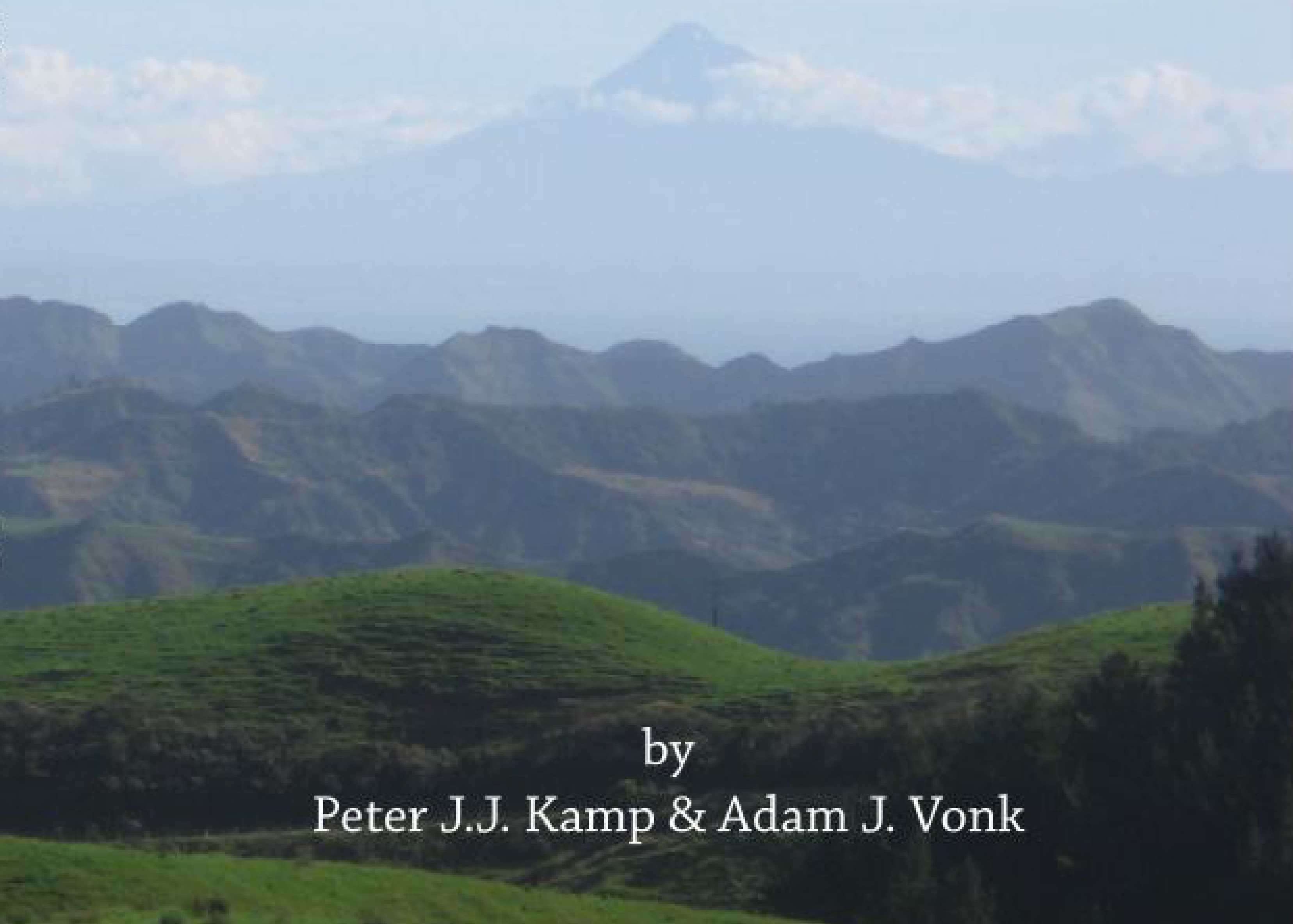
Linking the onshore and offshore parts of Eastern Taranaki Basin:

Insights to stratigraphic architecture, sedimentary facies, sequence stratigraphy, paleogeography and hydrocarbon exploration from the on land record

Eastern Taranaki Basin Field Guide



by

Peter J.J. Kamp & Adam J. Vonk

Ministry of Economic Development
Manatū Ōhanga
Crown Minerals

Petroleum Report Series
PR3463

PETROLEUM REPORT SERIES

PR 3463

Title **Eastern Taranaki Basin Field Guide.** Linking the onshore and offshore parts of Eastern Taranaki Basin: Insights to stratigraphic architecture, sedimentary facies, sequence stratigraphy, paleogeography and hydrocarbon exploration from the on land record.

Operator

Author Kamp, P.J.J. and Vonk, A.J.

Date 2006

This report has been compiled from material submitted to the New Zealand Government under legislation or voluntarily by exploration companies. An acknowledgement of this work in the following bibliographic format would be appreciated:

Kamp, P.J.J. and Vonk, A.J.; 2006; Eastern Taranaki Field Guide. Ministry of Economic Development New Zealand Unpublished Petroleum Report PR3463, Pp 97.

COVER PHOTOGRAPH : Betty-Ann Kamp (2007)

TABLE OF CONTENTS .... i - v

Day 2 Theme: *Stratigraphic architecture and depositional systems of a middle Miocene retrogradational continental margin, eastern Taranaki Basin*

Day 3 Theme: *Stratigraphic architecture below (Mokau Group) and above the Middle Miocene basin flooding (Otunui Fmn & Mt Messenger Fmn), Southern King Country and eastern Taranaki Peninsula*

Day 4 Theme: *Stratigraphic architecture below (Mokau Group) and above the Middle Miocene basin flooding (Otunui Fmn & Mt Messenger Fmn), Southern King Country and eastern Taranaki Peninsula*

Day 5 Theme: *Stratigraphic architecture and depositional systems of a late Miocene and early Pliocene progradational continental margin, eastern Taranaki Peninsula, with elements of a second progradational system (Tangahoe Fmn)*

LIST OF FIGURES

ROUTE MAPS

STRATIGRAPHIC LOGS

1.0 RATIONALE FOR FIELD GUIDE

For many years there has been ambiguity about the relationship between the Cenozoic successions exposed on land east of the northern Taranaki coastline, and the fill of Taranaki Basin in the offshore realm. In many ways the suites of data have been better for the offshore part of the basin than for the onshore part, where the stratigraphy has not even been properly described. The exception has been the development of the concept that the Mt Messenger Formation is a useful outcrop analogue as a basin floor fan for offshore parts of the same formation (e.g. King et al. 1993). The proximity of the Patea-Tongaporutu-Herangi structural high to the modern coastline has also contributed to the view that the eastern margin of Taranaki Basin has lain near the coastline, and that the bulk of the sediments exposed further inland accumulated in a different basin (e.g. King & Thrasher 1996).

Our recent research on the Cenozoic succession exposed on land in northern Taranaki (including eastern parts of Taranaki Peninsula) and King Country regions has clarified which parts of the succession accumulated in what can genuinely be regarded as Taranaki Basin, and what parts accumulated in separate depocentres. A key realisation has been the degree, extent and timing (Pliocene-Pleistocene) of a significant regional updoming and erosion phase of central-western North Island, and identification of the correlative formations that were removed. Although our research is not complete and written up, it is timely to present a field guide to allow those interested to examine in outcrop the marine formations otherwise buried offshore in Taranaki Basin.

The methods we have used in coming to a better understanding of the character of the successions on land, and the geological signals they contain, have in many ways been the traditional ones of developing a lithostratigraphy (including 1:50 000 geological mapping), a chronostratigraphy through biostratigraphy, facies analysis for paleoenvironmental interpretation, sequence stratigraphy, and petrography. In Taranaki Peninsula we have found wireline logs to be very useful in correlating individual Vail-type sequences that can be mapped in outcrop (Matemateaonga Formation) with correlative occurrences in the sub-crop of Taranaki Peninsula and southern parts of Taranaki Basin. Concurrently, we have been undertaking seismic mapping and wireline log analysis of the Neogene succession in northern Taranaki Basin, particularly of the Mohakatino, Ariki, Mangaa and Giant Foresets Formations, so as to better understand the development of the Northern Graben and associated structural inversion of the eastern margin of Taranaki Basin (e.g. Hansen & Kamp 2004, 2006). We have also undertaken new basin analysis work in Wanganui Basin to better understand the evolution of two continental margin wedges that have prograded from Wanganui Basin into the King Country region and northern Taranaki Basin.

The field guide has been designed to start in the Awakino area, where the succession rests on Murihiku Terrane basement, and then to work southward and upsection into the Matemateaonga Formation exposed in eastern Taranaki Peninsula. Our analysis of the fill of the basins reveals the occurrence of five 2nd order sequences of essentially tectonic origin. These include the late Eocene-Oligocene Te Kuiti Sequence, the early-early Miocene (Otaian) Mahoenui Group/Sequence, the late-early Miocene (Altonian) Mokau Group/Sequence, the middle Miocene to early Pliocene Whangamomona Group/Sequence, and the middle Pliocene-Pleistocene Rangitikei

Supergroup/Sequence. Higher order sequences are evident in the Whangamomona, and Rangitikei Sequences, with those of 5th (100 ka) and 6th (41 ka) order being especially common in the latter two sequences.

Several themes emerging from the stratigraphic architecture of the basins will recur during the field guide: (1) The stratigraphy and structure of the Te Kuiti Group, Mahoenui Group and Mokau Group around the southern end of the Herangi Range suggest that Taranaki and Manganui Faults were active, involving basement overthrusting and foreshortening of Taranaki Basin margin, during the late Oligocene and the early-early Miocene (Otaian Stage). (2) During the late-early Miocene and into the Middle Miocene, the eastern margin of Taranaki Basin collapsed and the contemporary continental slope retrograded into the King Country region. (3) The late Middle Miocene –Pliocene units (Whangamomona and Rangitikei Sequences) each comprise erosionally truncated shelf-slope-basin depositional systems that prograded northward through Wanganui and King Country Basin into eastern Taranaki Basin. (4) There has been a very significant Pliocene-Pleistocene tectonically driven uplift and erosion episode centred on central North Island including King Country Basin and extending out into Wanganui Basin and eastern parts of Taranaki Basin.

In the following text (Part A) we outline the general geology of the eastern margin of Taranaki Basin (onshore), and in (Part B) an itinerary and field stop notes for the trip.

1.1 Health and Safety

In terms of health and safety issues, please be aware of the inherent hazards of working along roads and adjacent areas. Some stops are on State Highway 3 which frequently carries heavy traffic, and importantly, heavy trucks; at other times we will be on provincial roads, which are narrow and sometimes unsealed. Some of the traffic may be of foreign tourists unfamiliar with driving on the left hand side; at other times it may involve local farm traffic, including machinery, where drivers are not expecting groups of people on the side of the road. Many of the sites will be at cliff faces over steepened by road construction. Cliffs may be unstable and collapse or shed debris at any time without warning. Caution should therefore be exercised when assessing exposures and examining rocks at the base of cliffs or road cuttings. One stop (No 51) at least one sea cliff south of Hawera. The west coast has a high energy wave climate, and wave, river and tidal conditions can combine to produce extreme hazards in walking and working along this coast, including the sudden collapse of sea cliffs.

1.2 Accommodation Options

Awakino Hotel	ph 06-752-9815; fax: 06-752-9829
Mokau Inn Motel	ph/fax: 06-7529725
Central Park Motel, Taumarunui	ph: 0800-238-030 or 07-895-7132
Whangamomona Hotel	ph/fax: 06-762-5823
Furlong Motor Inn, Hawera	ph: 06 278 5136, fax: 06-278-5134

PART A - BACKGROUND INFORMATION

2.0 GEOLOGICAL SETTING

A simplified geological map of central-western North Island is shown in Fig. 1. Fig. 2 is a structure map of the same region. Fig. 3 shows schematically the occurrence of major Neogene stratigraphic units in each of the three basins. The eastern margin of Taranaki Basin has traditionally been marked by the Taranaki Fault (e.g. King & Thrasher 1996). Note, however, in Fig. 1, how the boundaries of the late Miocene and Pliocene stratigraphic units cross the projected trace of the Taranaki Fault. This highlights the common geological history the basins have had during the late Neogene.

The King Country Basin lies to the east of the northern part of Taranaki Basin (Fig. 2). Its southern and common boundary with Wanganui Basin is poorly defined with no obvious structure between them. It broadly lies within a southward dipping monocline (Wanganui Monocline, Fig. 2) that reflects progressive southward onlap on to basement, which has been modified by later uplift and tilting to the south and southwest. For the purposes of defining the boundary between these basins, the base of the Matemateaonga Formation has been adopted. This marks the stratigraphic point at which substantial subsidence of basement in the northern part of Wanganui Basin started, with marked southward migration of the shoreline. The eastern margin of Wanganui Basin is marked by the axial ranges, and the western margin is marked by the offshore continuation of the Patea-Tongaporutu High and by the D'Urville High (Fig. 2).

2.1 Outcrop patterns

Much of the Neogene tectonic development of the region can be read from the geology and structure maps (Fig. 1, 2). A striking feature of the outcrop pattern in the northern part of Wanganui Basin and the southern part of King Country Basin is the west-east strike of the formations (Fig. 1). This involves the Mount Messenger Formation through to Nukumaruan strata (late Pliocene-early Pleistocene) (Fig. 3). These units are structurally conformable and dip 2-4° S or SW. The strike of these beds is normal to the orientation of the plate boundary zone, and therefore the origin of the bedding attitude is not simply related to upper crustal shortening driven by plate convergence. Significantly, the distribution of Castlecliffian (middle to late Pleistocene; Fig. 1, 3) strata only are influenced by the occurrence of the axial ranges (Tararua-Ruahine Range), suggesting that the uplift of these ranges occurred mainly during the Castlecliffian to Holocene interval.

In the central and northern parts of King Country Basin the stratigraphic units are Oligocene (Te Kuiti Group) and early Miocene (Mahoenui and Mokau Groups) in age and have shallow to negligible dip, being influenced more locally by tilting about the Herangi Range (Nelson et al. 1994), and faults (e.g. Ohura Fault) having northeast-southwest strikes sympathetic to those defining the Northern Graben in Taranaki Basin and the Taupo Volcanic Zone (Fig. 2). In central and western parts of Taranaki Peninsula the Urenui Formation through to Tangahoe Mudstone successions are overlain by Mount Taranaki Quaternary volcanics and volcaniclastic sediments of the ring-plain (Fig. 1).

2.2 Uplift and erosion of central North Island

The outcrop pattern of central-western North Island reflects long wavelength up-doming of central North Island and associated erosion of weakly lithified mudstone and associated lithologies. Fig. 4 is a map showing the magnitude and pattern of erosion calculated by kriging of estimates of the amount of erosion determined chiefly from analysis of the bulk density of mudstone cores (Kamp et al. 2004). There are two sets of bulk density data underpinning the map, including a DSIR dataset obtained during the 1960s for regional gravity mapping (Reilly 1965) and made available by the Institute of Geological & Nuclear Sciences Ltd, and a second data set collected as part of our University of Waikato work, which concentrated on high density sampling in the main river valleys of Wanganui Basin (Fig. 4).

Fig. 4 is essentially an erosion map as the data underpinning it reflect the amount of exhumation of the mudstone horizons sampled. The magnitude of erosion varies systematically, increasing northward from Wanganui Basin into King Country Basin, and eastward from eastern Taranaki Basin into the King Country region (Fig. 4). The maximum amount of erosion is probably about 2000 m. The zero erosion line offshore is presumed to have formed chiefly by wave planation and cliff retreat during successive Pleistocene marine transgressions and sea-level highstands, which also formed the uplifted flights of middle and late Pleistocene terraces in the vicinity of Taranaki Peninsula. Inland of the coastal zone, fluvial and slope processes acting on weakly lithified mudstone and sandstone are likely to have produced the erosion at rates that will have nearly approximated the rock uplift rates. In the Kaimanawa Range and northern Ruahine Range the Neogene cover rock succession has been almost completely removed and the exhumed basement surface, which is still evident in places, has been finely dissected (Fig. 4). The material eroded was dispersed to the surrounding basins, including northern Taranaki Basin (Giant Foresets Formation), Wanganui Basin (Rangitikei Supergroup), and Hawke's Bay Basin (Maungahururu Formation and Petane Group).

2.3 Stratigraphic units removed

The magnitude of erosion leads to the question of what stratigraphic units were removed. We consider that these included mainly the Mokau and Mahoenui Groups and the middle Miocene through Pliocene stratigraphic units involved in the Wanganui Monocline. The former occurrence of these units as evidenced by the results of analyses of the bulk density of exhumed mudstone beds, indicates that the King Country Basin was a long-lived marine sedimentary depocentre, and points to its probable former depositional continuity with northern parts of Wanganui Basin, and possibly the East Coast Basin during the early Miocene. This has implications for understanding of the Neogene paleogeographic development of central North Island.

3.0 STRATIGRAPHIC ARCHITECTURE OF THE BASIN FILLS

We illustrate the stratigraphic architecture of the fills of the three basins in central-western North Island by reference to two cross-sections and related time-stratigraphic panels (Kamp et al. 2004). Fig. 5 shows the lines of these cross-sections in relation to the distribution of the major stratigraphic units.

3.1 Wanganui Basin - King Country Basin: Parakino-1 to Ararimu-1 transect

Fig. 6 illustrates a cross-section through the axis of the Wanganui and King Country Basins. It shows the stratigraphic and structural concordance of the formations and how the slope on the basement surface is similar to the dip on the formation contacts. The Wanganui Monocline, defined from the dip of Neogene sediments (Fig. 2), is a reflection of the subsurface structure on basement. The cross-section also shows the persistent southward onlap of successive formations on to basement, suggestive of a north-facing paleoslope prior to later uplift and tilting to the south.

The time-stratigraphic section (Fig. 6) highlights particularly the occurrence of four major Neogene unconformity-bounded sequences (excluding the late Paleogene Te Kuiti Sequence). The first two are of early Miocene age. The Mahoenui Group comprises massive mudstone (Taumatamaire Formation) and flysch (Taumarunui Formation) facies (Hay 1967; Nelson & Hume 1977; Topping 1978; Cartwright 2003). The initial subsidence of the basin containing this succession occurred during the Oligocene (Te Kuiti Sequence) and is marked in the south by thin (up to 30 m) coaly incised valley fill deposits, thin transgressive (onlap) shellbeds, and overlying marine neritic sandstone and mudstone beds (Pungpunga Formation (new) of the Te Kuiti Group (2nd order) sequence; Cartwright 2003). A glauconitic mudstone a few dm thick locally at the base of the Mahoenui Sequence marks a prominent flooding surface. It reflects initial terrigenous sediment starvation associated with rapid subsidence and flooding of the basin, marked onlap of basement around the margins, and the establishment of deep-water conditions. This was followed locally by the accumulation of about 100 m of massive shelf mudstone and then by about 1000 m of redeposited sediments (turbidites) that accumulated at bathyal depths. The Mahoenui Group is predominantly of Otaian age (Topping 1978). Surprisingly, no regressive slope or shelf facies have been identified at the top of the Mahoenui Group. Presumably, if they were originally present, they were abridged and eroded during a short-lived and marked phase of uplift and erosion that affected the whole of the Mahoenui depocentre. The Herangi-Tongaporutu High separated the Mahoenui depocentre from Taranaki Basin. This depocentre was a piggy-back basin being transported westward during basement overthrusting on the Taranaki and Manganui Faults. The Taimana Formation and lower parts of the Manganui Formation are stratigraphic equivalents in Taranaki Basin of the Mahoenui Group in the King Country region.

The inversion of the Mahoenui depocentre was associated with reverse movement on the Ohura Fault. The upthrown block to the east of this fault partly sourced sediments to the area to the west of the Ohura Fault throughout the rest of the early Miocene (Altonian), where they formed the Mokau Group/Sequence (Fig. 6). The Mokau Sequence comprises lower transgressive sandstone (Bexley Sandstone), a coal measure, fluvial and intervening shoreface succession (Maryville Coal Measures), and an upper regressive shoreface sandstone (Tangarakau Sandstone) (e.g., Vonk 1999). The upper surface of the sequence appears to be conformable, especially in the southern part of the basin. The Manganui and Moki Formations exposed along the eastern margin of Taranaki basin are correlatives of the Mokau Group inland. The age of these units probably gets as young as lower Lillburnian.

The third Neogene megasequence is represented by the Whangamomona Group and this unit is common to parts of Wanganui, King Country, and Taranaki Basins (Fig. 6, 7). During the middle Miocene the whole of the King Country region subsided. This resulted in the accumulation of a transgressive shelf succession represented by the upper Lillburnian-Waiauan age Otunui Formation (Mohakatino Formation of Hay 1967). It overlies the Mahoenui Group east of the Ohura Fault, and Mokau Group west of this fault (Fig. 1). The basal facies of the Otunui Formation are heterolithic, commonly characterised by an onlap shellbed known as the Mangarara Formation (Henderson & Ongley 1923). The Otunui Formation is 100-200 m thick and comprises crudely bedded silty fine sandstone and sandy siltstone, with occasional conglomeratic channels. The Otunui Formation passes conformably upwards into the Mount Messenger Formation, which comprises a slightly calcareous siltstone containing very well sorted massive micaceous sandstone beds (sandy debris flow deposits). The transition to Mount Messenger Formation reflects rapid mid-Waiauan to lower Tongaporutuan subsidence of the basin to bathyal depths.

The Whangamomona Group comprises an asymmetric transgressive-regressive sequence. Soon after bathyal conditions were achieved in the King Country Basin (upper Waiauan - lower Tongaporutuan) the depositional sequence became regressive with the aggradation of bottom-sets (including basin floor – lower slope fan deposits) and the northward progradation of slope (Urenui and Kiore Formations) and shelf (Matemateaonga Formation, upper Tongaporutuan – lower Opoitian) deposits. Concurrently, the regressive units, and notably the Matemateaonga Formation, onlapped basement to the south. This geometry required there to be a persistent increase in sediment flux delivered to the continental margin, particularly from about 11 m.y. ago, after which most of the thickness of the megasequence accumulated.

The last megasequence comprises the upper Opoitian - upper Castlecliffian Rangitikei Supergroup. In the northern parts of Wanganui Basin the Tangahoe Mudstone is the basal unit of the Rangitikei Sequence and has also a major flooding surface at its base. It is marked by a 20-30 cm thick condensed horizon of glauconitic mudstone, which lies a few metres above inner shelf deposits. Within the condensed horizon the paleobathymetry changed from neritic to upper bathyal water depths and the condensed unit contains some 600 k.y. of time across the lower to upper Opoitian boundary. This is followed upwards, within a few tens of metres, by packets of redeposited sandstone beds that accumulated in broad submarine channels on a continental slope. The upper bathyal deposits (slope-sets) shallow upwards into shelf deposits as a result of shelf and slope progradation during the Waipipian. Mangapanian and younger units make up aggradational shelf deposits (top-sets) (e.g., Fleming 1953; Beu & Edwards 1984; Kamp & Turner 1990; Abbott & Carter 1994; Naish & Kamp 1995, 1997; McIntyre & Kamp 1998; Kamp & McIntyre 1998).

3.2 Wanganui Basin - eastern Taranaki Basin: Santoft-1A to Tuhua-1 transect

The cross-section from Santoft–1A to Tuhua-1 starts near the modern depocentre of Wanganui Basin, passes north to Parakino-1 in the Wanganui River valley, east across the Patea-Tongaporutu High to Manutahi-1, north along the eastern margin of Taranaki Basin, and crosses the Taranaki Fault between Rotokare-1 and Wingrove-1 (Fig. 7). It shows the consistent and shallow south to southwesterly dip of the beds irrespective of the basin containing them. The steeper dip of the beds between

Parakino-1 and Whangaehu-1 reflects the marked subsidence in Wanganui Basin associated with deposition of the Tangahoe Mudstone.

Fig. 7 also shows the chronostratigraphic distribution of the units along the cross-section line. The striking feature is the southward onlap on to basement of the middle Miocene to Pleistocene sedimentary succession, also evident in Fig. 6. This onlap followed the end of substantial displacement on the Taranaki Fault in the peninsula area. The rate of onlap increased markedly during the latest Miocene and earliest Pliocene. The southward onlap implies a north-facing paleoslope. This pattern was clearly reversed after deposition of the Tangahoe Mudstone, with southward tilting involving both the basement and cover succession and occurring without much differential movement on the Taranaki Fault.

In the Santoft-1A to Tuhua-1 cross-section the base of the middle to late Miocene Whangamomona Group/Sequence is placed at the base of a limestone succession lying unconformably on basement near the base of Rotokare-1. This limestone has a Clifdenian to Lillburnian age and probably corresponds to the Mangarara Formation. It is also known in other places on the Tongaporutu-Herangi High (Uruti-1 & 2). During accumulation of the Mount Messenger, Urenui, and Kiore Formations there must have been a very narrow shelf along the cross-section line between Rotokare-1 and Manutahi-1, which widened substantially during accumulation of the Matemateaonga Formation.

4.0 TWO PHASES OF NEOGENE CONTINENTAL MARGIN PROGRADATION

Fig. 8 is a block diagram that shows schematically the depositional and stratigraphic architecture of the two 2^{nd} order sequences comprising the middle Miocene to Pleistocene sedimentary succession in the Wanganui, King Country, and Taranaki Basins. Both the Whangamomona and Rangitikei Sequences formed as northward prograding continental margin wedges, and had similar top-set, slope-set, and bottom-set stratal architecture. Unusually, the onlap margin of the Whangamomona Sequence is the preserved component, the deeper-water more oceanward part of the sequence having been uplifted and truncated by erosion in the King Country region.

The Whangamomona Sequence can be mapped along the eastern margin of Taranaki Basin, upon, and to the west of the Tongaporutu-Herangi High, part of it being exposed in the northern Taranaki coastal section (Mount Messenger and Urenui Formations) (King et al. 1994; Browne & Slatt 2002). The Kiore and Matemateaonga Formations crop out to the south in the hill country of eastern Taranaki Peninsula (Vonk et al. 2002).

The Whangamomona Sequence accumulated mainly in the Wanganui and King Country Basins, which reflected the main sedimentary fairway and depositional axis, but the sequence also extended into eastern parts of Taranaki Basin, as outlined above. Correlative beds of the Whangamomona Sequence in Taranaki Basin (Manganui Formation) accumulated in bathyal environments and will be identified on the basis of age. The continental margin comprising the Rangitikei Sequence advanced northward on two fronts, one directly northward from the Southern Alps source through Wanganui Basin and into southern parts of the King Country Basin, while the other was directed west of the Patea-Tongaporutu High through the Toru Trough and into the Central and Northern Grabens of Taranaki Basin and ultimately on to the Western Stable Platform (Hansen & Kamp 2002, 2004). This sequence forms the thick and extensive deposits underlying the modern shelf and slope in the offshore parts of Taranaki Basin, where it is known as the Giant Foresets Formation. The equivalent sediments have been uplifted and totally removed from the King Country Basin and erosionally truncated in the northern parts of Wanganui Basin and over the Taranaki Peninsula. The Pliocene-Pleistocene erosion of the Whangamomona, Mokau, and Mahoenui Groups in the King Country Basin will have contributed to the source of the sediments making up the Giant Foresets Formation.

5.0 STRATIGRAPHIC ARCHITECTURE ACROSS THE BOUNDARY BETWEEN TARANAKI AND KING COUNTRY BASINS

In the vicinity of eastern Taranaki Peninsula and Wanganui Basin the major stratigraphic units, as described above, accumulated across the boundaries between all three basins (Figs. 1, 2, 9), reflecting the contemporary broad crustal downwarping and associated sedimentation. Further to the north where these units have been eroded, the stratigraphic and structural relationships between eastern Taranaki Basin and King Country Basin are much less clear, but are of particular interest as they relate to the timing of basement overthrusting on the Taranaki Fault, movement on other faults, and the change from early Miocene crustal shortening to middle Miocene broad crustal downwarping. Fig. 9 is a chronostratigraphic panel drawn for a cross-section between Awakino Heads in eastern Taranaki Basin and Waitui Saddle on the Hauhungaroa Range along the eastern margin of King Country Basin. This panel is based on various sources including Happy (1971), Cochrane (1988), King et al. (1993), Nelson et al. (1994), Wilson (1994), King & Thrasher (1996), Vonk (1999), Vonk et al. (2002), Cartwright (2003), Evans (2003), and our unpublished work. In this section we outline the late Oligocene through middle Miocene stratigraphic and structural development of this eastern Taranaki - King Country margin and its implications.

During most of the Oligocene a structural high (Herangi High) persisted as a semi-continuous paleogeographic feature from south of Awakino to Port Waikato (Nelson 1978). Nelson et al. (1994) have described a distinctive Te Kuiti Group succession at Awakino Tunnel on the eastern side of the Herangi Range where it is generally thick (300 m), has strong dips (40-30^{o}), exhibits an upsection decrease in the amount of dip, and the capping Orahiri Limestone includes several thick (up to 3 m) mass-emplaced units containing a variety of 1-10 cm-sized lithoclasts of older Te Kuiti Group rocks. Tilting of the southern part of the high began during the upper Whaingaroan around 30 Ma, concomitant with the onset of rapid subsidence along eastern Taranaki Basin, and continued through to the end of the Waitakian Stage (22 Ma, earliest Miocene), when erosion expanded on to the shelf at Awakino Tunnel, stripping out the Otorohanga Limestone in places.

In eastern Taranaki Basin the latest Oligocene (lower Waitakian) Tikorangi Formation is offset by the Taranaki Fault (Fig. 9), which has its present reverse character in this region as a result of overthrusting of basement into the eastern margin of Taranaki Basin (e.g., King & Thrasher 1996). The oldest sediments overlying the overthrust basement block are upper Otaian, and more regionally Altonian in age (King & Thrasher 1996). This brackets the emplacement of the overthrust basement into Taranaki Basin as lying between 23.8 (mid-Waitakian;

Oligocene-Miocene boundary) and 19.0 Ma (Otaian-Altonian Stage boundary). Taranaki Fault as a pre-existing structure appears to have accommodated part of the compressive regional strain that developed across North Island at that time associated with the development of the Australia-Pacific plate boundary to the east (e.g., Kamp 1986).

On the southeastern flank of Herangi Range near Awakino Tunnel, the Te Kuiti Group is onlapped and overlapped on to basement by early Miocene siliciclastic mudstone and sandstone of the Mahoenui and Mokau Groups, respectively (Fig. 9). The Mahoenui Group is Otaian in age (22-19 Ma) and throughout the King Country region is either a bathyal massive mudstone facies (Taumatamaire Formation) or a flysch facies (Taumarunui Formation). Near Awakino Tunnel, mapping shows that the Taumatamaire Formation clearly onlaps an unconformity cut across the Te Kuiti Group, which it oversteps to onlap basement (Cochrane 1988). The onlap shows that the basin margin subsided differentially during accumulation of Taumatamaire Formation, as indicated by the fanning of dips from 20-5^{o} (Cochrane 1988). The Manganui Fault (Campbell & Raine 1989) lies 3 km to the west of the eroded onlap margin and has the appropriate strike to have acted as the structure controlling the rotation of the block carrying the differentially tilted Taumatamaire Formation. We infer that the Manganui Fault was a high-angle reverse fault at this time, upthrown to the east, with several hundred to 1250 m of displacement.

5.1 Late-early Miocene to middle Miocene collapse of eastern Taranaki Basin margin

The youngest parts of the Mahoenui Group in King Country Basin are late Otaian to possibly earliest Altonian in age (Topping 1978). No regressive deposits are associated with this predominantly bathyal succession, even though its unconformable contact with the overlying Mokau Group and Otunui Formation formed through subaerial erosion. This emphasises the regional nature of an initial uplift phase that seems to have involved inversion of the whole of the Mahoenui depocentre (Fig. 9), and included reverse movement on the Ohura and Pungapunga-Hauhaungaroa Faults (Fig. 2) During the late Otaian and possibly continuing into the Altonian, movement on the Ohura Fault resulted in marked erosion of Mahoenui Group southeast of this fault; east of Pungapunga Fault, Mahoenui Group was completely eroded (Fig. 9).

Mokau Group accumulated during the Altonian to a thickness of about 340 m mainly northwest of Ohura Fault (Crosdale 1993; Vonk 1999) (Fig. 9). This group comprises three main units: (i) a ~60 m-thick lower transgressive shoreface sandstone (Bexley Sandstone); (ii) a ~100 m-thick middle unit of coal measures, fluvial conglomerate, and shoreface sandstone (Maryville Coal Measures); and (iii) an upper ~180 m-thick unit of regressive shoreface to innermost shelf sandstone conglomerates and coal measures (Tangarakau Fmn) (Vonk 1999). Concurrently, to the west of the Herangi High, transgressive shoreface facies (Bexley Sandstone) onlapped the basement east of Taranaki Fault (Fig. 9). This was followed by the accumulation of Manganui Formation mudstone, initially as a shelfal deposit, but by the middle Altonian as a mid-bathyal succession (King et al. 1993). Moki Formation accumulated as submarine channel and fan deposits on a lower slope to basin floor west of the modern coastline (King & Thrasher 1996) and as channel complexes on a continental slope to the east (Kamp et al. 2004). Hence a complete coastal plain-shoreface-shelf-slope-basin floor linked depositional system developed across the margin between Taranaki and King Country Basins during the Altonian and probably into the mid Lillburnian. This depositional system formed over a narrow belt some 35 km wide. We show in Fig. 9 the approximate positions of the shelf-slope break during the Altonian-lower Lillburnian and infer that this break migrated slowly inland (retrogressed). The system had a strong aggradational component during the Altonian-lower Lillburnian and a surprisingly narrow shelf, which will have been controlled by the balance between the rate of subsidence of the underlying basement block and by the rate of sediment flux.

The Altonian marked the start of the collapse (marked subsidence) of the Kawhia Harbour to Taranaki Peninsula sector of the eastern margin of Taranaki Basin. This collapse accelerated during the early-middle Miocene leading at the end of the middle Miocene to the development of a bathyal environment over the eastern Taranaki Basin margin and the King Country region. During the upper Lillburnian, the King Country region underwent marine flooding, possibly in response to emplacement of the subducted slab of Pacific plate beneath the region (Kamp 1999). The basal stratigraphic unit is the Mangarara Formation, which over most of the King Country is a transgressive shellbed. The Otunui Formation is a 100-200 m-thick sandstone to calcareous sandy siltstone, containing a variety of facies typical of an onlapping shoreline through shelf and upper slope succession, including glauconite-rich units (Gerritsen 1994; Vonk 1999, Cartwright 2003; Evans 2003). It passes gradationally upwards into massive siltstone facies of the Mt Messenger Formation. Channelised redeposited sandstone deposits occur within the upper parts of the Otunui Formation and near the transition zone to Mt Messenger Formation (Fig. 9). Within 10-50 m of the base of the Manganui Formation/Mt Messenger Formation the mass-emplaced sandstone beds (sandy debris flows) become more broadly channelised and are inferred to be part of the Mt Messenger Formation; thicker bedded sandstone units analogous to those exposed in the North Taranaki coastal section occur at higher stratigraphic levels in the southern King Country region and indicate that lower slope to basin floor environments developed there.

