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Hamilton November 25-28

Geoscience Society of New Zealand 2012 Conference

FIELD TRIP GUIDES

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GEOSCIENCES 2012
Hamilton November 25-28

Annual Conference of the Geoscience Society of New Zealand

Field Trip Guides

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Geosciences 2012

Annual Conference
of the Geoscience Society of New Zealand, Hamilton

Field Trip 3
Thursday-Friday 29-30 November 2012

**Oligocene-Miocene sedimentary record,
eastern Taranaki Basin margin**

Leaders: Cam Nelson and Peter Kamp
University of Waikato

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Frontispiece A. *Kawau Pa site on the coastline north of the Tongaporutu River mouth (Stop 23, Q18/492697) affords excellent exposures of light grey hemipelagic mudstone with thin tephra layers and thick-bedded, often amalgamated, brown fine sandstone of the late Miocene (lower Tongaporutuan, Tt) Mt Messenger Formation. The upper part of the section shows late Pleistocene Rapanui Formation deposits (beach-dune sediments) associated with Marine Isotope Stage 5e (see Stop 17).*

Frontispiece B. *Awakino Tunnel at the northern end of Awakino Gorge is cut through steeply dipping Orahiri Limestone (late Oligocene, Duntroonian, Ld) of the Te Kuiti Group (Stop 10, R17/615854).*

1. HEALTH AND SAFETY

PLEASE READ!

Certain hazards will be encountered on this field trip. General information is mentioned below and some more specific matters are given in Appendix 1. At all times, participants must heed and observe the warnings and directions of the trip leaders and/or quarry managers.

We expect the weather in late November to be warm and sunny, but participants also need to be prepared for cooler, wet and/or windy conditions. Sturdy, enclosed, shoes or boot-like footwear are required and eye protection (e.g. glasses or sunglasses) is desirable. A sunhat and sunscreen is recommended, as is a waterproof and/or windproof jacket. Participants must carry any personal medications for allergic reactions (e.g. insect stings, pollen, food allergies).

An average level of fitness and mobility is required for this trip. Participants must be surefooted enough to walk up to several hundred metres on farm or bush tracks and along sandy or gravelly beaches, and be able to walk up and down moderately steep tracks and grassed hilly paddocks exposing rock outcrops. Underfoot conditions could include beach sands and gravels, gravel or bush tracks, roadside curbs, grass slopes, wooden walkways and stepped rock outcrops.

Caution must be exercised when examining rocks at the base of natural or quarried or cut cliffs and banks on roadsides or backing beaches, due to the risk of rock fall from above and, in the case of road exposures, also from passing traffic. If you hammer rocks, wear eye protection and pay special heed to the safety of other participants. High-visibility vests will be provided for participants, and hard hats are also available. A hammer and hand lens will be useful but not essential, but a camera to record your trip is!

At all quarry sites, high-visibility vests and hard hats must be worn away from the vehicles.

Lunch, including a drink, is provided for both days, but participants may wish to bring some additional special food items and a water bottle. A food shop stop cannot be guaranteed during the trip. Overnight accommodation is at the Awakino Hotel or other arranged nearby premises, and meals will be provided at the hotel.

2. FIELD TRIP SYNOPSIS

A 2-day field trip departing 8 am Thursday 29 November 2012 from Hamilton south to Te Kuiti-Piopio-Awakino-Tongaporutu affords a fine north to south transect through examples of the Mesozoic to Quaternary succession in the Waikato-King Country region bordering the eastern margin of Taranaki Basin. The trip will view some of the onshore Oligocene and Miocene sedimentary record in the Waikato and King Country basins and comment on how this links into the offshore parts of eastern Taranaki Basin. Primarily under both local and more distant tectonic control, we will track the various carbonate and terrigenous (locally volcaniclastic)-dominated facies associated with marginal marine, shoreline, shelf and slope-to-basin depositional settings, and consider their stratigraphic architecture and wider sequence stratigraphic context. Visits are planned along the way to basement greywacke, serpentinite and limestone quarries.

