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Field Trip Guides – Contents

Field Trip 5

Stratigraphic Architecture and Sedimentology of King Country and Eastern Taranaki Basins

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Part A: Geological Setting

INTRODUCTION

This field trip will examine aspects of new work on the successions of mainly Neogene age exposed in King County and eastern Taranaki Basins. We aim to show participants evidence for the stratigraphic architecture of these basins, to identify the orders of cyclicity within them, and to draw tectonic interpretations, particularly for eastern Taranaki Basin margin. Our analysis of the fill of the basins reveals the occurrence of five 2nd order sequences of 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. On this trip we will not get to examine the Te Kuiti Group.

Several themes emerging from the stratigraphic architecture of the basins will recur during the field trip: (1) The late Miocene –Pliocene units (Whangamomona and Rangitikei Sequences) each comprise erosionally truncated shelf-slope-basin depositional systems that prograded northward into King Country Basin and Wanganui Basins. (2) Aspects of the structural development of eastern Taranaki Basin margin, particularly the timing of movement on Taranaki Fault and subsequent collapse of this margin, can be clarified from investigation of the stratigraphic record onshore. (3) Improved concepts of the paleogeographic development of the region and controls on source-to-sink sediment pathways are possible from analysis of the onshore record. (4) There has been a very significant Pliocene-Pleistocene tectonically driven uplift and erosion episode centred on central North Island and extending out into Wanganui Basin and eastern parts of Taranaki Basin.

GEOLOGICAL OUTLINE OF CENTRAL-WESTERN NORTH ISLAND

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).

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).

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. 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 this study, 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).

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.

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. Fig. 5 shows the lines of these cross-sections in relation to the distribution of the major stratigraphic units.

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.

This inversion of the basin 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 third Neogene megasequence is represented by the Whangamomona Group (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 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 10 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).

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 Whanganui 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.

TWO PHASES OF NEOGENE CONTINENTAL MARGIN PROGRADATION

Fig. 8 is a block diagram that shows schematically the depositional and stratigraphic architecture of the two 2nd 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.

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 (Fig. 1, 2), 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 30-5^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 1000 m of displacement.

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 260 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 120 m-thick middle unit of coal measures, fluvial conglomerate, and shoreface sandstone (Maryville Coal Measures); and (iii) an upper 80 m-thick unit of regressive shoreface to innermost shelf sandstone (Tangarakau Sandstone) (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 upper Altonian as a mid-bathyal succession (King et al. 1993). Moki Formation accumulated as submarine channel and fan deposits on a slope to basin floor west of the modern coastline (King & Thrasher 1996) and also to the east (unpublished data). 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 Clifdenian. 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 Clifdenian and infer that this break migrated slowly inland (retrogressed). The system had a strong aggradational component during the Altonian-lower Clifdenian 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 Clifdenian-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; Cartwright 2003; Evans 2003). It passes gradationally upwards into massive siltstone facies of the Manganui/Mt Messenger Formation. Channelised redeposited sandstone deposits occur within the upper parts of the Otunui Formation and near the transition zone to Manganui/Mt Messenger Formation (Fig. 11). 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 (Fig. 11), 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 18 Ma (upper Altonian) and 11 Ma (upper Waiauan) there was marked subsidence to bathyal (1000 m) basin floor environments of what had been land at about 19 Ma 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 12 Ma, when higher rates of uplift and erosion developed in the plate boundary zone, reflected in higher 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.

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. in press), 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.

Acknowledgments

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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.

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.

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.

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), in press.*

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.

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) in press*.

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. et al. 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.

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.; 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.

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.

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. in review: 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, in press.*

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.

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.

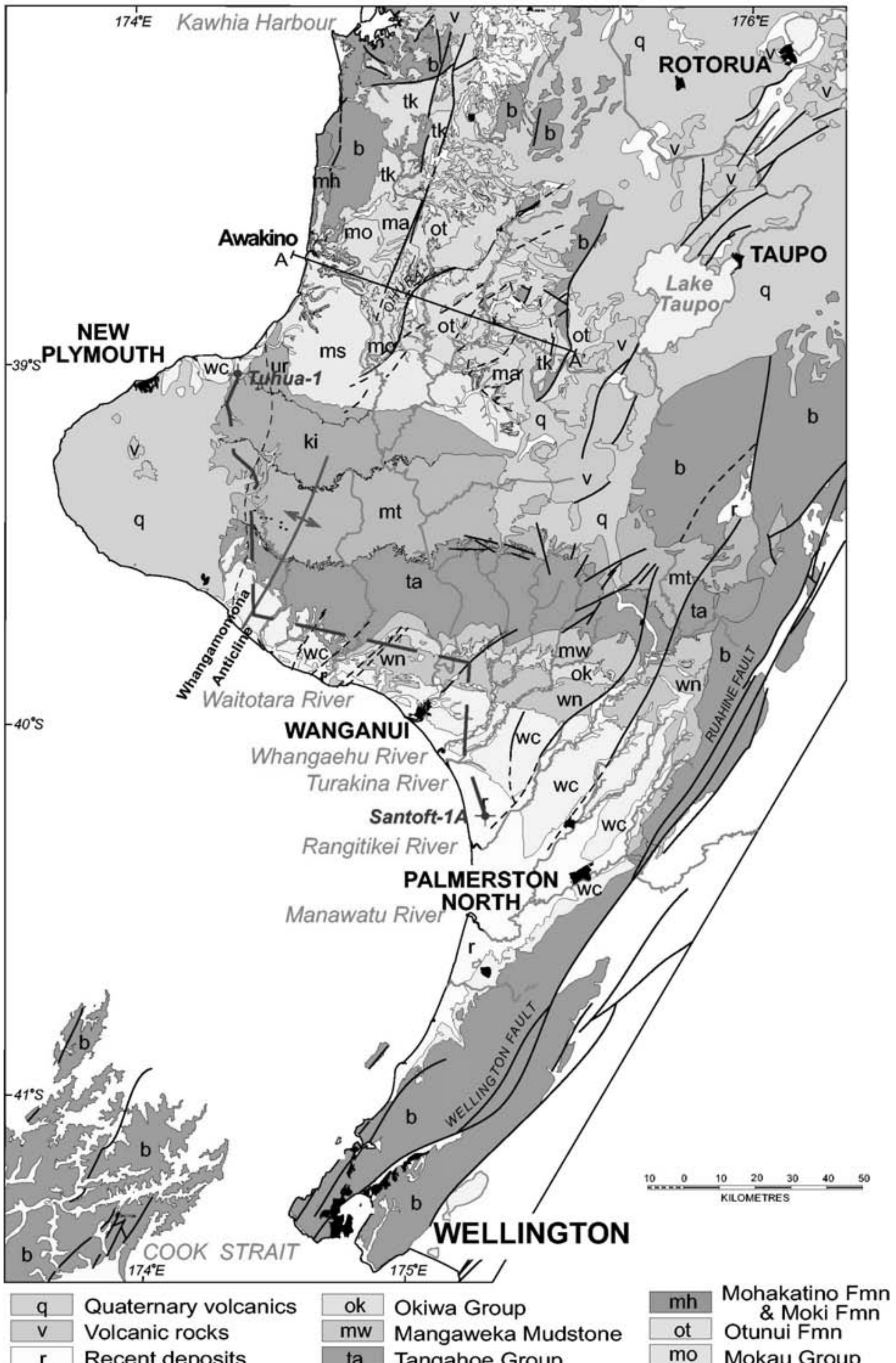


Fig. 1. Simplified geological map of western North Island (modified from New Zealand Geological Survey 1972), showing the main stratigraphic units in the eastern Taranaki, King Country, and Wanganui Basins (see Fig. 2). Cross-section line A-A'is the basis for the chronostratigraphic panel in Fig. 9.

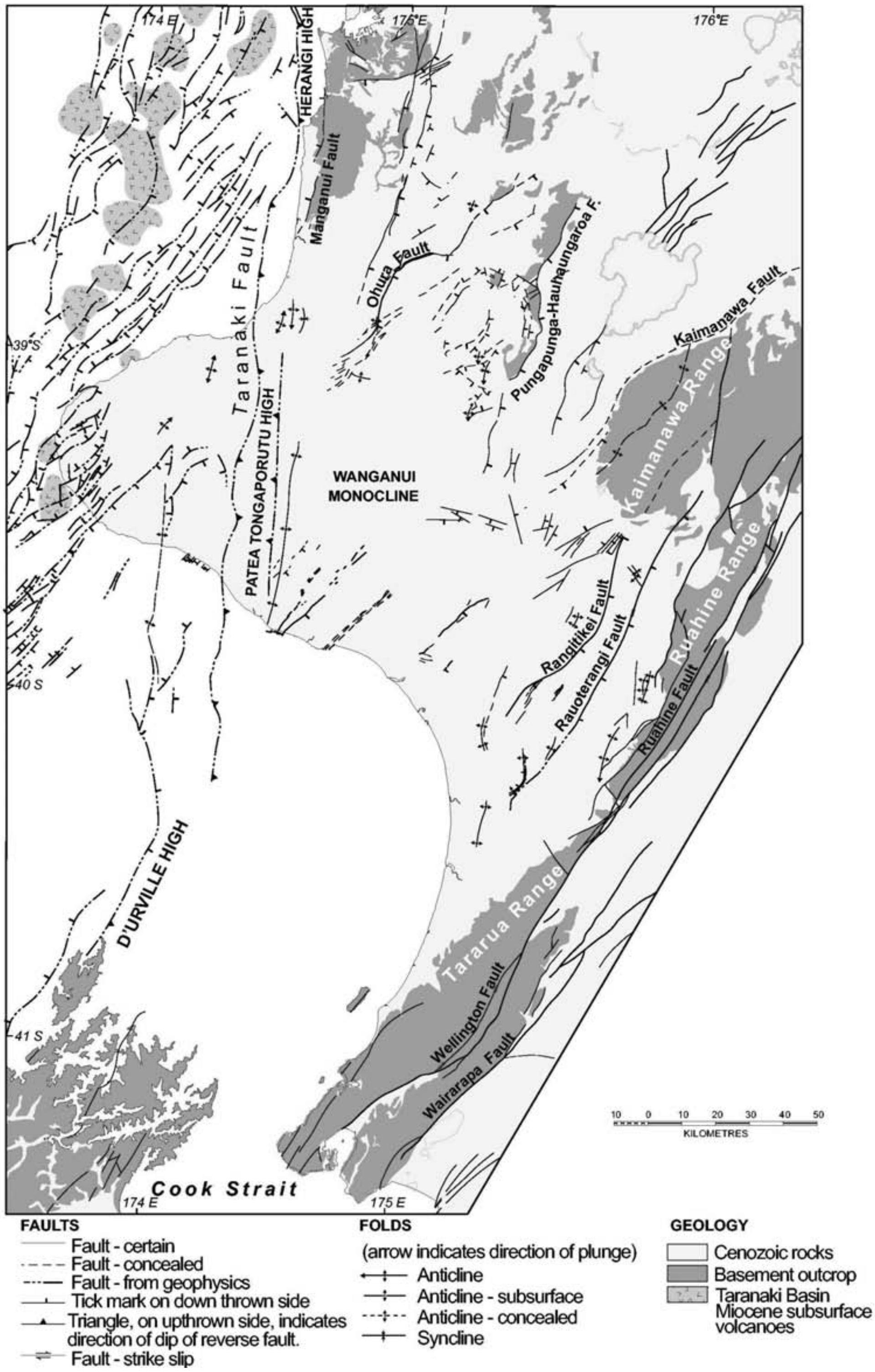


Fig. 2. Map of western North Island showing the major geological structures and the distribution of basement. While many of the structures are of Pliocene-Pleistocene age, some date back to the early Miocene and may not be currently active