The Mangarara Formation in the Awakino area comprises a Clifdenian (16-15 Ma), variably calcareous (slightly calcareous to limestone composition) glauconitic sandstone, which in all of the western river catchments accumulated as mass-emplaced beds on a continental slope. It is closely associated with thick-bedded, well sorted sandstone beds that accumulated as channelised sandy debris flows and turbidites, which we assign to Moki Formation, as described from other parts of Taranaki Basin by de Bock (1994), and King & Thrasher (1996). The mechanism(s) of emplacement and the continental slope environment of deposition of the Mangarara Formation are common to the Moki Formation, which differ only in carbonate content. The Mangarara Formation facies, which are rich in *Amphistegina* and rhodoliths (calcareous red algal balls), were sourced from areas of carbonate accumulation on the contemporary shelf to the east in the King Country region (Tangarakau Formation, Fig. 9) or to the south on the gently subsiding PT High, whereas the sandstone facies of the Moki Formation were transported across the shelf and upper slope from a shoreface in the southeast, where the sandstone had been well sorted by wave action. The sandstone beds of the Moki Formation, encased in background siltstone facies of the Manganui Formation, persist through the middle Miocene section. The Moki and Manganui facies pass gradationally upwards into

Mount Messenger Formation. The Mohakatino Formation comprises richly volcaniclastic sandstone sourced from andesitic volcanoes of middle to late Miocene age in northern Taranaki Basin. This formation occurs onshore but strongly volcaniclastic facies are restricted to coastal sections (Nodder et al. 1990a, b; King et al. 1993). These sediments occur as either airfall units, or dominantly as channelised mass-emplaced beds.

Between about 14 Ma (upper Lillburnian) and 11 Ma (lower Tongaporutuan) there was marked subsidence to bathyal (1000 m) basin floor environments of what had previously been land along the eastern margin of Taranaki Basin and in the King Country region (Fig. 9). This subsidence, in the absence of an oversupply of sediment, led to southeastward retrogradation of the continental margin that previously (in the Otaian) had been pinned to the Taranaki Fault. At about 11 Ma, when higher rates of uplift and erosion developed along the Alpine Fault, reflected in high rates of sediment flux, a continental margin wedge comprising Mt Messenger, Urenui, Kiore, and Matemateaonga Formations started to prograde northward into this basin as the progradational part of the Whangamomona Sequence (Fig. 6 - 9). There are no indications that any paleogeographic barriers separated the Taranaki Basin from the King Country Basin north of Taranaki Peninsula. We illustrate in Fig. 9 the Altonian-Lillburnian retrogradation of the continental margin and its subsequent (Tongaporutuan - lower Opoitian) progradation via red markings representing successive positions of the shelf-slope break. During the early Pliocene the Wanganui Basin subsided rapidly in response to the southward migration of the depocentre.

6.0 FOURTH, 5TH, AND 6TH ORDER SEQUENCES WITHIN WHANGAMOMONA AND RANGITIKEI SEQUENCES

Fourth, 5th, and 6th order sequences are considered to be of 400 ka, 100 ka, and 41 ka duration, the latter two being related to Milankovitch orbital parameters, widely considered to have modulated Earth's climatic and sea level history during the late Cenozoic. The 100 ka cyclicity characterises the last 900 k.y. of Earth history, whereas 41 ka cyclicity appears to have been the dominant climatic signal during the late Miocene, Pliocene, and early Pleistocene.

Fourth, 5th, and 6th order sequences are evident to various degrees within the Whangamomona and Rangitikei Sequences. These lower orders of cyclicity are reflected in the lithofacies character and stratal geometry of the formations and units occurring within the megasequences. Excluding the 5th order Castlecliffian sequences (Turner & Kamp 1990; Abbott & Carter 1994), 6th order sequences are most prevalent in upper parts of the Whangamomona and in Rangitikei Sequences. They are well developed in shelf top-sets of the Matemateaonga Formation (Kamp et al. 2002; Vonk et al. 2002, Hendy & Kamp 2004), the Whenuakura Subgroup (Naish et al. 2005), the Okiwa Subgroup (Kamp & McIntyre 1998), the Paparangi Subgroup (Kamp et al. 1998), and in Nukumaruan strata (Naish & Kamp 1995, 1997). This arises because of a very characteristic repetitive succession of shellbed-siltstone-sandstone lithofacies, typically of 25-70 m thickness. Sequences with durations of several hundred thousand years, possibly 4th order, are evident in the Matemateaonga Formation in axial parts of Wanganui Basin, and in parts of the Rangitikei Supergroup (e.g., Mangaweka Mudstone). Their origin is considered to relate to tectonically-driven pulses of subsidence rather than to climatic or sea level oscillations.

The identification of 4th, 5th, and 6th order sequences in the slope-sets and bottom-sets of the Whangamomona Sequence is more difficult to achieve and to date than for the top-sets. King et al. (1994) have described sequences in the Urenui Formation and Mount Messenger Formation in the northern Taranaki coastal section which are probably of 5th order cyclicity. The combination of the inclined depositional surface in slope environments, the more random depositional and mass movement processes that occur off the shelf, and the accidental position of outcrop sections and drill hole locations with respect to the depositional lobes, conspire to make it difficult to reconstruct a comprehensive record of higher order sequences in off-shelf settings, and so to establish their periodicity.

7.0 ACKNOWLEDGEMENTS

We acknowledge the Foundation for Research Science and Technology for research funding (contracts: UOW608 and UOWX0301).

8.0 REFERENCES

Abbott, S. T.; Carter, R. M. 1994: The sequence architecture of mid-Pleistocene (c. 1.1-0.4 Ma) cyclothems from New Zealand: facies development during a period of orbital control on sea level cyclicity. *In*: de Boer, P. L.; Smith, D. G. *ed*., Orbital forcing and cyclic sequences. *Special Publication of the International Association of Sedimentologists 19*: 367-394.

Beu A. G.; Edwards, A. R. 1984: New Zealand Pleistocene and late-Pliocene glacio-eustatic cycles. *Palaeogeography, Palaeoclimatology, Palaeoecology 46*: 119-142.

Browne, G. H.; Slatt, R. M. 2002: Outcrop and behind outcrop characterization of a late Miocene slope fan system, Mt. Messenger Formation, New Zealand. *American Association of Petroleum Geologists Bulletin 86*: 841-862.

Campbell, H. J.; Raine, J. I. 1989: Biostratigraphic evidence for the Manganui Fault, near Awakino, southwest Auckland. *Journal of the Royal Society of New Zealand 19*: 43-53.

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

Cochrane, P. R. 1988: The stratigraphy and structure of the early Miocene Mahoenui Group, northern Awakino Gorge: controls on cyclic carbonate-terrigenous sedimentation. Unpublished MSc Thesis, University of Waikato, Hamilton, New Zealand.

Crosdale, P. J. 1993: Regression-related coal-bearing sequences in the Neogene of New Zealand: relation to the developing Alpine fault transform. *In*: Ballance, P. F. *ed*. South Pacific sedimentary basins. Sedimentary Basins of the World 2. Amsterdam, Elsevier. Pp.279-293.

Cooper, R.A.(ed.) 2004: The New Zealand Geological Timescale. Institute of Geological and Nuclear Sciences Monograph 22, 284pp.

de Bock, J. F. 1994: Moki Formation, a Miocene reservoir sequence, its facies distribution and source in offshore southern Taranaki Basin. 1994 New Zealand Petroleum Conference Proceedings, The Publicity Unit, Crown Minerals

Operations Group, Energy and Resources Division, Ministry of Commerce. Pp. 155-167.

Fleming, C. A. 1953: The geology of Wanganui Subdivision. *New Zealand Geological Survey Bulletin 52*. 362 p.

Edbrooke, S.W. (compiler) 2005: Geology of the Waikato area. Institute of Geological and Nuclear Sciences 1:250 000 geological map 4. I sheet +68p. Lower Hutt, New Zealand.

Evans, T. P. H. 2003: Stratigraphy and sedimentology of early to middle Miocene strata, western Taumarunui region, King Country Basin. Unpublished MSc thesis, University of Waikato, Hamilton, New Zealand.

Gerritsen, S. W. 1994: The regional stratigraphy and sedimentology of the Miocene sequence in the Ohura-Taumarunui region. Unpublished MSc thesis, University of Waikato, Hamilton, New Zealand.

Glaessner, M. F. 1960: The fossil decapod crustacea of New Zealand and the evolution of the order decapoda. New Zealand Geological Survey Paleontological bulletin v. 31, Dept of Scientific and Industrial Research, Wellington, 63 pp.

Hansen, R. J.; Kamp, P. J. J. 2002: Evolution of the Giant Foresets Formation, northern Taranaki Basin, New Zealand. *Proceedings 2002 New Zealand Petroleum Conference, Auckland 24-27 February, 2002*. Ministry of Economic Development, Wellington. Pp. 419-435.

Hansen, R. J.; Kamp, P. J. J. 2004: Late Miocene - early Pliocene stratigraphic record in northern Taranaki Basin: Prelude to Northern Graben extension and progradation of the modern continental margin. *New Zealand Journal of Geology and Geophysics, 47(4),* 645-662.

Hansen, R.J. and Kamp, P.J.J., 2006: An integrated biostratigraphy and seismic stratigraphy of the late Neogene continental margin succession in northern Taranaki Basin, New Zealand. *New Zealand Journal of Geology and Geophysics. 49*: 39-46.

Happy, A. J. 1971: Tertiary geology of the Awakino area, North Taranaki. Unpublished MSc Thesis, University of Auckland, New Zealand.

Hay, R. F. 1967: Geological map of New Zealand, Sheet 7, Taranaki. 1:250,000. Wellington, Department of Scientific and Industrial Research.\

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

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

Hendy, A. J. W.; Kamp, P. J. J. 2004: Late Miocene-early Pliocene biofacies of Wanganui and Taranaki Basins, New Zealand: applications to paleoenvironmental and sequence stratigraphic analysis. *New Zealand Journal of Geology and Geophysics 47(4):*769-785.

Hendy, A.J.W. Kamp, P.J.J. and Vonk, A.J. 2006: Cool-water shell bed taphofacies from the Miocene-Pliocene shelf sequences in New Zealand: utility of taphofacies in sequence stratigraphic analysis. *In:* Pedley, H.M. & Carannante, G. (eds) *Cool-Water Carbonates: Depositional Systems and Palaeoenvironmental Controls*. Geological. Society, London, Special Publications, 255: 283-305.

Kamp, P. J. J. 1986: The mid-Cenozoic Challenger Rift System of western New Zealand and its implications for the age of Alpine Fault inception. *Geological Society of America Bulletin 97*: 255-281.

Kamp, P. J. J. 1999: Tracking crustal processes by FT thermochronology in a forearc high (Hikurangi margin, New Zealand) involving Cretaceous subduction termination and mid-Cenozoic subduction initiation. *Tectonophysics 307*: 313-343.

Kamp, P. J. J.; McIntyre, A. P. 1998: The stratigraphic architecture of late Pliocene (2.8-2.4 Ma) asymmetrical shelf sequences, western Wanganui Basin, New Zealand. *Sedimentary Geology 122*: 53-67.

Kamp, P. J. J.; Turner, G. 1990: Pleistocene unconformity bounded sequences (Wanganui Basin, New Zealand) correlated with global isotope record. *Sedimentary Geology 68*: 155-161.

Kamp, P. J. J.; Journeaux, T. D.; Morgans, H. E. G. 1998: Cyclostratigraphy of middle Pliocene mid-shelf to upper slope strata, eastern Wanganui Basin (New Zealand): correlations to the deep sea isotope record. *Sedimentary Geology 117*: 165-192.

Kamp, P. J. J.; Vonk, A. J.; Bland, K. J.; Griffin, A.G.; Hayton, S.; Hendy, A.J.W.; McIntyre, A.; Nelson, C.; Naish, T. 2002: Megasequence architecture of Taranaki-Wanganui-King Country Basins and Neogene progradation of two continental margin wedges across western New Zealand. *Proceedings 2002 New Zealand Petroleum Conference, Auckland 24-27 February, 2002.* Ministry of Economic Development, Wellington. Pp. 464-481.

Kamp, P.J.J., Vonk, A.J., Bland, K.J. Hansen, R.J., Hendy, A.J.W., McIntyre, A.P., Ngatai, M., Cartwright, S.J., Hayton, S., and Nelson, C.S. 2004: Neogene Stratigraphic architecture and tectonic evolution of Wanganui, King Country, and eastern Taranaki Basins, New Zealand. *New Zealand Journal of Geology and Geophysics* v.47 (4) 625-644.

King, P. R.; Browne, G. H.; Slatt, R. M. 1994: Sequence architecture of exposed late Miocene basin floor fan and channel-levee complexes (Mount Messenger Formation), Taranaki Basin, New Zealand. *In*: Weimer, P.; Bouma, A. H.; Perkins, B. F. *ed*. Submarine fans and turbidite systems. *Gulf Coast Section, Society of Economic Paleontologists and Mineralogists Foundation, 15th Annual Research Conference*. Pp. 172-192.

King, P. R.; Scott, G. H.; Robinson, P. H. 1993: Description, correlation and depositional history of Miocene Sediments outcropping along the North Taranaki coast. *Institute of Geological and Nuclear Sciences Monograph 5*. 199 p. Lower Hutt, Institute of Geological and Nuclear Sciences Ltd.

King, P. R.; Thrasher, G. P. 1996: Cretaceous – Cenozoic geology and petroleum systems of the Taranaki Basin, New Zealand. *Institute of Geological and Nuclear Sciences Monograph 13*. 243 p.

McIntyre, A. P.; Kamp, P. J. J. 1998: Late Pliocene (2.8-2.4 Ma) cyclothemic shelf deposits, Parikino, Wanganui Basin, New Zealand: lithostratigraphy and correlation of cycles. *New Zealand Journal of Geology and Geophysics 41*: 69-84.

Naish, T. R.; Kamp, P. J. J. 1995: Late Pliocene marine cyclothems, Wanganui Basin, New Zealand. *New Zealand Journal of Geology and Geophysics 38*: 223-243.

Naish, T. R.; Kamp, P. J. J. 1997: Sequence stratigraphy of 6th order (41 k.y.) Pliocene-Pleistocene cyclothems, Wanganui Basin, New Zealand: a case for the regressive systems tract. *Geological Society of America Bulletin 109*: 978-999.

Naish, T. R.; Wehland, F.; Wilson, G. S.; Browne, G. H.; Cook, R.; Morgans, H.; Rosenburg, M.; King, P. R.; Smale, D.; Nelson, C. S.; Kamp, P. J. J.; Ricketts, B. 2005: An integrated sequence stratigraphic, paleoenvironmental and chronostratigraphic analysis of the mid-Pliocene (c. 3.4-3.0 Ma) Tangahoe Formation, southern Taranaki Coast: implications for glacio-eustatic sea-level changes. *Journal of the Royal Society of New Zealand,* V. *35 Numbers 1&2, 151-196.*

New Zealand Geological Survey 1972: North Island (1st Ed.) Geological map of New Zealand 1: 1,000,000. Wellington, Department of Scientific and Industrial Research.

Nelson, C. S. 1978: Stratigraphy and paleontology of the Te Kuiti Group, Waitomo County, South Auckland, New Zealand. *New Zealand Journal of Geology and Geophysics 21*: 223-243.

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

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

Nodder, S. D.; Nelson, C. S.; Kamp, P. J. J. 1990a: Middle Miocene formational stratigraphy (Mokau-Mohakatino Groups) at Waikawau, northeastern Taranaki Basin margin, New Zealand. *New Zealand Journal of Geology and Geophysics 33*: 585-598.

Nodder, S. D.; Nelson, C. S.; Kamp, P. J. J. 1990b: Mass-emplaced siliciclastic - volcaniclastic - carbonate sediments in middle Miocene shelf-to-slope environments at Waikawau, northern Taranaki and some implications for Taranaki Basin development. *New Zealand Journal of Geology and Geophysics 33*: 599-615.

Reilly, W. I. 1965: Gravity map of New Zealand 1:4,000,000. Bouger and Isostatic Anomalies (1st ed.). Wellington, Department of Scientific and Industrial Research.

Topping, R. M. 1978: Foraminifera from the Mahoenui Group, North Wanganui Basin. Unpublished PhD Thesis, University of Auckland, New Zealand.

Turner, G. M.; Kamp, P. J. J. 1990: Paleomagnetic location of the Jaramillo subchron and Brunhes - Matuyama transition in the Castlecliffian Stratotype section, Wanganui Basin, New Zealand. *Earth and Planetary Science Letters* 100: 42-50.

Vail, P.R., 1987: Seismic stratigraphy interpretation using sequence stratigraphy Part I: Seismic stratigraphy interpretation procedure. In Bally, A.W. (ed) AAPG Atlas of Seismic Stratigraphy, volume 1. American Association of Petroleum Geologists studies in geology no. 27: 1-10. American Association of Petroleum Geologists, Tulsa.

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

Vonk, A. J.; Kamp, P. J. J.; Hendy, A. W. 2002: Outcrop to subcrop correlations of late Miocene-Pliocene strata, Taranaki Peninsula. *Proceedings 2002 New Zealand Petroleum Conference, Auckland 24-27 February, 2002*. Wellington, Ministry of Economic Development. Pp. 234-255.

Wilson, B. T. 1994: Sedimentology of the Miocene succession (coastal section), eastern Taranaki Basin margin: sequence stratigraphic interpretation. Unpublished MSc thesis, University of Waikato, Hamilton, New Zealand.

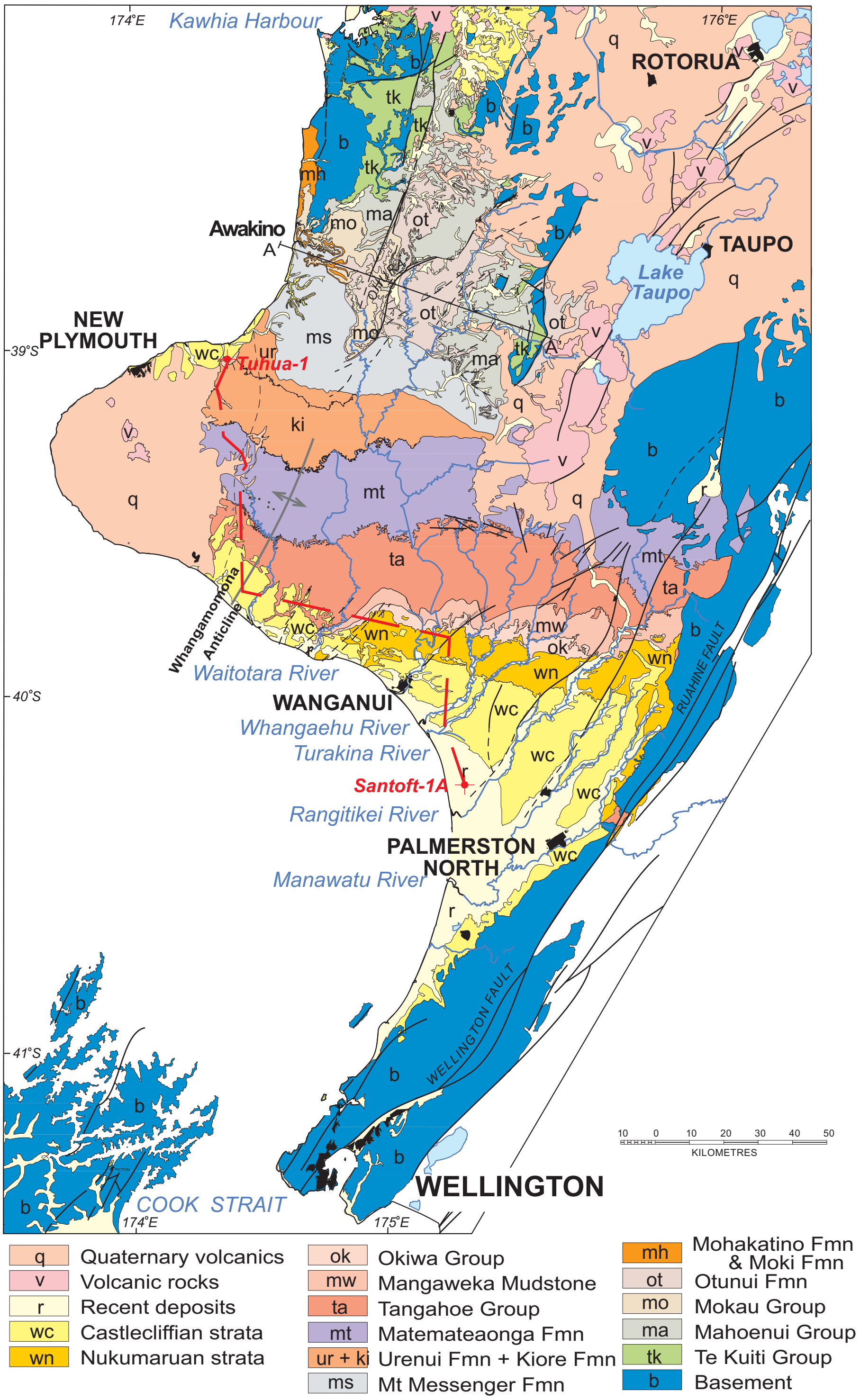


Fig. 1. Simplified geological map of western North Island (modified from New Zealand Geological Survey 1972), showing the main stratigraphic units in the eastern Taranaki, King Country, and Wanganui Basins (see Fig. 2). Cross-section line A-A'is the basis for the chronostratigraphic panel in Fig. 9. From Kamp et al. 2004 (Fig.1).

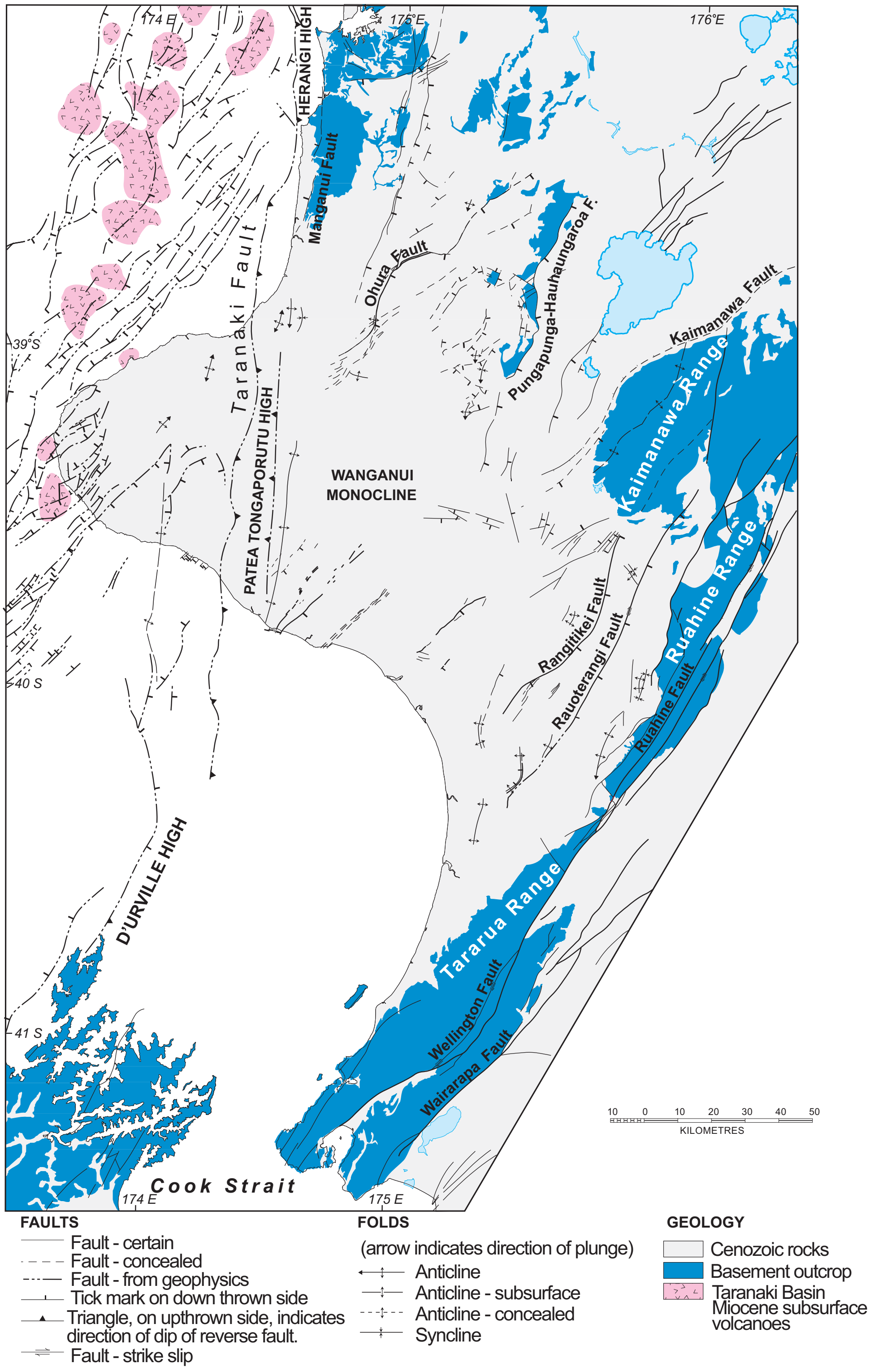


Fig. 2. Map of western North Island showing the major geological structures and the distribution of basement. While many of the structures are of Pliocene-Pleistocene age, some date back to the early Miocene and may not be currently active. From Kamp et al. 2004 (Fig. 2).

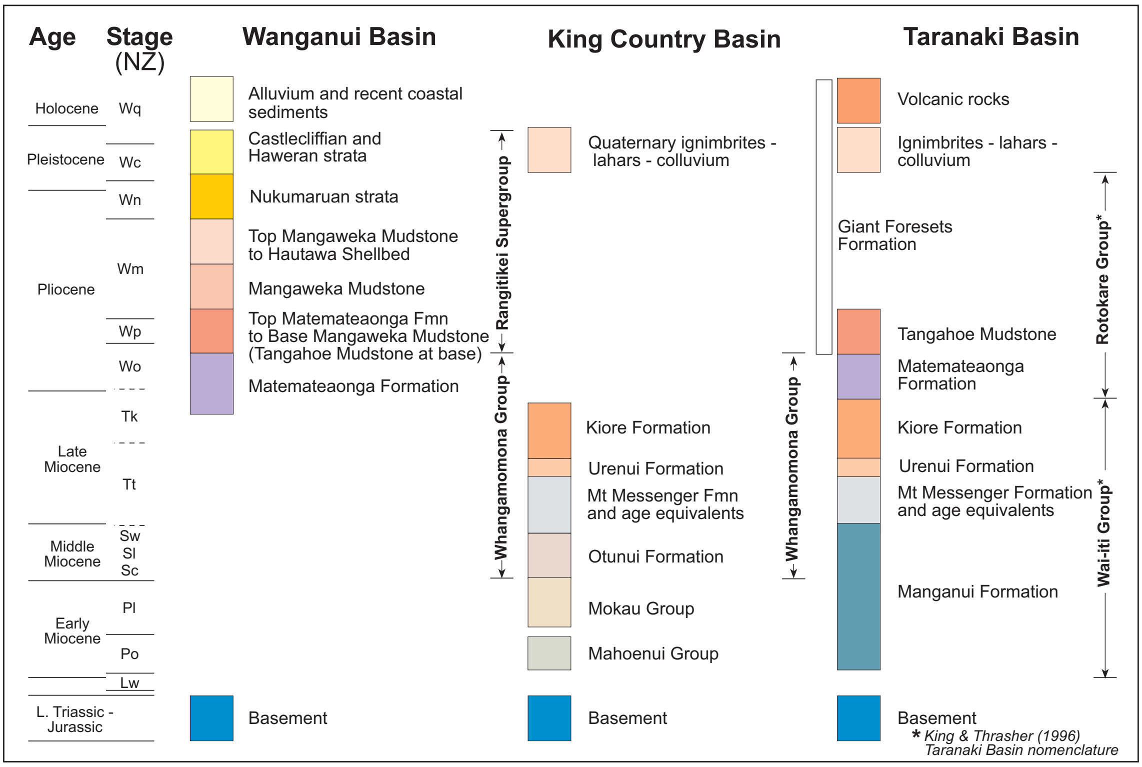


Fig. 3. The major Neogene stratigraphic units in each of Taranaki, King Country, and Wanganui Basins, and their age. The Moki and Mohakatino Formations, which occur within Manganui Formation in Taranaki Basin, are not shown. From Kamp et al. 2004 (Fig. 3).

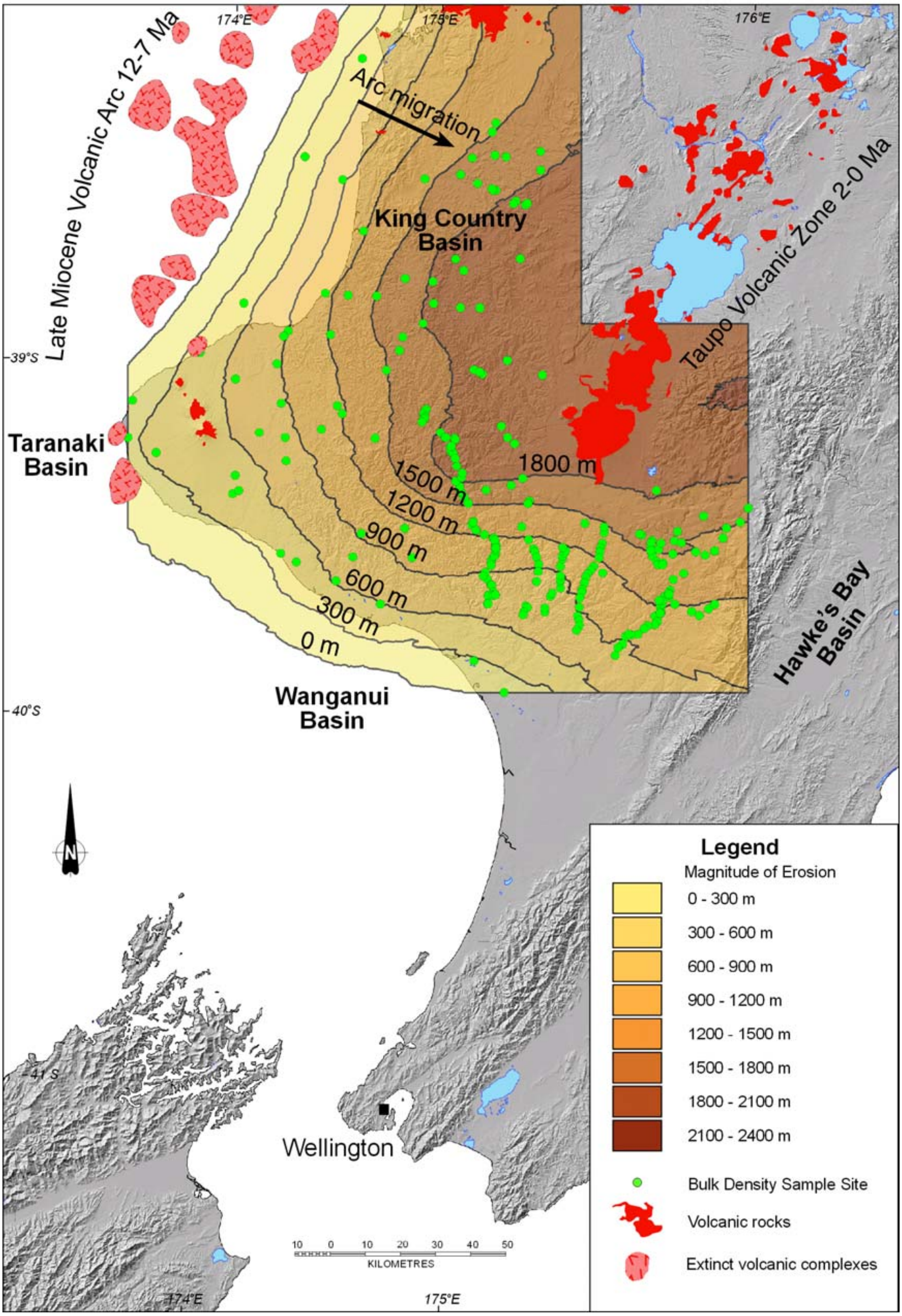


Fig. 4. Map showing the magnitude in 300 m contours and pattern of Pliocene-Pleistocene erosion over central North Island derived from mudstone bulk density data. See text for discussion. From Kamp et al. 2004 (Fig. 4).

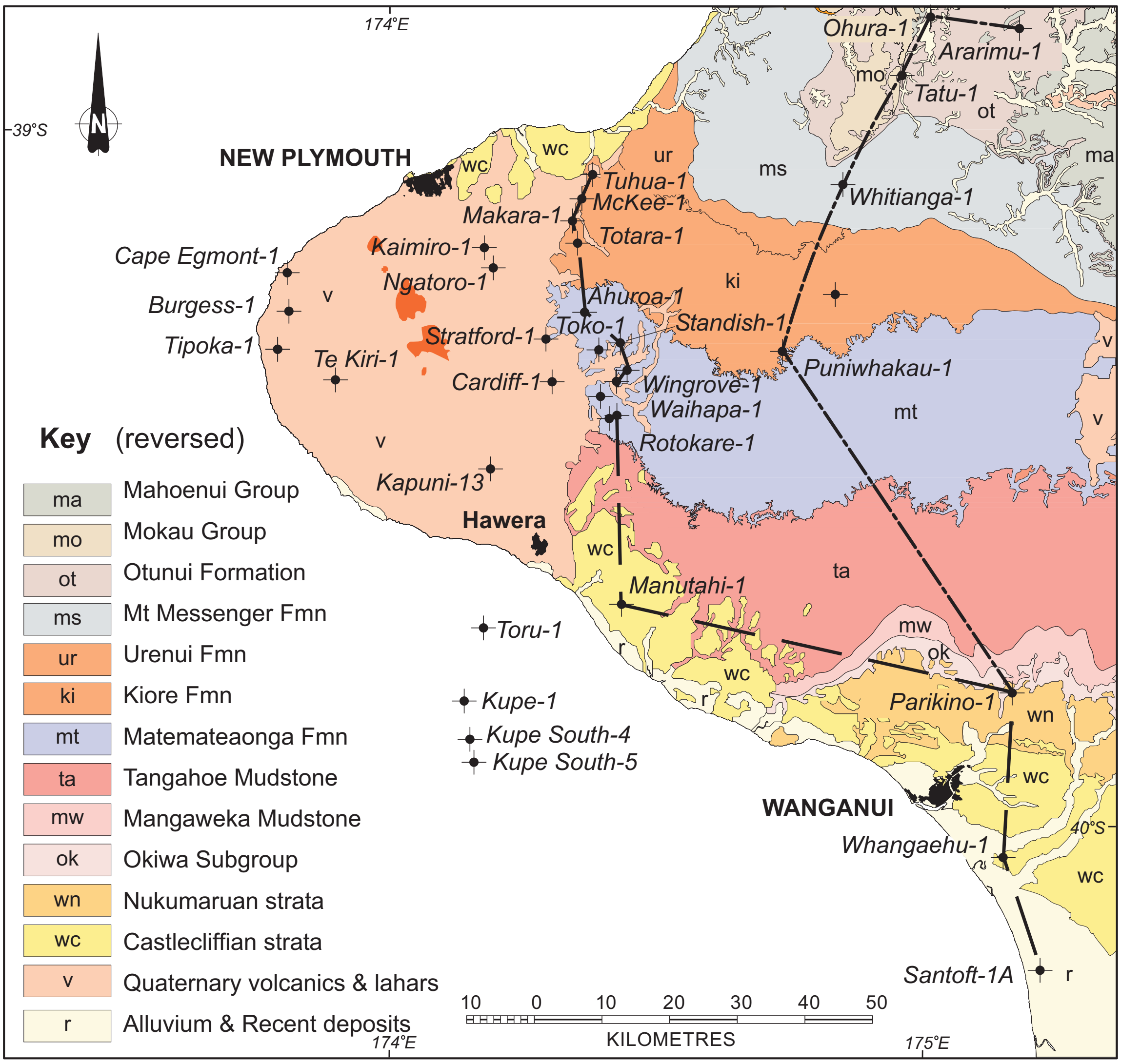


Fig. 5. Geological map of central-western North Island, including Taranaki Peninsula, showing the location of key hydrocarbon exploration holes and the line of two cross-sections illustrated in Fig. 6 & 7. Modified from Kamp et al. 2004 (Fig. 5).

