the Titiokura Formation immediately overlying the Mokonui Sandstone and underlying the Te Rangi Member.

Type locality

The type locality is designated on Pohokura Road at the crest of the Maungaharuru Range and within adjacent parts of Naumai Station (Fig. 7D, 13A, B). The basal conglomeratic and limestone facies of the member are very well exposed on the southern side of the intersection of Pohokura and Jeph Everett Roads (V19/389273) (Fig. 16B). The majority of the type section is displayed in natural outcrops in the paddock on Naumai Station on the north side of Pohokura Road (Fig. 13A). The top of the section is located at V19/386265. Reference sections are nominated for the section below Taraponui Trig (V19/331228) (Fig. 13C) and on Te Rangi Station (V19/412306-416301).

Lower and upper contacts

The base of the member coincides with the base of the Titiokura Formation in the area north of Ahuateatua Trig. Throughout the study area the lower contact is an unconformity, perhaps slightly angular, and almost always overlain by a conglomerate bed of varying lithologies. The contact varies from being sharp to displaying metre-scale relief. At the type section relief on the lower contact is up to 6 m over a 10 m length of outcrop (Bland *et al.* 2004) (Fig. 13B, D, E). Northwards and basinwards from the type section, towards Te Rangi Station, the lower contact appears to become more conformable.

The upper contact of the Naumai Member is considered to be a disconformity, and is a sharp surface displaying minor localised relief (Bland *et al.* 2004).

Fig. 13: Naumai Member, the basal member of the Titiokura Formation north of Ahuateatua Trig. **A)** Dip slope of the Naumai Member on Naumai Station at the Pohokura-Jeph Everett Road intersection (V19392272). This site is the type section for both the Naumai and overlying Te Rangi Members of the Titiokura Formation. Dashed white line defines the contact between the Naumai and Te Rangi Members. **B)** Base of the Naumai Member at the Pohokura-Jeph Everett Road intersection (V19/390273). Up to 6 m of relief is present on this basal contact (highlighted by dashed line). **C)** View of part of the Maungaharuru Range from near Naumai Station south to Taraponui Trig (T). It is along this section of the range that the Titiokura Formation diverges from a single limestone unit into multiple members. Near V19/372281 on Waitara Road looking southeast. **D)** Close-up view of the conglomeratic beds that characterise basal parts of the Naumai Member at the type section (V19/390273). **E)** Limestone bed (above white dashed line) developed in basal parts of the Naumai Member at the type section (V19/390273). The base of the member where it unconformably overlies the Mokonui Sandstone is highlighted.

Distribution and thickness

Naumai Member crops out along the western face of the Maungaharuru Range (Fig. 13C) from below Ahuateatua Trig to Te Rangi Station. Lateral equivalents extend northeast towards the Mohaka River in the Willowflat area, and the Putere Lakes.

At Taraponui Trig the member is 15 m thick, which increases northeast to about 60 m in the Te Rangi Station area (Graafhuis 2001). The increase in thickness results mostly from the thickening of sandstone facies in middle to upper parts of the member (Bland *et al.* 2004).

Description

Naumai Member comprises a succession of conglomerate, calcareous sandstone/limestone, silty sandstone and sandy limestone facies. While the internal composition varies through the outcrop area, basal beds of the Naumai Member consistently comprise a variety of conglomerate and breccia facies. At the type section (V19389273-386265) the basal beds consist of a channelised conglomerate with well rounded and angular pebble to boulder-sized clasts of mudstone (90%) and sandstone (10%) lithologies in a shelly sandstone matrix (Fig. 13B, D, E). This conglomerate passes upsection into differentially cemented, bipolar cross-stratified sandy limestone and calcareous sandstone with rare mudstone clasts. This succession is repeated two or three times in the lower 6 m of this section. Greywacke pebbles are not prominent in the type section, but occur at localities above the contact to the south at Taraponui Trig, where pumice clasts and charcoal fragments are conspicuous components of the conglomerate facies (Cutten 1994; Bland *et al.* 2004). The conglomerate bed is thickest in southwestern areas (6 m), reducing to 4 m in northeastern areas. However, the basal conglomerate may be lacking at any point along the outcrop extent, depending on the degree of channelisation.

Sandstone beds comprise the bulk of the member at the type section and localities to the northeast. Lower parts comprise variably silty fine sandstone with thin beds of sandy siltstone. Upper parts are variably cemented, comprising moderately cemented, concretionary fine sandstone with a few thin discontinuous pebbly beds. Sandstone facies grade southward into limestone facies of the undifferentiated Titiokura Formation. The upper limestone facies of the member is thickest in the southwest, being 9 m thick at Taraponui Trig (Bland *et al.* 2004).

Paleontology and age

Several valves of *Phialopecten marwicki* have been collected from the Naumai Member at Naumai Station. The small size of these specimens is indicative of an Opoitian age for the member. The underlying Mokonui Sandstone has a Lower Kapitean to Opoitian age in the Mohaka River section, and a Lower Opoitian age at Pohokura Road (Cutten 1994). As *Phialopecten* is not known in rocks of Lower Opoitian age in eastern North Island (Beu 1995, p.59) an Upper Opoitian age is assigned to the Naumai Member. Stratigraphic position above Lower Opoitian Mokonui Sandstone supports this interpretation.

Environment of deposition

The Naumai Member is inferred to have accumulated in shoreface to middle shelf water depths on the basis of sedimentary structures and macrofauna.

Te Rangi Member (tkb)

(Graafhuis 2001; formally defined by Bland *et al.* 2004)

Name and definition

The name Te Rangi Member is derived from Te Rangi Station at the end of Heays Access Road. Te Rangi Member was introduced by Graafhuis (2001) and formally defined by Bland *et al.* (2004). The Te Rangi Member comprises the succession immediately overlying the Naumai Member (Fig. 11H). It underlies the Taraponui Member.

Type locality and reference sections

The type section is on Naumai Station at V19/387273-386262 (Fig. 14A-G), and immediately overlies the type section of Naumai Member. Reference sections are designated at Taraponui Trig (V19/331228) (Fig. 13C), on Naumai Station (V19/392274; V19/407287) and on Te Rangi Station (V19/430297; V19/407287) where they were logged by Graafhuis (2001).

Lower and upper contacts

The lower boundary of the Te Rangi Member is disconformable. Towards the north at Te Rangi Station the contact is sharp, but possibly conformable. The upper boundary has a similar character to that of the lower contact, and locally displays relief of up to 0.6 m (Bland *et al.* 2004) (Fig. 14E).

Distribution and thickness

The Te Rangi Member immediately overlies the Naumai Member and is distributed in a broadly northeast-southwest trending belt immediately east of it, where it forms prominent dipslopes on the flanks of the Maungaharuru Range above deeply incised stream valleys (Bland *et al.* 2004).

At Taraponui Trig the member is 18 m thick, increasing to about 70 m thick in the region of Naumai and Te Rangi Stations (Graafhuis 2001). The increase in thickness is due almost entirely to substantial increases in the amount of siliciclastic sandstone within the member (Bland *et al.* 2004).

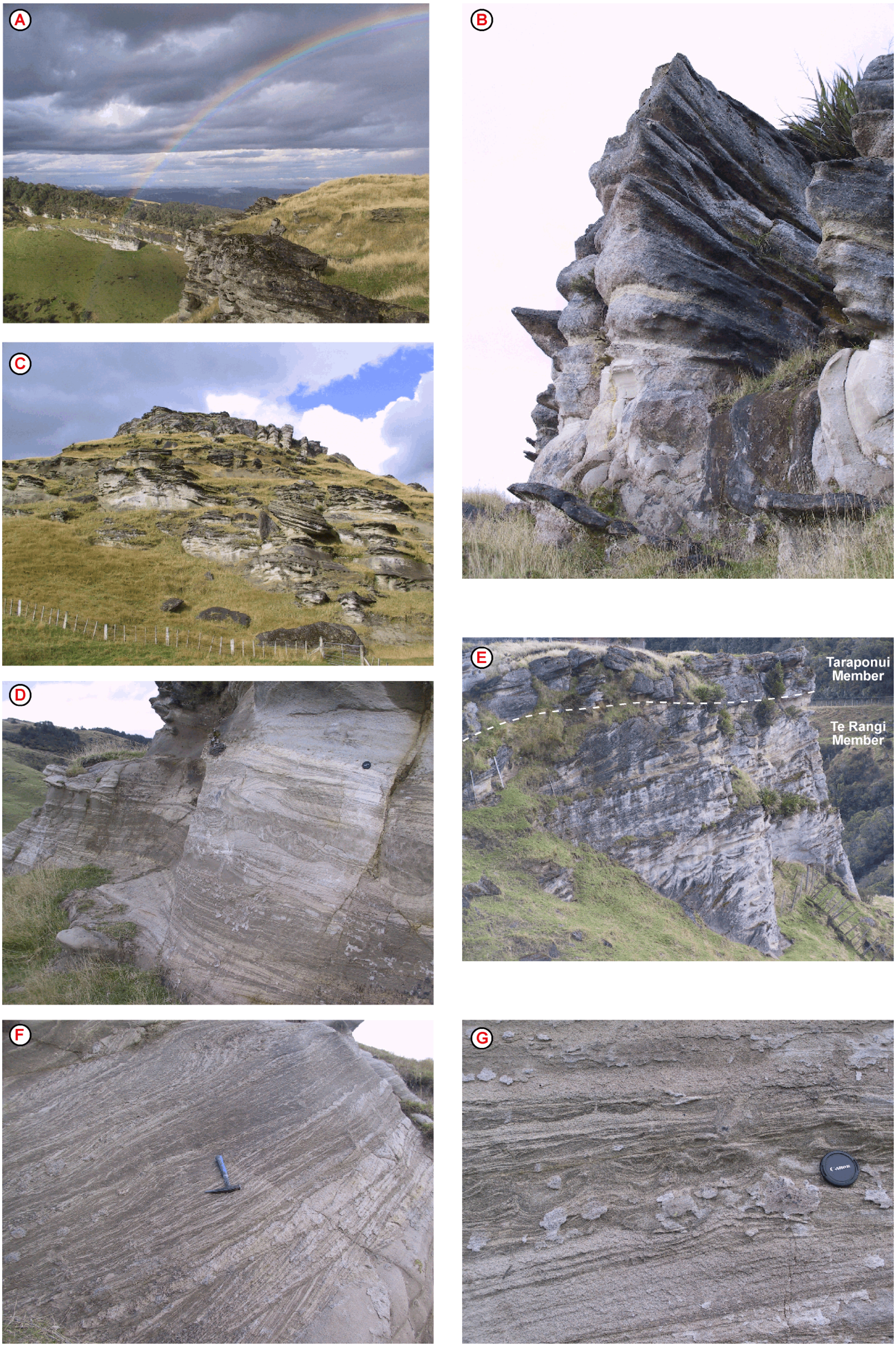
Description

The Te Rangi Member has a very similar content and facies succession to the Naumai Member (described above). At Naumai Station (type section) the base of the member (Fig. 14A) comprises a 0.5 m-thick fossiliferous pebble to cobble-sized greywacke conglomerate containing disarticulated and fragmented bivalves including *Crassostrea ingens*. This basal bed is overlain by 1-2 m of cross-stratified well sorted calcareous sandstone. This in turn is overlain by about 1 m of moderately to well cemented medium to coarse skeletal grainstone and packstone (Bland *et al.* 2004). Above this limestone is a 10 m-thick interval of massive, non cemented, well sorted fine sandstone with occasional thin interbeds of cemented skeletal grainstone. Overlying this is a 30 m-thick section comprising thin to medium bedded, non cemented fine sandstone, sometimes with internal ripple bedding, convolute bedding, thin skeletal grainstone beds and concretionary horizons. Bioturbation is a prominent element of this interval. The upper 30 m of the member comprises differentially cemented, medium to coarse calcareous sandstone with convolute bedding and disrupted mud drapes. Sandstone beds and sets become more thickly bedded (Fig. 14E) and cross-bedded towards the top of the member (Fig. 14B, C). Pumice and heavy minerals are conspicuous components of some cross-beds (Fig. 14D, F, G).

South of the type section at Taraponui Trig the Te Rangi Member comprises a basal 2 m-thick grey, calcareous fine sandstone, overlain by 16 m of cross-bedded, fossiliferous grainstone with greywacke pebbles and scattered large sandstone rip-up clasts throughout.

North of the type section in the region of Rangiora Stud and Te Rangi Station the member consists mostly of massive, bioturbated fine sandstone with mudstone drapes

Fig. 14 (facing page): Te Rangi Member (Titiokura Formation). **A)** View of differentially cemented limestone and calcareous sandstone bluffs of the Te Rangi Member (Titiokura Formation) at the type section, Naumai Station (V19/392271). **B)** Trough cross-bedded limestone and calcareous sandstone of the upper Te Rangi Member, Naumai Station (V19390268). **C)** Differentially cemented cross-bedded mixed bioclastic and siliciclastic sandstone bodies of the upper Te Rangi Member, Naumai Station (V19/390271). **D)** Cross-bedded, ripple-laminated, convolute-bedded pumiceous calcareous sandstone in upper parts of the Te Rangi Member, Naumai Station. Photo location: V19/392272. **E)** Cross-bedded sandstone of the Te Rangi Member, overlain by limestone of the Taraponui Member on Naumai Station. The Te Rangi Member comprises wavy-bedded and trough cross-bedded sandstone. Pohokura Road is visible across the gully in the background. Photo location: V19/393272. **F)** Strongly laminated, cross-bedded, ripple- and wavy-bedded calcareous sandstone of the Te Rangi Member, Naumai Station (V19/390271). **G)** Truncated convolute-bedding in the Te Rangi Member, Naumai Station. Bedforms in this interval are highlighted by fine-scale alternating layers of heavy mineral and pumiceous-dominated sediments. Naumai Station (V19/390271).


A
B
C
D
E
Taraponui Member
Te Rangi Member
F
G

Paleontology and age

Small fragmented pectinid valves tentatively identified as *Phialopecten marwicki* (Opoitian form) occur in the type section on Naumai Station. No other age diagnostic fauna have been observed. The Te Rangi Member is assigned an Upper Opoitian age on the basis of stratigraphic position, and the presence of *Phialopecten marwicki*.

Environment of deposition

Te Rangi Member is inferred to have accumulated at middle shelf to nearshore water depths on the basis of sedimentary structures and macrofauna.

Taraponui Member (tkc)

(Graafhuis 2001; formally defined by Bland *et al.* 2004)

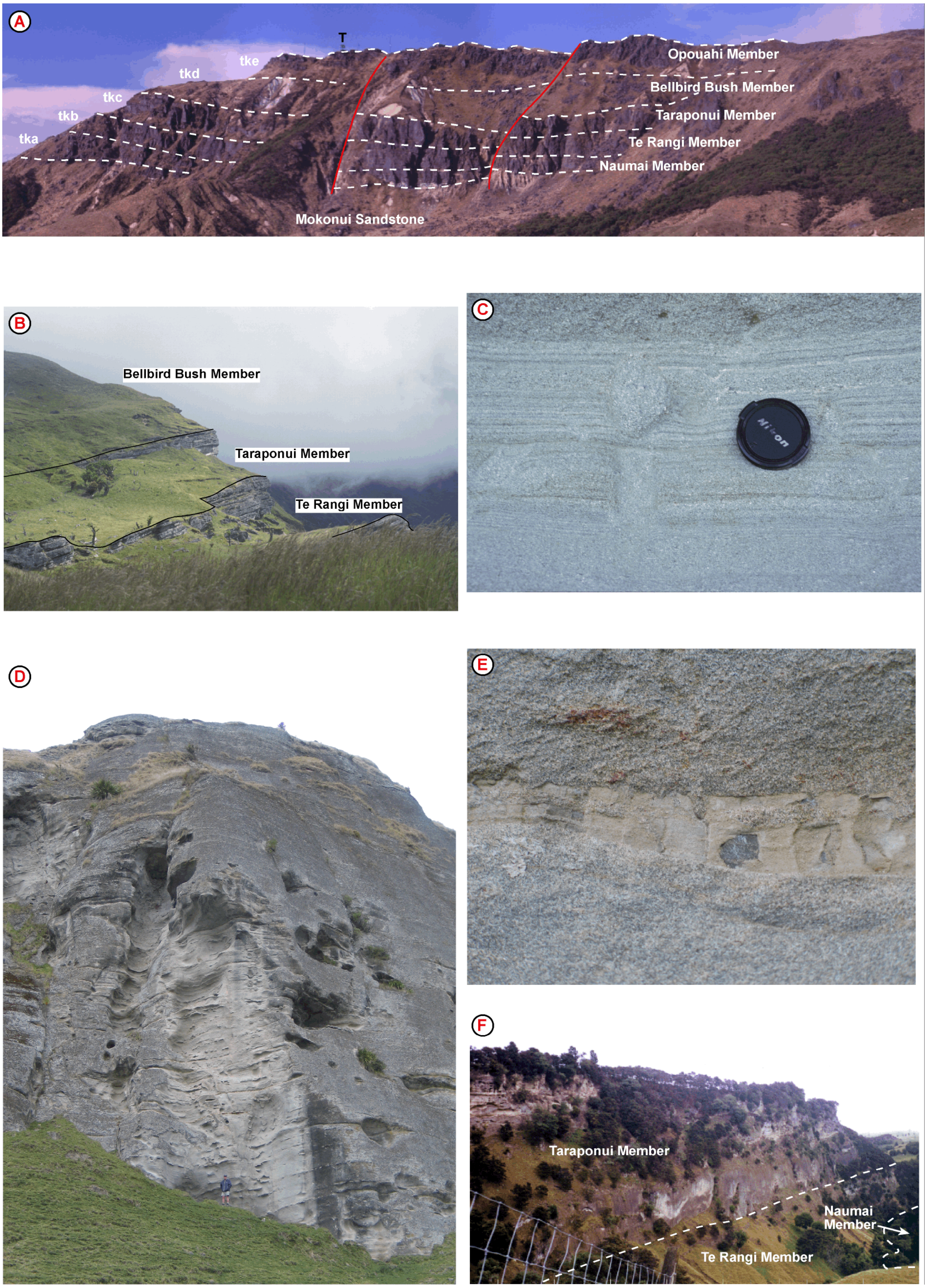
Name and definition

The name Taraponui Member is derived from Taraponui Trig (Fig. 15A) on the crest of the Maungaharuru Range. Taraponui Member was introduced by Graafhuis (2001) and formally defined by Bland *et al.* (2004). The Taraponui Member overlies the Te Rangi Member and underlies the Bellbird Bush Member (Fig. 11H, 15B).

Type locality and reference sections

The type section is designated at V19/430297 on Te Rangi Station. This is the most accessible section where the whole member is exposed and includes the lower contact. Reference sections established by Graafhuis (2001) are at Taraponui Trig (V19/331228-332231; Fig. 15A), Naumai Station (V19/408284; Fig. 14E), Boundary Stream Walkway (V19/440281-435271; Fig. 15D) and Rangiora Stud (V19/422270-423270).

Fig. 15 (facing page): Taraponui Member, Titiokura Formation. **A)** Panorama of Taraponui Trig from Waitara Road. This part of the Maungaharuru Range marks where the Titiokura Formation begins to diverge into its five constituent members. Photograph by Arne Pallentin. **B)** Relationship between the Te Rangi, Taraponui and Bellbird Bush Members on the western face of the Maungaharuru Range, south of Naumai Station. Photo location: V19/370265. **C)** Burrowed fine sandy packstone of the Taraponui Member, Boundary Stream Reserve (V19/446270). Photo by Arne Pallentin. **D)** Burrowed sandstone bluffs (over 40 m high) of the Taraponui Member at the northeastern end of the Boundary Stream walkway (V19445269). **E)** Close-up of a burrowed laminated siltstone lens in a mixed bioclastic-siliciclastic sandstone bed in the Taraponui Member at the northeastern end of the Boundary Stream walkway (V19/445269). **F)** Taraponui Member overlying the Te Rangi and Naumai Members on Te Rangi Station (V19/433288). Photograph by Rhys Graafhuis.


A
T
tke
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Opouahi Member
Bellbird Bush Member
Taraponui Member
Te Rangi Member
Naumai Member
Mokonui Sandstone
B
Bellbird Bush Member
Taraponui Member
Te Rangi Member
C
D
E
F
Taraponui Member
Naumai Member
Te Rangi Member

Lower and upper contacts

The lower boundary of the Taraponui Member is sharp and disconformable at localities between Taraponui Trig and Te Rangi Station (Fig. 14E). The upper boundary also has the form of a disconformity, showing relief of up to several decimetres, but tends to be poorly exposed (Bland *et al.* 2004).

Distribution and thickness

Taraponui Member is restricted in the study area to the eastern flanks of the Maungaharuru Range north of Ahuateatua Trig in a broadly northeast-southwest trending belt. The Taraponui Member overlies the Te Rangi Member and has a similar distribution pattern to it (Fig. 15B). The top of the member forms a prominent dipslope that runs out to bluffs above deeply incised streams (Graafhuis 2001; Bland *et al.* 2004).

The member is 10 m thick at Taraponui Trig, thickening to 75 m in the vicinity of Te Rangi Station and Rangiora Stud. The substantial increase in thickness reflects the increased amount of siliciclastic sandstone within the bulk of the member. South of Taraponui Trig the Taraponui Member amalgamates with other members of the Titiokura Formation, and by Ahuateatua peak cannot be easily differentiated.

Description

The Taraponui Member comprises two main lithologies - a lower limestone or shellbed facies and an overlying sandstone interval (Fig. 15C-E). The lowermost limestone portion of the Taraponui Member north of Taraponui Trig thickens southwards towards Taraponui Trig where it represents the bulk of the member (Fig. 15A). Sandstone facies overlying the basal limestone form the bulk of the member in the Naumai/Te Rangi Station and Rangiora Stud areas. At Taraponui Trig the base of the member comprises a 0.5 m-thick silty sandstone that is overlain by a 10 m-thick moderately cemented, cross-bedded glauconitic grainstone with mudstone rip-up clasts, rare pumice and greywacke pebbles. Bioclasts chiefly comprise barnacle and echinoderm plates with bryozoan and pectinid fragments.

At Naumai Station the same limestone is only 3 m thick, less calcareous, has a lesser shell content and is finer-grained than at Taraponui Trig. From Naumai Station toward Rangiora Stud the limestone grades into a sparsely fossiliferous cross-bedded amalgamated sandstone (Graafhuis 2001). This sandstone can be accessed from the Boundary Stream walkway (V19/440281-435271) (Fig. 15D, E).

On Naumai Station (V19/408284) the base of the member comprises a fossiliferous well cemented conglomerate containing sandstone and mudstone rip-up clasts and greywacke pebbles. Above is 1-2 m of cross-bedded sandstone, followed by a 0.5 m-thick shellbed with rip-up clasts and flame structures at its base. At V19/386262, also on Naumai Station, the basal unit is a cross-bedded sandy limestone (grainstone) with mudstone and pumice clasts at its base.

A very similar single shellbed at the base of the member crops out on Te Rangi Station at V19/430297, but lacks the pumice and greywacke clasts present on Naumai Station. Towards the northeast the lowermost beds appear to become amalgamated into a single shellbed, corresponding to a direction further out into the basin (Bland *et al.* 2004).

Sandstone facies in the Taraponui Member are 70-80 m thick, comprising most of the member away from Taraponui Trig. Lowermost parts of the sandstone interval are typically clean, fine-grained with low-angle megaripple cross-beds, passing up-section into massive and ripple-bedded bioturbated fine sandstone with mud drapes, reactivation surfaces and differentially cemented concretionary horizons. Further up-section the sandstone interval passes into amalgamated, well sorted, cross-bedded, fossiliferous fine sandstone (Graafhuis 2001).

Paleontology and age

No age diagnostic taxa have been observed in the Taraponui Member. An Upper Opoitian age is assigned on the basis of stratigraphic position.

Environment of deposition

On the basis of sedimentary structures and lithofacies a middle shelf to nearshore environment of deposition is envisaged for the Taraponui Member.

Bellbird Bush Member (tkd)

(Graafhuis 2001; formally defined by Bland *et al.* 2004)

Name and definition

Bellbird Bush Member (Fig. 11H) is named after Bellbird Bush, a DoC nature reserve near Boundary Stream Mainland Island in the Maungaharuru Range. Bellbird Bush Member was introduced by Graafhuis (2001) and formally defined by Bland *et al.* (2004). Bellbird Bush Member overlies the Taraponui Member and underlies the Opouahi Member (Fig. 15A).

Type locality

The type section was designated on Te Rangi Station by Bland *et al.* (2004) (V19/430297). At this locality the Bellbird Bush Member directly overlies the Taraponui Member, and the middle and lower parts of the Bellbird Bush Member, and its lower contact, are exposed (Graafhuis 2001).

A reference section is located at V19/440281-435271 on Boundary Stream Walkway where about 110 m of section is well exposed.

Lower and upper contacts

The lower contact of the Bellbird Bush Member tends to be poorly exposed, but is unconformable, displaying relief up to several decimetres (Bland *et al.* 2004). The upper boundary is disconformable at Taraponui Trig, but conformable in other sections located to the northeast (Bland *et al*. 2004).

Distribution and thickness

Bellbird Bush Member is extensively distributed along the eastern flanks of the Maungaharuru Range from Ahuateatua Trig north. At Taraponui Trig, Bellbird Bush Member is 25 m thick, 70 m thick in the Waikoau River, thickening dramatically towards the northeast to 240 m thick in the Waikare River catchment (Rangiora Stud) (Graafhuis 2001; Bland *et al.* 2004). The dramatic increase in thickness into the paleobasin is associated with the accumulation of sandstone facies (Bland *et al.* 2004) and a high rate of basin subsidence.

Description

Bellbird Bush Member is characterised by very thick accumulations of sandstone facies. At the type section, basal beds of the Bellbird Bush Member comprise a conglomerate containing subangular pebbles and numerous gastropods. This unit rests on a surface cut across the underlying Taraponui Member with 0.6 m of local relief. The basal conglomerate is overlain by clean, fine sandstone with low-angle cross-beds. The lower 20 m of this sandstone displays numerous zones of intricately convoluted and deformed beds, perhaps indicative of synsedimentary dewatering. Above this is 20 m of fine sandstone with megaripples and mud drapes (about 2 cm thick) that are internally cross-laminated. Both the mud drapes and sandstone beds are heavily burrowed. This section passes into a 50 m-thick succession of cross-stratified fine sandstone with differentially cemented calcareous sandstone horizons.

The reference section located above the Boundary Stream Walkway is characteristic of other sections on Rangiora Stud. It appears to show a conformable base without basal conglomerate or shellbed facies, and comprises sandstone facies throughout. The lower 25 m of the sandstone is planar-laminated to cross-bedded and heavily burrowed. Above is 40 m of cross-stratified sandstone with mud drapes and concretionary horizons. The uppermost 45 m comprises massive to planar-laminated sandstone with rare mudstone stringers and concretionary horizons. In general, the upper third of the member has common cemented horizons reflecting cleaner sandstone and higher carbonate content originating from finely comminuted shellhash.

At Taraponui Trig the Bellbird Bush Member comprises 23 m of thin-bedded fossiliferous sandy siltstone. At this locality the member may incorporate part of the underlying limestone, included above in the Taraponui Member as the position of the lower boundary here is uncertain. At Ahuateatua Trig the Taraponui Member can no longer be differentiated from other parts of the Titiokura Formation.

Paleontology and age

Macrofauna are uncommon in the Bellbird Bush Member (Graafhuis 2001) and are mainly gastropods. No age diagnostic macrofauna have been collected from the member, which is probably of uppermost Opoitian-Lower Waipipian age on the basis of stratigraphic position.

Environment of deposition

Bellbird Bush Member is inferred to have accumulated at middle shelf to nearshore water depths on the basis of sedimentary structures and lithofacies.

Opouahi Member (tke)

(Graafhuis 2001; formally defined by Bland *et al.* 2004)

Name and definition

Opouahi Member (Fig. 11H) is named after Lake Opouahi (V19/415215) near Pohokura Road on the eastern flank of the Maungaharuru Range. The member was introduced by Graafhuis (2001) and formally defined by Bland *et al.* (2004). Opouahi Member is the stratigraphically highest member of the Titiokura Formation (Fig. 11, 15A). It overlies the Bellbird Bush Member and underlies the Pohue Formation.

Type locality

The type section is designated on Quarry Road from V19/403227 to 402225 (Bland *et al.* 2004). The base of the member is well exposed in this section, overlying the upper 14 m of the Bellbird

Bush Member. A reference section is designated at V19/439235 to 449235 north of Matahorua Road where the member forms the topographically highest beds of a steep-sided ridge named "Sharkies" by local residents.

Lower and upper contacts

Opouahi Member disconformably overlies the Taraponui Member at Taraponui Trig, but conformably overlies Taraponui Member in sections to the northeast (Bland *et al*. 2004). The upper contact, while not observed, is likely to be conformable and gradational over a short distance into non fossiliferous siltstone facies of the Pohue Formation.

Distribution and thickness

Opouahi Member crops out on the eastern flank of the Maungaharuru Range to the south and east of the Bellbird Bush Member where it forms the uppermost member of the Titiokura Formation.

At the type section the member is 45 m thick although the top is eroded. The reference section displays a 75 m thick profile through the member, although the top is also eroded here.

Description

Opouahi Member is characterised by varied lithologies, including silty sandstone, sandstone, and limestone (Fig. 16A, B). At the type section the Opouahi Member comprises two 0.5 m-thick beds of cross-bedded bioclastic grainstone which are separated by ripple- to planar-bedded siltstone. The limestone beds contain about 5% greywacke granules, and sandstone and mudstone rip-up clasts (Graafhuis 2001). Above is 1 m of cross-bedded fossiliferous sandstone that passes up-section into 43 m of weathered calcareous sandstone with abundant concretionary horizons. This sandstone is in turn sharply, and probably disconformably, overlain by 12 m of cross-bedded fossiliferous limestone containing greywacke granules.

The thick limestone bed cropping out beside Pohokura Road above Lake Opouahi (Fig. 16) is assigned to the Opouahi Member (Graafhuis 2001). This limestone displays prominent master weathering surfaces (Fig. 16B), a feature common to most exposures of Opouahi Member limestone facies. It is inferred that these surfaces may be sequence stratigraphic surfaces defining "sequences" in the member, similar to those described by Caron (2002). However, the limestone is typically case-hardened which makes the determination of fine-scale composition, sedimentary structures and lithofacies difficult.

At the reference section two coarsening-upward packages are evident that are inferred to represent two cyclothems. In these packages approximately 20 m of massive, bioturbated silty sandstone passes gradationally up into bipolar cross-bedded fossiliferous concretionary sandstone containing greywacke granules. Two potential sedimentary sequences are also represented in the Opouahi Member at Taraponui Trig. The lower sequence comprises a 1-2 m-thick basal cross-bedded shelly limestone lens with a disconformable base that grades rapidly into a thin-bedded fossiliferous sandy siltstone. The upper sequence comprises a 9 m-thick cross-bedded fossiliferous limestone with greywacke granules. Like the lower sequence, it also has an unconformable base.

Fig. 16: Opouahi Member, Titiokura Formation. **A)** Alternating grainstone and packstone beds of the Opouahi Member cropping out beside Pohokura Road, Maungaharuru Range near Lake Opouahi. The base of the member is arrowed, person (circled) for scale. Photo location: Pohokura Road, V19/408218. **B)** Alternating packstone-grainstone beds passing up-section into more siliciclastic-rich beds in the Opouahi Member cropping out beside Pohokura Road, Maungaharuru Range. The locations of master weathering surfaces are arrowed. Photo location: V19/403222.

Cross-bedded calcareous sandstone facies capping the member in the Rangiora Stud region were viewed by Graafhuis (2001) as lateral equivalents of limestone beds cropping out above Lake Opouahi.

Paleontology and age

Dating the Opouahi Member has been somewhat problematic in the past, due to the case-hardened nature of the limestone in the member, and by the lack of obvious macrofossils. Limestone of the Opouahi Member cropping out above Lake Opouahi was assigned a Waipipian age by Beu *et al.* (1980) when included in their informal Titiokura limestone. This was based mostly on the presence of *Mesopeplum (Borehamia) crawfordi* which at that time was viewed as a pectinid restricted soley to the Waipipian stage. More recent work by Beu (1995) has identified definite occurrences of *M. crawfordi* in rocks of Opoitian age, therefore meaning a solely Waipipian age cannot be confirmed. Three fossil collections are reported in the fossil record file from beds of the Opouahi Member from Pohokura Road near Lake Opouahi. Sample V19/f8616 was assigned a Waitotoran age (therefore by implication either of Waipipian or Mangapanian age) on the basis of microfossils. Sample V19/f8529 was assigned an Opoitian-Waipipian age based on the presence of *M. crawfordi.* A comment in this record suggests that a Waipipian age is more probable, which is also the opinion of Beu (1995, p. 88) and Graafhuis (2001). Sample V19/f8615 reports a Waipipian age on the basis of microfossils.

On the basis of stratigraphic position and faunal content, the Opouahi Member is assigned a Lower Waipipian age.

Environment of deposition

A middle shelf to nearshore environment of deposition is inferred for the Opouahi Member on the basis of sedimentary structures, lithofacies and macrofauna. This is consistent with other members of the Titiokura Formation.

TE WAKA FORMATION (tw)

(McKay 1886; formally defined by Beu 1995)

Name and definition

Limestone prominently capping the northern end of the Te Waka Range above Te Pohue was initially named either the Te Whaka limestone beds (informal) or Pohui limestone by Hector (1877) and McKay (1886), the application of the names being unclear (Beu 1995). Beu *et al.* (1980) adopted Te Waka limestone as an informal limestone "sheet" name and applied it to limestone beds of Mangapanian age cropping out near the North Island axial ranges and faults on the western margin of the forearc basin in Hawke's Bay. Beu (1995) formally defined the Te Waka Limestone as the upper (Mangapanian) of two main limestone units on the Te Waka Range, those beds cropping out along the eastern slopes of the ranges around the Blowhard, Mount Kohinga and The Lizard near Kuripapango. Bland (2001) emended the name Te Waka Limestone to Te Waka Formation on the basis of the occurrence of prominent siliciclastic sandstone intervals in many parts of the formation. Bland (2001) also identified Waipipian-aged faunas in the lower and middle parts of the Te Waka Formation on the Te Waka Range. This meant a definition based entirely on age (i.e. Mangapanian only) was no longer sustainable. Caron (2002) also recognised Waipipian macrofauna in parts of the formation. Te Waka Formation is defined as a succession of interbedded sandstone and limestone beds cropping out along and near the eastern slopes of the Kaweka Range, the Maniaroa Range and Te Waka Range, of uppermost Waipipian to Mangapanian age. Te Waka Formation contains one separately named member, a non to highly fossiliferous greywacke conglomerate bed restricted in outcrop to the Puketitiri-Patoka region named the Hassal Conglomerate Member.

Type and reference sections

Beu (1995) defined the section exposed below Te Waka Trig at the northern end of the Te Waka Range as the type section for this unit (Column Tp-3). This section represents the northernmost outcrop of Te Waka Formation and is retained in this report. A reference section is nominated along Kurowski Road, a track through Te Waka Forest at the southern end of the Te Waka Range (Column Tw-4). The Gorges section below Puketitiri Road provides a detailed section through cyclothemic mixed bioclastic-greywacke pebble beds of the Te Waka Formation (Column Pt-8). Cuttings on Lizard Road provide a very well exposed section through the cyclothemic part of the Te Waka Formation (Column Gr-1). The section below the wind meter on Sandy Ridge provides detailed insight into the nature of the unconformable contact between the Te Waka Formation and the underlying basement (Column Gr-2). A section in Opau Stream shows the nature in which the Te Waka Formation may overstep older stratigraphic units (Column Pt-2). In this section the Te Waka Formation helps define a spectacular angular unconformity between itself and either the Te Ipuohape Sandstone Member (Waitere Formation) or Torlesse basement over only a few hundred metres.

Lower and upper contacts

The nature of the lower contact of the Te Waka Formation is different east and west of the Mohaka Fault. The Te Waka Formation overlies many stratigraphic units and because of this its lower contact has important implications for unravelling the history of deformation of the North Island Shear Belt. West of the Mohaka Fault the Te Waka Formation may unconformably overlie basement, the Blowhard Formation (Waikarokaro Sandstone Member), Mangatoro Mudstone, or Puketitiri Formation. The Te Waka Formation underlies and interdigitates with the Puketitiri Formation. The formation rests unconformably on basement along Sandy Ridge and the northern end of the Glenross Range in the Kuripapango area. A possible contact with basement is also present on Hawkston Station immediately west of the Mohaka Fault. The Te Waka Formation is inferred to overlie basement at The Lizard and on the northern end of the Glenross Range south of the Napier-Taihape Road. On Hukanui Hill above Puketitiri village Te Waka Formation sharply and unconformably overlies silty fine sandstone of the Puketitiri Formation. The basal 1 m of Te Waka Formation at this locality comprises a poorly sorted coarse-grained greywacke conglomerate to breccia bed with common *Crassostrea ingens*, particularly near the base of the unit. Te Waka Formation also unconformably overlies the Puketitiri Formation in sections near Puketitiri Road. Te Waka Formation conformably overlies Puketitiri Formation on Rocky Hill Station.

East of the Mohaka Fault the Te Waka Formation may unconformably overlie basement, Te Ipuohape Sandstone Member (Waitere Formation), Mokonui Sandstone, or Titiokura Formation (Fig. 17B). The lower contact of the Te Waka Formation is well exposed in Opau Stream near Patoka (Fig. 17D; Kingma 1958; Katz 1973). Over a distance of c. 200 m the formation progressively overlies steeply dipping (45ºENE) Tongaporutuan sandstone (Te Ipuohape Sandstone Member, Waitere Formation) and basement. Where the Titiokura Formation is present it conformably underlies the Te Waka Formation through a series of concretionary mixed siliciclastic-bioclastic sandstone beds (assigned to the Titiokura Formation) (Fig. 20B). One exception to this is at Oakmere Station at Te Pohue where a thick channelised limestone bed (Caron 2002) rests on siltstone above the Titiokura Formation with a slight (c. 2-4º) angular discordance (Brash 1982; Bland 2001).

Te Waka Formation is conformably overlain in areas north of the Omahaki Depression by the Pohue Formation. South of the Omahaki Depression Te Waka Formation interdigitates with the Puketitiri Formation. Along strike to the north of Te Waka Trig the Te Waka Formation passes laterally into siliciclastic beds of the Pohue Formation. The upper contact of the Te Waka Formation is observable in few places. Concretionary sandstone of the Pohue Formation conformably overlies Te Waka Formation in cuttings on Puketitiri Road above "The Gorges" section and just west of Patoka. A similar conformable contact is evident above Te Pohue village in cuttings on some forest roads.

Distribution and thickness

Te Waka Formation is widespread along nearly 50 km of the western margin of the mapping area from the northern end of the Te Waka Range to Whanawhana at the southern end of the Glenross Range. The Formation forms prominent ridges along the Te Waka and Maniaroa Ranges, particularly between Hawkston and Puketitiri Roads. Te Waka Formation is not present north of Te Waka Trig, and it is likely that lower parts of the Pohue Formation in the eastern side of the Maungaharuru Range area are lateral equivalents. Field *et al.* (1997) suggested that Te Waka Formation is confined to the downthrown block between the Ruahine and Kaweka Ranges. The eastern extent of the Te Waka Formation is marked by the Patoka Fault at Patoka, and the Rukumoana Fault at Te Pohue. The only occurrence west of the Ruahine Fault is at Mount Kohinga. The presence of the unit there is suggestive that it once extended across the present location of the Kaweka Range. Browne (2004a) included upper thin-bedded limestone and sandstone beds on The Lizard and Mount Kohinga at Kuripapango in the Kaumatua Formation. Examination of the Kaumatua Formation (now included in Puketitiri Formation) in the Ohara Depression shows it to be a sandy, relatively fine-grained formation quite distinct from “typical” Te Waka Formation. The upper beds on Mount Kohinga and The Lizard are very similar in lithology and of the same age to known Te Waka Formation beds exposed in adjacent and northern localities, and are therefore included here in the Te Waka Formation. Geological mapping has also demonstrated continuity between these areas. Beu (1995) also included these beds in the Te Waka Formation rather than the Kaumatua Formation.

Well cemented strongly fluted limestone near the intersection of Lawrence and Taihape Roads, and Blowhard Bush, Kaweka Forest are included in Te Waka Formation. Prominent limestone beds interbedded with differentially cemented sandstone forming the eastern dipslope of the Glenross Range is also included within the Te Waka Formation.

Te Waka Formation has not been identified south of the Ngaruroro River, although on the basis of age and some lithological similarities it is probable that Puketitiri Formation sediments exposed in the Ohara Depression are lateral, southern equivalents of the Te Waka Formation. However, it is desirable at present to keep these two units as separate formations due to lithological variations.

The Te Waka Formation thickens slightly southwards away from the type section toward Kuripapango, reflecting an increase in contemporary rates of subsidence and siliciclastic sediment flux. South of Kuripapango the formation thins into the Awapai Station area. At the type section the Te Waka Formation is approximately 100 m thick. At Kuripapango, Te Waka Formation is a maximum of 120 m thick.

Description

Lithologically the Te Waka Formation is a highly variable unit. Sandstone is usually the dominant lithology, but limestone is the distinctive lithology in the formation. Sandy to pebbly limestone facies are common and locally dominate outcrops. Conglomerate facies are minor and are usually restricted to lower parts of the formation, especially in close vicinity to greywacke basement. Te Waka Formation is characterised by varying amounts of soft to well cemented barnacle, bivalve and bryozoan sandy limestone beds separated by more siliciclastic-dominated beds. The lithology of Te Waka Formation in “The Gorges” at Patoka has been well documented by Caron (2002).

For much of its outcrop area, Te Waka Formation consists of a thick lower limestone unit overlain by packages of alternating limestone-siliciclastic sandstone beds each several metres thick. Siliciclastic lithologies become more common away from the type section, particularly towards the Kuripapango area. In northern outcrops (e.g. the type section on the Te Waka Range, Column Tp-3) Te Waka Formation consists of large lenses and pods of limestone in a siliciclastic sandstone unit. Towards the south the formation displays a more cyclothemic character, particularly in upper parts. This cyclothemic expression is perhaps best displayed in the Patoka and Kuripapango areas (The Gorges, The Lizard and Glenross Range sections). Cyclothems are also evident in the Glenross Range from Taihape Road through the Omahaki and Awapai Station areas (Fig. 18A-C).

At the type section (Fig. 17 A, C) the Te Waka Formation comprises a lower 80 m-thick silty fine sandstone that becomes coarser-grained and increasingly calcareous up-section. Two main limestone beds are present below Te Waka Trig, with the telecommunications tower constructed upon the uppermost of these beds. The upper limestone bed is 8 m thick, displays a coarsening-upward trend and comprises alternating bioclastic/siliciclastic-rich beds. The lower limestone is up to 2 m thick and is compositionally very similar to the upper limestone bed. Both limestone beds thin and become more siliciclastic towards the north and west. The 50 m-high bluff section exposed above Te Pohue on Oakmere Station is inferred to represent a broadly channelised unit that grades into the lower sandstone-dominated interval cropping out at Te Waka Trig (Fig. 18K-L). Bland (2001) included the channelised beds above Te Pohue in the Oakmere Member, although this unit cannot be traced away from the immediate Te Pohue region. The section sharply overlies fine-grained siltstone of the upper Titiokura Formation. A coarse-grained conglomerate bed that contains concretionary clasts from the underlying siltstone represents the basal beds of the Te Waka Formation there. Clasts in the conglomerate are of coarse pebble to boulder size and dominantly of sandstone and mudstone. The formation there consists of two main limestone packages separated by a siliciclastic sandstone interval. The lower part of the section comprises approximately 30 m of yellowish-brown, moderately to well cemented grainstone rich in barnacle plates and fragments with oysters, gastropod and bivalve grains.

In the section above Te Pohue Village (Fig. 18L; Column Tp-1) the lower half of the Te Waka Formation comprises alternating bioclastic/siliciclastic beds 0.2-0.25 cm thick. The brachiopod *Neothyris* aff. *obtusa* is common in this interval. Low-angle trough cross-stratification is evident throughout the section. Bioclastic beds tend to be coarser-grained (coarse sand texture) than their siliciclastic counterparts (fine sand). This interval coarsens up-section where, with macrofossils more common in the upper parts of the section. Case hardening over much of this section obscures large portions of the unit, although enough “windows” are visible to be able to document the interval. The lower limestone interval is overlain by a thin (1 m thick) moderately fossiliferous strongly bioturbated siltstone with thin layer of coarse sand-sized shellhash. This siltstone is in turn overlain by approximately 2 m of moderately fossiliferous alternating bodies of fine to medium sandstone containing significant amounts of shellhash.

Above this is approximately 10 m of olive-brown, non to moderately cemented, moderately fossiliferous strongly bioturbated sandstone with moderately fossiliferous concretionary lenses and horizons. Planar to low-angle cross-stratification is evident. Thin mudstone stringers (up to 8 cm thick) and drapes are present, with well-developed ripple and planar laminations evident (Bland 2001). This concretionary interval passes gradationally and conformably into the Pohue Formation.

Very pebbly limestone crops out prominently in the Hawkston-Seaview Station area and represents the lower bed of the formation (Fig. 17E, 18F). Large areas of slumped deposits are prominent in this area with failure occurring along the contact between Te Waka Formation limestone and the underlying Puketitiri Formation. In Te Kowhai Forest above Gorge Stream a large circular-shaped failure is currently growing with subsidence in the order of centimetres/ month. At V20/128995 the limestone comprises a very pebbly highly fossiliferous shellhash limestone. *Patro undatus* is abundant together with barnacles, common *Crassostrea ingens* and *Phialopecten thomsoni*. Barnacles are commonly attached to bivalves and more rarely pebbles. The limestone comprises a lower 3 m-thick zone of stacked shellhash beds each 2-5 cm thick. These beds are arranged in planar form, or as broad, low-angle trough cross-stratification. Upper parts of the unit (up to 10 m thick) are more massive and weakly laminated, though pebbles and whole shells are abundant throughout. Nearby at V20/130003 the same pebbly limestone bed is sharply overlain by concretionary fine to medium sandstone. The basal 0.5 m of this sandstone has a noticeable bioclastic content that rapidly diminishes up-section. Concretions are scattered through the sandstone and are up to 0.2 m wide and 0.4 m long.

The same pebbly limestone interval crops out on nearby Seaview Station (V20/141003 and V20/ 143007; Fig. 18F). Prominent bluffs crop out nearby east across the Mohaka Fault (e.g. V20/ 145999). Beu (1995) inferred that beds immediately east and west of the fault were the same horizon. The prominent lithological differences between these beds clearly demonstrate that they are unlikely to be the same horizon, and that calculating displacement on the Mohaka Fault is more difficult than appears at first.