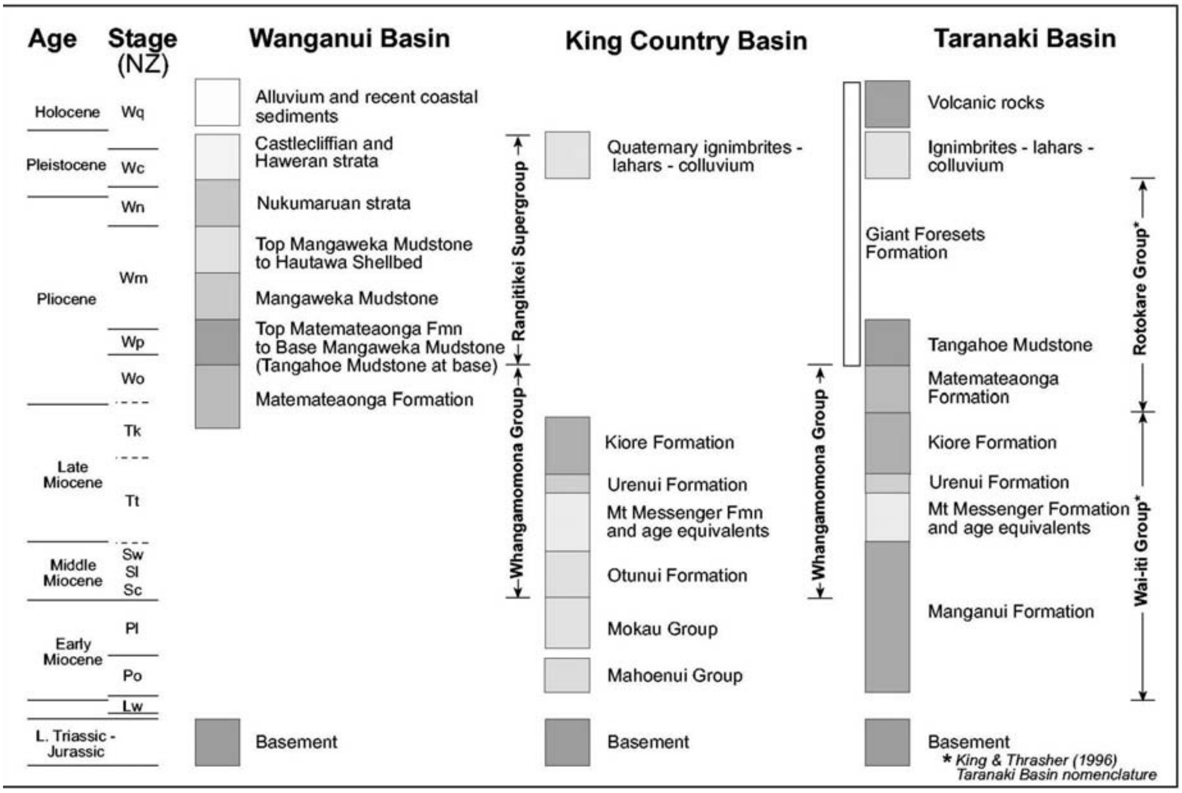


Fig. 3. The major Neogene stratigraphic units in each of Taranaki, King Country, and Wanganui Basins, and their age. The Moki and Mohakatino Formations, which occur within Manganui Formation in Taranaki Basin, are not shown.

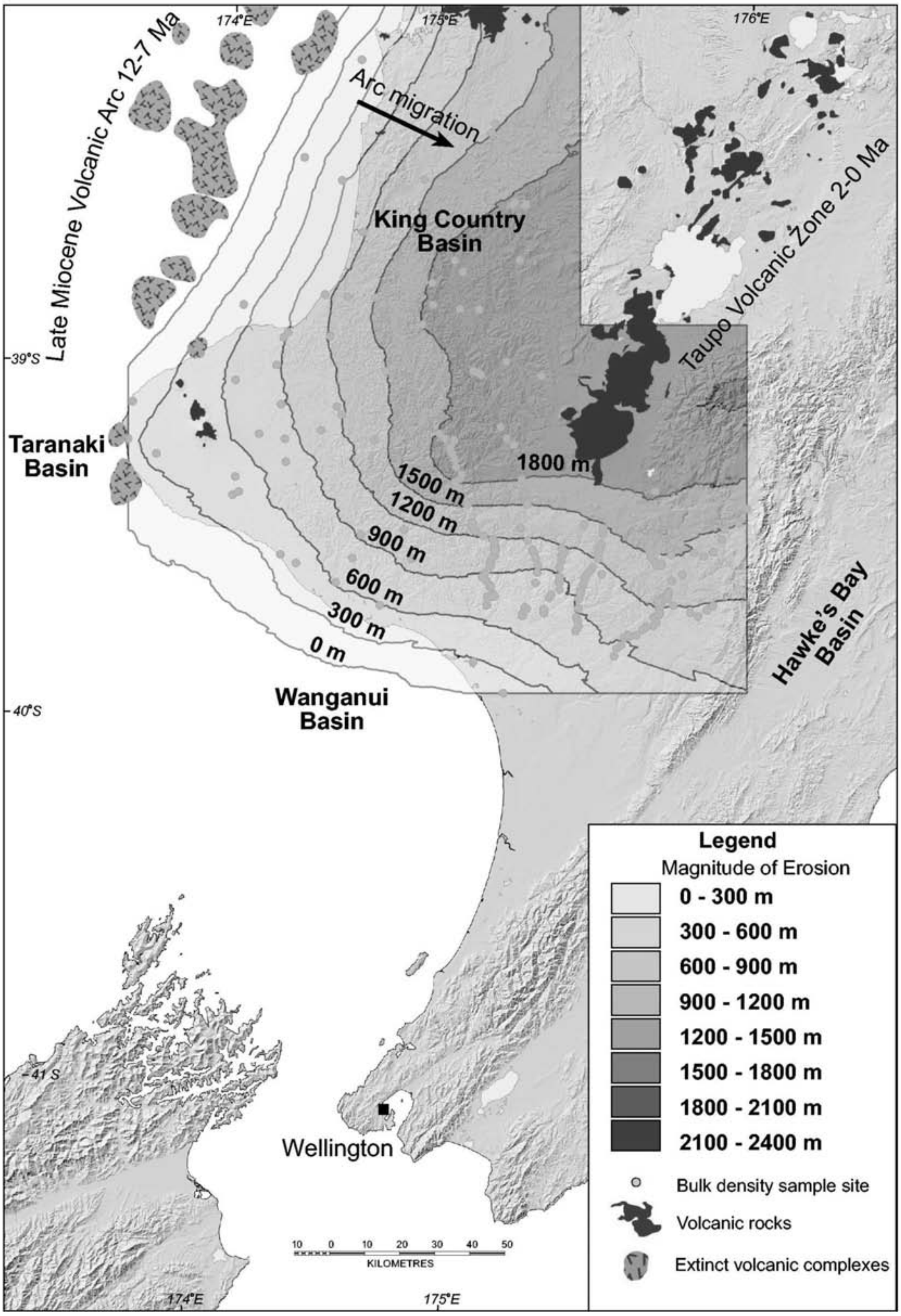


Fig. 4. Map showing the magnitude in 300 m contours and pattern of Pliocene-Pleistocene erosion over central North Island derived from mudstone bulk density data. See text for discussion.

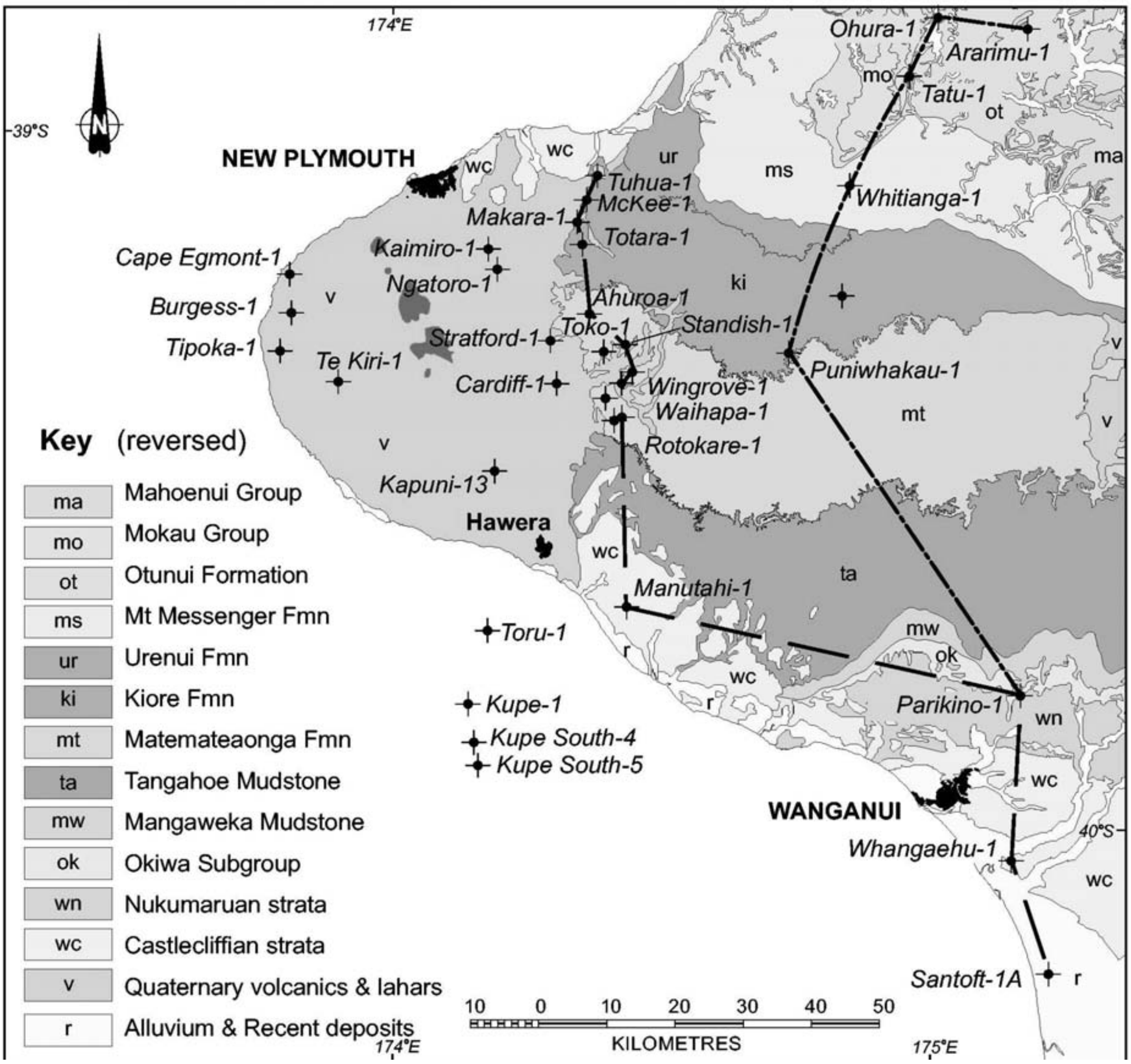
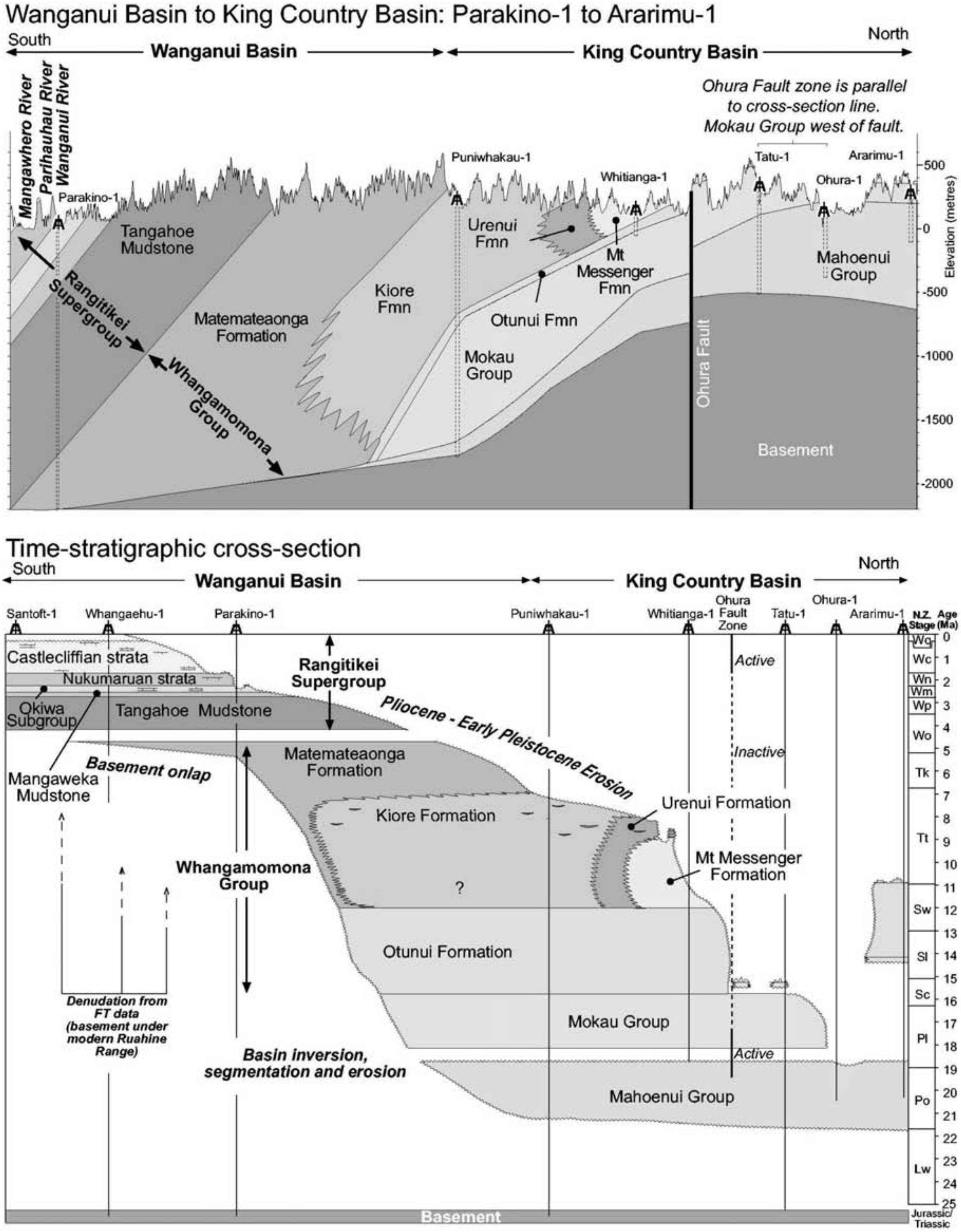


Fig. 5. Geological map of central-western North Island, including Taranaki Peninsula, showing the location of key hydrocarbon exploration holes and the line of two cross-sections illustrated in Fig. 6 & 7.