3. ROUTE MAP

The route map and planned stops for the trip are shown on Fig. 1 and listed below. On day 1 we travel from Hamilton to Awakino, and on day 2 we are in the Awakino-Tongaporutu area before returning to Hamilton. Several stops should be brief and could become optional depending on time and weather. Recorded grid references are approximate only and based on the 1:50,000 NZ 260 Topomap Series; the list below also shows in italics the grid reference equivalents for the new NZTopo50 Series 1:50,000 maps.

Day 1

Stop 1 - Hinuera Formation, Hamilton Airport (S15/151669; *BD34/049053*)

Stop 2 - Waipapa terrane greywacke, Tokanui (S15/153405; *BE34/051789*)

Stop 3 - Otorohanga Limestone and Mahoenui Gp mudstone, Oparure (S16/915159; *BF33/813542*)

Stop 4 - Wairere Serpentinite –Dun Mountain-Maitai terrane, Piopio (R17/859932; *BF32/758315*)

Stop 5 - Murihiku terrane "greywacke" and Piopio High, Piopio (R17/855003; *BF32/754386*)

Stop 6 - Aotea Formation - Orahiri Limestone, Mangaotaki Bridge (R17/761957; *BF32/660340*)

Stop 7 - Taumatamaire Formation of Mahoenui Group, Mangaotaki (R17/755946; *BF32/654329*)

Stop 8 - Mahoenui depocentre overview, Mahoenui (R17/729924; *BF32/628307*)

Stop 9 - Oligocene-early Miocene geology, Awakino Tunnel (R17/618853; *BG31/517236*)

Stop 10 - Orahiri Limestone, Awakino Tunnel (R17/615854; *BG31/514237*)

Stop 11 - Awakino Limestone Member, Awakino Gorge (R18/591795; *BG31/490178*)

Day 2

Stop 12 - Bexley Sandstone, south end Awakino Gorge (R17/559800; *BG31/458183*)

Stop 13 - Overview Miocene geology, western end of Ladies Mile (R17/547806; *BG31/446189*)

Stop 14 - Bexley Sandstone to Manganui Formation transition (R17/525818; *BG31/424201*)

Stop 15 - Manganui/Mangarara/Mohakatino Fms, Awakino Heads (R17/511808; *BG31/410191*)

Stop 16 - Mt Messenger Formation, Pahaoa Hill (R18/513799; *BG31/412182*)

Stop 17 - Rapanui Formation, Seaview Motor Camp (R18/509794; *BG31/408177*)

Stop 18 - Mt Messenger/Mohakatino Fms, Mokau River mouth (R18/510770; *BG31/409153*)

Stop 19 - Mt Messenger Fm sandstone, Mohakatino River bridge (R18/505736; *BG31/404119*)

Stop 20 - Mt Messenger Fm sandstone, Tongaporutu River mouth (Q18/486642; *BG31/385025*)

Stop 21 - Mt Messenger Fm thin-bedded sandstone, Okau Rd (R18/515578; *BG31/414961*)

Stop 22 - Otunui Formation and volcaniclastic interbed, Okau Rd (R18/574547; *BH31/473930*)

Stop 23 - Mt Messenger Formation, Kawau Pa site (Q18/492697; *BG31/391080*)

4. BACKGROUND INFORMATION

4.1 Hamilton Basin

Hamilton Basin is an c.30 km wide N-S oriented graben bounded by horst blocks of uplifted Mesozoic basement rocks to the west (Hakarimata Range) and east (Cambridge hills and Rangitoto Range). The graben is filled by a succession of Oligocene to Holocene sedimentary deposits (Edbrooke et al. 2005). Depth to basement in the Basin is up to 1.5-2.0 km (Kear & Schofield 1978). The capping Pliocene to Holocene volcaniclastic (pumiceous) terrestrial sediments, including occasional pyroclastic flow and airfall units, form the Tauranga Group for which exposures are few, scattered, and often weathered. The silicic volcanic material forming the bulk of these sediments was sourced initially from the Coromandel and later the Taupo Volcanic Zone. The thickness of the Tauranga Group deposits is highly variable, typically from 5-90 m, but occasionally reaches several 100 m. The prominent low hills within the Hamilton Basin (e.g. the elevated part of University of Waikato campus) are underlain by the older late Pliocene to middle Quaternary volcaniclastic sands and tephras of the Tauranga Group (e.g. Puketoka Formation, Karapiro Formation, Kauroa Ash Formation and Hamilton Ash Formation). The widespread flat surface surrounding the low hills is the Hinuera Surface, the maximum aggradation level of the ancestral braided Waikato River system during the late Pleistocene (c.50-15 ka). The alluvial deposits, known as the Hinuera Formation (**Stop 1**), consist of up to 90 m of unconsolidated, profusely cross-bedded, pumiceous and rhyolitic gravelly sands derived from active erosion and silicic volcanism in the central North Island during the Last Glacial period (Hume et al. 1975). In the Holocene, extensive (now drained) peat swamps developed on poorly drained parts of the Hinuera Surface, including the Rukuhia Swamp west of the highway on leaving Hamilton and the Tuatuamoana Swamp east of the highway near Ohaupo. The evolution of the Hamilton Basin landscape and the past wanderings of the Waikato River have been fully documented in the recent Geoscience of New Zealand Guidebook 16 by McCraw (2011).