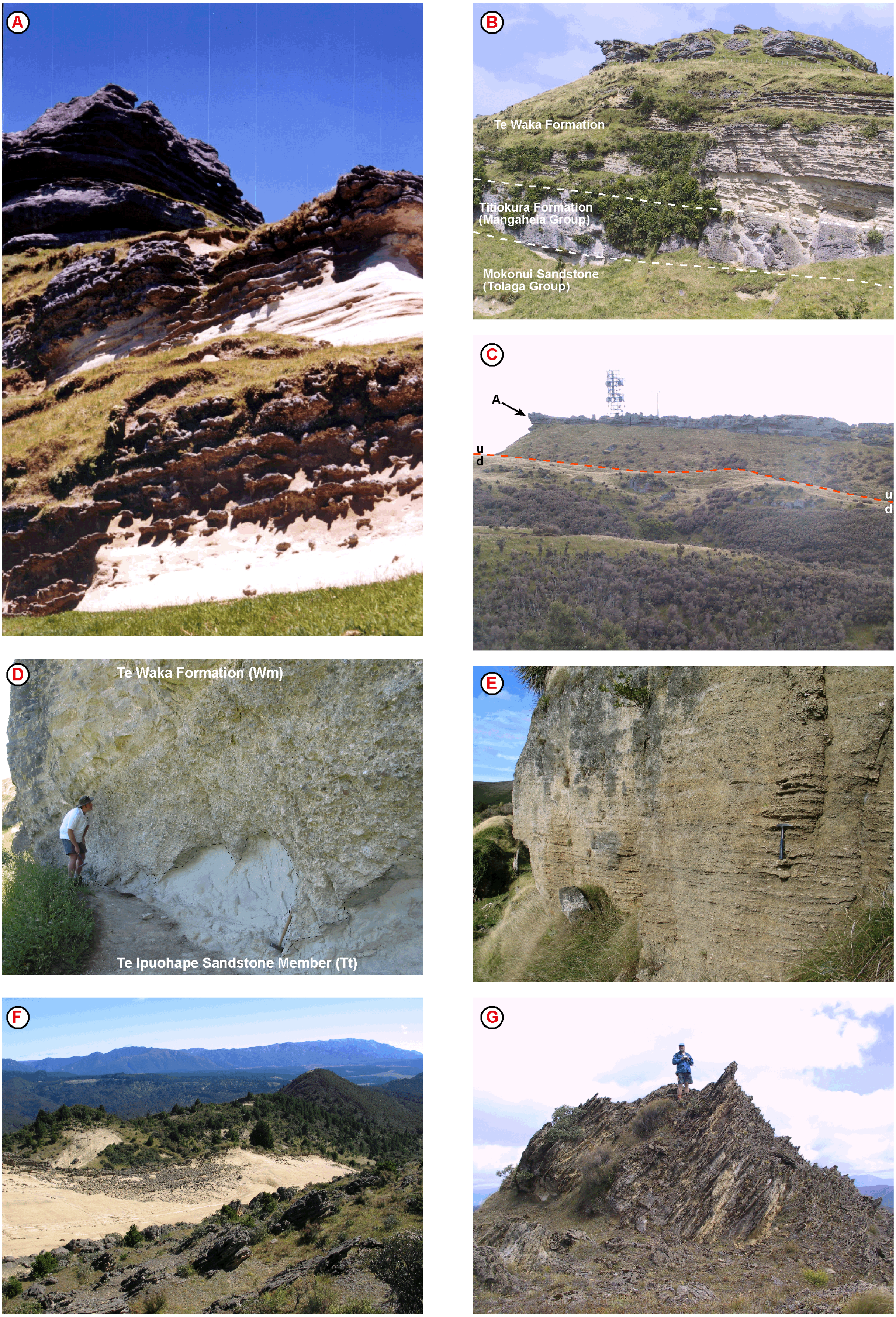
Caron (2002) studied a section of Te Waka Formation in the headwaters of Wai-iti Stream near Patoka which he referred to as “The Gorges” section, after the farm on which the section is located

(Fig. 18I; Column Pt-8). This section provides an important window into the cyclothemic expression of the Te Waka Formation through the Patoka region. The lowermost limestone exposed here is lithologically similar to Titiokura Formation present on the Te Waka Range. Caron (2002) tentatively included this bed in the Titiokura Formation, a view supported in this report. All strata above this lower bed to the modern land surface are assigned to the Te Waka Formation. The formation here comprises alternating coarsening-upward packages of sandstone and limestone.

Cycles at The Gorges differ from those at Kuripapango and the Glenross Range in that there is a more distinct differentiation between sandstone and limestone intervals than to the south. Pebbly and conglomeratic limestones are also more typical in The Gorges than in sequences further south. This probably reflects the presence of a greywacke outlier in Opau Stream (V20/208048).

In Opau Stream near Patoka (Fig. 18H; Column Pt-2) the Te Waka Formation successively overlies Tongaporutuan strata of the Te Ipuohape Member of the Waitere Formation and greywacke. The lowermost portion of the Te Waka Formation here is marked by a highly fossiliferous greywacke breccia 2.5 m thick (Fig. 17D). This unit contains abundant valves of *Crassostrea ingens* and Flabellum corals, with common *Phialopecten marwicki* and encrusting bryozoans. Angular, very poorly sorted clasts of greywacke are abundant, and are of granule to boulder size. Many of the more rounded clasts in the basal breccia are pholad bored. This bed passes up-section into about 10 m of barnacle-rich flaggy, well cemented sandy limestone with prominent alternating units of mixed bioclastic-siliciclastic sediments.

Fig. 17 (facing page): Te Waka Formation. **A)** Upper limestone beds of the Te Waka Formation at the type section. These beds mark the northernmost point of outcrop of the Te Waka Formation. The Te Waka Range microwave tower (Fig. 17C) rests on the limestone bed at the top of the photograph, approximately 50 m away. Photo location: Te Waka Trig, V20/257130. **B)** Alternating thin-bedded limestone and sandstone facies of the Te Waka Formation conformably overlying mixed skeletal-terrigenous limestone of the Titiokura Formation near Hell's Hole on the northern face of the Te Waka Range. Photo location: V20/235126. **C)** Uppermost limestone bed of the Te Waka Formation, Te Waka Trig. The microwave tower is visible on this unit. The location of the Te Waka Range Splinter Fault is indicated (dashed red line), and downthrows the upper limestone bed 30 m to the northwest. The location of Photo Fig. 17A is indicated. Photo taken at V20/252129 looking southeast. **D)** Strongly developed angular unconformity (highlighted) between Tongaporutuan (Late Miocene) Te Ipuohape Sandstone Member (Waitere Formation, Tolaga Group) and Mangapanian (Late Pliocene) Te Waka Formation (Mangaheia Group). A very coarse-grained breccia dominated by greywacke clasts and Flabellum corals forms the lowermost 2 m of Te Waka Formation at this site, and infills a spectacular paleorelief. Te Ipuohape Sandstone Member dips at approximately 45°ENE, Te Waka Formation dips at 18-13°NE-SE. Photo location Opau Stream, V20/207049. Photo by Cam Nelson. **E)** Stacked grainstone and packstone beds of Te Waka Formation on Hawkston Station beside Hawkston Lake. These beds contain abundant macrofossils including barnacles, *Patro undatus, Crassostrea ingens* and *Phialopecten thomsoni*. Photo location V20/128995. **F)** Steeply dipping (c. 58°) beds of the Te Waka Formation forming the summit of The Lizard, Kuripapango area. The Lizard is truncated by The Lizard Fault to the left of the photograph, and the Glenross Fault behind the photographer. Photo location: The Lizard looking northwest towards the Kaweka Range (U20/035912). **G)** Steeply-dipping alternating grainstone and packstone beds of the uppermost Te Waka Formation forming the summit of Mount Kohinga above Kuripapango. Photo location: Mount Kohinga looking south (U20/981937).


A
B
Te Waka Formation
Titiokura Formation
(Mangaheia Group)
Mokonui Sandstone
(Tolaga Group)
C
A
u
d
u
d
D
Te Waka Formation (Wm)
Te Ipuohape Sandstone Member (Tt)
E
F
G

Te Waka Formation overlies greywacke across an angular unconformity that displays decimetre-scale relief along the crest of Sandy Ridge (Fig. 18D; Column Gr-2). Greywacke clasts of granule to cobble size are common in the 1.5 m-thick basal beds of the Te Waka Formation in this area, and consist of a highly fossiliferous greywacke breccia to conglomerate with fauna dominated by the large robust oyster *Crassostrea ingens.* This coarse-grained lower bed passes conformably up-section into a moderately to well cemented flaggy shellhash limestone containing a variety of generally robust bivalve taxa including *Tucetona laticostata, Phialopecten thomsoni, Panopea* sp. and abundant barnacles.

At the northern end of Sandy Ridge Road an interval of siliciclastic sandstone crops out and overlies the bioclastic-dominated lower portion of the Te Waka Formation in this area. The Lizard section (Fig. 17F) displays steeply dipping Te Waka Formation in a spectacular outcrop south of Taihape Road (U20/035912, Column Ku-2). The steep dip (56-60° NW) of this section is a result of deformation associated with the Glenross and Lizard Faults, both of which are less than 100 m from the section. Immediately southeast of the Glenross Fault the same horizons dip 8-12° SE. This section clearly displays the cyclothemic character of middle and upper parts of the Te Waka Formation through the Mangatutu-Kuripapango-Glenross areas.

Beu (1995) regarded The Lizard section (Fig. 17F, 18C) as an overturned fault-bounded block. The order of stratigraphy observed at The Lizard is the same as present in the adjacent Glenross Range, and there is no reason to suggest that the succession has been overturned. The succession is merely dipping NW (albeit very steeply) instead of the more typical SE direction. The lowermost parts of The Lizard section are very poorly exposed in scrub and light forest below the ridge of The Lizard. Small glimpses of the lower beds are visible from the Glenross Range immediately southeast of The Lizard and appear to show a lower thick case-hardened limestone bed that probably overlies greywacke, as on nearby Sandy Ridge (U20/047927, Column Gr-2). The lower interval is inferred to be several tens of metres thick. Overlying this is the nearly 50-m thick series of beds that form The Lizard and provide continuous outcrop throughout. The base of the exposed section comprises a moderately cemented shellhash-rich sandy limestone containing common *Crassostrea ingens*, many of which are attached to each other in a reef-like fashion. *Crassostrea* become more common toward the base of this bed. The basal limestone package is conformably overlain by 11 m of non cemented fine sandstone with common moderately cemented concretionary horizons up to 0.3 m thick. This is in turn overlain by nearly 15 m of yellow-brown, non cemented, non to slightly fossiliferous fine sandstone with thick, discontinuous to continuous sandy limestone beds 0.6-2 m thick. These limestone beds have a mixed bioclastic-siliciclastic composition. They are in turn overlain by a 3 m-thick moderately cemented limestone bed consisting of alternating bioclastic and siliciclastic beds 0.3-0.6 m thick.

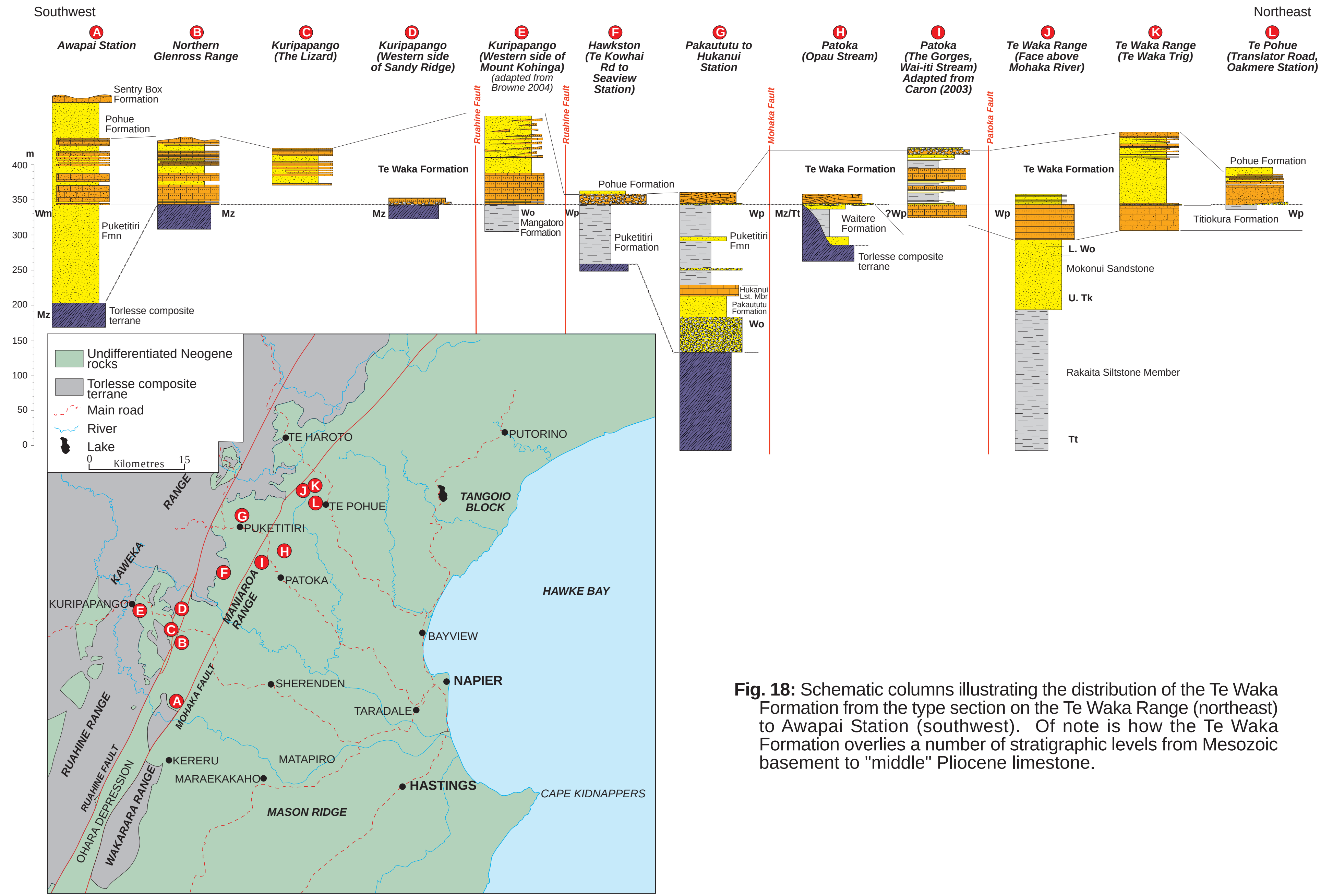


Fig. 18: Schematic columns illustrating the distribution of the Te Waka Formation from the type section on the Te Waka Range (northeast) to Awapai Station (southwest). Of note is how the Te Waka Formation overlies a number of stratigraphic levels from Mesozoic basement to "middle" Pliocene limestone.

The bioclastic component is rich in barnacle and bryozoan fragments. Rare *Phialopecten thomsoni* valves and fragments are present. A thin (0.6 m thick) sandstone interval overlies this limestone, followed by another thin (0.5 m thick) sandy shellhash-dominated limestone containing common bryozoan fragments. The following interval comprises the core of The Lizard and consists of yellow-brown, moderately to strongly bioturbated, non to slightly cemented muddy fine sandstone. Occasional concretionary bodies and horizons are present up to 30 cm thick, as are common thin mudstone stringers up to 10 cm thick. These mudstone stringers are commonly ripple- and flaser-bedded and are very continuous along section. Concretionary bodies are largely non fossiliferous, although many contain abundant biomoulds resembling *Tawera* sp. (dominant) and various mussel genera (e.g. *Perna, Modiolus*). This interval is approximately 12 m thick. Concretionary bodies increase in number and size up-section, before passing into the uppermost limestone package. This 3 m-thick interval consists of moderately cemented, medium to coarse sand-sized shellhash limestone interbedded with mixed bioclastic-siliciclastic packages. Individual packages are generally about 0.5 m thick.

Hard, well cemented and fluted limestone cropping out near Blowhard Bush and Lawrence Road are included in the Te Waka Formation. At U20/036937 this interval comprises a moderately to well cemented massive, case-hardened limestone with scattered oyster valves and bivalve fragments. At U20/03892 the fluted outcrops comprise moderately well cemented creamy-brown coarse-grained bioclastic sandy limestone dominated by moderately well sorted shell fragments. Beu (1995) reported common *Phialopecten thomsoni* in fluted beds near the intersection of Lawrence and Taihape Roads.

On Mount Kohinga above Kuripapango (Fig. 18E) the formation comprises an approximately 30 m-thick massive lower member separated by several metres of fine sandstone from numerous interbedded thin bioclastic grainstone and laminated sandstone beds (Fig. 17G). The upper thin-bedded interval is at least 50 m thick and was regarded by Browne (2003) as Kaumatua Formation, although Beu (1995) included these beds in the Te Waka Formation. The succession exposed on Mount Kohinga very closely resembles that present on The Lizard and Glenross Range, both known to be Te Waka Formation outcrops. This report confirms Beu's interpretation and regards all sandstone and limestone beds capping Mount Kohinga above the Mangatoro Formation as Te Waka Formation. The summit of Mount Kohinga involves a syncline, with many cross-cutting faults displacing the stratigraphic units present.

In the vicinity of greywacke outcrops Te Waka Formation contains abundant basement-derived clasts. Limestone beds in the Kuripapango region are particularly rich in basement clasts, although very pebbly limestone beds are present around Patoka and Puketitiri, among other areas.

The Glenross Range in the Omahaki-Awapai Station area (Fig. 18A, B) marks the southernmost extent of the Te Waka Formation (Column Gr-3). The cyclothemic character of the formation is well displayed there, particularly on Kohurau Station south of Omahaki Road, and up to three distinct sandstone-dominated cyclothemic packages can be identified.

Paleontology and age

Te Waka Formation contains a relatively diverse range of faunas that have been sampled throughout the outcrop belt. Barnacles, both as fragments and plates, dominate the faunal content of the formation. Bivalves are commonly present intact, although are mostly disarticulated. *Ostrea chilensis* is common in sections, as are specimens of the brachiopod *Neothyris* aff. *discors.* Large specimens of *Maoricardium spatiosum* have been collected from outcrops at Te Waka Trig and near Puketitiri Road north of the Maniaroa Range. *Crassostrea ingens* is common throughout the formation, particularly in the vicinity of basement rocks. This is presumably because the basement rocks provided substrate upon which these oysters could attach. In many localities around the Hawkston area the false oyster *Patro undatus* is locally abundant.

The age of Te Waka Formation appears to be mildly diachronous through the outcrop area. A small number of pectinids resembling *Phialopecten marwicki* in terms of their size and rib count have been collected from the base and middle of Te Waka Formation at the type section on the Te Waka Range, suggesting a Waipipian age for at least part of the formation in this area (Bland 2001). A scaphopod collected immediately below Te Waka Trig was tentatively identified as *Antalis pareorensis* (A. McIntyre pers. comm. 2000) and also suggests a Waipipian age for these beds (age range Tk-Wp, Beu and Maxwell 1990). Specimens of pectinids that exhibit characteristics of both *P. marwicki* and *P. thomsoni* have been collected immediately below Te Waka Trig, possibly representing the Waipipian-Mangapanian boundary (Bland 2001). The presence of *Maoricardium spatiosum* confirms an age no younger than Mangapanian for rocks at the northern end of the Te Waka Range, supported by the presence of uncommon *Phialopecten thomsoni*. *Phialopecten thomsoni* has been collected from numerous outcrops to the south of the Te Waka Range and in the upper beds at Te Waka Trig itself (Beu 1995). At its southernmost outcrop, Te Waka Formation is conformably overlain by lowermost Nukumaruan Sentry Box Formation (Beu, 1995) that contains both *P. triphooki* and *Zygochlamys patagonica delicatula.* This suggests that the Te Waka Formation in this area is of Upper Mangapanian age. *P.*

thomsoni has also been collected from several localities in the Patoka, Hawkston and Kuripapango areas, demonstrating that the formation in these areas is of Mangapanian age.

Environment of deposition

Deposition of the Te Waka Formation represents one end-member of a depositional system outlined by Caron *et al.* (2004a). The formation accumulated along the continent-attached margin of a paleo-seaway (the Ruataniwha Strait of Beu 1995) that developed during the Pliocene throughout Wairarapa and central Hawke's Bay. The mixed bioclastic-siliciclastic composition of the formation is entirely consistent with a continent-attached depositional setting, and contrasts with inferred continental-detached bioclastic-dominated limestones, such as the coeval Te Onepu Limestone, cropping out along the eastern margins of the forearc basin.

The continental shelf on which the Te Waka Formation accumulated is inferred to have been narrow, and bounded on it's landward side by elevated areas of Torlesse basement and areas of uplifted Neogene sediments. It is inferred that the coastline was irregular with areas of rocky coastline and sandy/gravelly beaches.

Macrofauna and sedimentary structures throughout the formation are consistent with nearshore to middle shelf environments of deposition. Te Waka Formation cropping out at Kuripapango and in the Hawkston Station areas are inferred to have accumulated in a more shoreward position than Te Waka Formation at Te Pohue. The onlap of Te Waka Formation onto Torlesse basement at Sandy Ridge, Kuripapango, demonstrates that some parts of the seaway had a rocky coastline during the Mangapanian. The formation contains a significant amount of siliciclastic material in places and illustrates that the continental shelf on which Te Waka Formation was accumulating was periodically supplied with terrigenous sediments.

Hassal Conglomerate Member (twh)

(Caron 2002)

Name and definition

Caron (2002) identified a greywacke conglomerate bed at the top of The Gorges section (Column Pt-8) at the headwaters of Wai-iti stream near Patoka that had not been observed in outcrops to the north by Bland (2001) or Pallentin (in prep.), and informally referred to the unit as the Hassal conglomerate. The name is derived from Mount Hassal Station, immediately west of The Gorges section. For consistency the unit is renamed here Hassal Conglomerate Member

Type locality and reference sections

The type section is designated as the southern face of Romulus hill on Mount Hassal Station, Patoka (V20/168027, Column Hw-2). Reference sections are nominated along Little Bush Road (V20/157059, V20/155056).

Lower and upper contacts

Both lower and upper contacts are poorly exposed in the study area, though are visible at the type section. The member unconformably overlies undifferentiated sandstone of the Te Waka Formation across an erosional surface, exposed on Romulus hill. The upper contact is also sharp and inferred to be unconformable, with non fossiliferous gravels of possible Castlecliffian age overlying the Hassal Conglomerate Member. This contact is also exposed on Romulus hill.

Distribution and thickness

Caron (2002) described one section through the Te Waka Formation in detail (The Gorges section), and identified the Hassal Conglomerate Member as occurring at the top of Mount Romulus on Mount Hassal Station. The upper units on The Gorges section of Caron (2002) represent the type section of the Hassal Conglomerate Member. Non fossiliferous greywacke conglomerate commonly crops out along Little Bush Road, and in gravel pits near the airstrip above Te Wairere. These sections are west of the type section and are inferred to represent a more shoreward expression of the member. The maximum observed thickness of this unit is about 7 m.

Description

On Mount Hassal, Caron (2002) described a conspicuous ravinement surface that placed a 5 m thick fossiliferous conglomerate (lower part of the Hassal Conglomerate Member) in direct contact with a 20-25 m thick siltstone to sandstone interval. This conglomerate bed contains mudstone and greywacke pebbles (up to 0.2 m across), interbedded with valves of oysters and various unidentified bivalves. The upper contact of this fossiliferous conglomerate is sharp and marked by a shell concentration that includes scattered large oyster valves. Overlying this zone is a package of fluvial gravel beds consisting of non fossiliferous, planar laminated pebbly sandstones with thin muddy horizons that contain lignite debris.

Further to the north in the vicinity of Little Bush Road near Puketitiri, the Hassal Conglomerate Member comprises well sorted, well rounded, laminated greywacke granule to cobble-sized clasts with no shelly sediments present that overlie clean, non cemented, slightly micaceous, well sorted medium sandstone. The greywacke clasts in the unit are dominated by spheroid-shaped grains, and are set in a matrix of non cemented silty fine sandstone. A finer-grained matrix tends to be present in coarser-grained portions of the conglomerate. A fining-upward pattern is visible in many of the outcrops in the Little Bush area, and imbrication in grains towards the southeast is also evident. It appears that the Hassal Conglomerate Member is overlain by a slightly micaceous, non cemented fine sandstone that contains thin (<0.1 m thick) greywacke conglomerate pebble stringers.

The lack of fossiliferous deposits in the Hassal Conglomerate Member towards the north suggests that the shelly deposits observed by Caron become more terrestrial to the west, and that in a basinward direction (towards the east) the Hassal Conglomerate Member becomes fossiliferous and grades into a limestone.

Non-marine greywacke gravels unconformably overlying the Hassal Conglomerate Member on Romulus are likely to be Castlecliffian deposits and are not included in the Hassal Conglomerate Member.

Paleontology and age

The Hassal Conglomerate Member is unsatisfactorily dated. On Mount Hassal the unit contains abundant specimens of the shallow-water gastropod *Zethalia* sp. However, these shells are highly abraded and the characteristic shell nodules, used to differentiate *Zethalia* species, are largely missing. Based on test size and broad shape these *Zethalia* most closely resemble the Nukumaruan to Recent species *Zethalia zelandica*, although this identification is very tenuous. It is inferred, based on stratigraphic position, that the Hassal Conglomerate Member is more probably of Mangapanian age.

Environment of deposition

Hassal Conglomerate Member cropping out around Little Bush Road was deposited in a non-marine fluvial and marginal-marine shoreface setting. Fauna in Hassal Conglomerate Member cropping out on Mount Hassal Station indicate a shoreface to nearshore environment of deposition, probably as part of a gravel beach setting. *Zethalia zelandica,* common in the Hassal Conglomerate Member at the type section, currently inhabits very shallow-water (3-5 m) environments off slightly protected sandy beaches (Beu and Maxwell 1990).

POHUE FORMATION (po)

(Smith 1877 (informal))

Name and definition

Pohue papa was introduced by Smith (1877) as a name for a series of interbedded sandstone-siltstone beds cropping out in the Te Pohue area of western Hawke's Bay. The name is derived from Te Pohue village, located approximately 40 km northeast of Napier along State Highway 5. Brash (1982) emended Smith's name and defined Pohue Formation as a series of alternating sandstone and siltstone beds with occasional shellbeds conformably overlying the uppermost limestone beds of the Te Waka Formation. This definition was adopted by McLennan (1990). Bland (2001) redefined the formation to exclude the siltstone and sandstone beds immediately below the first conglomerate bed of the Matahorua Formation. Similar units cropping out in the Waikoau and Waikare River catchments were defined by Graafhuis (2001) as the Rangiora Formation. The definition of the Pohue Formation is enlarged in this report to incorporate the Rangiora Formation of Graafhuis (2001) as there is little lithological difference between the two units, except for a gradual overall change to more siltstone-dominated facies towards the northeast. Pohue Formation is defined as alternating sandstone and siltstone beds with occasional shelly horizons conformably overlying the Te Waka Formation, and conformably underlying the first greywacke conglomerate bed of the Matahorua Formation. On the eastern side of the Maungaharuru Range, Pohue Formation is inferred to conformably overlie the Opouahi Member (Titiokura Formation) (Graafhuis 2001).

Type locality and reference sections

Brash (1982) defined the small sandstone exposure at the intersection of Ohurakura Road and State Highway 5 as the type section of the Pohue Formation (V20/291085). Bland (2001) proposed a new type section as Brash's section only displayed a 2 m-thick portion of one sandstone bed in a formation that is at least 350 m thick. Bland (2001) proposed a section along the Esk River upstream of a point near the confluence of the Esk River and Ohurakura Stream as the type section (V20/374114-378143). This section has been retained in this report as almost the entire formation is visible along this portion of the river.

A reference section is designated in the Mangaone River from V20/251065-V20/272019.

Upper and lower boundaries

In a regional sense Pohue Formation interdigitates with and overlies the Te Waka Formation, and conformably overlies the Titiokura Formation (Fig. 18). In the Maungaharuru Range Te Waka

Formation is absent, having passed laterally into Pohue Formation. Locally, such as in the Te Pohue area Te Waka Formation is conformably overlain by the Pohue Formation. At Te Pohue, Te Waka Formation gradually becomes more sandy and concretionary upwards, which marks the transition to the Pohue Formation (Column Tp-1). Mostly however, the base of the Pohue Formation is not exposed. In the Patoka area the base of Pohue Formation is truncated by the Patoka Fault, and the formation does not crop out west of the Mohaka Fault. Similarly, the Pohue Formation is juxtaposed against Te Waka Formation by the Rukumoana Fault at Te Pohue.

The upper boundary is well-defined through central parts of the study area from the Waikare River southwest to the Tutaekuri River. In this area the top of the formation is marked by a sharp to erosional contact between sandstone of the Pohue Formation and the first greywacke conglomerate bed of the Matahorua Formation (e.g. Column Pt-9).

Pohue Formation conformably grades down-dip into the Taradale Mudstone.

Distribution and thickness

Pohue Formation is widespread through much of the central portions of the study area cropping out in an almost continuous, though southwestward-narrowing belt. Pohue Formation is highly variable in thickness throughout its outcrop extent. In northern areas (such as on the eastern flank of the Maungaharuru Range) lower parts are equivalent to the Te Waka Formation.

The Pohue Formation is at least 350 m thick in the Mangaone and Esk River catchments. The thickness is difficult to accurately determine as the western edge of the formation has been truncated by the Patoka and Rukumoana Faults. In the Waikoau River catchment Pohue Formation is 350 m thick. The formation thickens dramatically into the Waikare River catchment where it is 800 m thick (Graafhuis 2001).

Description

Pohue Formation comprises siliciclastic siltstone and sandstone beds with minor reworked shell lenses. In northern areas (such as the Waikare River section) Pohue Formation is dominated by siltstone (Graafhuis 2001). In the Esk and Mangaone River sections, the formation is characterised by alternating siltstone and sandstone beds, each many tens of metres thick (Bland 2001). The formation records the development of cyclothemic strata in the study area during the "middle to late" Pliocene.

Sandstone beds are blue-grey, weathering to tan, non cemented, massive to faintly laminated and cross-bedded, weathering to tan, non to sparsely fossiliferous, and well sorted. Occasional highly fossiliferous thin shellbeds may occur in upper parts of sandstone beds though these are largely restricted to an area between the Mangaone and Esk Rivers. These shellbeds are usually dominated by inner shelf to shoreface taxa such as *Zethalia coronata, Myadora stephaniae, Eumarcia plana* and *Fellaster zelandiae.* A fossiliferous sandstone interval in the Mangaone River contained *Limatula maoria, Divaricella huttoniana* and *Trachycardium rossi* interbedded with a shellhash matrix. Siltstone beds are typically blue-grey in colour, non cemented, slightly to moderately fossiliferous and well sorted. In outcrop these beds commonly have a frittered appearance. Occasional tephra beds may be present within the siltstone units as discrete layers up to 0.6 m thick (Bland 2001). More commonly tephric sediments have been incorporated into the surrounding siltstone. Fauna are dominated by genera typical of soft-bottom middle to outer shelf settings such as *Pratulum pulchellum,* with *Atrina pectinata zelandica, Maoricolpus roseus, Polinices waipipiensis, Ostrea chilensis* and *Talochlamys gemmulata.*

Upstream of the Berry Road ford in the Esk River (V20/377125), the Pohue Formation is comprised of sandstone facies with a variable concretion content. This concretionary interval may be a lateral equivalent of the Te Waka Formation cropping out to the southwest in the Te Waka Range, though lateral continuity cannot be demonstrated due to extensive coverage of landslide debris in the southern Maungaharuru Range.

The Pohue Formation becomes consistently finer-grained towards the northeast of the study area (Graafhuis 2001), and the base of the formation progressively becomes older in the same direction. The formation becomes finer-grained in a down-dip direction.

In the Mangaone and Esk River sections the uppermost sandstone bed of the Pohue Formation is well sorted, fine to medium-grained, blue-grey weathering to brown coloured and non cemented. In the Mangaone River the upper 8 m are laminated to trough cross-bedded. The sandstone may contain common thin shell and fine-grained conglomerate lenses up to 0.3 m thick in the upper 4 m (Column Pt-9). Occasional large spheroidal concretions up to 0.5 m across also occur in the upper beds. The sandstone interval is a minimum of 13 m thick in this section. The sandstone package is conformably underlain by blue-grey, non to highly fossiliferous massive siltstone. Fall blocks contain abundant *Atrina pectinata zelandica* and very abundant *Maoricolpus roseus* that are particularly large. The siltstone is approximately 50 m thick and conformably passes up-section into the overlying sandstone bed (Column Pt-10).

Paleontology and age

Pohue Formation is sparsely to moderately fossiliferous with only occasional, relatively thin, highly fossiliferous shellbeds present. No age-diagnostic pectinid fossils have been observed in the Pohue Formation south of the Waikare River catchment where Graafhuis (2001) reported the presence of *Mesopeplum (Borehamia) crawfordi* (age range of Upper Opoitian-Waipipian). *Atrina pectinata zelandica* is common throughout much of the formation, with *Talochlamys gemmulata* and *Maoricolpus roseus* also widespread. In some sandstone units highly fossiliferous shell horizons and lenses dominated by the shallow-water gastropod *Zethalia coronata* occur, frequently as part of moderate-scale trough cross-beds. *Polinices waipipiensis* is common in association with *Pratulum pulchellum*, *Maoricolpus* and *Atrina* fossils in siltstone facies.

The age of the Pohue Formation is diachronous through the study area. The presence of *P. waipipiensis* indicates an age not younger than Mangapanian or older than Waipipian for the Pohue Formation in the Esk and Mangaone catchments. In the Esk and Mangaone Rivers the Pohue Formation contains common highly fossiliferous beds of the Mangapanian-restricted gastropod *Zethalia coronata*. The presence of *Mesopeplum crawfordi* (Wo-Wp) in the Waikare River catchment (Graafhuis 2001, p.33) confirms that at least part of the formation is of Waipipian age, as the formation here overlies Waipipian-aged Titiokura Formation. The Pohue Formation is assigned a Lower Waipipian-Upper Mangapanian age in northern parts of the study area (the Waikare and Waikoau River catchments) (Graafhuis 2001). In the Te Pohue region Pohue Formation is middle to upper Mangapanian in age. In southernmost outcrop areas Pohue Formation is Upper Mangapanian in age.

Environment of deposition

The type of facies within the Pohue Formation suggest shelf water depths of accumulation. Macrofauna in sandstone facies lived on a shoreface, perhaps off slightly protected beaches, but are transported fauna when observed. Siltstone facies probably accumulated on a shelf at inner to outer shelf water depths. The character of the formation strongly indicates that the basin increased in subsidence toward the northeast of the study area (Waikare River catchment).

MATAHORUA FORMATION (mt)

(Cutten 1994; redefined by Bland 2001 and Graafhuis 2001)

Name and definition

Cutten (1994) introduced the name Matahorua Gravel Member (as part of the Maungaharuru Formation) in reference to a continuous greywacke conglomerate bed present near the Napier-

Wairoa road northwest of Lake Tutira. The name was derived from Matahorua Road, along which there are excellent exposures through one of the conglomerate beds. Both Bland (2001) and Graafhuis (2001) redefined Matahorua Formation to include a series of up to four greywacke conglomerate beds and associated sandstone and siltstone beds that crop out through central Hawke's Bay from Putorino to the Mangaone River. The definitions of Bland and Graafhuis are retained in this report though the distribution of the formation has been extended greatly south of the Esk River catchment and the geological map of Bland (2001). The Matahorua Formation is defined as the series of greywacke conglomerate beds, interspersed with sandstone and siltstone beds above the Pohue Formation, and below the first sandstone beds of the Waipunga Formation.

Type locality and reference sections

The type section designated by Bland (2001) in the Esk River has been retained in this report. This section is located in the Esk River from a point downstream of the confluence of Ohurakura Stream to the confluence with Deep Stream (V20/373097-380068). Excellent reference sections are present in the Mangaone River (V20/273018-289937) and Waikoau River (V20/417145-434142), although access can be difficult due to the incised nature of these water bodies. The conglomerates crop out in hills along the Napier-Taupo Road from near Te Whanau homestead (V20/299069) to Eland Station (V20/320231).

Lower and upper contacts

The base of the formation was defined by Bland (2001) and Graafhuis (2001) as the base of the siltstone bed forming the first conglomerate-capped "sequence" in the Esk-Waikoau and Waikare River catchments. This definition was a combination of lithostratigraphy and allostratigraphy. In practice this definition is very difficult to map in the field and the base of the Matahorua Formation is now redefined as the base of the first greywacke conglomerate bed overlying the Pohue Formation.

The Matahorua Formation Interdigitates with the Pohue Formation south of the Tutaekuri River. Interdigitation also occurs with the Pohue Formation and the Esk Formation northeast of the Waikoau and Waikare Rivers.

The Matahorua Formation interdigitates with the Waipunga Formation north of Kaiwaka Stream. South of Kaiwaka Stream (Esk River catchment) the Matahorua Formation is overlain conformably by the Esk Mudstone (Fig. 19D, F).

Distribution and thickness

Rocks of the Matahorua Formation are widespread through the study area and crop out from Willowflat Road in the north to the Tutaekuri River at Flag Range in the south. The distribution pattern of the formation reflects the shape of the depositional braidplain system of the formation. The Matahorua Formation is thickest in the Esk-Mangaone River catchments and thins along strike from this area.

Description

Matahorua Formation is one of the most distinctive units cropping out in the study area and forms marked dipslopes. While the Matahorua Formation is volumetrically made up mainly of sandstone and siltstone facies, it is the prominent greywacke conglomerate beds that distinguish this formation from other formations. Indeed, it is in this unit that the first major influx of greywacke gravels into the basin is recorded, presumably reflecting accelerated uplift along the axial ranges. The formation is characterised by the presence of four members, all of which are present in the Esk and Mangaone Rivers, although the extent of some members decrease to the north and south of this section Bland 2001; Graafhuis 2001).

Paleontology and age

While general sparsely to moderately fossiliferous, a wide range of faunas have been sampled from the Matahorua Formation. The pectinid *Phialopecten triphooki* has been sampled from several outcrops, as well as many specimens of *Mesopeplum convexum*. Many valves of these species exhibit growth ridges that may indicate that they grew in a stressful, high-energy environment. Based on the presence of *P. triphooki,* and rare *Towaipecten mariae* in the upper half of the Matahorua Formation, an uppermost Mangapanian to lowermost Nukumaruan age (Late Pliocene) is inferred for this formation. The presence of *Struthiolaria* n. sp. aff. *frazeri* in lower parts of the formation firmly suggests a Mangapanian age for these beds, while the occurrence of *Phialopecten triphooki* and *Towaipecten mariae* indicates a Lower Nukumaruan age for upper beds.

Environment of deposition

The conglomerate beds reflect the progradation of a fluvial braidplain into the basin during the lowstands of four sea-level cycles. The lowstand shorelines are not readily apparent in outcrop, and probably occur downdip in the subcrop.

Deep Stream Member (mta)

(Bland 2001; Graafhuis 2001)

Name and definition

Deep Stream Member (Fig. 19F) was introduced by Bland (2001) and Graafhuis (2001) in reference to the lowest conglomerate "cycle" of the Matahorua Formation in the Esk-Waikoau region. Deep Stream Member is named after Deep Stream, a small but deeply incised tributary of the Esk River immediately north of Trelinnoe Station, Te Pohue.

Type locality and reference sections

The type section is located in banks of the Esk River from V20/373097 to V20/372089. A reference section is nominated in the Mangaone River from V20/273018 to V20/286991.

Lower and upper contacts

In the Waikoau, Esk and Mangaone River catchments the Deep Stream Member sharply overlies the Pohue Formation (Fig. 19F). Northeast towards the Waikare River section Deep Stream Member interdigitates with the upper Pohue Formation. Southwest of the Mangaone River toward the Tutaekuri River, Deep Stream Member also interdigitates with the Pohue Formation. The sequence representing the Deep Stream Member can be identified in the Tutaekuri River section although the overlying greywacke conglomerate bed is not present.

For much of the outcrop area the Deep Stream Member is conformably overlain by the Trelinnoe Member (Fig. 20A). The member is in fault contact with the Pohue Formation in the Patoka area.

Distribution and thickness

Deep Stream Member is the most poorly exposed member of the Matahorua Formation. Most outcrops occur in a northeast-southwest trending belt between the Waikoau River and Patoka where its western extent is truncated by the Patoka Fault. Deep Stream Member has not been observed in, or south of, the Tutaekuri River.

Deep Stream Member is poorly developed in the Tutaekuri River section where the basal conglomerate bed is not present. The member is absent in the Ngaruroro River. In the Mangaone River the Deep Stream Member is a minimum of 72 m thick. Throughout the Esk River catchment Deep Stream Member is a maximum of 50 m thick (Bland 2001). In the Waikoau River the member is 45 m thick (Graafhuis 2001). Adjacent to Matahorua Road (V20/436168) the member is 50 m thick. The basal conglomerate bed of the Deep Stream Member does not crop out north of this point. In the Waikare River the member is 45 m thick although the basal greywacke conglomerate bed is no longer present (Graafhuis 2001).

Description

The basal coarse-grained conglomerate facies of the Deep Stream Member mark the first major influx of greywacke gravels into the basin. Typically the member comprises a coarsening-upwards package of siltstone-sandstone facies overlying the basal greywacke conglomerate that reflects continually falling sea level during sedimentation. In westernmost parts of the outcrop area the siltstone facies are much reduced and at times may be non-existent, this interval instead being represented by non cemented fine to medium sandstone. Lower parts of the member comprise siltstone to fine to medium sandstone depending on the position of the outcrop.

Deep Stream Member is most clearly exposed in the Mangaone, Esk and Waikoau River sections. Exposures in the Mangaone River section occur upstream of the confluence with Patoka Stream. The 7 m-thick conglomerate bed in this section overlies non cemented sandstone through a sharp, erosional contact with decimetre-scale relief (Column Pt-9). Basal parts of the conglomerate contain prominent mudstone and sandstone rip-up clasts. Clasts are sub to well rounded, up to 8 cm across and average 3 cm across. The unit as a whole is poorly- to moderately well sorted with common sandstone lenses. The conglomerate is sharply overlain by non cemented siltstone of the Trelinnoe Member. The member is poorly exposed through the Te Pohue region. Only the uppermost 3 m of the sandstone interval and the 4 m-thick capping conglomerate are exposed on State Highway 5 (V20/298068). Exposures in the Esk River are located downstream of the confluence with the Ohurakura Stream.Siltstone and sandstone facies vary little in the member through the study area. Siltstone facies are approximately 3.5 m thick on State Highway 5. In proximity to the basal greywacke conglomerate bed of the overlying Trelinnoe Member, the sandstone bed at the top of the Deep Stream Member may contain common greywacke conglomerate lenses and pebble beds, with common, scattered pebbles.

Paleontology and age

The Deep Stream Member contains a sparse to moderately diverse macrofauna. Highly fossiliferous shell lenses are exposed in cuttings beside State Highway 5 and are dominated by shallow-water open-ocean bivalves such as *Eumarcia* and *Paphies subtriangulata*. These lenses are interpreted as event-concentrated shellbeds. The member contains the Mangapanian-restricted gastropod *Struthiolaria* n. sp. aff. *frazeri* ancestral to *S. frazeri* (A. Beu GNS Science pers. comm. 2003). Based on stratigraphic position the Deep Stream Member is confidently assigned an Upper Mangapanian age (Late Pliocene, c. 2.48 Ma).

Environment of deposition

The Deep Stream Member was deposited in a variety of shelfal to marginal-marine and non-marine settings. Conglomerate facies were deposited as part of fluvial braidplains and shingle beaches. Siltstone and sandy siltstone facies are consistent with inner to outer shelf depositional environments. Sandstone facies are inferred to represent beach and nearshore environments.

Trelinnoe Member (mtb)

(Bland 2001; Graafhuis 2001)

Name and definition

Cutten (1994) established the Matahorua Gravel Member as part of the Maungaharuru Formation. Bland (2001) and Graafhuis (2001) redefined this member as one of four conglomerate beds cropping out widely through the Esk and Waikoau areas. The name Matahorua Gravel Member was elevated to formation status to encompass these gravel beds, and a new name introduced to encompass Cutten's original definition. Trelinnoe Member (Fig. 19F) was established by Bland (2001) and Graafhuis (2001) to account for the second oldest greywacke conglomerate bed and overlying siltstone and sandstone facies in the Matahorua Formation. The conglomerate bed at the base of the Trelinnoe Member is equivalent to the Matahorua Gravel Member of Cutten (1994). The Trelinnoe Member is sharply overlain by the basal conglomerate of the Papakiri Member. The unit is named after Trelinnoe Station and arboretum near Te Pohue where the member forms conspicuous bluffs and hilltops.

Type locality and reference sections

The type locality is located in the Esk River from V20/372089 to V20/371084.

A reference section is nominated beside Matahorua Road where Cutten (1994) had his type section for the Matahorua Conglomerate Member (V19/490216).

Lower and upper contacts

The Trelinnoe Member sharply overlies the Deep Stream Member. This contact is exposed in the Esk River (V20/372089), beside Matahorua Road (V19/490216; Fig. 20A), and beside the Napier-Taupo Road (V20/299066).

The Trelinnoe Member is sharply overlain by the Papakiri Member. This contact is exposed in the Esk River (V20/371084), near Huiarangi Road (Fig. 20F; V20/256004, Column Pt-5) and beside the Napier-Taupo Road at Glengarry Hill (V20/371084, Column Gg-1).

Distribution and thickness

Trelinnoe Member crops out in a nearly continuous northeast-southwest trending belt from Putorino to Patoka. In southern regions the western extent of the member is truncated by the Patoka Fault. Trelinnoe Member is best exposed between the Esk and Mangaone Rivers catchments, especially in the Glengarry Forest region. The basal greywacke conglomerate bed of the Trelinnoe Member is not developed in the Tutaekuri River and the member is not present in the Ngaruroro River. Near Patoka and Waihau Road the member is a minimum of 50 m thick, 60 m thick in the Mangaone River, 20-40 m thick around Te Pohue, 50-60 m thick in the Esk River, 70 m thick in the Waikoau River and 45 m thick in the Waikare River.

Description

Trelinnoe Member comprises a package of greywacke conglomerate, siliciclastic siltstone and sandstone of variable thickness. The member is usually dominated by sandstone lithologies, although siltstone units are thick and prominent (>60 m) in many, particularly in southern and eastern, outcrops. The general character of siltstone and sandstone facies of the member change little through the study area. Siltstone units comprise non cemented, non to slightly fossiliferous blue-grey weathering to brown-grey fine-grained facies that coarsen up-section through silty sandstone beds into overlying sandstone. The lower siltstone interval is thinnest in more westerly (shoreward) exposures. The basal 0.5 m of the siltstone interval is commonly marked by a pebbly siltstone comprising abundant to common well sorted and well rounded greywacke clasts of granule to fine pebble size that rapidly decrease in volume up section. This pebbly zone is interpreted to represent reworking of the underlying Trelinnoe Member conglomerate bed during sea level transgression. The siltstone interval is approximately 45 m thick in Glengarry Forest, over 50 m thick near Huiarangi Road, and over 20 m thick on Cascade Farm (V20/204966).

The transition from siltstone to sandstone-dominated intervals is typically marked by a zone of alternating siltstone-sandstone beds. Sandstone facies consist of well sorted, non cemented clean, non to moderately fossiliferous fine to medium sandstone. Colour is blue-grey when fresh, but more typically light brown. The sandstone interval is a maximum of 5 m thick on State Highway 5, and 25 m thick on Trelinnoe Station (Bland 2001). In both Deep Stream and the Esk River the lower siltstone interval is not present and is instead represented by fine to medium sandstone. In Deep Stream the sandstone interval is nearly 40 m thick, and in the Esk River is approximately 30 m thick (Bland 2001). This is interpreted to represent a more shoreward depositional setting than sections containing this lower siltstone (e.g. Glengarry Forest).

Greywacke conglomerate lenses, pebble stringers and scattered pebbles are all common in upper parts of the sandstone interval near the contact with the overlying conglomerate bed. Conglomerate and pebble lenses are typically up to 0.5 m thick, well sorted and dominated by greywacke clasts. Such lenses and bodies are normally contained within 4 m of the base of the main conglomerate bed of the member. The Trelinnoe Member is similar in character to other members of the Matahorua Formation typically comprising a lower siltstone interval which is conformably and gradationally overlain by a sandstone unit.

Sandstone facies of the Trelinnoe Member become less fossiliferous from the Esk River towards the Waikoau and Waikare catchments (Graafhuis 2001).

Paleontology and age

Fauna in siltstone facies are typical of soft-bottom Pliocene rocks through Hawke's Bay. Siltstone facies commonly contain *Pratulum pulchellum, Talochlamys gemmulata, Atrina pectinata zelandica* and *Maoricolpus roseus.* The first occurrence of the Lower Nukumaruan index scallop *Phialopecten triphooki* in the overlying Papakiri Member helps confirm an uppermost Mangapanian age for the Trelinnoe Member (Late Pliocene, approx. 2.44 Ma).

Environment of deposition

Fauna in siltstone facies are consistent with deposition in middle to outer shelf water depths. Sandstone facies were typically deposited in inner shelf to shoreface water depths. Conglomerate facies are inferred to largely be products of deposition at the shoreward-end of a braided river system. Conglomerate lenses and stringers in upper parts of the member are inferred to reflect sea level fall and the migration of gravel deposits further basinward during storm events.