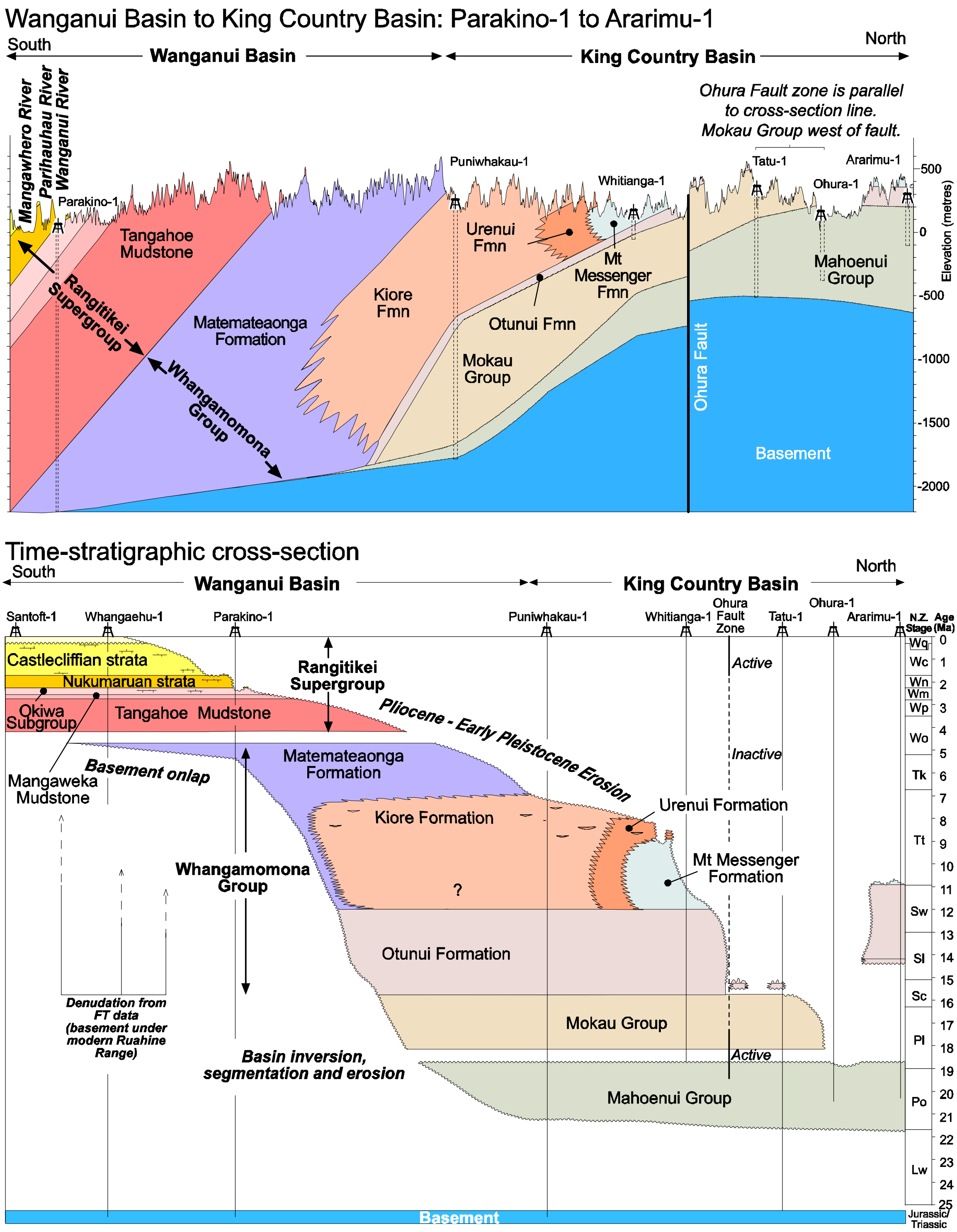


Fig. 6. Wanganui Basin to King Country Basin (Parakino-1 to Ararimu-1) stratigraphic panel built up from well-to-well correlations, and related time-stratigraphic cross-section. The timing of denudation of basement underlying the present Ruahine Range, determined from apatite fission track analysis, is also shown. From Kamp et al. 2004 (Fig. 6).

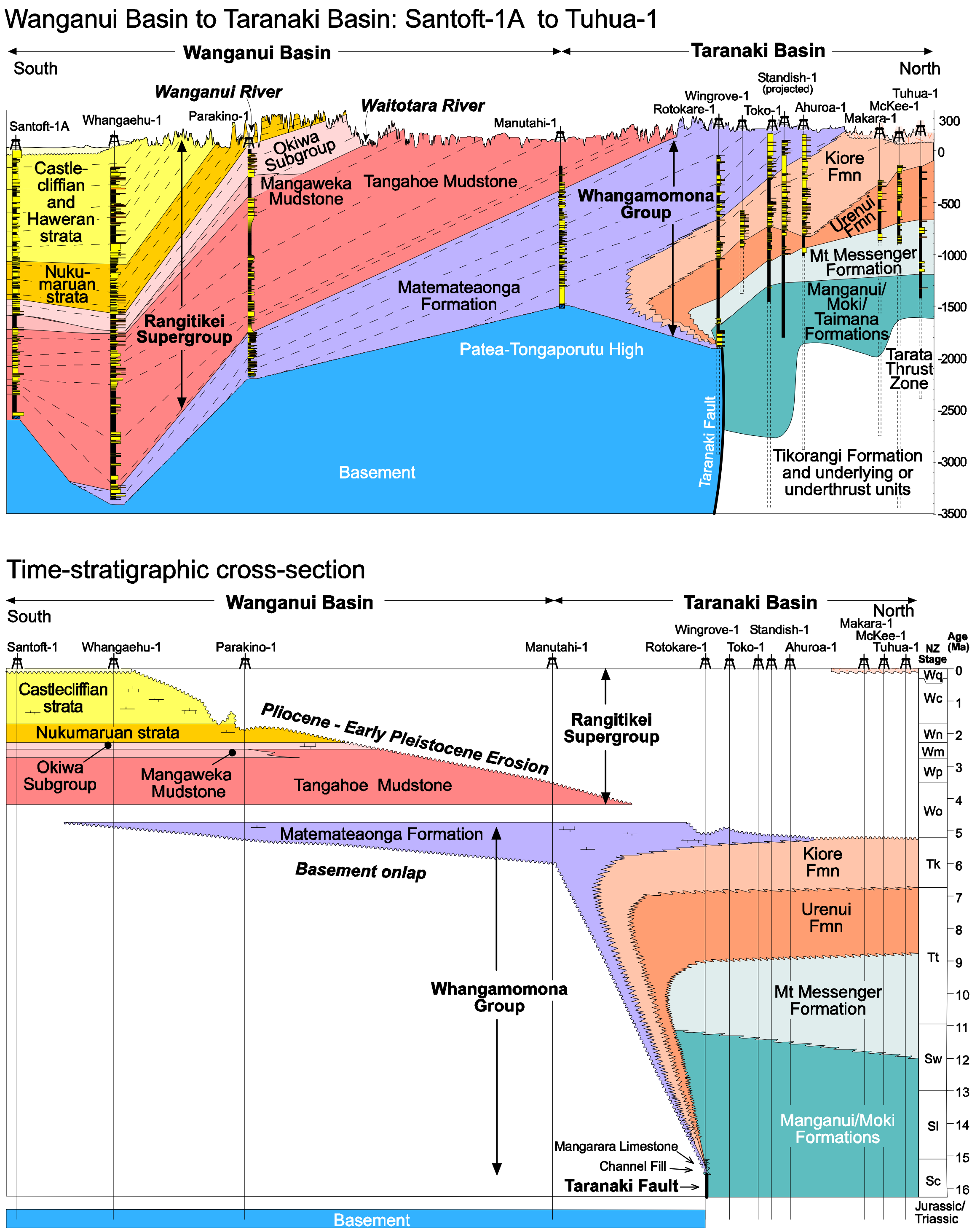


Fig. 7. Wanganui Basin to Taranaki Basin (Santoft-1A to Tuhua-1) stratigraphic panel built up from well-to-well correlations, and related time-stratigraphic cross-section. From Kamp et al. 2004 (Fig. 7).

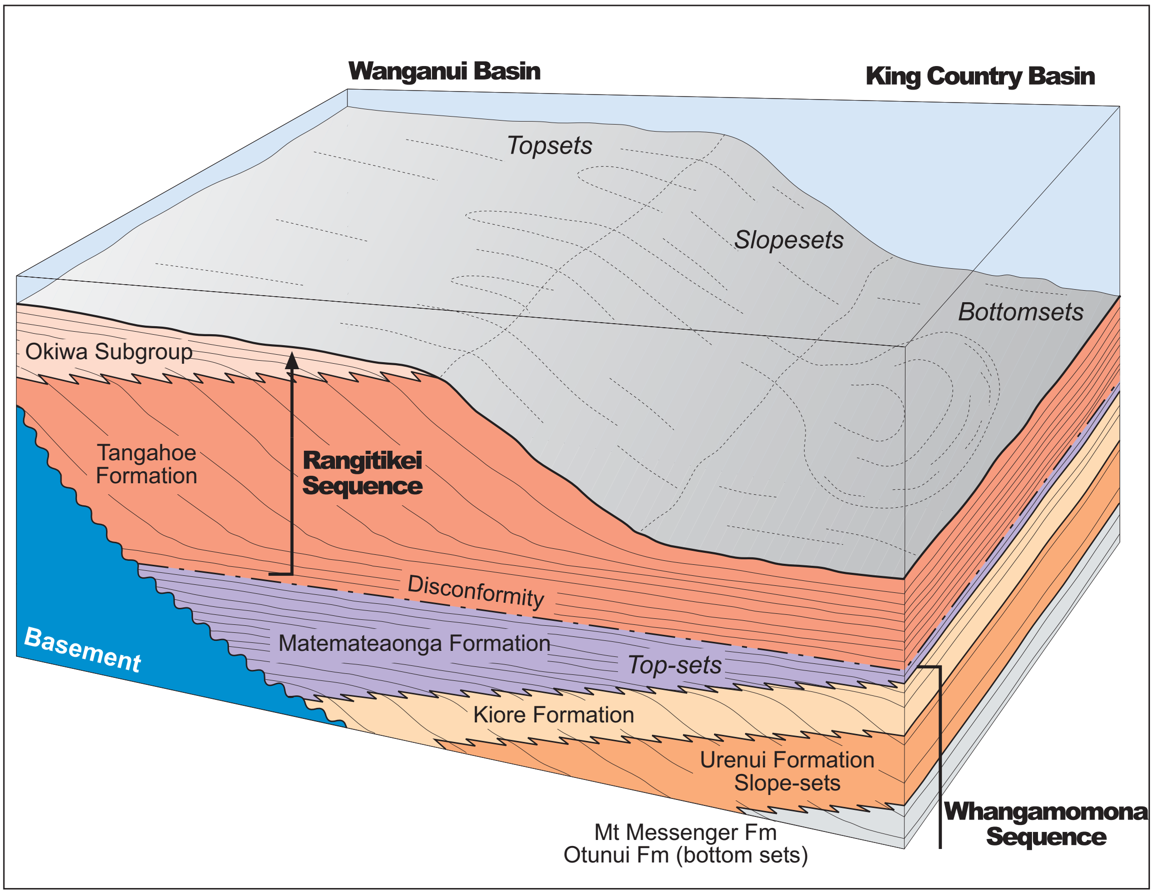


Fig. 8. Block diagram showing schematically the occurrence of two continental margin wedges representing the Whangamomona and Rangitikei Sequences, each having prograded northward through central-western North Island during the late Neogene. North is to the right. From Kamp et al. 2004 (Fig. 10).

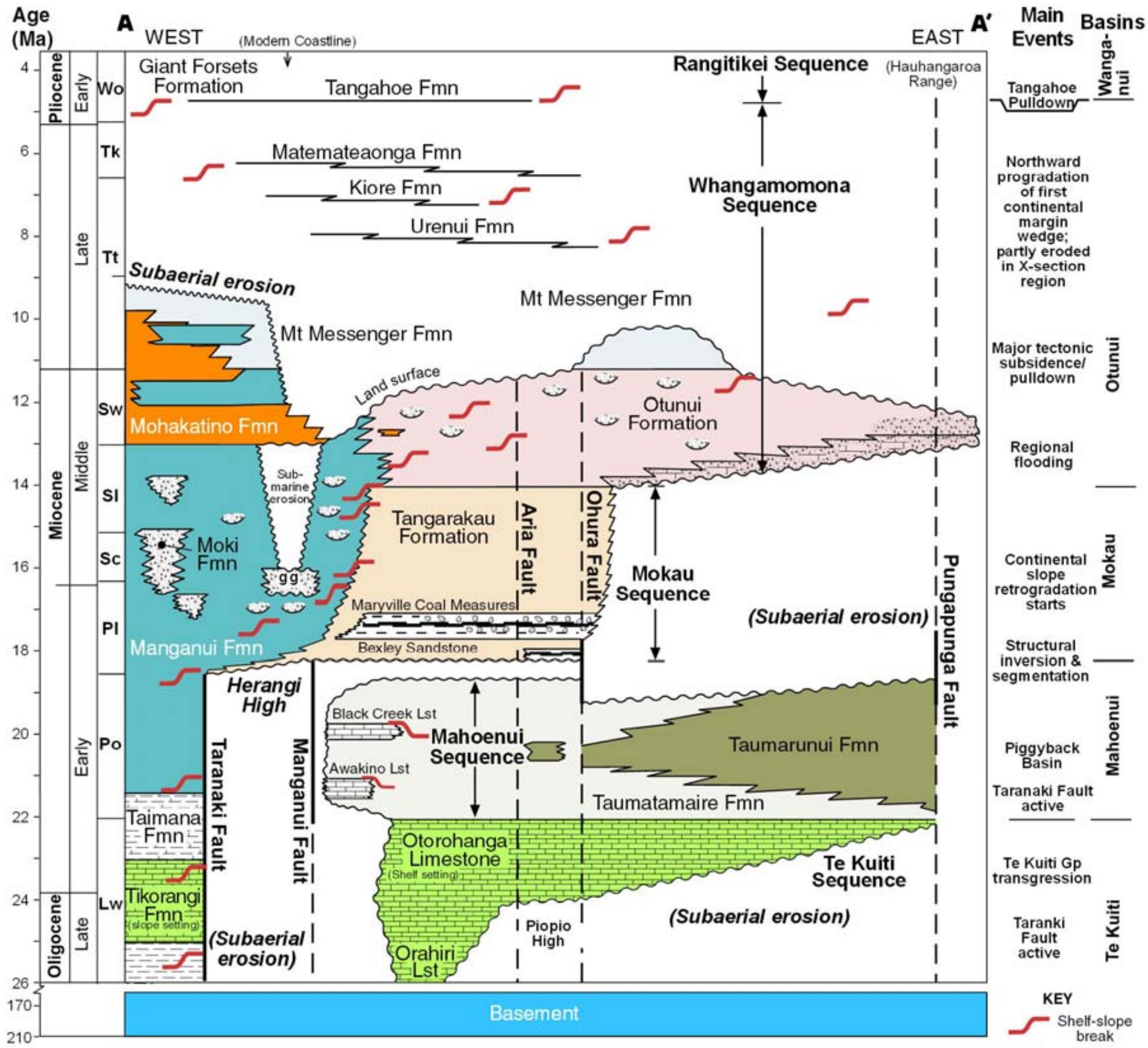


Fig. 9. Chronostratigraphic panel representing the relationship between formations and 2nd order sequences of Cenozoic age cropping out in a cross-section between Awakino Heads in eastern Taranaki Basin and Waitui Saddle on the Hauhungaroa Range along the eastern margin of the King Country region (line of section A-A'on Fig. 1). "g" represents occurrence of glauconite. Depocentres within the King Country and Wanganui Basins are noted on the right. Modified from Kamp et al. 2004 (Fig. 11).

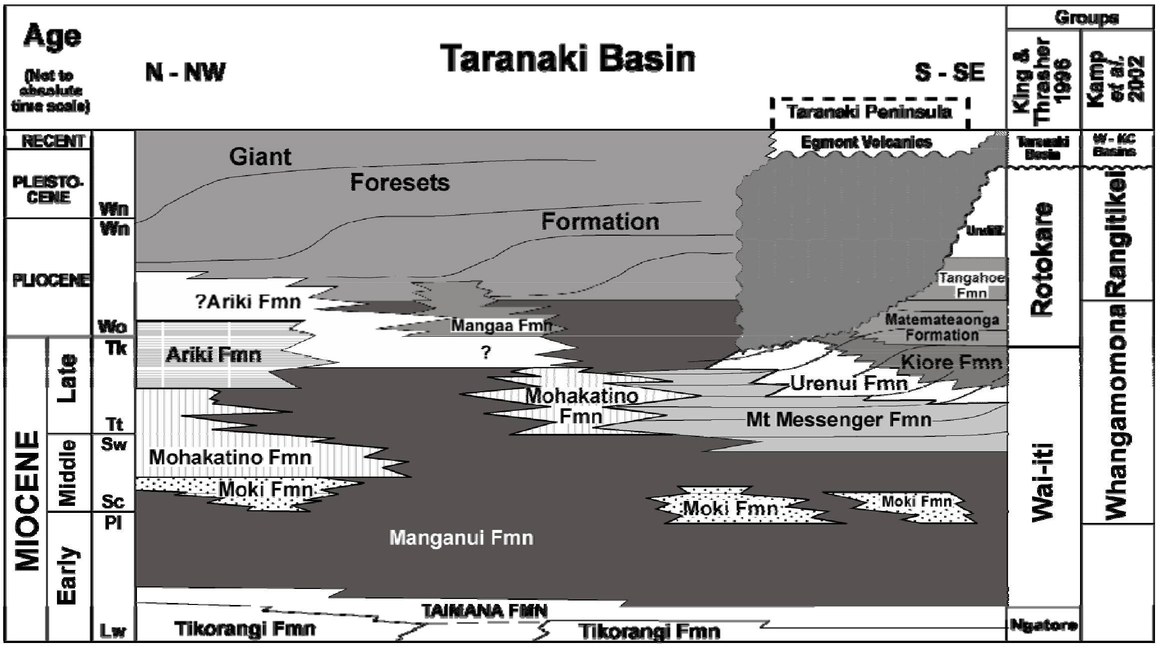


Fig. 10. Simplified Neogene stratigraphic nomenclature for Taranaki basin modified from King & Thrasher (1996) in Hansen & Kamp (2004, Fig. 2)). The Whangamomona Group is a name for a unit in the King Country region; its base is shown approximately.

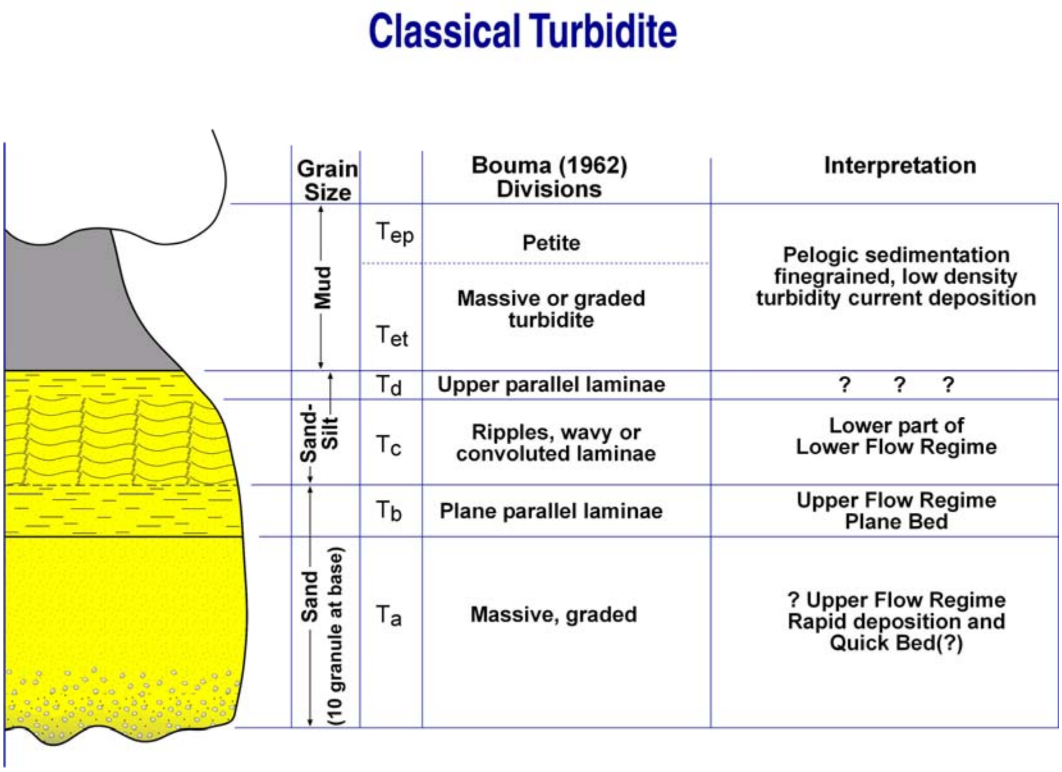


Fig. 11. Sketch of the features of a classical turbidite.

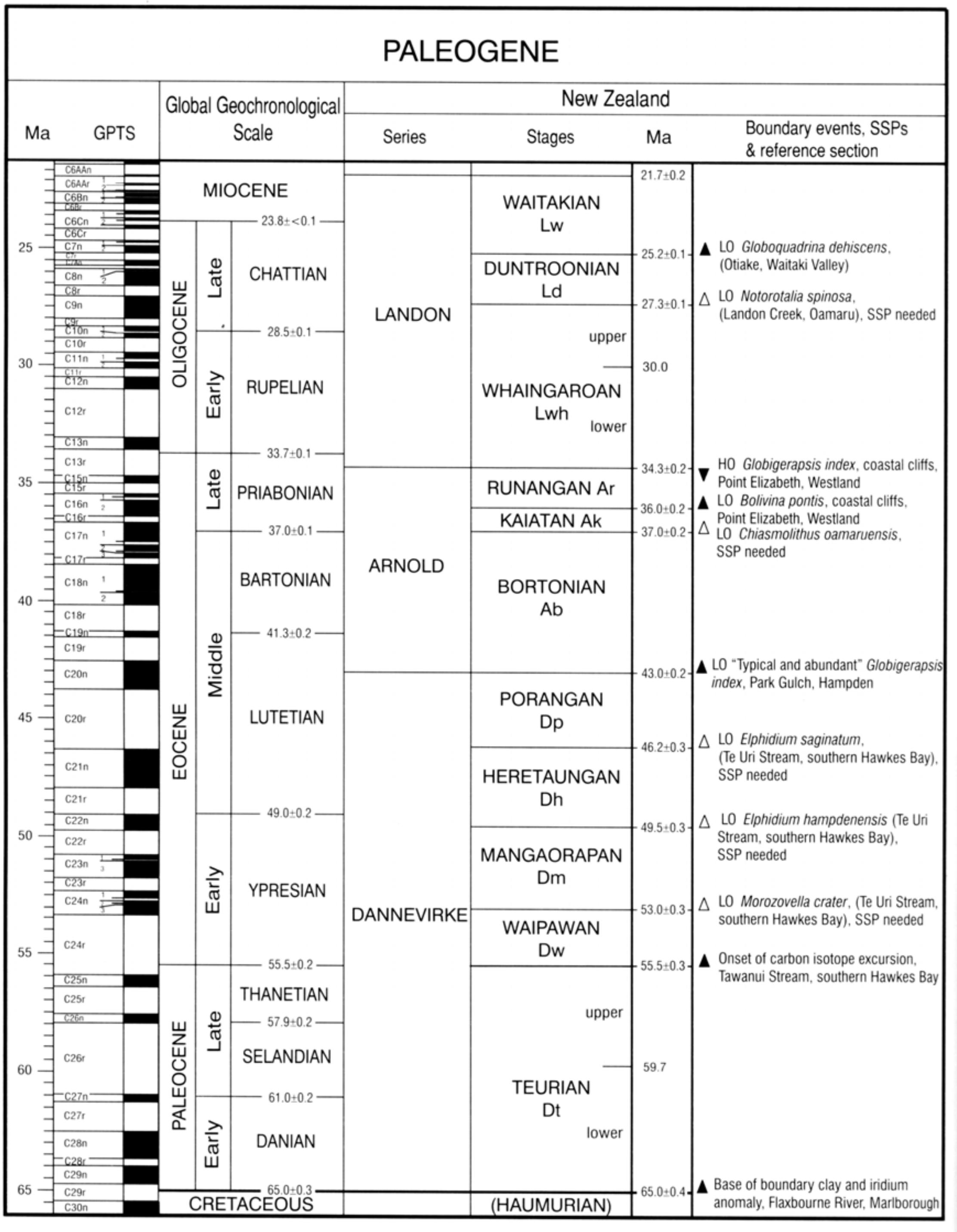


Fig.12a. Paleogene Time Scale showing the age of New Zealand Stages. From H.E. Morgans et al. (Fig. 11.1) in Cooper (ed.) (2004).

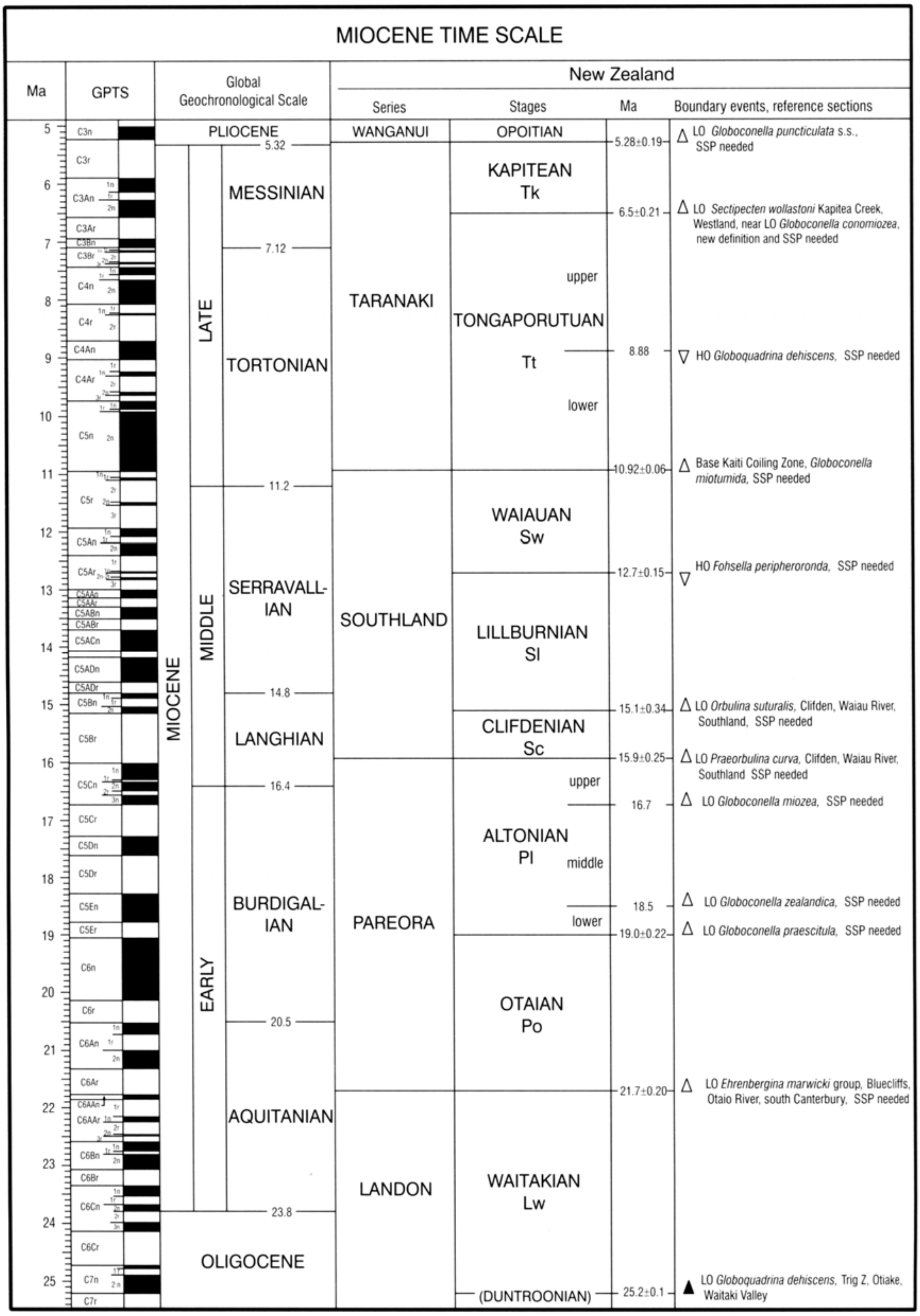


Fig.12b. Neogene Time Scale showing the age of New Zealand Stages. From M.P. Crundwell et al. (Fig. 12.1) in Cooper (ed.) (2004).

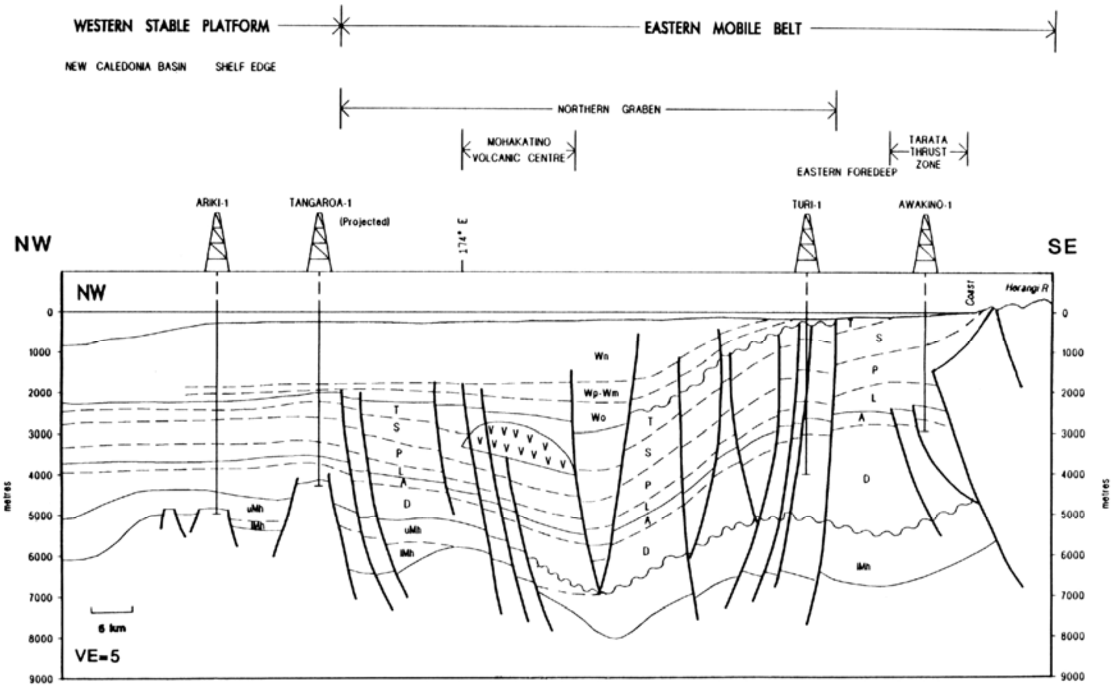


Fig 13. NW-SE structural cross-section intersecting the coastline 8 km north of Awakino, and extending across the Northern Graben to the edge of the continental shelf. Note the upward flexure of the Cenozoic succession, which continues onshore, where it is progressively beveled by Pliocene-Pleistocene erosion. From King et al. 1993 (Fig. 8).