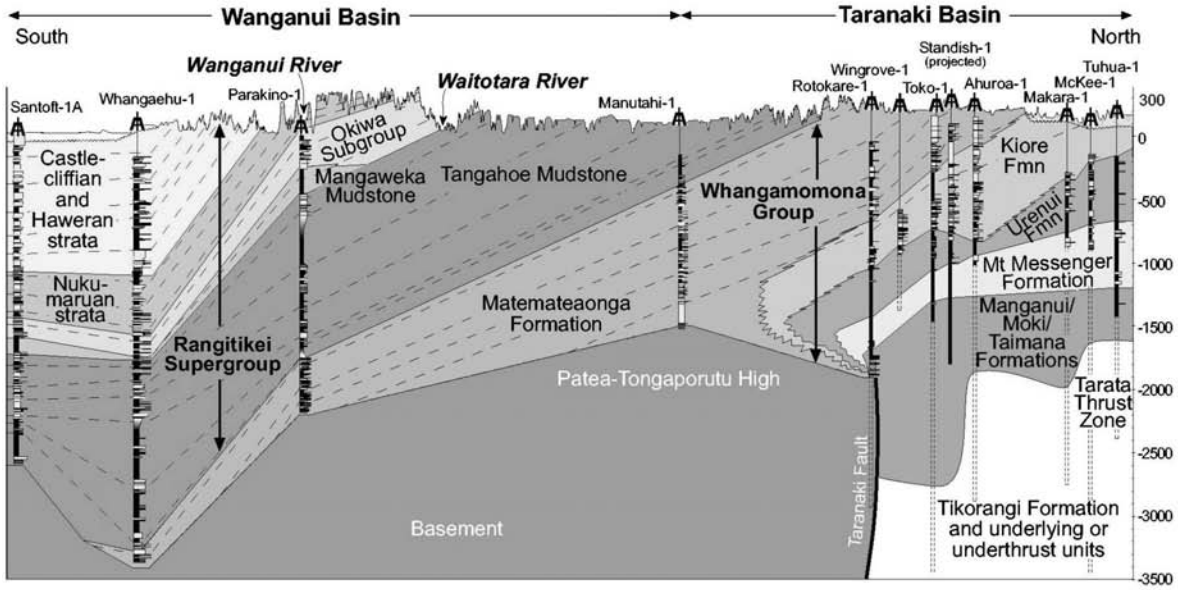


Wanganui Basin to King Country Basin: Parakino-1 to Ararimu-1

Time-stratigraphic cross-section

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.

Wanganui Basin to Taranaki Basin: Santoft-1A to Tuhua-1



Time-stratigraphic cross-section

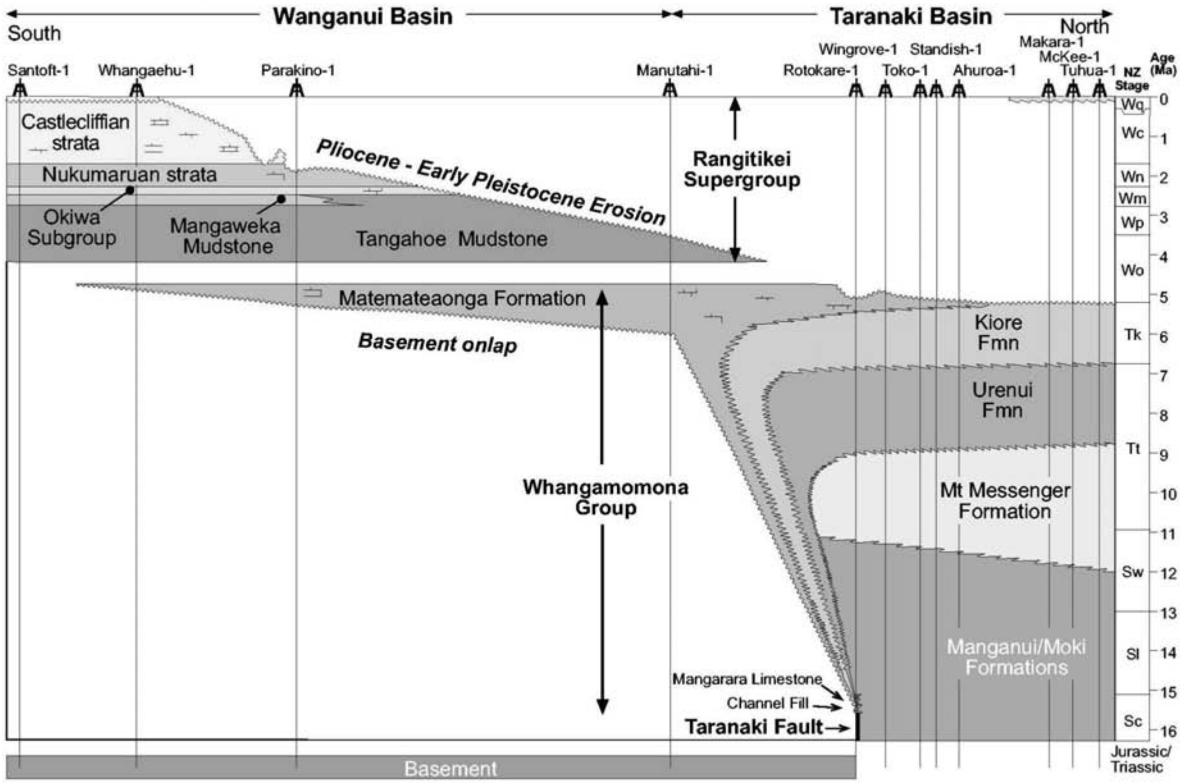


Fig. 7. Wanganui Basin to Taranaki Basin (Santoft-1A to Tuhua-1) stratigraphic panel built up from well-to-well correlations, and related time-stratigraphic cross-section.

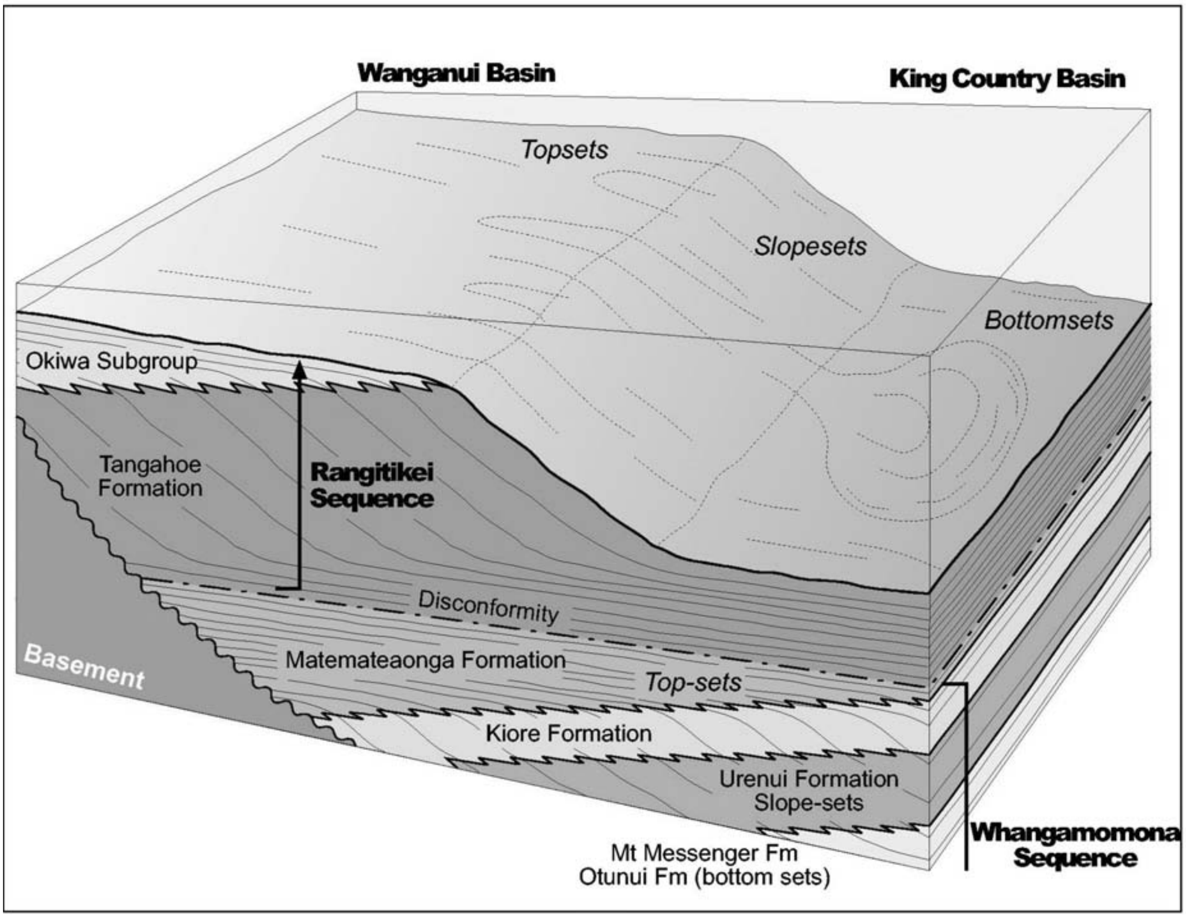


Fig. 8. Block diagram showing schematically the occurrence of two continental margin wedges representing the Whangamomona and Rangitikei Sequences, each having prograded northward through central-western North Island during the late Neogene. North is to the right.