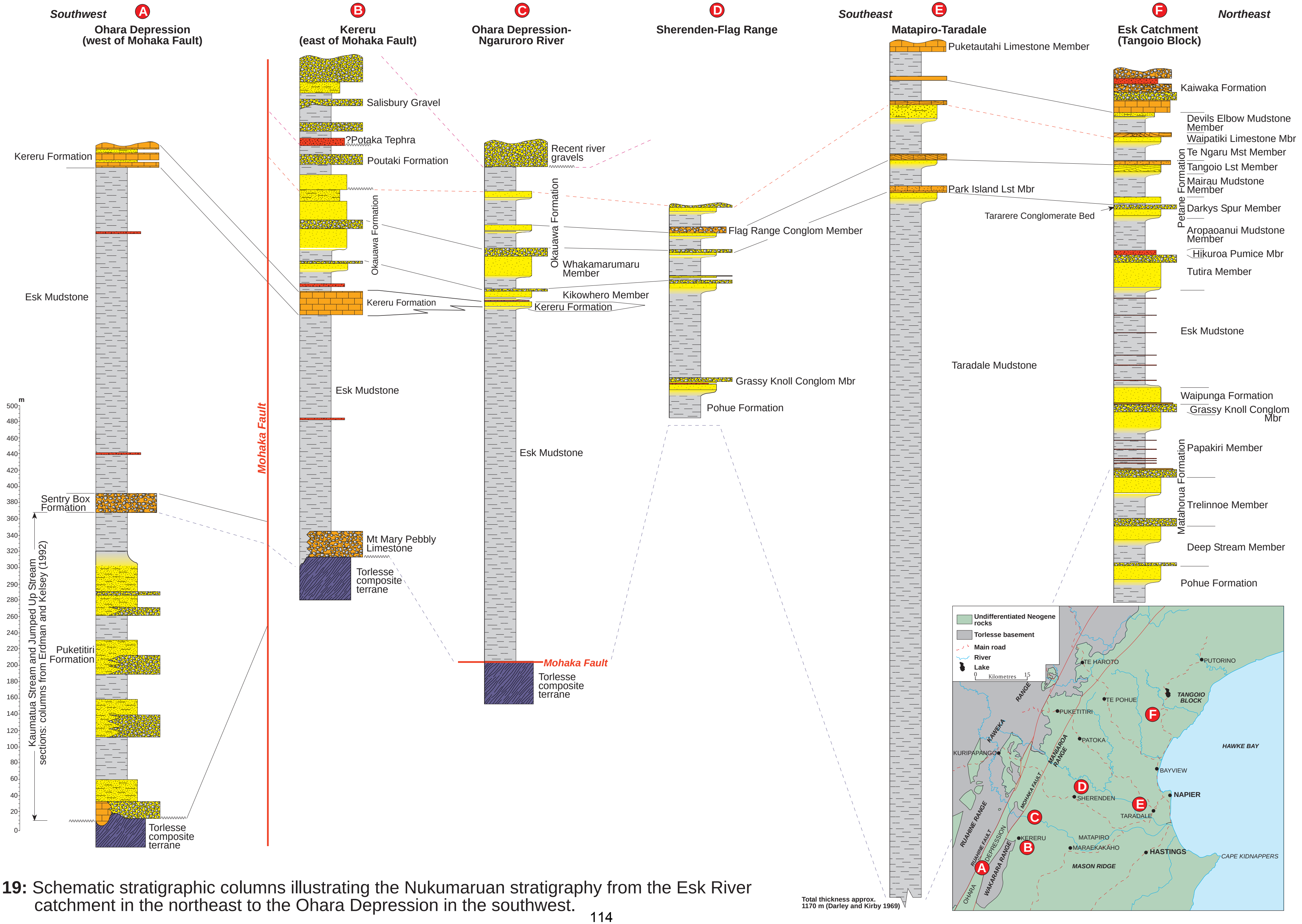


Fig. 19: Schematic stratigraphic columns illustrating the Nukumaruan stratigraphy from the Esk River catchment in the northeast to the Ohara Depression in the southwest.

Papakiri Member (mtc)

(Bland 2001; Graafhuis 2001)

Name and definition

Papakiri Member (Fig. 19F) is named after Papakiri Stream, a small stream that flows into the northern end of Lake Tutira. It sharply overlies the Trelinnoe Member, and is sharply overlain by the Grassy Knoll Conglomerate Member

Type locality and reference sections

The type section designated by Bland (2001) is retained. This section is located in the Esk River between V20/371084 (Column Tp-4) and V20/378067 (Column Tp-7). A reference section is designated at Glengarry Hill beside the Napier-Taupo Road (V20312037-V20/309036) (Column Gg-1).

Lower and upper contacts

The base of the Papakiri Member almost always corresponds to the base of a greywacke conglomerate, except in places (such as the Tutaekuri River) where a basal conglomerate is not developed. The lower contact of the Papakiri Member is exposed in several localities. At Glengarry Hill (V20/309036) coarse-grained greywacke conglomerate of the Papakiri Member sharply overlies interbedded sandstone and conglomerate of the Trelinnoe Member (Fig. 20F). At Huiarangi Road (V20/260002) near Patoka, marginal-marine sandy siltstone, rich in plant fossils, of the Trelinnoe Member is sharply overlain by conglomerate of the Papakiri Member (Column Pt-4).

The upper contact has been observed in numerous outcrops through the study area with pebbly and fossiliferous sandstone of the Papakiri Member sharply overlain by greywacke conglomerate of the Grassy Knoll Conglomerate Member. The contact is exposed in the Esk River (V20/378067, Column Tp-7), Kaiwaka Stream (V20/364052), the Mangaone River (V20/292951), and on the northeastern face of The Dome at Patoka (V20/265000).

Distribution and thickness

Papakiri Member crops out prominently in a northeast-southwest trending belt from the Waikare River in the north, through the Waikoau, Te Pohue and Patoka districts to the Waihau and Tutaekuri River area. Papakiri Member is well exposed in the Waikoau, Esk and Mangaone Rivers. The Papakiri Member cannot be differentiated in the Tutaekuri River from other parts of the Matahorua Formation.

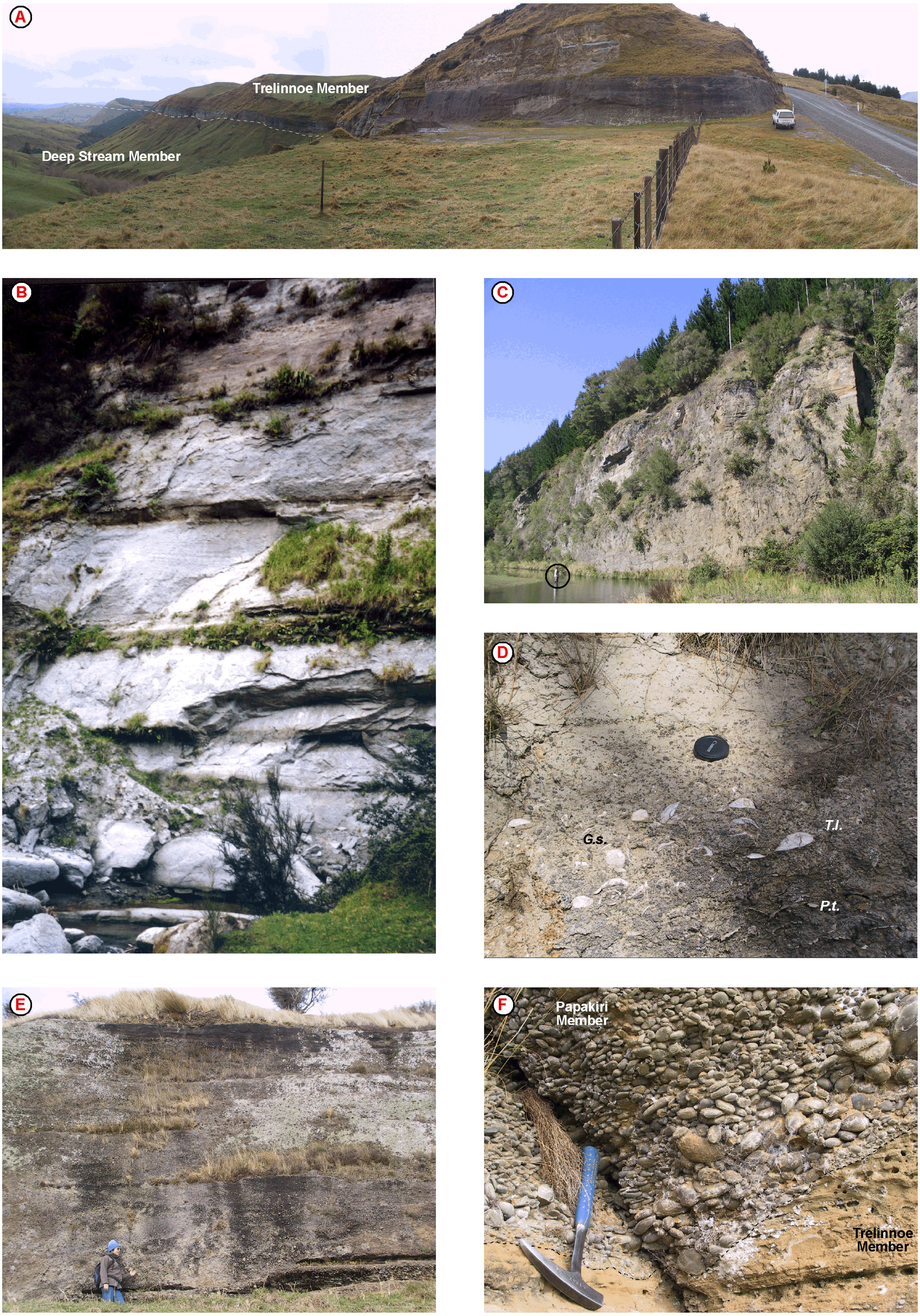
At Matahorua Road the basal conglomerate bed is approximately 8 m thick (Graafhuis 2001), 3.5 m thick in the Waikoau River, 4 m thick in the Esk River, at least 4 m thick in Deep Stream (Column Tp-5), a maximum of 10 m thick on Trelinnoe Station, thickening dramatically to over 20 m in the Mangaone River (Fig. 20C; V20/30096, Column Gg-5), and 6 m at Huiarangi Road (Fig. 20E; Column Pt-4).

In the Tutaekuri River section the Papakiri Member is about 40-50 m thick. In the Patoka area the member is a minimum of 50 m thick. In the region of State Highway 5 the Papakiri Member is approximately 15 m thick, and at Glengarry Hill up to 60 m thick. The member thickens into the Esk River (80 m), thins to 25 m thick in the Waikoau River, and thins further northeast into the Waikare River where it is 12 m thick (Bland 2001; Graafhuis 2001). It is only a few metres thick where last observed in outcrop around the Willowflat Road area.

Description

Papakiri Member typically comprises a basal conglomerate overlain by siltstone and sandstone. The greywacke conglomerate is dominated by non fossiliferous units, although moderately to highly fossiliferous beds are common (although typically thin (<1 m thick)). Clasts in the conglomerate are almost exclusively greywacke, with rare to minor contributions from Late Neogene sandstone and siltstone. Clasts in the conglomerate are poorly to very well sorted and average 3 cm across, although sizes vary between coarse sand and cobble. Clast shapes are sub to well rounded and include all of spheroidal, lensoidal and oblate types with spheroidal and oblate pebbles dominating. Sandstone lenses are common in lower parts of the conglomerate bed and are inferred to reflect dune migration in river channels. These beds are generally up to 0.3 m thick and may be continuous for up to several metres. Internal planar lamination and trough cross-stratification is common in sandstone bodies. Siltstone lenses and stringers, while present, are generally less common and thinner than sandstone beds. In the Waikoau River (V20/429144) a 10 cm thick lignite bed caps the conglomerate and is in turn overlain by marine mudstone (Graafhuis 2001).

Fig. 20 (facing page): Deep Stream, Trelinnoe, and Papakiri Members. **A)** Reference section of the Trelinnoe Member in an old quarry beside Matahorua Road (V19/490216). Location of the contact between the Trelinnoe Member and underlying Trelinnoe Deep Stream Member is highlighted. **B)** Tephra beds (dark bands) in middle to outer shelf siltstone facies of the Papakiri Member. Kaiwaka Stream, Trelinnoe Station (V20/347058). **C)** Thick (over 15 m) conglomerate bed at the base of the Papakiri Member, Mangaone River (V20/300963). **D)** Shellbed overlying non-marine conglomerate facies, Papakiri Member. This shellbed contains the first occurrence of *Phialopecten triphooki* and is therefore assigned a basal Nukumaruan age. *G.s.* is *Glycymeris shrimptoni, T.l.* is *Tucetona laticostata*. Huiarangi Road, Patoka (V20/260000). **E)** Conglomerate facies at the base of the Papakiri Member forming a prominent high bluff above Huiarangi Road, Patoka (V20/256004). **F)** Close-up view of the basal contact of the Papakiri Member where it sharply overlies shallow-water sandstone facies of the Trelinnoe Member. Note how the coarser clasts are concentrated into the bottom of a hollow in the underlying sandstone (V20/256004).


A
Trelinnoe Member
Deep Stream Member
B
C
D
G.s.
T.l.
P.t.
E
F
Papakiri Member
Trelinnoe Member

Fossiliferous zones in upper parts of the conglomerate bed mark a return to marine sedimentation under a regime of rising sea level (Fig. 20D). The thickest pebbly shellbed development occurs in southern and eastern exposures of the Papakiri Member, such as at Glengarry Hill and Huiarangi Road (Fig. 20D). Fauna are typically dominated by robust, thick-shelled semi-infaunal bivalves such as *Glycymeris shrimptoni* and *Tucetona laticostata,* with common epifauna such as *Ostrea chilensis* and *Phialopecten triphooki.*

Gastropods tend to be minor in number. The upper conglomerate bed is moderately to highly fossiliferous in Deep Stream and the Esk River. Upper parts of the conglomerate are moderately to highly fossiliferous at Glengarry Hill, Glengarry Forest and in Kaiwaka Stream. Sandstone facies are typically non fossiliferous and massive to weakly laminated and cross-bedded (tabular and trough bed forms dominate).

The Papakiri Member contains the first interval of prominent airfall tephra beds observed in the study area (Fig. 20B). These beds are well exposed in the Esk River and Deep Stream. While tephric detritus is present in underlying formations, it is generally present as reworked sediments and not the intact sharp-based bodies 5-50 cm thick with common burrows that are abundant in the Grassy Knoll Conglomerate Member. The tephra beds occur in the lower siltstone bed of the member which itself tends to be thicker than those in the underlying members. Excellent exposures of the siltstone interval with tephra beds occur in the Esk River upstream of the Deep Stream confluence and in Kaiwaka Stream on Trelinnoe Station below the farm bridge (Fig. 20B). The siltstone interval passes conformably up-section into the sandstone interval.

Sandstone facies are generally massive and consist of well sorted, clean, non cemented, non fossiliferous, fine to medium facies. The sandstone interval gradationally overlies the siltstone interval, usually through a series of alternating siltstone-sandstone beds. Upper parts of the sandstone interval are commonly pebbly with scattered grains and pebble lenses. The pebbly sandstone interval is largely non fossiliferous although tightly packed shellbeds are common in the Esk River. The sharp transition from pebbly sandstone to the overlying Grassy Knoll Conglomerate Member is well exposed in the Esk River, Kaiwaka Stream, and several locations on the north side of The Dome, Patoka (e.g. V20/265000).

Paleontology and age

Although it is mostly sparsely fossiliferous, the Papakiri Member often contains a diverse molluscan fauna with excellent fossil-rich beds present in Deep Stream, the Esk River, Glengarry Hill, and in Glengarry Forest.

The observation of the first occurrence of *Phialopecten triphooki* (Lower Nukumaruan-restricted) in lowermost beds of the Papakiri Member in the Esk River catchment (Bland 2001) provides a correlation tool for use away from this area (V20/371084, Column Tp-4). Specimens of *P. triphooki* have been collected in many localities in the study area, with excellent well preserved valves being observed in Deep Stream (V20/361073, Column Tp-5), Glengarry Forest (V20/ 293023), Glengarry Hill (V20/309038, Column Gg-1), and at the Huiarangi Road gravel pit near Patoka (Fig. 20D; V20/259002, Column Pt-4). The member is coeval with parts of the Scinde Island Formation at Napier, the lower limestone bed at Mason Ridge southwest of Hastings (Dyer, 2004), Pakipaki Limestone south of Hastings and Sentry Box Formation in the Ohara depression/ Whanawhana/Kuripapango regions. *Phialopecten* valves typically occur with other robust, thick-shelled and often semi-infaunal bivalves such as *Glycymeris shrimptoni, Tucetona laticostata, Purpurocardia purpurata* and *Ostrea chilensis. Mesopeplum convexum* has also been collected from a few sites such as the Huiarangi Road gravel pit. Such faunal assemblages indicate deposition in high-energy, current swept environments such as tidal channels, entrances to harbours and current-swept embayments.

Upper parts of the conglomerate bed frequently contain estuarine-restricted taxa such as *Austrovenus stutchburyi*, reflecting more shoreward, estuarine, depositional settings. Siltstone facies commonly contain clusters of the thin-shelled bivalves *Pratulum pulchellum*, generally an indicator of middle to outer shelf water depths in the study area.

The underlying Trelinnoe Member was assigned a Mangapanian age by Cutten (1994) and Beu (1995; pers. comm. 2003) on the basis of the occurrence of the Mangapanian-restricted gastropod as *Struthiolaria* n. sp. aff. *frazeri*. The first occurrence of *Phialopecten triphooki* in the study area occurs in the pebbly shellbed near the base of the Papakiri Member. On this basis this shellbed is likely to be of basal Nukumaruan age (2.4 Ma; Beu *et al.* 2004) and is perhaps coeval with the Hautawa Shellbed in Wanganui Basin (McIntyre 2002).

Environment of deposition

Conglomerate facies accumulated in non-marine to shoreface environments as part of a fluvial braid-plain system that developed in response to sea level fall and the consequent drop in base level. Fossiliferous conglomerate beds reflect drowning of a non-marine fan-delta system caused by a glacio-eustatically-driven rise in sea level. Sandstone facies were generally deposited in inner shelf to shoreface environments, typically during periods of falling sea level. They are inferred to represent the regressive systems tract and mark a period of falling sea level and basinward progradation of the sedimentary system. Pebbly sandstone in upper parts of the member marks the influence of falling sea level and the progradation of a fan-delta system. Siltstone facies accumulated in shelfal environments, probably at inner to middle shelf depths.

Grassy Knoll Conglomerate Member (mtd)

(Bland 2001; Graafhuis 2001)

Name and definition

Grassy Knoll Conglomerate Member derives its name from the prominent greywacke conglomerate-capped hill on Trelinnoe Station (V20/339052) locally known as the Grassy Knoll (Fig. 21A). The unit was established by Bland (2001) and Graafhuis (2001) to account for the youngest of the four major greywacke conglomerate beds of the Matahorua Formation (Fig. 19F). The definition of Bland (2001) and Graafhuis (2001) is emended in this report. The name Grassy Knoll Conglomerate Member is restricted to the stratigraphically highest greywacke conglomerate bed of the Matahorua Formation.

Grassy Knoll Conglomerate Member sharply overlies the Papakiri Member and underlies either the Waipunga Formation or Esk Mudstone (Fig. 21D). Siltstone and sandstone beds underlying this conglomerate were included in the Grassy Knoll Member by Bland (2001) and Graafhuis (2001). These beds are now included in the Papakiri Member.

Type locality and reference sections

The type section designated by Bland (2001) in the Esk River downstream of the Deep Stream confluence is retained in this report (V20/378067, Column Tp-7). An excellent reference section is present exposing the entire member in the Tutaekuri River from the confluence of the Waikonini Stream (V21/220885, Column Sh-5) to a point several hundred metres upstream (V21/203877, Column Sh-4). Both lower and upper contacts are exposed in a reference section in the Mangaone River (V20/297956-289937) (Fig. 21B).

Distribution and thickness

Grassy Knoll Conglomerate Member is one of the most widespread members of the Matahorua Formation through northern and central parts of the study area. Grassy Knoll Conglomerate Member crops out prominently from the Waikoau to Tutaekuri River catchments in a broadly northeast-southwest belt. To the north of the Waikoau River the unit thins and becomes less prominent, and by the Waikare River the member cannot be differentiated from finer-grained sediments of the Waipunga Formation. To the southwest, the member passes into fine-grained siltstone facies of the Taradale Formation. The extent of the member is truncated by the Mohaka Fault Zone southwest of the Tutaekuri River and the Napier-Taihape Road.

Fig. 21: Grassy Knoll Conglomerate Member. **A)** Landscape photograph of "Grassy Knoll" hill from State Highway 5 at Glengarry Hill (V20/309038). **B)** Grassy Knoll Conglomerate Member sharply overlying shallow-water sandstone facies of the Papakiri Member in the Mangaone River. The contact is highlighted by the white dashed line. V20/292951. **C)** Highly fossiliferous Grassy Knoll Conglomerate Member cropping out in the lower reaches of Kaiwaka Stream, Trelinnoe Station (V20/365052). Several small specimens of *Phialopecten triphooki* have been collected from this outcrop, helping to confirm a Lower Nukumaruan age for the member. **D)** Grassy Knoll Conglomerate Member conformably overlain by Esk Mudstone beside Puketitiri Road near Trigham Farm (V20/258955).

Grassy Knoll Conglomerate Member is the thinnest member of the Matahorua Formation as it comprises only a greywacke conglomerate interval. The member is 9 m thick in the Waikoau River (Graafhuis 2001), at least 4.5 m thick in the Esk River (V20/378068, Column Tp-7), 5 m thick in the Mangaone River (V20/292951; Fig. 21B), at least 2.5 m thick at The Dome, Patoka (V20/265000), over 10 m thick along Waihau Road (V20/193905), and 11 m thick in the Tutaekuri River and Flag Range region (V21/220885, Columns Sh-4, Sh-5).

Description

Grassy Knoll Conglomerate Member comprises greywacke conglomerate beds that vary in thickness across the study area.

The Grassy Knoll Conglomerate Member is highly fossiliferous in outcrops through the Esk River and Deep Stream areas, and largely non fossiliferous through the rest of the study area. Upper parts of the conglomerate in these other areas may be capped by thin slightly to moderately fossiliferous shellbeds rich in estuarine fauna such as *Austrovenus*. Lower parts of the conglomerate are generally coarser-grained and less sorted than upper parts. Bedding also tends to be cruder and more massive in lower parts relative to upper parts. In some places sandstone and mudstone clasts, assumed to be sourced from the underlying Papakiri Member, are incorporated into basal parts of the Grassy Knoll Conglomerate Member. Upper intervals of the conglomerate are characterised by alternating very well sorted beds of granule/fine pebble greywacke clasts.

Prominent fossiliferous conglomerate to pebbly shellbeds crop out on Waihau Road and are assigned to the Grassy Knoll Conglomerate Member. Fauna are dominated by *Ostrea* with *Purpurocardia purpurata, Lutraria solida* and glycymerid bivalves.

Paleontology and age

Grassy Knoll Conglomerate Member contains a rich molluscan fauna. The fauna of the member are dominated by species that are inferred to have lived in shallow-water, high-energy environments, and had to be robust enough to survive among greywacke pebbles and cobbles. Thick-shelled bivalves such as *Glycymeris shrimptoni* and *Ostrea chilensis* are common constituents of many conglomerate beds. The presence of *Paphies australis, Paphies subtriangulata* and *Fellaster zelandiae* indicate a shallow-water environment perhaps open to oceanic waters.

The member is almost always capped by a thin (<0.5 m thick) very pebbly shellbed rich in estuarine to shallow-marine bivalves such as *Austrovenus* (cockle)*, Tawera, Glycymeris* and *Ostrea.* In the Esk River and Deep Stream the conglomerate conspicuously contains common to abundant pectinids of which *Phialopecten triphooki* and *Mesopeplum convexum* are the dominant species. The conglomerate in the Esk River sharply overlies highly fossiliferous, very well sorted sandstone (Papakiri Member) rich in very shallow-water taxa such as *Paphies, Fellaster* and *Zethalia zelandica.* Pectinids are much rarer in Kaiwaka Stream, although the conglomerate here is still highly fossiliferous and sharply overlies well sorted, non fossiliferous sandstone to slightly pebbly sandstone. Fauna here are typical of shallow-water, high-energy environments and include *Paphies australis* ("Pipi") (Fig. 21C)*, Glycymeris shrimptoni* and uncommon *Phialopecten triphooki.* A 0.7 m-thick pebbly shellbed capping the conglomerate on Trigham Farm (V20/ 251941) comprises two distinct beds. The lower bed is dominated by characteristic estuarine taxa such as *Xenostrobus huttoni* and *Barytellina crassidens.* The upper bed comprises fauna more typical of open-marine conditions such as *Tawera subsulcata* and *Ostrea chilensis.* This suggests flooding of a non-marine river system by sea level rise and the progression through marginal-marine to open-marine environments through time.

In many outcrops, particularly through the Esk-Glengarry regions (e.g. V20/251941, V20/301992), the upper portion of the conglomerate bed contains a fauna rich in the estuarine bivalve *Austrovenus stutchburyi*. At V20/289927 this same upper shellbed contains common *Paphies australis* and *Purpurocardia purpurata*.

The pectinid *Phialopecten triphooki* has been collected from numerous outcrops of the Grassy Knoll Conglomerate Member through the study area. Small juvenile pectinid specimens from Kaiwaka Stream (V20/364052), a tributary of the Esk River, exhibit characteristics of both *P. triphooki* and its immediate ancestor *P. thomsoni.* Mature specimens of *P. triphooki* have been collected from Eland Station (V20/324033), from fall blocks in Deep Stream near the Esk River confluence (V20/373070), as well as from highly fossiliferous conglomerate exposures in the Esk River itself (V20/378067, Column Tp-7). A single valve of *Towaipecten mariae* was also collected from Deep Stream. Like the underlying Papakiri Member, *Phialopecten* valves in this member are always found with other robust, thick-shelled bivalves such as *Tucetona laticostata* and *Glycymeris shrimptoni*. Other shallow-water bivalves such as *Paphies australis* are common in the capping shellbed. Many of the *P. triphooki* specimens from the Esk River exposures display prominent growth ridges, as do the majority of *Mesopeplum convexum* valves collected from the same outcrops. The appearance of such features is indicative of a high-energy stressful environment, where the scallops have regrown old shell injuries (A. Hendy Univ. Cincinnati pers. comm. 2001; cf. Beu 1995, p. 142).

Based on the presence of *Phialopecten triphooki* and *Towaipecten mariae,* a Lower Nukumaruan age is assigned to the Grassy Knoll Conglomerate Member. The occurrence of *Phialopecten triphooki* and *Zygochlamys patagonica delicatula* in limestones of the Pakipaki and Sentry Box Formations mean that these units are likely to be lateral equivalents. The Grassy Knoll Conglomerate Member is probably also a lateral equivalent of the Torran Limestone Member (Mason Ridge Formation), and middle parts of the Scinde Island Formation (perhaps Member C; see below).

Environment of deposition

Grassy Knoll Conglomerate Member was mostly deposited in a non-marine environment as part of a fluvial braid-plain system. Down-dip exposures of the member record marginal-marine to shoreface environments. Estuaries and embayments in the coastline during deposition were common, and best developed in the Te Pohue-Patoka area where the member is at its greatest extent. The well sorted and laminated conglomerate beds in the Grassy Knoll Member are interpreted as representing shingle beach deposits. The depositional environment for the Grassy Knoll Member may have resembled the current Napier coast in the vicinity of Ahuriri Lagoon, with nearby braided rivers occurring in association with estuaries and gravel beaches.

SCINDE ISLAND FORMATION (si)

(Hector 1877; McKay 1877)

Name and definition

The name Napier Limestone was originally used by early geologists such as Buchanan (1870) and McKay (in reports before 1877) in relation to the limestone forming the hill on which the original city of Napier was built (Beu 1995). Hector and McKay adopted the name Scinde Island Limestone in 1877, and it is this name that has been subsequently used by geologists (e.g. Hill 1887; Kingma 1971; Beu *et al.* 1980; Boyle 1987; Kamp *et al.* 1988). Now known as Bluff Hill and Hospital Hill, Scinde Island ceased being an island after the 1931 Napier earthquake. Boyle (1987) introduced the term Scinde Island Formation, although it was emended by Beu (1995) to Scinde Island Limestone.

Boyle (1987) referred to all beds at Scinde Island, except for a thin capping layer of Pleistocene siltstone, as the Scinde Island Formation. Kingma (1971) had previously subdivided the strata at Scinde Island into three informal "formations" and mapped them through the Te Aute subdivision. Geological mapping in this report has demonstrated that beds cropping out at Scinde Island are restricted to that area and a small surrounding region in the subsurface only. This report has also demonstrated that beds Kingma (1971) correlated with rocks at Scinde Island are significantly younger. For these reasons Kingma's lithostratigraphic nomenclature for this part of the succession is not continued. Boyle argued that although beds at Scinde Island could be subdivided into mappable intervals their limited geographic distribution meant that having them as individual formations was inappropriate. She therefore established one formation and named five individual members within that formation. The definition of Boyle (1987) is retained in this report. Beu (1995) restricted the name Scinde Island Limestone to only the lowest limestone-dominated package exposed at Scinde Island (and it's assumed lateral correlatives elsewhere in the study area). This corresponded to Kingma's "lower Scinde Island limestone" and Boyle's "Member A". The remainder of the beds exposed at Scinde Island remained unnamed and undescribed in the descriptions of Beu (1995). Geological mapping in this report has demonstrated that beds cropping out at Scinde Island are restricted to the immediate Scinde Island and Onekawa region at Napier and rapidly pass laterally into mudstone facies of the Taradale Formation. As with Kingma's (1971) stratigraphy for the Scinde Island Formation, that proposed by Beu (1995) is also discontinued. The term "Formation" is maintained over "Limestone" in the name of the Scinde Island Formation to reflect the diverse lithologies present in the unit.

Type locality and reference sections

The type section designated by Beu (1995) is retained in this report. This section was described by Boyle (1987) and Kamp *et al.* (1988). Caron (2002) described in detail a section above a car yard at Scinde Island which is nominated as a reference section.

Lower and upper contacts

Scinde Island Formation is sporadically overlain by Pleistocene silts and clays on Scinde Island (Boyle 1987). The lower contact of the Scinde Island Formation is not exposed.

Distribution and thickness

Scinde Island Formation is restricted in outcrop to Scinde Island itself at Napier city (Hospital and Bluff Hills). This locality corresponds with a structural high associated with the sub-surface Napier Fault. The presence of this fault (and the associated anticline) led to the drilling of hydrocarbon exploration hole Hukarere-1 by Westech Energy New Zealand Ltd in 2000 (Westech Energy New Zealand Ltd 2001, PR 2656).

Scinde Island Formation was intercepted in a drillhole sited at Onekawa and extends its distribution slightly to the west from Scinde Island. Scinde Island Formation is inferred to rapidly pass into mudstone facies of the Taradale Mudstone in all directions away from Scinde Island and Onekawa. Scinde Island Formation was not intercepted in the Taradale-1 drillhole where, Rather than limestone, mudstone with an outer shelf environment of deposition was intercepted (Darley and Kirby 1969). Scinde Island Formation was not intercepted in Hukarere-1 drillhole, probably because Kelly Bushing was below the base of the formation.

Correlations have been made in the past between Scinde Island Formation and limestone cropping out at Park Island (e.g. Kingma 1971). Geological mapping in this report has clearly demonstrated that these units are not correlatives, and that Park Island Limestone Member (Petane Formation) is significantly younger than beds at Scinde Island.

Description

The subdivision of the Scinde Island Formation into five members by Boyle (1987) has been retained in this report. The character of each member is presented below based on Boyle (1987).

Paleontology and age

The type locality for the Lower Nukumaruan pectinid *Phialopecten triphooki* (Zittel) is located low in Scinde Island Formation at Napier (Beu 1995). Near the base, the formation has yielded reliable planktic foraminiferal ages at two localities. The diagnostic Lower Nukumaruan zonal species *Truncorotalia crassula* and dextral *Truncorotalia crassiformis* have been identified from both of these sample sites (Hornibrook 1981, p. 282; Beu 1995). Together with the presence of *Pelicaria convexa*, Beu (1995) suggests that this biostratigraphy provides a highly reliable Lower Nukumaruan age independent of *Phialopecten*, and allows for the occurrence of *P. triphooki* in a Lower Nukumaruan, post-Mangapanian zone to be relied on as a correlation tool away from Napier.

Samples from Scinde Island Formation intercepted by a New Zealand Geological Survey drillhole at Onekawa (V21/436815) contained *Truncorotalia truncatulinoides, T. crassiformis* (dextral), *T. crassula* (dextral), and *Globoconella punticulionoides* (Hornibrook 1981, p. 282; A. Beu GNS Science, pers. comm. 1986, cited in Boyle 1987 p.45). This assemblage is similar to that reported from Scinde Island itself by Beu (1995).

Scinde Island Formation is in part a lateral equivalent of the upper Matahorua Formation (top of Papakiri Member and Grassy Knoll Conglomerate Member) based on the first occurrence of *Phialopecten triphooki* in the Papakiri Member. Scinde Island Formation is also a lateral equivalent (at least in part) of the Mason Ridge Formation, and Sentry Box Formation.

Environment of deposition

Scinde Island Formation possibly developed on a growing anticlinal high during the Lower Nukumaruan. This was during a time when large braided river systems were actively supplying significant quantities of sediment to a proto-Hawke Bay (Bland 2001). The effect of the structural high was to keep carbonate factories above and away from the major supplies of siliciclastic sediment in the basin. Fauna in the Scinde Island Formation indicate deposition at shelf water depths.

tidal currents swept the sea floor as evidenced by the giant-scale cross-beds exposed at the type section (Kamp *et al.* 1988). Boyle (1987) suggested that variations in the degree of cementation, siliciclastic content, crude bedding and the amount of micrite present in Member A may mean that deposition of at least lower parts of the formation occurred episodically

The correlation of Scinde Island Formation with Matahorua Formation, Mason Ridge Formation and Sentry Box Formation has interesting implications in terms of paleogeography as it suggests that limestone was accumulating in a proto-Hawke Bay at the same time that large volumes of siliciclastic sandstone and greywacke gravels were being deposited by major river systems to the west.

Member A

Definition, distribution and thickness

Member A is the basal and thickest member defined for the Scinde Island Formation. Beu (1995) restricted his definition of Scinde Island Limestone to only this member, leaving the remainder of the rocks at Scinde Island undifferentiated. The distribution of Member A at Scinde Island mostly corresponds to that shown by Kingma (1971) for his "lower Scinde Island limestone". Member A is the most widespread of the five Scinde Island Formation members and forms the base of the block of Scinde Island. The member reaches its maximum thickness of 90 m at the end of Bluff Hill overlooking the Port of Napier. Towards the southwest Member A dips beneath the overlying sandy siltstone of Member B at Battery Point (Boyle 1987).

Contacts

The lower contact of Member A is not exposed. Logs from adjacent drillholes suggest that the Member overlies blue-grey siltstone of the Taradale Mudstone. It is not known if this contact is conformable, however, similar contacts in other parts of the study area are typically conformable and gradational.

In southwest parts of Scinde Island, Member A is unconformably overlain by Member B. In the north and east of Scinde Island, Member A is overlain by loess.

Description

Member A is characterised by very large-scale cross-beds that are well-exposed at the northern end of Scinde Island adjacent to the Port of Napier. The member consists of strongly cross-bedded, differentially cemented, calcareous sandstone interbedded with lenses of sandy coquina limestone (Boyle 1987). shellhash occurs scattered through the less well cemented sandstone beds. Mud-lined *Ophiomorpha* burrows averaging 6 cm long and 0.5 cm wide occur frequently on the underside of preferentially cemented sandstone beds towards the base of the section at Scinde Island (Boyle 1987).

Around Centennial Gardens (V21/457840) the member comprises large-scale trough cross-bedded calcareous sandstone in sets up to 1 m thick.

Member B

Definition, distribution and thickness

Member B is restricted to northern and western parts of Scinde Island. It is thickest in southwestern parts of Scinde Island (16 m) and thins towards the northeast to 1 m thick (Boyle 1987).

Contacts

Member B unconformably overlies Member A, and is disconformably overlain by Member C in the southwest of Scinde Island. Member B is overlain by loess in the northeast of Scinde Island (Kingma 1971; Boyle 1987).

Description

Member B comprises light brown, massive, calcareous sandstone with occasional scattered fragments of *Talochlamys gemmulata*. Well cemented concretions 2-3 cm in diameter occur in the upper few metres of the member. The member is extensively burrowed and reworked resulting in obliteration of any sedimentary structures (Boyle 1987).

Member C

Definition, distribution and thickness

Member C was mapped by Hutton (1886) and Kingma (1971) as part of the upper Scinde Island limestone and correlated with the Waipatiki Limestone Member (Petane Formation) by Kingma. Geological mapping in this report has clearly illustrated no correlation between these two limestone intervals, which are separated by over 500 k.y. and many tens of metres of stratigraphic section. Boyle (1987) subdivided the upper Scinde Island limestone (of Kingma 1971) into three members, all of which are retained in this report. Member C is applied to the lowest of these three members.

Member C is mostly restricted in outcrop to the southwestern (Hospital Hill) end of Scinde Island. It is thickest at Scandinavian Point (30 m) and gradually thins northward towards Battery Point (18 m). The distribution of Member C has been strongly controlled by erosion such that the member is absent in the south and east of Scinde Island, and that only the more erosion-resistant limestone part of the member is present in the northeast (Boyle 1987).

Contacts

Member C disconformably overlies Member B toward the southwest end of Scinde Island. The contact is exposed at Scandinavian Point and Pandora Point (Boyle 1987). The upper gradational contact between Member C and Member D is poorly exposed. It has been recorded half-way between Battery Point and Pandora Point (Boyle 1987). Occasionally the contact may be marked by a thin, poorly sorted pebbly conglomerate.

Description

Member C is characterised by alternating thin (6 cm-thick) beds of shellhash and mudstone, and small-scale shallow trough cross-bedded limestone. Minor sandy units, conglomerates and shellbeds are also present (Boyle 1987).

Member D

Definition, distribution and thickness

Member D is restricted in outcrop to the southwestern end of Scinde Island near Pandora Point. The member is thickest south of Battery Point (V21/447833) and thins to 13 m at Pandora Point (Boyle 1987).

Contacts

Member D gradationally overlies Member C. In rare cases the contact may be marked by a thin poorly sorted pebbly conglomerate. Member D is overlain either by Member E or by a thin covering of Pleistocene loess (Boyle 1987). Although the contact between Members D and E was difficult to determine, (Boyle 1987) inferred it to be well defined and disconformable.

Description

Member D consists of up to 11 m of extensively bioturbated flaser to wavy and lenticular-bedded sandstone and mudstone which are overlain by up to 13 m of pumiceous muddy sandstone. The pumiceous muddy sandstone is finely laminated, and contains mudstone clasts and poorly sorted greywacke pebbles (Boyle 1987).

Member E

Definition, distribution and thickness

Member E is the stratigraphically highest member of the Scinde Island Formation as defined by Boyle (1987). Member E is restricted in outcrop to one small poorly exposed section at the southwestern end of Scinde Island toward the top of Pandora Point. The member is approximately 10 m thick (Boyle 1987).

Contacts

At Battery Point, muddy sandstone of Member D grades conformably into Member E (Boyle 1987).

Description

Member E comprises a whitish brown barnacle-rich limestone. The unit displays crude horizontal bedding. Around Pandora Point, Member E is unconformably overlain by Pleistocene loess (Boyle 1987).

WAIPUNGA FORMATION (wp)

(Haywick 1990; formally defined by Haywick *et al.* 1991)

Name and definition

Waipunga Formation (Fig. 19F) was formally defined by Haywick *et al.* (1991), and applied to soft to friable Nukumaruan sandstone exposed at the base of northwestern parts of the Tangoio Block. This definition replaced the informal Waikoau sandstone of Beu and Edwards (1984) as this name was pre-occupied elsewhere. Bland (2001) emended this definition and applied it to sandstone facies of Nukumaruan age lying stratigraphically above the last conglomerate bed of the Matahorua Formation, and below siltstone of the Esk Mudstone in the Esk River catchment. Graafhuis (2001) also extended the definition of the Waipunga Formation of Haywick *et al.* (1991) to include a series of sandstone and siltstone beds above the uppermost conglomerate bed of the Matahorua Formation, and below the siltstone of the Esk Mudstone in the Waikoau and Waikare River catchments.

Lower and upper contacts

Although generally poorly exposed, both the lower and upper contacts of this unit are conformable through outcrop extent. The lower contact is exposed in Kaiwaka Stream (V20/368064) and in the Esk River downstream of the Deep Stream confluence (V20/378067, Column Tp-7).

Distribution and thickness

Waipunga Formation is one of the least widespread formations in the upper parts of the Mangaheia Group and is geographically restricted to northern parts of the Tangoio Block between the Esk and Waikare River catchments. In southeast and southwest directions Waipunga Formation passes laterally into mudstone and siltstone facies of the Esk and Taradale Mudstones. Towards the northeast the formation passes into upper members (Grassy Knoll Conglomerate and Papakiri Members) of the Matahorua Formation and the Esk Mudstone.

Description

The Waipunga Formation is a siliciclastic-dominated unit that varies between a single non cemented fine sandstone bed in the south, and fine-grained siltstone to sandy siltstone units in the north.

Paleontology and age

Waipunga Formation is sparsely fossiliferous and few age-diagnostic species have been recognised. Occasional valves of *Atrina pectinata zelandica* were collected in Kaiwaka Stream. On the basis of stratigraphic position between the H.O. of *P. triphooki* and the L.O. *Pelicaria convexa* a Lower Nukumaruan age is assigned to the Waipunga Formation.

Environment of deposition

Waipunga Formation was deposited in a number of shelf-dominated environments from nearshore to middle shelf water depths. Waipunga Formation probably accumulated in a region of slightly shallower water than surrounding areas.

ESK MUDSTONE (ek)

(Smith 1877; formally defined by Haywick *et al.* 1991)

Name and definition

Smith (1877) used the name Esk Papa for siltstone exposed along the Esk River to the west of the Tangoio Block. Beu and Edwards (1984) applied the name Taradale mudstone (informal) to this succession after the interval intercepted in the Taradale-1 drillhole (Darley and Kirby 1969). Esk Formation was introduced by Haywick (1990) and formally defined by Haywick *et al.* (1991). They preferred the name "Esk" over "Taradale" as they felt the sequence in Taradale-1 was not clearly correlated with the sequence exposed in the Tangoio Block. Haywick *et al.* (1991) argued that Esk Formation had priority over, and was preferred to, Taradale Mudstone. Esk Formation was also adopted by Bland (2001) and Graafhuis (2001). Beu (1995) emended Esk Formation to Esk Mudstone to highlight the dominant lithofacies of the formation. The name of Beu (1995) is retained in this report although the definition has been emended to include beds previously omitted.

Erdman and Kelsey (1992) formally defined the Ohara Mudstone in reference to a Lower Nukumaruan mudstone-dominated interval cropping out widely in the Ohara Depression and Kereru region. Geological mapping in this report has demonstrated that a continuous northeast-southwest trending belt of Lower Nukumaruan mudstone and siltstone crops out from Putorino in the north of the study area to Kereru in the south. This belt includes mudstone assigned by Haywick *et al.* (1991) and Beu (1995) to the Esk Mudstone, and beds assigned by Erdman and Kelsey (1992) to the Ohara Mudstone. As Esk Mudstone is a well established stratigraphic unit in the study area, and outcrop is relatively continuous, the Ohara Mudstone of Erdman and Kelsey (1992) is now incorporated into Esk Mudstone and use of the name Ohara Mudstone is discontinued.

Type locality and reference sections

The type section designated by Haywick *et al.* (1991) on Dunvegan Farm has been retained (V20/386042). A reference section was designated by Bland (2001) in the Esk River from Island Farm up-stream to a point near the confluence with Deep Stream (V20/386042-383063).

Well exposed reference sections through southern outcrops of the Esk Mudstone are designated in the Ngaruroro River and Jumped Up Stream. The Jumped Up Stream section is the type section for the Ohara Mudstone of Erdman and Kelsey (1992). It extends from the top of the Sentry Box Formation (U21935665, Column Ke-3) 1 km downstream to a cliff face at the confluence of Jumped Up and Ohara Streams (Fig. 19A). This section is continuous up to the base of the Kereru Formation in a high bluff on the east bank of Ohara Stream (about U21/946653). The Ngaruroro River section occurs from the faulted lower contact between greywacke and the Esk Mudstone (Mohaka Fault; U21/022770) to the conformable lower contact with the Kereru and Okauawa Formations (Fig. 19C; U21/092760, Column Mt-1).

Lower and upper contacts

Esk Mudstone everywhere sharply overlies shallow-water formations throughout its outcrop extent, although in places on the Wakarara Range the formation unconformably overlies Torlesse basement. The formation coarsens upwards and is conformably overlain by a variety of formations. In the Tangoio Block and Eskdale areas it passes into the lower sandstone facies of the Tutira Formation (Fig. 22D). Southwestwards through the Rissington (Fig. 22A) and Crownthorpe/Sherenden areas (Fig. 22B) the formation is conformably and successively overlain by the Tangoio Formation (Flag Range Member) and the Okauawa Formation. In the Ohara Depression, Esk Mudstone is overlain by the Kereru Formation. Esk Mudstone laterally interdigitates with the Tutira Formation, Aropaoanui Mudstone, Taradale Mudstone and Kereru Formation.

Where Mount Mary Formation is absent, Esk Mudstone rests directly and unconformably on greywacke comprising the Wakarara Range. In the Ngaruroro River section several hundred metres below the Whana Valley Cable, Esk Mudstone lies in fault contact with greywacke due to displacement on the Mohaka Fault (Fig. 22E).

Distribution and thickness

Esk Mudstone is perhaps the most widespread formation in the upper Mangaheia Group, cropping out through central to western parts of the study area from Putorino (Fig. 22F, G) in the northeast to the Ohara Depression in the southwest (Fig. 22C). Lateral equivalents are likely to occur at the mouth of the Mohaka River where Lower Nukumaruan mudstone crops out.

Esk Mudstone is approximately 120 m thick through the Esk and Tangoio area (Fig. 19F) and thickens significantly north of the Tangoio Block into the Waikare River. In the Ohara Depression the formation is c. 410 m thick (Erdman and Kelsey 1992) (Fig. 19C).

Description

Esk Mudstone comprises blue-grey, non cemented, non to slightly fossiliferous sandy siltstone that becomes sandier up-section. It typically grades into the Tutira Formation, except in Rautoitoi Stream (Fig. 22D). The Esk Mudstone is characterised by many well sorted, frequently bioturbated tephra beds that punctuate the unit. Tephra beds are particularly well exposed in the Waikare (Fig. 22F, G), Esk, and Mangaone Rivers (Fig. 22A), although tephra beds are present in the Tutaekuri and Ngaruroro River and Ohara Stream sections. Tephra beds vary from fine ash to medium-lapilli-sized pumiceous materials, are 0.1-0.6 m thick (Fig. 22G), and are more common in lower to middle portions of the formation. Tephra beds appear to be less common in southern areas.

In the Jumped Up Stream section the lower 80 m of the Esk Mudstone consists of massive, slightly fossiliferous siltstone. This grades into interbedded sandstone and mudstone over 2-3 m. Sandstone beds are 2-30 cm thick and alternate with 0.5-3 cm thick finely laminated fine-grained siltstone beds. Sandstone beds are blue-grey and locally fossiliferous and bioturbated. Siltstone layers are more calcareous and locally disrupted by burrows (Erdman and Kelsey 1992).

Paleontology and age

Scattered macrofossils occur throughout the Esk Mudstone, and are typical of shelfal soft-bottom assemblages in Hawke's Bay. In the lower parts of Otakowai Stream clusters of the large foraminifera *Purgo anomola* are visible (V20/372041). *Pratulum pulchellum, Talochlamys gemmulata* and *Maoricolpus roseus* are the dominant fauna, with *Atrina pectinata zelandica* and *Pelicaria acuminata* also common. Rare valves of *Ostrea chilensis* are occasionally present.