4.2 King Country Basin (including aspects of bounding Wanganui and Taranaki Basins)

South of Te Awamutu, Hamilton Basin merges into King Country Basin (Kamp et al. 2004), formerly known as North Wanganui Basin. Beyond about the latitude of Hawera in Taranaki, King Country Basin in turn merges southwards into Wanganui Basin (formerly called South Wanganui Basin). All these basins pass offshore into eastern Taranaki Basin. Apart from the brief consideration of Hamilton Basin in section 4.1, the remainder of this field trip is entirely within the northern portion of King Country Basin. However, it is relevant at times to relate what we see at the various stops to the wider central-western North Island geology, especially in regard to possible major depositional controls on facies types and successions. To this end, the following background information draws heavily on material appearing in Petroleum Report PR3463 by Kamp & Vonk (2006), which also provides detailed information about many other useful field trip stops throughout the wider King Country Basin.

4.2A Geological setting

A simplified geological map of central-western North Island is shown in Fig. 2. Note that the rocks to be seen on this field trip range upwards from Basement (Mesozoic; blue), Te Kuiti Group (Oligocene; green), Mahoenui Group (dark grey; early Miocene), Mokau Group (fawn; late early Miocene), Otunui Formation (pale brown; middle Miocene), Mohakatino & Moki Formations (orange; middle Miocene), and Mt Messenger Formation (light grey; early late Miocene). Apart also from the Urenui and Kiore Formations (light orange; late Miocene) these are the dominant geological units in the King Country.

Fig. 3 is a structure map of the same region. A Miocene time scale showing the names, symbols and ages of New Zealand Stages is reproduced from Cooper et al. (2004) in Fig. 4. Fig. 5 shows schematically the occurrence of the major Neogene stratigraphic units in each of the King Country, Wanganui and Taranaki Basins. The eastern margin of Taranaki Basin has traditionally been marked by the Taranaki Fault (e.g. King & Thrasher 1996). Note, however, in Fig. 2, 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. 6). 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. 3) 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. 3).

4.2B Basement rocks

The Mesozoic basement rocks in central western North Island form parts of three tectonostratigraphic terranes. The late Triassic to late Jurassic Murihiku terrane rocks are fossiliferous lithic sandstones ("greywackes"), siltstones and occasional conglomerates, broadly folded into the Kawhia Regional Syncline, beneath the area to the west of Waipa Fault (Fig. 3; **Stop 5**). To the east of Waipa Fault is the Waipapa (composite) terrane of mainly highly sheared and faulted Jurassic volcaniclastic sandstones (greywackes) (**Stop 2**). The Dun Mt-Maitai terrane, represented at the surface by a sliver of serpentinite near Piopio, has been intruded along the Waipa Fault (**Stop 4**); otherwise it is recognised in the subsurface in western North Island by the linear positive magnetic anomaly known as the Junction Magnetic Anomaly (Hatherton 1967).

4.2C Outcrop patterns

Much of the Neogene tectonic development of the region can be read from the geology and structure maps (Figs. 2, 3). 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. 2). This involves the Mount Messenger Formation through to Nukumaruan (late Pliocene-early Pleistocene) strata (Fig. 5). 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; Figs. 2, 5) 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/High (Nelson et al. 1994; Fig. 3). Faults (e.g. Ohura Fault) have roughly NE-SW strikes sympathetic to those defining the Northern Graben in Taranaki Basin and the Taupo Volcanic Zone (Fig. 3). 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. 2).