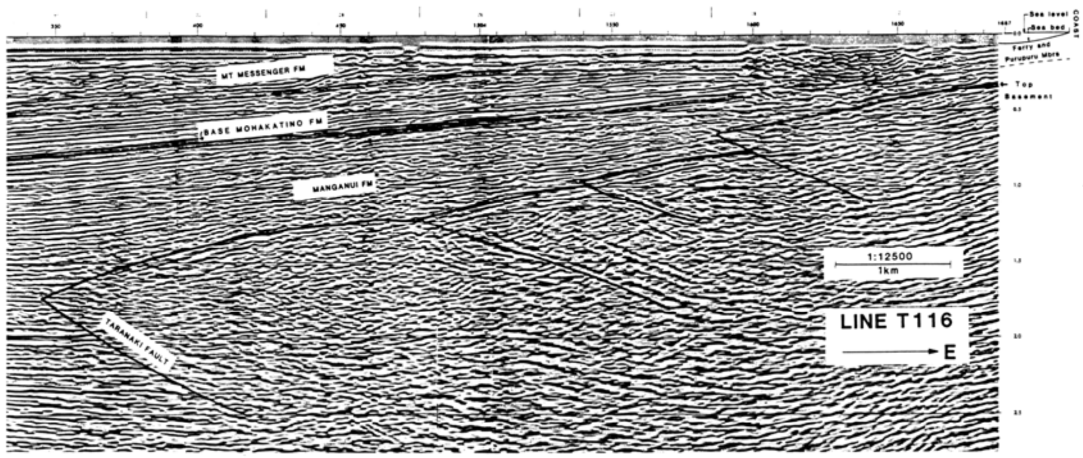


Fig. 14. E-W seismic reflection line T116. The eastern end lies just offshore between the Mohakatino and Tongaporutu River mouths. Vertical axis in seconds TWT. The Manganui, Mohakatino and Mt Messenger Fmns successively overlie the overthrust block east of the Taranaki Fault, representing onlap and foundering of the block during the Miocene. The sediments exposed in the coastal cliffs, and inland, project westward and southwestward into the offshore succession. From King et al. 1993 (Fig. 9)

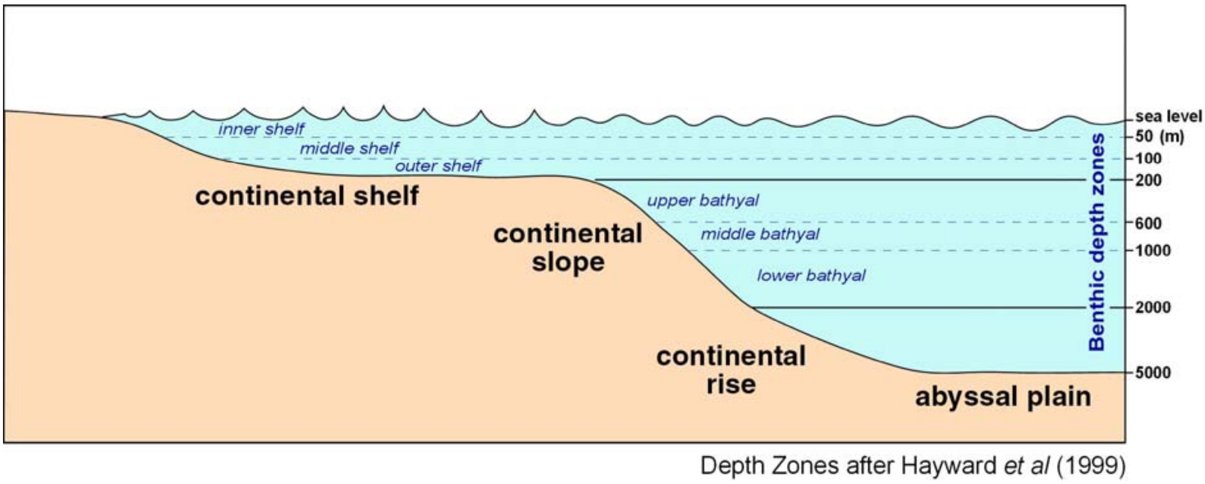


Fig.15. Sketch showing exaggerated "typical" morphology of a passive continental margin, and associated water depth zones of Hayward et al (1999).

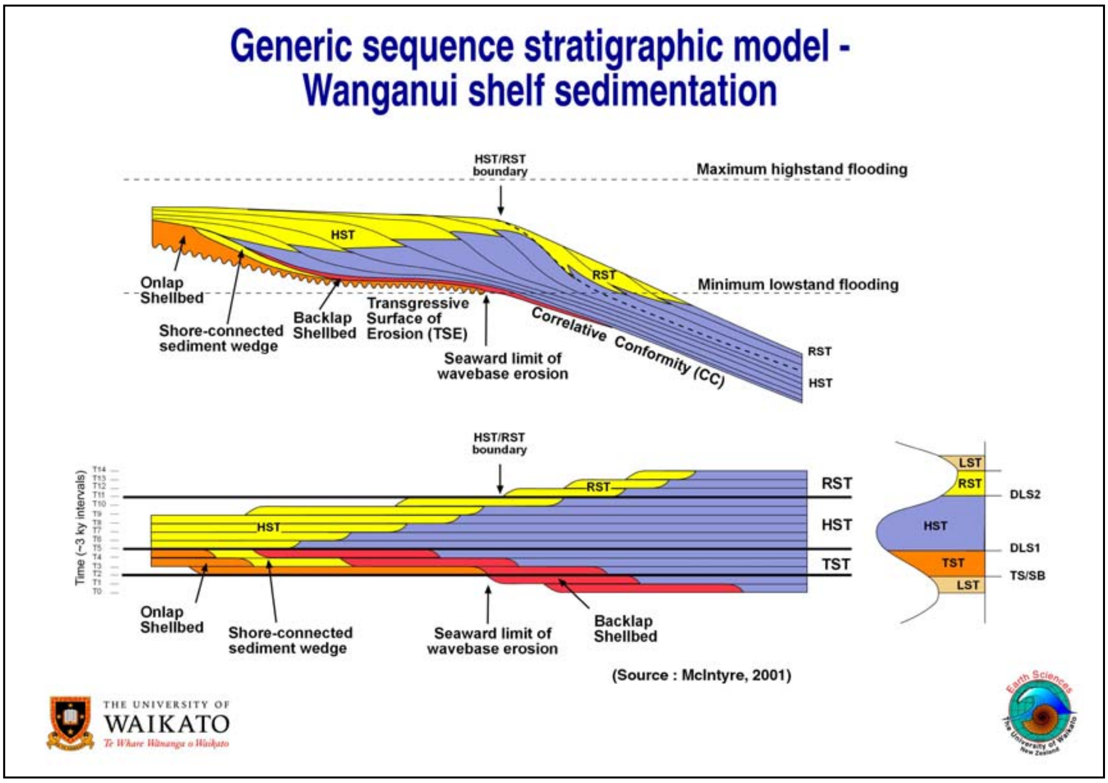


Fig. 16. Sequence stratigraphic model developed from Wanganui Basin shelf sequences by McIntyre (2001) showing the distribution of systems tracts in thickness and time.

Order of Sea-level Changes

Order	Duration	Origin	Amplitude
1st	c. 100 million	Ocean basin volume changes	100 - 300m
2nd	5 - 30 million	Tectonic subsidence megacycles	50 - 100m
3rd	1 - 5 million	Tectonic subsidence cycles	50 - 100m
4th	200 - 600 k.y.	Tectonic subsidence cycles	50 -100m
5th	c. 100 k.y.	Milankovich eccentricity	50 - 135m
6th	41 k.y.	Milankovitch tilt/obliquity	50 - 100m
7th	21 k.y.	Milankovitch precession	0 - 20m

Milankovitch Frequencies

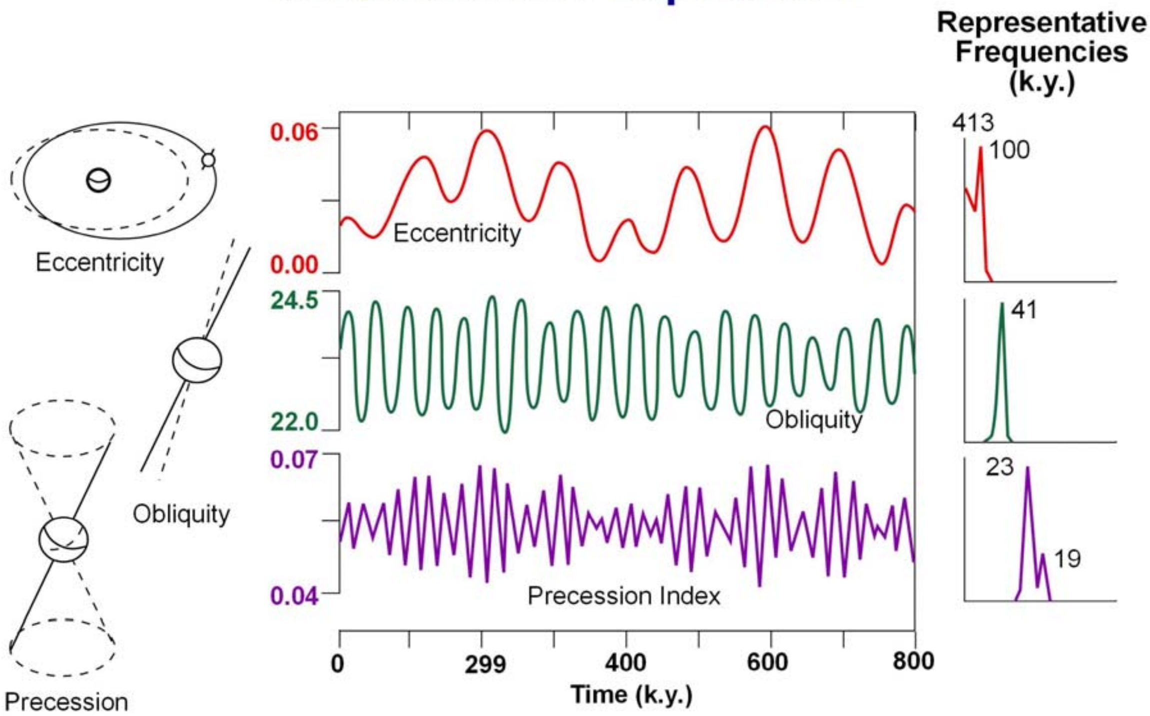


Fig. 17. Orders of sea level change, duration, origin and magnitude, and Milankovitch frequencies and inferred astronomical origins.

PART B –NOTES FOR FIELD SITES

The field guide notes are written for the start of the excursion at Awakino and for it to end at Hawera. See Maps 1-3 for the location of each of the stops.

Themes for each day

DAY 1: *Structural and Stratigraphic expression onshore of late Oligocene – early Miocene basement overthrusting on the Taranaki Fault.*

Stops: 1-10, with accommodation options at Awakino

DAY 2: *Stratigraphic architecture and depositional systems of a middle Miocene retrogradational continental margin, eastern Taranaki Basin.*

Stops 11-21, with accommodation options at Taumarunui

DAY 3 *Stratigraphic architecture below (Mokau Group) and above the Middle Miocene basin flooding (Otunui Fmn & Mt Messenger Fmn), Southern King Country and eastern Taranaki Peninsula*

Stops 22-28, with accommodation options at Taumarunui

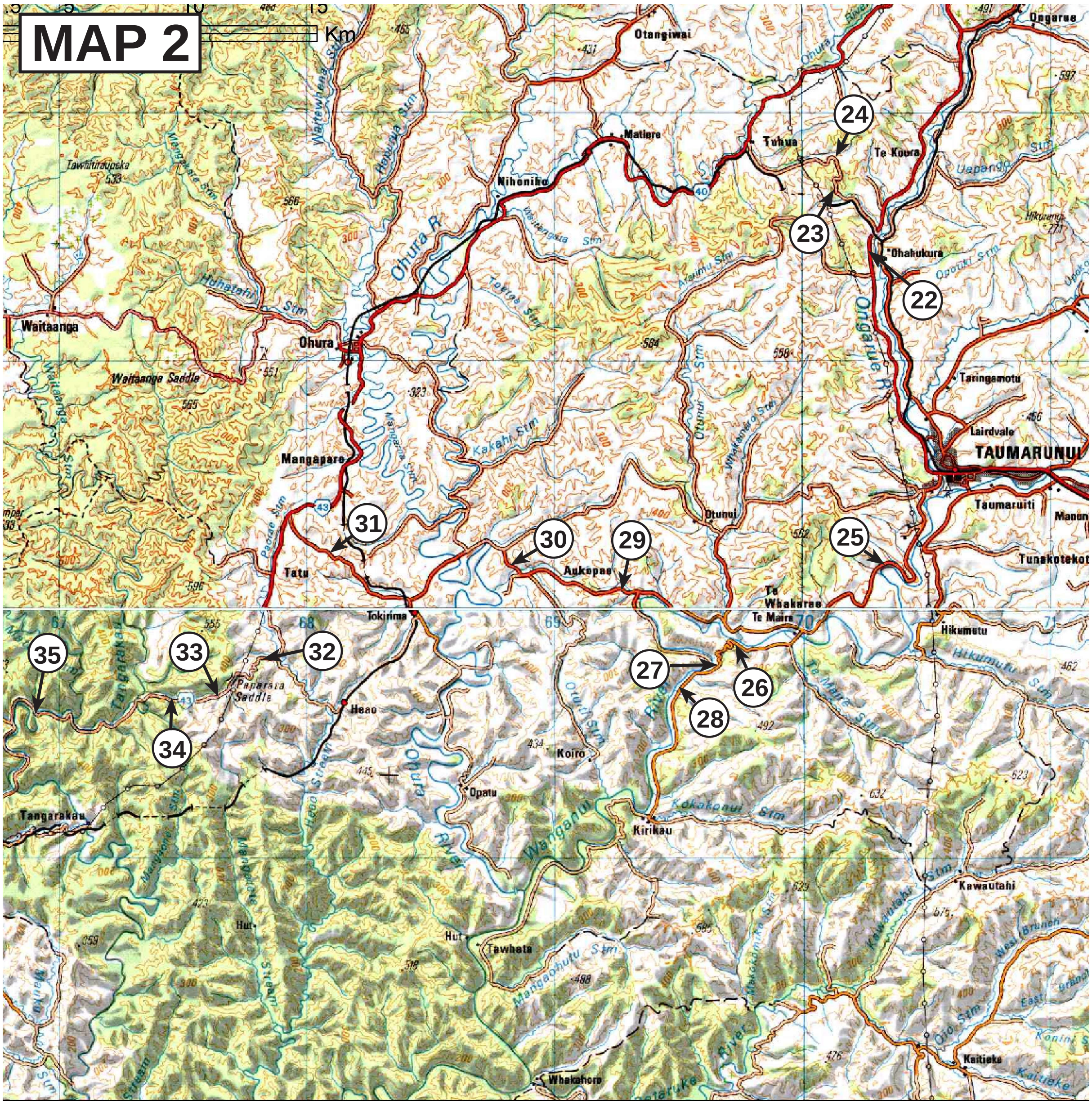
DAY 4 *Stratigraphic architecture below (Mokau Group) and above the Middle Miocene basin flooding (Otunui Fmn & Mt Messenger Fmn), Southern King Country and eastern Taranaki Peninsula*

Stops 29-38, with accommodation at Whangamomona

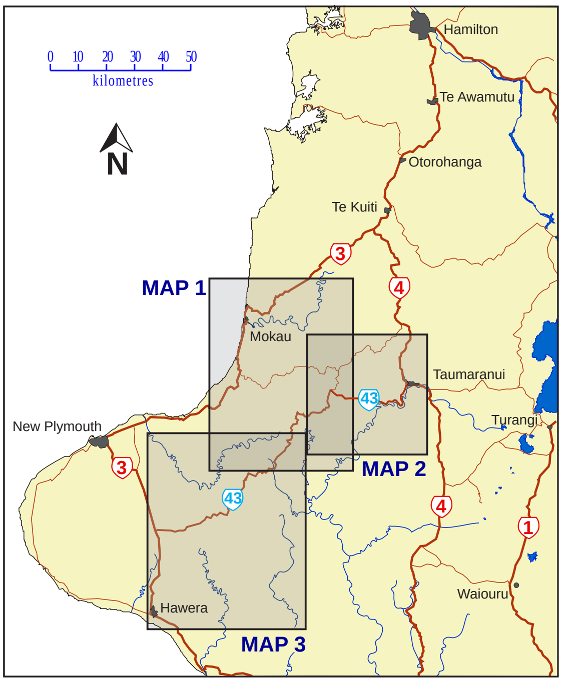
DAY 5 *Stratigraphic architecture and depositional systems of a late Miocene and early Pliocene progradational continental margin, eastern Taranaki Peninsula, with elements of a second progradational system (Tangahoe Fmn)*

Stops 39-51, with accommodation options at Hawera

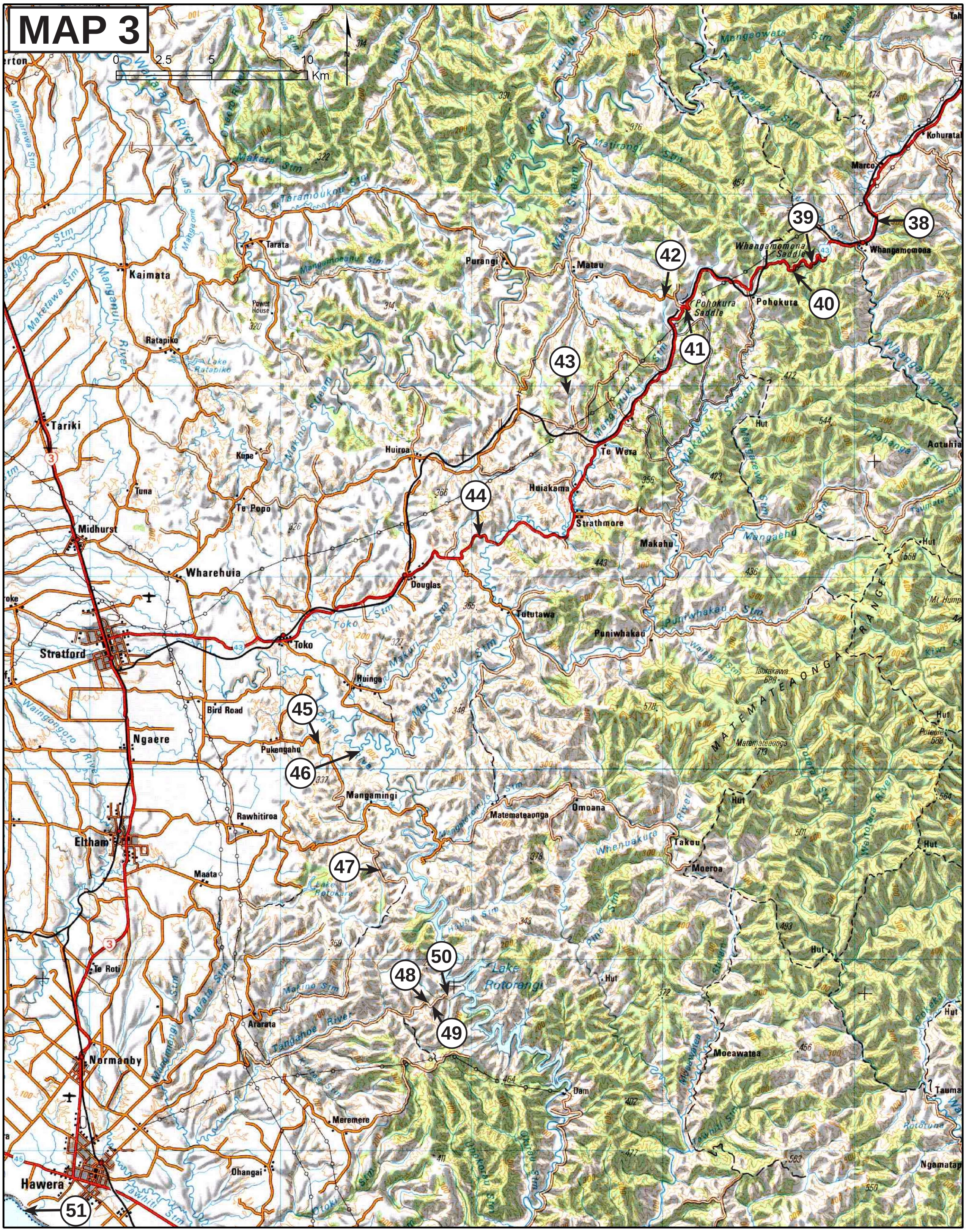
Map 1: Northern Taranaki and King Country, showing route and stops 1 - 20 and 32 - 38



Map 2: King Country, showing route stops 22 - 35



Inset map showing the relative locations of the three route maps



Map 3: Eastern Taranaki, showing route stops 38 - 51

DAY 1: Depart from Awakino and drive about 5 km east via State Highway 3 to the end of Ladies Mile and the start of the Awakino Gorge.

Stop 1. SH3, western end of Awakino Gorge (R17 – 559 800) (Fig. 18)

Examine the Bexley Sandstone resting unconformably on steeply dipping Murihiku Terrane of Late Triassic age, (Warepan Stage, *Monotis richmondiana*). Bexley Sandstone is a transgressive shoreface deposit comprised of well sorted fine sandstone with weakly developed low-angle cross-bedding and fossil casts. It represents eastward-directed marine onlap of basement during the late-early Miocene (Altonian Stage), following cessation of basement overthrusting on the Taranaki and Manganui Faults during the early-early Miocene (Otaian Stage). **Discussion**: this facies is expected to occur offshore on basement as far west as the Taranaki Fault.

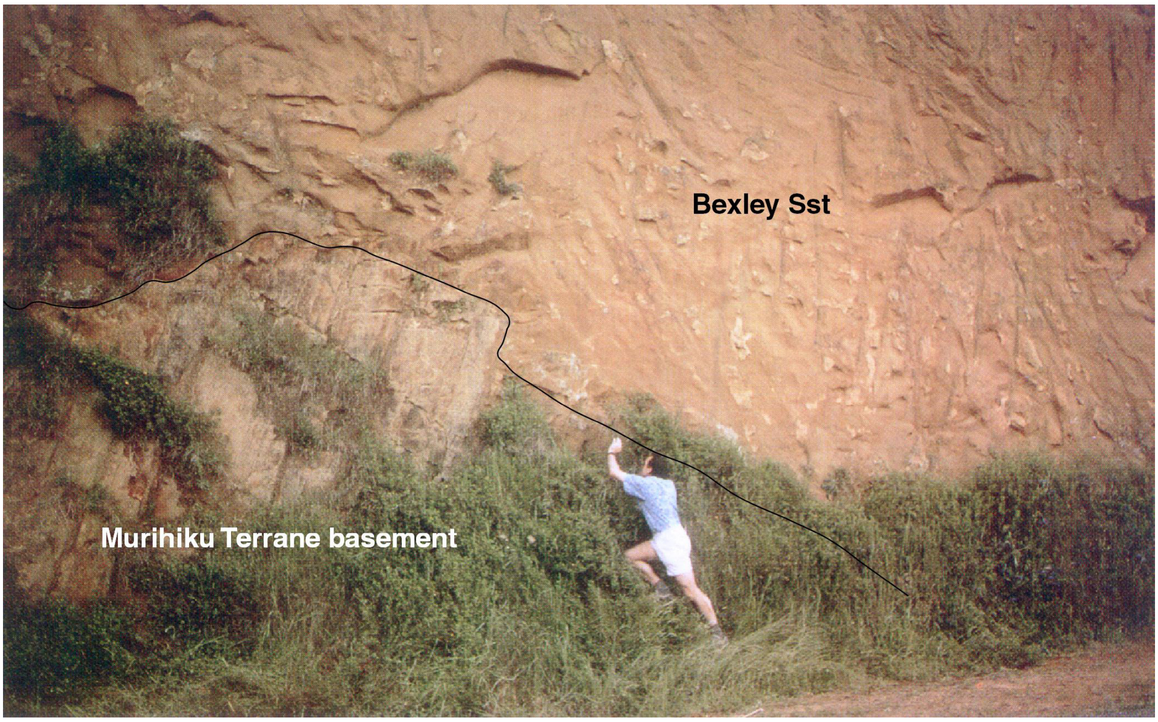


Fig. 18: *Photo of Bexley Sandstone on late Triassic Murihiku Terrane basement at the western end of Awakino Gorge. Stop 1, R17 – 559 800. Photo from King et al. (1993, Plate 2).*

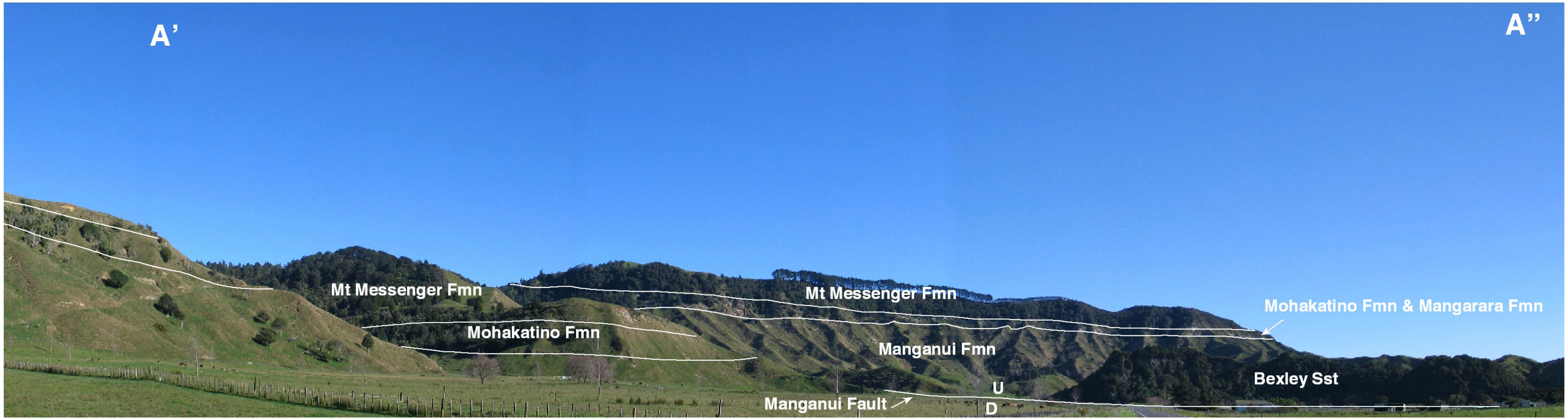
Stop 2. SH3, eastern end of Ladies Mile (R17 – 547 806) (Fig. 19)

Brief stop to view the geological units exposed in the valley sides and the QMAP Waikato Sheet 4 geological map. Note Manganui/Moki Formation in the middle to lower part of the southern hillsides immediately to the left, Mohakatino Fmn (brown volcaniclastic sandstone) forming a prominent buttress high up on the left, and thin Mt Messenger Fmn at the top of hill and beyond. The trace of the Manganui Fault crosses the valley from right to left, upthrown on the west side, bringing a full thickness of Bexley Sandstone into the bluff outcrop at the end of Ladies Mile. In the vicinity of the Awakino Valley Manganui Fault has normal throw of Pliocene-Pleistocene age, a reversal of the sense of early Miocene (Otaian Stage) throw. The prominent hill section at the end of the valley on the south side contains thick (c. 20 m) Mangarara Formation calcareous sandstone and limestone as submarine channel complexes above the upper part of Manganui/Moki Fmn and below Mohakatino Fmn. The Mt Messenger Fmn is immediately below the line of pine trees at the top of the bluff. On the northern side of Awakino Valley the Bexley Sandstone and overlying Manganui Fmn dip southward off the Herangi Range forming dip-slopes.

Note the marked local variation in the thickness of the transgressive Bexley Sandstone, thickening eastward into a fault-angle depression on the footwall side of the reverse Manganui Fault. Note also the virtually continuous Altonian – Tongaporutuan section that dips obliquely offshore into Taranaki Basin, which thickens in that direction as the degree of Plio-Pleistocene erosion reduces to the west. Plio-Pleistocene displacement on the Manganui Fault is part of an extensional fault system between the Northern Graben and the Taupo Volcanic Zone.

Fig. 19 (facing): *Photo panorama split into two segments (A-A' and A'-A") looking east to west at the hills on the southern side of Ladies Mile, lower Awakino Valley. Stop 2, R17 – 547 806.*


A
A’
Mt Messenger Fmn
Mohakatino Fmn
Manganui Fmn
Mt Messenger Fmn
Mohakatino Fmn
Manganui Fmn


A’
A”
Mt Messenger Fmn
Mohakatino Fmn
Mt Messenger Fmn
Manganui Fmn
Mohakatino Fmn & Mangarara Fmn
Bexley Sst
Manganui Fault
U
D

Stop 3. Taumatamaire Road past disused airstrip (R17- 595 840) (Figs 20 & 21)

From this site on Taumatamarie Road a few hundred metres east of Telecom tower there is a clear view eastward from the southern part of the Herangi Range and across Oligocene Te Kuiti Group and early Miocene (Otaian) Mahoenui Group units that onlap the basement one is standing on. We also get a good distant view into the bush-clad tiger country of the King Country region, underlain by variably eroded Altonian-Tongaporutuan formations that were formerly continuous with the Taranaki Basin succession.

The three Te Kuiti Gp formations (Whaingaroa, Aotea and Orahiri Fmns) dip at 33 degrees ESE (Aotea-Orahiri contact) to possibly 35-40 degrees ESE within the Aotea and Whaingaroa Fmns (Figs 21 & 22). This may indicate subtle synsedimentary tilting during the mid to late Oligocene. The basement dips at 45 degrees ESE, so locally the Kawhia Syncline has had significant Neogene deformation. Awakino Tunnel is formed in Orahiri Limestone.

Discussion points on the Te Kuiti Gp: Lithologies and paleoenvironments of the lower Te Kuiti Gp suggest a seaway across this area and into Taranaki Basin, whereas the upper Te Kuiti Group units suggest structural mobility of the Herangi High associated with reverse movement on the Manganui Fault. The Aotea Fmn (Hauturu Sandstone Mbr) has an exotic basement provenance (quartz rich) and suggests longshore transport from the south hinged to a shoreline along the east of an emergent Herangi high uplifted on the Manganui Fault.

There is a subtle but important angular unconformity of c.15 degrees between the Orahiri Limestone and the Mahoenui Group (Taumatamaire Fmn), representing an earliest Miocene interval of erosion and beveling of the Te Kuiti Gp, followed by subsidence and onlap, such that the Mahoenui Gp overstepped the Te Kuiti Gp onto basement at higher elevations on the structural high (Fig. 23). Marked synsedimentary tilting occurred on the flanks of the high through the accumulation of the Mahoenui Gp (Otaian Stage), resulting in a fanning of dips ranging from 20-5 degrees) (Figs 21 & 23). The rate of tilting slowed into the Altonian Stage during accumulation of the Bexley Sandstone, but its continuation is evidenced by the overstepping of Bexley Sandstone onto basement west of the most western extent of the Mahoenui Gp beds (see geological map, Fig. 26).

Discussion points on Mahoenui Gp: There was marked basin margin generation of accommodation during the early Miocene (Otaian) as indicated by synsedimentary tilting, caused by reverse movement on the Manganui Fault. Concurrent relative sea-level movements resulted in the formation of narrow progradational carbonate shelves separated by hemipelagic mudstone. Awakino and Black Creek Limestone Members may be Transgressive Systems Tracts. The Bexley Sandstone locally has a Murihiku basement provenance.

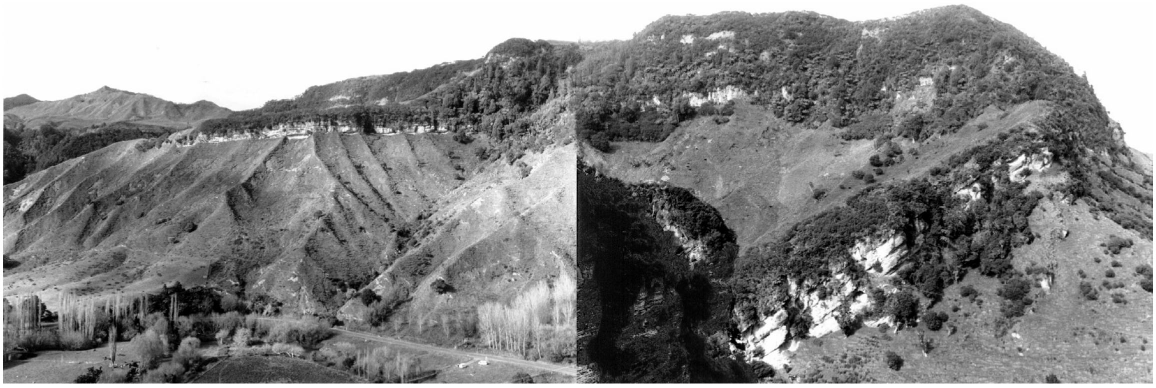


Fig. 20: *Photo composite of the section exposed on the southern side of the Awakino Tunnel, eastern end of Awakino Gorge. Fig. 21 shows the wider geological setting of this photo, and inset, its extent and the stratigraphic nomenclature. From Kamp et al. 2004, (Fig. 11).*

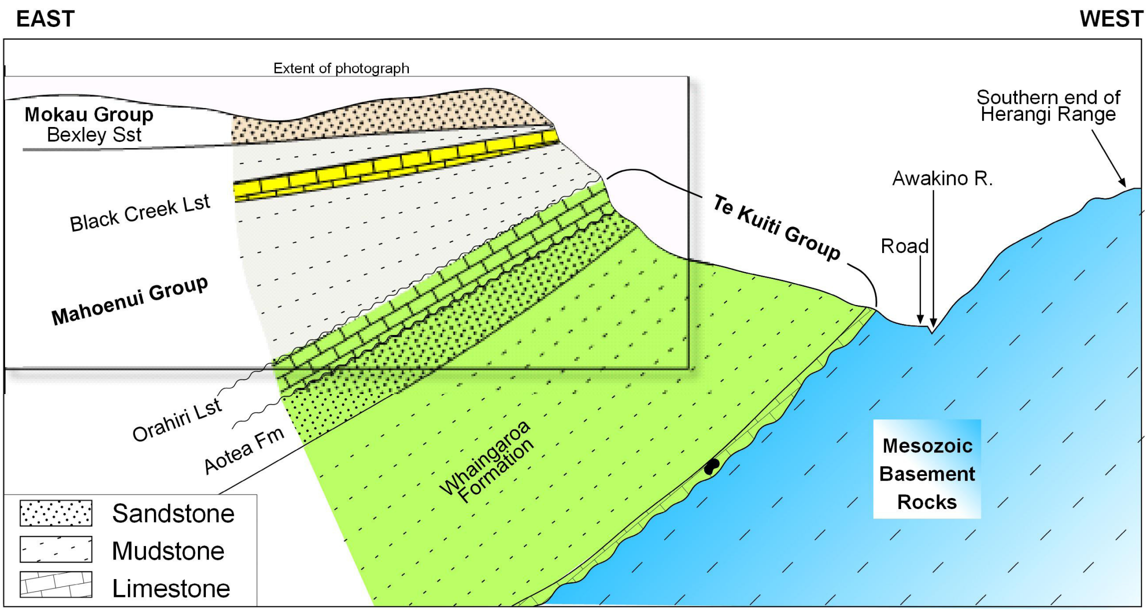


Fig. 21: *Sketch illustrating the stratigraphy and structure of the Te Kuiti, Mahoenui Group, and Mokau Group in relation to basement for the eastern end of Awakino Gorge. The inset box shows the approximate extent of the photo composite illustrated in Fig. 20. From Kamp et al. 2004, (Fig. 12). Stop 3, R17- 595 840.*

Stop 4. Taumatamaire Road, Awakino Limestone, and track to ridge (R17- 611 876) (Figs 22 - 26)

At this site, examine the 20 m-thick Awakino Limestone Member next to the road, which rests on basement. This is a well-cemented bioclastic conglomeratic limestone with angular greywacke pebbles and a marked content of calcareous red algae, mostly as broken fragments but sometimes as rhodoliths. The carbonate components are transported from the places where they formed, possibly a rocky shoreline a few hundred metres to the west and on the basement block rotated and uplifted as a result of reverse movement on the Manganui Fault. The limestone formed on a narrow continental shelf, it accumulated as a carbonate apron over a very limited area on the southeastern flank of the Herangi High, and post-depositional channels at the base of the Bexley Sandstone have completely eroded Awakino Limestone Mbr in places.

Discussion: There may be age equivalents (Otaian) of the Awakino Limestone Mbr distributed offshore around the edge of the overthrust basement block-Taranaki Fault. The Tikorangi Formation (limestone) in Taranaki Peninsula may be another example of this setting of carbonate production, composition and distribution but of an older age (Figs 24 & 25). Note the degree of induration, dissolution along flag-seam boundaries, and cementation of Awakino Limestone. There has been about 1200 m of burial (Fig. 4) by younger deposits (Altonian/Opoitian), which will have driven the burial and diagenesis of Awakino Limestone Mbr.