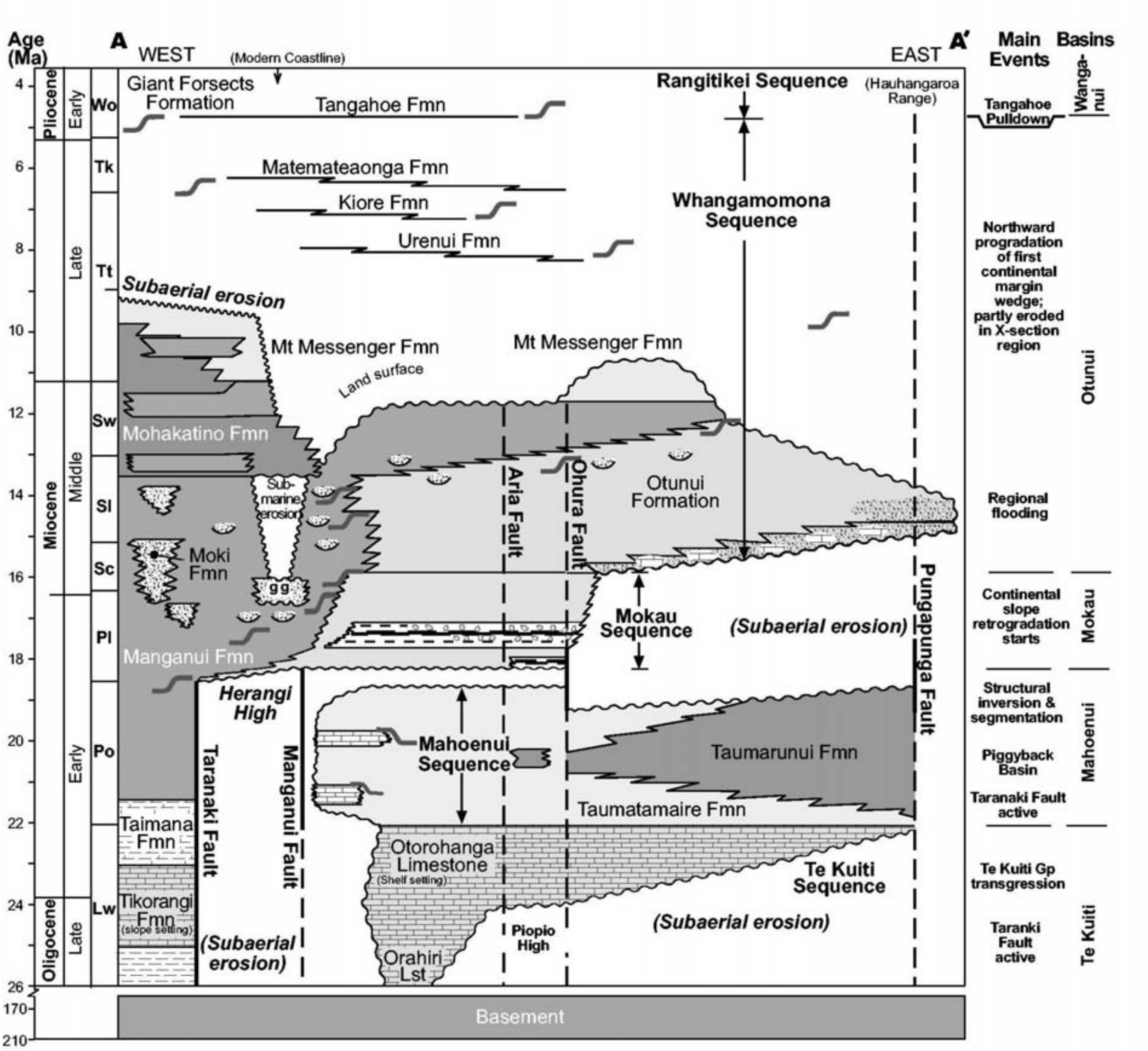


Fig. 9. Chronostratigraphic panel representing the relationship between formations and 2nd order sequences of Cenozoic age cropping out in a cross-section between Awakino Heads in eastern Taranaki Basin and Waitui Saddle on the Hauhungaroa Range along the eastern margin of King Country Basin (line of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


Optional stops
1
2
3
4
5
6
7
8
9
10
11
12
13
14
TAUMARUNUI
Ongarue R
Ohura R
Ohura River
Whakapapa River
Ohura
Owhango
Kakahi
Tunakatokoto
Te Koura
Ohura
Ohura
Aukopae
Mangaparo
Tatu
Kiritehere
0
2.5
5
10
15
Km

Map 1


0
2.5
5
10
Km
White Cliffs
Pariokariwa Pt
Mimi River
Urenui
Ahititi
Okau
Kotare
Waitaanga
Pakaaruhe
Uruti
Okoki
Kaimikai
Purangi
Matau
Tangarakau
Tahora
Tahora Saddle
Kohuratahi
Marco
Whangamomona
Whangamomona Saddle
Pohokura
Pohokura Saddle
Paparata Saddle
Te Wera
Huiroa
Huiakama
Strathmore
Makahu
Douglas
Toko
Tututawa
Puniwhakau
Aotuhia
Mangamingi
Matemateaonga Range
11
12
13
14
15
16
17
18
19
20
21
22
23

Map 2


Tariki
Midhurst
East Egmont
Manganui River
Patea River
Pembroke
Wharehuia
Stratford
Cardiff
Toko
Douglas
Te Wera
Strathmore
Makahu
Ngaere
Pukengahu
Bird Road
Mangamingi
Matemateaonga
Kapongai
Mangatoki
Eltham
Rawhitiroa
Matapu
Te Roti
Lake Rotorangi
Okaiawa
Normanby
Ohawe
Tokaora
Hawera
Waingongoro River
Meremere
Ohangai
Mokoia
Manutahi
Alton
Hurleyville
Tangahoe River
Manawapou River
Kakaramea
Patea
Kohi
Waverley
Rangikura
NAKI BIGHT
24
25
26
27
28
29
30
0
2.5
5
10
Km

Map 3

Part B – Itinerary and field stop notes

Thursday 9th December

Depart Taupo conference venue at 5:15 pm. Travel via State Highway 1 to Turangi, then via State Highway 41 to Taumarunui. **Accommodation at Central Park Motor Inn (ph 0800 238 030).**

Waituhi Saddle (T18 – 307 569) (Optional stop depending on time)

Road cuttings leading up to Waitui Saddle and in the vicinity of the saddle expose Middle Miocene Otunui Formation. At the saddle the lithology is a fine-grained siltstone, probably near the transition to the base of the Mt Messenger Formation.

Grand views of the King Country Basin are evident from the road and the lookout tower a short walk to the north.

Optional stop. State Highway 41, near Hohotaka Road (S18 – 235 535).

Road cuts expose Mahoenui Group flysch beds (Taumarunui Formation) a short distance west of the contact on basement, which is virtually where the bush meets the farm land uphill to the east. We infer from the occurrence of the flysch beds that the basin margin is currently erosionally truncated and that the contemporary basin margin lay much farther to the east.

Friday 10th December

Stop 1. Okahukura Rest Area - State Highway 4 (S18 – 029 645)

Stop to view the geology of the surrounding region 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 Miocene faulting on the outcrop distribution of geological units.

Stop 2. Okahukura Saddle Road, (S18 – 015 667)

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. 10). 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.

Stop 3. Okahukura Saddle Road (S18 – 015 675)

At this location we will observe road cuttings through a submarine channel system. Appendix II 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 we consider to be the Otunui Fmn – Mt Messenger Fmn contact. Discussion points: submarine channel architecture and fill; contemporary continental shelf - slope position.

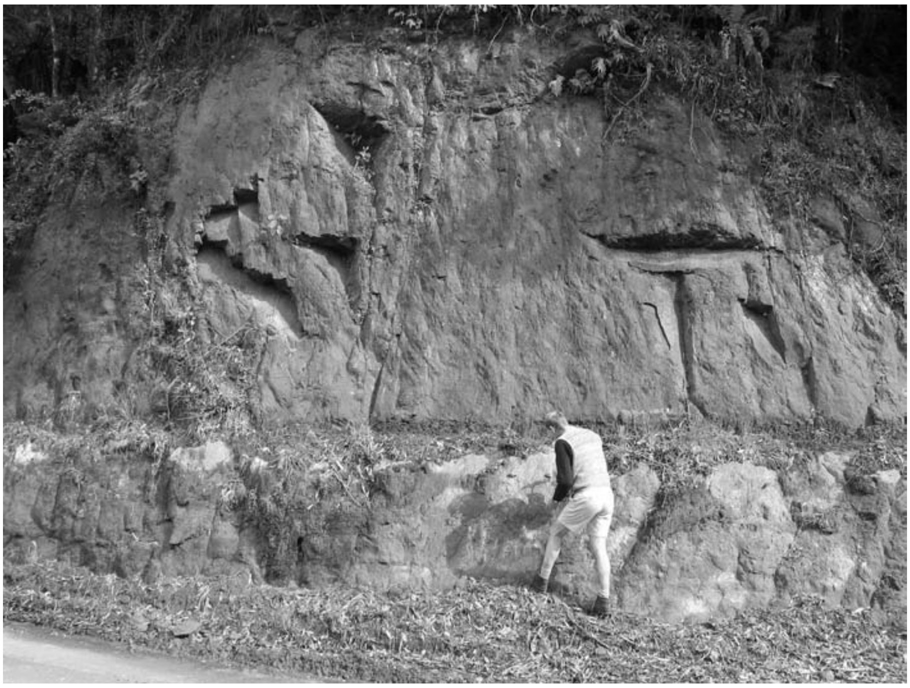


Fig. 10. Photo of lower part of Otunui Fmn and glauconitic horizon, Okahukura Saddle Road (Stop 2).

Stop 4. Herlihy Bluff, River Road (S18 - 033 516)

This stop shows spectacular development of turbidites in the Taumarunui Formation, Mahoenui Group (Fig. 11). 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.11. Taumarunui Formation, Herlihy Bluff, River Road (Stop 4).

Stop 5. Paparoa Road, west of Kaituna (S19 – 970 486)

This new road cutting shows a fantastic section through the lower part of the Otunui Fmn (Appendix III). 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?

Stop 6. Paparoa Road, Okaretoa Stream north (Museum section) (S19 – 961 475)

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 (Appendix IV). The upper shellbed is equivalent to the shellbed at the base of the section at Stop 5.
Above the shellbeds 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 6.

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)

Stop 7. Paparoa Rapids, Wanganui River (S19 – 945 461)

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. 12). The southern end of the outcrop is faulted. The lower 2 m of the Otunui Fm comprises a highly cemented silty limestone, with a less cemented sandy interval in the middle part. The limestone 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 disturbed by blasting and digging in efforts to make the rapids navigable.

Fig. 12. Photo of the Mahoenui-Otunui contact at Paparoa Rapids, Wanganui River.

Stop 8. River Road, Aukopae Saddle (S18 – 913 509).

This road cutting (Fig. 13) corresponds to a level within the lower part of the Mt Messenger Fmn near the transition with Otunui Fmn, which we observed previously at Stop 3. 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.

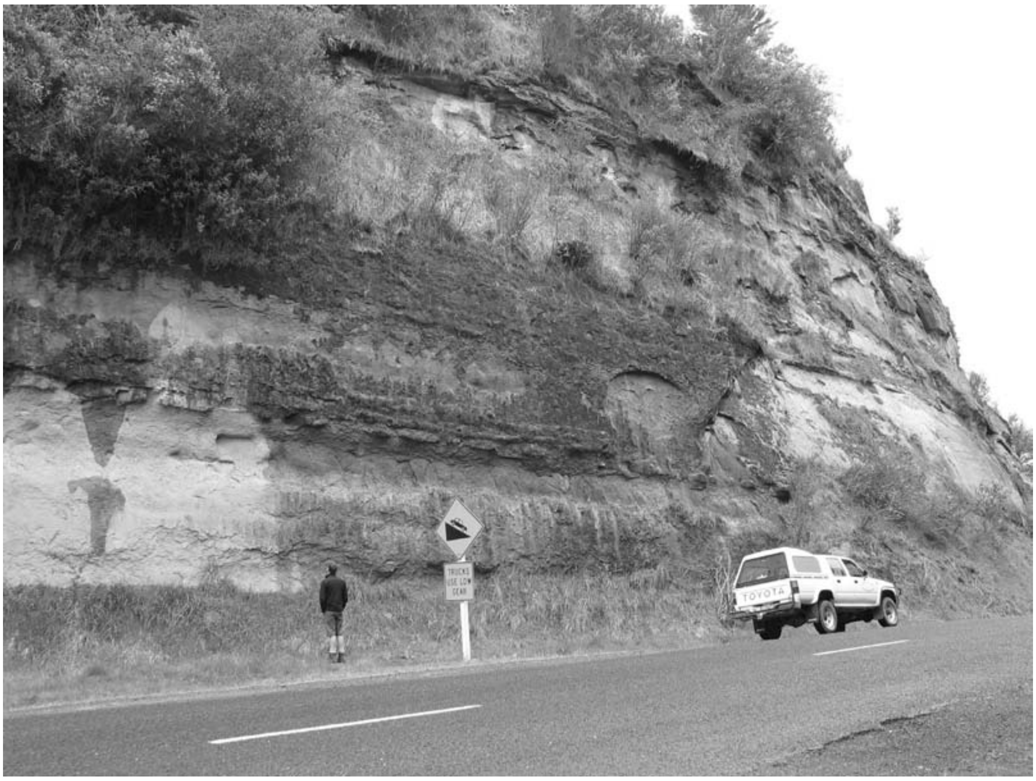


Fig. 13. Road cutting in lower part of Mt Messenger Fmn, River Road, Aukopae Saddle (Stop 8).

Stop 9. River Road, Opetea Stream (R18 – 882 517)

At this stop we will cross the fence and 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. 15) there is a good exposure of the base of a channelised sandstone unit cutting into fine-grained mudstone facies with conchoidal fracture. Note the medium bedded redeposited sandstone beds that make up the channel fill. Discussion points: environment of deposition; mechanisms of deposition; contrasts with lithologies in previous stop.

Fig. 14. Mt Messenger Fmn channel facies exposed on River Road, Aukopae Saddle (Stop 9).

Stop 10. 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 we stand 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 we stand.

Stop 11. SH43, Heao Road Junction (R19 – 780 481)

Brief stop to view the Ohura Fault, which has a throw of about 400 m (Fig. 15). 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. 15. View across the Ohura Fault, near the intersection of State Highway 43 and Heao Road (Stop 11).

Stop 12. SH43, Paparata Fault intersection, Coal Creek. (R19 – 755 463)

At this site the Paparata Fault passes between the Maryville Coal Measures exposed in the western cutting and the Otunui Fmn making up the main outcrop. 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 (Appendix V). 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.