In Jumped Up Stream diagnostic bathyal faunas have been collected from near the base of the Esk Mudstone where it abruptly but gradationally overlies upper muddy limestone beds of the Sentry Box Formation (Beu 1995). Fauna in this lower part of the Esk Mudstone include *Aeneator orbita, Comitas onokeana*, and the very diagnostic bathyal taxon *Sassia kampyla jobbernsi* (Beu *et al.* 1977; Beu 1995).

Based on the age of underlying units, the presence of *Pelicaria acuminata* and stratigraphic position, the Esk Mudstone is of Lower Nukumaruan (Late Pliocene) age. Foraminiferal samples from Mangatutu and Willowford (V20/f443 and U20/f149) confirm a Nukumaruan age, constrained by both planktic and benthic taxa. The Mangatutu sample includes *Truncorotalia crassula, Globoconella inflata triangula* and *Notorotalia zelandica,* while the Willowford sample is constrained by *Truncorotalia crassula* and *Notorotalia zelandica.*

Fig. 22 (facing page): Esk Mudstone throughout the study area. **A)** High cliff face exposure of Esk Mudstone in the lower reaches of the Mangaone River upstream of Rissington (V21/303896). Two prominent tephra beds (arrowed) occur in this exposure, the lower one of which has been sampled for major element glass geochemical analysis (sample WP 1011). **B)** Esk Mudstone cropping out in the Tutaekuri River below Flag Range (V21/248857). The prominent dark-coloured horizon dipping through the outcrop is a tephra layer. **C)** Esk Mudstone in Ohara Stream below Mangleton Road sharply overlain by thick poorly sorted Holocene fluvial terrace deposits (U21/009721). **D)** Esk Mudstone sharply underlying Tutira Member (Petane Formation) in Rautoitoi Stream (V20/375000). This sharp contact is inferred to represent a regressive surface of erosion (arrowed) in terms of sequence stratigraphy. **E)** Esk Mudstone in fault contact with Torlesse basement rocks in the Ngaruroro River at Whana Valley (U21/022770). The trace of the Mohaka Fault is marked on the photo by a red line. It is a vertical trace, with over 100 m of fractured and strongly deformed rocks cropping out both upstream and downstream of the fault. **F)** Exposure of Esk Mudstone in the lower reaches of the Waikare River downstream of Putorino (W19/569221). Tephra beds (arrowed) are visible as thin prominent horizons near the top of the exposure. **G)** Close-up view of a tephra bed in Esk Mudstone, Glenbrook Road, near Putorino (W19/579211). Note the well-developed burrows in the tephra bed.


A
B
C
D
Tutira Member
RSE
Esk Mudstone
E
Mohaka
Fault
Esk
Mudstone
Torlesse
Basement
F
G

Environment of deposition

Foraminiferal sample U20/f149 from Willowford (U20/096904) contains an assemblage that indicates an inner to middle shelf (0-100 m) depositional environment with a slight brackish influence. The sample contained 1% planktics which suggests a sheltered inner neritic water mass. Foraminiferal sample V20/f443 from V20/157915 suggests deposition in an outer shelf (100-200 m) environment under normal marine conditions.

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Macrofossil collections from the upper Esk Mudstone at V20/397107 along Darkys Spur Road contain *Jupiteria, Talochlamys gemmulata* (dominant)*, Atrina pectinata, Ostrea chilensis, Stiracolpus* and *Notocallista.* A collection from V20/403107, also on Darkys Spur Road, contained *Jupiteria, Pratulum pulchellum, Talochlamys, Ostrea, Nucula, Pelicaria* ?*acuminata, Dosinia greyi, Myadora, Pleuromeris* and *Stiracolpus*. This fauna suggests a deep-water assemblage towards the edge of the continental shelf (A. Hendy, University of Cincinnati, pers. comm. 2004). Bathyal deposition is indicated in basal parts of the formation in the Ohara Depression where Esk Mudstone gradationally overlies Sentry Box Formation (Beu 1995).

PETANE FORMATION (pe)

(McKay 1886)

Name and definition

Bioclastic beds of the Tangoio Block were termed the "Petane Limestone" by McKay (1886), and were subsequently incorporated into the more regional Petane Series defined by McKay (1887). This series included all rocks between the Pohui Series (Pliocene) and Patangata Series (?Pleistocene). McKay (1886) derived the name Petane from a Maori Pa located on the north side of the Esk River, just up-stream of where modern State Highway 2 crosses the river. The Petane Series was subdivided into the Mahia, Waipatiki and Kaiwaka Beds. Beu and Edwards (1984) introduced the first detailed lithostratigraphic scheme for central Hawke's Bay, forming the basis for the lithostratigraphy established by Haywick (1990). The Petane Group was introduced by Haywick (1990) and formally defined by Haywick *et al.* (1991), emending the "Petane Limestone" of McKay (1886). Haywick *et al.* (1991) could not accurately define the base of the group, and tentatively placed it at the base of the Waipunga Formation.

The top of the group was placed at the top of the Kaiwaka Formation, which coincided with either the modern land surface or an unconformable contact with Castlecliffian (Middle Pleistocene) Kidnappers Group gravels. Bland (2001) and Graafhuis (2001) placed the base of the Petane Group at the base of the Matahorua Formation, extending the group into rocks of Upper

Mangapanian age. The age of the basal surface of the Petane Group, as defined by Bland (2001) and Graafhuis (2001), is inferred to be approximately 2.48 Ma (see Chapter 4). This definition was supportable in the Esk and Waikoau River sections of which the Tangoio Block is a part.

Fieldwork during this report demonstrated that the base of the group could not be consistently or accurately defined away from the Tangoio Block. Formations within the Petane Group (such as the Tangoio and Waipatiki Formations) have been confidently mapped from the Tangoio Block southwest to Taradale and Puketapu near Napier. The succession here comprises Taradale Mudstone, overlain by the Park Island Limestone Member, Mairau Formation and higher formations above this. The Matahorua Formation is not present here, having passed laterally into the Taradale Mudstone, as have the Esk Mudstone, Tutira and Aropaoanui Formations. Beu (1995, p. 126) placed the base of the Petane Group in the Napier area at the inferred position of the base of the Nukumaruan stage determined in Taradale-1. However, this level occurs *within* a lithologically identical massive mudstone facies which continues downwards for a further 550 m where the beds have a Waipipian age. It is accepted that biostratigraphy and chronostratigraphy cannot be employed for defining the boundaries of lithological groups. Further to this, the position of the base of the Nukumaruan Stage in Taradale-1 could not be accurately determined. Similar problems with identifying and defining the base of the Petane Group occur through the Sherenden, Otamauri and Matapiro areas.

An important conclusion of this report is that the maintenance of Petane as a group name is unsustainable in a regional context, and it is proposed that the Petane Group, as defined by Haywick *et al.* (1991) and Beu (1995), be incorporated into the Mangaheia Group. It is proposed that the group be demoted to a formation, and the name Petane retained in this context. Petane Formation is applied to a similar although more restricted interval of the Nukumaruan succession than in its previous usage. Mangaheia Group, as defined by Mazengarb *et al.* (1991) and Mazengarb and Speden (2000), is a well-defined interval of Kapitean to Waipipian shelfal rocks extending from the Tauwhareparae area north of Gisborne to the Wairoa District. The top of the group was defined as the top of the youngest marine beds in their study areas. This report has extended Mangaheia Group into the current study area to encompass rocks very similar in character to those for which the original definition was applied. In the current study area shelfal beds continue above "typical" Mangaheia Group beds into the Early Pleistocene succession with no major unconformities or breaks. It is logical, therefore, to incorporate all these units within the Mangaheia Group.

Abolishing the Petane Group has several benefits including: 1) it simplifies the stratigraphy of the Hawke's Bay part of the forearc basin in that only three groups are now defined, each reflecting key phases in the development of the area; 2) it better links stratigraphy north of the study area to the study area itself, and is an important step towards a more regional stratigraphy. This is important as the QMAP programme continues south through the eastern North Island; and 3) it means that the base of each of the groups is easily defined and identifiable in the field. It removes any ambiguity as to where a group boundary should be placed.

Petane is retained as a formation name for much of the succession in the Tangoio Block and its lateral equivalents because of historical usage, and because the interval can still be usefully subdivided and geologically mapped. The new definition of Petane Formation assembles together an interval comprising all or part of five shelfal sequences containing sandstone, siltstone, limestone and conglomerate lithofacies. This is consistent with other formations in the Mangaheia Group that also represent intervals of multiple sequences and similar lithologies such as the Titiokura, Matahorua, Mason Ridge, Kereru, and Okauawa Formations. The stratigraphic thickness (over 100 m) and diversity of lithofacies in the Kaiwaka Formation of Haywick *et al.* (1991), the stratigraphically highest unit of the old Petane Group, means that it is defined in this report to remain as a separate distinct formation. The internal composition of the Kaiwaka Formation, and lateral continuity of constituent beds also remains poorly resolved at this point, and it is desirable to maintain it as a separate formation until a higher degree of differentiation can be achieved. Likewise, the Esk Mudstone, part of the Petane Group of Haywick *et al*. (1991), is retained as a formation due to its significant stratigraphic thickness and lateral persistence across the entire study area from Putorino to the Ohara Depression. The Esk Mudstone gradationally underlies the Petane Formation.

The Petane Formation (Fig. 19F) is therefore defined as an interval comprising shallow-marine cyclothems that conformably overlie the Esk Mudstone and its lateral equivalent the Taradale Mudstone, and sharply underlie the Kaiwaka Formation. A consequence of demoting the name Petane from group to formation level is that all formations defined by Haywick *et al.* (1991) and Beu (1995) in the Petane Group between the Esk Mudstone and Kaiwaka Formation must also be demoted in rank. Consequently they are now incorporated as members in the Petane Formation, although they have been maintained as separate geological mapping units in this report. These members are the **Tutira Member, Hikuroa Pumice Member, Aropaoanui Mudstone Member, Darkys Spur Member, Tararere Conglomerate Bed, Mairau Mudstone Member, Tangoio Limestone Member, Te Ngaru Mudstone Member, Waipatiki Limestone Member,** and **Devils Elbow Mudstone Member.** In addition to these members, the Petane Formation is defined to incorporate beds that geological mapping has demonstrated are lateral equivalents to units in the Tangoio Block These include the **Park Island Limestone Member** (Darkys Spur Member equivalent) and **Flag Range Conglomerate Member** (Tangoio Limestone Member equivalent).

Type locality and reference sections

The type locality of the Petane Formation is defined as the section exposed in the valley of the Waikoau/Aropaoanui River near State Highway 2 and the Devils Elbow Road Section (V20448109-458070, Column Tg-4). Reference sections for parts of the formation are nominated along the Darkys Spur Road section (V20/390109-411096, Column Tg-3), and in coastal seacliffs from the mouth of the Aropaoanui River (W20/555067, Column Ap-1) to Tangoio Settlement (V20/469985, Column Tg-5).

Lower and upper contacts

Petane Formation typically overlies sandy mudstone of the Esk Mudstone and Taradale Mudstone across a conformable gradational contact. In the Tangoio Block this gradational interval is marked by the transition from the Esk Mudstone to sandstone of the Tutira Member. In the region around Taradale and Roys Hill the interval is marked by the transition from Taradale Mudstone to calcareous sandstone of the Park Island Limestone Member. Rautoitoi Stream is the only exposure known where Esk Mudstone is sharply overlain by sandstone of the Tutira Member (Fig. 24D). In the Matapiro area Mairau Mudstone Member (Petane Formation) abruptly overlies the uppermost conglomerate bed of the Okauawa Formation (Whakamarumaru Member). Lower members of the formation such as the Tutira, Aropaoanui, Mudstone Darkys Spur and Mairau Mudstone Members pass laterally into mudstone facies of the Esk Mudstone and Taradale Mudstone.

The Kaiwaka Formation sharply overlies the Devils Elbow Mudstone Member (Petane Formation) across a transgressive surface of erosion at the top of the Devils Elbow section on State Highway 2 (Column Tg-4). Decimetre-scale relief is common on this contact. The contact is well exposed in two localities on Ohiti Road (V21/298733 and V21/233722).

Distribution and thickness

Petane Formation is widespread across the study area in a northeast-southwest trending belt from the Tangoio Block to the Roys Hill area. The formation is thickest and best developed in the Tangoio Block (Fig. 19F) where it is up to 340 m thick. Away from the Tangoio Block Petane Formation is typically less than 150 m thick, reflecting the transition of lower members (e.g. Tutira) into mudstone lithofacies of the Esk Mudstone and Taradale Mudstone (Fig. 19D-F).

Tutira Member (tu)

(Haywick, 1990; formally defined by Haywick *et al.* 1991)

Name and definition

The Tutira Formation was referred to as an un-named "conglomerate member" of the Taradale mudstone by Beu and Edwards (1984). The name Tutira Formation was introduced by Haywick (1990) and formally defined by Haywick *et al.* (1991) for a prominent greywacke conglomerate bed and associated sandstone and volcaniclastic units immediately overlying Esk Mudstone. This definition was adopted by Bland (2001). Beu (1995) emended the name of Haywick *et al.* (1991) to the Tutira Conglomerate. Tutira Member is re-defined in this report as the basal member of the Petane Formation. It is a package of siliciciclastic sandstone and greywacke conglomerate that conformably overlies the Esk Mudstone and conformably underlies either the Hikuroa Pumice Member or the Aropaoanui Mudstone Member.

Type locality and reference sections

The type section nominated by Haywick *et al.* (1991) on Tutira Station is retained in this report (V20/441126). Reference sections are nominated in bluffs below Darkys Spur Road (V20/402108; Fig. 23B), in bluffs around Beattie Road (V20/355964; Fig. 23E, F), and in the lower reaches of Rautoitoi Stream (V20/379992; Fig. 22D).

Lower and upper contacts

In almost all cases Tutira Member gradationally overlies Esk Mudstone through a coarsening-upward interval of up to several metres. The only exception observed to this is in Rautoitoi Stream where Tutira Member sharply overlies Esk Mudstone (Fig. 22D).

Tutira Member is usually sharply overlain by the Hikuroa Pumice Member. In situations when the Hikuroa Pumice Member is absent, Tutira Formation is abruptly overlain by the Aropaoanui Mudstone (Fig. 23A) across an inferred downlap surface. Laterally Tutira Formation interdigitates with the Esk Mudstone and Taradale Mudstone (State Highway 2).

Distribution and thickness

Tutira Member is restricted in outcrop to the Tangoio Block, and a small area between the lower Esk and Mangaone Rivers. Tutira Member does not crop out west and south of an area near Glengarry and Beattie Roads (Eskdale). Geological mapping demonstrates that the member is coeval with lower parts (Kikowhero Member) of Okauawa Formation exposed in the Ohara-Whana Valley regions.

Description

Tutira Member comprises a coarsening-upwards package of sandstone to greywacke conglomerate facies with a combined thickness of up to 60 m. The lower sandstone interval comprises non cemented, massive, well sorted fine to medium sandstone that gradationally overlies Esk Mudstone. This sandstone is sharply overlain by a prominent greywacke conglomerate bed. The conglomerate bed is massive to strongly cross-bedded, with prominent trough cross-beds well exposed around Tiokapu and Parakowhai Stations. A distinctive element of the Tutira Member is the thick volcanic ash bed (Hikuroa Pumice Member) that consistently overlies the greywacke conglomerate beds (see below) in its upper parts. The member is typically non fossiliferous throughout, although around Eland Station (V20/346033), and in the Waikoau River (V20/449106) a capping shellbed rich in estuarine macrofauna, such as *Austrovenus stutchburyi,* occurs (Fig. 23D).

Paleontology and age

Tutira Member is generally unfossiliferous and no age diagnostic faunas have been sampled. Geochemical determination of glass shard composition with tephra in ODP 181 cores suggest that the overlying Hikuroa Pumice Member has an approximate age of about 2.15 Ma. On the basis of stratigraphic position, Tutira Formation is "middle" Nukumaruan (Late Pliocene) in age (approx 2.15 Ma).

Environment of deposition

Tutira Member was deposited in a combination of depositional paleoenvironments. Sandstone facies represent shallowing-upward nearshore to shoreface environments. Greywacke conglomerate facies are inferred to have been deposited in non-marine braid-plain settings and as part of shingle beaches.

Hikuroa Pumice Member (tuh)

(Haywick 1990; formally defined by Haywick *et al.* 1991)

Name and definition

Hikuroa Pumice Member was formally defined by Haywick *et al.* (1991) for a significant pumiceous unit present in upper parts of the Tutira Member overlying the main greywacke conglomerate bed and underlying the Aropaoanui Mudstone. It is now defined as a member of the Petane Formation. The name is derived from Hikuroa Farm on the Tangoio Block (V20/393109).

Type locality and reference sections

The type section designated by Haywick *et al.* (1991) on Hikuroa Farm is retained (V20/400105). Reference sections are designated along Darkys Spur Road and near Beattie Road (Fig. 23E, F) where the member is well exposed.

Lower and upper contacts

Hikuroa Pumice Member sharply overlies Tutira Member. In the Eskdale region the Hikuroa Pumice Member is abruptly overlain by the Aropaoanui Mudstone.

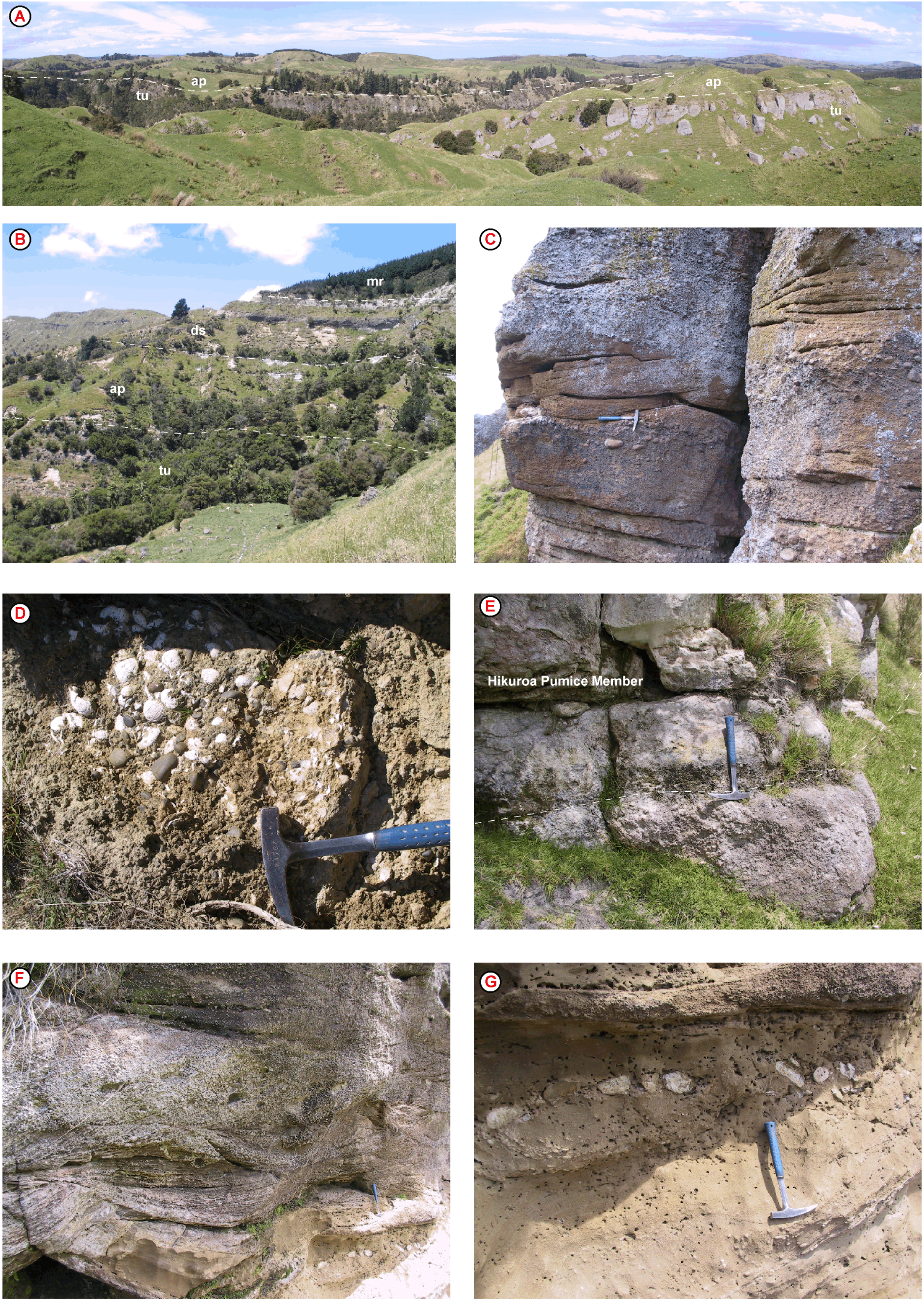
Distribution and thickness

Hikuroa Pumice Member is an easily recognisable member of the Petane Formation and provides an important marker bed that aids confident geological mapping through the Tangoio and Esk regions. Hikuroa Pumice Member is well exposed on Darkys Spur Road, on Eland Station, in low hills around Belmont Station and Beattie Road, and in cliffs along Rautoitoi Stream. Throughout the Tangoio Block the member is 8-15 m thick (Haywick *et al.* 1991).

Description

The Hikuroa Pumice Member comprises a basal primary ignimbrite overlain by reworked pumiceous ash and lapilli. Siliciclastic sand, silt and greywacke pebble lenses and interbeds are common. Carbonaceous fragments and plant imprints are common, with rare *in situ* rootlets (Haywick *et al.* 1991). The member is white to pale-cream in colour, and massive to strongly cross-stratified. Very well-developed trough cross-bedding is preserved in the Beattie Road area (Fig. 23F).

Fig. 23 (facing page): Tutira and Hikuroa Pumice Members, Petane Formation. **A)** Landscape view of the Tutira Member cropping out in the Tiokapu and Parakowhai Station area, near Glengarry Hill. The contact between the Tutira Member and the overlying Aropaoanui Mudstone Member is highlighted (V20/304994). **B)** View of part of the Darkys Spur section from Darkys Spur Road highlighting the relationship between the Tutira Member and overlying members in the Tangoio Block (V20/402107). **C)** Close-up view of the prominent conglomerate facies of the Tutira Member, Tiokapu Station (V20/301991). Note the well developed trough cross-beds illustrating the inferred fluvial deposition environment of much of this facies. **D)** Highly fossiliferous shellbed dominated by the estuarine-restricted bivalve *Austrovenus stutchburyi* (V20/299988). This shellbed commonly overlies conglomerate facies of the Tutira Member in the Glengarry-Parakowhai area and is assigned to a TST in terms of sequence stratigraphy. **E)** Hikuroa Pumice Member sharply overlying Tutira Member near Beattie Road (V20/362967, Column Ek-3). The hammer lies over the contact between the Hikuroa Pumice and Tutira Members. **F)** Close-up view of sedimentary structures within the Hikuroa Pumice Member. Note the well-developed trough cross-beds (V20/360968). **G)** Sandstone of the Tutira Member underlying the prominent conglomerate facies. Clearly visible are mudstone clasts (V20/360968).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Major element geochemical electron microprobe analyses has been undertaken on glass shards in samples from the Hikuroa Pumice Member collected from several localities by K. Bland (this report), B. Alloway and T. Naish (GNS Science), and by A. Palmer (Massey University). Results have helped to confirm correlations made in the field between inferred outcrops of Hikuroa Pumice Member. Average silica content is 77.42%, with 12.25% Al_2O_3, 0.94% CaO and 3.72% K_2O.

Paleontology and age

No age-diagnostic macrofossils have been collected from the Hikuroa Member. Volcanic glass from the Hikuroa Pumice Member has been correlated on the basis of major element geochemistry to tephras 1124C 7H 3W 71-71 and 1124C 7H 3W 117-119 in ODP 1124 (B. Alloway GNS Science pers. comm. 2004). These tephras have been assigned ages of approximately 2.14 Ma.

Hikuroa Pumice Member is assigned a "Middle" Nukumaruan age of approximately 2.15 Ma based on stratigraphic position and geochemical matching of glass shards with the ODP 1124C tephra record. This datum is an important absolute age marker for the Petane Formation and helps in correlating cyclothems in the Nukumaruan succession in the study area with other records.

Environment of deposition

Hikuroa Pumice Member was deposited in a combination of non-marine and marginal-marine to estuarine environments (Haywick *et al.* 1991).

Aropaoanui Mudstone Member (ap)

(Haywick 1990; formally defined by Haywick *et al.* 1991)

Name and definition

Aropaoanui Formation, introduced by Haywick (1990) and formally defined by Haywick *et al.* (1991), was applied to sandy siltstone facies overlying the Tutira [Member], and underlying the Darkys Spur [Member]. The name is derived from the Aropaoanui River which dissects the Tangoio Block, and along which the formation is exposed. This interval was included as part of the informal Taradale mudstone of Beu and Maxwell (1984). The definition of Haywick *et al.* (1991) was emended by Beu (1995) to Aropaoanui Mudstone. The definition of Beu (1995) is emended in this report to Aropaoanui Mudstone Member of the Petane Formation. The unit is not regarded as a distinct formation.

Type locality and reference sections

The type section in the Aropaoanui River nominated by Haywick *et al.* (1991) has been retained (V20/456086). A reference section is designated by Haywick *et al.* (1991) and Beu (1995) on Tutira Reserve (V20/456086).

Lower and upper contacts

Aropaoanui Mudstone Member is gradationally overlain by Darkys Spur Member (Fig. 24B, C). This contact is well exposed on Darkys Spur Road (Fig. 23B; Column Tg-3) and in sea-cliffs north of the mouth of the Aropaoanui River (Column Ap-1). Landslide deposits appear to have mostly obscured the contact at the base of the Devils Elbow Section, although it is exposed on the west side of the farm bridge across the Waikoau River at the base of the Devils Elbow on State Highway 2.

The Aropaoanui Mudstone Member abruptly overlies the Hikuroa Pumice Member. In the Tangoio Block the lower contact is poorly exposed on Darkys Spur Road (V20/402107). Away from the Tangoio Block it is well exposed in the region of Beattie Road, in Rautoitoi Stream (V20/375994), and in rare outcrops on Belmont Station.

Distribution and thickness

Aropaoanui Mudstone Member is locally widespread, though restricted to the Tangoio Block and an area south of the Esk River in the Glengarry and Eskdale areas. Beu (1995) suggested that Aropaoanui Mudstone Member is a lateral equivalent of upper parts of the Taradale Mudstone, a correlation that geological mapping in this report has confirmed. Geological mapping has demonstrated that the Aropaoanui Mudstone Member is a lateral equivalent of lower parts of the Okauawa Formation cropping out in the Kereru-Ohara-Sherenden areas.

The Aropaoanui Mudstone Member is 35-60 m thick through the Tangoio Block (Haywick *et al.* 1991).

Description

Aropaoanui Mudstone Member comprises non cemented slightly to moderately fossiliferous siltstone that coarsens up-section through silty sandstone into fine sandstone (Fig. 24E).

Paleontology and age

The Aropaoanui Mudstone Member is non to moderately fossiliferous. In the Tangoio Block the formation contains an open marine fauna (Haywick 1990). Based on stratigraphic position Aropaoanui Mudstone Member is of “middle” Nukumaruan age.

Environment of deposition

Macrofauna indicate a middle to outer shelf environment of deposition in the Tangoio Block (Haywick 1990) that shallows up-section to an inner shelf setting. The member is gradationally overlain by inner shelf sandstone of the Darkys Spur Member.

Darkys Spur Member (ds)

(Haywick 1990; formally defined by Haywick *et al.* 1991)

Name and definition

Darkys Spur Formation was introduced by Haywick (1990) and formally defined by Haywick *et al.* (1991) to describe a sandstone-dominated unit cropping out in western and northern portions of the Tangoio Block overlying the Aropaoanui Mudstone Member and underlying the Mairau Mudstone Member. The name is derived from Darkys Spur, a steep cliff above the community of Waikoau (Fig. 24A). Beu and Edwards (1984) included this formation in the Park Island Limestone, a correlation supported by Beu (1995). Haywick *et al.* (1991) viewed this correlation as inappropriate as Park Island is many tens of kilometres from the Tangoio Block, and that any correlation between the two areas was far from certain. Also, Park Island Limestone and Darkys Spur Formation are very different in lithology, reflected by separate names. Geological mapping in this report has demonstrated that these two units are most probably correlatives. The definition of the Darkys Spur Formation is emended in this report with the formation now regarded as a member of the Petane Formation, and renamed Darkys Spur Member. The Tararere Conglomerate Member, defined in the Darkys Spur Formation by Haywick *et al.* (1991), is now defined as a discrete bed within the Darkys Spur Member.

Type locality and reference sections

Road cuts midway up Darkys Spur Road, a now renamed part of Kaiwaka Road, are designated as the type section (V20/404104-407105, Column Tg-3). This is the type section established by Haywick *et al.* (1991). Reference sections are designated along the Napier-Wairoa Road at Devils Elbow (V20/447080, Column Tg-4) and immediately north of the mouth of the Aropaoanui River (W20/552065, Column Ap-1).

Lower and upper contacts

On Darkys Spur Road the Darkys Spur Member gradationally overlies the Aropaoanui Mudstone Member through a series of alternating sandstone-siltstone lenses 0.2-1.5 m thick (Fig. 24B, C). It is abruptly overlain by the Mairau Mudstone Member.

Distribution and thickness

Darkys Spur Member is widespread across the Tangoio Block. It is best exposed in road cuts along Darkys Spur Road, in the Devils Elbow section on the Napier-Wairoa Road and at the mouth of the Aropaoanui River. Darkys Spur Formation is age equivalent to middle parts of the Okauawa Formation cropping out in the Ohara Depression, although lateral continuity cannot be demonstrated. The member is a lateral equivalent of the Park Island Limestone Member cropping out in the hills above Taradale, at Fernhill and at Roys Hill.

Conglomerate beds interbedded in the member (Tararere Conglomerate Bed) are restricted to western outcrop areas and are best exposed in the road cutting along Darkys Spur Road (Fig. 26B). Conglomerate facies are also exposed on Eland and Belmont Stations near the Napier-Taupo Road and near Glengarry Road.

Throughout the Tangoio Block the Darkys Spur Member averages 68-90 m thick (Haywick *et al.* 1991). The member thins towards the south. Darkys Spur Member is at least 27 m thick on Darkys Spur Road (Column Tg-3), 16 m thick on the Napier-Wairoa Road (State Highway 2) (Column Tg-4), and 20 m thick at the Aropaoanui River mouth (Column Ap-1).

Description

Darkys Spur Member comprises a wide variety of generally coarse-grained facies that indicate relatively shallow-water to marginal-marine environments of deposition. In the Tangoio Block Darkys Spur Member comprises soft blue-grey to brown-weathering non to highly fossiliferous sandstone with lenses of greywacke conglomerate and minor calcareous sandstone and minor limestone.

The entire member is well exposed from bottom to top at the type section on Darkys Spur Road (Column Tg-3). In this section a variety of facies are present recording several depositional settings. Basal parts of the formation comprise alternating sandstone-siltstone beds (Fig. 24C). Siltstone beds get less common over about 4 m and are eventually overlain by 2 m of clean, well sorted, non to slightly cemented, non fossiliferous, slightly micaceous sandstone. This passes into a 0.5 m-thick bed of sandstone as below, but with abundant siltstone stringers up to 0.1 m thick. The following 6 m of section comprises non cemented very well sorted slightly micaceous fine to medium sandstone. This interval is weakly laminated throughout, though planar laminations are more prominent in the lower 1.5 m. Scattered concretions up to 0.2 m-thick are present in this layer, with one large, very well cemented concretionary body up to 0.6 m thick prominent in the outcrop. The upper half of this interval is broadly trough cross-bedded with prominent moderately- to tightly-packed shell lenses dominated by disarticulated concave-down shallow-water bivalves such as *Dosinia anus, Rexithaerus spenceri, Tellinota edgari, Peronaea gaimardi,* and the barnacle *Austromegabalanus decorus.* Shell lenses become less prominent up-section. The fossiliferous trough cross-bedded sandstone interval passes gradually into approximately 2 m of non cemented, broadly trough cross-bedded to swaley-bedded, fine to medium sandstone with a 0.15 m-thick greywacke pebble lens. This in turn is capped by a ripple and flaser-bedded siltstone interval 0.2 m thick, and then sharply overlain by an 8 m-thick interval dominated by greywacke conglomerate (Tararere Conglomerate Bed). The lower 2 m of the conglomerate contains lenses and interbeds of non cemented, fine to medium sandstone. The 2 m of greywacke conglomerate itself comprises a crudely trough cross-bedded moderately sorted interval with coarse pebble-sized well rounded lensoidal to spheroidal-shaped clasts. This passes abruptly into 2.5 m of very well sorted strongly laminated greywacke conglomerate. This interval is characterised by alternating packages of granule and fine pebble-dominated beds up to 0.5 m thick. The conglomerate is overlain by a massive non fossiliferous siltstone that itself is truncated by a massive, moderately well sorted medium pebble-dominated greywacke conglomerate.

A variety of facies occur in the succession that overlies the conglomerate interval. This 4 m-thick interval comprises a basal massive, non fossiliferous very fine-grained siltstone that passes into massive, highly carbonaceous very fine-grained siltstone with occasional plant fragments and no marine macrofossils. Overlying this is a non fossiliferous fine-grained siltstone with pumiceous lapilli and fine ash, a greywacke conglomerate lens with angular pebble-sized clasts, and a ripple- and flaser-bedded non fossiliferous pumiceous siltstone. This is capped by a non fossiliferous fine-grained siltstone with scattered fine lapilli-sized pumice clasts. The siltstone is sharply overlain by a 0.2 m-thick blue-grey, moderately fossiliferous silty fine sandstone. Macrofauna are dominated by *Maorimactra ordinaria,* with *Panopea zelandica* and *Nucula nitidula.* This sandstone coarsens rapidly into the overlying 4 m-thick moderately to highly fossiliferous sandstone interval that characterises the Darkys Spur Member in this area. Lowermost parts of this sandstone comprises moderately fossiliferous fine to medium sandstone faunally dominated by *Maorimactra ordinaria.* The remainder of this section comprises well sorted fine to medium sandstone (Fig. 26D) dominated by shallow-water taxa representative of nearshore environments, such as *Fellaster, Struthiolaria frazeri, Dosinia anus,* and *Panopea.*

Fig. 24: Darkys Spur Member (Petane Formation) and adjacent units. **A)** Landscape photograph from Darkys Spur, western Tangoio Block. Major stratigraphic units (named) can be identified from geomorphology. Photograph taken from V20/402108, looking north. **B)** Cliff-face below Darkys Spur Road illustrating the stratigraphic relationship between members of the Petane Formation in this area (V20/403107). This is the type section of the Darkys Spur Member and Tararere Conglomerate Bed. Units conformably overlie each other, although the Tararere Conglomerate Bed has a scoured base. The location of Photo D is marked. **C)** Gradational transition from Aropaoanui Mudstone Member into sandstone of the Darkys Spur Member. Darkys Spur Road (V20/404104). **D)** Highly fossiliferous sandstone of the Darkys Spur Member on Darkys Spur Road (V20/407105). This sandstone overlies non- to marginal-marine conglomerate and siltstone facies. Macrofauna in the sandstone are dominated by shallow-water taxa such as *Fellaster* and *Zethalia*, and are characterised by the large Nukumaruan gastropod *Struthiolaria frazeri*. **E)** Moderately fossiliferous sandstone of the Darkys Spur Member cropping out beside Ridgemount Road, northern Tangoio Block (V20/498145). Shallow-water macrofauna are less common here, and the Tararere Conglomerate Bed is absent suggesting that the member here accumulated in a deeper water setting to that at Darkys Spur, and basinward of the lowstand shoreline.

Darkys Spur Member cropping out on the Napier-Wairoa Road at the Devils Elbow (V20/447080, Column Tg-4) represents a transitional unit between outcrops in the west and east of the Tangoio Block. Greywacke conglomerate beds prominent on Darkys Spur Road are absent at this site, as is the high component of calcareous sediment evident at the Aropaoanui River mouth (V20/ 552065, Column Ap-1). Darkys Spur Member at Devils Elbow comprises at least 2.5 m of orange-brown, non cemented, massive sandstone with macrofossils both scattered through the unit and concentrated with shellhash into small clusters. The base of the formation at this site has not been accurately located due to the large landslides that have occurred into the Waikoau/Aropaoanui River valley in this area. Fauna are *Fellaster* dominated, with *Gonimyrtea, Calliostoma, Sigapatella, Tanea, Gari lineolata, Maorimactra,* and *Stiracolpus,* and barnacles are also present. This interval is overlain by 1.8 m of sandstone as below with 0.1-0.15 m-thick concretionary beds that are continuous through the section. These more cemented intervals are present every 0.3-0.4 m. This section is overlain by 12 m of differentially cemented medium sandstone with a variable shellhash content. This interval is generally slightly fossiliferous throughout although some moderately fossiliferous areas occur. Fauna are dominated by *Fellaster zelandiae* at the base and changes up-section to be dominated by *Sigapatella novaezelandiae.* In one bed, *Oxyperis komakoensis* was observed. Crudely and broadly laminated slightly cemented bioclastic sandstone intervals up to 1.5 m-thick occur through this 12 m interval which is capped by 2 m of non to slightly cemented concretionary sandstone. Similar sandstone crops out beside Ridgemount Road in the northern Tangoio Block (Fig. 24E). The transition from the concretionary sandstone of the Darkys Spur Member to siltstone of the overlying Mairau Mudstone Member is not exposed in either this section or at Devils Elbow due to vegetation cover, although the change seems to occur quite abruptly at V20/449080.

Darkys Spur Member crops out in high sea-cliffs north of the mouth of the Aropaoanui River (V20/ 552065, Column Ap-1). Here the formation broadly comprises concretionary sandstone gradationally overlying fossiliferous fine-grained siltstone to sandy siltstone, and in turn is overlain by siltstone. Lower parts of the sandstone unit (at least 10 m thick) comprise several metres of intensely bioturbated non cemented clean, very well sorted, fine to medium sandstone with abundant concretionary lenses and horizons 0.1-0.3 m thick. The sandstone is ripple-laminated to small-scale cross-bedded. Common shell lenses are present and are characterised by shallow-water taxa such as *Dosinia* sp., many of which are articulated, and *Amalda, Zegalerus* and *Zethalia zelandica.* Abundant 1.5-2 cm-thick siltstone stringers are present in the non cemented sandstone layers. Scattered shellhash is present throughout this unit, as are flakes of mica. Up-section the sandstone appears to become slightly more calcareous and passes into concretionary shellhash fine to medium sandstone before passing into a siltstone (Mairau Mudstone Member).

Paleontology and age

Darkys Spur Member contains one of the most diverse shallow-water macrofossil assemblages present in Nukumaruan strata in the study area. Fauna at Darkys Spur are dominated by shallow-water species such as *Fellaster zelandiae, Struthiolaria frazeri, Dosinia* spp., and *Zethalia zelandica*.

Environment of deposition

Fauna observed in the Darkys Spur Member in the Tangoio Block show a deepening pattern from west to east. Fauna at V20/407105 beside Darkys Spur Road (Column Tg-3) are characteristic of shallow-water high-energy settings (e.g. *Fellaster zelandiae*). *Fellaster* are also common on Belmont Station (V20/374987). Fauna at V20/447080 (Column Tg-4) on State Highway 2 (at Devils Elbow) suggest an environment of deposition slightly on the shelf than at Darkys Spur. At Aropaoanui Beach (W20/552065, Column Ap-1) fauna indicate an environment slightly deeper on the shelf than either Devils Elbow or Darkys Spur. Subaerial exposure occurred in the western portion of the Tangoio Block and the Glengarry-Eland-Belmont Station region during deposition of the Darkys Spur Member, as evidenced by the distribution of the Tararere Conglomerate Bed.

Tararere Conglomerate Bed (dst)

(Haywick 1990; formally defined by Haywick *et al*. 1991)

Name and definition

In the western portion of the Tangoio Block the Darkys Spur Member is interbedded with a prominent greywacke conglomerate bed for which Haywick (1990) introduced the name Tararere Member. The name is derived from Tararere Stream (V20 405105). The member was formally defined by Haywick *et al.* (1991). The name has been emended to Tararere Conglomerate Bed, and the unit is now defined as a bed within the Darkys Spur Member.

Type locality and reference sections

The type section designated by Haywick *et al.* (1991) on Darkys Spur Road (Column Tg-3) is retained in this report (V20/405105).

Lower and upper contacts

In the Tangoio Block Tararere Conglomerate Bed is interbedded with the Darkys Spur Member. The lower contact of the Tararere Conglomerate Bed is well exposed on Darkys Spur Road where it sharply overlies a cross-bedded fossiliferous sandstone of the Darkys Spur Member (V20/

405105). The lower contact is well exposed on Belmont Station (V20/372985) where cross-bedded fine to medium sandstone of the Darkys Spur Member is sharply overlain by the Tararere Conglomerate Bed.

In the Tangoio Block Tararere Conglomerate Bed is overlain by a discontinuous oyster and greywacke cobble layer and carbonaceous siltstone of the Darkys Spur Member (Haywick *et al.* 1991). On Eland Station (V20/347020) the conglomerate is overlain by a highly fossiliferous shellbed. At Belmont Station the Tararere Conglomerate Bed is overlain by highly fossiliferous sandstone of the Darkys Spur Member, rich in reworked shallow-water taxa. Although the upper contact is not exposed at on Lucky Hill (V20/337980), fossiliferous float blocks nearby suggest the Tararere Conglomerate Bed is capped by a pebbly shellbed.

Distribution and thickness

The Tararere Conglomerate Bed is restricted to western parts of the Tangoio Block (Haywick 1990), Lucky Hill near Glengarry Road (V20/337980), "Cellphone Tower Hill" on Eland Station, and Belmont Station. In central and eastern parts of the Tangoio Block, Tararere Conglomerate Bed has probably graded into shallow marine sandstone facies. Geological mapping demonstrates that the Tararere Conglomerate Bed is likely to be a lateral equivalent of the conglomerate bed capping the Whakamarumaru Member of the Okauawa Formation, although lateral continuity cannot be demonstrated.

Tararere Conglomerate Bed is 8-15 m thick in the Tangoio Block (Haywick 1990). In the Belmont and Eland Station the member is about 5-6 m thick.

Description

The lower parts of the Tararere Conglomerate Bed at Darkys Spur Road dominantly comprises a non cemented massive, poorly to moderately sorted, fine to medium pebble greywacke conglomerate with clasts 1-2 cm across. Small to moderate-scale trough cross-stratification may be present. Upper parts of the member are better sorted, and display well-developed fine-scale laminations. The average clast size in this upper part is smaller, although larger pebble-sized clasts and layers are still common. Macrofossils are absent to rare, and tend to be concentrated in uppermost capping parts of the member.

In the Glengarry and Belmont Station areas the Tararere Conglomerate Bed comprises laminated to massive greywacke conglomerate. It is often capped by a pebbly shellbed, or fossiliferous sandstone.

Paleontology and age

On Belmont Station (V20/372985) upper parts of the Tararere Conglomerate Bed are moderately fossiliferous. Estuarine and nearshore fauna occur, such as abundant *Austrovenus stutchburyi, Paphies australis* and *Patro undatus.* On "Cellphone Tower Hill", Eland Station (V20/347020), the conglomerate is capped by a 0.15 m-thick highly fossiliferous shellbed containing broken, disarticulated bivalves dominated by *Tawera*.

No age diagnostic macrofossils have been identified in the Tararere Conglomerate Bed. On the basis of stratigraphic position the Tararere Conglomerate Bed is designated a confident "middle" Nukumaruan (Late Pliocene) age.

Environment of deposition

Outcrops on Darkys Spur Road indicate deposition in a combination of shoreface and non-marine settings, with shoreface deposits dominating. Haywick *et al.* (1991) interpreted the lower parts of the bed as representative of a shingle beach. This report interprets lower parts of the bed at the type section as representing non-marine river deposits and upper parts of the bed as shingle beach deposits. Occasional lenticular beds of gravels and rootlet-bearing silts were interpreted by Haywick *et al.* (1991) as non-marine braided stream deposits.

Park Island Limestone Member (dsa)

(Beu and Edwards 1984 (informal); formally defined by Beu 1995)

Name and definition

Kingma (1971) mapped outcrops of limestone cropping out in low hills behind Taradale, near Park Island, as the lower Scinde Island limestone. This unit was named informally Park Island limestone by Beu and Edwards (1984) and formally defined by Beu (1995). Geological mapping has demonstrated that Park Island Limestone Member is equivalent to Darkys Spur Member (Fig. 19E, F), a correlation initially proposed by Beu and Edwards (1984) and supported by Beu (1995). On the basis of stratigraphic position the name Park Island Limestone of Beu (1995) is emended to Park Island Limestone Member, and is incorporated into the Petane Formation. It is defined as a limestone-dominated interval overlying Taradale Mudstone. It is overlain by Mairau Mudstone.

Park Island Limestone Member is named after Park Island, which itself is named after Robert Park, Chief Surveyor of Hawke's Bay (1851-1860). It ceased to be an island after the 1931 Napier earthquake (Beu 1995).

Type locality and reference sections

The type section established by Beu (1995) is retained in this report (V21/417817). This locality comprises long, although incomplete, exposures around the southeastern face of Park Island (Column Td-1).

Lower and upper contacts

In no known location north of the Ngaruroro River is the lower contact of the Park Island Member exposed. The lower contact is exposed at Fernhill immediately south of the Ngaruroro River where the underlying Taradale Mudstone passes gradationally through friable, well sorted fine sandstone into the coarse-grained lower facies of the Park Island Limestone Member (Dyer 2005). The upper contact is exposed in a long section on the southeastern side of Park Island near Taradale (Column Td-1). At this locality siltstone of the Mairau Formation abruptly overlies an *Ostrea-Patro*-rich shellbed that caps the Park Island Limestone Member.

Distribution and thickness

Park Island Limestone Member is restricted in outcrop to southeastern parts of the study area and is present in hills behind Taradale and Puketapu, at Park Island, and the isolated erosional features of Fern Hill and Roys Hill (V. Caron, pers. comm. 2003; Dyer 2005) (Fig. 25A-D). The member is the first coarse-grained, shallow-water unit present in the Taradale area, overlying the Taradale Mudstone.

The outcrop pattern of the Park Island Limestone Member near Napier defines the form of the Taradale Anticline, with low to moderate dips towards the west in the Puketapu area, and low to moderate easterly dips around Taradale and Greenmeadows. The topographic features of Roys Hill and Fern Hill are inferred to represent isolated, fault-bounded blocks. Typically, exposures of Park Island Limestone Member are about 5 m thick, with some up to 8 m thick. A high exposure in an old quarry near Oak Road was described by Moore and Hatton (1985), who estimated a thickness of 18 m. Park Island Limestone Member capping Roys Hill and Fern Hill was estimated by Dyer (2005) to be a maximum of 20 m thick.

Description

Park Island Limestone Member is lithologically quite different to other limestone facies of the upper Mangaheia Group, lacking the greywacke pebbles and relatively intact macrofauna present in other beds (e.g. Waipatiki Limestone Member and limestone facies of the Kaiwaka Formation). Also the colour tends to be grey rather than cream which is typical of other upper Mangaheia Group limestones. Park Island Limestone Member is a lateral, although perhaps slightly more offshore, equivalent of sandstone facies of the Darkys Spur Member cropping out in the central and eastern Tangoio Block (Fig. 19E, F).

Although not present in one single outcrop, composite sections appear to show that Park Island Limestone Member comprises non to slightly cemented medium- to coarse-grained strongly calcareous bioclastic sandstone that passes up-section into the biomouldic limestone exposed at Park Island. In cuttings on Puketitiri Road (e.g. V21/386824) the lower bioclastic sandstone displays moderate to large-scale foresets up to 3 m high by 15 m long. Thin (< 4 cm thick) highly calcareous siltstone stringers are also present at this locality.