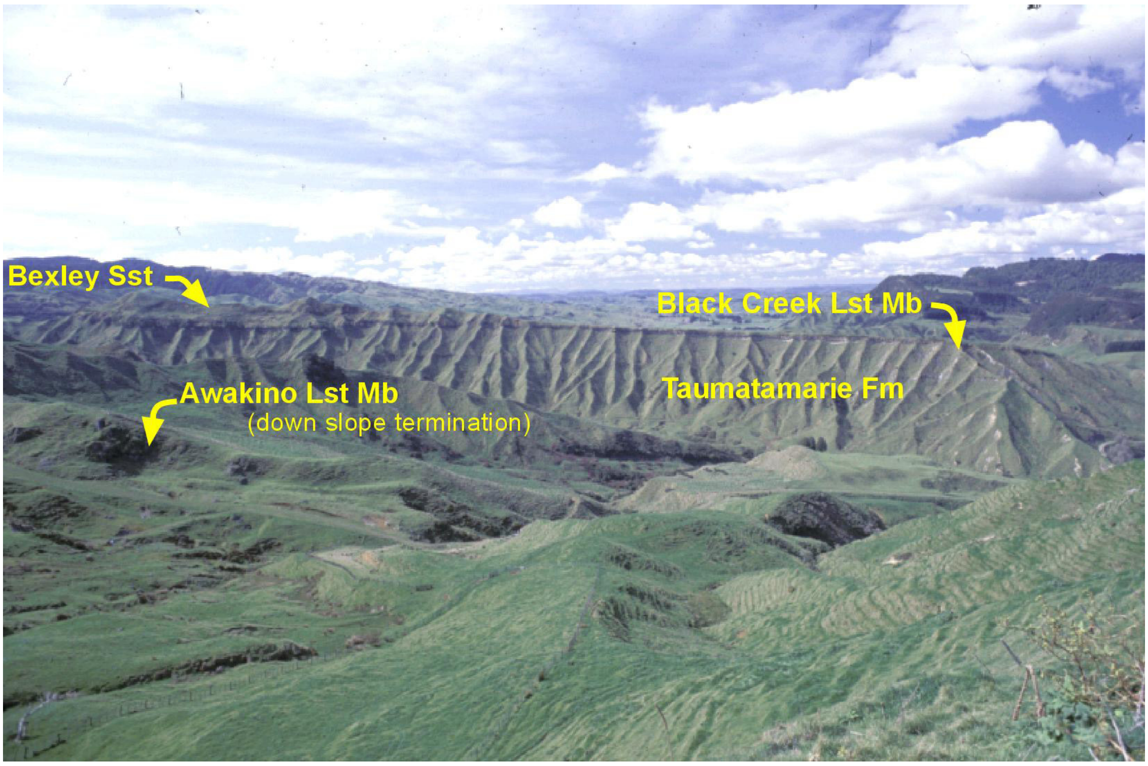


Fig. 22: *Photo view from the ridge east of Taumatamaire Road, southern Herangi Range, looking towards the southeast in land to northern King Country, prior to this area being planted in pine trees. Fig. 23 illustrates the stratigraphy and structure. From Kamp et al. 2004, (Fig. 14). Stop 3, R17- 595 840.*

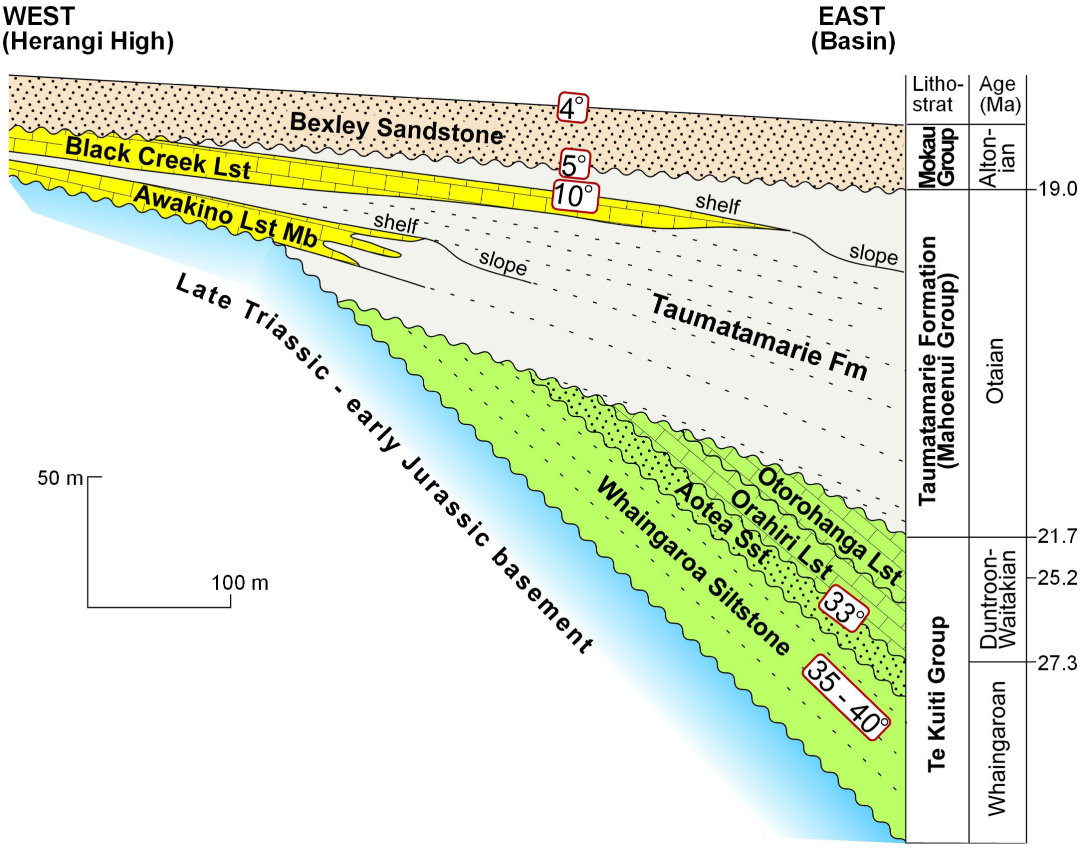


Fig. 23: *Sketch illustrating the stratigraphy and structure of the Te Kuiti Group, Mahoenui Group, and Mokau Group in relation to basement for the area in the view in Fig. 22. From Kamp et al. 2004, (Fig. 13). Stop 3, R17- 595 840.*

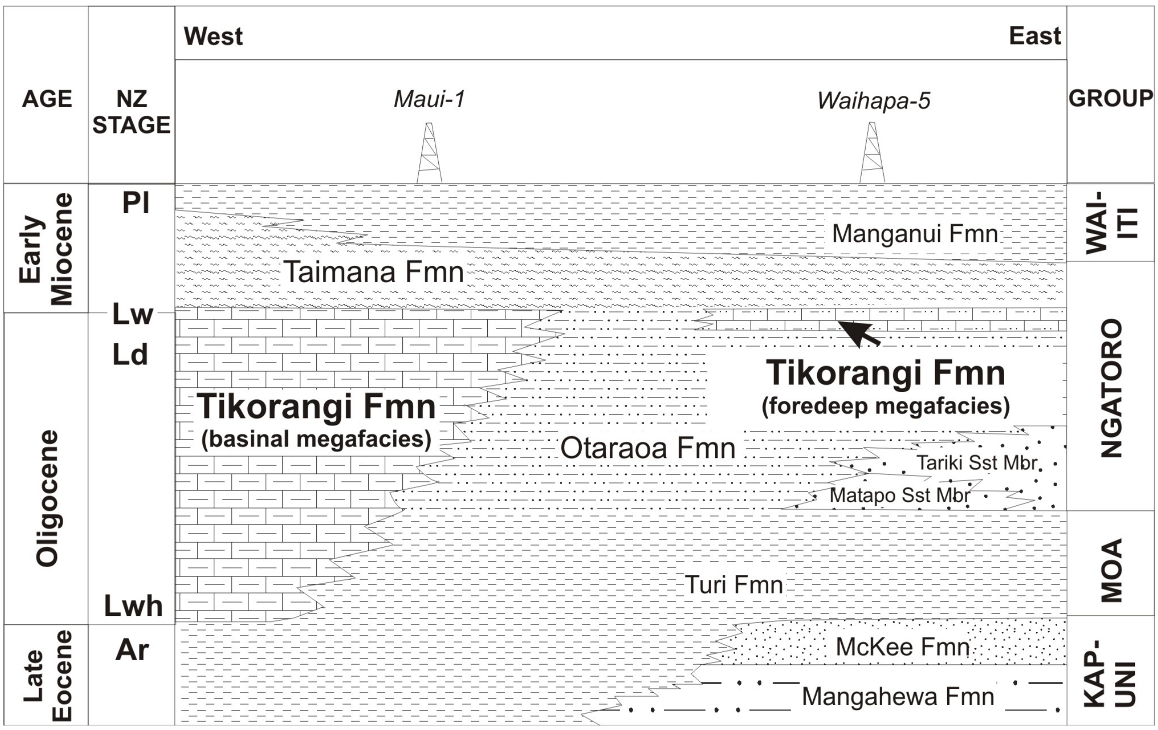


Fig. 24: *Stratigraphy of part of Taranaki Basin fill. From Hood et al. 2003 (Fig. 2).*

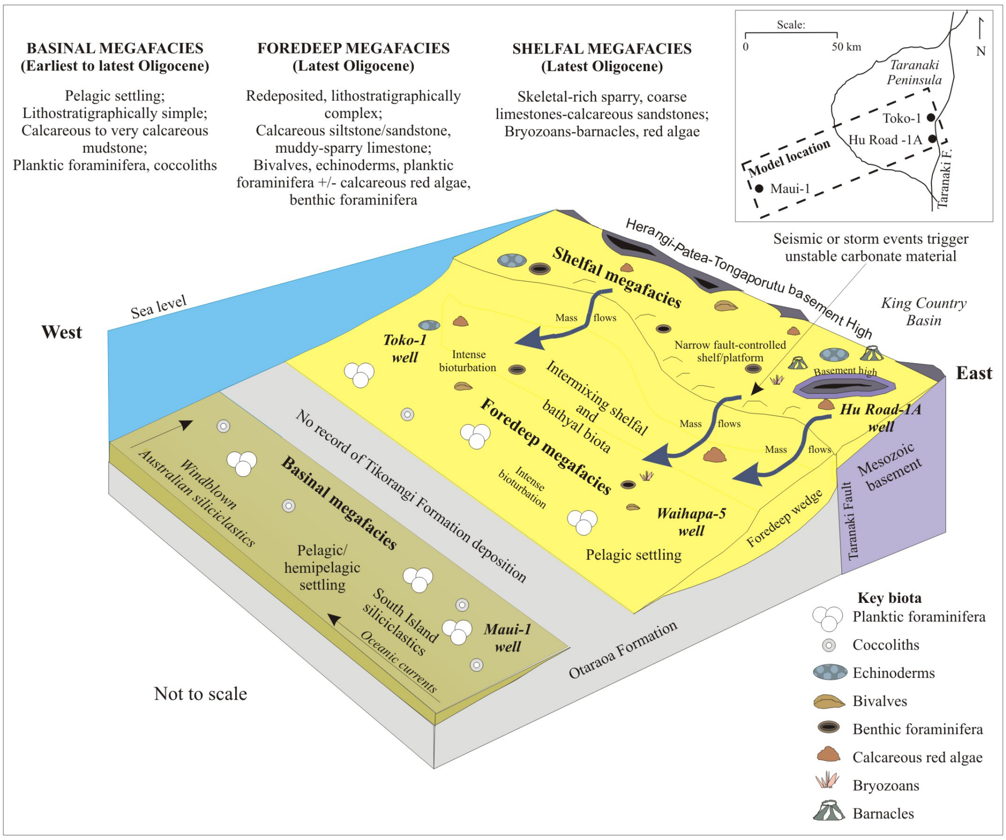


Fig. 25: *Sketch summarizing sedimentology and depositional model for the Tikorangi Fmn, eastern Taranaki Basin. From Hood et al. 2004 (Fig. 3).*

With permission from Greenplan Forestry (Te Kuiti) one could walk up the track from the road to the ridge top through the *Pinus radiata* forest. The view (Fig. 22) is one to the ESE, down dip, as well as down the early Miocene (Otaian) paleoslope. On the ridge, one is standing on or about the base of the Black Creek Limestone Mbr, which forms a prominent dipslope facing away on the opposite side of the valley. The "depositional" termination of the shelfal Awakino Limestone Mbr lies about half way across the valley. This enables one to appreciate the style and degree of accommodation (for sediments) that was generated east of the hingeline during the Otaian by rotation of the basement block about the Manganui Fault (Fig. 26, map and x-section). The Mahoenui Gp/Taumatamaire Fmn has a minimum thickness of 120 m at the scarp, whereas behind us west of the road, this unit is c. 20 m thick. This rate of eastward increase in accommodation must flatten out into the Mahoenui depocentre. Calcareous turbidites form the thin bedding lines in the valley scarp. One can also appreciate from this locality that despite the rate of generation of accommodation, the narrow lowstand shelf represented by the successive limestone members progressively extended farther out into the basin, thereby widening the shelf. At the end of Mahoenui Gp accumulation, lowstand conditions led to fluvial incision along the basin margin. The channels were infilled with conglomerate (incised valley fill) and followed by the accumulation of shoreface sandstone (Bexley Sandstone). Concurrently, the Bexley Sandstone transgressed from the west, and the whole of the southern end of the Herangi High was probably buried, reflecting the end of crustal shortening across the eastern margin of Taranaki Basin in the vicinity of Awakino and to the north.

Discussion: Te Kuiti Gp (Oligocene) and Mahoenui Gp (Otaian age) are now restricted to the eastern side of the Herangi Range, which bears on the mechanism of by which the accommodation was generated. In Fig. 26 note the map extent of these groups in relation the position of the Manganui Fault. Envisage the bottomsets, slopesets and topsets of the Whangamomona Group (Lillburnian-Opoitian section) prograding northward across this area, concurrent with submergence of the Herangi High.

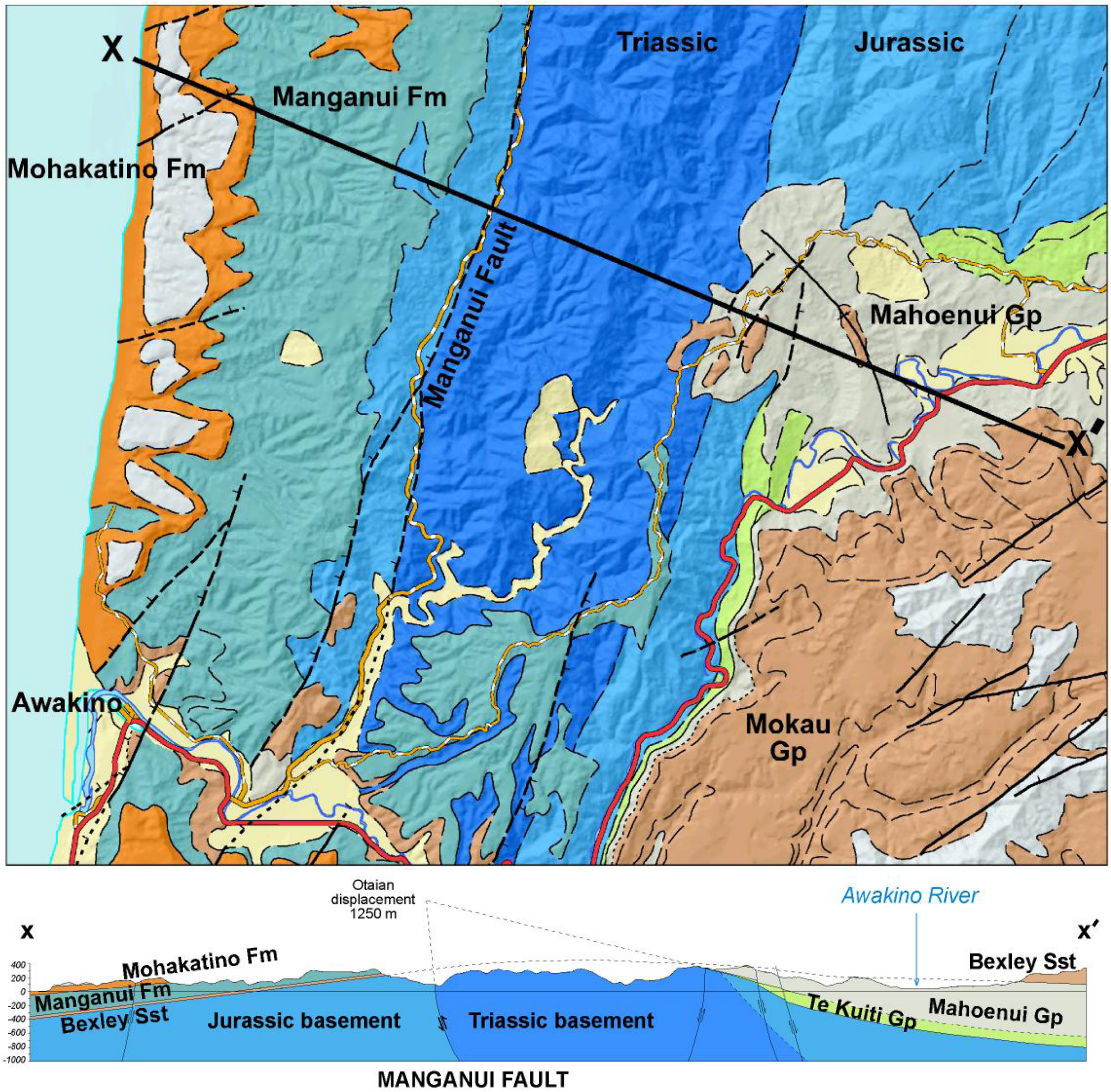


Fig. 26: *Geological map and cross-section of the southern end of the Herangi Range. Source of map: S. Edbrooke (compiler) Institute of Geological and Nuclear Sciences, 1:250 000 Waikato Sheet, 2004.*

Stop 5. SH3, east of Awakino Tunnel (R17- 618 853)

Stop to view the prominent dipslope developed on the Orahiri Limestone at the top of the Te Kuiti Gp. The Otorohanga Limestone (Waitakian Stage, latest Oligocene – earliest Miocene), widespread elsewhere in the northern King Country, is not present here, possibly due to erosion during the early Miocene, reflecting initial uplift due to crustal shortening. This is consistent with a decrease in sedimentation rate upwards through the Te Kuiti Gp (70 mm/y, Whaingaroa Fmn; 12.5 mm/y, Aotea Fmn; 8.5 mm/y Orahiri Limestone; Nelson et al. 1994), and the angular unconformity of c. 15 degrees between the Orahiri Limestone and the Taumatamaire Formation (Fig. 23).

Note the absence of Awakino Limestone Mbr in the section above the tunnel on its southern side, due to its limited apron-like depositional extent. However the Black Creek Limestone Mbr is present. It thins depositionally downdip and passes rapidly into concretionary mudstone.

Stop 6. SH3, Awakino Tunnel (R17- 615 854) (Figs 27-30)

Stop to examine the sedimentology of the Aotea Formation (Hauturu Sandstone Mbr) and Orahiri Limestone at the western end of the tunnel entrance and their tectonic significance. A stratigraphic column is reproduced in Fig. 27. These stratigraphic units, their sedimentology and petrography are described and interpreted in Nelson et al. 1994.

The Whaingaroa Fmn is of early Whaingaroan age (34.3 – 30.0 Ma, Cooper et al. 2004), c. 200 m thick, massive to thin-bedded in its lower part, and composed of calcareous mudstone (45-55% CaCO3). A significant unconformity separates the Whaingaroa and Aotea Fmns. It is a sharp burrowed contact, overlain by a bioturbated, glauconitic pebbly sandstone for 0.5 m. The Aotea Fmn is c. 30 m thick, upper Whaingaroan-Duntroonian in age, concretionary, massive to bedded, calcareous fine sandstone (40-60% CaCO3). At the tunnel it includes a few limestone beds. The sand is quartzofeldspathic and cannot have been sourced from the Murihiku Terrane (Herangi High) and more probably basement to the south. A sharp eroded contact marks the boundary between the Aotea Fmn and the Orahiri Limestone, which is c. 40 m thick.

The Orahiri Limestone at the tunnel comprises three facies. 1. Flaggy limestone beds – sandy, bryozoan-benthic, foraminiferal-echinoid skeletal limestone, comprising the lower 8 m in the lower portion of the formation. 2. Oyster beds – large oysters of the genus *Flemingostrea sp.* in a pebbly, micritic, very coarse, bryozoan-bivalve-benthic foraminiferal limestone. This facies dominates in the upper few metres of the formation. The oysters formed as low relief banks in a fully marine tide-swept seaway, probably at inner to mid-shelf depths. 3. Limestone-in-limestone beds – interbedded flaggy and "conglomeratic" limestones, the individual beds ranging from 0.5-3.0 m thick, occurring in the bulk of the thickness of the formation in the vicinity of the tunnel (Figs 28, 29). There are six such beds, interpreted to have been mass-emplaced as debris flows. This facies has a variably micritic matrix, containing highly irregular clasts of dark grey calcareous sandstone and limestone, 1-10 cm in size (Figs. 30, 31), and some well-rounded greywacke and igneous clasts derived from basement. The calcareous lithoclasts are commonly bored, possibly by intertidal pholad bivalves. Calcareous red algae encrust some clasts.

We infer that the limestone lithoclasts, and the enclosing mass-emplaced beds represent sedimentological evidence for deposition on an actively tilting shelf on the flanks of a Herangi High, that was starting to become mobile as a result of initial Late Oligocene crustal shortening along eastern Taranaki driven from the plate boundary to the east. The situation is more complicated in that the lithoclasts probably represent cannibalization of older (Whaingaroan) Te Kuiti Gp formations, which had undergone prior burial and cementation, the succession having been inverted during the Late Oligocene. This inverted depocentre must have been located in more axial parts of the Herangi High, possibly in and around the Manganui Valley prior to the start of reverse faulting during the Late Oligocene (Duntroonian).

Discussion: Redeposited beds are uncharacteristic of the Orahiri Limestone regionally, and are the sedimentological observations at the Tunnel section consistent with the stratigraphic and structural development of the Oligocene-early Miocene basin margin succession? What is the provenance of the Aotea Formation sandstone and its paleogeographic implications?

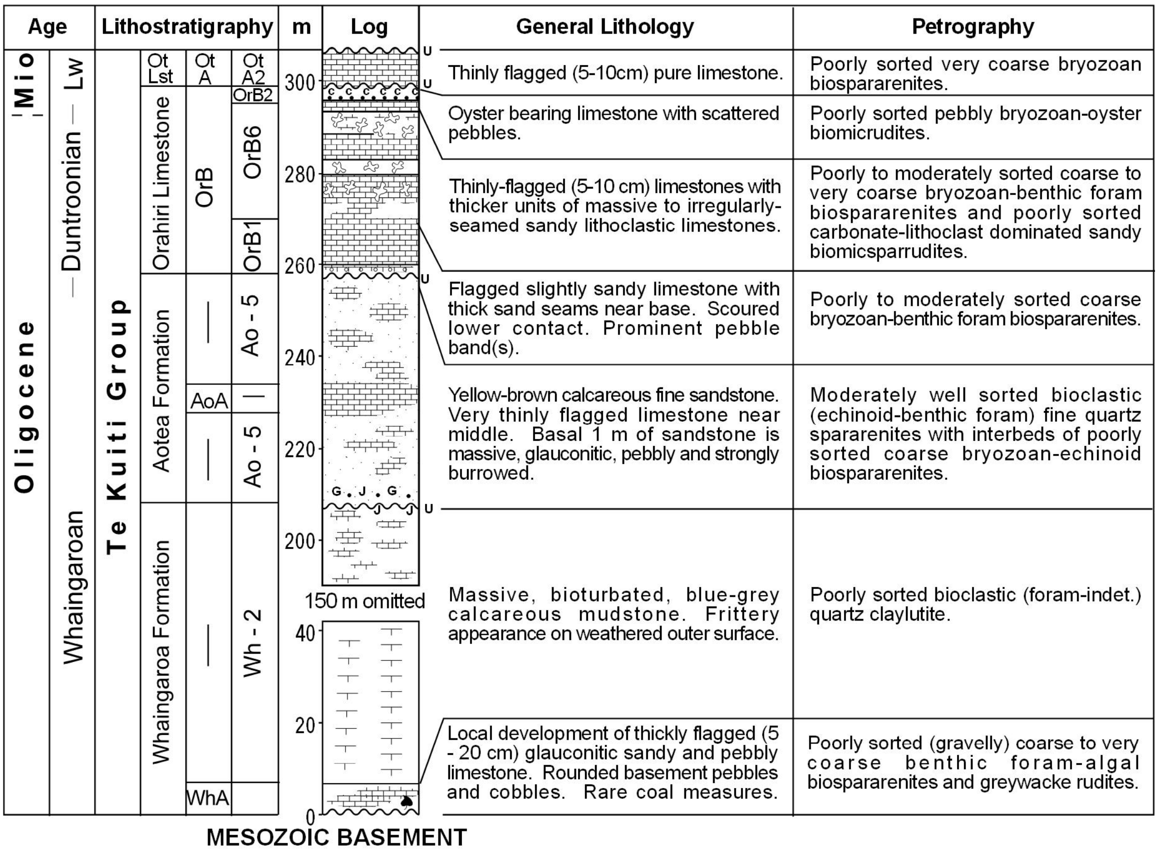


Fig. 27: *Stratigraphic column for Te Kuiti Group exposed in the Awakino Tunnel and vicinity. From Nelson et al. 1994 (Fig. 4). Stop 6, R17- 615 854.*

Fig. 28.: *Photo of Orahiri Limestone (late Oligocene) exposed at Awakino Tunnel. The recessive beds in the cliff above the tunnel entrance are a succession of redeposited beds containing lithoclasts. Stop 6, R17- 615 854. Photo: C.S. Nelson.*

Fig. 29: *Close-up photo of a fresh outcrop of a redeposited bed within Orahiri Limestone at Awakino Tunnel. The dark parts are pholad-bored lithoclasts (Fig. 31). From Nelson et al. 1994 (Fig. 5A). Stop 6.*

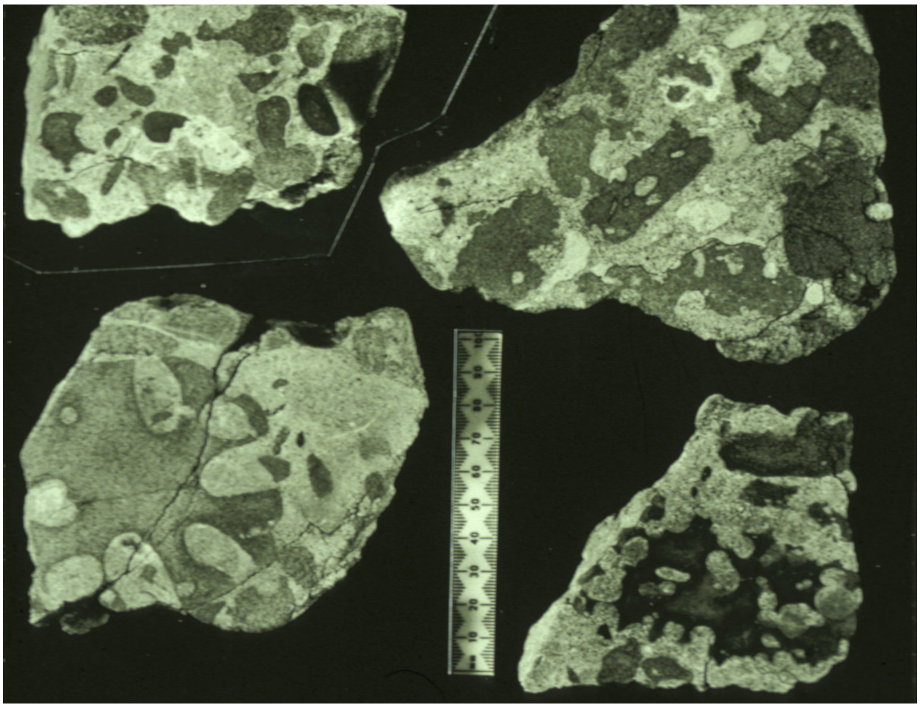


Fig. 30: *Photo of cut slabs of samples from a redeposited bed within Orahiri Limestone at Awakino Tunnel, showing pholad-bored lithoclasts. From Nelson et al. 1994 (Fig. 6). Stop 6.*

Stop 7. SH3, Bexley Tunnel section (R17- 609 827)

Stop to examine the section through the Bexley Tunnel, which is developed in Orahiri and Otorohanga Limestones, and the onlapping Early Miocene Mahoenui Group and Mokau Group. The Awakino River in much of the gorge lies between the basement and the Te Kuiti Gp and has eroded out the contact, thereby removing much of the evidence for stratigraphic onlap. The Bexley Tunnel entrance lies at the contact between Aotea Formation and Orahiri Limestone, although cave formation makes it difficult to precisely locate the contact. Good concretionary and very well sorted quartzofeldspathic sandstone of Aotea Formation (Hauturu Sandstone Mbr) is accessible along the bluff to the north of the tunnel entrance. Note a very porous bryozoan facies of Orahiri Limestone on the right hand side of the tunnel entrance. Thin-bedded Otorohanga Limestone is visible forming a bluff high up in the bush some distance to the right of the tunnel entrance.

Through the tunnel, note the steep dipslope developed on Otorohanga Limestone above the tunnel. Massive mudstone of the Taumatamaire Formation onlaps Otorohanga Limestone with an angular unconformity in the stream section immediately to the north of the tunnel, just as it does near Awakino Tunnel. This section is along strike to the southwest from Awakino Tunnel. Walking up the road, one passes through variably sandy and muddy facies of the Taumatamaire Formation, possibly reflecting subtle changes in paleobathymetry, and then into Awakino Limestone, more mudstone facies, and then Black Creek Limestone, before passing into thick massive Bexley Sandstone. Upwards through this succession the dips shallow, reflecting the decreasing tectonic mobility of the eastern flank of the Herangi High, as discussed at Stops 3 & 4 on Taumatamaire Road.

Discussion: Note parallels with stratigraphy and structure in the vicinity of Awakino Tunnel.

Stop 8. Awakino Heads (R17- 511 808) (Figs 31 & 32)

Examine here a 10 m-thick succession exposed on the southern side of the Awakino River mouth, including the upper part of the Manganui Fmn, Mangarara Fmn, and Purupuru Tuff (Mohakatino Fmn). This section has been down-faulted on a Blacks Fault running more-or-less along SH3, and is comparable to the section exposed in the bluff above the road. The differences are that the Mangarara Fmn is not present there, and the Purupuru Tuff is overlain by Mt Messenger Fmn.

Fig. 32a illustrates the section, and Fig. 31 gives a simplified stratigraphic log from King et al. (1993). The upper part of the Manganui Fmn is (dangerously) well exposed in a cave/bluff at the inland end of the section. This is overlain by channelised Mangarara Fmn. A 20-50 cm-thick channelised conglomerate (concretions) bed with a volcaniclastic matrix overlies Mangarara Fmn. Mohakatino Formation (Purupuru Tuff) comprises thin to medium bedded volcaniclastic succession 8 m thick. It is has a Marine Oxygen Isotope Stage 5e (last interglacial) ravinement surface cut across it. Late Quaternary Terrace deposits of the Rapanui Formation overlie the ravinement surface.

The Manganui Fmn is a pale grey massive mudstone facies, with sticks of solitary coral (*Truncatoflabellum* sp.) scattered within it, jarasite and occasional phosphate nodules and concoidal fractures. The part of the formation exposed is of middle to late Altonian age, and the sediments accumulated at mid bathyal depths (c. 600-1000 m) (King et al. 1993). The Manganui Formation is well exposed in the hill country to the east of SH3 where it is about 125 m thick, and includes a variety of facies, including thin turbidite facies, channelised beds of mass-emplaced siliciclastic very fine sandstone, and large wavelength (50 m) wavy concretionary siltstone channel facies high in the succession. The channelised sandstone facies would be regarded as Moki Formation in eastern Taranaki Basin well records. This would include the Mangarara Fmn channel at Awakino Heads and the more carbonate rich (i.e. limestone facies) beds in the section above Ladies Mile. At low tide, examples of these channelised beds are exposed in the river bed at Awakino Heads.

Fig. 32b illustrates the upper part of the Manganui Fmn and the transition to Mangarara Fmn. A subtle normal fault with more than 4 m of throw offsets the Manganui Fmn, down-faulting the uppermost part to the west. In this block we can observe the transition from Manganui Fmn into Mangarara Fmn. The lower part comprises 1.5 m of very glauconitic siltstone. The glauconite occurs mainly as rounded pellets and angular coated siltstone grains. This is overlain by a 10 cm-thick calcareous redeposited bed, followed by 2 m of laminated siltstone, which is cut into by a 2.5 m-thick channelised deposit of Mangarara Fmn. Further along the outcrop the Mangarara Fmn comprises two or three sedimentation units. Mangarara Fmn at Awakino Heads is glauconitic, gritty, shelly muddy sandstone with abundant foraminifera. In the steep section at the western end of Ladies Mile there are channelised beds of calcareous sandstone that grade upwards into limestone.

We interpret the upper Manganui – Mangarara succession as having accumulated on a paleo continental slope. The mudstone facies represent background hemipelagic slope sedimentation, and the calcareous sandstone and limestone represents submarine channel fill and upper fan facies. The carbonate material, chiefly large benthic foraminifera and algal fragments, will have been sourced from a narrow shelf to the east, or from the south along submarine portions of the Patea-Tongaporutu High. The glauconite would have been sourced from near the shelf-slope break and incorporated into the debris flows as they passed over the shelf edge and down the paleo slope channels. The unconformity at the top of the Mangarara Fmn at Awakino Heads represents the base of another submarine channel, where submarine erosion at slope depths has removed sedimentary section of late Clifdenian through to Waiauan age, some three million years of time (Figs 9 & 31). The Purupuru Tuff, being the on land equivalent of the lower part of the Mohakatino Fmn accumulated at lower slope depths, and the beds accumulated as sedimentation from tephra fallout, and as mass-emplaced debris flows or sandy debris flows sourced from the collapse and erosion of the contemporary Mohakatino Volcanoes in northern Taranaki Basin. The conglomerate at the base of the Purupuru Tuff contains concretions, some pholad-bored (having passed through an intertidal zone), that were probably sourced out of older Neogene beds (e.g. Mahoenui Gp) exposed to the east, and deposited as a submarine channel fill. The clast-supported conglomerate may have been infiltrated by andesitic volcaniclastic sand soon after deposition. The unconformity between the Rapanui Formation and older beds formed a few metres above present sea level by wave erosion during the end of the last interglacial sea-level rise. Most of the present elevation of this surface has been achieved through tectonically-driven uplift since about 125 ka.