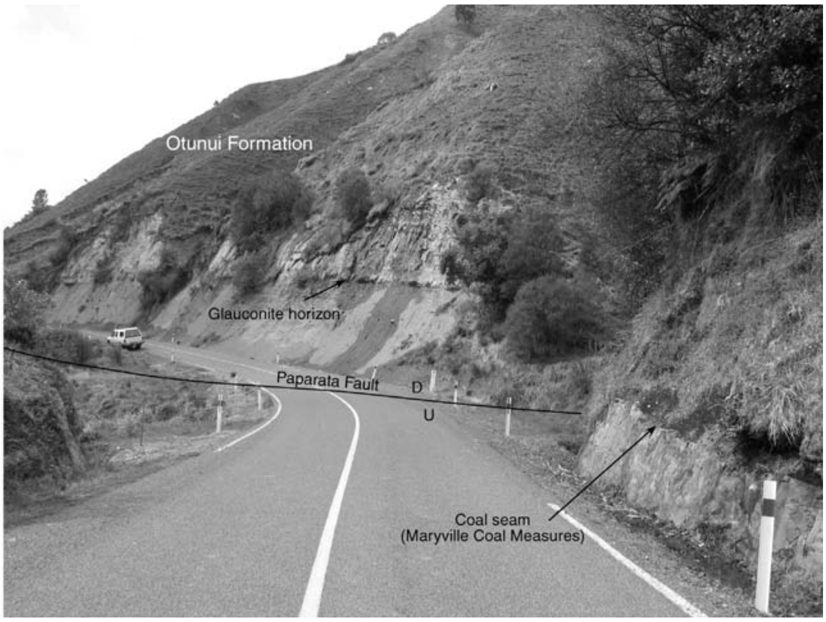


Fig. 16. Photo of section (Stop 12) on SH43 near Coal Creek.

Stop 13. SH43, Maryville Coal Measures outcrop, Paparata Stream. (R19 – 743 464)

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.

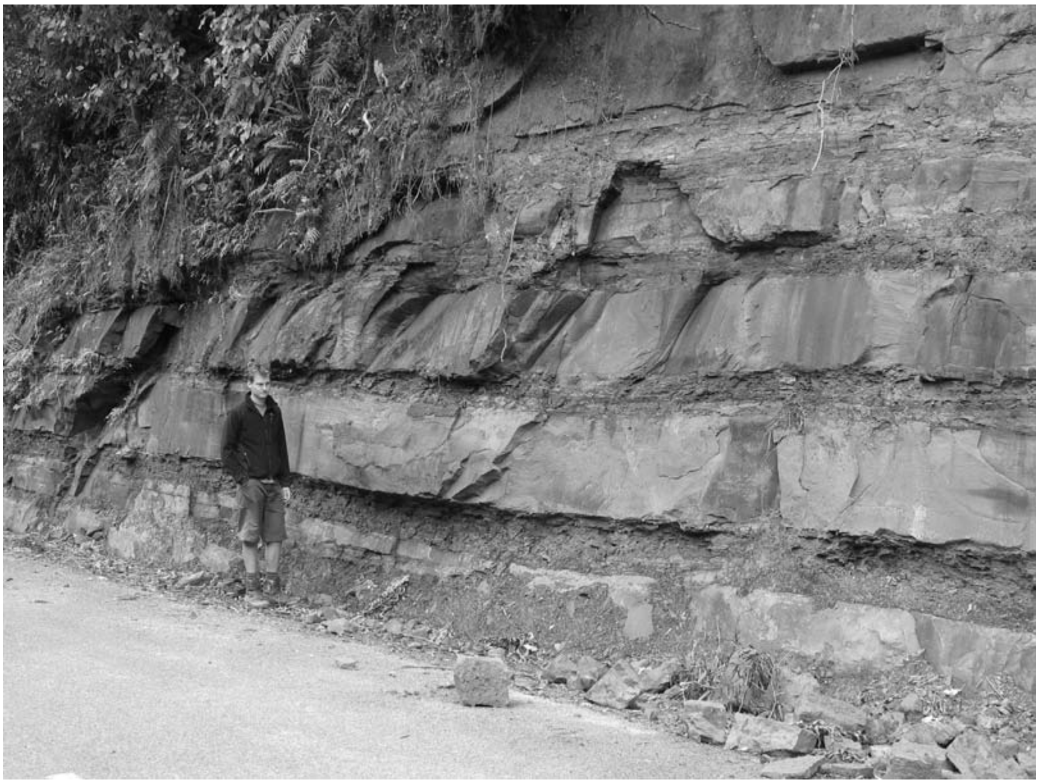


Fig. 17. Maryville Coal Measures cropping out on SH43 (Stop 13), at the eastern end of the Tangarakau Gorge, adjacent to the Paparata Stream.

Stop 14. SH43, Morgans Grave (R19 – 689 457)

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. 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 Clifdenian-Lillburnian.

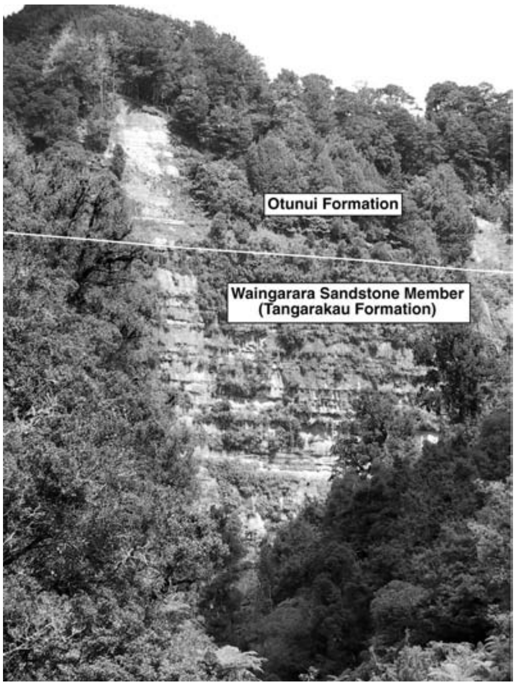


Fig. 18. View from the road bridge at Morgan's Grave, SH43, of Waingarara Sandstone (Tangarakau Formation), conformably overlain by Otunui Formation (Stop 14).

Stop 15. Okau Road – Papakino Stream (R18 – 640 541)

Between Stops 14 and 15 we have climbed 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. We have then decended back down through the Otunui Fmn to its base, which we observe at this site conformably overlying Moki Fmn, which continues 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. 19 and occurs between the bedded Moki Fmn and overlying massive silty sandstone. The beds in the Moki Fmn are turbidites that accumulated on a slope fan during the Middle Miocene. Note a phosphatic horizons 3 m below the top of the Moki Formation, which is an example of a correlative conformity in a slope setting.

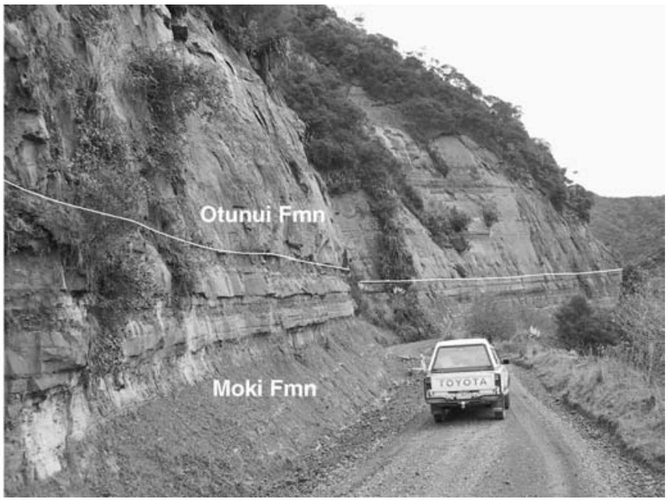


Fig. 19. Cliff exposure on Okau Road (Stop 15), with bedded Moki Fmn and overlying Otunui Formation.

Stop 16. SH43, Tahora Saddle (R19 – 658 359)

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 sandstone-filled broad channel complexes **(Tahora Member (new))** in the upper parts of the ridges and high hills. Northeast – southwest striking faults offset Mt Messenger Formation, with throws of 10 to 100 m.

Fig. 20. View from Tahora Saddle of the ridge to the west (Kaieto Trig) of sandstone-filled broad channel complexes (Stop 16).

Stop 17. SH43, Vera Road, Mt Messenger Fmn channel complex (R19 – 609 286).

At this stop the geometry of the base of a channel cut into mudstone and the architecture of the sandstone-dominated channel fill can be observed (Fig. 21).

Fig. 21. Photo of channel complex in the upper Part of the Mount Messenger Fmn, viewed from SH43 near Vera Road, looking to the south (Stop 17).

Accommodation – Whangamomona Hotel (ph/fax 06 762 5823)

Saturday 11th December

Stop 18. SH43, Whangamomona Saddle east side (R19 – 580 263)

This site represents the highest stratigraphic level in Mt Messenger Fmn of massive (calcareous) mudstone with redeposited, channelised sandstone facies. This site marks the top of the Mt Messenger Formation. The sandstone beds were probably deposited as sandy debris flows within slope channels. Beware of traffic.

Stop 19. SH43, Whangamomona Saddle west side (R19 – 567 262)

At this site we will walk down the road and examine a variety of facies within the lower part of the Kiore Formation. We 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 sandstones. 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 20. SH43, Pohokura Saddle (R19 – 509 239)

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. 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; the comparisons with the lower part of the Mt Messenger Fmn on the North Taranaki coast.

Fig. 22. Slump packets in the Kiore Formation, themselves comprising redeposited slope channel facies, west side, Pohokura Saddle (Stop 20).

Stop 21. Junction Road, Kiore Formation (Q19 – 498 244)

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. 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. 24).

Fig. 23. Panorama of channelised facies, Kiore Formation, Junction Road (Stop 21).

Fig. 24. Close up view of thin-bedded turbidites in channelised facies (Fig. 23), Kiore Formation, Junction Road (Stop 21).

Stop 22. Te Wera Quarry, channelised limestone facies, Kiore Fmn (Q20 – 448 195)

A remarkably thick carbonate-dominated channel fill succession of Tongaporutuan age within the Kiore Formation is exposed in the now disused Te Wera Quarry. Mapping has shown that this deposit accumulated within a broad channel at least 2.5 km wide. Internally it comprises barnacle- and bivalve-dominated sandy limestone organised into metre-scale depositional units showing a variety of sedimentary structures. The channel must have accumulated at a time when carbonate sediment was accumulating up-slope on the contemporary shelf. 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. We suggest that the channel cutting occurred during lowstand conditions, and the channel fill accumulated during the subsequent transgression, the carbonate having been swept into shelf channels during storm conditions on a wave-dominated shelf. There is a significant thickness of sandstone beneath the limestone facies, which is analogous to the sandstone observed at Stop 19 (Whangamomona Saddle west side), and we infer similar depositional processes.

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

Fig. 25. View of Te Wera Quarry where a carbonate dominated channel fill facies is well exposed (Stop 22).

Stop 23. SH43, Strathmore Saddle (Q20 – 398 115)

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. We will examine the section exposed down the road on the western side of the saddle. 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 us to interpret the cyclicity and the relative sea-level changes evident in this succession.