Fig. 25: Park Island Limestone Member (Petane Formation) A) Stacked biomouldic grainstone beds of basal Park Island Limestone Member. Note the prominent tabular cross-beds. (V21/285701) B) Typical outcrops of Park Island Limestone Member, Roys Hill (V21/285701) C) Limestone bluffs around the summit of Roys Hill. D) *Atrina pectinata zelandica* in moderately fossiliferous silty sandstone underlying limestone facies of the Park Island Limestone Member. This silty sandstone gradationally overlies Taradale Mudstone (V21/294701).

In the Puketapu-Penrith Road area (Column Pk-2) the Park Island Limestone Member comprises a grey, slightly to well cemented, shellhash sandy medium-grained limestone with abundant biomoulds and uncommon intact macrofauna. Biomoulds in outcrops near Penrith Road (e.g. V21/379829) contain common calcite needles. Near Penrith Road (V21/379829) dissolution of macrofauna makes identification of taxa very difficult. However, valves of Anomidae bivalves (*Patro/Anomia*) and *Zethalia* were observed, with occasional polychaete tubes.

At Roys Hill (Fig. 25A-D) and Fern Hill lower parts of the Park Island Limestone Member comprise creamy, strongly bioturbated, cross-bedded skeletal coarse-grained sandy limestone with a high bryozoan content (Fig. 27A-C). Upper parts of the unit consist of grey, coarse-grained well-bedded and strongly cemented recrystallised limestone (Dyer 2005). The unit contains abundant, biomoulds of aragonitic gastropod and bivalves.

Paleontology and age

Fauna is dominated by aragonitic infaunal bivalves that are largely dissolved and partially recrystallised, giving Park Island Limestone Member a prominent biomouldic texture. From fall blocks at the southern end of Park Island, Beu (1995) identified a shallow-water nearshore soft-bottom infaunal assemblage containing *Ostrea chilensis, Tucetona laticostata, Dosinia* sp., *Eumarcia plana, Dosina zelandica,* abundant *Tawera subsulcata, Purpurocardia purpurata, Lutraria solida, Zethalia zelandica* and *Trochus tiaratus. Atrina pectinata zelandica* is present in silty sandstone facies below the main limestone interval (Fig. 25D). Most biomoulds have polychaete tubes and encrusting bryozoans on their interiors indicating empty, single valves (Beu 1995).

Zethalia zelandica (Nukumaruan-Recent) is the only age diagnostic macrofossil observed in the Park Island Limestone Member. Based on stratigraphic position Park Island Limestone Member is of “middle” Nukumaruan (Late Pliocene) age.

Environment of deposition

Sedimentary structures and faunal composition indicate a nearshore to inner shelf, high-energy environment of deposition for the Park Island Limestone Member. It is possible that the lower, bioclastic sandstone facies represents a regressive deposit that accumulated during a period of falling sea level, and the upper limestone bed a transgressive unit that developed during the subsequent sea level rise. The abrupt contact between the Park Island Limestone Member and overlying Mairau Mudstone Member may represent a downlap surface. The nature of the capping *Ostrea* and *Patro*-rich shellbed supports this interpretation.

Development of the Park Island Limestone Member probably reflects synsedimentary uplift of the Taradale Anticline.

Mairau Mudstone Member (mr)

(Haywick 1990; formally defined by Haywick *et al.* 1991)

Name and definition

Beu and Edwards (1984) informally named the siltstone unit between the Darkys Spur Member and the Tangoio Limestone Member the Petane mudstone, a name that has had a long informal usage (Beu 1995). Haywick (1990) introduced Mairau Formation to avoid confusion with the (now redefined) Petane Group, the name formally being defined by Haywick *et al.* (1991). The name is derived from Mairau Stream (V20/460078). Beu (1995) emended the name to Mairau Mudstone to reflect the dominant lithology. The definition of Beu (1995) is emended in this report to Mairau Mudstone Member as the unit is now incorporated into the Petane Formation. Mairau Mudstone Member is mostly equivalent to the undefined "Waitio pumiceous siltstone" mapped by Kingma (1971). Mairau Mudstone Member is defined as a siltstone to sandy siltstone interval that conformably overlies the Darkys Spur Member and is overlain by the Tangoio Limestone Member (Fig. 19D-F).

Type locality and reference sections

The type section established by Haywick *et al.* (1991) on Te Taihoa Farm is retained (V20/ 467087).

Lower and upper contacts

Mairau Mudstone Member gradationally overlies fossiliferous sandstone beds of the Darkys Spur Member, or the Tararere Conglomerate Bed. It is inferred to gradationally overlie the Whakamarumaru Member of the Okauawa Formation in an northeast-southwest-trending outcrop belt from Mount Cameron, through Flag Range to Crownthorpe Road.

Mairau Mudstone Member coarsens up-section and grades over 5-10 m into sandstone of the Tangoio Limestone Member throughout the outcrop area.

Distribution and thickness

Mairau Mudstone Member is widespread throughout central and eastern parts of the study area, cropping out widely through the Tangoio and Eskdale regions. Towards the southwest it is probable that Mairau Mudstone Member interdigitates with middle to upper parts of the Okauawa Formation. In the lower reaches of the Mangaone River, near Rissington, the Mairau Mudstone Member cannot be differentiated from the Esk Mudstone.

Away from the Tangoio Block and Bayview areas the Mairau Mudstone Member is poorly exposed, although the unit is almost certainly present in the subsurface. The member is not exposed through the central parts of the Matapiro Syncline in the Okawa-Matapiro area where it is in the subsurface. Very limited exposures are present around Puketapu.

The Mairau Mudstone Member thickens westward across the Tangoio Block from 10 to 60 m thick (Haywick *et al.* 1991). The member thins southwest into the Matapiro district where it is between 20 and 30 m thick (Baggs 2004).

Description

Mairau Mudstone Member mostly comprises non cemented, slightly to moderately fossiliferous siltstone passing up-section into silty fine sandstone. In the Ahuriri/Bayview area, Mairau Mudstone Member may be represented by moderately fossiliferous fine sandstone facies.

The Mairau Mudstone Member has a similar character through the Sherenden and Crownthorpe regions where it comprises bioturbated massive sandy siltstone to silty sandstone with scattered macrofossils (Baggs 2004).

Paleontology and age

Mairau Mudstone Member contains a moderately diverse macrofossil assemblage through the area of outcrop. Fauna present are indicative of open marine circulation (Haywick 1990).

Mairau Mudstone Member contains a well constrained biostratigraphic molluscan content. The member contains the last occurrence of *Pelicaria acuminata* (Beu and Edwards 1984) and first occurrence of *Pelicaria convexa* (Beu 1995). Stratigraphic position and the co-occurrence of *P. acuminata* and *P. convexa* confirm an Upper Nukumaruan age for Mairau Mudstone Member (Late Pliocene).

Environment of deposition

Macrofauna from the Mairau Mudstone Member in the Tangoio Block are consistent with a middle shelf (50-100 m) environment of deposition with open marine circulation (Beu 1967; Haywick 1990). To the southwest in the Okawa-Matapiro area, macrofauna are similar to those in the Tangoio Block (Baggs 2004), and a middle shelf depositional environment is also inferred.

Tangoio Limestone Member (tg)

(Beu and Edwards 1984; formally defined by Haywick *et al.* 1991)

Name and definition

Tangoio limestone was introduced as an informal name by Beu and Edwards (1984), and applied to a carbonate-dominated unit conformably overlying the Mairau Mudstone in the Tangoio Block. The unit was given formation status by Haywick *et al.* (1991). The name is derived from Tangoio Settlement in the southeastern part of the Tangoio Block (V20/474101). The definition of Tangoio Formation has here been emended from that of Haywick *et al.* (1991) and Beu (1995) to Tangoio Limestone Member, incorporated into the Petane Formation.

Type locality and reference sections

The type section established by Haywick *et al*. (1991) has been retained in this report. It is located on Hikuroa Farm (V20/393098).

Lower and upper contacts

In the Devils Elbow section (Column Tg-4) calcareous sandstone of the Tangoio Limestone Member gradationally overlies siliciclastic silty sandstone of the Mairau Mudstone Member. The Te Ngaru Mudstone Member abruptly overlies the upper limestone facies of the Tangoio Formation in this section, as it does in exposures along the Pacific coast between Tangoio Beach and Waipatiki Beach. This contact is marked by a concentration of large articulated bivalves such as *Glycymeris* and *Ostrea* (Haywick *et al*. 1991). The upper contact is not exposed through the Puketapu (Column Pk-3) and Omahu (Column Ou-1) areas, but it seems probable that limestone in these regions is also abruptly overlain by siltstone of the Te Ngaru Mudstone Member. Limestone beds in these regions are also capped by a shellbed rich in *Ostrea*.

Distribution and thickness

Tangoio Limestone Member is widely distributed throughout the Tangoio Block and Matapiro Syncline areas. The member is well exposed in sea cliffs north and south of Waipatiki Beach (Fig. 26A, B, D, F). The member prominently crops out on the eastern limb of the Matapiro Syncline around Puketapu (Fig. 26E, G). Outcrops on Swamp Road (Fig. 26C), identified as Matapiro (Waipatiki) Limestone by Beu (1995), have been demonstrated by Baggs (2004) to be Tangoio Limestone Member, extending the occurrence of the member south into low hills around Omahu. The member dips into the subsurface in these areas, and re-emerges on the western limb of the Matapiro Syncline as the Flag Range Conglomerate Member.

A faulted limestone outlier at the northern end of Waipatiki Beach where State Highway 2 turns inland is included in Tangoio Limestone Member on the basis of lithological similarity with nearby known Tangoio Limestone Member exposures (D. Haywick, University of South Alabama, pers. comm. 2003) and stratigraphic position.

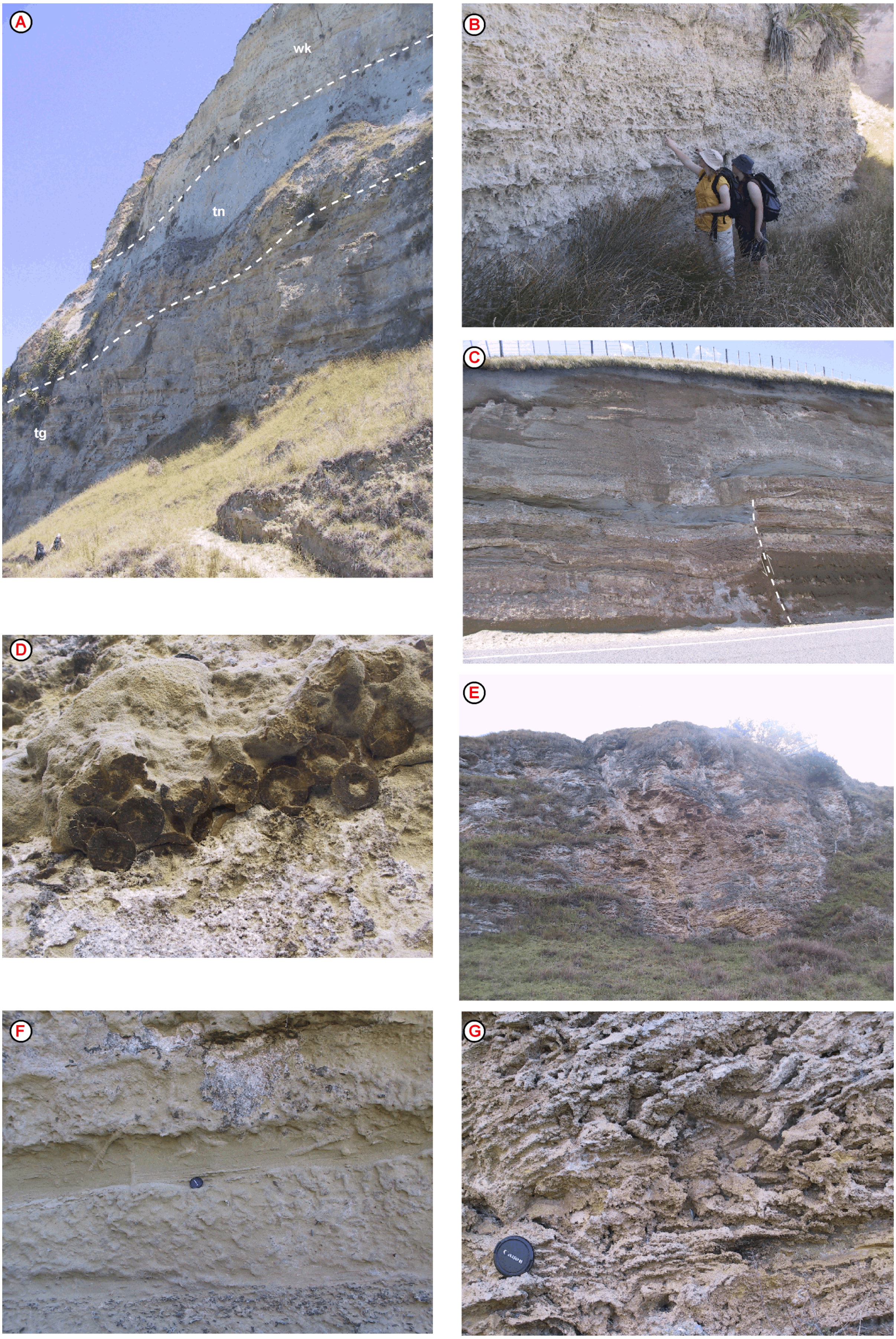
Outcrops of Tangoio Limestone Member through the Taradale and Omahu areas were mapped in part as Lower Scinde Island limestone by Kingma (1971), a correlation that this report has demonstrated from geological mapping is not possible.

Tangoio Limestone Member is 10-50 m thick (Haywick *et al.* 1991) in the Tangoio Block, 10 to 20 m thick in the Puketapu, Taradale, and Okawa-Matapiro areas (Baggs 2004).

Description

Tangoio Limestone Member varies in content through its outcrop extent, ranging from sandstone overlain by sandy limestone, to calcareous sandstone to pebbly oyster-rich limestone. The member passes laterally and up-dip into non to highly fossiliferous conglomerates of the Flag Range Conglomerate Member. The change in lithological character of the member reflects differing paleogeography on the margins of the basin during sedimentation. As a rule, coarser-grained and more siliciclastic facies in the member occur in more westerly positions than bioclastic facies. Throughout the study area, Tangoio Limestone Member contains a diverse range of sedimentary structures. Such structures include small to moderate-scale cross-stratification, planar lamination, flaser-bedding and soft-sediment deformation structures. Well developed bedforms are particularly well exposed along the Devils Elbow Section and on Swamp Road near Puketapu (Fig. 26C).

Fig. 26 (facing page): Tangoio Limestone Member, Petane Formation. **A)** Sea-cliff exposure of Tangoio Limestone Member south of Waipatiki Beach (W20/523032). The Tangoio Limestone Member is gradationally overlain by the Te Ngaru Mudstone Member (tn) which then grades into the Waipatiki Limestone Member (wk). **B)** Tangoio Limestone Member cropping out in sea-cliffs south of Waipatiki Beach (W20/521029). The member here comprises stacked grainstone bodies. Case-hardening is common. **C)** Tangoio Limestone Member exposed in a road cutting beside Swamp Road between Puketapu and Omahu. A small fault (dashed white line) highlights offset of the member, indicating syn-depositional deformation in the basin. **D)** Bed of the shallow-water echinoid *Fellaster zelandiae* in Tangoio Limestone Member south of Waipatiki Beach (W20/521029). Thin shellbeds containing this and other shallow-water molluscs are common in this area. **E)** Tangoio Limestone Member cropping out beside the Tutaekuri River near Puketapu (V21/358804). This outcrop contains abundant soft-sedimentary deformation structures, including inferred water escape structures, that indicate syn-depositional deformation of the basin during the Upper Nukumaruan. **F)** Burrowed sandy interbed in lower parts of the Tangoio Limestone Member, south of Waipatiki Beach (W20/521029). **G)** Close-up of Tangoio Limestone Member near Puketapu showing prominent deformation structures (V21/358804).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In the Devils Elbow section (Column Tg-4) the Tangoio Limestone Member comprises strongly cross-bedded and laminated sandstone that passes conformably up into sandy mixed bioclastic-siliciclastic limestone. Tangoio Limestone Member cropping out around Puketapu comprises strongly cross-bedded, moderately to well cemented, medium to coarse-grained cream limestone. Foresets are of small to large-scale, and low to high-angle. In the main, large areas of most outcrops display case-hardening, and the internal stratification of the formation is not easily visible. Few intact fossils have been found in this area, although shellhash dominates the composition.

In the Puketapu area (Fig. 26D, G) this limestone bed contains a higher bioclastic content (though still with noticeable siliciclastic material) and overlies calcareous sandstone with mudstone stringers. The contact between these two layers is not exposed here, but a similar exposure is present in a cutting along nearby Swamp Road (Fig. 26C). At this locality the limestone sharply overlies calcareous sandstone with common cross-stratification and mudstone stringers via a wavy, broad-amplitude contact. This outcrop was miscorrelated by Beu (1995) to the Waipatiki [Limestone Member], as geological mapping in this report can demonstrate a confident correlation with Tangoio Limestone Member.

At the base of sea cliffs south of Waipatiki Beach (W20/521029) the Tangoio Limestone Member is exposed as a sandy limestone with abundant shelly layers, often dominated by the shallow-water echinoid *Fellaster* (Fig. 26D). The lower contact here is not exposed, although the limestone is sharply overlain by siltstone of the Te Ngaru Mudstone Member.

The most southerly outcrops recognised of Tangoio Limestone Member occur in low hills immediately east of the small village of Omahu where the formation comprises weathered sandy limestone a few metres thick with abundant biomoulds capped by a thin *Ostrea*-dominated shellbed. The distribution of the Tangoio Limestone Member in this area was geologically mapped by Baggs (2004). The formation here is commonly strongly cross-bedded and has the form of stacked mixed bioclastic-siliciclastic sheets, each 0.1-0.3 m thick. This area of outcrop occurs on the eastern limb of the Matapiro Syncline.

Throughout the outcrop extent of the Tangoio Limestone Member, case hardening of the limestone facies is common. Fauna are dominated by aragonitic infaunal bivalves and because of this dissolution and partially recrystallisation of these shells is widespread. Biomoulds are also abundant.

Paleontology and age

Fauna are dominated by aragonitic infaunal bivalves such as *Tawera,* identification of which is often difficult due to dissolution of valves. An *Ostrea*-rich shellbed is common capping the limestone, especially through the Puketapu-Omahu areas. A limited macrofossil assemblage has been collected from the Devils Elbow section. Fauna through the formation here are dominated by *Tawera subsulcata*, with *Maorimactra ordinaria, Oxyperis* and *Ostrea chilensis.* Intact macrofauna near Waipatiki Beach are dominated by beds of the shallow-water echinoid *Fellaster zelandiae* (Fig. 26D).

A confident Upper Nukumaruan (Late Pliocene) age is assigned to the Tangoio Formation based on the occurrence of several Nukumaruan molluscs, such as *Pelicaria convexa*, and stratigraphic position.

Environment of deposition

Fauna and sedimentary structures within the Tangoio Limestone Member are consistent with a shoreface to inner shelf environment of deposition. Tangoio Limestone Member in western parts of the outcrop area were deposited at more shallow marine depths than beds in eastern areas.

Flag Range Conglomerate Member (tga)

(Beu 1995)

Name and definition

Beu (1995) formally defined Flag Range Limestone and Sherenden Conglomerate Member to include a prominent variably fossiliferous conglomeratic interval cropping out widely in the Sherenden and Matapiro districts. The name is emended in this report to Flag Range Conglomerate Member. The name is derived from the prominent conglomerate-capped ridge named Flag Range near Sherenden. This interval has in the past been included in a wide variety of stratigraphic units. Rocks of the Flag Range Conglomerate Member were included in part in the informal Sherenden greywacke gravels of Kingma (1971). Baggs (2004) mapped this interval as the Sherenden Conglomerate Member of the Flag Range Formation. It is proposed that the Flag Range Limestone of Beu (1995) be redefined as a member of the Petane Formation for several reasons. Firstly, Beu considered his Flag Range Limestone to be a lateral equivalent of the Tangoio Limestone Member. Geological mapping in this report has demonstrated that both the Tangoio Limestone Member (as mapped by Haywick 1990) and the Flag Range Limestone (and Sherenden Conglomerate Member) of Beu (1995) are most probably the same stratigraphic unit. Secondly, there is *very little if any* true limestone in Beu's definition of Flag Range Limestone.

In reality the formation is greywacke gravel-dominated with a localised increase in macrofossil content along the crest of Flag Range. In all other areas the Flag Range Limestone consists of a significant thickness of non fossiliferous greywacke conglomerate that is capped by up to 2.5 m of fossiliferous conglomerate. Thirdly, by including the Flag Range Conglomerate Member in the Petane Formation the stratigraphy of the study area is simplified by reducing the number of stratigraphic units.

The name Flag Range (from Beu 1995) is retained over Sherenden (from Kingma 1971) as Flag Range was formally defined, whereas Kingma's name remained informal. The Sherenden Conglomerate Member of Beu (1995) is incorporated into the Flag Range Conglomerate Member of this report.

Flag Range Conglomerate Member sharply though conformably overlies either siltstone and sandstone beds of the Okauawa Formation, or silty sandstone of the Mairau Mudstone Member, and is abruptly though conformably overlain by siltstone of the Te Ngaru Mudstone Member (Fig. 19D).

Type locality and reference sections

The type locality established by Beu (1995) on the crest of Flag Range (Fig. 29A) is retained in this report (V21/193851). Caron (2002, column F1) logged this section and documented elements of the diagenetic history of this section.

Excellent reference sections are common through the study area. Very well preserved, highly fossiliferous horizons are well exposed in Kikowhero Stream immediately above and below the Matapiro Road bridge (V21/192726). A cutting on Puketitiri Road, near Apley Road, clearly displays a highly fossiliferous estuarine variant of the member (V21/315884). The transition from the lower non fossiliferous into upper fossiliferous parts of the member are well exposed in a gravel pit on Muritai Station near Crownthorpe Settlement Road (V21/156786). The transition from the upper fossiliferous part of the member to overlying Te Ngaru Mudstone Member is well exposed on Taihape Road south of the Flag Range Road intersection (V21/185827, Column Sh-1). Large parts of the member are exposed in a farm track leading up to the summit of Mount Cameron from Waihau Road (V21/251881, Column Da-1).

Distribution and thickness

Flag Range Conglomerate Member crops out in a northeast-southwest belt from Puketitiri Road to Matapiro Road, capping the prominent hilltops of McNeil, Mount Cameron (Column Da-1) and

Flag Range (Fig. 27A; Column Sh-2). The distribution of the unit through the Matapiro area was mapped by Baggs (2004) Cuttings through the Flag Range Conglomerate Member occur along Taihape Road, south of the Flag Range Road intersection, and along Crownthorpe Road. The member occurs as far south as Kikowhero Stream on Matapiro Station, where it dips beneath fluvial terrace gravels comprising the modern land surface, and re-emerges on the eastern side of the Matapiro Syncline near Swamp Road and Omahu as a limestone facies of the Tangoio Limestone Member. Towards the southwest into the Ohara Depression the Flag Range Conglomerate Member appears to pass into highly fossiliferous fine sandstone facies of the Okauawa Formation. Superposition indicates that Flag Range Conglomerate Member is a lateral equivalent of Tangoio Limestone Member limestone facies cropping out widely in the low hills around the Tangoio Block, Bayview, Puketapu, Taradale and Omahu, an interpretation supported by the geological mapping of Baggs (2004).

Fossiliferous gravel facies of the member are perhaps thickest in the lower reaches of Kikowhero Stream at the Matapiro Road bridge, and on the summits of Flag Range and Mount Cameron (Fig. 29D). The non fossiliferous gravel facies are thickest in the Crownthorpe and Sherenden regions.

The Flag Range Conglomerate Member is a maximum of 20 m thick.

Lower and upper contacts

Flag Range Conglomerate Member sharply overlies fine sandstone of the Okauawa Formation. This lower contact is only exposed at Mount Cameron (V21/251880, Column Da-1).

The upper contact is exposed in three locations. In the lower reaches of Kikowhero Stream below the Matapiro Road bridge the member is gradationally overlain by siltstone of the Te Ngaru Mudstone Member (V21/251880). This gradational contact is also exposed in cuttings on Taihape Road immediately south of the Flag Range Road intersection (V21/185827). On Flag Range oyster-dominated pebbly limestone is gradationally overlain by siltstone (V21/196844).

Description

Flag Range Conglomerate Member represents a more westerly and shoreward expression of the Tangoio Limestone Member and appears to have developed in close proximity to a major source of greywacke detritus adjacent to a fan-delta fluvial system. Flag Range Member comprises two distinctive units: a lower non fossiliferous greywacke conglomerate similar to those present in the Matahorua Formation; and a pebbly limestone to shelly conglomerate rich in valves of robust, shallow-water dwelling bivalves (Fig. 27B-E). The pebbly limestone expression of the upper beds is restricted to the top of Flag Range and parts of adjacent Mount Cameron. Fossiliferous gravels are more widespread cropping, out from the lower reaches of Kikowhero Stream northeast to Puketitiri Road.

The upper shelly conglomerate typically comprises moderately to highly fossiliferous clast-supported greywacke conglomerate rich in fauna characteristic of shallow-water, relatively high-energy settings. In the lower reaches of Kikowhero Stream (Fig. 27B, C), the Flag Range Conglomerate Member comprises alternating gravelly-sandy bodies. *In situ*, articulated *Tawera subsulcata* valves are abundant in the finer-grained sandy layers which interfinger with, and are erosionally overlain by, shelly gravel beds. Fauna in gravelly layers are rich in *Zethalia zelandica* and *Dosinia,* with common *Lutraria* and *Alcithoe*. Below the Matapiro Road bridge the member gradationally passes into fine-grained fossiliferous siltstone of the Te Ngaru Formation through a pebbly fossiliferous basal zone.

The thickness of both main facies of the Flag Range Member varies through the study area. The lower non fossiliferous conglomerate interval is thickest in the region of Crownthorpe Settlement Road. The upper shelly conglomerate interval is thickest along the crest of Flag Range. A higher bioclastic content in the area of Flag Range, Mount Cameron and McNeil has led to increased cementation of the Flag Range Conglomerate Member relative to other areas, and hence more resistance to erosion (and the resulting higher topography than surrounding areas).

Fig. 27 (facing page): Flag Range Conglomerate Member. **A)** Panorama of the crest of Flag Range around the type section of the Flag Range Conglomerate Member (V21/191842). ok, Okauawa Formation; tga, Flag Range Conglomerate Member. **B)** Highly fossiliferous *Tawera subsulcata*-dominated (arrowed "t") shellbeds in the Flag Range Conglomerate Member, Kikowhero Stream, Matapiro Station (V21/192726). Other arrowed macrofossils common at this site are "p"-*Patro undatus*, "a"-*Atrina pectinata zelandica*, and "pp"-*Panopea zelandica*. **C)** Slightly to highly fossiliferous conglomerate in cliff-face exposure, Kikowhero Stream, Matapiro Station (V21/192726). **D)** Fossiliferous conglomerate to pebbly limestone facies of Flag Range Conglomerate Member at the summit of Mount Cameron (V21/251880). This locality is directly along strike and northeast and across the Tutaekuri River from the type section at Flag Range. **E)** *Ostrea chilensis*-dominated pebbly limestone facies of the Flag Range Conglomerate Member on Flag Range (V21/200838).


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E

Paleontology and age

Macrofauna in the Flag Range Conglomerate Member are dominated by thick-shelled, robust, epifaunal to semi-infaunal taxa such as *Ostrea, Tucetona, Glycymeris.* Locally *Zethalia zelandica* is very abundant. *Patro undatus, Ostrea chilensis* and *Purpurocardia purpurata* are common in outcrops along the summit ridge of Flag Range Road. Abundant estuarine bivalves such as *Austrovenus stutchburyi* and *Xenostrobus huttoni* are present in a cutting on Puketitiri Road immediately north of Apley Road. A similar *Xenostrobus*-rich shelly conglomerate occurs on Hedgeley Station near the series of lakes (V20/353266). Assemblages rich in *Tawera, Purpurocardia* and *Tucetona* are common in exposures in Kikowhero Stream, above Crownthorpe Road and in cuttings along Taihape Road (Between Flag Range Road and Black Bridge).

A confident Upper Nukumaruan age can be assigned to the Flag Range Conglomerate Member based on faunal content and stratigraphic position. The co-occurrence of *Lutraria solida* (Wp-Wn) and *Zethalia zelandica* (Wn-Wq) confirms a Nukumaruan age for this unit.

Environment of deposition

Flag Range Conglomerate Member accumulated in a variety of contemporaneous non-marine, marginal-marine and shallow-water nearshore settings in proximity to a large source of greywacke detritus. The dominant lithology of the member is the basal non fossiliferous massive to laminated and cross-bedded greywacke conglomerate. This basal interval is inferred to have been deposited in a non-marine to shoreface setting as part of a prograding fan-delta system. Progradation probably occurred during a sea level lowstand. The overlying highly fossiliferous conglomerate beds of the member are inferred to have been deposited during the subsequent sea level transgression over the fan-delta.

The common to abundant presence of *Zethalia zelandica* is a clear indicator of high-energy very shallow nearshore environments. Assemblages rich in *Tawera, Purpurocardia* and *Tucetona* are common in modern environments such as tidal channels near the heads of harbours such as Whangarei. Such assemblages are common at Crownthorpe Road, and in cuttings along Taihape Road (Between Flag Range Road and Black Bridge).

Based on the diverse macrofaunal association observed in Kikowhero Stream (Fig. 27B, C), a harbour-type sheltered embayment very close to a high-bedload river system supplying abundant greywacke detritus is envisaged for this site. The fauna present at this locality are consistent with modern day faunal assemblages in many harbours and semi-enclosed water bodies, such as Whangarei Harbour and the Hauraki Gulf. Sandstone lenses exposed in Kikowhero Stream are inferred to represent normal background sedimentation and were quickly colonised by large numbers of *Tawera subsulcata,* abundant specimens of which are preserved articulated and in life position. In the Hauraki Gulf, modern beds of *Tawera* can reach densities of up to 25,000 individuals/m^2 (Hendy and Kamp 2004). Periodically shifting substrate buried and scoured into these sandy layers, which themselves were buried and scoured in time by more sandy horizons. Overlying coarser-grained pebbly substrates were colonised by robust semi-infaunal bivalves such as *Tucetona laticostata, Purpurocardia purpurata* and *Glycymeris shrimptoni*. The shallow-water-restricted (3-5 m water depth; Beu and Maxwell 1990, p. 347) gastropod *Zethalia zelandica* is very abundant in these gravelly beds and its presence with *Tucetona, Purpurocardia and Glycymeris* strongly suggests remobilisation of nearshore beds out into deeper water. These coarser-grained intervals may therefore represent storm or flood-emplaced deposits. Uncommon highly-abraded fragments and valves of *Austrovenus stutchburyi* were observed and further suggest remobilisation of nearshore deposits. *Xymene plebeius* is a further indicator species for a nearshore, shallow-water environment (Beu and Maxwell 1990, p. 360).

Contemporaneous estuarine settings are evident in the Puketitiri Road and Hedgley Station areas, supported by the common to abundant presence of diagnostic estuarine taxa such as *Austrovenus stutchburyi* and *Xenostrobus huttoni*. The occurrence of common flaser bedding, mud drapes and ripple lamination also support an estuarine setting in these areas. By contrast, a nearby slightly deeper water setting is envisaged for areas around the summit ridge of Flag Range (Fig. 27A), and to a lesser degree Mount Cameron and McNeil. The *Ostrea*-rich assemblage in these areas is suggestive of a high-energy current-swept tidal channel, with common *Purpurocardia purpurata*.

The more fossiliferous, bioclastic-rich nature of beds capping Flag Range may represent a slightly deeper water broad channel more favourable to *Ostrea* than surrounding areas.

In essence the Flag Range Conglomerate Member represents the more shoreward, marginal-marine part of the Tangoio Formation. In the Tangoio Block equivalent depositional facies of the member are not present and have probably been removed through erosion of the western margin of the block by the modern Esk and Waikoau River systems.

Te Ngaru Mudstone Member (tn)

(Beu and Edwards 1984; formally defined by Haywick *et al.* 1991)

Name and definition

The mudstone overlying the Tangoio Limestone Member and underlying the Waipatiki Limestone Member was informally referred to as Te Ngaru mudstone by Beu and Edwards (1984), and was formally defined by Haywick *et al.* (1991). The name is derived from Te Ngaru Stream (V20/ 431029). The definitions of Haywick *et al.* (1991) and Beu (1995) are emended in this report to Te Ngaru Mudstone Member, with the interval included in the Petane Formation. Geological mapping has demonstrated that Te Ngaru Mudstone Member in the Tangoio Block and the Waitio Mudstone of Beu (1995) are likely the same stratigraphic unit. Because Te Ngaru Mudstone has precedence over Waitio Mudstone, Waitio Mudstone is now included within the Te Ngaru Mudstone and the name Waitio disestablished.

Type locality and reference sections

The type section nominated by Haywick *et al.* (1991) in Te Ngaru Stream (V20/431029) has been retained in this report.

A good section through the southern part of the member occurs on the true left bank of the lower reaches of Kikowhero Stream, 300-400 m north of the Omapere Road bridge (V21/213703) (Baggs 2004). This section, known as "Shrimptons", incorporates the type section of the old Waitio Mudstone (now part of the Te Ngaru Mudstone Member). Shrimptons has been an important fossil collection site for nearly 100 years, the name derived from the original owner of Matapiro Station, Walter Shrimpton (Beu 1995).

Lower and upper contacts

In the Tangoio Block, Te Ngaru Mudstone Member abruptly overlies the *Ostrea*-rich capping shellbed of the Tangoio Limestone Member. The upper contact varies through the Tangoio Block, with Te Ngaru Mudstone Member either grading into, or sharply overlain by, the Waipatiki Limestone Member. The gradational contact is well exposed in the Devils Elbow section (Column Tg-4), in sea cliffs around Waipatiki Beach, and on Puketitiri Road (Column Gg-2). The sharp contact is visible in the Darkys Spur area.

In the Glengarry-Puketitiri Road area (e.g. Columns Gg-2, Rs-1) Te Ngaru Mudstone Member coarsens up-section and is gradationally overlain by interbedded sandy and muddy horizons of the Waipatiki Limestone Member. In the Matapiro-Okawa districts the upper contact is not exposed and it is inferred that shellbeds of the Waipatiki Limestone Member gradationally overlie Te Ngaru Mudstone Member.

Distribution and thickness

Geological mapping in this project has extended the occurrence of Te Ngaru Mudstone Member south of the Tangoio Block into the Puketapu and Matapiro areas. Good exposures through the Te Ngaru Mudstone Member occur on State Highway 2 near White Pine Bush reserve. The member is also well exposed in sea-cliffs from Tangoio settlement north to Waipatiki Beach. Te Ngaru Mudstone Member, while present, does not crop out widely through the Matapiro-Okawa area. Exposures are largely limited to the lower reaches of Kikowhero Stream below the Matapiro Road bridge, and occasional, weathered outcrops along Taihape Road between Black Bridge and Flag Range Road.

In the Tangoio Block, Te Ngaru Mudstone Member is 10-40 m thick. Baggs (2004) estimated Te Ngaru Mudstone Member in the Matapiro-Okawa area to be 30-50 m thick.

Description

Te Ngaru Mudstone Member typically comprises non cemented blue-grey to pale-brown, massive siltstone and silty sandstone with scattered to common macrofossils. Around Puketapu, Te Ngaru Mudstone Member comprises blue-grey to light-grey, non cemented, slightly micaceous siltstone that coarsens upsection into fine sandstone.

The Te Ngaru Mudstone Member tends to be less fossiliferous south of the Tangoio Block, although macrofossils are still common. A particularly fossiliferous section occurs at “Shrimptons” in the lower reaches of Kikowhero Stream, near Matapiro Station (V21/212702) (Beu 1995).

Paleontology and age

Abundant valves of juvenile and adult *Talochlamys gemmulata* occur, together with juvenile *Ostrea chilensis, Maoricolpus roseus* and brachiopods. Other partially dissolved and unidentified bivalves and gastropods also occur. Exposures in Kikowhero Stream at “Shrimptons” comprise moderately fossiliferous siltstone with a diverse macrofossil assemblage.

The Te Ngaru Mudstone Member contains common *Pelicaria convexa* form *“fossa”,* indicating a depositional environment slightly deeper than that for the underlying Aropaoanui and Mairau Mudstones. The occurrence of *Pelicaria convexa* form *“fossa”* and *Austrofusus taitae*, together with stratigraphic position, constrain the Te Ngaru Mudstone Member to an Upper Nukumaruan (Late Pliocene) age.

Environment of deposition

The molluscan fauna, rich in *Pelicaria convexa* form *"fossa"* through the Tangoio Block, indicate an open marine, middle to outer shelf environment of deposition (Beu 1995). *P. convexa* form. *"fossa"* further suggests that water depths over the Tangoio Block during deposition of the Te Ngaru Mudstone Member were greater than during deposition of the underlying Mairau Mudstone Member (Beu 1995).

Pelicaria convexa form *"fossa"* is also common in Te Ngaru Mudstone Member cropping out through the Matapiro district (Baggs 2004), confirming an open marine, middle to outer shelf depositional setting in this area.

Waipatiki Limestone Member (wk)

(McKay 1887; formally defined by Haywick *et al.* 1991)

Name and definition

McKay (1887) referred to the upper beds at Petane as the Waipatiki Beds. Beu and Edwards informally named these units the Waipatiki limestone, with Haywick *et al.* (1991) formally defining the unit. The name is derived from the settlement of Waipatiki Beach, midway along the eastern coastal margin of the Tangoio Block. These definitions are emended in this report, and the interval is now named the Waipatiki Limestone Member, part of the Petane Formation. Waipatiki Limestone Member is defined as a limestone-dominated succession conformably overlying the Te Ngaru Mudstone Member and overlain by the Devils Elbow Mudstone Member.

Kingma (1971) mapped limestone beds in the Matapiro-Crownthorpe region as upper Scinde Island limestone (informal), and by implication assigned a Lower Nukumaruan age to them. As these limestone beds are actually significantly younger (i.e. they are of Upper Nukumaruan age) than any limestone at Scinde Island, Beu (1995) introduced Matapiro Limestone as a formal name for these Upper Nukumaruan beds. Geological mapping in this report has demonstrated lateral continuity between the Matapiro limestone of Beu (1995) and the Waipatiki Limestone Member. This correlation was first proposed by Beu (1995). Given the long historical usage of the name Waipatiki, the Matapiro Limestone is now incorporated into the Waipatiki Limestone Member and the name Matapiro discontinued.

Type locality and reference sections

The type locality designated by Haywick *et al.* (1991) on Hikuroa Farm is retained in this report (V20/393097).

Complete exposure of the member occurs on Puketitiri Road, near the Glengarry Road intersection from the gradational lower contact with the Te Ngaru Mudstone Member to the abruptly gradational upper contact with the Devils Elbow Mudstone Member (V21/333882, Column Gg-2). This section provides an excellent window into the character of the formation through its central outcrop area. The Devils Elbow section on State Highway 2 provides an excellent section through the central part of the member in the Tangoio Block with complete exposure of the formation, including lower and upper contacts (V20/458079, Column Tg-4).

Other useful reference sections are widespread through the study area. Excellent well exposed sections through the lower shellbed member and upper limestone member occur on Waipunga Road, at Lambs Corners (local name) on Taihape Road (V21/293749), and Kawera Road, Ngamahanga Station (V21/273811, Column Ok-1). Coastal cliffs south of Waipatiki Beach display the transition from the Te Ngaru Mudstone Member to Waipatiki Limestone Member (Fig. 28A), although access is difficult. A strongly cross-stratified expression of the limestone part of the formation is well exposed on Ohiti Road near Taihape Road, (V21/300732).

Lower and upper contacts

Where exposed the lower contact is always observed to be gradational. This transition is well exposed at the Devils Elbow Section (Column Tg-4), in coastal cliffs south of Waipatiki Beach (Fig. 28A), and at Puketitiri Road (Fig. 28D, E; Column Gg-8). The upper contact is abruptly gradational at Puketitiri Road, and abrupt at the Devils Elbow section.

Distribution and thickness

Waipatiki Limestone Member is one of the most widespread of the Mangaheia Group limestone units, and correlation of this formation has been a key in determining the Nukumaruan stratigraphy throughout the study area. The member is expressed mostly as a limestone unit (with common sandstone facies) in a northeast-southwest trending belt that extends from Ridgemount Road in the northern Tangoio Block to Matapiro Station just north of the Ngaruroro River. The well cemented nature of the upper limestone beds of the member means that outcrops are common, and the unit, compared to others in the study area, can be mapped relatively easily across the basin. Outcrop is relatively continuous, except for a small area in the Hedgley Road-Eskdale area, and correlation between outcrops in the Tangoio Block and the Matapiro-Okawa area is confident. This correlation was suggested, but not confirmed by Beu (1995) and Baggs (2004).

Two prominent limestone bodies, separated by a 20 m-thick siliciclastic interval (Caron 2002) crop out on Ohiti Road, near Omahu, and were both incorporated into the Matapiro Limestone of Beu (1995), Caron (2002) and Baggs (2004). As discussed above, geological mapping has demonstrated that the Matapiro Limestone is an equivalent of the Waipatiki Formation, and as such has been incorporated into the Waipatiki Limestone Member. At no known locality are two separate "cycles" present in the Waipatiki Formation. Indeed, in no other locality of "Matapiro Limestone" did any of Beu (1995), Caron (2002) or Baggs (2004) identify a second, upper limestone unit or cycle. The upper limestone unit present at Ohiti Road has been correlated with a prominent, sharp-based shellbed well exposed further along Ohiti Road towards the Matapiro Road intersection. A more logical interpretation of the Ohiti Road section is that siltstone overlying the lower limestone body at Ohiti Road is equivalent to the Devils Elbow Mudstone Member cropping out north of this area, and that the upper limestone unit and correlative shellbed are basal units of the Kaiwaka Formation. The lower limestone at Ohiti Road is lithologically and topographically equivalent to beds of known Waipatiki Limestone Member cropping out nearby along Taihape Road and on Ngamahanga Station. Therefore, assignment of this lower bed to the Waipatiki Limestone Member is confident, as is assignment of the upper shellbed unit on Ohiti Road to the Kaiwaka Formation.

Prominent exposures occur in high sea cliffs between the Aropaoanui River mouth and Tangoio Beach (Fig. 28A). Geological mapping has extended the occurrence of the member south through the Glengarry and Brooklands area to the Tutaekuri River at Puketapu and Dartmoor. An almost continuous line of limestone outcrops occurs from Glengarry Road (Columns Gg-3, Gg-4) to Ruawai Station at Dartmoor (Column Da-2), where they are truncated by the Tutaekuri River. Exposure continues across the river however through Ngamahanga Station (Column Ok-1) to Matapiro Station. Small blocks of limestone assigned to the Waipatiki Limestone Member crop out beside Ohiti Road and on the north bank of the Ngaruroro River in this same area. These blocks are likely to represent erosional remnants of a wider outcrop belt.

Throughout the Tangoio Block the Waipatiki Limestone Member is 10-40 m thick (Haywick *et al.* 1991). The member is at least 15 m thick near Puketitiri Road and gradually thins towards the Ngaruroro River. In the Matapiro area Waipatiki Limestone Member is 10-15 m thick (Baggs 2004).

Description

Variations in lithology occur through the formation from northern to southern outcrops, with three dominant "motifs" identified. A general trend from northeast to southwest shows an increase in greywacke pebble content. Central outcrops are characterised by partially to largely recrystallised, pale-grey to dirty-cream, medium to coarse-grained shellhash limestone with common biomoulds of infaunal bivalves. Waipatiki Limestone Member typically comprises a lower, fossiliferous sandstone interval sharply overlain by a package often containing two distinct limestone units.

Throughout much of the outcrop area, particularly in western parts, the Waipatiki Limestone Member is characterised by a lower highly fossiliferous packed shellbed rich in *Tawera, Sigapatella* and *Crepidula,* fossils among many others. This shellbed is especially well exposed along Waipunga Road, Puketitiri Road, Taihape Road at Lambs Corners, and along Kawera Road on Ngamahanga Station. The highly fossiliferous lower part of the Waipatiki Limestone Member (e.g. Fig. 28E) is an easily recognisable attribute of the member in western and central parts of the outcrop extent and aids geological mapping. The faunal composition of this shellbed appears to indicate shallower depositional environments than more eastern exposures of Waipatiki Limestone Member, such as those present at Puketapu, the Devils Elbow section, Waipatiki Beach and Tangoio Quarry. Greywacke clasts also appear to be more common in western parts of the formation, probably reflecting closer proximity to paleo-river mouths.

In most areas (e.g. Matapiro-Glengarry) the Waipatiki Limestone Member can be subdivided into three packages. The best and clearest example of this is at V21/333882 (Column Gg-2) on Puketitiri Road (Fig. 28D). The lower zone comprises alternating bioclastic-siliciclastic-dominated beds up to 0.5 m thick. In sequence stratigraphy this interval is assigned to the regressive systems tract (RST) and records falling sea level. This interval is sharply overlain by two beds of bioclastic-dominated limestone assigned to the transgressive systems tract (TST), recording a period of rising sea level. The sharp contact between the two zones is inferred to be a transgressive surface of erosion (TSE) and a sequence boundary is superimposed on this surface. No deposits representing sea level lowstand have been identified. The lower limestone bed is a 1.5 m-thick coarsening-upward well cemented shellhash-dominated limestone with a coarse sand to granule-sized matrix of shellhash. Scattered greywacke clasts are present in this limestone. Fauna are dominated by *Eumarcia plana, Tawera subsulcata, Ostrea chilensis, Lutraria solida* and *Purpurocardia purpurata.* This limestone is sharply overlain by a 10 cm-thick non fossiliferous siltstone that may represent a small part of a shore-connected wedge. The siltstone is itself sharply overlain by a 1.5 m-thick well cemented bioclastic limestone with virtually no siliciciclastic content.

Macrofauna comprise *Eumarcia, Talochlamys gemmulata, Tawera subsulcata* and *Amalda novaezelandiae.* The two 1.5 m-thick limestone beds probably represent onlap and backlap shellbeds following the nomenclature of Kidwell (1991). The upper limestone grades over 40 cm into fine-grained sandy siltstone of the Devils Elbow Mudstone Member. In some localities, such as the Ohiti area, the transition from Waipatiki Limestone Member to Devils Elbow Mudstone Member is abrupt and may be marked by a concentration of oysters (*Ostrea chilensis*). This contact records is a downlap surface and the oyster-concentration a downlap shellbed. The positions of such shellbeds have been noted elsewhere in the Hawke's Bay area by Caron *et al.* 2004b).

Above Puketapu and Brooklands Station, upper parts of Waipatiki Limestone Member outcrop typically consist of a weathered biomould-rich grey limestone package. Lower parts consist of stacked alternating packages of bioclastic-siliciclastic-rich sediments that are overlain by weathered massive to laminated and trough to planar cross-stratified slightly pebbly limestone. Fauna are dominated by infaunal bivalves such as *Tawera* that are largely dissolved and partially recrystallised. Biomoulds are common to abundant. The prominent tightly-packed *Tawera-Crepidula-Sigapatella* shellbeds, common in nearby areas (such as Ngamahanga Station), do not occur in this region.