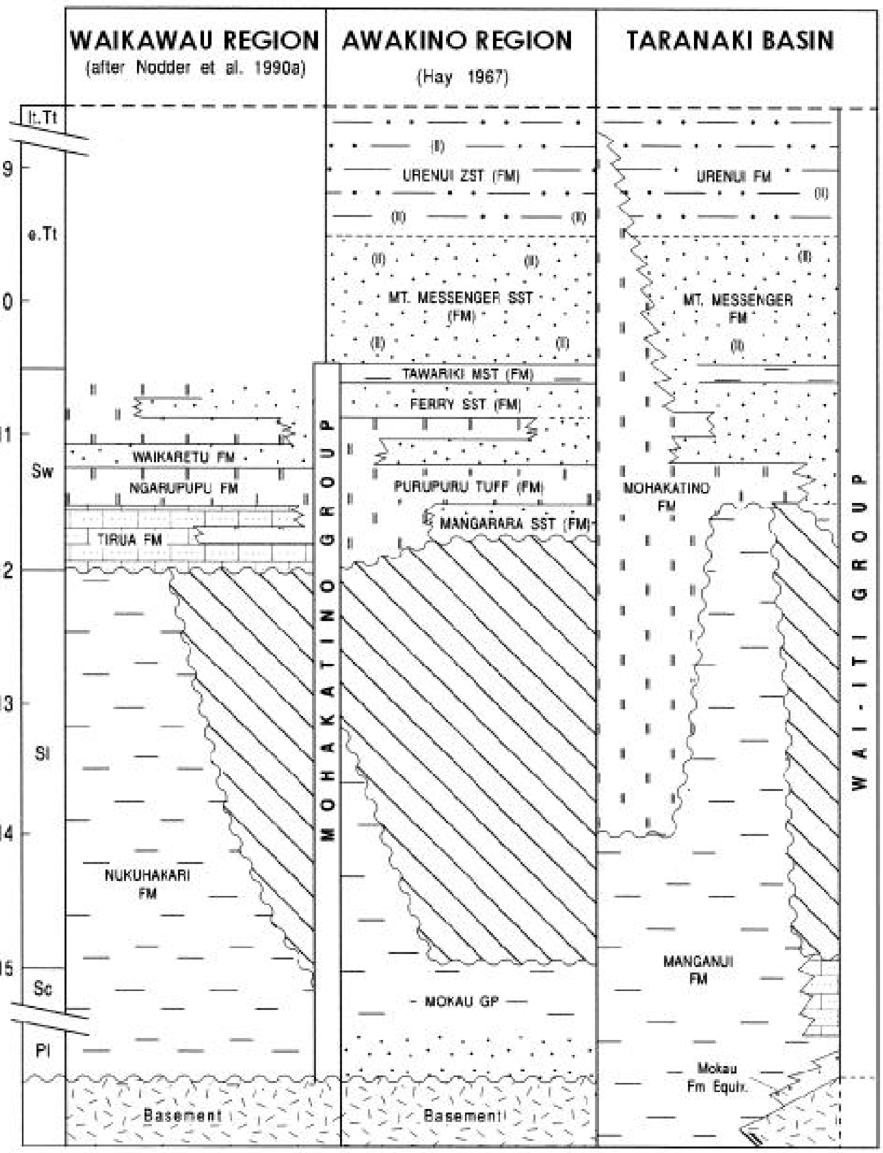


Fig. 31: *Time-stratigraphic logs for the Waikawau and Awakino areas, and for offshore parts of Taranaki Basin. Waikawau is north of Awakino Heads along the Taranaki Coast. Mangarara Fmn is shown for Awakino area as being of Waiauan age, but it contains Clifdenian microfauna (King et al. 1993). From King & Thrasher 1996 (Fig. 4.7). Stop 8.*

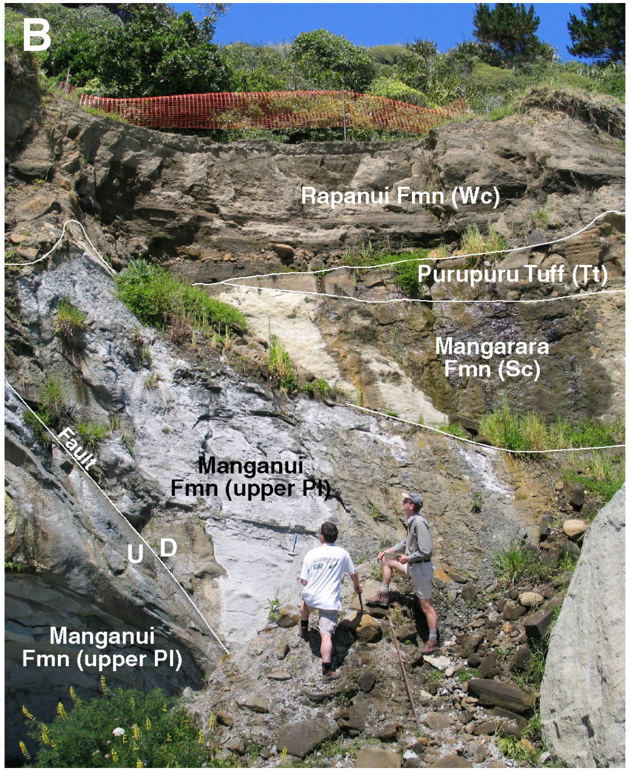


Fig. 32a: *Photo of Awakino Heads Section showing the extent of Manganui Fmn, Mangarara Fmn, Purupuru Tuff (Mohakatino Fmn) and Rapanui Fmn. Note the channel occurrence of the Mangarara Formation. Stop 8, R17- 511 808.*

Fig. 32b: *Close-up photo of the eastern end of the section with the formation names and ages annotated. Note the 10 cm thick redeposited carbonate bed below the Mangarara Fmn channel. The 1.5 m-thick mudstone bed below this thin carbonate bed is loaded with glauconite pellets and angular glauconite coated mudstone clasts. Stop 8, R17- 511 808. Pl, Altonoan; Sc, Clifdenian; Tt, Tongaporutuan; Wc, Castlecliffian (Fig. 12B for ages of Stage boundaries)*

Stop 9. Pahaoa Hill Section (R18- 513 799) (Figs 33 & 34)

Stop to examine the Pahaoa Hill section (Fig. 33) through the Mt Messenger Formation exposed in natural outcrops and on the sides of a farm track past the Mokau town water works. The Mt Messenger Formation is of lower Tongaporutuan age in this section (King et al. 1993; M.P. Crundwell, personal communication, 2003). It rests conformably on the Purupuru Tuff, both units having accumulated on a lower continental slope to basin floor. The base of the Mt Messenger Formation here at Awakino and to the north (Waikawau) is sand-dominated, by contrast with a mud-dominated base to the formation inland to the southeast around Tahora (Kohu Member). This raises an issue about the definition of the Mt Messenger Fmn and differences between on land mapping approaches to stratigraphy, versus a definition more restricted to sandstone facies, as identified from wireline records in Taranaki Basin exploration holes.

Amalgamated yellow-brown siliciclastic sandstone beds form a prominent unit at the base of the hill section. The beds are well sorted fine sandstone and probably accumulated as sandy debris flows, forming a basin floor fan. Overlying beds are siliciclastic mudstone (hemipelagic sedimentation) or individual or amalgamated redeposited sandstone beds. Higher up in the section in the road cutting (Fig. 34) the bedding comprises interbedded siliciclastic sandstone and mudstone, and andesitic volcaniclastic sandstone and mudstone. The contrasting provenance of the sediments reflects the concurrent activity of the andesitic volcanoes in northern Taranaki Basin, supplying sediments semi-radially into the basin from the volcanic centres, and the bottom sets (Mt Messenger Fmn) of the continental margin prograding into the basin from the south, being sourced from erosion of the continental collision zone across the Alpine Fault.

Fig. 33: *Photo of Pahaoa Hill, showing exposures of Mt Messenger Fmn. Note the amalgamated sandstone beds in the lower part of the section, which are interpreted as a paleo basin floor fan deposit. Siliciclastic sandstone and mudstone beds are intercalated with andesitic volcaniclastic beds in the cuttings along the upper part of the farm track (Fig. 34). Stop 9, R18-513 799.*

Fig. 34: *Photo of intercalated siliciclastic sandstone and mudstone beds with andesitic volcaniclastic beds in the farm track shown in Fig. 33. The volcaniclastic sediments were sourced from late Miocene andesitic volcanoes in northern Taranaki Basin much like modern day Mt Egmont/Taranaki seen here in the background. Stop 9, R18- 513 799.*

Stop 10. Mokau River Mouth (R18 – 510 770) (Fig. 35)

Brief stop to view the section exposed on the south side of the Mokau River mouth (Fig. 35). Several SW-NE striking normal faults displace the section in the vicinity of the river mouth. The major fault passes to the north of the Mokau Heads, up-throwing the Purupuru Tuff on the south side of the estuary. Another subparallel fault to the SW follows the road through the gut as it comes down to the estuary, down-throwing Mt Messenger Formation relative to Purupuru Tuff. An array of associated small faults displaces Mt Messenger Formation to the SW of this second fault. The main cliff comprises Ferry Sandstone Member of the Mt Messenger Formation. This is the sand-dominated lower part of the formation. In the hill to the south above the road bridge a mudstone interval is the Tawariki Mudstone Member, and this is overlain by younger sandstone packets that probably represent basin floor fan deposits.

Fig. 35: *Photo of south head of Mokau River showing Ferry Sandstone Member in the main cliff and Mohakatino Fmn beds at the South Heads. Stop 10, R18 – 510 770.*

DAY 2 Depart Awakino Hotel and drive south via State Highway 3 to Mohakatino Valley Road, then to the end of the road on to Ben Hutchinson's farm, parking at the woolshed.

Stop 11. Mohakatino Valley (R18 – 590 698) (Figs 36 – 38); Farmer: Ben Hutchinson Ph 06-752 9097

Drive up Mohakatino Valley to the farm at the end of the road. Mt Messenger Fmn occurs on both sides of the valley at its seaward end, and Moki Fmn underlies the hills at the landward end. At this site, with the farmer's permission, one can walk up the farm track on the south side of the Mohakatino River to observe in the steep slopes a variety of paleo submarine channels and fan deposits, many composed of limestone, and enclosing background facies (Fig. 36). The calcareous sandstone and limestone channel and fan facies possibly correlate with Mangarara Formation at Awakino Heads and in the section above the western end of Ladies Mile, lower Awakino Valley.

The channel fills are of two types. One is comprised of siliciclastic deposits, including mass-emplaced sandstone beds and associated mudstone facies (Figs 36-38). The sandstone is massive fine to very fine sandstone and the beds probably represent sandy debris flows, also known as plastic sandy debris flow deposits. The texture is generally slightly finer grained than similar deposits in the Mt Messenger Fmn. The other channel fill type is carbonate-dominated, varying from conglomeratic calcareous sandstone, as in the Mangarara Fmn at Awakino Heads, to bioclastic limestone. A particular limestone type is a rhodolith limestone, which one can examine in the track (Fig. 38). Farther up the track a 10-20 m-thick limestone unit crops out on both sides of the valley, extending many km in land. It may represent the upper part of a submarine fan, the carbonate having been sourced from a carbonate factory on a narrow shelf to the east, or possibly to the south on the Patea-Tongaporutu High. The degree of algal material in the limestones requires that the carbonate was produced at photic depths, generally no more than 50 m, which emphasises the redeposited origin of the sediments in this section.

Fig. 36: *Photo of hills at the eastern end of Mohakatino Valley Road, which are underlain by Moki Fmn. The beds standing proud are limestone slope channel/upper fan deposits. Stop 11, R18 – 590 698.*

Fig. 37: *Photo of part of Moki Fmn exposed adjacent to the woolshed at the end of Mohakatino Valley Road. It shows redeposited siliciclastic very fine sandstone beds forming the fill of a slope channel to upper submarine fan deposit. Stop 11, R18 – 590 698.*

Fig. 38: *Photo of part of Moki Fmn exposed along a farm track on the southern side of the Mohakatino River beyond the end of the valley road. The knobby bed standing out from the outcrop is comprised of a rhodolith limestone. This unit is fault bound. Stop 11, R18 – 590 698.*

Stop 12. Mohakatino Valley, west end (R18 – 575 717)

Brief stop on road side to note the contact between the Moki Fmn and the Mt Messenger Fmn.

Stop 13. Tongaporutu River Mouth, Rest Area (R18 – 484 642) (Fig. 39)

Brief stop to view the Tongaporutu River estuary, and a very thick sandstone bed, considered to have accumulated on a lower continental slope as a basin floor fan (King et al. 1993, 1994) (Fig. 39). The boundary between the lower and upper Tongaporutuan Stage (Fig. 12b) lies at about the stratigraphic level of the sediments exposed in the cliffs around the estuary (King et al. 1993). The road cutting above the Rest Area exposes very well a 30 m-thick section of amalgamated sandstone beds in a basin floor fan also cropping out on the southern side of the estuary (Sequence No. 1 of King et al. 1993). Some of the individual sandstone beds are many metres thick. The base of this bed is well exposed in the cliff above the road some 50 m south towards the road bridge. In the base of it is a huge mudstone raft 1 m high and several m long, which is completely enclosed in sandstone. This raft has been ripped up from the underlying mudstone and is graphic evidence for the dense viscous flow character of the bed prior to its deposition.

Fig. 39: *Photo of the Tongaporutu River mouth and estuary taken from the Rest Area adjacent to State Highway 3 north of the road bridge. Stop 13, R18 – 484 642.*

Stop 14. Okau Road, SH40 (R18 – 515 578) (Fig. 40)

At this stop there are well exposed medium to thinly bedded sandstone beds and associated mudstone (Fig. 40). The more prominent and thicker sandstone beds are examples of sandy debris flow deposits, as distinct from classical turbidites, which are deposited out of a more fluid medium.

The beds in this exposure lie in a transition between the lower part of the Mt Messenger Fmn characterised in the coastal section by thick (10-40 m) amalgamated sandstone beds (basin floor fan deposits), and the upper part of the formation, characterised by muddy turbidites, which accumulated as parts of slope fans (Browne & Slatt 2003).

Fig. 40: *Photo of medium to thin-bedded Mt Messenger Fmn exposed on Okau Road. Stop 14, R18 – 515 578.*

Stop 15. Okau Road, east of Kiwi Road intersection SH40 (R18 – 574 547) (Fig. 41)

Brief stop to view a 4 m-thick interval of andesitic volcaniclastic sandstone facies within Otunui Fmn (Fig. 41). These beds are compositionally similar to the Purupuru Tuff of the Mohakatino Fmn at Awakino Heads. At this site however the volcaniclastic beds are demonstrably of Waiauan age. Hence they are the lowest stratigraphic occurrence in the on land record of the products of northern Taranaki andesitic volcanism. The beds are considered to have been mass-emplaced, the flows either having ridden part way up the contemporary slope from the northwest, or to have been emplaced down the slope, having accumulated higher up as airfall into the sea.

This outcrop is also amongst the most western occurrence in outcrop of the Otunui Fmn. This formation does not occur in the Mohakatino Valley, where correlative beds (Moki Fmn) are slope channel complexes with a finer grained mudstone matrix than occurs in Otunui Fmn. We infer accumulation of the lower parts of Otunui Fmn in outer shelf to upper slope environments (200-600 m depth from forminifera), whereas the Moki Fmn accumulated on a mid to lower continental slope (Fig. 9).

Fig. 41: *Photo of Otunui Fmn at Okau Road with a thin interbedded succession of Mohakatino Fmn. Site: SH40. Stop 15, R18 – 574 547.*

Stop 16. Tongaporutu-Ohura Road, east of Kotare Stream, Moki – Otunui Fmn contact (R18 – 651 596) (Fig. 42)

Stop to examine the upper part of the Moki Fmn and the lower part of the Otunui Fmn (Fig. 42). The Moki Formation is characterised by the occurrence of turbidites and associated frittery siltstone, which we infer to have accumulated in broad channels or on a slope fan. The sandstone beds have a fine- to very fine-grained sandstone texture. There is up to 140 m of Moki Fm variably exposed in the Mangatawa Valley to the west of this site. The upper part of the formation is of upper Lillburnian age. The overlying Otunui Fmn is massive to very thick-bedded, indurated, bioturbated silty sandstone to sandy siltstone. We infer that it accumulated in an outer shelf to upper slope setting. Regionally the Otunui Formation has an upper Lillburnian to Waiauan age. As this unit overlies the Tangarakau Fmn to the east it is likely that the Moki beds exposed in this outcrop are correlative of the upper part of the Tangarakau Formation. Although the continental margin overall was retrogradational, clearly it was progradational at times, possibly due to relative sea-level changes, as Otunui Fmn overlies deeper water Moki Fmn at this site.

it is likely that the Moki beds exposed in this outcrop are correlative of the upper part of the Tangarakau Formation. Although the continental margin overall was retrogradational, clearly it was progradational at times, possibly due to relative sea-level changes, as Otunui Fmn overlies deeper water Moki Fmn at this site.

Fig. 42: *Photo of section on the Tongaporutu-Ohura Road, east of Kotare Stream, showing the Moki – Otunui Formation stratigraphic contact. Stop 16, R18 – 651 596.*

Stop 17. Tongaporutu-Ohura Road, east of Kotare Stream, lower part of Otunui Fmn (R18 – 661 597) (Fig. 43 & 44)

Stop to examine lower part of Otunui Fmn upsection from Stop 16. Here, the formation is massive silty sandstone (Fig. 43). During road reconstruction fantastic specimens of *Tumidocarcinus giganteus* (Glaessner, 1960), a deep water crab fossil, were exposed in the lower part the outcrop commonly associated with concretions (Fig. 44). There seems to be a widespread zone in the lower part of the Otunui Fmn containing these fossil, forming a useful basis for intrabasinal correlation. Also at this location there have been exposed examples of paramoudra concretions oriented semi-vertically in the outcrop. They may be diagenetic expressions of cold methane seeps in the paleo- shelf edge to upper slope setting.

Fig. 43: *Photo of section on the Tongaporutu-Ohura Road, east of Kotare Stream, showing the lower part of Otunui Formation. Stop 17, R18 – 661 597.*

Fig. 44: *Photo of Tumidocarcinus giganteus (Glaessner, 1960) within Otunui Fmn. Stop 17, R18 – 661 597.*

Stop 18. Tongaporutu-Ohura Road SH40, west of Waitiaanga (R18 – 671 607) (Fig. 45)

Stop to view the western part of the Waitiaanga Plateau and its geology (Fig. 45). The hills are underlain by Otunui Fmn, with Recent alluvium/swamp deposits in the bottom of the valley. This part of the plateau is drained to the south by the Tangarakau River, the watershed with the Tongaporutu River lying more-or-less at the western end (right hand side) of the grassland.

Fig. 45: *Photo of view to south from the Tongaporutu-Ohura Road SH40, west of Waitaanga. Stop 18, R18 – 671 607.*

Stop 19. Tongaporutu-Ohura Road SH40, south of Huhatahi Valley, Waingarara Sandstone Member (Tangarakau Fmn – Mokau Group) (R18 – 771 593) (Fig. 46)

Stop to examine part of the Waingarara Sandstone Member of the Tangarakau Formation exposed in new road cuts (Fig. 46). The outcrop is partitioned by thin shell beds (0.1-0.2 m) into 3-5 m-thick packets of well sorted fine sandstone, which accumulated in shoreface environments. There are very large siderite concretions in this section at multiple horizons that were wine coloured during recent (2005) road construction. This formation is very extensive in the Ohura-Tangarakau Coalfield, varying from 30-200 m thick. Its age is very poorly known, the upper limit being constrained by the age of the base of the Otunui Fmn. It probably ranges in age between Altonian and mid-Lillburnian. The Waingarara Sandstone Mbr is characterised by a very uniform and well sorted sandstone texture, reflecting the development of extensive shoreface deposits, which aggraded in a situation where there was persistence of a fine balance for several million years between subsidence and sedimentation. The well sorted texture of the sandstone reflects the physical processes on the contemporary foreshore and shoreface environments. This is the siliciclastic sandstone that was captured by shelf channels and feed down the slope channels to accumulate as Moki Fmn in Taranaki Basin.

Fig. 46: *Photo of Waingarara Sandstone Member (Tangarakau Formation, Mokau Group) on the Tongaporutu-Ohura Road SH40, south of Huhatahi Valley. Stop 19, R18 – 771 593.*

Stop 20. Tongaporutu-Ohura Road SH40, south of Huhatahi Valley, Maryville Coal Measures (R18 – 774 597) (Fig. 47)

Stop to examine part of the Maryville Coal Measures exposed in degraded road cuts (Fig. 46). Note the intense weathering of the sediments promoted by the acid leaching below the coal measures.

Fig. 47: *Photo of Otunui Fmn at Okau Road with a thin interbedded succession of Mohakatino Fmn. Site: SH40. Stop 15, R18 – 574 547.*

Stop 21. Tongaporutu-Ohura Road SH40, Huhatahi Valley dip slope (R18 – 781 608) (Fig. 48).

Brief stop to appreciate the outcrop pattern of the formations we have just observed in outcrop (Fig. 48). One is standing on a dipslope developed in the top of the Maryville Coal Measures (Fig. 47). Dip-slopes similar to this one are commonly developed on the Maryville Coal Measures. The light bush-covered bluff immediately above the dipslope is underlain by the Tangarakau Fmn, which we observed at the last stop (Stop 20). Sharply and conformably overlying the Tangarakau Fmn is the Otunui Fmn. This contact represents very sudden marine flooding of the King Country region, and biostratigraphic dating implies that it occurred within the Lillburnian (Fig. 11). We will observe this contact again to the south in the vicinity of Tangarakau Gorge, where it has the same features and involves the same formations. To the southeast of Ohura, the Otunui Fmn rests mainly on Mahoenui Group, as late early Miocene displacement on the Ohura Fault gave rise to erosion and exhumation of Mahoenui Group beds (and possible restricted accumulations of Mokau Group).

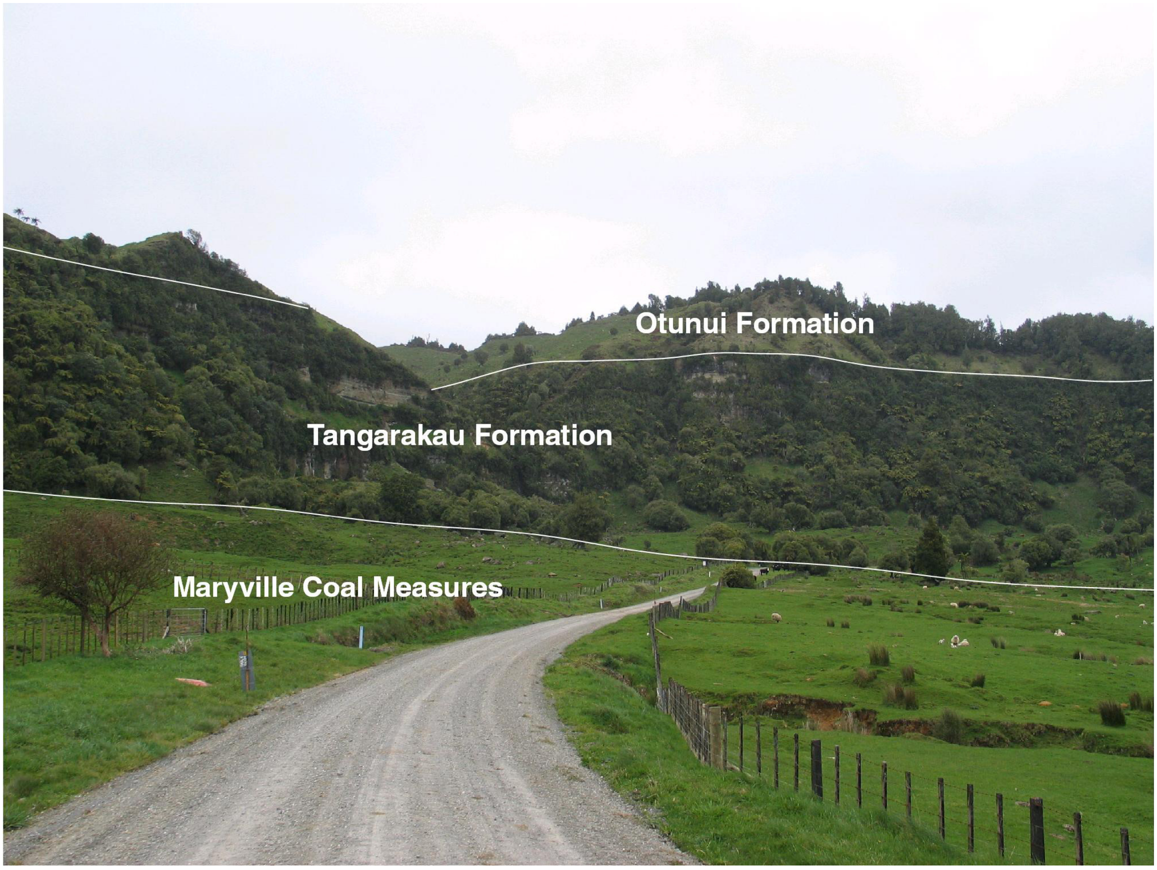


Fig. 48: *Photo of the dipslope developed on the Maryville Coal Measures on the Tongaporutu-Ohura Road SH40, Huhatahi. Stop 21, R18 – 781 608.*

DAY 3. Drive north on SH 4 from Taumarunui to Okahukura Rest Area

Stop 22. Okahukura Rest Area - State Highway 4 (S18 – 029 645)

Stop to view the geology of the surrounding valley with reference to S18 geological map. Note in particular the extent of the Mahoenui Group, the contact with the Otunui Formation (poorly exposed on the western side of the road), and the map extent of the Otunui Formation. Discuss structure of the Miocene units and the influence of extensional Quaternary Faults, and the influence of late-early Miocene faulting on the outcrop distribution of geological units.

Stop 23. Okahukura Saddle Road, (S18 – 015 667) (Fig. 49; Log 1)

This stop is to examine the lower part of the Otunui Formation. The section shows a lower sandy siltstone, a prominent glauconitic horizon with small phosphate nodules, a thin very fine mudstone and an overlying thick sandy siltstone unit (Fig. 49). Appendix I is a stratigraphic log of this part of the section. Discussion points: sequence stratigraphic interpretation and inferred Mid-Miocene eustatic sea-level changes.

Fig. 49: *Photo of lower part of Otunui Formation and glauconitic horizon within it, Okahukura Saddle Road (Stop 23).*

Stop 23 - Stratigraphic log

Date: 10 (day) 8 (month) 2004 (year)

Page 1 of 1

Stratigraphic Column Name: Okahukura Saddle Road

NZMS 260 Sheet: S18 Taumarunui

Region: Taumarunui

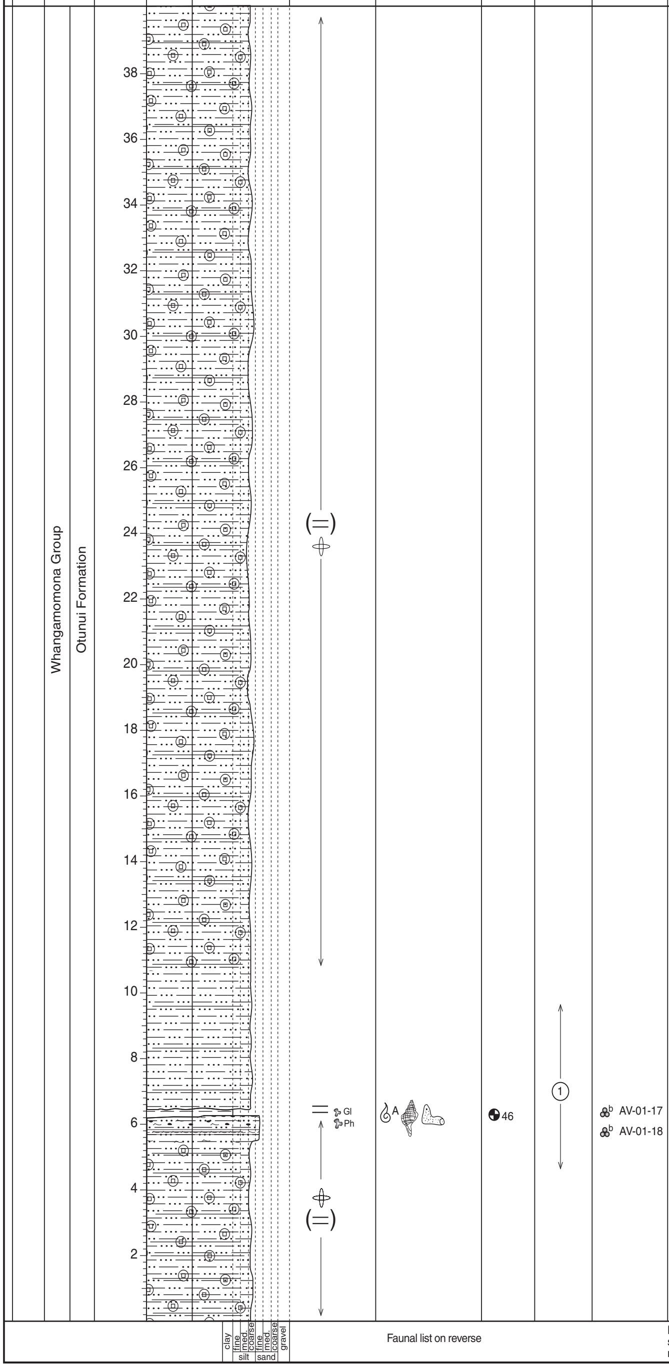
Grid Reference: Top E: 2701541
N: 6262674
Altitude: 378

Location: Road cuttings on Okahukura Saddle Road. Column starts in cuttings to the northeast of a prominent switch back near the base of the hill. The top of the column is where channelised sandstones grade into massive mudstones approximately 150 m due east from height point 464.

Bottom E: 2701419
N: 6266372
Altitude: 270

GPS Waypoint No(s): 46, 47, N723, N724

Stage	Strat Unit	Thick. (m)	Ratio	Lithology	Structures	Fossils	GPS WP No.	Photo No.	Sample No	Description	Structural Data



Sandy siltstone, blue-grey, massive to faintly planar bedded (m scale) or cryptically bedded , slightly bioturbated, slightly weathered with limonite and jarosite spheroidal weathering.

25 cm thick, mudstone, planar laminated (mm-cm scale), blue-grey, frittery, sharp base and top. 60 cm interval of sandy siltstone below this mudstone is glauconitic, contains phosphate nodules and fauna in top 15 cm (*Sigapatella* sp., *Seratina ferrari*, *Penion* sp., *Crepidula* sp., *Fissidentalium solidum*., *Antalis* sp., bryozoans and barnacles), is calcite cemented and has a sharply gradational contact with the overlying mudstone.

Sandy siltstone, blue-grey, massive to faintly planar bedded (m scale) or cryptically bedded , slightly bioturbated, slightly weathered with limonite and jarosite spheroidal weathering.

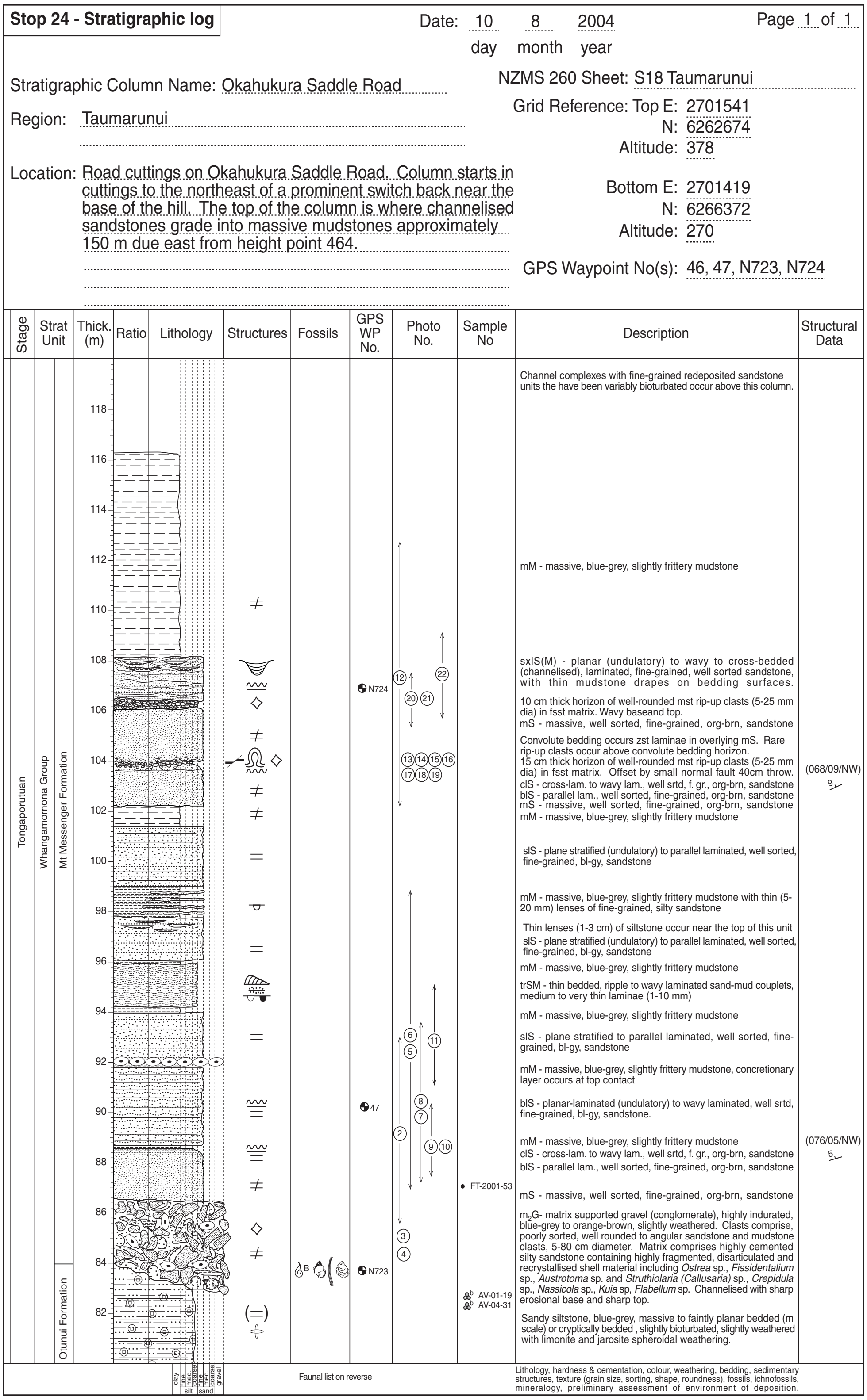
Faunal list on reverse

Lithology, hardness & cementation, colour, weathering, bedding, sedimentary structures, texture (grain size, sorting, shape, roundness), fossils, ichnofossils, mineralogy, preliminary assessment of environment of deposition.