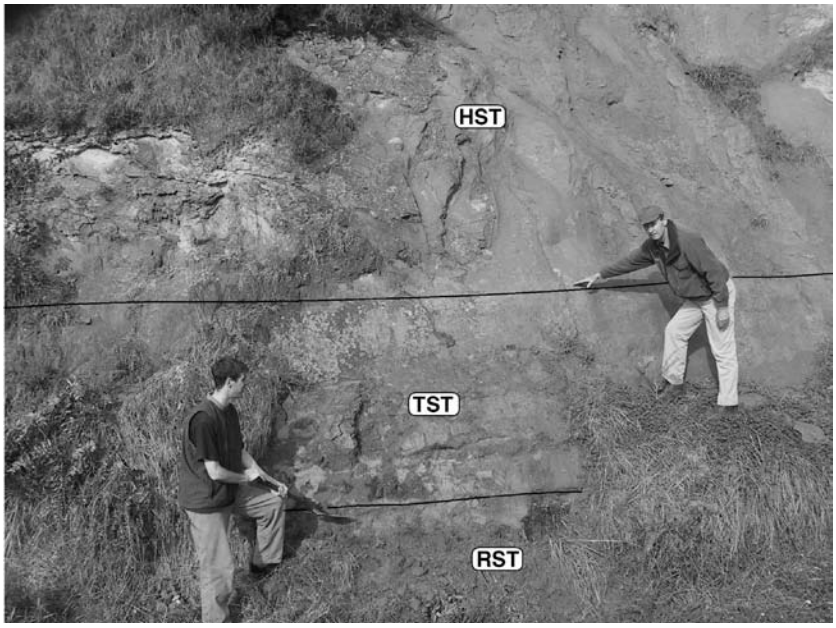
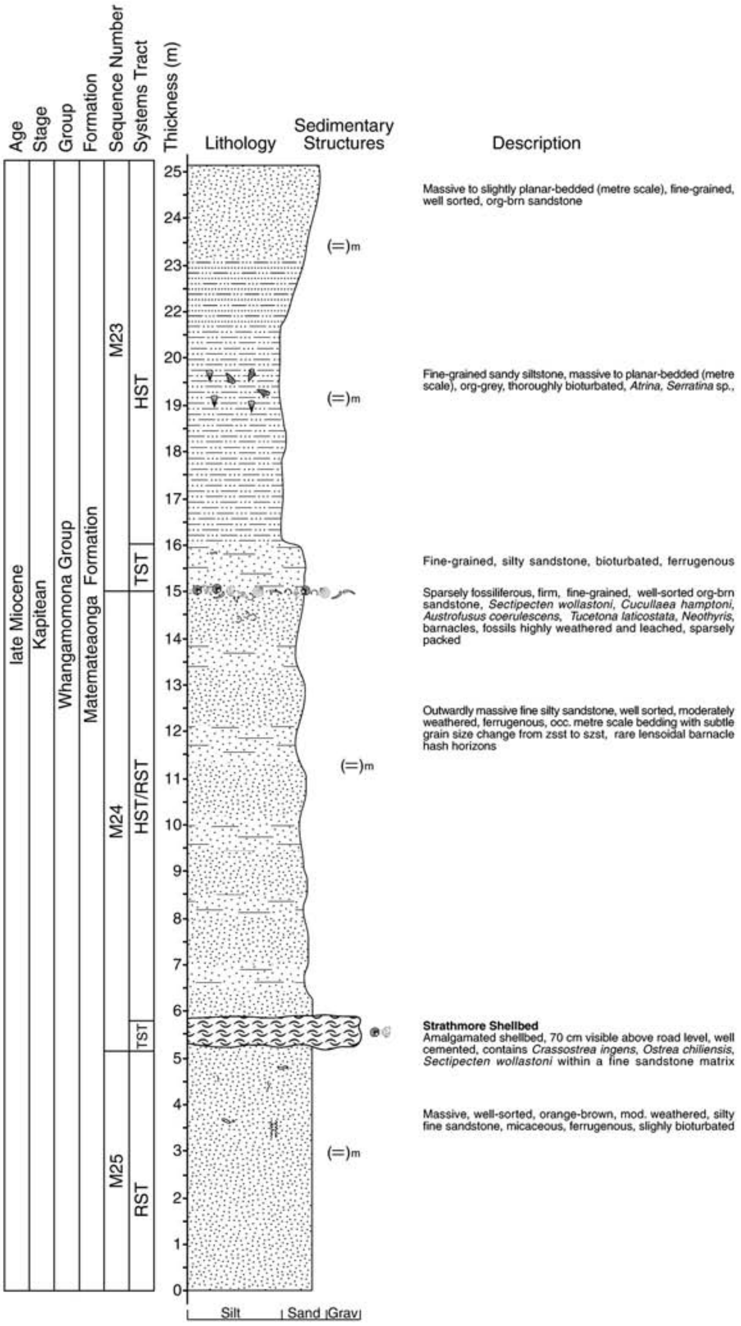


Fig.26. View of part of two sequences in the middle part of the western side of Strathmore Saddle, Matemateaonga Formation (Stop 23). RST= regressive systems tract, TST= transgressive systems tract, HST= highstand systems tract.



Massive to slightly planar-bedded (metre scale), fine-grained, well sorted, org-brn sandstone

Fine-grained sandy siltstone, massive to planar-bedded (metre scale), org-grey, thoroughly bioturbated, *Atrina*, *Serratina* sp.,

Fine-grained, silty sandstone, bioturbated, ferrugenous

Sparsely fossiliferous, firm, fine-grained, well-sorted org-brn sandstone, *Sectipecten wollastoni*, *Cucullaea hamptoni*, *Austrofusus coerulescens*, *Tucetona laticostata*, *Neothyris*, barnacles, fossils highly weathered and leached, sparsely packed

Outwardly massive fine silty sandstone, well sorted, moderately weathered, ferrugenous, occ. metre scale bedding with subtle grain size change from zsst to szst, rare lensoidal barnacle hash horizons

Strathmore Shellbed
Amalgamated shellbed, 70 cm visible above road level, well cemented, contains *Crassostrea ingens*, *Ostrea chiliensis*, *Sectipecten wollastoni* within a fine sandstone matrix

Massive, well-sorted, orange-brown, mod. weathered, silty fine sandstone, micaceous, ferrugenous, slighly bioturbated

Fig. 27. Stratigraphic column, Strathmore Saddle, west side (Stop 23).

Stop 24. Wingrove Road, Pukengahu. (Q20 – 307 013)

This is a brief stop to examine regressive shoreface facies within a regressive systems tract in the Maben Member, Matemateaonga Formation.

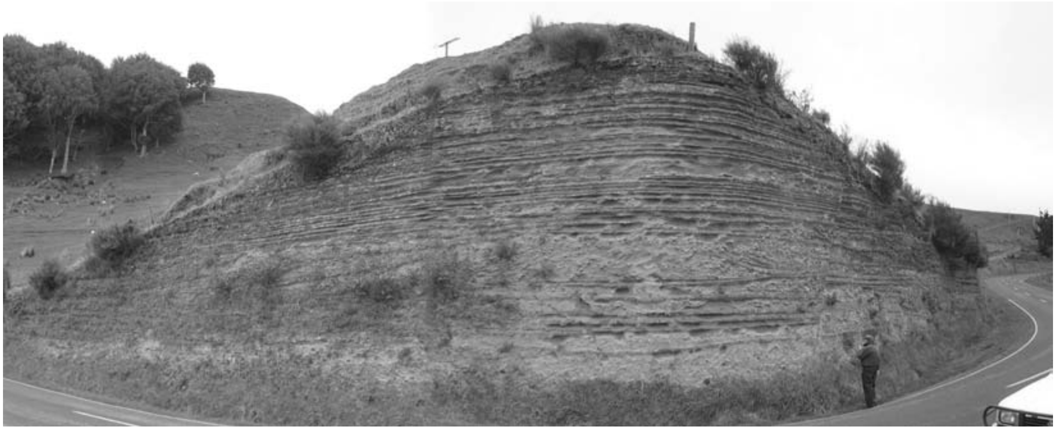


Fig. 28. Exposure of well-developed regressive sandstone beds, Wingrove Road, Pukengahu (Stop 24).

Stop 25. Cutting on Kevin Down's farm track, Patea River. (Q20 – 342 010)

To get to this section we will need to cross a farm over 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. 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. After viewing the cliff section, participants are free to roam and view the succession.

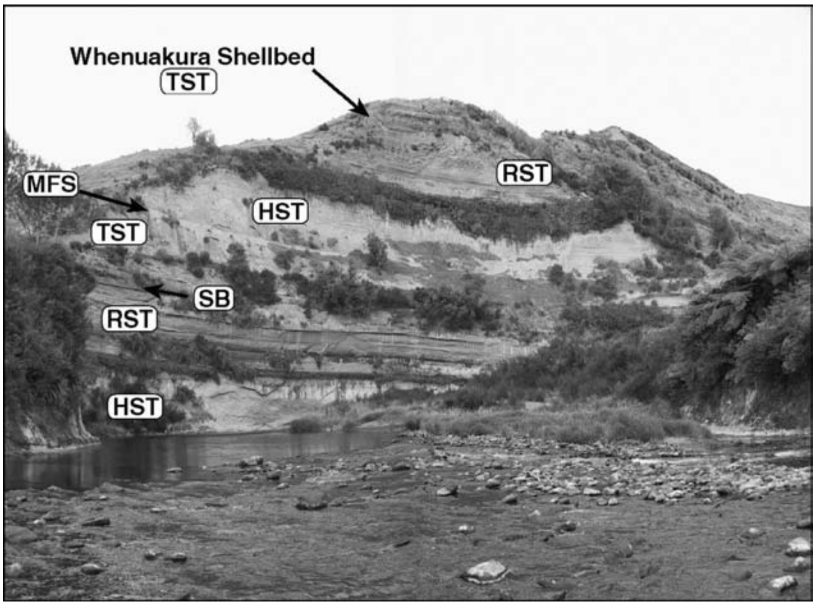


Fig. 29. Cliffed exposure of two cycles within the Waitiri Member, Matemateaonga Formation, Patea River, near Makaria Stream. SB = sequence boundary, MFS = maximum flooding surface (Stop 25).

Stop 26. Aorere Road, Mangamingi (Q20 – 349 947)

At this site we can observe the Parangarehu Shellbed and the underlying sequence boundary cut across regressive sandstone of the underlying sequence (Kuraiti Member).

There are great views from this site to the east of the upper part of the Matemateaonga Formation, which we will point out in relation to the geological map.

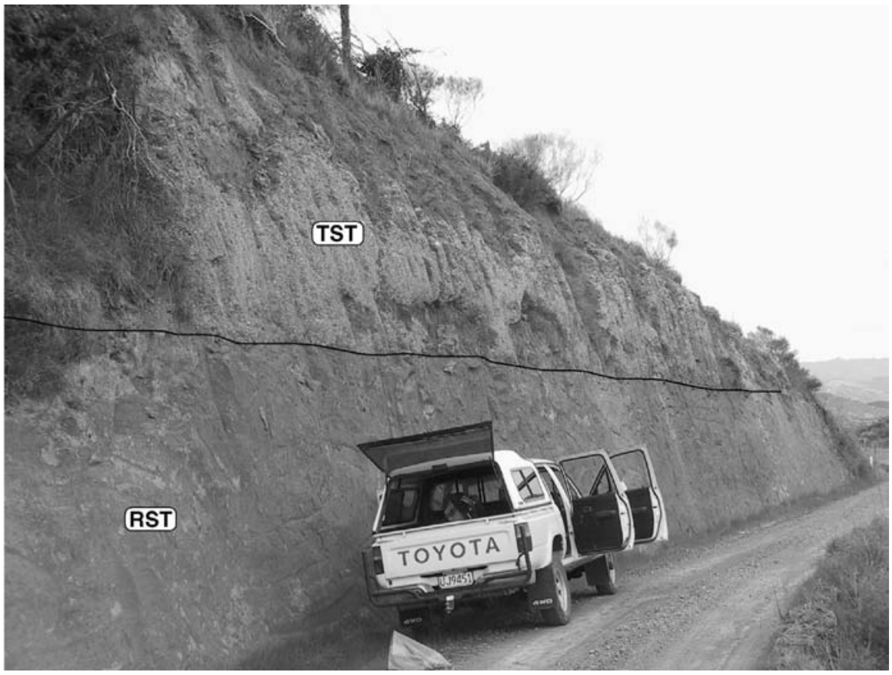


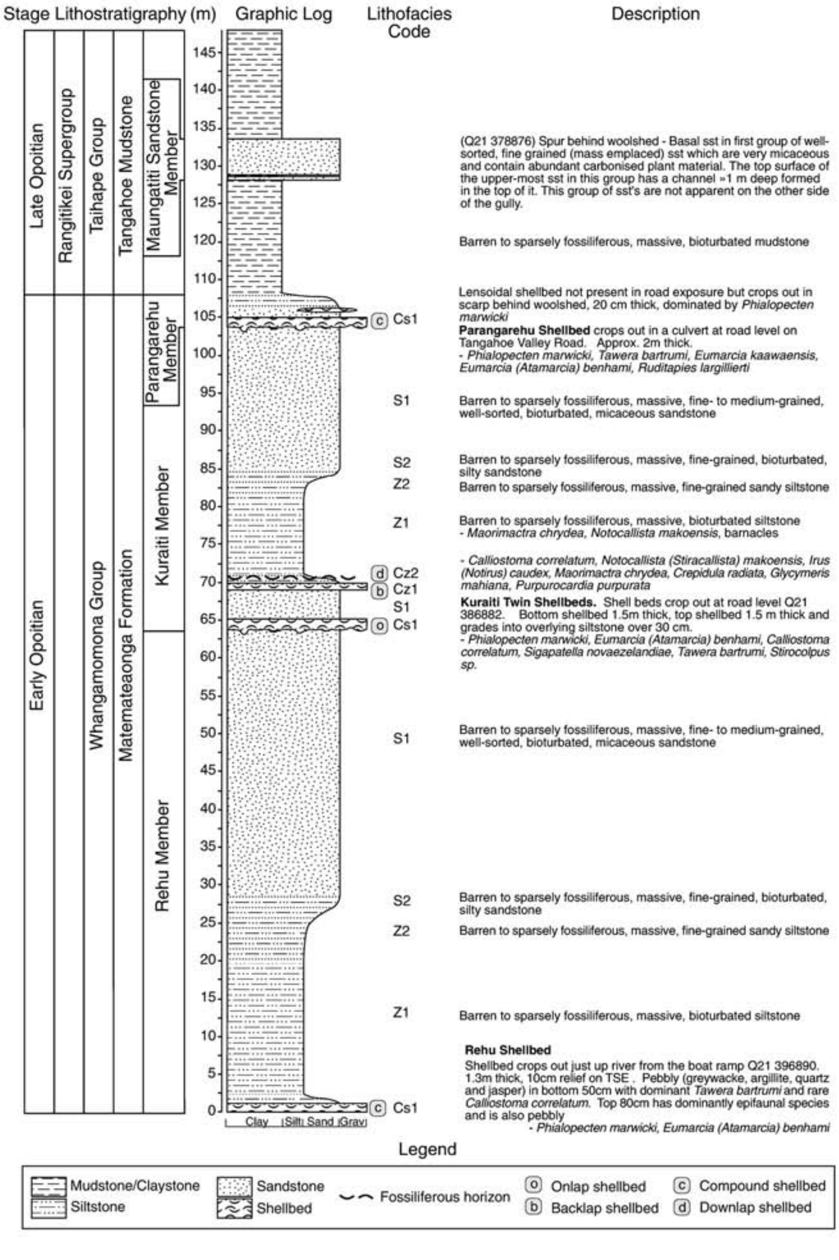
Fig. 30. Parangarehu Shellbed (TST) and underlying sandstone (RST) of the Kuraiti Member cropping out on Aorere Road, Mangamingi (Stop 26).