Fig. 28 (facing page): Waipatiki Limestone Member (Petane Formation). **A)** Waipatiki Limestone Member cropping out in sea cliffs south of Waipatiki Beach (W20/524032). Here Waipatiki Limestone Member conformably overlies Te Ngaru Mudstone Member. The basal unit exposed in these sea cliffs is the Tangoio Limestone Member. **B)** Deformed mixed siliciclastic-bioclastic sandstone and limestone beds unconformably underlying massive to laminated limestone. Note the abrupt change between deformed and undeformed units in this exposure, Okawa Stream near Pukehaumoamoa School (V21/250781). **C)** Herringbone, trough and sigmoidal cross-stratification in the lower highly fossiliferous shellbed facies of the Waipatiki Limestone Member, Okawa Stream (V21/250781). Fauna in this interval are characterised by abundant *Tawera, Sigapatella* and *Crepidula.* This outcrop is directly opposite that shown in the above photograph (Fig. 30B), and is in the deformed interval. **D)** Road cutting on Puketitiri Road near the Glengarry Road intersection where the entire Waipatiki Limestone Member is exposed (V21/333882). Below the level of the vehicle the lower gradational contact with the Te Ngaru Mudstone Member is exposed. The Waipatiki Limestone Member then passes through interbedded shellbed and silty sandstone beds (Fig 30E), before passing into two well cemented limestone beds. The base of the lower limestone here is sharp and mildly erosional. The member is conformably overlain by the Devils Elbow Mudstone Member. **E)** Close-up view of the interbedded shellbed-silty sandstone facies exposed beside Puketitiri Road, typical of lower parts of the Waipatiki Limestone Member (V21/333882). **F)** *Eumarcia*-rich, biomouldic and partially recrystallised limestone of the Waipatiki Limestone Member exposed in Tangoio Quarry at the southern end on the Tangoio Block near Tangoio Settlement (V20/490006). Limestone facies of the member here are thicker than any other observed area of outcrop. The quarry also shows good separation of RST and TST parts of the limestone.


A
B
C
D
TOYOTA
E
Canon
F

A non fossiliferous greywacke conglomerate bed cropping out above the Flag Range Conglomerate Member on Flag Range is inferred to be a more shoreward non-marine equivalent of the Waipatiki Limestone Member, and was probably deposited during sea level lowstand. The interval representing this deposit is inferred to be tied-up in the TSE surface recognised in the Tangoio and Puketitiri Road areas, and not lithologically expressed there. The Flag Range area is the only place where the non-marine to marginal-marine edge of the Waipatiki Limestone Member has been identified.

Sandstone facies, prominent in lower parts of the formation through the Tangoio Block, are much less significant southwest through the Taradale-Matapiro regions. The thinning of lower sandstone facies is reflected in the thinner nature of the formation in the Matapiro-Okawa region compared with the Tangoio Block.

Paleontology and age

Waipatiki Limestone Member contains a diverse fauna throughout the outcrop area, dominated by shallow-water taxa. A large number of bulk samples have been collected and analysed from the Waipatiki Limestone Member, and many field observations have been documented. Identifiable fauna are dominated by the Venerid bivalve *Tawera subsulcata,* with common to abundant *Crepidula radiata* and *Sigapatella novaezelandiae*. The member is often capped by a shellbed dominated by *Ostrea chilensis*, with valves dispersed in a muddy siliciclastic-rich matrix.

Uncommon *Pelicaria convexa* indicate an Upper Nukumaruan age for the formation. The Plio-Pleistocene boundary was identified in the Waipatiki Limestone Member by Beu and Edwards (1984). The top of the Olduvai paleomagnetic subchron has been recognised in the overlying Devils Elbow mudstone (P. Kamp, U.O.W, unpublished data). On the basis of stratigraphic position and micro/macrofaunal content, the Waipatiki Formation is assigned an Upper Nukumaruan age. The formation lies across the Plio-Pleistocene boundary.

Environment of deposition

The Waipatiki Limestone Member was deposited during a period of falling sea level and the subsequent rise, with facies recording regressive, transgressive and very rarely lowstand sea level states. Bioclastic-dominated beds in the form of limestones are typically representative of shoreface to inner shelf environments of deposition. This is supported by the rich macrofauna collected from the formation. A non-marine expression of the Waipatiki Limestone Member is present on Flag Range and indicates that river systems with a high greywacke gravel bed load were present and active during the period of deposition. In all other areas the shoreward edge of the unit has been removed through erosion.

Devils Elbow Mudstone Member (de)

(Beu and Edwards 1984; formally defined by Haywick *et al.* 1991)

Name and definition

Beu and Edwards (1984) informally referred to the siltstone sharply overlying their Waipatiki limestone as the Devils Elbow mudstone. This interval was formally defined by Haywick *et al.* (1991). The name is derived from Devils Elbow corner on State Highway 2 south of Tutira. The name is emended in this report to Devils Elbow Mudstone Member (Petane Formation). Mudstone overlying the Matapiro Limestone (name now abolished, see Waipatiki Limestone Member below) of Beu (1995) was included in the Moteo Mudstone, a formation established by Beu (1995). Kingma (1971) had previously mapped this unit as the Puketautahi pumiceous siltstone (informal). Baggs (2004) following Beu (1995), geologically mapped this same interval as the Moteo Mudstone, and both appreciated that the Moteo Mudstone and Devils Elbow Mudstone Member were possible lateral equivalents. Geological mapping in this report has demonstrated that the Moteo Mudstone is most probably a correlative of the Devils Elbow Mudstone Member. As the name Devils Elbow has precedence over Moteo, the Moteo Mudstone of Beu (1995) and Baggs (2004) is disestablished in favour of the name Devils Elbow Mudstone Member.

Type and reference sections

The type section established at the top of Devils Elbow on State Highway 2 by Haywick *et al.* (1991) is retained in this report (V20/460079-461078, Column Tg-4). Reference sections are relatively limited through the study area.

Lower and upper contacts

On Puketitiri Road (V21/333882), Devils Elbow Mudstone Member abruptly but gradationally though overlies coarse-grained limestone facies of the Waipatiki Limestone Member (Column Gg-2).

Devils Elbow Mudstone Member is sharply overlain by limestone of the Kaiwaka Formation at the top of Devils Elbow (V20/461078, Column Tg-4). Similarly, Devils Elbow Mudstone Member is sharply overlain by a highly fossiliferous shellbed of the Kaiwaka Formation on Ohiti Road (V21/ 233722; Fig. 29C, D).

Distribution and thickness

The Devils Elbow Mudstone Member is widespread across the Tangoio Block, particularly south of the Aropaoanui River (Haywick *et al.* 1991). Haywick *et al.* (1991) suggested that no equivalent was known outside of the Tangoio Block. However, correlation of the underlying Waipatiki Limestone Member southwest towards the Ngaruroro River has provided a known surface on which to "hang" stratigraphy away from the Tangoio area. Siltstone overlying the Waipatiki Formation through the Matapiro and Okawa areas are therefore included in the Devils Elbow Mudstone Member. Devils Elbow Mudstone Member is therefore widespread through central portions of the study area, in a northeast-southwest trending outcrop belt from Ridgemount Road in the Tangoio Block to the Ngaruroro River near Matapiro Station. Devils Elbow Mudstone Member does not occur south of the Ngaruroro River, where it is truncated by the Ngaruroro River Fault.

Devils Elbow Mudstone Member is 10 to 40 m thick in the Tangoio Block (Haywick *et al.* (1991), and up to 30 m thick in the Matapiro and Okawa areas, although usually less than 20 m here (Baggs 2004).

Description

Devils Elbow Mudstone Member dominantly comprises slightly to moderately fossiliferous siltstone that coarsens up into silty sandstone. Through the Tangoio Block the Devils Elbow Mudstone Member contains a diverse molluscan fauna that lessens in abundance away from the Tangoio region. Through the Matapiro and Okawa areas macrofossils are sparse. This is inferred to represent the movement into positions higher on the paleoshelf from the Tangoio region into the Matapiro region and a corresponding loss of macrofaunal diversity.

In the Devils Elbow section fauna reflect a coarsening and shallowing-upwards trend.

Paleontology and age

Devils Elbow Mudstone Member contains one of the most diverse offshore Pliocene fossil assemblages in the Hawke's Bay region (Beu 1995). Fauna are mostly gastropod dominated, although bivalves are common. The assemblage is characteristic of Upper Nukumaruan rocks in the study area, involving *Pelicaria convexa, Austrofusus taitae, Austrofusus glans,* and *Cominella excoriata,* among many other gastropod-dominated species (Beu 1995). The occurrence of common *Pelicaria convexa* form "*fossa"* in the Tangoio Block in the Devils Elbow Mudstone

Member is consistent with a period of deepening over this area during the Upper Nukumaruan, as highlighted also in the underlying Te Ngaru Mudstone Member.
The top of the Olduvai paleomagnetic subchron (1.784 Ma; Cooper 2004) has been identified in the Devils Elbow Mudstone Member (P. Kamp U.O.W. unpublished data). The Plio-Pleistocene boundary (1.8 Ma) was identified in the underlying Waipatiki Formation by Beu and Edwards (1984). On the basis of stratigraphic position and faunal content the Devils Elbow Mudstone Member is assigned a confident Upper Nukumaruan age (Early Pleistocene).

Environment of deposition

Devils Elbow Mudstone Member is inferred to have accumulated on an open marine shelf at middle to outer shelf water depths (60-150 m). Water depths were likely greater over the Tangoio area than the Matapiro district as reflected in the macrofaunal content and thickness of the member.

KAIWAKA FORMATION (kw)

(McKay 1887; formally defined by Haywick *et al.* 1991)

Name and definition

The term Kaiwaka Beds was introduced by McKay (1887) for limestone beds exposed near the top of the Tangoio Block, north of Napier. Beu and Edwards (1984) used the informal name Kaiwaka limestone, and the unit was formally defined as the Kaiwaka Formation by Haywick *et al.* (1991). Beu (1995) reverted the name back to Kaiwaka Limestone. This report, however, has for reasons of consistency, retained the original formal definition of Haywick *et al.* (1991) to reflect the varied lithofacies that comprise this formation. The definition is emended to include the Puketautahi Limestone of Beu (1995) as a member of the Kaiwaka Formation as geological mapping has demonstrated that it, and beds of the Kaiwaka Formation in the Tangoio region, are lateral equivalents.

Baggs (2004) included a prominent shellbed cropping out in isolated exposures in the Matapiro region within the Moteo Mudstone (now incorporated in the Devils Elbow Mudstone Member). The base of this shellbed marks a prominent, possible ravinement surface (Fig. 29C, D). For consistency with other Mangaheia Group formations, the base of the Kaiwaka Formation through the Matapiro region is therefore placed at the base of this shellbed.

The two limestone packages present in cuttings beside Ohiti Road have previously been mapped and described as Matapiro Limestone (now incorporated in the Waipatiki Limestone Member (see above; e.g. Hood 1993; Caron 2002; Baggs 2004). At no other locality in the study area does the Waipatiki Formation comprise two such limestone packages. The lower limestone bed at Ohiti Road has confidently been mapped and correlated with known Waipatiki Limestone Member outcrops on Taihape Road and at Ngamahanga Station. The upper limestone bed is now assigned to the Kaiwaka Formation, and correlated with a shellbed cropping out further along Ohiti Road near the Tauhara Road intersection.

Three members are defined in the Kaiwaka Formation in this report (Puketautahi Limestone Member, Ruataha Conglomerate Member, and Taihoa Pumice Member). However, only the Puketautahi Limestone Member has been mapped as a separate unit during the course of this report due to its thickness and lateral continuity.

Type locality and reference sections

The type section established by Haywick *et al.* (1991) is retained on Te Taihoa Farm (V20/461101). A well exposed reference section is nominated along the southern end of Waipunga Road where it ascends the western face of the Tangoio Block (V20/398983; Fig. 29E).

Lower and upper contacts

Near the top of Devils Elbow on the Napier-Wairoa Road the Kaiwaka Formation sharply overlies fossiliferous fine sandstone of the Devils Elbow Mudstone Member (Petane Formation). The base of the Kaiwaka Formation in the Matapiro district is exposed on Ohiti Road near the intersection with Tauhara Road (V21/233722; Fig. 29C, D). The base is also well exposed on Ohiti Road near the Taihape Road intersection (V21/298733). This section was logged by Caron (2002) who also documented elements of the diagenesis of limestones at this locality. This section was previously studied by Hood (1993).

The top of the Kaiwaka Formation is usually marked by the modern land surface. In some places the formation may be overlain by a thin veneer of Castlecliffian gravels.

Distribution and thickness

Kaiwaka Formation discontinuously crops out in a northeast-southwest belt from the northern Tangoio Block to the north bank of the Ngaruroro River in the Matapiro district. The single largest area of outcrop occurs in the Tangoio Block. Kaiwaka Formation is up to 100 m thick. The member is well exposed along Waipunga Road (Fig. 29E), and can be seen from Waipatiki and Ridgemount Roads (Fig. 29A, B).

Description

Kaiwaka Formation contains a diverse range of facies reflecting a wide variety of depositional environments. The formation predominantly comprises cross-stratified, coarse-grained carbonate sand/sandstone with massive to cross-stratified limestone (Fig. 29F, G). Lateral interdigitation of all lithologies is common in the Kaiwaka Formation (Haywick *et al.* 1991).

Greywacke clasts are common components throughout the outcrop area (Fig. 29G). Although limestone facies are perhaps most common, conglomerate, sandstone and even (locally) pumiceous beds are all common. Kaiwaka Formation is much thicker than other formations within the upper Mangaheia Group (up to 100 m thick) and probably accumulated during several 41 k.y. sea-level cycles while this part of the basin was emerging from the ocean due to net uplift.

Kaiwaka Formation becomes coarser-grained from northern to southern outcrops. In the Puketapu area the unit comprises very coarse-grained, non to highly fossiliferous conglomerate to pebbly limestone. In the Glengarry and Matapiro areas Kaiwaka Formation appears to be represented by a number of differentiated cyclothems that can be traced (albeit poorly) through the region. It appears that these sequences are condensed in the Tangoio region.

Paleontology and age

Below "The Gums" (V21/340898) near Glengarry Road, Kaiwaka Formation comprises a highly fossiliferous very pebbly limestone bed with virtually all shells being of *Paphies australis*. Rare valves of *Ostrea chilensis* and *Lutraria solida* also occur in this unit. A similar *Paphies*-dominated unit occurs above Hendley Road, though the shell-pebble ratio is lower in this area.

Environment of deposition

The *Paphies*-dominated beds prominent in the Glengarry-Hedgley areas were deposited in a nearshore, semi-enclosed, possibly estuarine setting.

Ruataha Conglomerate Member (kwr)

(Haywick 1990; formally defined by Haywick *et al.* 1991)

Name and definition

Ruataha Conglomerate Member was introduced by Haywick (1990) and formally defined by Haywick *et al*. (1991). The name is derived from Ruataha Farm in the western part of the Tangoio

Block near Kaiwaka Road. Brown siltstone facies in the Ruataha Member are equivalent to the (informal) Tareha laminated siltstone of Beu and Edwards (1984) (Haywick *et al.* 1991).

Type locality and reference sections

Ruataha Conglomerate Member is poorly exposed in the Tangoio Block. Isolated exposures occur on Ruataha Farm (V20/412088; 423073), on Waipunga Road (V20/413066) and sporadically along Kaiwaka and Aropaoanui Roads (Haywick *et al.* 1991). Outcrop is constrained to a small area around the top central parts of the Tangoio Block. This area is between the junction of Waipunga and Kaiwaka Roads (V20/415091), Glenview homestead (V20/475065) and Koraki Homestead (V20/416057) (Haywick *et al*. 1991).

Conglomeratic units exposed above Puketapu village and Glengarry Road are probably lateral equivalents of the Ruataha Member, although confident lateral continuity cannot be demonstrated. The Ruataha Conglomerate Member is up to 20 m thick.

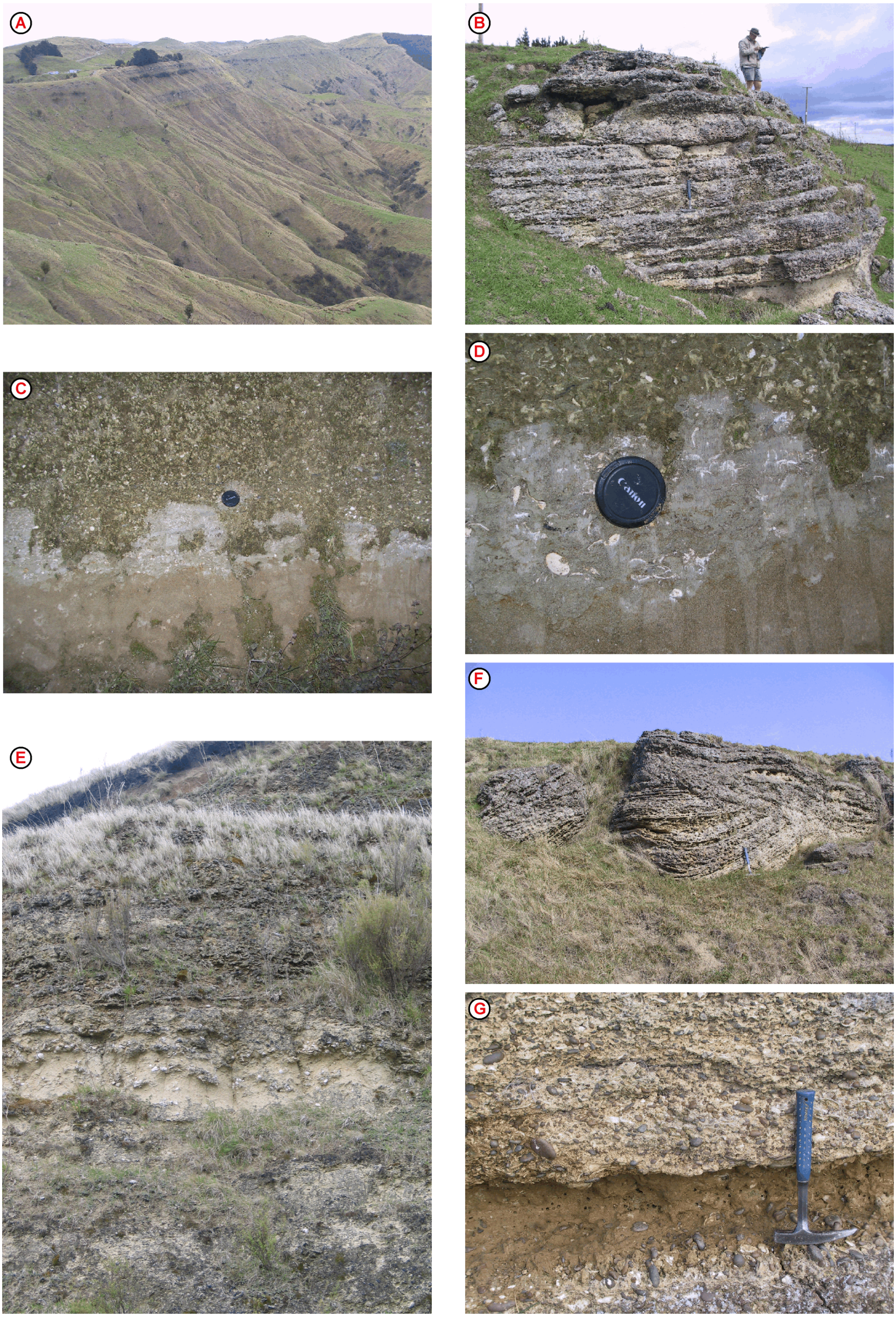
Description

The Ruataha Conglomerate Member consists of uncemented poorly sorted siliciclastic sandstone interbedded with lenses and continuous bodies of greywacke gravel and laminated brown siltstone. Silt beds contain scattered carbonaceous material, rare *in situ* rootlets and rare shell moulds. In a few localities, sand and gravel beds contain shellhash (Haywick *et al.* 1991).

Environment of deposition

The Ruataha Conglomerate Member was mostly deposited in a non-marine fluvial environment with rare estuarine incursions (Haywick *et al.* 1991).

Fig 29 (facing page): Kaiwaka Formation. **A)** Landscape view of the Kaiwaka Formation forming the bluffs capping dip slopes on the Tangoio Block around Ridgemount Road (W20/537133 looking west). **B)** Bluff-forming pebbly limestone facies of the Kaiwaka Formation near Ridgemount Road (W20/535130). **C)** Basal *Tawera subsulcata*-dominated shellbed of the Kaiwaka Formation unconformably overlying Devils Elbow Mudstone Member (Petane Formation), Ohiti Road, Matapiro district (V21/233722). **D)** Close-up of base of shellbed in above photograph (Fig. 31C; V21/233722). **E)** Kaiwaka Formation cropping out beside Waipunga Road, southwestern Tangoio Block (V20/398983). **F)** Strongly cross-bedded Kaiwaka Formation near "The Gums", above Glengarry Road (V20/340898). Macrofauna in the limestone shown here are dominated almost entirely by valves of the estuarine to brackish water-dwelling bivalve *Paphies australis.* **G)** Very pebbly fossiliferous shellbed of the upper Kaiwaka Formation below The Gums (V20/340898).


A
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Taihoa Pumice Member (kwt)

(Haywick 1990; formally defined by Haywick *et al.* 1991)

Name and definition

Taihoa Pumice Member was introduced by Haywick (1990) and formally defined by Haywick *et al.* (1991). The name is derived from Te Taihoa Farm and homestead in the Tangoio Block (V20/452108). It is defined as a fossiliferous interval of pumiceous sediments within the Kaiwaka Formation.

Type locality and reference sections

The type section established by Haywick *et al.* (1991) on Te Taihoa Farm (V20/461101) is retained.

Distribution and thickness

The Taihoa Pumice Member only occurs in the Tangoio Block in the vicinity of the type section, and around V20/399983 on Waipunga Road. It is a maximum of 10 m thick (Haywick *et al.* 1991).

Description

Taihoa Conglomerate Member comprises massive, bioturbated silty volcanic ash interbedded with a fine to very coarse pumice sand (Haywick *et al.* 1991). It is fossiliferous with an estuarine-restricted macrofauna, and contains carbonaceous rootlets.

Paleontology

At the type section Taihoa Conglomerate Member contains an estuarine-restricted faunal assemblage comprising *Austrovenus stutchburyi, Macomona liliana* and *Zeacumantus perplexus.* In other localities the member contains a significant amount of shellhash (broken and abraded shell material) and common interbeds of carbonate sand/bioclastic limestone (Haywick *et al.* 1991).

Environment of deposition

Taihoa Conglomerate Member was deposited in a marginal-marine setting adjacent to a supply of greywacke gravels. It probably represents the deposits of an estuary that developed near the mouth of a river system actively supplying greywacke sediments.

Puketautahi Limestone Member (kwp)

(Kingma 1971; formally defined by Beu 1995)

Name and definition

Puketautahi limestone was introduced by Kingma (1971) as an informal name for small patches of the stratigraphically highest limestone in the Matapiro-Crownthorpe area in his Te Aute subdivision map. The name is derived from Puketautahi (Trig 61), on Ngamahanga Station. Because Kingma (1971) had also applied the name "Puketautahi" to his informal Puketautahi pumiceous siltstone, Beu (1995) formally defined the Puketautahi Limestone, and renamed the siltstone the Moteo Siltstone. Geological mapping in this report demonstrates that Puketautahi is most likely a lateral equivalent of Kaiwaka Formation in the Tangoio Block and is hence included in Kaiwaka Formation. However, the Puketautahi Limestone Member is a thick, prominent limestone bed that can be mapped as a distinct stratigraphic unit through the Matapiro area, as demonstrated by Baggs (2004). Because of this, the name Puketautahi is retained, but now the unit is referred to member status of the Kaiwaka Formation.

Type locality and reference sections

The type section established by Beu (1995) for the Puketautahi Limestone is retained in this report. This section occurs along the summit ridge capping Puketautahi hill (Trig 61, 353 m; V21/ 253829).

Lower and upper contacts

In no known location is the lower contact between Puketautahi Limestone Member and underlying parts of the Kaiwaka Formation exposed. It is inferred to sharply overlie sandstone and siltstone facies of the Kaiwaka Formation.

The upper surface of the Puketautahi Limestone Member represents the modern land surface, although there may be a thin veneer of Castlecliffian and/or Haweran gravels present.

Distribution and thickness

It appears probable that the distribution of Puketautahi Limestone Member, as described by Beu (1995) and mapped by Baggs (2004), contains a mixture of stratigraphically separate limestone beds that overlie Waipatiki Formation and Devils Elbow Formation rocks in the Matapiro-Okawa area. Puketautahi Member occurs for nearly 800 m along the summit ridge of Puketautahi hill on Ngamahanga Station where it comprises a series of large jumbled blocks, none of which are *in situ*, up to about 15 m high. It also sporadically crops out in hills around the Matapiro Station area.

Puketautahi Limestone Member is not known north of the Tutaekuri River or south of the Ngaruroro River.

Description

At the type section Puketautahi Limestone Member typically comprises several metres of dirty cream to grey, well cemented, hard, recrystallised coarse-grained shellhash limestone. Outcrop on Puketautahi hill is restricted to large blocks of intact limestone capping the summit ridge. In some places greywacke granules and pebbles are common. Blocks are massive to flaggy, with common case hardening. Where relatively clean surfaces are visible, well-developed tabular cross-bedding and laminations are visible. Foresets are of moderate to large-scale. Some valves of *Ostrea chilensis* are present, with biomoulds of inferred aragonitic bivalves common.

Paleontology and age

Few relatively intact identifiable macrofossils have been observed in the Puketautahi Limestone Member. Those identified are typically shallow-water dwelling infaunal bivalves. *Tawera subsulcata* is most common with *Glycymeris shrimptoni, Ostrea chilensis* and *Patro undatus* also present (Beu 1995).

Few age diagnostic macrofossils were identified in this unit. The presence of *Glycymeris shrimptoni* and *Patro undatus* demonstrate that Puketautahi Limestone Member is no younger than Nukumaruan (Beu 1995). Stratigraphic position strongly suggests that the Puketautahi Limestone Member is Upper Nukumaruan (Early Pleistocene) in age.

Environment of deposition

Fauna and sedimentary structures in the Puketautahi Limestone Member support deposition at inner shelf water depths in a current-swept environment, probably on a sandy to gravelly seafloor.

TARADALE MUDSTONE (td)

(Beu and Edwards 1984; formally defined by Beu 1995)

Name and definition

Taradale Mudstone derives its name from Taradale, a township southwest of Napier around which the formation crops out. Taradale Mudstone is equivalent in part to Roys Hill siltstone of Kingma (1971), a unit that is regarded as a synonym of Makaretu Formation (Beu 1995; Dyer 2005).

Taradale Mudstone was introduced by Beu and Edwards (1984) for the succession recovered from the Taradale-1 drillhole. It was correlated to Esk Mudstone strata cropping out in the Tangoio Block. Haywick *et al.* (1991) formally defined the Esk Mudstone for this unit as this name had priority over Taradale Mudstone (Esk papa of Smith 1877). Beu (1995) redefined and formally introduced Taradale Mudstone in reference to Nukumaruan mudstone present in the Taradale-1 drillhole and the immediately surrounding hill country between Taradale and Puketapu. The Waipipian and Mangapanian mudstone interval present in Taradale-1 was unnamed by Beu (1995), despite being the same lithology and not separated by any obvious stratigraphic break. For these reasons all of the Waipipian to Nukumaruan mudstone intercepted in Taradale-1 is here assigned to the Taradale Mudstone. It is defined as a Waipipian to Nukumaruan mudstone-dominated unit underlying the Park Island Limestone Member of the Darkys Spur Formation. Due to lack of exposure a definite lower contact is not defined, although it is taken as any deviation from mudstone-dominated lithology.

Lower and upper contacts

The lower contact of the Taradale Mudstone has not been observed in outcrop. In Taradale-1 the Taradale Mudstone overlies Mangaorapan (Early Eocene) glauconitic calcareous mudstone across an angular unconformity (Darley and Kirby 1969).

Taradale Mudstone is conformably overlain by the Park Island Limestone Member in hills behind Taradale (Fig. 19E), at the Taradale Sugarloaf, Roys Hill and Fern Hill. It is inferred that Taradale Mudstone conformably underlies and interdigitates with the Scinde Island Formation beneath Napier city. It also interdigitates with many other Mangaheia Group formations, including the Matahorua Formation, Esk Mudstone, Tutira Member, Aropaoanui Mudstone Member and Mason Ridge Formation.

Type locality and reference sections

Beu (1995) designated the first large road cut on the north side of Springfield Road west of Taradale as the type section for the Taradale Formation (V21/386766). This section has been retained. The type section represents the stratigraphically lowest exposure of the formation, and is located only 700 m east of the location of the Taradale-1 drillhole.

Distribution and thickness

In outcrop Taradale Mudstone is restricted to the southern end of the Taradale Anticline (see Chapter 5, p. 179) between State Highway 50 and the northern end of Springfield Road, at Fern

Hill and Roys Hill. The formation is inferred to be widespread in the subsurface through much of the central and eastern parts of the study area.

Much of what is known of the Taradale Mudstone is derived from information acquired by the Taradale-1 drillhole. Geological mapping in this report demonstrates that at least 60 m of Taradale Mudstone crops out around the Taradale Anticline. Taradale-1 intercepted a further 1170 m of Taradale Mudstone (Darley and Kirby 1969; Beu 1995). The formation therefore has a minimum thickness of 1230 m in Taradale-1. Beu (1995) suggested that at least 300 m of Taradale Mudstone cropped out behind the hills of Taradale. This appears to be a significant over-estimation of outcrop thickness, the reason for which is unclear.

Taradale Mudstone was mapped in isolated areas in the Maraekakaho and Fern Hill areas by Dyer (2005), where it conformably underlies the Park Island Limestone Member (Darkys Spur Formation). In this area Taradale Mudstone is separated from younger Upper Nukumaruan beds to the north of the Ngaruroro River by a large fault. The Taradale Mudstone is also separated from beds of equivalent age in the nearby Mason Ridge Formation by a fault or series of faults.

Lower Nukumaruan mudstone intercepted in Hukarere-1 (Westech Energy Ltd 2001, PR 2656) is also assigned to the Taradale Mudstone. At this site the formation is inferred to conformably underlie the Scinde Island Formation.

Description

The upper 60 m of the Taradale Mudstone comprises blue-grey to light-grey, massive, non cemented, non to slightly fossiliferous sandy siltstone. Macrofossils are sparse, although the formation contains a diverse microfossil assemblage (Beu 1995).

The lower 800 m of the Taradale Mudstone comprises soft grey mudstone with thin sandy intervals in the upper 160 m (Darley and Kirby 1969). Shell material is typically more common in the upper 370 m of the formation. Apart from the slightly fossiliferous, sandy and more massive “intervals”, the Taradale Mudstone intercepted in Taradale-1 cannot be subdivided further.

Paleontology and age

Scattered macrofossils are present in outcrop. Beu (1995) has identified specimens of *Pelicaria acuminata* and only one fragmented *Pelicaria convexa.* The presence of both *P. acuminata* and *P. convexa* in upper parts of the Taradale Formation indicates that this part of the formation is at least age equivalent to Mairau Formation exposed north and west of Taradale (Beu 1995). Valves of *Atrina pectinata zelandica* were observed in upper beds of the formation on Roys Hill.

Beu (1995) has recognised a diverse foraminiferal fauna. The Lower Nukumaruan planktic assemblage of *Truncorotalia crassula* and dextral *Truncorotalia crassiformis* has been identified in Taradale-1 (Beu and Edwards, 1984).

Taradale Formation is of Late Pliocene age. Microfossil dating of strata in the Taradale-1 drillhole indicates continuous sedimentation from possibly the Waipipian through to the Upper Nukumaruan (Darley and Kirby 1969; Beu 1995).

Environment of deposition

Taradale Formation represents a very broadly shallowing-upwards succession. Microfauna from Taradale-1 indicate an inner shelf depositional environment. Throughout the Pliocene the region around Taradale-1 remained at relatively deep water depths, and only at the time of deposition of the Darkys Spur Formation (Park Island Limestone Member) in this region did water depths reduce to innermost shelf and subaerial levels. This may reflect the start of growth of the Taradale Anticline.

Approximately 800 m of Lower Nukumaruan section was intercepted in Taradale-1, indicating rapid sedimentation during this period (about 2.6 m/k.y.). The remaining 370 m was deposited during the Mangapanian and Waipipian (sedimentation rate of about 0.3 m/k.y.). It is probable that the Taradale Formation represents the main depocentre during the sedimentation history of central parts of the study area.

MAKARETU MUDSTONE (mk)

(Thomson 1926; formally defined by Kelsey *et al.* 1993)

Name and definition

The Makaretu clays were introduced by Thomson (1926) for beds overlying the "Te Aute limestone" (Te Onepu Limestone) and underlying the "Pukeora oyster-beds" (equivalent to the lower limestone of the Mason Ridge Formation (Kelsey *et al.* 1993)). The name appears to be derived from the Makaretu River where the formation was first described by Thomson (1926). The Makaretu clays were formally renamed and defined as the Makaretu Mudstone by Kelsey *et al.* (1993), a definition retained by Dyer (2005) and this report. Makaretu Mudstone is defined as the fine-grained interval overlying the Te Onepu Limestone and underlying the Mahana Limestone

Member of the Mason Ridge Formation. It was included as part of the undefined Roys Hill Siltstone of Kingma (1971).

Type locality and reference sections

The type section established by Thomson (1926) is retained for the Makaretu Mudstone (U22/ 085308). This section occurs along a short section of road now abandoned by the realignment of State Highway 2 around the northern end of Pukeora Hill.

Lower and upper contacts

Makaretu Mudstone conformably overlies the Te Onepu Formation, and is gradationally overlain by the Mahana Limestone Member (Mason Ridge Formation) (Dyer 2005). Over approximately 0.3 m the top of the Makaretu Mudstone coarsens into a 0.7-1.2 m-thick fine sandstone before passing into a limestone. This transition is best exposed at V22/165584 above the Maraekakaho River on Mason Ridge Station.

Distribution and thickness

The Makaretu Mudstone is a minimum of 20 m thick (Kelsey *et al.* 1993) in the region of the Makaretu River where described by Thomson (1926). The unit is at least 40 m thick at the southern end of the Raukawa Range, increasing to several hundred metres at the northern end of the range (Kelsey *et al.* 1993). Dyer (2005) reported thicknesses of 50-60 m for the Makaretu Mudstone in the study area.

The Makaretu Mudstone passes laterally into the Taradale Mudstone.

Description

The Makaretu Mudstone comprises a massive, blue-grey, slightly to moderately fossiliferous siltstone. Occasional bioturbated intervals are evident. The unit becomes firmer with increased proximity to limestone of the overlying Mason Ridge Formation, and near the contact with this formation comprises a very firm biomouldic unit with common moulds of *Talochlamys* and *Tawera.*

Paleontology and age

Ostrea, Zeacolpus, Talochlamys and *Tawera* are common in the Makaretu Mudstone. Dyer (2005) reported rare *Pelicaria convexa* although given the likely Upper Mangapanian to Lower Nukumaruan age of the Makaretu Mudstone, *Pelicaria* specimens present are more likely to be *P. acuminata* than *P. convexa.*

Environment of deposition

The Makaretu Mudstone was probably deposited at inner to middle shelf water depths based on macrofauna.

MASON RIDGE FORMATION (ms)

(Kelsey *et al.* 1993)

Name and definition

The name Mason Ridge Limestone was introduced by Kelsey *et al.* (1993) for Nukumaruan rocks cropping out in the Mason Ridge-Maraekakaho area, which were earlier part of the informal, stratigraphically complex Petane limestone of Beu *et al.* (1980). As this stratigraphic interval contains significant thicknesses of sandstone and mudstone it is here renamed the Mason Ridge Formation. Unravelling the stratigraphy of this area has been important in determining the evolution of Nukumaruan rocks south of the Ngaruroro River, and has recently been reported by Dyer (2005). The cyclothemic disposition of the Mason Ridge Formation, as documented by Dyer (2005), is remarkably similar to that of the Petane Formation in the upper parts of the Mangaheia Group within the Tangoio Block. On the basis of age, lithology, stratigraphic position, and its cyclothemic character, the Mason Ridge Formation is included here in the Mangaheia Group.

Mason Ridge Formation was mapped as the (informal) lower Scinde Island limestone and (informal) upper Scinde Island pebbly limestone by Kingma (1971). Beu (1995) referred to the lower limestone bed of the Mason Ridge Formation as the Scinde Island Limestone, but didn't describe, define, or name the two other stratigraphically higher limestone beds at Mason Ridge. Beu (1995) included the basal limestone at Mason Ridge in the Napier Group, which he established in the same study. This work strongly suggests that the Napier Group is not sustainable as its base and top were not defined, Beu provided no type section, reference section or stratigraphic columns, and it could not be differentiated from rocks of his Petane Group. As Petane Group has now been redefined as Petane Formation and incorporated into the Mangaheia Group, it is proposed that the Napier Group be disestablished.

Although hypothetically containing at least part of the Scinde Island Formation at its base (Beu 1995), the name Mason Ridge Formation, as defined by Kelsey *et al.* (1993), was retained by Caron (2002, p. 30) for several reasons including:

- The geographical extent of the formation is well delineated
- The limestone units (of which there are three) are vertically and laterally well-developed and can easily be mapped south of the Ngaruroro River (Fig. 32A).

Although several authors have attempted to correlate the lower limestone bed of the Mason Ridge Formation with other limestone units in the basin (Kingma 1971; Kelsey *et al* 1993; Beu 1995), correlation of the upper sheets with more geographically restricted outcrops of limestone remains doubtful. It was therefore viewed appropriate to retain rocks in the Mason Ridge region as a separate formation. Any direct correlation between the Scinde Island Formation at Napier and the lower limestone bed at Mason Ridge (such as Beu 1995) is far from certain. No Lower Nukumaruan limestone units were intercepted in the Taradale-1 drillhole, suggesting lateral continuity is not present. Neither were any intercepted in Whakatu-1. The thickness of limestone at Scinde Island, coupled with the stratigraphic form of this interval, strongly indicates sedimentation during several glacio-eustatic sea-level cycles. It is viewed as inappropriate to use the name Scinde Island Limestone Member for only one cycle at Mason Ridge when clearly at least three such cycles are present.

Five members were defined and geologically mapped in the Mason Ridge Formation by Dyer (2005) and are all retained in this report. These members are the Mahana Limestone, Maharakeke Mudstone, Torran Limestone, Whakapirau Mudstone and Pakihirua Limestone Members. The Maharakeke Mudstone and Whakapirau Mudstone Members were included as part of the undefined Roys Hill Siltstone of Kingma (1971), and the undefined "interbedded sandstones and siltstones of the Mason Ridge Formation" by Kelsey *et al.* (1993). Kingma (1971) mapped two distinct limestone intervals in the Mason Ridge area as the lower Scinde Island limestone and the upper Scinde Island pebbly limestone, separated by the Waitio pumiceous siltstone. In his accompanying report (Kingma 1971) he acknowledged that three limestone beds occurred in this area, but offered no formal explanation or reason as to why only two limestone beds were mapped.

Type locality and reference sections

Although defined by Kelsey *et al.* (1993), no type section was designated. No type section was nominated by Dyer (2005), who studied the Mason Ridge Formation at Mason Ridge. This report nominates the section exposed in road cuttings along Raukawa Road as the type section (V22/204586-V22/201581). At this locality the entire formation is exposed, including the lower contact with the Makaretu Mudstone (Dyer 2005, Column 7).

Lower and upper contacts

The lower contact of the Mason Ridge Formation is poorly exposed, and has only been clearly observed on Mason Ridge Station (V22/165584), and at the type section (V22/204586). The formation gradationally overlies the Makaretu Mudstone through a coarsening upward interval.

The upper contact of the Mason Ridge Formation is usually marked by the modern land surface, although in places a thin veneer of Kidnappers Group Castlecliffian gravels is present. In western parts of Mason Ridge the formation is inferred to be unconformably overlain by both the Okauawa and Poutaki Formations. Although the contacts with both the Okauawa and Poutaki Formations are concealed, geological mapping strongly suggests that the contacts are unconformable, recording a period of uplift, erosion, and subsidence between deposition of the Mason Ridge Formation and the Okauawa-Poutaki Formations of at least 500 k.y.

Distribution and thickness

Mason Ridge Formation is widespread in the area south of the Ngaruroro River and Heretaunga Plains. Outcrop is mostly around Mason Ridge itself from near Maraekakaho south to Argyll East. The distribution has been mapped by Dyer (2005). In essence the extent of the unit appears to be restricted to an area of elevated hill country with a strong structural control. The formation does not crop out north of the Ngaruroro River. A large inferred fault in the region of Maraekakaho and Roys Hill (Kingma 1971) has juxtaposed Upper Nukumaruan limestone beds north of the river against Lower Nukumaruan Mason Ridge Formation limestone beds south of the river. The Mason Ridge Formation may underlie the Matapiro and Okawa regions at depth, and interdigitate with conglomerate facies of the Matahorua Formation, although a lack of subsurface data means this relationship cannot be confirmed. More likely is that the Mason Ridge Formation occupies, and is restricted to a, paleohigh occupying the area of the modern Mason Ridge, while north of the current outcrop area the formation rapidly passes into mudstone of the Taradale Mudstone.

The Mason Ridge Formation is chronostratigraphically equivalent, at least in part, to upper beds of the Matahorua Formation, Scinde Island Formation, Sentry Box Formation and Pakipaki Limestone.

On the basis of the presence of *Phialopecten triphooki*, Kelsey *et al.* (1993) suggested that the lower limestone of the Mason Ridge Formation is a lateral equivalent of the Pakipaki and Scinde Island Formations. Any direct correlations with these two formations are far from certain due to structural complexity, and it is probable that each formation has developed in isolation. Certainly, it appears that limestone exposed at Pakipaki has been brought into its present topographic position through strike-slip faulting on the Waipukurau-Poutaki fault system (Beu 1995).

Description

The Mason Ridge Formation comprises a succession of at least three siltstone-sandstone-limestone packages that are inferred to represent individual 41 ka cyclothems. Members defined for the formation by Dyer (2005) reflect siliciciclastic-dominated and limestone-dominated packages. Other cyclothemic intervals have been identified in the study area in rocks of similar age, such as the Matahorua Formation.

Paleontology and age

The lowest limestone bed of the Mason Ridge contains the Lower Nukumaruan index pectinids *Phialopecten triphooki* and *Towaipecten mariae. P. triphooki* has also been identified in the uppermost limestone bed (Dyer 2005). The formation is inferred to be of Lower Nukumaruan age. Kelsey *et al.* (1993) proposed that the middle and upper limestone beds of the Mason Ridge Formation were Upper Nukumaruan in age. Caron (2002) collected a single specimen of *Phialopecten triphooki* from the uppermost limestone bed (Pakihirua Limestone Member) at his Mangatai section (V22/163494). Dyer (2005) has also identified fragmented *Phialopecten triphooki* in the Pakihirua Limestone Member at both the Mangatai section (V22/163494) and other localities in the Mason Ridge area. The presence of *Phialopecten triphooki* in both the lowest and highest limestone beds of the Mason Ridge Formation strongly suggests an age no older than Lower Nukumaruan (Late Pliocene).

It is possible that the lower limestone bed of the Mason Ridge Formation (Mahana Limestone Member) may contain the basal Nukumaruan index pectinid *Zygochlamys patagonica delicatula*, although no specimens have yet been observed. Specimens of *Zygochlamys* have been collected from the adjacent Pakipaki Limestone (Beu 1995) as well as the Sentry Box Formation (Erdman and Kelsey 1992; Beu 1995), although none have been reported from the Lower Nukumaruan Scinde Island Formation. It is possible that poor exposure of the Mahana Limestone Member means that simply not enough sections have been sampled to locate any *Zygochlamys* valves.

Environment of deposition

The Mason Ridge Formation was deposited in a combination of inner to middle shelf environments. It is probable that the unit accumulated in a region of slightly higher elevation than surrounding areas, perhaps developing above a thrust zone. No trace of the formation is evident in the Taradale-1 drillhole (Darley and Kirby 1969), suggesting that water depths there were too great, or the siliciclastic sediment flux was too high.

Mahana Limestone Member

(Dyer 2005)

Name and definition

Mahana Limestone Member was introduced by Dyer (2005). The name is applied to the stratigraphically lowest of three limestone intervals cropping out in the Mason Ridge area. Mahana Limestone Member is defined as the lowermost, limestone-dominated member of the Mason Ridge Formation, which overlies Makaretu Mudstone, and underlies Maharakeke Mudstone Member.

The name Mahana Limestone Member replaces lower Scinde Island limestone (informal, Kingma 1971) and Scinde Island Limestone (Beu 1995) as Mahana Limestone Member and Scinde Island Formation (as defined and geologically mapped in this report) are not depositionally linked. Kingma (1971) and Beu (1995) both correlated the Mahana Limestone Member with Scinde Island Limestone on the basis of them both containing the Lower Nukumaruan index pectinid *Phialopecten triphooki.* Abandoning the name "Scinde Island" in reference to the Mahana Limestone Member removes any inference that only the Mahana Limestone Member is equivalent to Scinde Island Formation at Scinde Island, Napier, as *P. triphooki* has been collected, albeit rarely, in all limestone members of the Mason Ridge Formation (Dyer 2005). This means that all of the Mason Ridge Formation may be equivalent to Scinde Island Formation in a stratigraphic sense, however no lateral continuity is believed to exist and because of this it is desirable to maintain the Lower Nukumaruan stratigraphy in a separate formation.

Type locality and reference sections

The type locality designated by Dyer (2005) is retained. The section is on Mahana Station at V22/ 174509.

Lower and upper contacts

The lower contact of the Mahana Limestone Member is poorly exposed, though can be clearly observed on Mason Ridge Station above the Maraekakaho River (V22/166582; Fig. 32E). The Makaretu Mudstone grades over 0.2-0.4 m into sandstone at the base of the Mahana Limestone Member.

The upper contact is poorly exposed, but can be observed on Torran Station at V22/208588 and along Pakihirua Stream at V22/192551. In these sections the Mahana Limestone Member is abruptly overlain by Maharakeke Mudstone Member.

Distribution and thickness

Mahana Limestone Member is widespread across the Mason Ridge area occurring from Mahana Station (Anaroa Road) to Glencoe Station (State Highway 50) (Dyer 2005). The Mahana Limestone has a relatively uniform thickness of approximately 15 m across the outcrop area (Dyer 2005).

Description

The Mahana Limestone Member mostly comprises a differentially cemented, cream to almost white, barnacle-dominated unit similar in lithology to the underlying Te Onepu Limestone, but slightly coarser in texture (Dyer 2005). It further differs from the Te Onepu Limestone in lacking common *Phialopecten thomsoni* and *Crassostrea ingens.* The member comprises three main intervals. The lower interval comprises differentially cemented skeletal coarse sandstone (Fig. 30G). Cementation increases up-section and coincides with a general decrease in grain-size to medium skeletal sand in the middle parts of the member. Weak to strongly-developed, low to moderate angle, moderate scale sigmoidal, tabular and trough cross-stratification is common in these middle parts (Fig. 30B, C). The Mahana Limestone Member is capped by a 1-1.5 m-thick *Ostrea*-dominated shellbed. In terms of sequence stratigraphy this is inferred to represent a backlap shellbed following the nomenclature of Kidwell (1991). The *Ostrea* bed is best exposed at V21/227659, above the Ngaruroro River. This interval tends to be better cemented than the lower two intervals.

Paleontology and age

The Mahana Limestone Member contains abundant *Mesopeplum convexum* and *Ostrea chilensis.* The member also contains *Glycymeris shrimptoni* and the Lower Nukumaruan index pectinid *Phialopecten triphooki* (Beu 1995; Dyer 2005). Based on the presence of *Phialopecten triphooki* an Lower Nukumaruan age is confidently assigned to this member (Late Pliocene).

Environment of deposition

The Mahana Limestone Member accumulated during regressive and transgressive phases of a sea-level cycle. Middle cross-stratified elements of the member are inferred to represent the early phase of sea level rise during marine transgression. Macrofauna and sedimentary structures are consistent with a high-energy inner shelf environment of deposition. The upper oyster bed, corresponding to a backlap shellbed of Kidwell (1991), is inferred to have accumulated at middle to outer shelf water depths under a regime of very low siliciclastic sediment input during the middle to late stages of sea level rise.

Maharakeke Mudstone Member

(Dyer 2005)

Name and definition

Maharakeke Mudstone Member was introduced by Dyer (2005) for the fine-grained siliciclastic interval separating the Mahana and Torran Limestone Members of the Mason Ridge Formation. Maharakeke Mudstone Member replaced in part the term "interbedded sandstone and mudstone" used by Kelsey *et al.* (1993).

Type locality and reference sections

A road cutting on Raukawa Road at V22/205587 is designated as the type section for the Maharakeke Mudstone Member.