Stratigraphic Log 1 (Stop 23)

Stop 24. Okahukura Saddle Road (S18 – 015 675) (Log 2)

At this location one can observe road cuttings through a submarine channel system. Stratigraphic Log 2 is a stratigraphic column for this section. Several styles of deep water mass flow units are evident, including debris flows, sandy debris flows, grain flows and turbidites. The base of this channel is considered to be the Otunui Fmn – Mt Messenger Fmn contact.



Stratigraphic Log 2 (Stop 24)

Stop 25. Herlihy Bluff, River Road (S18 - 033 516) (Fig. 50)

This stop shows spectacular development of turbidites in the Taumarunui Formation, Mahoenui Group (Fig. 50). Note in particular erosional flute marks at the base of sandstone beds, Bouma sedimentary structures within the turbidite divisions, and the organic matter content within the sandstones forming parting surfaces. Discussion points: paleocurrent directions, position within and geometry of the contemporary submarine fan; and sediment source areas.

Fig.50: *Taumarunui Formation, Herlihy Bluff, River Road (Stop 25).*

Stop 26. Paparoa Road, west of Kaituna (S19 – 970 486) (Log 3)

This new road cutting shows a fantastic section through the lower part of the Otunui Fmn (Stratigraphic Log 3). The lower contact is c. 10 m below the base of the section, but section could be lost through faulting. There is a lower glauconitic shellbed, overlain by a mudstone, which grades up into a silty sandstone with thin redeposited sandstone beds. In the middle part of the section is a shelly glauconite horizon, with egg-shaped concretions, which is overlain by a mudstone with several channelised sandstone beds deposited as sandy debris flows. This grades upwards into a massive bioturbated sandy siltstone. Discussion points: is the whole section Otunui Formation, with deepening and shallowing cycles or do the redeposited beds represent a transition into Mt Messenger Fmn? What are the environments of deposition represented in this section?

Appendix III

Date: 14 (day) 2 (month) 2001 (year)

Page 1 of 1

Field Trip No: 2

Stratigraphic Column No / Name: Paparoa Road - Kaituna west

NZMS 260 Sheet: S19 Raurimu

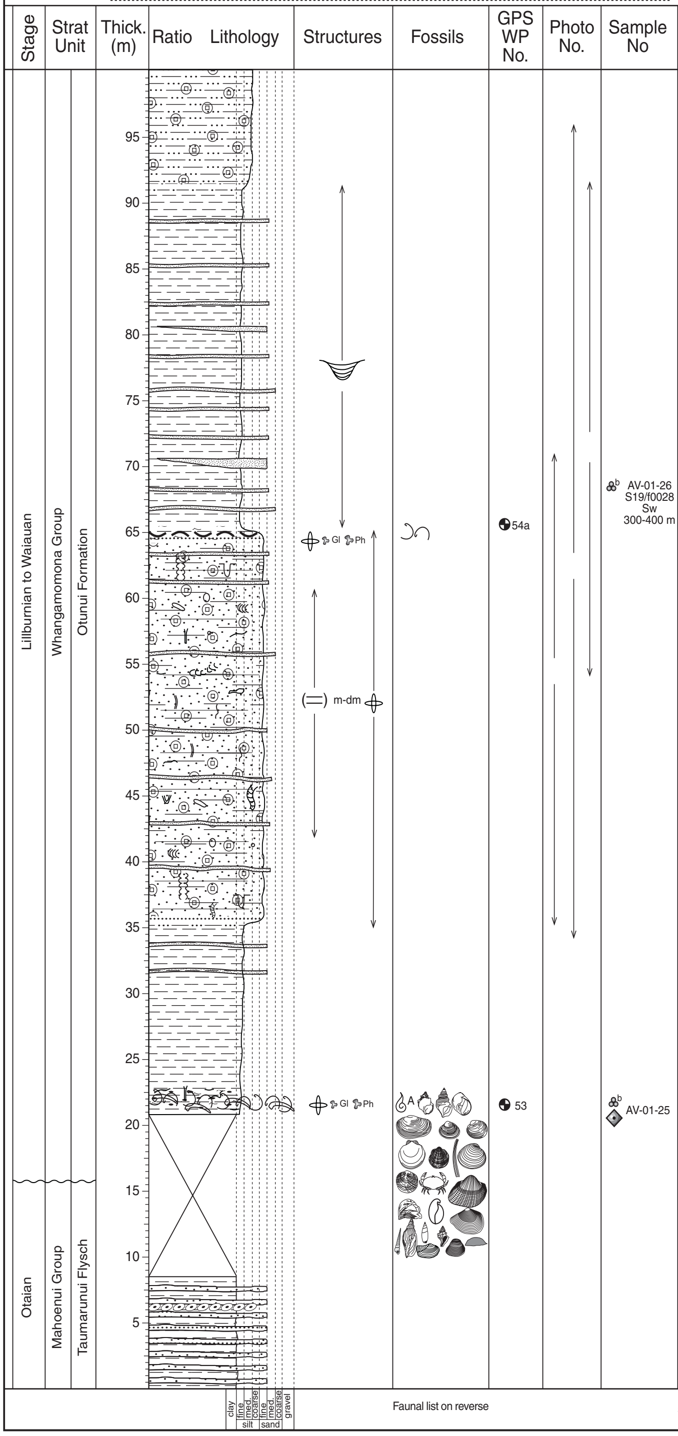
Region: Wanganui River - Te Maire

Grid Reference: Top E: 2696957
N: 6248690
Altitude: 310

Location: Paparoa Road, 500 m west of Kaituna. Column starts at the base of a hill section climbing to the west to a sharp corner which marks the top of the column.

Bottom E: 2697510
N: 6248539
Altitude: 280

GPS Waypoint No(s): 53, 54a



Description	Structural Data
Silty sandstone, massive to faintly planar bedded (thick to very thick (m scale), blue-grey to grey brown, well indurated, slightly calcareous, slightly bioturbated, spheroidal weathering with limonite and jarosite mottling.	
Mudstone, massive, blue-grey, frittery, slightly calcareous. Contains 5-40 cm thick mS to sS - massive to planar laminated thin (dm scale) (Bouma A & B), redeposited fine-grained well sorted sandstone and silty sandstone beds. Sandstone beds have sharp wavy bases, sharp tops and are broadly channelised or lensidal in their geometry. Occasional concretions and concretionary layers.	
Silty sandstone rapidly grades into massive, blue-grey, frittery, slightly calcareous mudstone over 20 cm. A 50 cm thick horizon of glauconite and finely disseminated shell hash (mudstone matrix) overlies this contact, phosphate nodules and small concretions occur within this horizon.	
	(168/05/SW)
Silty sandstone, massive to faintly planar bedded (thick to very thick (m scale) at base with bedding becoming more pronounced toward the top of the unit, blue-grey to grey brown, well indurated, slightly calcareous, slightly bioturbated, spheroidal weathering with limonite and jarosite staining. Thin 20-45 cm thick, massive ,well-sorted, fine-grained sandstone beds occurs through this unit (mass emplaced sandy debris flows).	
Mudstone, massive, blue-grey, frittery, slightly calcareous with two 10-20 cm thick, massive ,well-sorted, fine-grained sandstone beds (mass emplaced sandy debris flows).	
30 cm thick horizon of sparsely packed shell material, typically whole, articulated and disarticulated specimens that have undergone slight compression and recrystallisation, glauconitic with phospahate nodules near in the to 10 cm.	
Section not exposed, could be faulted.	
Flysch - comprising ~60% vol. massive, frittery, blue-grey calcareous claystone, with thinly interbedded mS to sS - massive to planar laminated (v. thin) sandstone beds, sharp bases and tops. Bouma (A,B,D,E) structures evident, flute and scour marks at base of sandstone with common carbonaceous (plant material) and common *Scolicia* (exhibiting poisitive hyporelief) on the basal surface of individual sandstone beds	

Lithology, hardness & cementation, colour, weathering, bedding, sedimentary structures, texture (grain size, sorting, shape, roundness), fossils, ichnofossils, mineralogy, preliminary assessment of environment of deposition.

Stratigraphic Log 3 (Stop 26)

Stop 27. Paparoa Road, Okaretoa Stream north (Museum section) (S19 – 961 475) (Log 4)

At this stop the Mahoenui – Otunui contact is below road level and above the adjacent Wanganui River level. The base of the section contains a mudstone with two shellbeds, the lower one possibly an onlap shellbed, and the upper one, which is glauconitic, is possibly a backlap shellbed, together defining a transgressive systems tract (Stratigraphic Log 4). The upper shellbed is equivalent to the shellbed at the base of the section at Stop 26. Above the upper shellbed is a 30 m thick coarsening upwards succession comprised of highly mottled and burrowed alternating sandy siltstone and silty sandstone typical of the Otunui Formation, reflecting deposition in outer neritic to upper bathyal conditions. At the top of the bluff is the deepening horizon equivalent to the egg-shaped concretion horizon in the previous section. Discussion points: faunal composition of shellbeds listed below; environments of deposition, and sequence stratigraphic interpretations.

Macrofauna collected from the shellbeds at Stop 27**.**

Glycymerita rangatira (King, 1934). Tt (Sc-Wo)
Panopea worthingtoni Hutton, 1873. Lw? (Ld-Tt)
Kuia macdowelli Marwick, 1927. Sw (Sw-Tk)
Zeacolpus pukeuriensis Marwick, 1934. Pl (Pl-Sl)
Struthiolaria calcar Hutton, 1886. Pl (Ld?; Lw-Sc; Sw?)
Struthiolaria (Callusaria) callosa Marwick, 1924. Tt (Sc-Tt)
Cucullaea (Latiarca) ponderosa Hutton, 1873. Sl? (Sc-Sw)
Eumarcia (Atamarcia) thomsoni Marwick, 1927. Tt (Sl-Tt)
Glycymerita sp. indet.
Bartrumia tenuiplicata (Bartrum, 1919). Sl? (Pl-Tt)
Dosinia (Raina) bensoni Marwick, 1927. Pl (Pl-Sw)
Mauira oliveri (Marwick, 1926). Sw
Notocallista (Fossacallista) parki (Marwick, 1927). Pl (Po-Sl)
Polinices huttoni Ihering, 1907. Pl (Pl-Sl)
Buccinidae sp. gen. indet.
Bryozoa sp. gen. indet.
Diplodonta (Zemysina) globus (Finlay, 1926). R (Pl-R)
Marama (Hina) hendersoni Marwick, 1927. Sl (Sc-Sl)
Dosinia (Raina) paparoaensis Marwick, 1927. Sw
Alcithoe sp. indet.
Crepidula radiata (Hutton, 1873). Tk? (Ld?-Wn?)
Sigapatella novaezelandiae (Lesson, 1830). R (Pl?-R)
Tucetona finlayi (Laws, 1939). Sl (Pl-Sw)
Echinophoria pollens (Finlay, 1926) Pl (Po-Sc)

Appendix IV

Date: 14 2 2001 (day month year)

Page 1 of 1

Field Trip No: 2

Stratigraphic Column No / Name: Paparoa Road - Okaretoa Stream north

NZMS 260 Sheet: S19 Raurimu

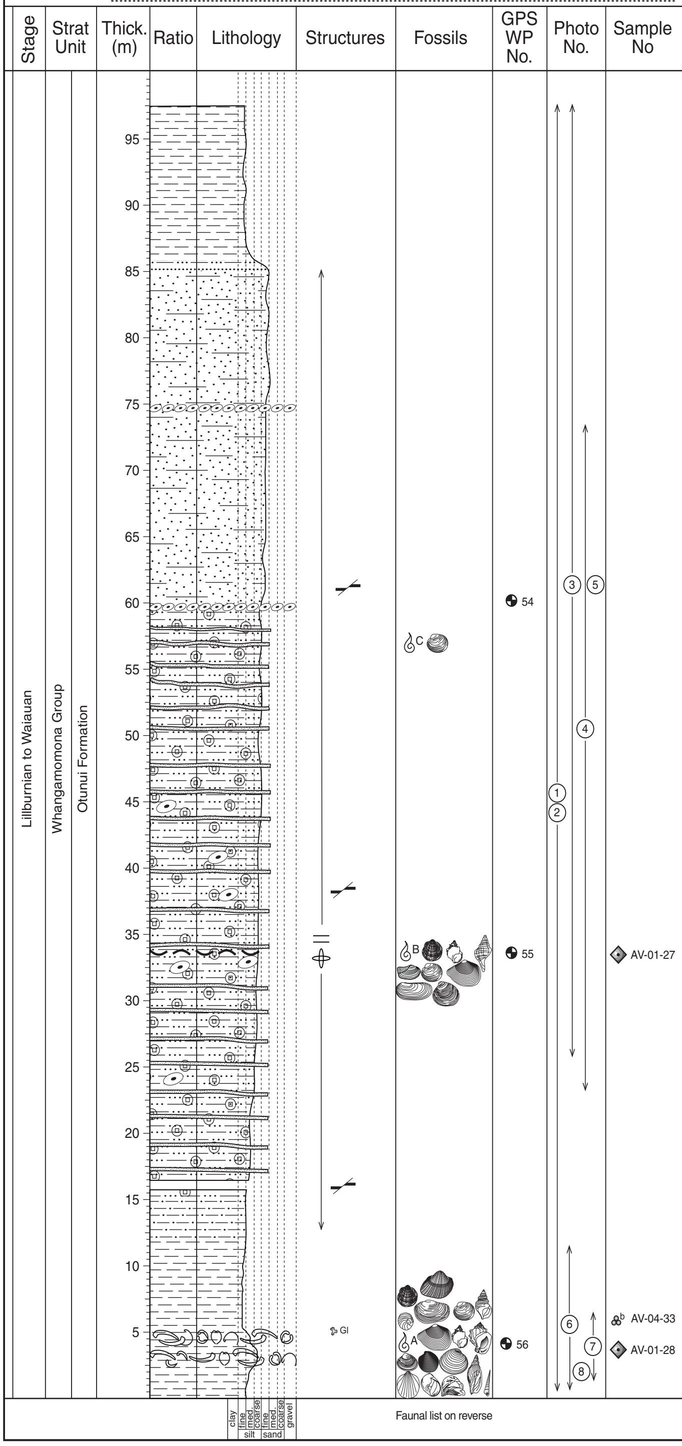
Region: Wanganui River - Te Maire

Grid Reference: Top E: 2696506
N: 6247952
Altitude: 180

Location: Paparoa Road, 600 m east of Okaretoa Stream. Exposures are in road-side cuttings and cliffs on the eastern side of Paparoa Road.

Bottom E: 2696103
N: 6247537
Altitude: 130

GPS Waypoint No(s): 54, 55, 56



Description	Structural Data
Poorly exposed, inaccessable section above the silty sandstone shows a gradation back into mudstone	
Siltstone coarsens to silty sandstone above a continuous concretionary layer, massive to thinly planar bedded, org-brown to grey, mottly weathering	
A set of minor NE-SW tending faults intersects the concretionary horizons at WP 54.	
Well preserved whole, articulated and disartulated, bivalves and gastropods occur within the siltstone. Rounded microbored concretions occur in this interval.	
Siltstone, massive to crudely planar bedded (dm to m-scale), blue-grey, frittery, slightly calcareous. Contains 5-40 cm thick mS to sS - massive to planar laminated thin (dm scale) (Bouma A & B), redeposited fine-grained well sorted sandstone and silty sandstone beds. Sandstone beds have sharp wavy bases, sharp tops and are broadly channelised or lensidal in their geometry. Occasional concretions and concretionary layers.	
An east west trending fault is inferred through the gully separating the two main outcrops	
Mudstone, frittery, blue-grey, calcareous containing two insitu, loosely packed uncemented shellbeds within a sandy siltstone matrix. The lower shellbed is 70 cm thick and the upper one is 20 cm thck, separated by 1m of mudstone. The matrix of the upper shellbed contains glauconite and is moderately bioturbated. Shell matrial comprises, articulated and diarticulated but closely associated, well preserved bivalves and gastropods, high diversity (many species), soft bottom dwellers, some fragmentary material, compressed, recrystallised, unabraded, with no biological modification. Shellbeds reflect stratigraphic condensation.	
Mudstone, frittery, blue-grey, calcareous, massive to faintly planar bedded (thick to very thick (m scale),well indurated, slightly calcareous, slightly bioturbated.	
Lithology, hardness & cementation, colour, weathering, bedding, sedimentary structures, texture (grain size, sorting, shape, roundness), fossils, ichnofossils, mineralogy, preliminary assessment of environment of deposition.	

Stratigraphic Log 4 (Stop 27)

Stop 28. Paparoa Rapids, Wanganui River (S19 – 945 461) (Fig. 51)

At this site, but on the western side of the river, there is a good exposure of the lower part of the Otunui Fmn and its unconformable (angular) contact with the underlying Mahoenui Group (Fig. 51). The southern end of the outcrop is faulted. The lower 2 m of the Otunui Fm comprises a highly cemented silty shellbed, with a less cemented sandy interval in the middle part. The shellbed represents transgressive facies with a very diverse Middle Miocene macrofaunal assemblage, notably including *Glycymerita robusta, Cucullaea (Latiarca) ponderosa* and *Eumarcia pareoraensis.* The beds accessible on the eastern riverbank are blocks that have been deformed by movement at the toe of a deep-seated slump to the east of the road.

Fig. 51: *Photo of the Mahoenui-Otunui contact at Paparoa Rapids, Wanganui River.*

DAY 4 Drive southwest along SH43 (Forgotten Highway)

Stop 29. River Road, Aukopae Saddle (S18 – 913 509) (Fig. 52)

This road cutting (Fig. 52) corresponds to a level within the lower part of the Mt Messenger Fmn near the transition with Otunui Fmn, which one observed previously at Stop 24. The outcrop comprises massive to faintly bedded sandy siltstone interbedded with metre-scale redeposited sandstone beds with diffuse or sharply gradational contacts at their bases and tops. Note the normal fault in the section.

Fig. 52: *Road cutting in lower part of Mt Messenger Fmn, River Road, Aukopae Saddle (Stop 29).*

Stop 30. River Road, Opetea Stream (R18 – 882 517) (Fig. 53)

At this stop one can observe the extensive distribution of Mt Messenger Fmn to the south and east with some prominent dip-slopes developed on sandstone beds in the lower part of the Mt Messenger Fmn. At the road cutting (Fig. 53) there is a good exposure of the base of a channelised sandstone unit cutting into fine-grained mudstone facies with concoidal fracture. Note the medium bedded redeposited sandstone beds that make up the channel fill. Discussion points: mechanisms of deposition; environment of deposition; contrasts with lithologies in previous stop.

Fig. 53: *Mt Messenger Formation channel facies exposed on River Road, Aukopae Saddle (Stop 30).*

Stop 31. River Road, Nevins Lookout (R18 – 814 520)

View to the south of the high topography of Harvey Trig hill, all underlain by Mt Messenger Formation. Note the sandstone beds at the top of the hill, which are either faulted or more probably comprise stacked channel complexes with margins at different levels. The Ararimu Fault passes just to the west of where one is standing and has a northeast-southwest strike, with about 170 m throw down to the southeast. The Waiaraia Range to the west comprises Mokau Group upthrown to the west on the Ohura Fault, which strikes roughly north-south to the west of where one stands.

Stop 32. SH43, Heao Road Junction (R19 – 780 481) (Fig. 54)

Brief stop to view displacement across the Ohura Fault, which has a throw of about 400 m (Fig. 54). Note Mt Messenger Fmn underlies the hills in the foreground. Maryville Coal Measures form eroded dip slopes facing east on the flanks of the **Mangakoromiko Anticline (new).** The Tangarakau Formation underlies the bush at higher elevations in the range.

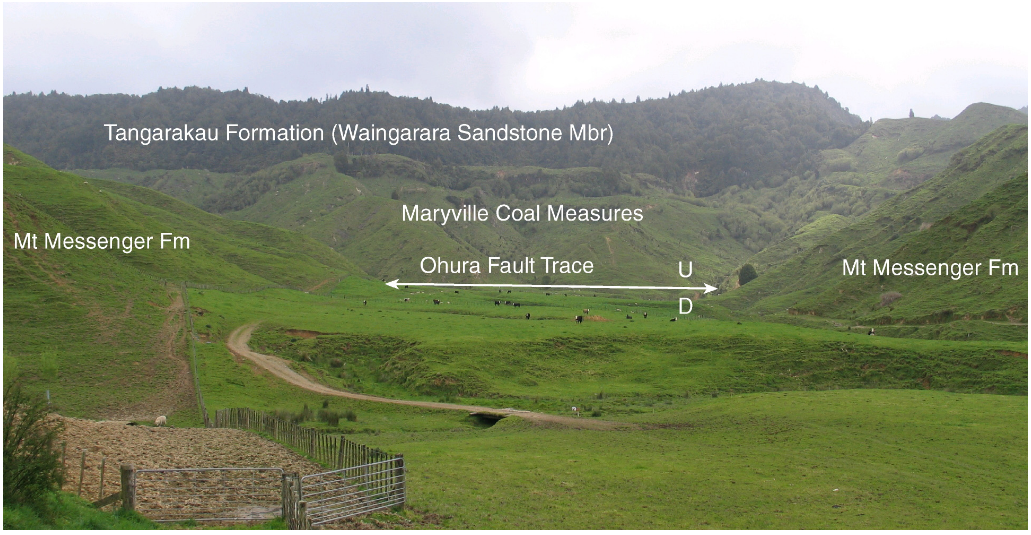


Fig. 54: *View across the Ohura Fault, near the intersection of State Highway 43 and Heao Road. Stop 32, R19 – 780 481.*

Stop 33. SH43, Paparata Fault intersection, Coal Creek. (R19 – 755 463) (Fig. 55) (Log 5)

At this site the Paparata Fault passes between the Maryville Coal Measures exposed in the western road cutting and the Otunui Fmn making up the main outcrop (Fig. 55). The Paparata Fault is a prominent NE-SW striking splay off the Ohura Fault on its south west side. The lower part of the Otunui Fmn outcrop comprises a concretionary mudstone, which is separated from a coarser-grained mudstone by a prominent concretionary glauconitic horizon that stands proud from the outcrop (Stratigraphic Log 5). Higher up in the hillside, the Otunui Fmn is finer-grained and includes thin (10-20 cm) redeposited sandstone beds. Mt Messenger Fmn occurs at the top of the hill.

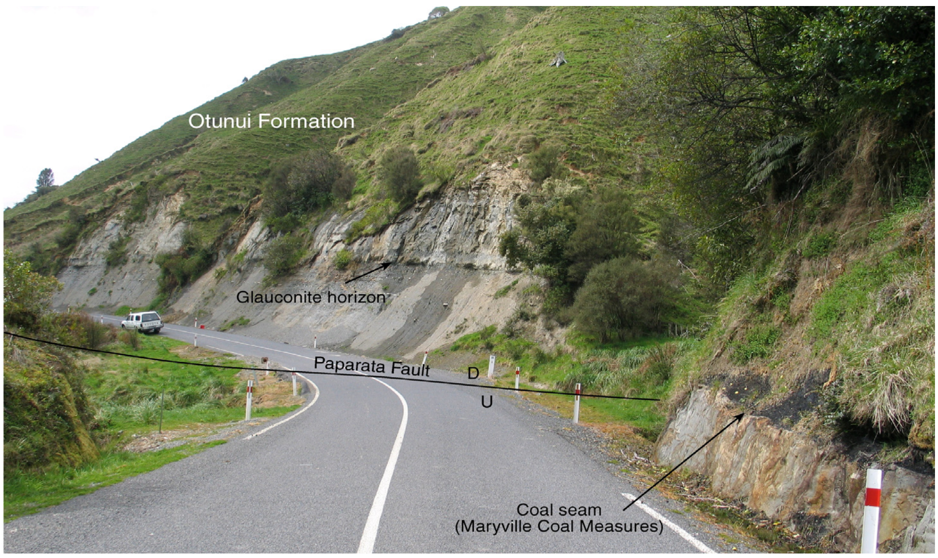


Fig. 55: *Photo of section on SH43 near Coal Creek. Stop 33, R19 – 755 463.*

Appendix V

Date: 25 (day) 2 (month) 2001 (year)

Field Trip No: 3

Stratigraphic Column No / Name: Paparata Saddle WP 113

NZMS 260 Sheet: R19 Whangamomona

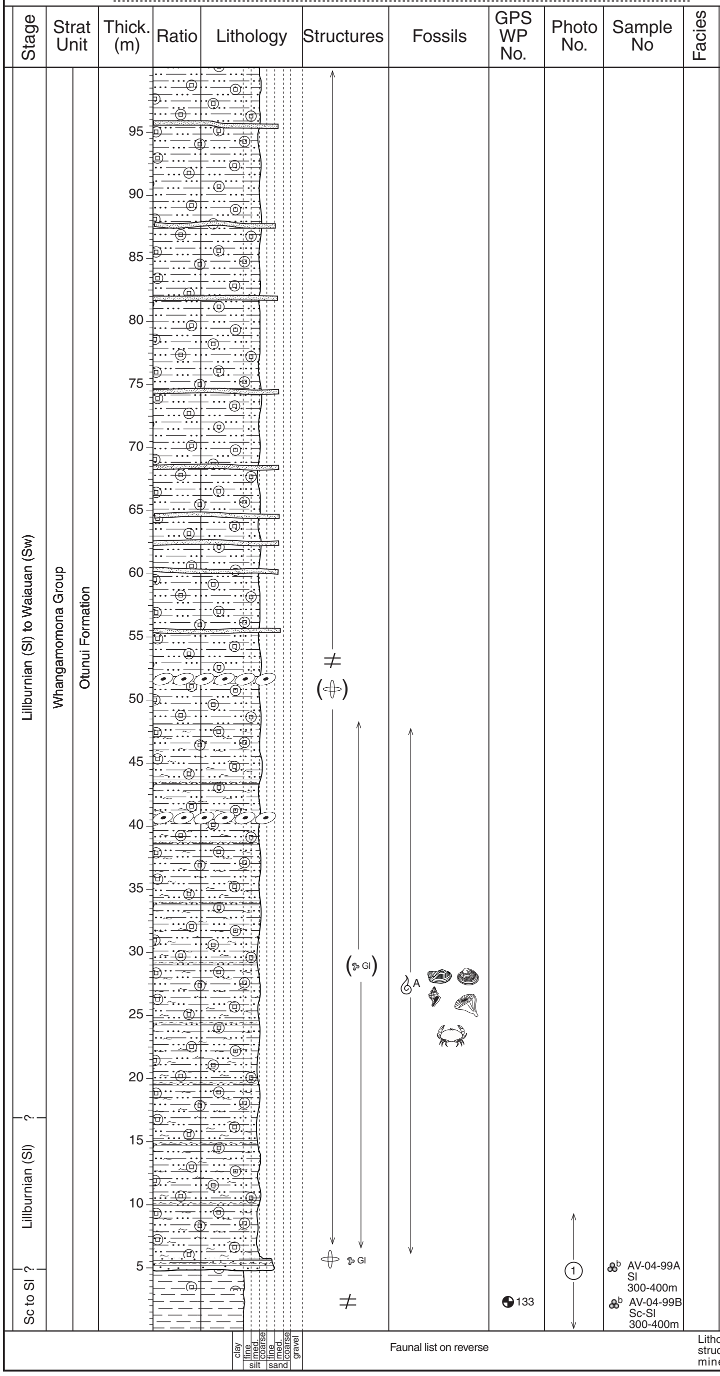
Region: Tangarakau Gorge

Grid Reference: Top E: 2675859
N: 6246127
Altitude: 420

Location: Column starts in road cuttings on SH43 immediately east of the Paparata Fault, near the rest area and heritage trail sign, approximately 300 m east of the junction of Coal Creek with the Paparata Stream. The column continues up the hill to the southeast

Bottom E: 2675642
N: 6246372
Altitude: 283

GPS Waypoint No(s): 113



Description

mS - Thin (10 to 30 cm) massive, well sorted, fine-grained, orange-brown, sandstone beds with sharp bases and sharply gradational tops occur within sandy siltstone, massive, slightly frittery, blue grey, slightly weathered. Spheroidal limonite and jarosite weathering pattern.

Sandy siltstone, massive, slightly frittery, light grey to blue grey, slightly weathered. Spheroidal limonite / haematite weathering pattern. Glauconitic with glauconite content decreasing upwards.

Glauconitic sandy siltstone, dark-green to grey, glauconite pellets comprise sand component of 40 cm thick unit with a matrix of blue-grey siltstone, sharp base, gradational top, thoroughly bioturbated, small concretions

Mudstone, massive, frittery, blue-grey, slightly weathered, limonite staining in top 1metre

Structural Data

Lithology, hardness & cementation, colour, weathering, bedding, sedimentary structures, texture (grain size, sorting, shape, roundness), fossils, ichnofossils, mineralogy, preliminary assessment of environment of deposition.

Stratigraphic Log 5 (Stop 33)

Stop 34. SH43, Maryville Coal Measures outcrop, Paparata Stream. (R19 –743 464) (Fig 56)

Examine fresh exposures through the Maryville Coal Measures (Mokau Group), comprising thick cross-bedded, fine- to medium-grained, green-purplish sandstone interbedded with dark grey-purplish carbonaceous mudstone, all of which accumulated in a fluvial to marginal marine setting during the Altonian (Fig. 56).

Fig. 56: *Maryville Coal Measures cropping out on SH43, at the eastern end of the Tangarakau Gorge, adjacent to the Paparata Stream. Stop 34, R19 –743 464.*

Stop 35. SH43, Morgans Grave (R19 – 689 457) (Fig. 57)

From the road bridge at Morgan's Grave, the view to the south shows a spectacular cliff of Waingarara Sandstone (Tangarakau Formation), conformably overlain by Otunui Formation (Fig. 57). The Waingarara Sandstone Member comprises thick-bedded, fine-grained, cross-bedded, sandstone with interbedded thin shellbeds and mudstone that accumulated in shoreface environments. The conformable boundary with Otunui Formation represents marked subsidence of the basin and flooding, resulting in outer neritic to upper bathyal environments being established during the upper Lillburnian.

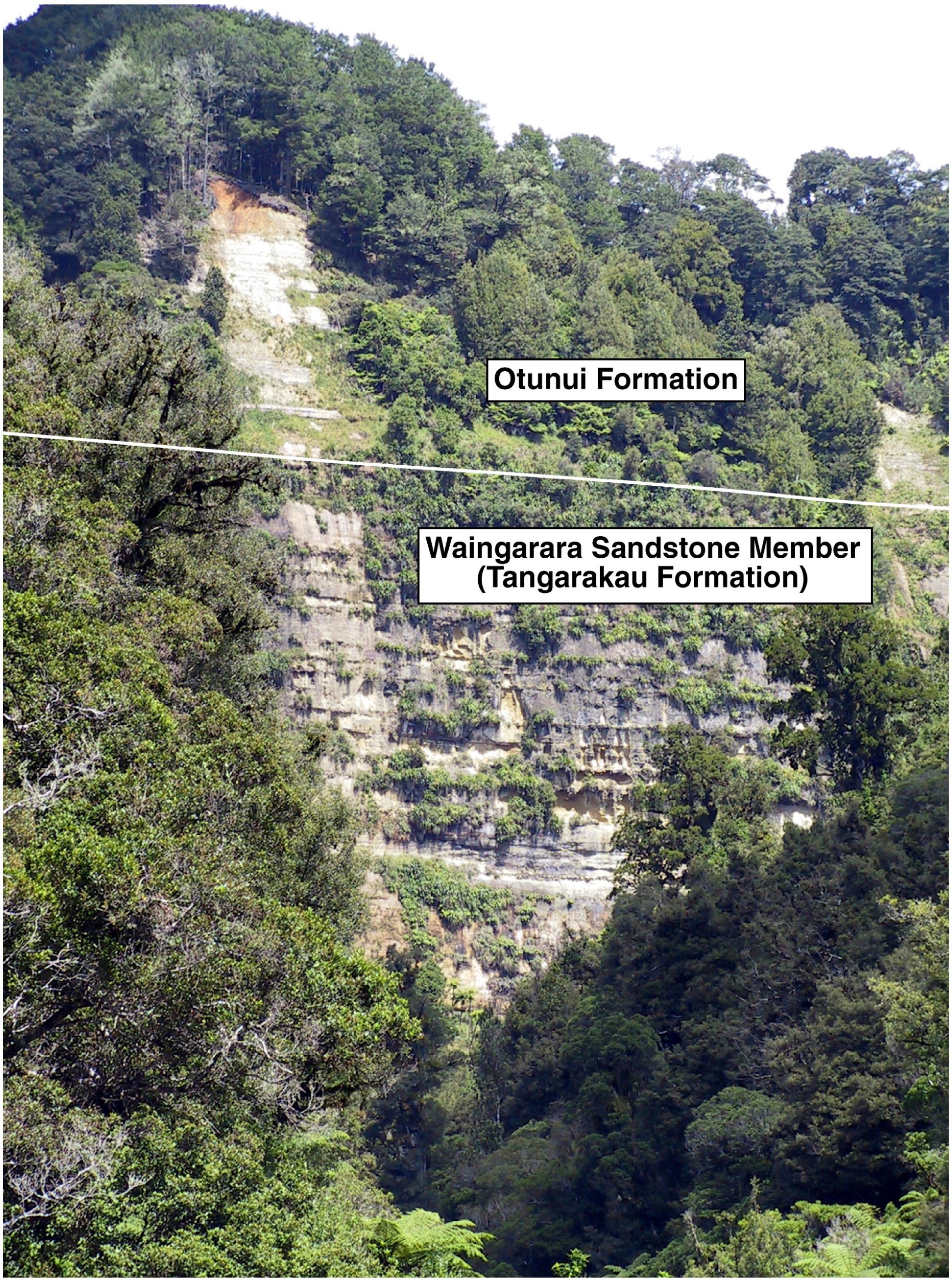


Fig. 57: *View from the road bridge at Morgan's Grave, SH43, of Waingarara Sandstone (Tangarakau Formation), conformably overlain by Otunui Formation. Stop 35, R19 – 689 457.*

Stop 36. Okau Road – Papakino Stream (R18 – 640 541) (Fig 58)

Between Stops 35 and 36 one climbs up through the Otunui Fmn to the Mt Damper Plateau, which is developed in the top of the Otunui Fmn and the base of the Mt Messenger Fmn. one then descends back down through the Otunui Fmn to its base, which one observes at this site (36) conformably overlying Moki Fmn, which continues down in outcrop for about 50 m to the Mt Damper Stream below the road. The contact between the Moki and Otunui Formations is marked in Fig. 58 and occurs between the bedded Moki Fmn and overlying massive silty sandstone of the Otunui Fmn. The beds in the Moki Fmn are turbidites that accumulated on a slope fan during the Middle Miocene. Note a phosphatic horizon 3 m below the top of the Moki Formation, which is an example of a correlative conformity in a slope setting.