Accommodation – Furlong Motor Inn, Hawera (ph 06 278 5136).

Sunday 12th December

Stop 27. Tangahoe Valley Road, Tangahoe cutting, Maungatiti Sandstone Member exposure. (Q21 – 375 877)

At this deep road cutting (take care for falling rocks) we are at the base of the Tangahoe Mudstone, which accumulated in upper bathyal water depths (400 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 base of the Mt Messenger Formation.



(Q21 378876) Spur behind woolshed - Basal sst in first group of well-sorted, fine grained (mass emplaced) sst which are very micaceous and contain abundant carbonised plant material. The top surface of the upper-most sst in this group has a channel »1 m deep formed in the top of it. This group of sst's are not apparent on the other side of the gully.

Barren to sparsely fossiliferous, massive, bioturbated mudstone

Lensoidal shellbed not present in road exposure but crops out in scarp behind woolshed, 20 cm thick, dominated by *Phialopecten marwicki*

Parangarehu Shellbed crops out in a culvert at road level on Tangahoe Valley Road. Approx. 2m thick.
- *Phialopecten marwicki, Tawera bartrumi, Eumarcia kaawaensis, Eumarcia (Atamarcia) benhami, Ruditapies largillierti*

S1 Barren to sparsely fossiliferous, massive, fine- to medium-grained, well-sorted, bioturbated, micaceous sandstone

S2 Barren to sparsely fossiliferous, massive, fine-grained, bioturbated, silty sandstone

Z2 Barren to sparsely fossiliferous, massive, fine-grained sandy siltstone

Z1 Barren to sparsely fossiliferous, massive, bioturbated siltstone
- *Maorimactra chrydea, Notocallista makoensis*, barnacles

- *Calliostoma correlatum, Notocallista (Stiracallista) makoensis, Irus (Notirus) caudex, Maorimactra chrydea, Crepidula radiata, Glycymeris mahiana, Purpurocardia purpurata*

Kuraiti Twin Shellbeds. Shell beds crop out at road level Q21 386882. Bottom shellbed 1.5m thick, top shellbed 1.5 m thick and grades into overlying siltstone over 30 cm.
- *Phialopecten marwicki, Eumarcia (Atamarcia) benhami, Calliostoma correlatum, Sigapatella novaezelandiae, Tawera bartrumi, Stirocolpus sp.*

S1 Barren to sparsely fossiliferous, massive, fine- to medium-grained, well-sorted, bioturbated, micaceous sandstone

S2 Barren to sparsely fossiliferous, massive, fine-grained, bioturbated, silty sandstone

Z2 Barren to sparsely fossiliferous, massive, fine-grained sandy siltstone

Z1 Barren to sparsely fossiliferous, massive, bioturbated siltstone

Rehu Shellbed

Shellbed crops out just up river from the boat ramp Q21 396890. 1.3m thick, 10cm relief on TSE . Pebbly (greywacke, argillite, quartz and jasper) in bottom 50cm with dominant *Tawera bartrumi* and rare *Calliostoma correlatum*. Top 80cm has dominantly epifaunal species and is also pebbly
- *Phialopecten marwicki, Eumarcia (Atamarcia) benhami*

Fig. 31. Composite stratigraphic column of the uppermost Matemateaonga Formation, and lower part of the Tangahoe Mudstone, Tangahoe Valley Road, Lake Rotorangi (Stops 27 – 29).

Fig. 32. Exposures of the Tanghoe Mudstone and the Maungatiti Sandstone Member in the cutting on Tangahoe Road, Lake Rotorangi (Stop 27).

Stop 28. Parangarehu Shellbed outcrop, Larkhams woolshed. (Q21 – 378 876)

At this stop we observe the contact between the Parangarehu Shellbed and the Tangahoe Mudstone, noting the occurrence of a 5 m thick silty sandstone, which fines up rapidly 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 29. Kuraiti Twin Shellbeds road outcrop (Q21 – 387 881).

At this site we 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.

We will then drive a short distance up the lake to the water ski club where we can view an extensive outcrop of the Kuraiti Twin Shellbeds.

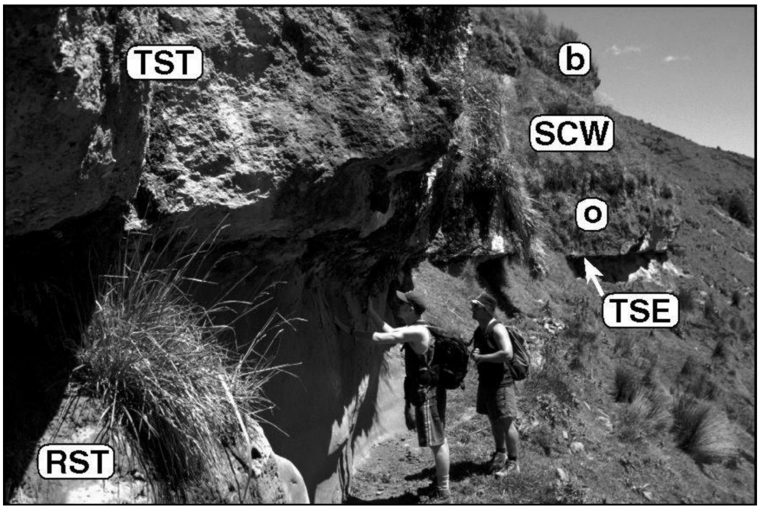


Fig. 33. Exposure of the Kuraiti Twin Shellbeds in hills to the north of the water ski club, Lake Rotorangi (Stop 29).

Fig. 34. 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 30. Waihi Beach, Denby Road, Hawera. (Q21 – 166 769)

The track that runs from the car park at the end of Denby Road 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 has 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 shelfal Matemateaonga Formation over Kiore, Urenui and Mt Messenger Formations. Fauna occurring in the sandstone include *Ostrea chiliensis*, *Mesopeplum crawfordi, Polincies waipipiensis* and *Phialopecten marwicki*.

Fig. 35. Coastal cliff exposing shelfal Ohawe Sandstone, Whenuakura Subgroup, overlain by Rapanui Formation, Waihi Beach, Denby Road, Hawera (Stop 30).

Appendix I

Date: 10 8 2004
day month year

Page 1 of 3

Field Trip No: 35

Stratigraphic Column No / Name: Okahukura Saddle Road

NZMS 260 Sheet: S18 Taumarunui

Region: Taumarunui

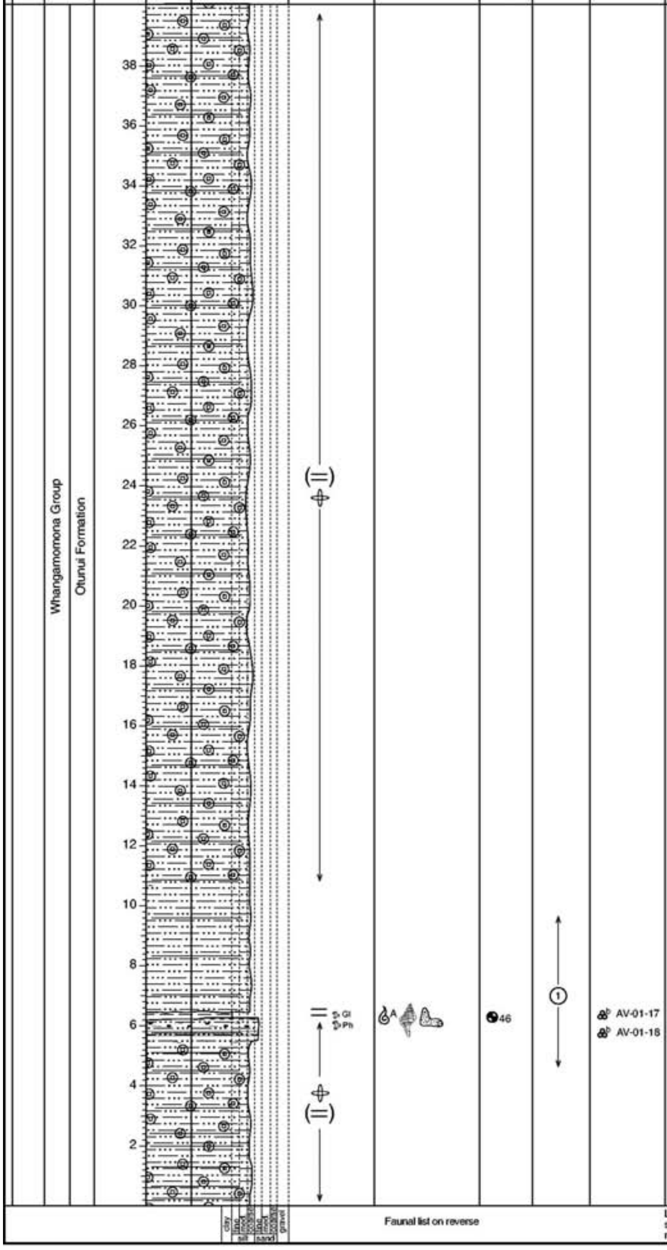
Grid Reference: Top E: 2701541
N: 6262674
Altitude: 378

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 (*Seratina ferrari*, *Penion* sp. and bryozoans), 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.

Appendix II

Date: 10 8 2004
day month year

Page 3 of 3

Field Trip No: 35

Stratigraphic Column No / Name: Okahukura Saddle Road

NZMS 260 Sheet: S18 Taumarunui

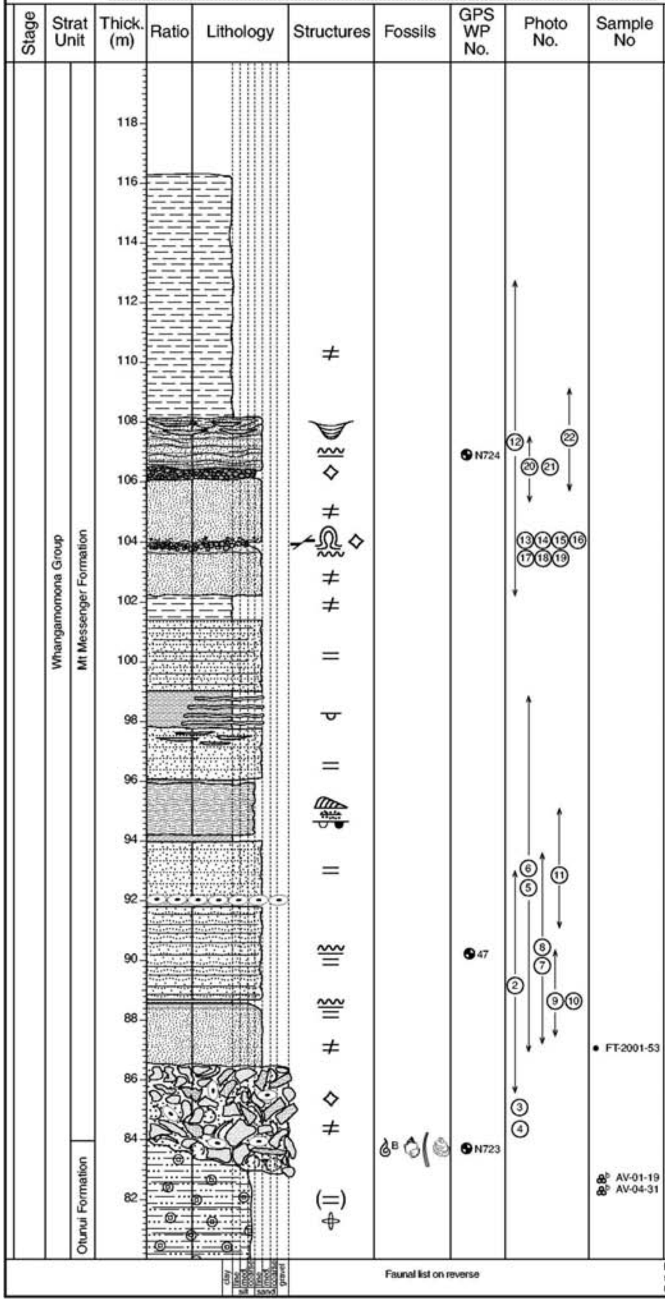
Region: Taumarunui

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



Description

Channel complexes with fine-grained redeposited sandstone units the have been variably bioturbated occur above this column.

mM - massive, blue-grey, slightly frittery mudstone

sxlS(M) - planar (undulatory) to wavy to cross-bedded (channelised), laminated, fine-grained, well sorted sandstone, with thin mudstone drapes on bedding surfaces.