Lower and upper contacts

The lower contact is poorly exposed, although can be observed on Torran Station (V22/208588) and in Pakihirua Stream (V22/192551) where it abruptly overlies the capping oyster bed of the Mahana Limestone Member. The member is sharply overlain by skeletal grainstone of the Torran Limestone Member.

Distribution and thickness

The Maharakeke Mudstone Member is poorly exposed, and only crops out through central parts of the Mason Ridge area (Dyer 2005). The member is a maximum of 5 m thick.

Description

Maharakeke Mudstone Member comprises blue-grey, massive, sparsely fossiliferous, poorly cemented, calcareous mudstone. Superficially the member resembles the Makaretu Mudstone but can be distinguished on the basis of stratigraphic position above *Phialopecten triphooki*-bearing limestone of the Mahana Limestone member. Maharakeke Mudstone Member becomes increasingly sandy up-section before passing abruptly into the Torran Limestone Member (Dyer 2005).

Paleontology and age

The poorly exposed nature of Maharakeke Mudstone Member means that macrofossils are not commonly observed. *Tawera subsulcata* and *Zeacolpus ?vittatus* were reported as common by Dyer (2005), with occasional *Pelicaria ?convexa* also present. Clark (1976) noted the occurrence of *Patro undatus, Tugali pliocenica* and *Sigapatella novaezelandiae*.

Stratigraphic position demonstrates a Lower Nukumaruan age for the Maharakeke Mudstone Member (Late Pliocene).

Environment of deposition

Macrofauna support an inner to middle shelf environment of deposition for the Maharakeke Mudstone Member.

Torran Limestone Member

(Dyer 2005)

Name and definition

Torran Limestone Member was introduced by Dyer (2005) for the second of three limestone units cropping out in the Mason Ridge area. The name is derived from Torran Station where the type section is located. Torran Member is defined as the interval from the base of the siliciclastic bed forming upper parts of the Maharakeke Mudstone Member, to the base of the lower siliciclastic beds of the Pakihirua Limestone Member.

Type locality and reference sections

The type section nominated by Dyer (2005) on Torran Station is retained (V22/207589).

Lower and upper contacts

The Torran Limestone Member sharply overlies the Maharakeke Mudstone Member. It is abruptly overlain by the Whakapirau Mudstone Member, and can be observed on Ibstone Station at V22/174539 (Dyer 2005).

Fig. 30 (facing page): Mason Ridge Formation. **A)** Typical outcrop and geomorphology of the Mason Ridge area. White dotted line marks the base of the Mahana Limestone Member. Photo taken on Glen Coe Station. **B)** Outcrop of Mahana Limestone Member (V22/107615). Note the cross-bedding in upper parts of the exposure. **C)** Mahana Limestone Member cropping out around V22/154596. Note person for scale. **D)** Torran Limestone Member exposed in a quarry on Marae Downs Station (V22/201622). The upper rubbly-looking skeletal grainstone sharply overlies shelly packstone across a sharp wavy contact. Upper parts of the exposure comprise the capping *Ostrea*-dominated shellbed (Dyer 2005). **E)** Mahana Limestone Member, the basal unit of the Mason Ridge Formation, gradationally overlying Makaretu Mudstone on Mason Ridge Station (V22/166582). **F)** Torran Limestone Member in a quarry on Marae Downs Station (V22/201622). Person is examining the lower shelly packstone part of the member. **G)** Orange-coloured sandy skeletal packstone overlying poorly cemented skeletal grainstone, Mahana Limestone Member. Photo location Glen Coe Station (V22/154596).


A
B
C
D
E
Mahana Limestone Member
Makaretu Mudstone
F
G

Distribution and thickness

The Torran Limestone Member thins from 15 m in eastern parts of the Mason Ridge area to 8 m in the west (Dyer 2005).

Description

Torran Limestone Member comprises a basal skeletal packstone and grainstone unit that becomes increasingly biomouldic and more cemented up-section (Dyer 2005). Cross-stratification also becomes more common up-section. The transition from the skeletal grainstone to oyster beds of the member are well exposed in an old quarry on Marae Downs Station (V22/202224; Fig. 30D, F). These two intervals are separated by a sharp wavy contact. Small greywacke clasts up to 3 mm across are scattered through the member. The member is capped by a 1.6 m-thick bed of *Ostrea chilensis* valves and brachiopods in a grey-tan coloured silty matrix.

Paleontology and age

Macrofauna reported in the Torran Limestone Member are typical of those present in Nukumaruan limestones in the study area and include *Purpurocardia purpurata, Mesopeplum convexum, Glycymeris shrimptoni, Ostrea chilensis, Zethalia zelandica* and *Tawera subsulcata.*

The presence of *Towaipecten mariae, Zethalia zelandica* and *Glycymeris shrimptoni* assigns the member to the Nukumaruan Stage. Its stratigraphic position between two limestone beds containing *Phialopecten triphooki* (Beu 1995; Caron 2002; Dyer 2005) suggests that the Torran Limestone Member is of Lower Nukumaruan age (Late Pliocene).

Environment of deposition

Macrofauna in the Torran Limestone Member are typical of those observed in coarse-grained shallow-water deposits in the study area, and are common in harbour channel and nearshore settings around the modern New Zealand coastline. The abundance of *Zethalia zelandica* indicates deposition in a shoreface to nearshore setting on sandy to gravelly substrates, perhaps in or near tidal channels.

Whakapirau Mudstone Member

(Dyer 2005)

Name and definition

Whakapirau Mudstone Member was introduced by Dyer (2005). The name is derived from Whakapirau Station and replaced in part the term "interbedded sandstone and mudstone" used by Kelsey *et al.* (1993). The unit is defined as a coarsening-upward interval of mudstone that overlies the Torran Limestone Member and underlies the Pakihirua Limestone Member.

Type locality and reference sections

The type section designated on Raukawa Road (V22/201583) by Dyer (2005) is retained. Reference sections are located on Whakapirau Station (V22/196597) and along Pakihirua Stream (V22/191551).

Lower and upper contacts

Whakapirau Mudstone Member abruptly overlies the oyster bed capping the Torran Limestone Member. The member is gradational over 0.5 m into the overlying Pakihirua Limestone Member.

Distribution and thickness

The Whakapirau Mudstone Member is restricted in outcrop to central parts of the Mason Ridge area. The member is 10 m thick at Whakapirau Station, and thins to 4 m in western parts of Mason Ridge (Dyer 2005).

Description

The Whakapirau Mudstone Member comprises a blue-grey, sparsely fossiliferous, massive, calcareous sandy mudstone that passes upsection into friable, shelly, fine sandstone. Macrofauna are commonly concentrated into thin layers.

Paleontology and age

The member comprises typical Nukumaruan macrofauna in the study area, such as *Tawera subsulcata, Atrina pectinata zelandica, Ostrea chilensis, Zethalia zelandica* and *Purpurocardia purpurata,* together with *Pelicaria convexa* and *Zeacolpus* sp. (Dyer 2005). Dyer (2005) reported *Towaipecten mariae* in the Whakapirau Mudstone Member. Based on the presence of *Towaipecten mariae, Zethalia zelandica* and *Pelicaria convexa* a Nukumaruan age is inferred for the member. The stratigraphic position of the Whakapirau Mudstone Member below the Pakihirua

Limestone Member (which contains *Phialopecten triphooki*) implies a Lower Nukumaruan age (Late Pliocene).

Environment of deposition

Macrofauna and sedimentary structures in lower parts of the member suggest an inner shelf environment of deposition for the Whakapirau Mudstone Member. Deposition is likely to have occurred adjacent to a shoreface-nearshore sandy wedge as indicated by the presence of *Zethalia zelandica. Atrina pectinata zelandica* is common around the modern New Zealand coastline in nearshore to inner shelf settings, such as in Coromandel Harbour and the inner Hauraki Gulf, consistent with the inferred paleoenvironment for the member.

Macrofauna in upper parts of the Whakapirau Mudstone Member are consistent with a shallow nearshore environment of deposition, reflecting shallowing induced by sea level fall. *Austrovenus* is an important indicator of estuarine environments, and typically *Maoricolpus* presently occupies coarse-grained substrates in harbour channels. *Zethalia zelandica* presently occurs in shallow-water (<3 m deep) (Beu and Maxwell 1990) off sandy beaches around New Zealand. It is probable that the upper parts of Whakapirau Mudstone Member accumulated slightly offshore of a sandy beach with nearby estuarine environments. The abraded and fragmented nature of *Austrovenus* valves are consistent with redeposition of them from estuarine settings.

Pakihirua Limestone Member

(Dyer 2005)

Name and definition

Pakihirua Limestone Member was introduced by Dyer (2005) for the stratigraphically highest of three limestone units in the Mason Ridge area. The name is derived from Pakihirua Stream above which the type section is located. The top of the Pakihirua Limestone Member is equivalent to the top of the Mason Ridge Formation.

Type locality and reference sections

The type section nominated by Dyer (2005) in Pakihirua Stream is retained (V22/190551).

Lower and upper contacts

Pakihirua Limestone Member grades up over about 0.5 m from the Whakapirau Mudstone Member. The contact is exposed on Whakapirau Station (V22/196595) (Dyer 2005).

The upper surface of the Pakihirua Limestone Member, which also marks the top of the Mason Ridge Formation, is usually marked by the modern land surface. Although not exposed, it is inferred through geological mapping that the overlying Okauawa and Poutaki Formations unconformably overlie the Pakihirua Limestone Member with > 500 k.y. "missing" in the unconformity. In places the member may be unconformably overlain by a thin veneer of non cemented gravels of undifferentiated Kidnappers Group.

Distribution and thickness

The Pakihirua Limestone Member underlies central parts of the Mason Ridge area (Dyer 2005); typically cropping out in scrappy uncommon exposures. The clearest outcrops occur along Pakihirua Stream in the vicinity of the type section. The unit thins from 15 m thick along Pakihirua Stream and Torran Station to 8 m at the southern end of Glencoe Station (Dyer 2005).

Description

Although generally poorly exposed, a number of different lithologies were identified in the Pakihirua Limestone Member by Dyer (2005) including: 1) basal differentially cemented, calcareous fine to coarse sandstone beds. These beds increase in their degree of cementation up-section and laterally interdigitate with each other; 2) a middle part comprising creamy-grey coloured, well cemented tabular cross-bedded biomouldic limestone, and 3) a 1.5 m-thick skeletal packstone capping bed dominated by valves of *Ostrea chilensis* and biomoulds of aragonitic bivalves. Separating these three main units are intervals of moderately cemented skeletal grainstones dominated by fragments of bryozoans with discontinuous sandstone and siltstone interbeds. The layer separating the lower and middle intervals of the member is frequently highly bioturbated with *Ophiomorpha* burrows (V. Caron, pers. comm. 2002 *in* Dyer 2005, p. 38). Greywacke granules (<0.3 cm across, up to 5% abundance) are more common in the Pakihirua Limestone Member than the underlying Torran Limestone Member. The upper *Ostrea*-dominated shellbed contains rare well rounded spheroidal greywacke pebbles up to 5 cm across (Dyer 2005).

Paleontology and age

Dyer (2005) reported *Pelicaria convexa, Ostrea chilensis, Maoricolpus roseus, Zethalia zelandica* and fragmented and abraded *Austrovenus* sp. from the Pakihirua Limestone Member.

Kelsey *et al.* (1993) assigned an Upper Nukumaruan age to this limestone. Both Caron (2002) and Dyer (2005) identified *Phialopecten triphooki* in the Pakihirua Limestone Member. This pectinid is not known in rocks younger than Lower Nukumaruan (Beu 1995), and so a Lower Nukumaruan age is adopted for the member (Late Pliocene).

Environment of deposition

Only a sparse macrofauna was noted in the Pakihirua Limestone Member by Dyer (2005). *Phialopecten triphooki* is typically collected from coarse-grained rocks such as limestones and conglomerates that are inferred to have a nearshore to innermost shelf environment of deposition. The presence of *P. triphooki* indicates a period of deepening following deposition of the Whakapirau Mudstone Member.

SENTRY BOX FORMATION (sb)

(Erdman and Kelsey 1992)

Name and definition

Sentry Box Limestone was introduced and formally defined by Erdman and Kelsey (1992) in reference to a fossiliferous pebbly grainstone cropping out on the western margin of the Ohara Depression at the foot of the Ruahine Range. The name is derived from the Sentry Box, a prominent hill and scenic reserve immediately southwest of the type section (U21/925664; Fig. 31A, C). Sentry Box Formation was included within the informal Kereru limestone by Beu *et al.* (1980), a stratigraphic unit that contained limestones of multiple ages. Detailed geological mapping by Erdman and Kelsey (1992) clearly demonstrated that the Kereru limestone could be subdivided into three distinct limestone intervals occupying different stratigraphic positions. Sentry Box Formation is applied to the oldest of these three intervals, the others being Mount Mary Pebbly Limestone and Kereru Formation (see below). Although mostly limestone dominated, the term “Formation” is preferred over “Limestone” in this report to reflect the varied lithologies in the unit.

Sentry Box Formation has been redefined to incorporate the Whanawhana Limestone, named by Beu (1995), for a geographically-restricted lowermost Nukumaruan limestone containing both *Phialopecten triphooki* and *Zygochlamys patagonica delicatula.* The co-occurrence of these two pectinids indicates Beu’s Whanawhana Limestone is of the same age as the Sentry Box Formation. Given that Beu (1995) described Sentry Box Formation both north and south of the Whanawhana region, and that the Sentry Box Formation contains the same diagnostic basal Nukumaruan pectinids, it seems appropriate to include Whanawhana Formation in the Sentry Box Formation. This simplifies the stratigraphy through this region without masking any structural or depositional influences.

Sentry Box Formation also incorporates the Seconds Ridge Conglomerate, introduced by Beu (1995). Seconds Ridge Conglomerate comprises a very small area of fossiliferous conglomerate cropping out in one locality on the northern end of the Ruahine Range. As with the Sentry Box

Formation, the Seconds Ridge Conglomerate contains a diagnostic, very basal Nukumaruan fauna (Beu 1995). Erdman and Kelsey (1992) had included this unit within the Sentry Box Formation, but it was excluded from the definition of Beu (1995) on the basis of lithology. This report views the Seconds Ridge Conglomerate merely as a very shallow-water, nearshore facies variation of Sentry Box Formation cropping out elsewhere in the study area, and not requiring a separate formation name. A further point is that the only known outcrop of the Seconds Ridge Conglomerate is a 200 m-long by 30 m-high exposure at Seconds Ridge. Given the units limited geographical extent it seems inappropriate to give it formation status. However, because of the distinctive lithology reported for the Seconds Ridge Conglomerate by Beu (1995), the name is retained as a member of the Sentry Box Formation. Sentry Box Formation is defined to incorporate all basal Nukumaruan limestone and minor sandstone, conglomerate and mudstone facies containing *Zygochlamys delicatula* cropping out along the western margin of the study area from Sentry Box Scenic Reserve in the south, northwards to Mount Miroroa and the Gentle Annie at Kuripapango.

Type locality and reference sections

The type section for the Sentry Box Formation was designated by Erdman and Kelsey (1992) and is located in Jumped Up Stream where crossed by Mangleton Road from a point approximately 50 m above the road bridge to a point 50 m downstream (U21/934666, Column Ke-3). The section near Awapai Station gate (U21/043805, Column Wh-3) is designated as an excellent, easily accessible reference section for the formation in this particular area.

Lower and upper contacts

Sentry Box Formation overlies several stratigraphic units. The formation conformably to unconformably overlies the Puketitiri Formation, unconformably overlies the Blowhard Formation and unconformably overlies basement. In Jumped Up Stream Sentry Box Formation conformably and gradationally overlies fine sandstone facies of the Puketitiri Formation. Sentry Box Formation conformably overlies At Rocky Outcrop beside Gull Flat Road (U21/971717, Column Ke-6) Sentry Box Formation unconformably overlies the Puketitiri Formation across an erosional contact. The base of the formation here comprises a poorly sorted greywacke conglomerate to breccia. On the Napier-Taihape Road at the Gentle Annie a fossiliferous conglomerate of the Sentry Box Formation overlies greywacke through an angular unconformity with a paleo-high or sea-stack relief (U20/956957) (Browne 2003). Although the contact is not exposed, on Mount Miroroa ("Cattle Hill") the Sentry Box Formation is inferred to unconformably overlie the Blowhard Formation (Browne 2003, 2004a). At Seconds Ridge on the northern end of the Ruahine Range, Sentry Box Formation unconformably overlies the Omahaki Formation of Opoitian age (Beu 1995).

At the type section (Columns Ke-2, Ke-3), Sentry Box Formation is conformably overlain by fine-grained sediments of the Esk Mudstone through a 1 m-thick muddy limestone with few macrofossils. A thin (10 cm thick) shellbed above this gradational zone was found by Beu (1995) to contain common faunas diagnostic of bathyal environments.

Distribution and thickness

Sentry Box Formation crops out along the western margins of the Ohara Depression (Fig. 31A-C), prominently in the Whanawhana/Awapai Station area (Fig. 31E, F) and on isolated hilltops as far north as Mount Miroroa (Fig. 31D) and the Gentle Annie in the Kuripapango area (Browne,1981, 2004a, b). Sentry Box Formation does not crop out east of the Mohaka Fault, though it is probably present in the subsurface. In the Whanawhana area the Mohaka Fault truncates the eastern margin of Sentry Box Formation.

In the Kuripapango region the Sentry Box Formation crops out in several largely fault-bounded areas. At Mount Miroroa the formation forms a steep cliff face on the northern side of the mountain that is clearly visible from Taihape Road (Fig. 31D). The formation also crops out below Mount Kohinga and on the Gentle Annie on Taihape Road. At both of these locations the distribution of the unit is controlled by fault-bounded blocks. Sentry Box Formation is not known in outcrop east of the Mohaka Fault, or north of Taihape Road. Limestone beds south of the Ohara Depression containing *Zygochlamys delicatula* reported by Beu (1995) may be lateral equivalents of the Sentry Box Formation. The Pakipaki Limestone, Scinde Island Formation, Papakiri/Grassy Knoll Members (Matahorua Formation) and lower parts of the Mason Ridge Formation are all chronostratigraphic equivalents of the Sentry Box Formation. Erdman and Kelsey (1992) considered the Mount Mary Formation to be a lateral equivalent of the Sentry Box Formation as it also is overlain by the Esk Mudstone. However, the Mount Mary Formation lacks all diagnostic Lower Nukumaruan taxa and is most probably slightly younger.

Johnston and Francis (1996) correlated Sentry Box Formation into the Kereru-1 drillhole to a sandstone interval they named the Homeward Sandstone.

Sentry Box Formation is typically 20-25 m thick through the Ohara Depression, although outcrop thickness is generally much less than this. The thickest exposures of the Sentry Box Formation occur in the region of Jumped Up Stream and Sentry Box Scenic Reserve, and the northern face of Mount Miroroa. At Mount Miroroa Sentry Box Formation is up to 30 m thick (Browne 2003).

Description

Around the type section at Sentry Box hill and Jumped Up Stream, Sentry Box Formation consists of slightly to moderately-well cemented barnacle-dominated grainstone (Fig. 31A, B) to packstone that conformably overlies shelly conglomerate beds of the Puketitiri Formation and Sentry Box Formation. Basal conglomerate beds are highly fossiliferous, with a muddy matrix. A very diverse macrofauna are recorded from this area (Column Ke-3). Interbeds of well sorted shelly conglomerate up to 1 m thick are common throughout the main package of the formation. Master weathering surfaces are prominent in the Sentry Box hill section, and may record syndepositional fluctuations in sea level (Fig. 31A). Up-section the formation becomes increasingly muddy before passing into the Esk Mudstone. The macrofauna within the formation are dominated by the barnacles *Austromegabalanus decorus* and *Fosterella dubulatus* with common *Phialopecten triphooki, Ostrea chilensis* and *Crassostrea ingens. Zygochlamys delicatula* is locally common.

While typically limestone-dominated, facies within the Sentry Box Formation vary throughout the Ohara Depression, reflecting proximity to a paleo-shoreline. Along Gull Flat Road at Rocky Outcrop (Column Ke-6) the formation comprises a steeply dipping package of sandstone containing scattered shellhash overlain by a 0.5 m-thick greywacke conglomerate and breccia, and capped by 5 m of massive to laminated and cross-bedded slightly pebbly limestone. In Kaumatua Stream limestone of the Sentry Box Formation grades laterally into fossiliferous sandstone containing *Zygochlamys patagonica delicatula* (Erdman and Kelsey 1992).

Sentry Box Formation through the Whanawhana and Corbin Road areas (Fig. 31E, F) comprises a lower package of stacked alternating bioclastic/siliciclastic-dominated sheets overlain by an upper shellbed dominated by large aragonitic bivalves with some to common *Phialopecten triphooki* and uncommon *Zygochlamys delicatula.*

Very shallow-water deposition of the Sentry Box Formation is expressed at Seconds Ridge on the northern Ruahine Range (Seconds Ridge Conglomerate Member). shallow-water, nearshore deposition is also recognised at Kuripapango along the Gentle Annie (Browne 2003). In the Kuripapango region the Sentry Box Formation crops out as a combination of sandstone, siltstone, conglomerate and shellhash facies (Browne 2003). Browne (2004a) recognised two lithofacies in the Kuripapango region, a gravelly grainstone and fossiliferous sandstone and siltstone. The section exposed on Mount Miroroa comprises 30 m of dark-yellowish-coloured, very poorly sorted fine sandstone to gravelly grainstone. *Zygochlamys patagonica delicatula* and *Jacquinotia edwarssi* have been collected from siltstone overlying the main limestone bluff on Mount Miroroa (Beu *et al.* 1977; Beu 1995; Browne 2004a).

Paleontology and age

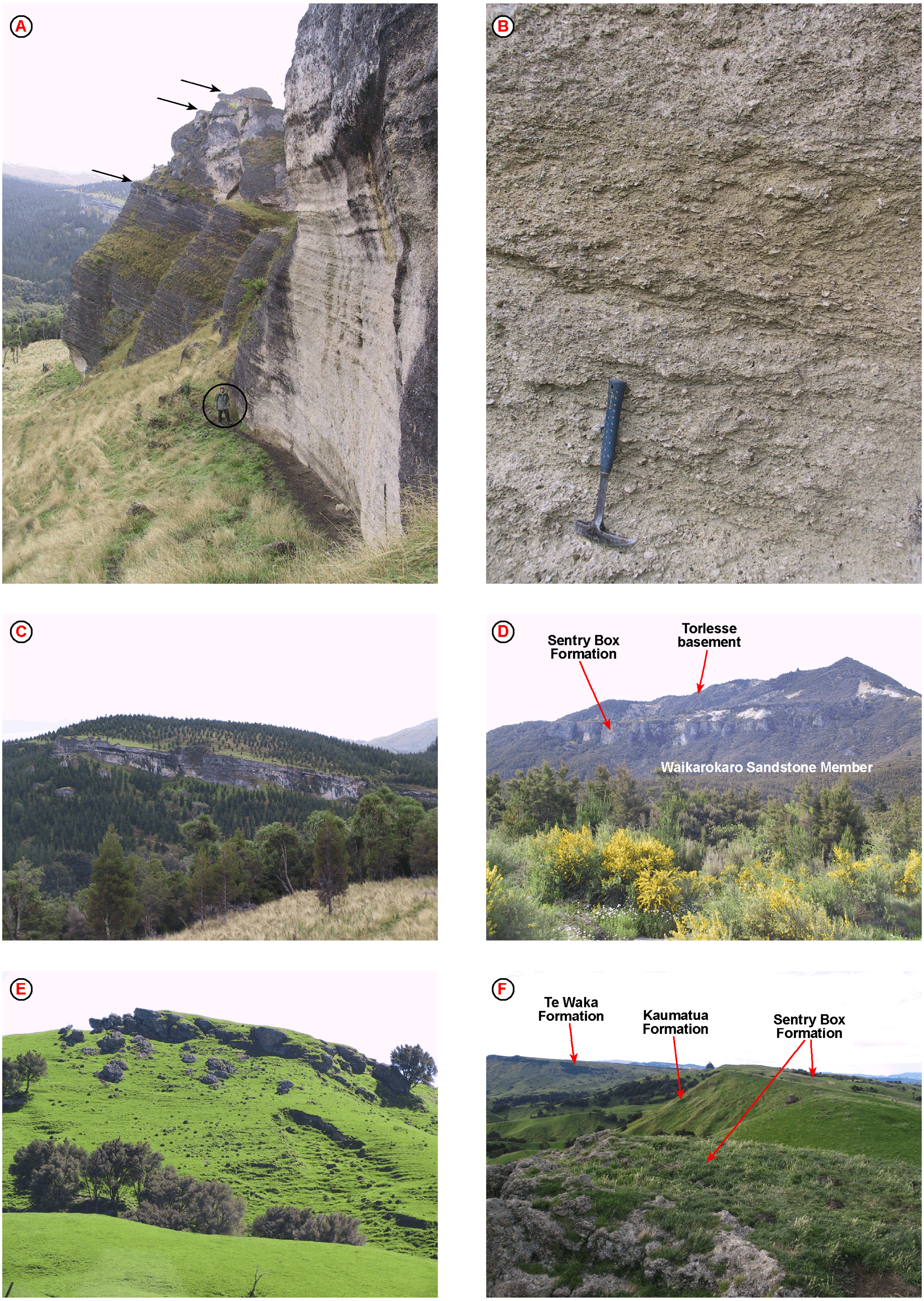
Both *Zygochlamys patagonica delicatula* and *Phialopecten triphooki* are present throughout the formation and allow for confident correlation of the unit from the Ohara Depression, through the Whanawhana region to Kuripapango. In Jumped Up Stream, Sentry Box Formation contains a very diverse faunal assemblage which contains some *Zygochlamys patagonica delicatula* and common *Phialopecten triphooki*.

The presence of *Crassostrea ingens* in association with *P. triphooki and Z. delicatula* at Jumped Up Stream and Seconds Ridge demonstrates a very basal Nukumaruan age for lower parts of this unit. Only at Seconds ridge is *Crassostrea ingens* at all common (Beu 1995). Beds here also contain specimens of Mangapanian pectinids *Phialopecten thomsoni* and *Towaipecten katieae,* together with the Nukumaruan pectinid *Towaipecten mariae,* further demonstrating a very basal Nukumaruan age for lowermost parts of the formation (Beu 1995).

Environment of deposition

The presence of many subantarctic species in the Sentry Box Formation indicates a change to very cold waters from the underlying Puketitiri Formation. This flux of cold, subantarctic waters north into the study area (and many other parts of New Zealand such as Wanganui Basin) effectively marks the base of the Nukumaruan Stage.

Fig. 31 (facing page): Sentry Box Formation. **A)** Stacked grainstone and packstone beds of the Sentry Box Formation on the western side of Sentry Box hill (U21/925664). Person (circled) for scale. Master weathering horizons are arrowed. Sentry Box Formation here comprises packages of coarse-grained skeletal limestones with common pebbly interbeds up to 2 m thick. The formation is moderately to highly fossiliferous with a diverse ranges of bivalve and gastropod faunas. **B)** Close-up view of barnacle-dominated grainstone and packstone beds of the Sentry Box Formation at the outcrop in A (U21/925664). **C)** Sentry Box Formation in a ridge on the north side of Jumped Up Stream. Viewed looking northeast from the summit of Sentry Box Hill (U21/924664). **D)** View of Mount Miroroa from Taihape Road, Kuripapango area. Kapitean (Late Miocene) Waikarokaro Sandstone Member (Blowhard Formation) is unconformably overlain by Sentry Box Formation. The Miroroa Thrust has placed Torlesse greywacke over the Sentry Box Formation. Viewed from about U20/022935 looking south. **E)** Sentry Box Formation cropping out above the entrance to Awapai Station, Whana Valley (U21/041804). **F)** Dipslopes of Sentry Box Formation on Awapai Station. The Sentry Box Formation overlies Puketitiri Formation (arrowed). The bluffs of Te Waka Formation arrowed in this image mark the southernmost outcrop of the formation. Te Waka Formation here interdigitates with Puketitiri Formation. Viewed from U21/040806 looking northeast.


A
B
C
D
Sentry Box Formation
Torlesse basement
Waikarokaro Sandstone Member
E
F
Te Waka Formation
Kaumatua Formation
Sentry Box Formation

The rugged nature of the onlap surface exposed along the Gentle Annie (U20/956957) suggests deposition on a very rocky coastline. Throughout the Kuripapango region a shallow marine (<50 m) depositional setting is inferred. The wide variety of facies present (from siltstone to gravel) suggests varied localised depositional settings

Seconds Ridge Conglomerate Member (sba)

(Beu 1995)

Name and definition

Beu (1995) introduced the informal Seconds Ridge limestone for a fossiliferous conglomerate cropping out on the northern Ruahine Range which was included in the Sentry Box Limestone (renamed Sentry Box Formation in this report) by Erdman and Kelsey (1992). Seconds Ridge Conglomerate Member has a very localised distribution, and a basal Nukumaruan macrofauna very similar to that of the Sentry Box Formation. These factors suggest that maintaining Sentry Box Conglomerate Member as a distinct formation is inappropriate. However the unit is mappable and lithologically distinct enough to have member status. Seconds Ridge Conglomerate Member is defined as a coarse-grained interval of basal Nukumaruan age cropping out on the northern Ruahine Range that overlies Early Pliocene Omahaki Formation.

Type locality

The type section defined for the Seconds Ridge Conglomerate Member by Beu (1995) is retained (U21/972802).

Lower and upper contacts

Seconds Ridge Conglomerate Member unconformably overlies the Omahaki Formation of Opoitian age (Beu 1995). The upper contact is marked by the modern land surface.

Distribution and thickness

Seconds Ridge Conglomerate Member is not known away from the type locality on Seconds ridge where it crops out in a single 200 m-long by 30 m high exposure (Beu 1995).

Description

The only description of the Seconds Ridge Conglomerate Member is that by Beu (1995). It comprises flat-lying, parallel-bedded to low-angle cross-bedded calcareous-cemented conglomerate. Individual beds vary from 0.2-1 m thick and consist of pebble-supported very well rounded Torlesse basement clasts with a minor fine calcareous matrix. The matrix varies from fine-grained calcarenite to coarse-grained barnacle plate grainstone. Beds 0.3-0.5 m thick are present that are less conglomeratic, and richer in the matrix sediments. *Crassostrea ingens* is scattered through all lithologies, although is more common in beds richer in calcareous sediments. Pectinids occur more rarely in the calcareous beds.

Paleontology and age

Crassostrea ingens is the only mollusc at all common in the Seconds Ridge Conglomerate Member (Beu 1995). Pectinids present in small numbers include *Phialopecten thomsoni, Towaipecten katieae* n.sp., *T. mariae, Mesopeplum convexum, Talochlamys gemmulata,* and *Zygochlamys delicatula.*

A very basal Nukumaruan age is assigned to the Seconds Ridge Conglomerate Member based on the co-occurrence of *C. ingens, P. thomsoni* and *Towaipecten katieae* (a Mangapanian assemblage) with *T. mariae* and *Z. delicatula* (Beu 1995). The fauna at Seconds Ridge (GS12421, U21/f5; Beu 1995, p. 141) is unique in the study area and comprises a very shallow-water, high-energy assemblage that can be correlated with the Sentry Box Formation based on the occurrence of *Z. delicatula* with *P. thomsoni* and *C. ingens.*

Environment of deposition

Seconds Ridge Conglomerate Member is viewed as being a nearshore, very shallow-water expression of deeper water Sentry Box Formation beds in Jumped Up Stream, at Rocky Outcrop, Whanawhana and Mount Miroroa. It was deposited immediately adjacent to an exposed basement hinterland, and probably records the final stages of the Kuripapango Strait before it was finally uplifted in the Upper Nukumaruan.

MOUNT MARY PEBBLY LIMESTONE (mm)

(Erdman and Kelsey 1992)

Name and definition

Erdman and Kelsey (1992) introduced the name Mount Mary Limestone in reference to a series of interbedded grainstone and conglomerate beds capping Mount Mary (from where the name is taken) in the Ohara Depression. This formation was originally included in the Kereru limestone (informal) of Beu *et al*. (1980). Mount Mary Formation is older than limestone of the Kereru Formation, and the separate formation name reflects this.

Type locality and reference sections

The type section designated by Erdman and Kelsey (1992) on Mount Mary (U21/969681) is retained in this report. Although the section is incomplete, the type locality contains the greatest thickness of the formation.

Lower and upper contacts

The Mount Mary Pebbly Limestone everywhere unconformably overlies Torlesse basement with common metre-scale relief on the contact.

Mount Mary Pebbly Limestone is gradationally overlain by, and interdigitates with, the Esk Mudstone (Erdman and Kelsey 1992).

Distribution and thickness

Mount Mary Pebbly Limestone is restricted in outcrop to margins of the Wakarara Range in the Ohara Depression, and does not occur west of the Mohaka Fault. Mount Mary Pebbly Limestone is absent where mudstone of the Esk Mudstone rests directly on basement greywacke. Mount Mary Pebbly Limestone is a maximum of 30 m thick.

In the Ohara Depression the formation crops out on the northwestern summit of Mount Mary on Glendale Station (e.g. U21/969681), and beside Mangleton Road (U21/279701).

Description

Mount Mary Pebbly Limestone is typically a moderately to well cemented grainstone composed of shellhash and fragmented bryozoans with common greywacke pebbles averaging 3-15 mm across (Kelsey *et al*. 1993). At the type section the Mount Mary Pebbly Limestone comprises 30 m of calcareous-cemented matrix-supported greywacke conglomerate with a few interbeds of grey-brown coarse sandstone (Beu 1995). Greywacke clasts are supported in a matrix of mudstone to shellhash and display parallel to low-angle cross-stratification in stacked beds 0.2-0.5 m thick (Beu 1995). In a cutting on Mangleton Road, where the unit rests on greywacke basement, Mount Mary Pebbly Limestone consists of thin (<0.3 m thick) alternating grainstone, pebbly limestone and greywacke conglomerate beds. Rare pebbly beds up to 0.7 m thick are present. Clasts are well rounded and well sorted, typically 2-3 cm across, rarely up to 6 cm. Bryozoan fragments are common in the more carbonate-dominated interbeds, and presumably reflect organisms that encrusted an irregular greywacke seafloor. This locality is adjacent to where the Mohaka Fault crosses Mangleton Road.

A cyclothemic expression of the formation is evident in Matthews Stream, based on descriptions by Erdman and Kelsey (1992). In this section the formation comprises three distinct packages comprising a coarse-grained pebbly limestone gradationally overlain by 5-10 m of massive mudstone (Kelsey *et al.* 1993). it is probable that this section accumulated in a slightly more offshore setting than that exposed at the type section.

Paleontology and age

Samples of Mount Mary Pebbly Limestone from cuttings on Mangleton Road are rich in sheet and branching bryozoans, presumably derived from organisms attached to a nearby rocky substrate of basement. Kelsey *et al.* (1993) suggested that Mount Mary Pebbly Limestone was age equivalent to Sentry Box Formation (i.e. basal Nukumaruan). No specimens of typical Lower Nukumaruan fauna have been collected from Mount Mary Pebbly Limestone. Because Mount Mary Pebbly Limestone is overlain by Esk Mudstone (as is Sentry Box Formation), it must be of a similar age to the Sentry Box Formation. However, Mount Mary Pebbly Limestone lacks all diagnostic basal Nukumaruan index fossils, such as *Phialopecten triphooki* and *Zygochlamys delicatula,* and is therefore younger than the Sentry Box Formation. On the basis of stratigraphic position beneath the Esk Mudstone, the Mount Mary Pebbly Limestone is assigned a Lower Nukumaruan (Late Pliocene) age.

Environment of deposition

Mount Mary Pebbly Limestone probably developed adjacent to a greywacke "island" (the proto-Wakarara Range) on the margins of a region of otherwise relatively deep-water (outer shelf to perhaps uppermost bathyal). Mount Mary Pebbly Limestone is only present in the vicinity of the Wakarara Range. It is envisaged that the emerging Wakarara Range acted as a shoal area, with Mount Mary Pebbly Limestone accumulating on and around it. The cyclothemic expression of the formation indicates that strata in Matthews Stream were deposited in a slightly deeper water setting than those at the type section on Mount Mary (hence more accommodation space). The presence of metre-scale relief on the lower contact on Mount Mary (U21/969681) indicates a rocky coastline environment in areas proximal to the Wakarara Range.

KERERU FORMATION (ke)

(McKay 1887; formally defined by Erdman and Kelsey 1992)

Name and definition

Kereru Formation derives its name from Kereru Station, one of the earliest established stations in Hawke's Bay. Limestone in this area was first described by McKay (1887) and originally all limestone beds in the Ohara Depression, such as those at Sentry Box and Mount Mary, were included in the Kereru Limestone (e.g. Beu *et al.* 1980). Erdman and Kelsey (1992) recognised that there are in fact limestone units of multiple ages and depositional settings in the Kereru and Ohara Depression areas and redefined the Kereru Limestone. Erdman and Kelsey (1992) restricted the name Kereru Limestone to very pebbly limestone and sandy oyster beds cropping out in very steeply-dipping (c. 90º) ridges along most of the eastern edge of the Wakarara Range, and on several small platforms along the western edge of the range. Outcrops in the western areas are still relatively shallow-dipping. Elements of the diagenetic history of the Kereru Limestone were described by Caron (2002). As sandstone and siltstone beds are common in this unit, the Kereru Limestone of Erdman and Kelsey is here emended to Kereru Formation.

Type locality and reference sections

No type locality was nominated for the Kereru Formation by either Erdman and Kelsey (1992), Kelsey *et al.* (1993, or Beu (1995). The section on Glendale Farm off Mangleton Road, described in detail by Caron (2002), is nominated as the type section for the Kereru Formation (Fig. 32B-E; U21/967687, Column Ke-8). This section exposes the base of the formation.

Lower and upper contacts

On Glendale Farm (U21/967687) the Kereru Formation sharply overlies coarsening upwards siltstone to fine sandstone of the upper part of Esk Mudstone (Caron 2002) (Fig. 32B, C, E). The upper contact, where abruptly although gradationally overlain by the Kikowhero Member of the Okauawa Formation, is exposed in Ohara Stream in several locations (e.g. U21/050731, U21/041726). The Kereru Formation is in fault contact with basement southwest of Poporangi Road due to displacement on the Wakarara Fault (U21/996654).

Distribution and thickness

Kereru Formation is restricted in outcrop to an area proximal to the North Island axial faults south of the Ngaruroro River, largely in the vicinity of elevated regions of greywacke basement. Kereru Formation underlies and interdigitates with Okauawa Formation, as exposed at the confluence of the Big Hill and Ohara Streams. To the east of the Wakarara Range, Kereru Formation crops out as a series of near-vertically dipping ridges truncated by the Wakarara Fault. Northwards from the Wakarara Range the Kereru Formation grades into massive to laminated muddy fine sandstone and highly fossiliferous pebbly shellbeds.

The Kereru Formation is clearly visible from Mangleton Road near the Sentry Box as a long ridge extending along the western side of the Wakarara Range. A steeply dipping ridge of Kereru

Formation is prominent southwest of Poporangi Road (U21/996654). At this locality the formation is truncated to the west by the Wakarara Fault and juxtaposed against basement.

Kereru Formation has been correlated into the Kereru-1 drillhole, where it is represented by a sandstone interval (Johnston and Francis 1996). The formation is not present in either the Mason Ridge-1 or Taradale-1, drillholes by which time it has likely graded into mudstone dominated facies of the Taradale Formation. An 8 m-thick sandstone body underlying the Kikowhero Member of the Okauawa Formation in the Ngaruroro River (U21/092883, Column Mt-1) is a potential, more offshore lateral equivalent of at least part of the Kereru Formation.

The formation crops out widely, in small areas, south of the study area, around the southern end of the Wakarara Range, and as far south as Ashley Clinton (Beu 1995). Raub (1985) reported Kereru Formation as far south as Waipawa River.

Kereru Formation is age equivalent to upper parts of the Esk Mudstone in the Tangoio-Esk areas which were at that time probably accumulating in deeper water environments. The presence of the Kereru Formation records concurrent early uplift on the Wakarara Range associated the Wakarara Fault movement.

Description

Details of the diagenetic history of the Kereru Formation were studied by Caron (2002). Kereru Formation comprises alternating pebble-rich siliciclastic-carbonate beds, each of several metres thickness. Bioclastic beds typically consist of distinctive tightly packed beds rich in *Ostrea chilensis* as well as calcarenites and hard, calcareous-cemented fine to medium litharenites (Erdman and Kelsey 1992). Greywacke pebbles comprise up to 25% of bioclastic beds along the western edge of the Wakarara Range. Clasts are well rounded, 3-20 mm across, with some larger grains up to 150 mm across.

In Ohara Stream near the Big Hill Stream confluence (Fig. 32F, G) Kereru Formation was observed to comprise highly fossiliferous shellbeds with a fine-grained muddy matrix (U21/026720, Column Ke-7). Fauna were dominated by the shallow-water bivalve *Tawera subsulcata*.

On Glendale Farm (U21/968684, Column Ke-8), Kereru Formation comprises three distinct carbonate units separated by 5-6 m thick siltstone-sandstone intervals comprising a succession of coarsening-upward packages, individually 0.15-0.2 m thick. Each package consists of a lower bioturbated siltstone to sandstone capped by poorly cemented shelly sandy beds (Caron 2002).


A
B
Balcony Syncline
Mohaka Fault
Kereru Formation
Torlesse basement
Esk Mudstone
C
Mount Mary Pebbly Limestone
Basement
Esk Mudstone
Kereru Formation
D
E
Kereru Formation
Esk Mudstone
F
G

The lower carbonate bed comprises a 3-4 m thick, massive moderately cemented shellbed packed with oyster and brachiopods with a muddy matrix. The unit is sharp-based and overlies fine sandstone of the uppermost parts of the Esk Mudstone. The upper 5-6 m thick carbonate bed erosionally overlies the siltstone-sandstone interval and consists of two broad units. The lower 2 m-thick part comprises a moderately cemented, tangential to trough cross-bedded packstone containing common mudstone clasts from the underlying interval. The upper package (4 m thick) consists of a coarsening-upward well cemented barnacle packstone/grainstone comprising stacked beds 0.2-0.3 m thick (Caron 2002). The upper surface of this layer is not exposed.

Paleontology and age

Kereru Formation cropping out along the western edge of the Wakarara Range contains a limited macrofauna, mostly restricted to valves of *Ostrea chilensis, Talochlamys gemmulata, Patro undatus* and little else (Beu 1995). At Glendale Farm, below Mount Mary (Fig. 32B-E; U21/968684, Column Ke-8), fauna are dominated by *Ostrea* with common *Neothyris, Patro, Talochlamys* and some *Mesopeplum convexum* and *Tucetona.* While still *Ostrea* dominated, Kereru Formation exposed in Ohara Stream below the Big Hill Road bridge also contains common *Purpurocardia purpurata* and some *Dosina* sp. Kereru Formation in these outcrops is much thinner and finer-grained than beds at the type section, and also is generally less pebbly. At the confluence of Big Hill and Ohara Streams, where an upper shelly limestone bed of Kereru Formation is conformably overlain by the Okauawa Formation (U21/026720; Fig. 32F, G), the Kereru Formation is dominated by valves of *Tawera subsulcata,* with common *Ostrea chilensis, Patro undatus, Purpurocardia purpurata* and some *Dosina* sp. *Purpurocardia* become more common as the limestone coarsens up-section.

Fig. 32 (facing page): Kereru Formation, Ohara Depression. **A)** Landscape photograph from U21/934665 on Mangleton Road near Sentry Box Reserve, looking east of a ridge of Kereru Formation cropping out adjacent to the Wakarara Range. **B)** Kereru Formation cropping out on Glendale Farm adjacent to the Mohaka Fault (arrowed). Kereru Formation overlies Esk Mudstone which is juxtaposed by the Mohaka Fault against Torlesse basement in the Wakarara Range. Displacement on the Mohaka Fault has folded Kereru Formation and the underlying Esk Mudstone into the Balcony Syncline (arrowed). Photograph is taken from the slopes of Mount Mary looking north (U21/968682). **C)** Eastern limb of the balcony syncline showing steeply dipping Kereru Formation cropping out adjacent to the Mohaka Fault (Glendale Farm, U21/968684). **D)** Steeply dipping Kereru Formation cropping out at the type section on Glendale Farm (U21/968684). **E)** Western limb of the Balcony syncline on Glendale Farm beside Mount Mary looking south from U21/967686. **F)** Steeply dipping Kereru Formation cropping out at the Ohara Stream-Big Hill Stream confluence (viewed from U21/028720). Folding here is a result of subsurface displacement on the Wakarara Fault and formation of the Wakarara Monocline. In this outcrop highly fossiliferous Kereru Formation is conformably overlain by the Kikowhero Member of the Okauawa Formation. **G)** Close-up view of Kereru Formation in F. Macrofauna in this outcrop are dominated by *Tawera subsulcata* with common *Ostrea chilensis, Patro undatus, Purpurocardia purpurata* and some *Dosina* sp. (U21/026720).

Kereru Formation underlies and interdigitates with lower parts of the Okauawa Formation, and is assigned an Upper Nukumaruan age. Kereru Formation is age equivalent to upper parts of the Esk Mudstone in the Tangoio region to the northeast.

Environment of deposition

Greywacke clasts in the Kereru Formation tend to be larger, and comprise more of the formation closer to the Wakarara Range. Throughout the study area fauna in the Kereru Formation are typically dominated by robust bivalves characteristic of reasonably high-energy environments with a coarse-bottom substrate. Faunal diversity increases away from the Wakarara Range, reflecting increased water depth away from what is inferred to have been a shoal area during depositional times.

OKAUAWA FORMATION (ok)

(Erdman and Kelsey 1992)

Name and definition

Okauawa Formation was introduced and formally defined by Erdman and Kelsey (1992). The name is derived from Okauawa Stream in the Kereru region. The Okauawa Formation incorporates the undefined Kikowhero and Crownthorpe Formations of McLennan (1990), and western parts of the Roys Hill siltstone (informal) of Kingma (1971). The formation was studied in part by Clarke (1976) who informally referred to it as the upper Petane clays.

The Okauawa Formation in the Wakarara, Kereru and Sherenden areas contains two members that have been newly defined in this report. These two units, the Kikowhero and Whakamarumaru Members, are defined to accommodate the distinctive coarse-grained lower parts of the formation and the greywacke conglomerate beds present. However, the two members have not been individually mapped, although descriptions of them are presented below. The discussion that follows for the Okauawa Formation relates mostly to the more uniform fossiliferous siltstone-sandstone succession present east of Kereru. Detailed mapping of the lower conglomerate facies of the Okauawa Formation has been crucial to determining the stratigraphy of this region, and establishing the relationship of beds in the Tangoio area with those in the Ohara Depression. This has led to more unified stratigraphic nomenclature for the Nukumaruan stratigraphy throughout central Hawke's Bay.

Type locality and reference sections

The type section designated by Erdman and Kelsey (1992) was first described by Clark (1976) and is retained in this report. A well exposed reference section is present in Ohara Stream downstream from the confluence with Big Hill Stream to the confluence of Poporangi Stream (U21/026720-U21/055737; Columns Ke-4, Ke-5, Ke-7). Along this section the coarse-grained conglomerate facies of the formation are well exposed in stream cliffs. Cliff faces in the Ngaruroro River downstream of Whana Valley are designated as clear, well exposed reference sections for the formation, although they are relatively difficult to access due to river levels and flow strength (U21/092760-V21/104750, Column Mt-1). The highly fossiliferous facies of the Okauawa Formation are easily accessible along Kereru Road near the entrance to Whanakino Station (U21/094689, Column Ke-1). This section displays the upper parts of one cyclothem and the lower parts of the subsequent cyclothem.

Lower and upper contacts

In Ohara and Waitangi Streams the Okauawa Formation conformably overlies and interdigitates with the Kereru Formation. Away from these streams the Kereru Formation passes laterally into Esk Mudstone, so consequently east of the Ohara Depression it is over Esk Mudstone that the Okauawa Formation conformably lies.