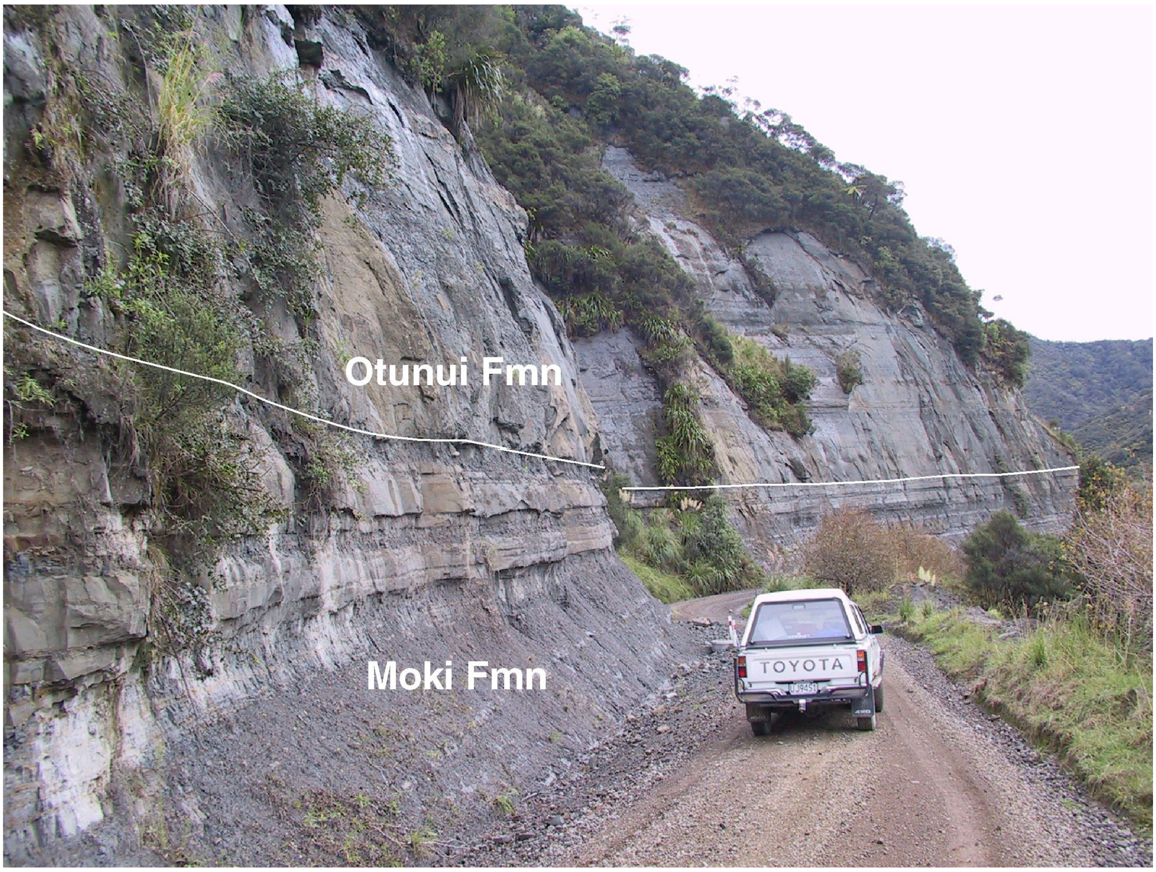


Fig. 58: *Cliff exposure on Okau Road (Stop 36), with bedded Moki Formation and overlying Otunui Formation.*

Stop 37. SH43, Tahora Saddle (R19 – 658 359) (Fig. 59)

From Tahora Saddle observe the occurrence of thick massive mudstone (Kohu Member) comprising the lower part of the Mt Messenger Formation, especially in southern and eastern sectors, and overlying sandstone-filled broad channel complexes **(Kaieto Member (new))** in the upper parts of the ridges and high hills (Fig. 59). Northeast – southwest striking faults offset Mt Messenger Formation, with throws of 10 to 100 m.

Fig. 59: *View from Tahora Saddle of the ridge to the west (Kaieto Trig) of sandstone-filled broad channel complexes. Stop 37, R19 – 658 359.*

Stop 38. SH43, Vera Road, Mt Messenger Formation channel complex (R19 – 609 286) (Fig. 60)

At this stop one can observe the geometry of the base of a channel cut into mudstone and the architecture of the sandstone-dominated channel fill (Fig. 60).

Fig. 60: *Photo of channel complex in the upper part of the Mount Messenger Formation, viewed from SH43 near Vera Road, looking to the south. Stop 38, R19 – 609 286.*

DAY 5 Drive south on SH 43

Stop 39. SH43, Whangamomona Saddle east side (R19 – 580 263)

This site represents the top of the Mt Messenger Formation and the highest stratigraphic occurrence of redeposited, channelised sandstone facies within fine grained mudstone. The sandstone beds were probably deposited as sandy debris flows within slope channels. Be particularly aware of traffic at this site.

Stop 40. SH43, Whangamomona Saddle west side (R19 – 567 262)

At this site one can walk down the road and examine a variety of facies within the lower part of the Kiore Formation. The cuttings start in a 6 m-thick, massive, fined-grained, well-sorted sandstone, that accumulated as one sedimentation unit. Note the burrowing at the top of this unit. This is overlain by 8 m of bioturbated sandy siltstone, which represents background non-channelised slope facies. Note the diffuse boundaries between sandier and siltier beds and the degree of bioturbation. The next unit is a 15 m thick channel deposit with multiple redeposited sandstone beds. Discussion points: sedimentation regime on the paleo-slope; comparisons with the facies in the upper part of the Otunui Fmn. Watch the traffic and enjoy the beautiful native bush setting.

Stop 41. SH43, Pohokura Saddle (R19 – 509 239) (Fig. 61)

Road cut exposures of slumped packets in the Kiore Formation, internally comprised of thin-bedded sandy siltstone and silty sandstone, considered to have accumulated on the upper part of the contemporary slope, and to have moved down slope by mass-wasting processes without being totally disaggregated (Fig. 61). Note the disharmonic tight isoclinal folds at the base of the slumped packet and over steepened channel margin. Watch the traffic. Discussion point: origin of slumping (lateral calving of submarine channel walls?); comparisons with the lower part of the Mt Messenger Fmn on the North Taranaki coast.

Fig. 61: *Slump packets in the Kiore Formation, themselves comprising redeposited slope channel facies, west side, Pohokura Saddle. Stop 41, R19 – 509 239.*

Stop 42. Junction Road, Kiore Formation (Q19 – 498 244) (Figs 62 & 63)

A new road cutting gives an expanded view of migrating, stacked, mainly aggradational channel facies that formed in upper slope environments under sediment satiated conditions (Fig 62). The outcrop gives an insight into the type and scale of depositional structures, this insight usually being limited by the size of outcrops. These channels are an important architectural element of the Kiore Formation. Internally there are erosive channel margins as well as conformable, draping and aggradational channel margin geometries. The beds accumulated as thin-bedded turbidites (Fig. 63).

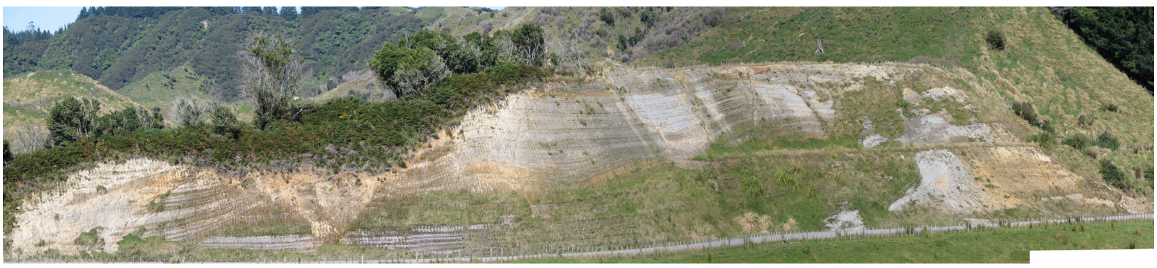


Fig. 62: *Photo of channelised facies, Kiore Formation, Junction Road. Stop 42, Q19 – 498 244 .*

Fig. 63: *Close photo of thin-bedded turbidites in channelised facies (Fig. 57), Kiore Formation, Junction Road. Stop 42, Q19 – 498 244.*

Stop 43. Te Wera Quarry, channelised limestone facies, Kiore Fmn (Q20 – 448 195) (Fig. 64)

A remarkably thick carbonate succession of Tongaporutuan age is well exposed within the Kiore Formation in the now disused Te Wera Quarry. Mapping has shown that this deposit accumulated within a localised shelf environment, whereas sediments below and above accumulated in continental slope facies. This locality sits atop the Patea-Tongaporutu High, and Kiore-1 was drilled a few hundred metres to the west of this quarry. There may have been some renewed mobility of this structural high, and or some regional tectonic uplift that shallowed the water depth in the basin allowing shelf deposits to accumulate. The carbonate succession in the quarry cannot be mapped widely and it is possible that the carbonate source area was located over the Patea-Tongaporutu High. The limestone beds comprises barnacle- and bivalve-dominated sandy limestone organised into metre-scale depositional units showing a variety of sedimentary structures, possibly large scale crossbeds or delta fronts. This may reflect reworking of carbonate gravel and sand off the structural high into surrounding deeper water. From the sequence stratigraphy of the shelfal Matemateaonga Formation we know that shellbeds and the bulk of the carbonate formed during transgressions associated with eustatic sea-level rise. There is a significant thickness of sandstone beneath the limestone facies, which may have accumulated in shoreface (inner neritic) environments rather than as slope channel complexes, as one observed at Stop 40, which nevertheless have similar textural character. This limestone developed on a high that was detached from a shoreface-inner shelf system to the south.

Discussion points: Faunal composition of limestone; timing of sedimentation within a sequence stratigraphic context.

Fig. 64: *View of Te Wera Quarry where carbonate dominated facies are well exposed. Stop 43, Q20 – 448 195.*

Stop 44. SH43, Strathmore Saddle (Q20 – 398 115) (Fig. 65) (Log 6)

From the top of Strathmore Saddle there are great views to the southeast of the lower part of the Matemateaonga Formation. Note the tabular geometry of the strata in the formation, which dip 2-4 degrees to the southwest. The tabular geometry reflects the shelfal depositional setting and the occurrence of multiple Vail-type sequences. One can examine the section exposed down the road on the western side of the saddle (Fig 65 & 66). The lower sequences in the Matemateaonga Formation in this section have cryptic development of TSTs (transgressive systems tracts). Nevertheless the utility of the sequence stratigraphic model enables one to interpret the cyclicity and the relative sea-level changes evident in this succession.

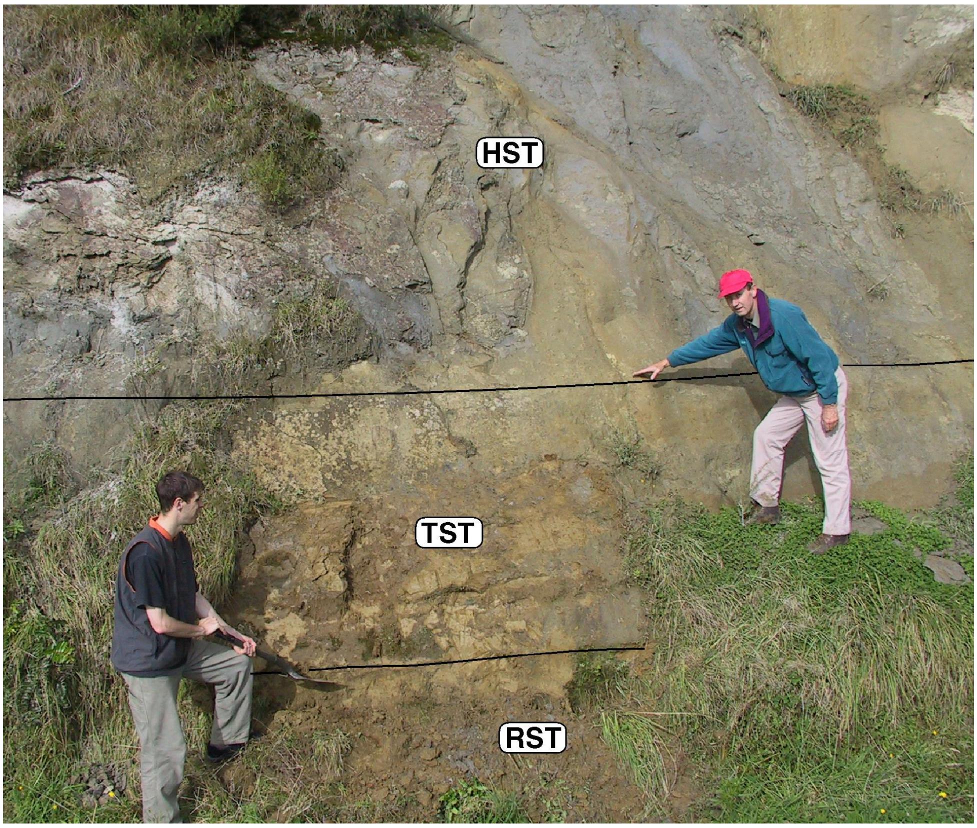
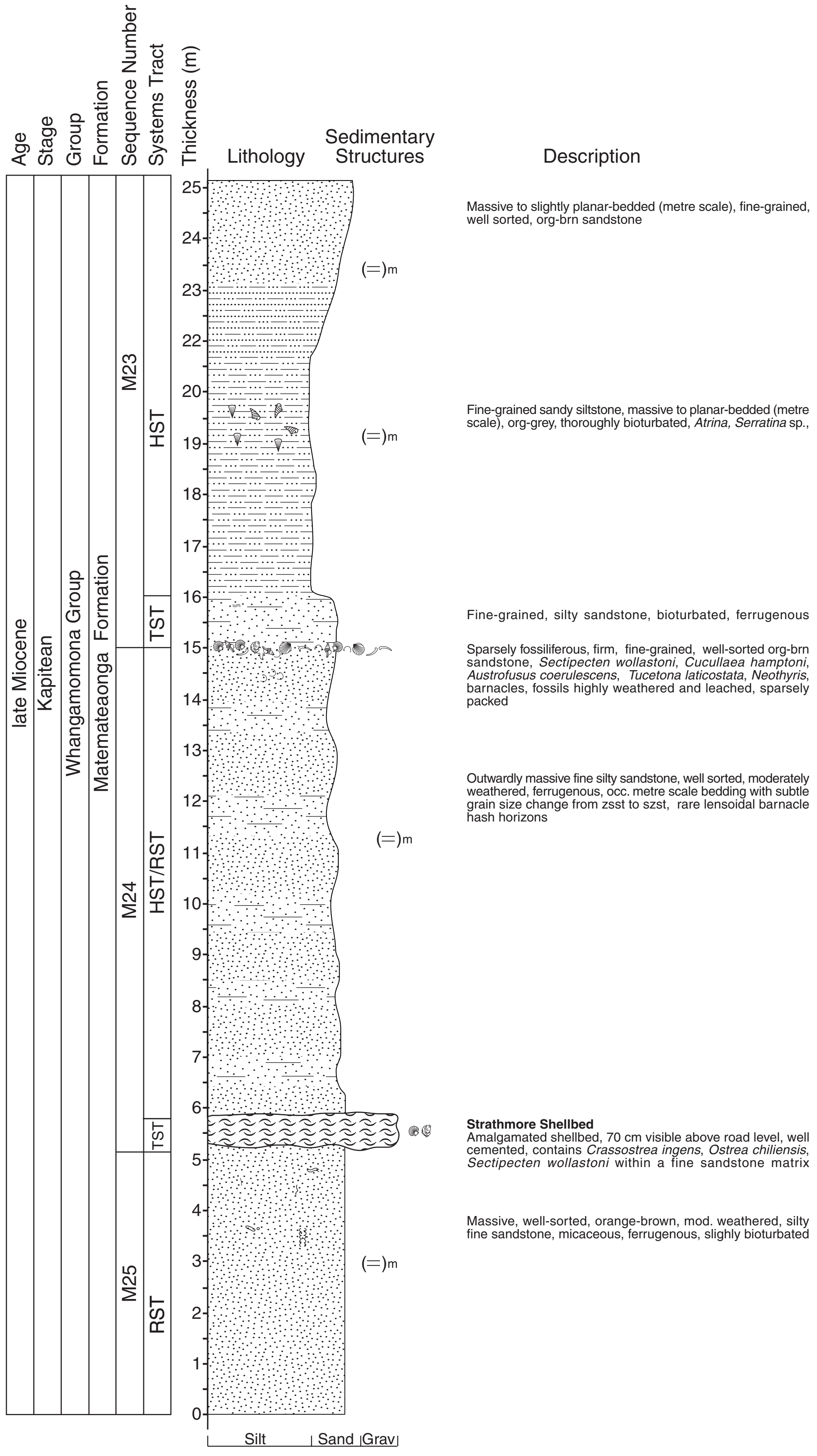


Fig. 65: *View of part of two sequences in the middle part of the western side of Strathmore Saddle, Matemateaonga Formation. Stop 44, Q20 – 398 115. RST= regressive systems tract, TST= transgressive systems tract, HST= highstand systems tract.*



Stratigraphic Log 6 (Stop 44): *Stratigraphic column, Strathmore Saddle, west side, Q20 – 398 115.*

Stop 45. Wingrove Road, Pukengahu. (Q20 – 307 013) (Fig. 66)

This is a brief stop to examine faulted subtidal sandstone within a regressive systems tract in the Maben Member, Matemateaonga Formation (Fig. 66).

Fig. 66: *Exposure of well-developed regressive sandstone beds, Wingrove Road, Pukengahu. Stop 45, Q20 – 307 013.*

Stop 46. Patea River bank section (Q20 – 342 010) (Fig. 67); Farmer: Kevin Downs, 06-762 2743

To get to this section one needs to cross to the back of Kevin Down's farm via a well-formed farm track, taking about 20 minutes. At this site there is excellent exposure across three sequences in the Waitiri and Whenuakura Members of the Matemateaonga Formation (Fig. 67). Particular features to be observed are the cryptic sequence boundary in the lower sandstone, a thick TST forming the lower part of a symmetrical sequence, thick HST and RST components, and the compound Whenuakura Shellbed.

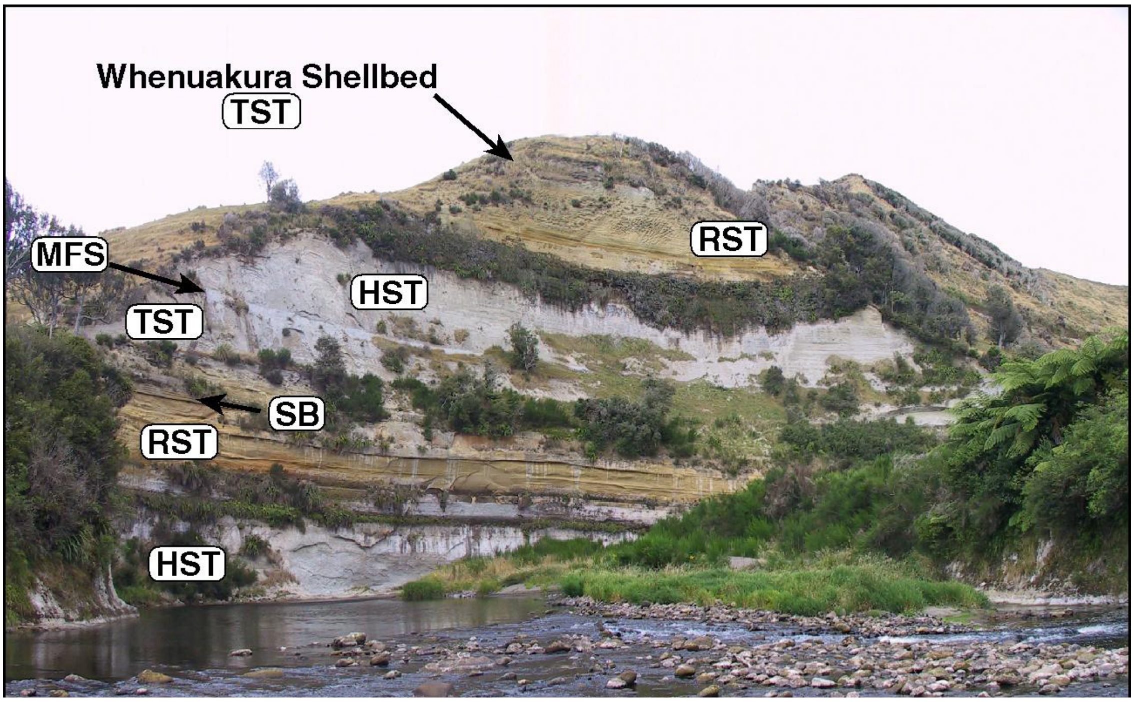


Fig. 67: *Cliffed exposure of two cycles within the Waitiri Member, Matemateaonga Formation, Patea River, near Makaria Stream. SB = sequence boundary, MFS = maximum flooding surface. Stop 46, Q20 – 342 010.*

Stop 47. Aorere Road, Mangamingi (Q20 – 349 947) (Fig. 68) (Log 7)

At this site one can observe the Parangarehu Shellbed and the underlying sequence boundary cut across regressive sandstone of the underlying sequence (Kuraiti Member) (Fig. 68 & Log 7).

There are great views from this site to the east of the upper part of the Matemateaonga Formation.

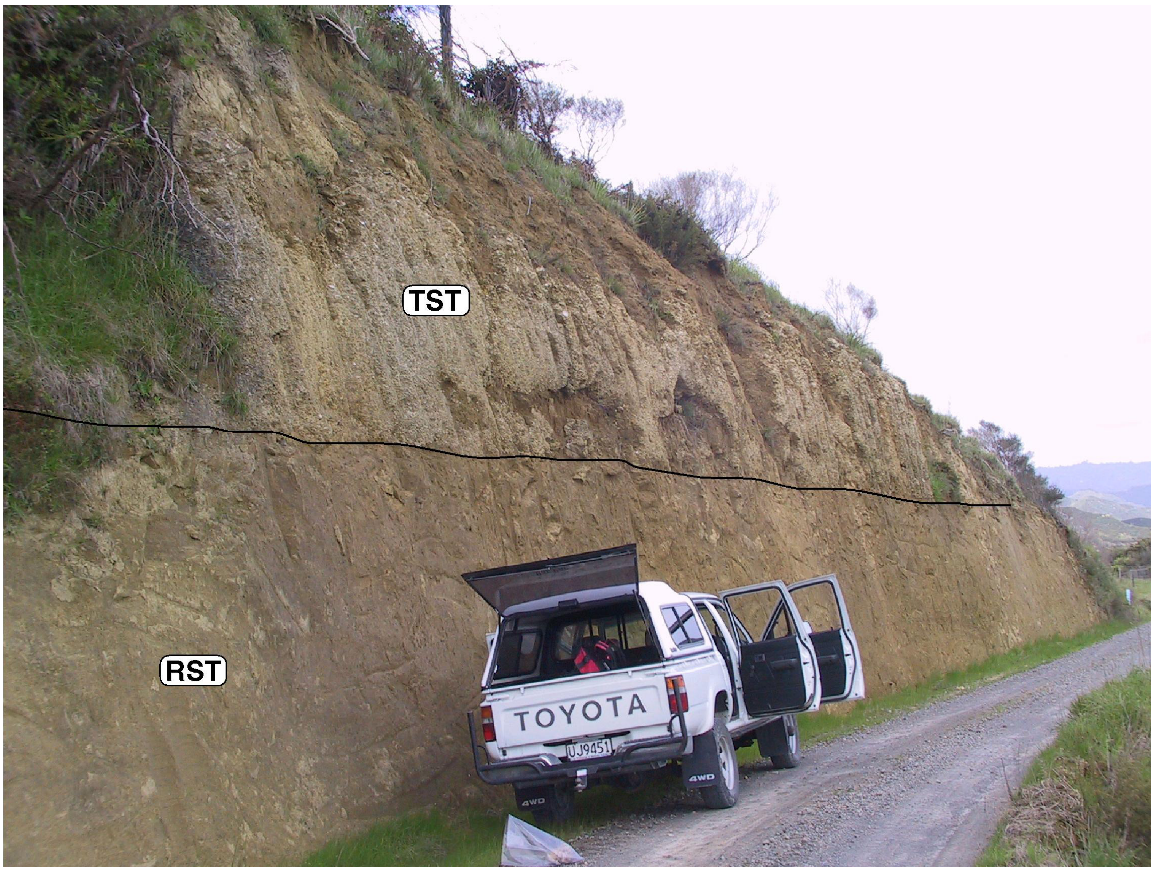
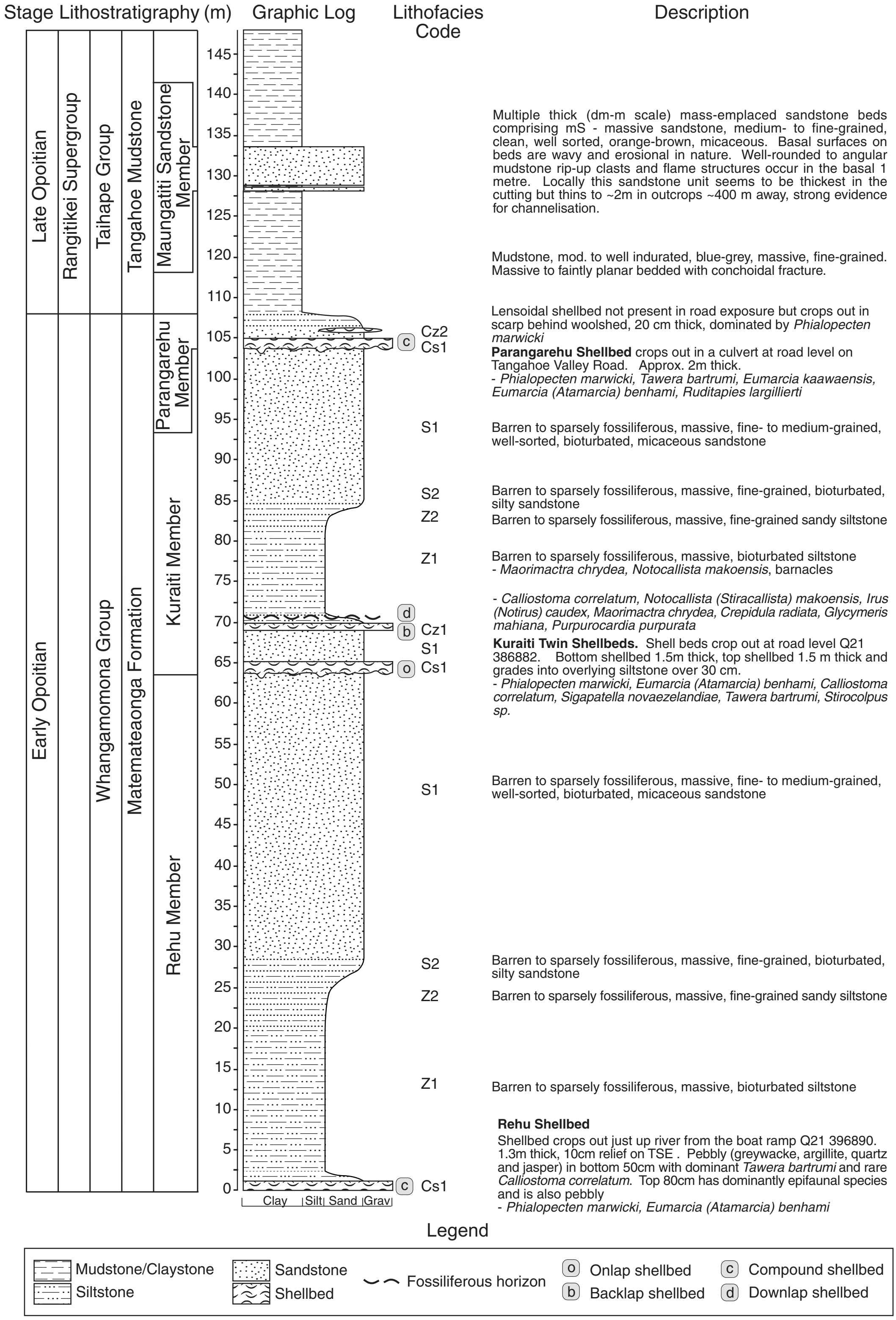


Fig. 68: *Parangarehu Shellbed (TST) and underlying sandstone (RST) of the Kuraiti Member cropping out on Aorere Road, Mangamingi. Stop 47, Q20 – 349 947.*



Stratigraphic Log 7 (Stops 47, 48, 49, 50): *Composite stratigraphic column of the uppermost Matemateaonga Formation, and lower part of the Tangahoe Mudstone, Tangahoe Valley Road, Lake Rotorangi (Stop 47).*

Stop 48. Tangahoe Valley Road, Tangahoe cutting, Maungatiti Sandstone Member exposure. (Q21 – 375 877) (Fig 69)

At this deep road cutting (take care for falling rocks) one is at the base of the Tangahoe Mudstone, which accumulated in upper bathyal water depths (400-600 m). The thick sandstone is named the **Maungatiti Sandstone Member (new)** and we infer deposition as one bed as a sandy debris flow. This bed has been mapped from Patea Dam to the Mangamingi Valley, a distance of 20 km. Elsewhere this interval comprises multiple sandstone beds. This unit is inferred to represent a broad channelised sandstone to basin floor fan deposit. The marked subsidence reflected in the Tangahoe Mudstone records the formation of the Wanganui Basin as a discrete depocentre, and there are parallels with the subsidence at the base of the Mt Messenger Formation.

Fig. 69: *Exposures of the Tanghoe Mudstone and the Maungatiti Sandstone Member in the cutting on Tangahoe Road, Lake Rotorangi (Stop 48).*

Stop 49. Parangarehu Shellbed outcrop, Larkhams woolshed. (Q21 – 378 876)

At this stop one can observe the contact between the Parangarehu Shellbed and the Tangahoe Mudstone, noting the occurrence of a 5 m thick silty sandstone above the shellbed, which rapidly fines upward into mudstone facies. Discussion point: marked tectonic subsidence event; excision of shelf facies; and the occurrence of dramatic flooding, marking the boundary between the Whangamomona and Rangitikei (mega) Sequences.

Stop 50. Kuraiti Twin Shellbeds road outcrop (Q21 – 387 881) (Fig. 70 & 71)

At this site one can examine the Kuraiti Twin Shellbeds form the base of the second to top sequence within the Matemateaonga Formation. The lower shellbed shows characteristics of a classic onlap shellbed; the upper shellbed is a classic backlap shellbed, and has a downlap shellbed superimposed on its upper surface.

One can then drive a short distance up the lake to the water ski club where one can view an extensive outcrop of the Kuraiti Twin Shellbeds (Figs 70 & 71).

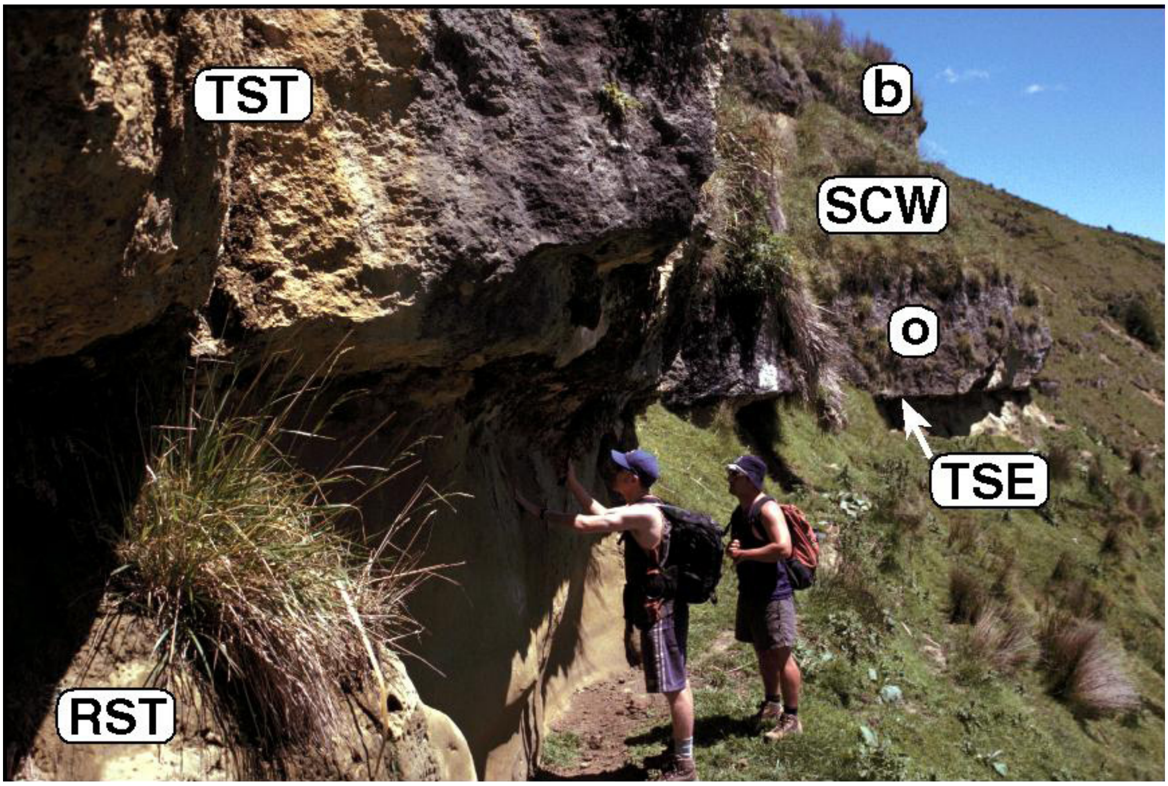


Fig. 70: *Exposure of the Kuraiti Twin Shellbeds in hills to the north of the Water Ski Club, Lake Rotorangi (Stop 50).*

Fig. 71: *View of the upper part of the Matemateaonga Formation, including Kuraiti Twin Shellbeds, in ridge on Lake Rotorangi at the end of the Tangahoe Valley Road.*

Stop 51. Waihi Beach, Denby Road, Hawera. (Q21 – 166 769) (Fig. 72)

The track to the beach runs from the car park at the end of Denby Road. It intersects the contact between the Rapanui Terrace and the Ohawe Sandstone of the Whenuakura Subgroup. The Rapanui Formation corresponds to Oxygen Isotope Stage 5e and is approximately 125 ka in age. This contact is a prominent, planar, wave cut surface bored by the bivalve pholad *Barnea similis,* marking a sequence boundary at the base of the terrace succession. The sequence boundary is overlain by a TST, including a lower onlap shellbed of a disarticulated and well preserved bivalve assemblage. The TST is overlain by lahar deposits from Egmont Volcano, and terrestrial deposits. The sea cliff (take care for rock falls) exposes Waipipian-aged sequences within the Whenuakura Subgroup, and at high levels the Rapanui Formation terrace deposits. The Whenuakura Subgroup represents the development of a shelf succession over the bathyal Tangahoe Mudstone. There are parallels with the development of shelfal Matemateaonga Formation over Kiore Formation. Fauna occurring in the sandstone include *Ostrea chiliensis*, *Mesopeplum crawfordi, Polincies waipipiensis* and *Phialopecten marwicki*.

Fig. 72: *Coastal cliff exposing shelfal Ohawe Sandstone, Whenuakura Subgroup, overlain by Rapanui Formation, Waihi Beach, Denby Road, Hawera (Stop 51).*