10 cm thick horizon of well-rounded mst rip-up clasts (5-25 mm dia) in fsst matrix. Wavy baseand top.

mS - massive, well sorted, fine-grained, org-brn, sandstone

Convolute bedding occurs zst laminae in overlying mS. Rare rip-up clasts occur above convolute bedding horizon.

15 cm thick horizon of well-rounded mst rip-up clasts (5-25 mm dia) in fsst matrix. Offset by small normal fault 40cm throw.

clS - cross-lam. to wavy lam., well srtd, f. gr., org-brn, sandstone

blS - parallel lam., well sorted, fine-grained, org-brn, sandstone

mS - massive, well sorted, fine-grained, org-brn, sandstone

mM - massive, blue-grey, slightly frittery mudstone

Structural Data: (068/09/NW) 9

slS - plane stratified (undulatory) to parallel laminated, well sorted, fine-grained, bl-gy, sandstone

mM - massive, blue-grey, slightly frittery mudstone with thin (5-20 mm) lenses of fine-grained, silty sandstone

Thin lenses (1-3 cm) of siltstone occur near the top of this unit

slS - plane stratified (undulatory) to parallel laminated, well sorted, fine-grained, bl-gy, sandstone

mM - massive, blue-grey, slightly frittery mudstone

trSM - thin bedded, ripple to wavy laminated sand-mud couplets, medium to very thin laminae (1-10 mm)

mM - massive, blue-grey, slightly frittery mudstone

slS - plane stratified to parallel laminated, well sorted, fine-grained, bl-gy, sandstone

mM - massive, blue-grey, slightly frittery mudstone, concretionary layer occurs at top contact

blS - planar-laminated (undulatory) to wavy laminated, well srtd, fine-grained, bl-gy, sandstone.

mM - massive, blue-grey, slightly frittery mudstone

clS - cross-lam. to wavy lam., well srtd, f. gr., org-brn, sandstone

blS - parallel lam., well sorted, fine-grained, org-brn, sandstone

Structural Data: (076/05/NW) 5

mS - massive, well sorted, fine-grained, org-brn, sandstone

m_2G- matrix supported gravel (conglomerate), highly indurated, blue-grey to orange-brown, slightly weathered. Clasts comprise, poorly sorted, well rounded to angular sandstone and mudstone clasts, 5-80 cm diameter. Matrix comprises highly cemented silty sandstone containing highly fragmented, disarticulated and recrystallised shell material including *Ostrea*, *Fissidentalium*, *Austrotoma* and *Struthiolaria (Callusaria)* sp. Channelised with sharp erosional base and sharp top.

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

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

Appendix III

Date: 14 2 2001
day month year

Page 1 of 1

Field Trip No: 2

Stratigraphic Column No / Name: Paparoa Road - Kaituna west

NZMS 260 Sheet: S19 Raurimu

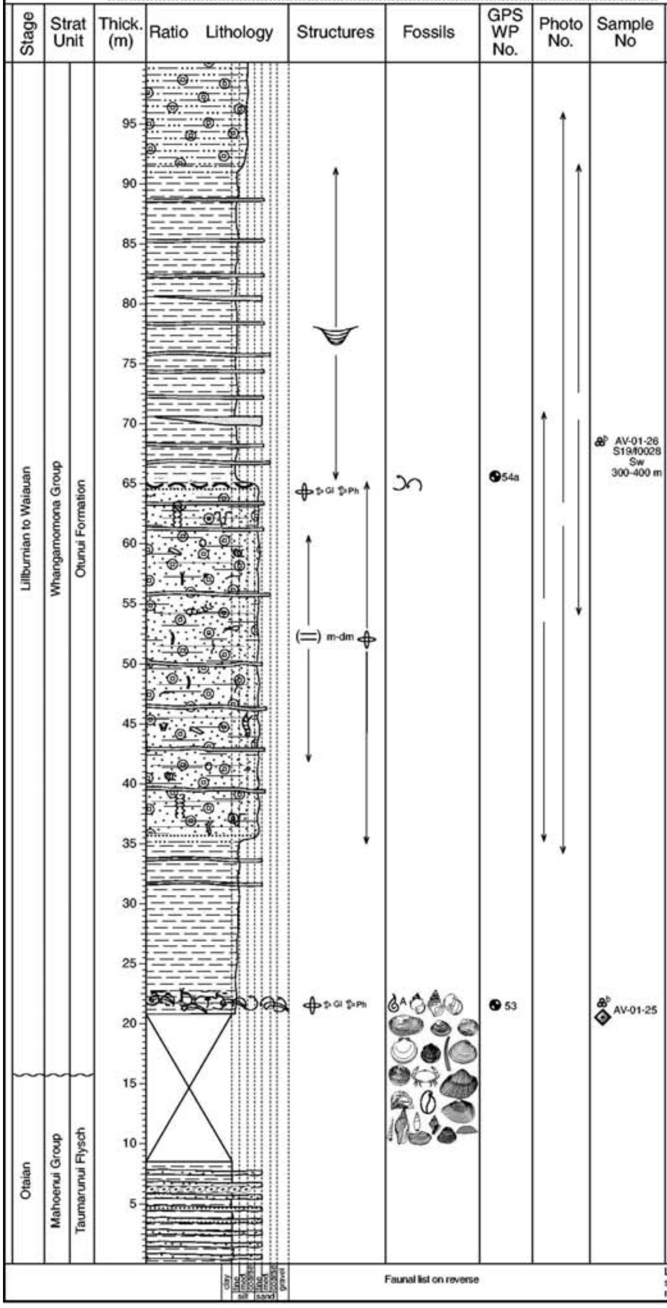
Region: Wanganui River - Te Maire

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

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 lamminated 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.

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.

Structural Data

(168/05/SW)

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

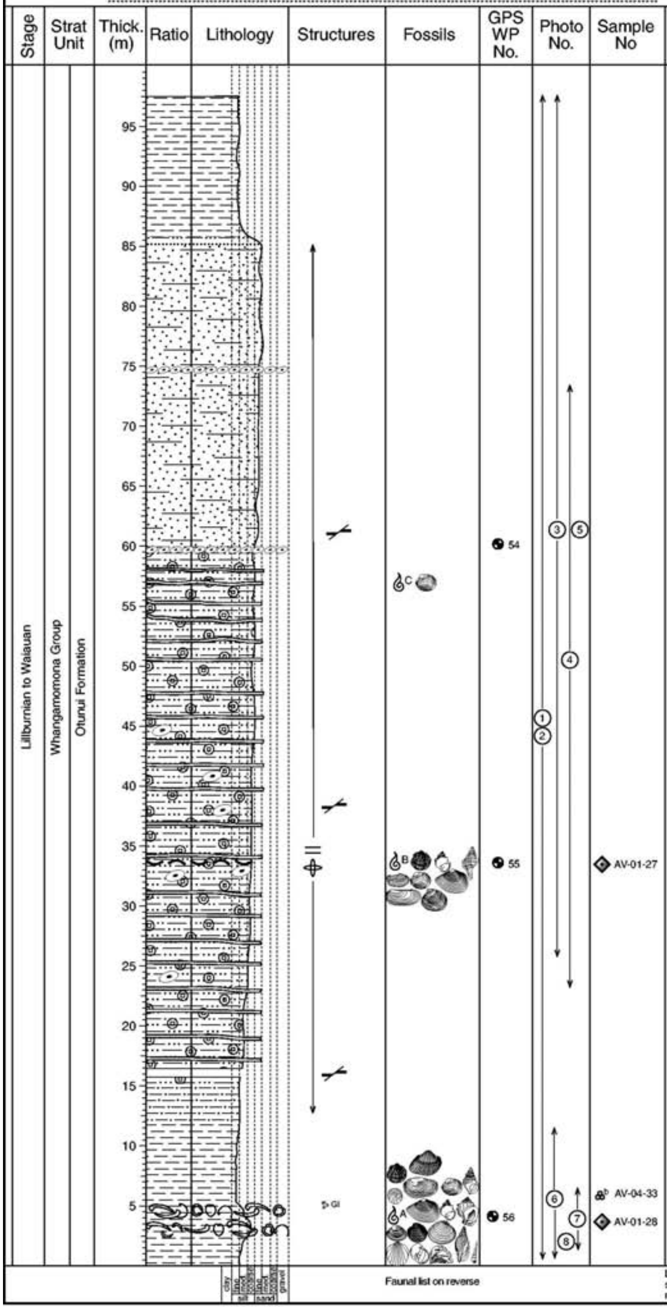
Region: Wanganui River - Te Maire

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.

Appendix V

Date: 25 2 2001 Page 1 of 2
day month year

Field Trip No: 3

Stratigraphic Column No / Name: Paparata Saddle WP 113

NZMS 260 Sheet: R19 Whangamomona

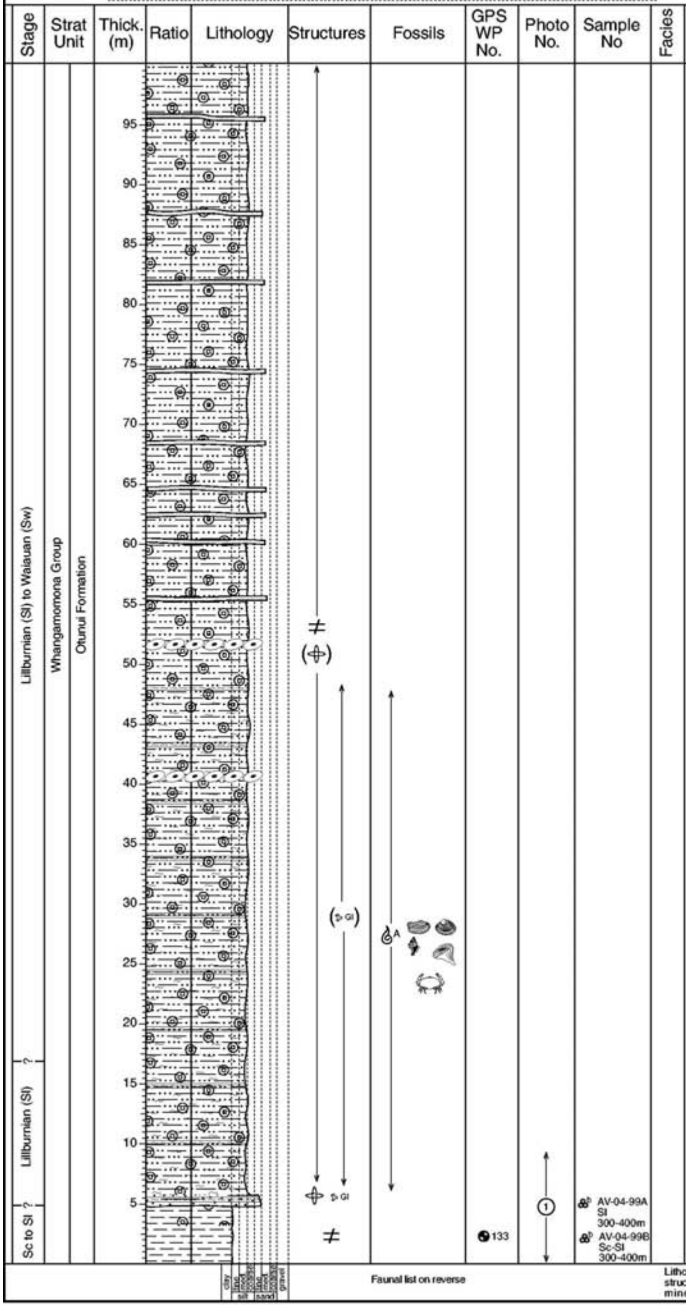
Region: Tangarakau Gorge

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