Throughout the Waihau, Sherenden and Crownthorpe areas the Okauawa Formation is conformably overlain by the Mairau Mudstone and subsequently Flag Range Conglomerate Members of the Petane Formation. In the region of Kereru Road it is probable that the Flag Range Member has graded into the upper parts of the Okauawa Formation and may be equivalent to one of the highly fossiliferous sandy shellbeds present in this area (e.g. that exposed at Whanakino Station gate). In the Kereru region the Okauawa Formation is overlain by the Poutaki Formation (Erdman and Kelsey 1992).

Distribution and thickness

Okauawa Formation is widely distributed in a northeast-southwest trending outcrop belt from Mount Cameron to the northern Ohara Depression. Distribution of the formation through the Ohara Depression and wider Kereru area was mapped by Erdman and Kelsey (1992) and Kelsey *et al.* (1993). The Okauawa Formation is not present west of the Mohaka Fault. The conglomerate facies are well exposed in Ohara Stream from the Big Hill Stream confluence, downstream to the Poporangi Stream confluence. Kelsey *et al.* (1993) indicate that the conglomerate facies are also well exposed in Waitangi Stream, stratigraphically above the last grainstone bed of the Kereru Formation. Mapping has demonstrated that conglomerate beds in the Ohara depression crop out nearly continuously through the Ngaruroro River, Whakamarumaru Station, the Crownthorpe and Sherenden districts to the Tutaekuri River near Flag Range. The lowermost conglomerate is probably equivalent to the Tutira Member, and the upper conglomerate to the Tararere Conglomerate Bed (Darkys Spur Member). It is important to note that conglomerate beds in the Okauawa Formation and the Tutira/Darkys Spur Formations do not pass into one another, and appear to be separated by an interval of the Esk Mudstone.

Along the eastern front of the Wakarara Range the formation is a minimum of 100 m thick, which increases away from this region. The formation is at least 150 m thick in Ngaruroro River cliffs below Whana Valley.

Description

Okauawa Formation comprises fossiliferous sandstones, shelly conglomerates, and siltstones that are often highly fossiliferous. Conglomerate facies, where present, are restricted to basal parts of the formation. The conglomeratic interval has been differentiated into two members that have been mapped through a large part of the study area (see below).

In basal parts, Okauawa Formation contains prominent greywacke conglomerate beds, though these beds are lacking in Okauawa Stream (Kelsey *et al.* 1993). These beds probably reflect the start of acceleration of uplift of the north end of the Wakarara Range late in the Lower Nukumaruan. The conglomeratic lower part of the formation has been differentiated into two lithostratigraphic members that are discussed below. This section details the nature of the siltstone-sandstone dominated parts of the Okauawa Formation.

Cyclothemic deposits are present through the formation. In Ngaruroro River cliffs above the Whakamarumaru Member, siltstone-sandstone cycles are well exposed (Columns Mt-1, Mt-2). Cyclothemic deposits have been recognised at the Whanakino Station gate along Kereru Road (U21/094689, Column Ke-1). Previously this section was interpreted as a single fossiliferous silty sandstone bed (e.g. McLennan 1990). Faunal sampling from this site has revealed prominent variations in water depth. The lower 1 m of the section comprises non cemented silty sandstone dominated by *Tawera* with *Gonimyrtea, Zeacolpus, Maorimactra, Zethalia* and *Fellaster* among many other species. This in turn is overlain by a 3 m-thick interval of non cemented fine sandstone containing *Dosinia, Fellaster, Myadora* and *Bassina.* Both of these two intervals indicate shallow-water deposition in proximity to a sandy beach. Above is a 0.5 m-thick highly fossiliferous shellbed dominated by *Tawera* and notably containing common large *Struthiolaria frazeri,* with *Talochlamys, Ostrea, Dosina* and the brachiopod *Waltonia inconspicula.* The fauna in this shellbed, and overlying units, strongly suggests an increase in water depth and is inferred to represent a transgressive deposit.

The 2 m of section above this shellbed comprises a highly fossiliferous shellbed with a fine sandstone matrix dominated by *Tawera* with *Ostrea, Patro, Purpurocardia, Zeacolpus* and *Maoricolpus.* This shellbed is capped by scattered *Waltonia inconspicula*. The section above this fines-upwards over 3 m through silty sandstone into at least 10 m of fine-grained non cemented siltstone and is inferred to record highstand sedimentation. The silty sandstone is less fossiliferous than lower beds and contains common *Tawera* and *Dosina.* The overlying siltstone is dominated by *Talochlamys* with common *Ostrea.* The gastropod *Pelicaria convexa* is also present in this interval. Very large valves of *Austrovenus crassitesta* (an estuarine bivalve) are present in fall blocks at the base of the section, and have presumably come from beds above the road section. These *Austrovenus* valves presumably record a subsequent fall in sea level and another cyclothem. Further along Kereru Road is a small series of road cuttings rich in *Austrovenus* valves and may be the equivalent bed responsible for the valves visible at Whanakino Station gate. In this section *Austrovenus* valve are abundant with common *Barytellina crassidens* in a muddy fine sandstone containing well-developed flaser bedding, mud drapes and ripple laminations, supportive of an estuarine setting.

The Ngaruroro River section (U21/092760-V21/104750) is similar to that exposed along Kereru Road and consists of coarsening-upward siltstone-sandstone packages generally 30-40 m thick. Although well exposed, sections are difficult to access due to the vertical nature of cliffs in the river valley. What this section does demonstrate, however, is the character of cyclothemic deposits in this part of the Okauawa Formation.

Paleontology and age

Okauawa Formation comprises non to highly fossiliferous beds containing a large variety of macrofauna typical of Nukumaruan rocks through the study area. Shellbeds crop out beside Kereru Road at Whanakino Station gate (U21/094689, Column Ke-1). Macrofauna in sandstone facies at this site are characterised by shallow-water taxa such as *Fellaster, Tawera, Struthiolaria frazeri* and *Zethalia*. Siltstone lithofacies contain *Talochlamys gemmulata, Ostrea chilensis* and *Pelicaria convexa*. Estuarine *Austrovenus stutchburyi/A. crassitesta* occur in fall blocks. A diverse shelfal macrofaunal assemblage was observed in a cutting on Salisbury Road (V21/ 138651). At this site a highly fossiliferous sandstone passes rapidly into a non fossiliferous siltstone. Fauna comprise *Sigapatella, Talochlamys, Ostrea, Purpurocardia, Pelicaria convexa, Penion, Struthiolaria frazeri, Tawera, Amalda mucronata, Patro, Maoricolpus, Zeacolpus,*

?*Waltonia inconspicula* and ?*Glycymeris modesta.* Conglomerate beds near the base of the formation interdigitate with beds of the Kereru Formation, a unit that has been demonstrated to have an Upper Nukumaruan (Late Pliocene) age. Beu (1995) described taxa in the Okauawa Formation that are consistent with the Upper Nukumaruan Devils Elbow Mudstone Member in the Tangoio Block (*Amalda mucronata* form *erica, Aeneator comptus, Glaphyrina plicata* and *Cominella excoriata*). This assemblage is also known only at "Shrimptons" in the lower reaches of Kikowhero Stream near Matapiro Station, and in Okauawa Formation in Okauawa Stream and Mangatahi River near Kereru Road. These fauna appear to be indicative of Upper Nukumaruan age in Hawke's Bay (Beu 1995). Several key Nukumaruan index macrofossils such as *Struthiolaria frazeri* and *Austrovenus crassitesta* have been collected from the Okauawa Formation and help confirm a Nukumaruan age. The presence of *Pelicaria convexa* throughout the formation constrains the age further to Upper Nukumaruan. Okauawa Formation is therefore of Upper Nukumaruan age based on superposition and macrofaunal content.

Environment of deposition

Facies in the Okauawa Formation indicate deposition at shelf water depths with occasional non- to marginal-marine influxes, demonstrating that the formation was deposited under a regime of eustatically-driven sea-level oscillations. The presence of coarse-grained conglomerate beds in the Okauawa Formation reflects an increase in the rate of deformation of the study area during the Upper Nukumaruan. Conglomerate facies represent deposition in non-marine to shoreface settings in conjunction with fluvial braid-plain progradation during periods of sea level lowstand (see below, Kikowhero Member and Whakamarumaru Member). Greywacke clasts transported as bedload in these rivers were derived from the Ruahine and Wakarara Ranges, which were actively rising at this time. Sandstone beds were deposited in shoreface to inner shelf environments, as indicated by macrofauna such as *Bassina, Struthiolaria frazeri* and *Zethalia zelandica*. Siltstone beds were deposited at inner to middle shelf water depths, an inference supported by macrofauna typical of such settings. Occasional periods of estuarine deposition are indicated by the presence of restricted taxa such as *Austrovenus stutchburyi* and *A. crassitesta*.

Kikowhero Member (oka)

(Kingma 1971 (informal))

Name and definition

Kikowhero Member is named after Kikowhero Stream in the Otamauri-Matapiro area, and is in part equivalent to the undefined Kikowhero gravels of Kingma (1971). Kikowhero Member is probably an age equivalent of the Tutira Member in the Tangoio Block, although the two units are not continuous across the basin, and represent the development of different fan-delta systems during the early part of the Upper Nukumaruan. The member is defined to include all strata from the conformable lower contact with the Kereru Formation to the top of the greywacke conglomerate bed that caps the member.

As part of a large-scale geological map through the Esk-Kereru districts, McLennan (1990) mapped the Kikowhero Member as the Mistletoe Conglomerate Member of the Kikowhero Formation. The Kikowhero Member was wrongly correlated by McLennan (1990) to one of the Upper Mangapanian conglomerate beds (Matahorua Formation) cropping out through the Patoka-Esk-Waikoau districts. Geological mapping and macrofaunal analyses in this report has demonstrated that the conglomerates in the Okauawa Formation are significantly younger than those in the Matahorua Formation. This distinction is important as it highlights the development of two separate fan-delta systems in different parts of the basin at different times.

Type locality and reference sections

The type locality is designated as the section exposed in Ohara Stream from the confluence with Big Hill Stream (Fig. 33C; U21/026720, Column Ke-7) to a point just downstream of the Big Hill Road bridge over Ohara Stream (Fig. 35A; U21/046727, Column Ke-4). This section is the most accessible place where the entire member can be viewed.

An excellent reference section is present in the Ngaruroro River downstream of Whana Valley (U21/092760). Nearly the entire member is exposed in high cliff sections in this area, although access is difficult and only readily achievable through raft or jet boat, or by walking downstream when the Ngaruroro River is in very low-flow conditions.

Lower and upper contacts

In the Ohara/Poporangi Stream section, Kikowhero Member gradationally overlies the Kereru Formation (Fig. 33E) over less than 0.2 m. Where the Kereru Formation is absent the base of the member is defined as the conformable contact between a prominent sandstone bed and overlying siltstone, as exposed in the Ngaruroro River below the Whanawhana cable. The sandstone is likely to be a distal equivalent of pebbly limestone facies of the Kereru Formation cropping out in the Ohara Depression. The overlying siltstone is assigned to the Kikowhero Member. The lower contact of the Kikowhero Member is not exposed between the Ngaruroro River and Mount Cameron, although it is assumed that the member conformably overlies the Esk Mudstone.

Kikowhero Member is abruptly overlain by siltstone of the Whakamarumaru Member. In the Whana Valley region this contact occurs through a thin pebbly shellbed rich in *Tawera* valves with common, largely dissolved bivalves (U21/096771, Column Wh-1). The upper contact is also exposed in Kikowhero Stream on Whakamarumaru Station where the Whakamarumaru Member abruptly overlies fossiliferous conglomerate facies of upper parts of the Kikowhero Member (Fig. 33B; V21/124773, Column Wh-2).

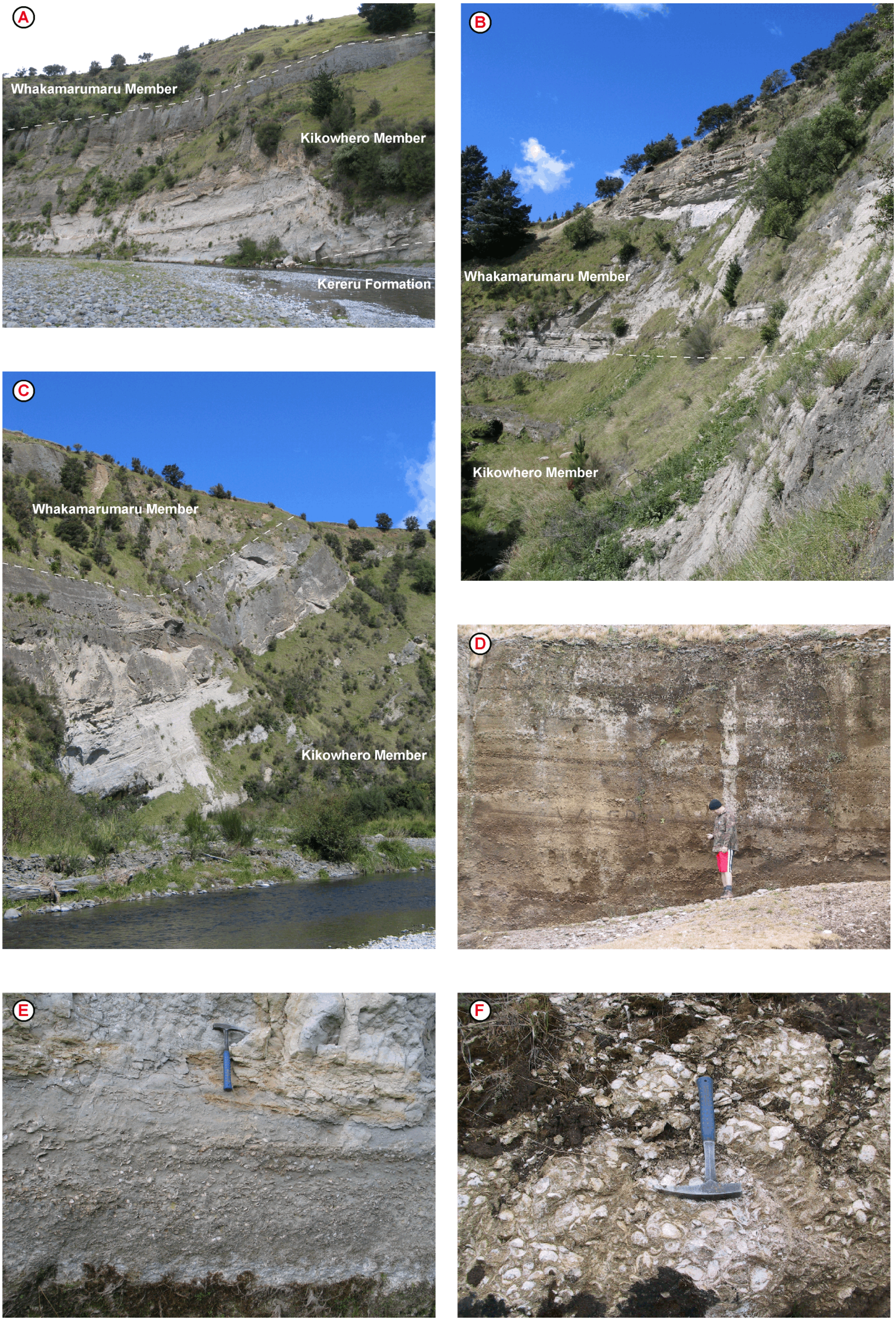
Distribution and thickness

The Kikowhero Member is widespread through southwestern parts of the study area from the Ohara Stream (Fig. 33A, C, E), through the Ngaruroro River, Whakamarumaru Station (Fig. 33B) to Flag Range and Mount Cameron. The member has not been identified north of Waihau Road near Dartmoor. Away from the Ohara and Poporangi Streams and the Ngaruroro River only the upper greywacke conglomerate bed tends to crop out. The entire member is well exposed in cuttings along Ohara Stream below the Big Hill Stream confluence to the Poporangi Stream confluence. Complete exposure is also present in the Ngaruroro River at Whana Valley. The transition from the upper sandstone bed into greywacke conglomerate is well exposed at and near a gravel pit located at the western end of Matapiro Road (Fig. 33D). Partial exposures of the member are present west of Crownthorpe Settlement Road.

Towards the east, away from the Ohara Depression, the Kikowhero Member passes into a more fine-grained siltstone and sandstone-dominated expression of the Okauawa Formation. The most eastern exposures of the member occur on the prominent northerly ridge extending from the main block of Mount Cameron between the Tutaekuri River and Waihau Road. The member cannot be differentiated in the nearby Mangaone River from relatively massive mudstone facies of the Esk Mudstone.

In the Ohara Stream section the Kikowhero Member is 20 m thick. In the Ngaruroro River section the member is approximately 15 m thick. At Flag Range and Mount Cameron the member is at least 25-30 m thick.

Fig. 33 (facing page): Okauawa Formation. **A)** Okauawa Formation (Kikowhero Member) conformably overlying Kereru Formation in Ohara Stream below the Big Hill Road bridge (U21/046727). The grey-coloured conglomerate bed at the top of the Kikowhero Member is clearly visible in this image. **B)** Kikowhero and Whakamarumaru Members cropping out in the upper reaches of Kikowhero Stream, Whakamarumaru Station (V21/124773). **C)** Okauawa Formation cropping out at the Ohara Stream-Big Hill Stream confluence (U21/026720). The prominent large-scale folding evident in this section is the result of deformation of the sub-surface Wakarara Fault and the resulting Wakarara Monocline. **D)** Parallel bedded conglomerate bed of the Kikowhero Member cropping out beside Matapiro Road near Whana Valley (U21/094774). A non-marine depositional environment is inferred for this unit. **E)** *Tawera*-dominated shellbed at the top of the Kereru Formation overlain conformably by siltstone of the Okauawa Formation (Kikowhero Member) in Ohara Stream below the Big Hill Road bridge (U21/050731). **F)** Shellbed overlying the Kikowhero Member at the base of the Whakamarumaru Member near Matapiro Road, Whana Valley (U21/096771). The shellbed is dominated by the bivalve *Tawera subsulcata*.


A
Whakamarumaru Member
Kikowhero Member
Kereru Formation
B
Whakamarumaru Member
Kikowhero Member
C
Whakamarumaru Member
Kikowhero Member
D
E
F

Description

The Kikowhero Member is similar in character to members of the Matahorua Formation in that it comprises a coarsening-upwards succession comprising a lower siltstone unit that passes up into sandstone that is sharply overlain by a greywacke conglomerate bed. Each major facies package is inferred to represent systems tracts during a single sea-level cycle; siltstone reflects maximum water depth or highstand conditions, sandstone represents falling sea level or regressive conditions, and upper conglomerate facies reflect sea level lowstand and early rise conditions.

Most of the member is well exposed in the Ngaruroro River where the reference section has been designated (U21/092760). The lower parts of the member comprise 2 m of siltstone that passes rapidly up section into 8 m of sandstone. The lower siltstone abruptly overlies a sandstone bed inferred to represent a lateral equivalent of the Kereru Formation. The siltstone passes gradationally over < 1 m into sandstone, which is in turn sharply overlain by approximately 5 m of greywacke conglomerate.

The transition from the middle sandstone facies into the capping conglomerate facies is well exposed along Matapiro Road, near Whana Valley (U21/099771-093775). Approximately 5 m of non cemented, massive, well sorted fine to medium sandstone passes up section into 2.5 m of non cemented, cross-stratified, fine to medium sandstone with scattered (<5%) greywacke pebbles and conglomerate lenses up to 30 cm thick. These conglomerate lenses are typically cross-bedded to laminated. The greywacke clast content increases up-section with the next 1 m of section comprising coarse pebble to cobble greywacke conglomerate with abundant cross-stratified to laminated sandstone lenses (Fig. 33D). Cross-beds are of tabular and trough forms and typically low-angle. This interval is conformably overlain by 2.5 m of coarse-grained massive conglomerate, in turn passing up-section into 5 m of alternating granule-fine pebble/pebble-cobble beds 0.05-0.3 m thick. Packages are non cemented and internally massive to laminated. The interval displays a fining-upward pattern throughout. The transition to the overlying Whakamarumaru Member is obscured at this locality.

Uppermost parts of the Kikowhero Member are exposed in Kikowhero Stream on Whakamarumaru Station (V21/124773; Fig. 33B). A non cemented 1.5 m-thick slightly fossiliferous fine sandstone is exposed at stream level. Fauna are dominated by *Dosinia*, *Tawera* and *Austrofusus.* The sandstone is abruptly overlain by 2 m of highly fossiliferous greywacke conglomerate to pebbly sandstone. This interval is equivalent to the non fossiliferous upper greywacke conglomerate facies exposed in the Ngaruroro River and at Matapiro Road. Clasts are of coarse sand to fine pebble size and the bed as a whole is non to slightly cemented. Above this bed is a non fossiliferous 2 m-thick greywacke grit bed, followed by nearly 3 m of variably fossiliferous greywacke grit and conglomerate beds. Fauna are typically robust shallow-water bivalves such as *Tawera, Purpurocardia* and *Tucetona.* The member is abruptly overlain by pebbly siltstone of the Whakamarumaru Member.

Paleontology and age

Fauna are typically sparse in the Kikowhero Member and are largely confined to the lower siltstone interval and the upper conglomerate bed. Fauna in the conglomerate are typically dominated by relatively shallow-water, robust, high-energy dwelling bivalves of which *Tawera* and *Purpurocardia* are most common (Fig. 33F). *Glycymeris shrimptoni, Tucetona, Panopea, Ostrea, Xenostrobus* and *Dosinia*, all common components of other fossiliferous conglomerate beds in the study area, are also present in this member.

On the basis of stratigraphic position the Kikowhero Member is assigned a confident Upper Nukumaruan age.

Environment of deposition

Siltstone and sandstone facies of the member were deposited at inner to middle shelf water depths. Greywacke conglomerate facies were deposited in a non-marine fluvial braid-plain setting. Capping intervals of fossiliferous conglomerate reflect a return to marine sedimentation following a rise in sea level and the submergence of the braid-plain environment. Alternating fine-grained/coarse-grained conglomerate facies are inferred to represent shingle beach deposits. Similar facies are evident in the Tararere Member of the Darkys Spur Member and throughout the Matahorua Formation.

Whakamarumaru Member (okb) (*new*)

Name and definition

Whakamarumaru Member is named after Whakamarumaru Station on and around which the member widely crops out. The Whakamarumaru Member incorporates all strata from the conformable contact with the greywacke conglomerate bed capping the Kikowhero Member to the upper surface of the greywacke conglomerate capping this member.

McLennan (1990) mapped the conglomerate facies of what is now considered Whakamarumaru Member as the Tiokapu Conglomerate Member of the Crownthorpe Formation. Tiokapu Member was named after a tributary of the Mangaone River near Te Pohue. McLennan (1990) wrongly correlated conglomerate beds in the Ohara Depression with conglomerate beds in the Te Pohue region. Detailed geological mapping and macrofossil analysis during this report clearly demonstrate that conglomerate beds in the Ohara Depression are significantly younger than those present at Te Pohue. This mean that conglomerate beds exposed in Tiokapu Stream are not the same those in the Ohara Depression. Because of this the name Tiokapu is not appropriate for units in the Ohara Depression, because of the geographical separation of the two areas. The new name Whakamarumaru Member is therefore introduced here.

The Whakamarumaru Member incorporates upper parts of the informal Kikowhero gravels of Kingma (1971). Geological mapping demonstrates that the member is most probably an age equivalent of the Tararere Conglomerate Bed and Park Island Limestone Members of the Petane Formation. Conglomerate facies of the Whakamarumaru and Darkys Spur Formation (Tararere Member) were deposited by different fan-delta systems reflecting uplift and erosion of separate greywacke blocks.

Type locality and reference sections

A type section for the member is designated in the Ngaruroro River below Whana Valley. While access is difficult, the entire member is exposed in cliffs along the course of the river. Reference sections are nominated on Whakamarumaru Station where the member is widely exposed.

Lower and upper contacts

Whakamarumaru Member abruptly overlies the Kikowhero Member across a thin, pebbly shellbed. The lower contact is well exposed in Kikowhero Stream on Whakamarumaru Station (V21/124773) where highly fossiliferous conglomerate of the Kikowhero Member is abruptly overlain by siltstone of the Whakamarumaru Member (Fig. 33B).

The upper contact is generally poorly exposed through the study area. It is clearly exposed in the Ngaruroro River below Whana Valley and in cuttings along a driveway below the crest of Flag Range. Although the contact is not exposed on Mount Cameron it appears that the upper conglomerate bed of the Whakamarumaru Member is abruptly overlain by siltstone of the Mairau Formation. The member cannot be recognised in either the Tutaekuri or Mangaone Rivers where it appears to have passed conformably into mudstone facies of the upper Esk Mudstone. The member is overlain by undifferentiated siltstone facies of the Okauawa Formation in the Kereru and Whana Valley regions. Through the Crownthorpe, Sherenden and Waihau regions the Whakamarumaru Member is abruptly overlain by siltstone of the Mairau Mudstone Member and subsequently the Flag Range Conglomerate Member (Petane Formation).

Distribution and thickness

The Whakamarumaru Member is widespread across southwestern parts of the study area from the Ohara Stream (Fig. 33A, C), through the Ngaruroro River, Whakamarumaru Station to Flag Range and Mount Cameron. The member has not been observed north of Waihau Road near Dartmoor. Exposures are generally restricted to the upper greywacke conglomerate bed of the member. The member as a whole is well exposed In the Ngaruroro River below Whana Valley and in the middle reaches of Kikowhero Stream on Whakamarumaru Station (Fig. 33B). Prominent exposures of the upper conglomerate facies are present along Flag Range road where it descends from the range crest towards the Tutaekuri River. Numerous cuttings along the western end of Matapiro Road display the conglomerate facies of the member.

Many exposures of the Whakamarumaru Member are present west of Crownthorpe Settlement Road, and in occasional outcrops between Ringarua and Sherenden Stations. The northernmost outcrops of the member occur on the northern face of Mount Cameron above Waihau Road, although the unit is fairly poorly exposed.

The Whakamarumaru Member passes laterally northeast into the Esk Mudstone.

In the Ngaruroro River and Matapiro Road sections near Whana Valley the member is 53 m thick. In Kikowhero Stream the unit is 35 m thick. At Flag Range the member is 40 m thick and at Mount Cameron it is at least 41 m thick.

Description

Whakamarumaru Member is lithologically very similar to the Kikowhero Member, and can only be differentiated on the basis of stratigraphic position. The member is also very similar to the four members of the older Matahorua Formation.

The Whakamarumaru Member overlies the Kikowhero Member through a pebbly shellbed. The matrix in this 0.5 m-thick interval is dominated by fine-grained siliciclastic siltstone. The capping greywacke conglomerate bed is dominantly non fossiliferous, although it may be capped by a thin pebbly shellbed in a few locations.

In the Ngaruroro River below Whana Valley, the Whakamarumaru Member is well exposed in high clean cliff-face exposures. The lower siltstone facies of the member abruptly overlies the capping conglomerate bed of the Kikowhero Member. Fauna in the siltstone are dominated by *Maoricolpus* with *Ostrea* and *Atrina.* This siltstone is approximately 15 m thick and coarsens up-section through silty sandstone into approximately 10 m of fine to medium sandstone. The sandstone is in turn sharply overlain by 8-10 m of greywacke conglomerate representing the upper beds of the member. The conglomerate is subsequently overlain by siltstone of the undifferentiated Okauawa Formation.

In outcrops on the northern face of Mount Cameron a 3 m-thick interval of blue-grey massive fine-grained siltstone to sandy siltstone crops out, corresponding with the lower part of the member. Approximately 22 m of section is not exposed, followed by a 6 m-thick interval of greywacke conglomerate. The lower 2 m of this conglomerate comprises moderately to poorly sorted, fine pebble to cobble-sized spheroidal to oblate-dominated clasts. A fluvial/marginal-marine environment is inferred for this lower conglomerate interval. It is in turn gradationally overlain by 4 m of fine to medium pebble-sized clasts dominated by oblate-shaped grains. This upper interval consists of alternating fine pebble/medium pebble beds each 0.05-0.3 m thick and is interpreted as a shingle beach deposit based on clast shape, sorting and stacking. The conglomerate is abruptly overlain by pale-grey slightly micaceous siltstone of the undifferentiated Okauawa Formation. This siltstone is equivalent to the Mairau Mudstone cropping out in the Matapiro-Glengarry-Tangoio areas.

Paleontology and age

The Whakamarumaru Member contains a sparse macrofauna. A confident Upper Nukumaruan age is assigned based on stratigraphic position.

Environment of deposition

Most interpretation of the depositional setting for the member is based on facies stacking and sedimentary structures. Few environmentally-indicative macrofossils have been observed. The basal siltstone bed is inferred to have been deposited in an inner to middle shelf environment. The overlying sandstone was most likely deposited in a shallowing-upward inner shelf to nearshore setting. The upper conglomerate facies represents the development and progradation of a fan-delta system during a sea level lowstand. The bedding and clast morphology in the lower half of the conglomerate bed indicates non-marine deposition. The pattern of alternating granule-fine pebble beds in the upper half of the conglomerate, the degree of sorting and clast morphology is consistent with deposition in a shoreface shingle beach environment. Greywacke detritus was derived from erosion of the emerging Wakarara, Kaweka and Ruahine Ranges (Erdman and Kelsey 1992).

POUTAKI FORMATION (pp)

(Erdman and Kelsey 1992)

Name and definition

Poutaki Formation was mapped and formally defined by Erdman and Kelsey (1992) and represents the uppermost unit of the Mangaheia Group in the Kereru region. Poutaki Formation is named after Poutaki Stream. The formation was included by Kingma (1971) as part of his undefined Roys Hill siltstone.

Type locality and reference sections

The type section designated by Erdman and Kelsey (1992) is retained. This section occurs in Poutaki Stream at U21/007653.

Lower and upper contacts

The Poutaki Formation unconformably overlies the Okauawa Formation across a 1-1.5 m thick pumiceous sandstone interval containing mudstone and sandstone rip-up clasts. A 0.3-1 m thick grainstone bed may be present at or within 0.3 m of the basal contact at some localities (Erdman and Kelsey 1992).

The Poutaki Formation coarsens up-section and passes into the Salisbury Gravel. This contact is marked by the first prominent ignimbrite in the Kereru region (Erdman and Kelsey 1992), inferred to be the Kidnappers A Ignimbrite (Wilson *et al.* 1995).

Distribution and thickness

Distribution of the Poutaki Formation in the Mason Ridge area was documented by Dyer (2005). In the Kereru region the Poutaki Formation is a minimum of 60 m thick, and up to 100 m thick further east (Erdman and Kelsey 1992; Beu 1995). The formation is well exposed in cuttings and banks beside Duff Road, near Kereru, near the Poporangi Stream. In the general Mason Ridge area the formation is 40 m thick (Dyer 2005). The member is well exposed in cuttings along Duff Road.

The Ngaruroro River section is similar to that exposed along Kereru Road and consists of coarsening-upward siltstone-sandstone packages generally 30-40 m thick. Although well exposed, sections are difficult to access due to the vertical nature of cliffs in the river valley. What this section does demonstrate however is the character of cyclothemic deposits in this part of the Okauawa Formation. Poutaki Formation does not occur north of the Ngaruroro River and is restricted to the Kereru-western Mason Ridge area. The Poutaki Formation may be a lateral equivalent to beds of the Kaiwaka Formation in the Tangoio Block. However, lateral continuity cannot be demonstrated and it is desirable to use different names in these two widely separated areas.

Description

Beu (1995) described the Poutaki Formation as 60-100 m of coarse pumiceous sandstone, granule to cobble pumice conglomerate, dark-green medium sandstone, alternating thin-bedded sandstone and mudstone, and massive mudstone (Fig. 34A, B). In the Maraekakaho region the Poutaki Formation comprises medium- to coarse-grained pumiceous conglomerate beds and massive, non calcareous mudstones. Mudstone beds commonly contain rounded but highly weathered pumice clasts up to 15 cm across. The pumiceous conglomerate beds are typically planar laminated to low angle (<2°) trough cross-bedded (Erdman and Kelsey 1992). The formation is non to sparsely fossiliferous.

In cuttings on Duff Road (Fig. 34A, B), Kereru, the Poutaki Formation comprises several intervals of highly volcaniclastic sediments. Very well-developed sedimentary structures (Fig. 36B) such as trough cross-bedding and convolute bedding indicate significant reworking of the pumiceous sediments. Water escape structures are common. No macrofossils were observed in this area.

Paleontology and age

Few macrofossils have been collected from the Poutaki Formation, although Beu (1995) reported the presence of *Pelicaria convexa*. This confirms that at least part of the formation is still Nukumaruan in age. Poutaki Formation is probably uppermost Nukumaruan in age, most likely close to the Castlecliffian boundary.

Environment of deposition

The Poutaki Formation is inferred to have accumulated in a combination of marginal-marine to shallow-marine settings similar to that envisaged for the Kaiwaka Formation. Like the Kaiwaka Formation, the Poutaki Formation is inferred to represent the shoaling and emergence of much of the study area from a marine environment into a non-marine environment during the Upper Nukumaruan.

Fig. 34: Poutaki Formation (Mangaheia Group) and Kidnappers Group. **A)** Poutaki Formation, Duff Road, Kereru (U21/010644). **B)** Close-up of road cutting in Fig. 34A (U21/010644). Lens cap (58 mm) for scale. Note the well-developed sedimentary structures in this outcrop. **C)** Unconformable base of the Kidnappers Group at the type section, overlying Black Reef Calcareous Sandstone. Photo viewed from Black Reef looking southwest (W21/596661). **D)** Panorama along the Kidnappers section from Black Reef southwest towards Rabbit Gully (from W21/596661). Black Reef Calcareous Sandstone (Waipipian age) forms the dark-coloured rocks in the ocean. E) Shelly lenses within the Maraetotara Sandstone, the basal unit of the Kidnappers Group at the type section (W21/583655). **F)** Ignimbrite within thick non fossiliferous greywacke conglomerates. Photo location: Kidnappers Section (approx. W21/554651).

QUATERNARY DEPOSITS

KIDNAPPERS GROUP

(Hill 1887; formally defined by Kingma 1971)

Name and definition

Kidnappers Group is named after Cape Kidnappers, the landform that marks the southern end of Hawke Bay. Kingma (1971) formalised the long usage of the name "Kidnappers" in reference to the well exposed section between Clifton and Black Reef. The name itself was introduced by Hill (1887) who referred to the strata in this area as the Kidnapper Beds or Kidnappers Section, and in 1891 as the Kidnapper Conglomerates and the Kidnapper Pumice and Conglomerate Beds.

The definition of Kingma (1971) is retained, and extended to incorporate the prominent thick Castlecliffian gravel beds cropping out adjacent to the northern Ruahine and Wakarara Ranges. These more westerly beds are inferred to represent proximal non-marine equivalents of the marginal-marine strata exposed in the Clifton-Black Reef Section.

Type and reference section

The Kidnappers coastal section extending from the unconformable lower contact with the Black Reef Calcareous Sandstone west to Clifton is designated as the type section for the Kidnappers Group (Fig. 34C, D). This section was nominated as the Standard Section in the Te Aute subdivision for Castlecliffian strata by Kingma (1971).

Lower and upper contacts

The lower contact of the Kidnappers Group is well exposed at Black Reef in the Kidnappers section (W21/597662; Fig. 34C). Here the Maraetotara Sandstone, the basal unit of the Kidnappers Group in the section, overlies Waipipian Black Reef Calcareous Sandstone across an angular unconformity. Sediments and some macrofauna from the underlying Black Reef Calcareous Sandstone are reworked into the basal shellbed on the Kidnappers Group in this section. The basal contact is also exposed in several localities in the Kereru district where the Salisbury Gravel (Kidnappers Group) overlie the Poutaki Formation (Mangaheia Group).

The upper surface of the Kidnappers Group is typically marked by the modern land surface, although may be mantled by a thin veneer of Recent alluvium and/or tephras.

Distribution and thickness

Rocks of the Kidnappers Group crop out sporadically across the study area, although tend to be concentrated in two main regions (Fig. 1). Kidnappers Group beds *sensu stricto* crop out in the southeastern part of the study area, where they underlie northernmost parts of the Maraetotara Plateau. The second main outcrop region is in the Kereru district along the eastern flanks of the northern Ruahine and Wakarara Ranges, where rocks of the Salisbury Gravel form the prominent Salisbury terraces. Small outcrops occur at Waiohiki beside Springfield Road, at Petane Corner, and at Whirinaki Bluff. Veneers of Castlecliffian gravels are present on the highest hills of Mason Ridge, and above the Dartmoor-Puketapu area.

Kidnappers Group is thickest and best developed in the Kidnappers section where it has an aggregate thickness of approximately 400 m. (Kingma 1971).

Description

Description of the Salisbury Gravel in the southwest of the study area is given below. In the Kidnappers section thick conglomerates (Fig. 34D) are interbedded with thin blue-grey siltstones, brown sandstones, ignimbrites and pumiceous beds (Fig. 34F). Macrofossils are mostly uncommon and are restricted to finer-grained beds. Highly fossiliferous shell lenses are common in the uncemented Maraetotara Sandstone, the 33 m-thick basal formation of the Kidnappers Group at the type section (Fig. 34E). This formation contains a diverse assemblage of shallow-water taxa. The Maraetotara Sandstone has as its basal unit a coarse-grained shellbed named the "basal shellbed" by Kingma (1971). This shellbed overlies the Black Reef Calcareous Sandstone across a mild angular unconformity. Shellhash dominates the composition of the basal shellbed, including notably fragments of Waipipian *Phialopecten marwicki* that have been reworked from the underlying Black Reef Calcareous Sandstone. The Maraetotara Sandstone is overlain by a prominent tephric horizon (the Kidnappers Ignimbrite) and then by thick interbedded gravels, sandstones, siltstones, and minor peat beds that extend west along the Kidnappers Section to Clifton.

Paleontology and age

A diverse macrofauna have been collected from the Kidnappers Group in the coastal section, though most from the Maraetotara Sandstone and overlying siltstone beds. Shellbeds in the Maraetotara Sandstone are typical of "event concentrated shellbeds", and are dominated by *Dosinia anus.* Estuarine-restricted bivalves such as *Austrovenus stutchburyi* and *Barytellina crassidens* have been collected from siltstones between Rabbit Gully and Clifton. The Kidnappers Ignimbrite has been assigned an age of 1.05 Ma by Wilson *et al.* (1995).

Environment of deposition

Kidnappers Group in the Maraetotara Plateau area was deposited in a marginal-marine environment following a period of uplift, erosion, and subsequent subsidence. Thick gravels in the section reflect rapid uplift and erosion of the North Island axial ranges. Siltstones and sandstones reflect shallow-marine incursions into the basin, supported by estuarine and shallow-water taxa in these beds (e.g. *Austrovenus, Barytellina*). Thick volcaniclastic deposits reflect contemporaneous volcanism from the Taupo Volcanic Zone. It is inferred that the Salisbury Gravel (see below) record the deposits of the river systems that fed the Cape Kidnappers area.

SALISBURY GRAVEL

(Kingma 1971)

Name and definition

Salisbury Gravel is named after the Salisbury terraces in the southern part of the study area. The name was first introduced by Kingma (1971). Beu (1995, p. 140) excluded the informal Salisbury gravel lithofacies of Erdman and Kelsey (1992) from his Poporangi Group (now Mangaheia Group) as he viewed these beds to paraconformably or unconformably overlie older marine-dominated units. He suggested that the Salisbury Gravel lithofacies should be included in the Kidnappers Group, a well-established stratigraphic unit conspicuously dominated by non-to marginal-marine gravel facies of Castlecliffian age. Kingma (1971) had initially included the Salisbury Gravel in the Kidnappers Group, as does this report. The Salisbury Gravel is defined as a thick interval of basement-derived gravels and conglomerates, with minor sandstones and volcaniclastic interbeds that overlie older marine to marginal-marine rocks. They are of Castlecliffian age.

Type locality and reference sections

As the Salisbury Gravel has only been mapped as an informal unit by both Kingma (1971) and Erdman and Kelsey (1992), no type section has been designated. No reference sections were nominated by Erdman and Kelsey (1992), the reason for this being that the formation is poorly exposed. Although no one section displays the entire formation, the type section designated by Dyer (2005) is retained. It is located in Poutaki Stream (U21/007653) where the lower contact with the Poutaki Formation is exposed.

Lower and upper contacts

Salisbury Gravel gradationally overlie the Poutaki Formation (Erdman and Kelsey 1992). The base of the formation is defined as the first prominent ignimbrite bed (6 m thick) and is exposed in the Kereru region, inferred to be the Kidnappers A Ignimbrite (Wilson *et al.* 1995). This contact is exposed at the type section (U21/007653). The upper surface of the Salisbury Gravel represents the modern land surface.

Distribution and thickness

Salisbury Gravel is widely distributed in southwestern parts of the study area adjacent to the northern Ruahine and Wakarara Ranges although outcrop is generally poor. In this area they form prominent high flights of terraces well above the level of Recent deposits. The thickness of the Salisbury Gravel is uncertain due to their poor exposure. Dyer (2005) estimated a thickness of 40 m based on cross-sections, but this is likely to be an underestimate based on the topographic heights of terraces underlain by the formation.

Description

With the exception of the ignimbrite beds at the base of the Salisbury Gravel, the lower part of the formation is difficult to distinguish from the Poutaki Formation, as both formations contain massive mudstone interbedded with pumiceous sandstone and conglomerate beds (Erdman and Kelsey 1992). Conglomerate beds are frequently trough cross-bedded, and sorting is generally poor (Dyer 2005). The pebble-cobble conglomerates of the Salisbury Gravel become more prevalent up-section to the east of the Kereru district, and are interbedded with pumiceous sandstone and ignimbrites (Erdman and Kelsey 1992). Kingma (1971) identified that the Salisbury Terraces comprised the same components as beds exposed in the Kidnappers section, but differed in being less well sorted and non fossiliferous (a result of their more inboard topographic position). They can be differentiated from post-Castlecliffian terrace deposits due to the more advanced weathering of their greywacke components and by their distinct but irregular pumice interbeds (Kingma 1971).

Paleontology and age

No macrofossils have been observed or reported in the Salisbury Gravel. Erdman and Kelsey (1992) assigned a Lower Castlecliffian age to the formation. Beu (1995) suggested that the basal ignimbrite of the Salisbury Gravel is the Potaka Tephra (Shane 1994), although Wilson *et al.* (1995) regard this bed as the Kidnapper Ignimbrite. This ignimbrite is inferred to lie within the Jaramillo normal subchron (1.07-0.99 Ma) (Kamp 1990), and the formation is therefore of Castlecliffian age (Turner and Kamp 1990).

Environment of deposition

Salisbury Gravel was deposited in a non-marine environment proximal to rapidly rising and eroding Torlesse basement blocks bounded by the Ruahine, Mohaka and Wakarara Faults. The generation of large volumes of terrigenous material during this period indicates an acceleration in the rate of deformation of the study area. The presence of prominent tephra beds indicates contemporaneous volcanic eruptions from the Taupo Volcanic Zone, which was active by this time.

UNDIFFERENTIATED KIDNAPPERS GROUP

Distribution and thickness

A thin veneer of Castlecliffian gravels occurs throughout much of the study area, with noticeably thicker deposits occurring near Puketapu, Taradale, Petane Corner and Whirinaki Bluff. These units have been mapped as undifferentiated Castlecliffian deposits. The interval is thickest above Apley-Dartmoor Roads, at Taradale and Whirinaki Bluff.

Description

Undifferentiated Castlecliffian beds are dominated by poorly sorted, non cemented greywacke gravels. Interbedded sand and silt layers are common, as are rip-up clasts of similar lithologies. These gravels typically form thin veneer deposits throughout the study area.

LATE QUATERNARY DEPOSITS

Distribution and thickness

Late Quaternary deposits are very widespread throughout southeastern parts of the mapping area in proximity to the Tutaekuri and Ngaruroro Rivers. Late Quaternary deposits are 50 m thick in the vicinity of Taradale-1 (Darley and Kirby 1969), and 75 m thick at Whakatu-1 (Ozolins and Francis 2000).

Description

Late Quaternary deposits are dominated by coarse-grained, non cemented, poorly sorted greywacke gravels derived from erosion of the adjacent axial range belt.

High Level Terraces 1 and 2 (h1, h2)

(Kingma 1971)

Name and definition

High level terraces 1 and 2 are defined as the second and third major terraces above modern river level. They occur geomorphically above the Ripia Alluvium terrace (see below). The names are derived from alluvial terraces mapped by Kingma (1971).

Distribution

H1 alluvial terrace are moderately well distributed along the margins of major river systems in the study area. H1 terraces are typical about 60 m above modern river level. H2 terraces are less widespread, and are up to about 120 m above modern river level.

Ripia Alluvium (ra)

(Cutten 1994)

Name and definition

Cutten (1994) introduced and formally defined Ripia Alluvium, the name derived from the Ripia River, a major tributary of the Mohaka River near Pakaututu. Cutten (1994) mapped aggradational and degradational Ripia Alluvium terraces. These two units have not been differentiated in this report. Ripia Alluvium is defined as the first major terrace above modern river level.

Lower and upper contacts

The lower contact of Ripia Alluvium is everywhere erosional and unconformable. Metre-scale relief is common on its lower contact, reflecting the inferred depositional paleoenvironment of high-energy river systems.

Distribution and thickness

Ripia Alluvium is widely distributed in river terraces near the axial ranges, and in river valleys seaward from here. Thick gravel beds are well exposed in the Ngaruroro River downstream of Whana Valley, with large-scale channel incision prominent. Similar, well-developed channel incision is also exposed in Ohara Stream above the Mangleton Road bridge and below the Big Hill Road bridge.

Ripia Alluvium is typically 10-20 m thick in the Ngaruroro River-Ohara Stream area, with some strongly incised deposits up to 50 m thick.

Description

Ripia Alluvium comprises poorly sorted sandy greywacke gravel with interbedded sand and minor tephric materials forming post-glacial terraces of the last glaciation. Ripia Alluvium terraces are typically 20-40 m above modern river level. In the Mohaka River these terraces may be as high as 140 m above present river level (Cutten 1994).

Age

By definition, Cutten (1994) designated a last glaciation to post-glacial age for the Ripia Alluvium.

Undifferentiated Taupo Pumice (tp) (informal)

(Kear and Schofield 1968)

Name and definition

Taupo Pumice derives its name from Lake Taupo, the volcanic centre from which the stratigraphic unit was erupted. Kear and Schofield (1968) introduced the name Taupo Pumice Alluvium (TPA) to describe volcaniclastic deposits from the most recent eruption from Taupo Caldera. Undifferentiated Taupo Pumice is used in this report in an informal way in reference to both TPA and Taupo Ignimbrite deposits through western parts of the study area.

Distribution and thickness

Undifferentiated Taupo Pumice is widely distributed through western parts of the study area in the vicinity of the axial ranges. Occurrences of this unit in the study area are summarised in Segscheider *et al.* (2002). Bluffs of pumice and ash up to 70 m thick are prominent where the Ngaruroro, Ripia, Mohaka and Waipunga Rivers emerge from gorges through the Kaweka and Ahimanawa Ranges. Excellent exposures occur at the Mohaka-Ripia River confluence near Pakaututu Bridge, and in road cuttings on the Kaweka Range side of the bridge.

Description

Undifferentiated Taupo Pumice includes all primary and reworked products of pyroclastic deposits associated with the last Taupo eruption. The unit comprises non welded massive to strongly laminated and trough cross-stratified pumiceous ash and lapilli-sized clasts, with rare blocks and lithics. In many localities carbonised logs and branches are common.

Age

Undifferentiated Taupo Pumice has been dated at 1850 ± 10 years B.P. (Froggatt and Lowe 1990).

Recent Alluvium (qa)

This mapping unit includes all modern-day stream and river bed alluvium, Holocene alluvial plain deposits and Holocene lake deposits. The composition of this alluvium (and minor lacustrine sediment) is typically similar to that of the Ripia Alluvium. Greywacke clasts dominate the composition of much of the alluvium, although limestone pebbles and boulders, and pebbles of Cretaceous and Tertiary sandstone (Cutten 1994) may be locally important.

Reclaimed Land (qr)

A particular feature of the study area is the large extent of reclaimed land in the area around Napier, much of which has occurred since the 1931 Napier earthquake.

At least 25 m of reclaimation fill was intercepted in Hukarere-1 (Westech Energy New Zealand Ltd 2001).

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