4.2D 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. 6 is a map showing the magnitude and pattern of erosion calculated by kriging of estimates of the amount of erosion determined chiefly from analysis of the bulk density of mudstone cores (Kamp et al. 2004). There are two sets of bulk density data underpinning the map, including a DSIR dataset obtained during the 1960s for regional gravity mapping (Reilly 1965) and made available by the Institute of Geological & Nuclear Sciences Ltd, and a second data set collected as part of our University of Waikato work, which concentrated on high density sampling in the main river valleys of Wanganui Basin (Fig. 6).

Fig. 6 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. 6). 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. 6). 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).

4.2E 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.

4.3 Stratigraphic architecture of the basin fills

We illustrate the stratigraphic architecture of the fills of the three basins in central-western North

Island by reference to two cross-sections and related time-stratigraphic panels (Kamp et al. 2004). Fig. 7 shows the lines of these cross-sections in relation to the distribution of the major stratigraphic units.

4.3A Wanganui Basin to King Country Basin

Fig. 8 illustrates a N-S cross-section through the axis of the Wanganui and King Country Basins between Parakino-1 well in the south and Ararimu-1 well in the north. 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 (Fig. 3), defined from the dip of Neogene sediments, 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. 8) highlights particularly the occurrence of four major Neogene unconformity-bounded sequences (excluding the late Paleogene Te Kuiti Sequence, portions of which will be seen at **Stops 3, 6 & 10**). 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 (Pungapunga 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 to slope mudstone (**Stops 3, 5 & 7**) and then by about 1000 m of redeposited sediments (turbidites) that accumulated at bathyal depths. The Mahoenui Group is predominantly of Otaian age (Topping 1978). Surprisingly, no regressive slope or shelf facies have been identified at the top of the Mahoenui Group. Presumably, if they were originally present, they were abridged and eroded during a short-lived and marked phase of uplift and erosion that affected the whole of the Mahoenui depocentre. The Herangi-Tongaporutu High separated the Mahoenui depocentre from Taranaki Basin. This depocentre was a piggy-back basin being transported westward during basement overthrusting on the Taranaki and Manganui Faults (Fig. 3). The Taimana Formation and lower parts of the Manganui Formation are stratigraphic equivalents in Taranaki Basin of the Mahoenui Group in the King Country region (see Figs. 11, 12).

The inversion of the Mahoenui depocentre was associated with reverse movement on the Ohura Fault (Fig. 3). 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. 8). The Mokau Sequence comprises lower transgressive sandstone (Bexley Sandstone; **Stop 14**), a coal-bearing fluvial and intervening shoreface succession (Maryville Coal Measures), and an upper regressive shoreface sandstone (Tangarakau Sandstone) (e.g., Vonk 1999). The upper surface of the sequence appears to be conformable, especially in the southern part of the basin. The Manganui and Moki Formations exposed along the eastern margin of Taranaki basin are correlatives of the Mokau Group inland. The age of these units probably gets as young as lower Lillburnian (Fig. 4).

The third Neogene megasequence is represented by the Whangamomona Group and this unit is common to parts of Wanganui, King Country, and Taranaki Basins (Figs. 8, 9). During the middle Miocene the whole of the King Country region subsided. This resulted in the accumulation of a transgressive shelf succession represented by the upper Lillburnian-Waiauan age Otunui Formation (Mohakatino Formation of Hay 1967; **Stop 22**). It overlies the Mahoenui Group east of the Ohura Fault, and Mokau Group west of this fault (Figs. 2, 3). 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 middle Miocene Mangarara Formation (**Stop 15**) has been described fully by Puga-Bernabéu et al. (2009). It is a thin (1-60 m), laterally discontinuous unit of moderately to highly calcareous (40-90%) facies of sandy to pure limestone, bioclastic sandstone, and conglomerate that crops out sporadically in a few valleys across the transition from the King Country Basin into offshore Taranaki Basin. It occurs within hemipelagic (slope) mudstone of Manganui Formation, is stratigraphically associated with redeposited sandstone of Moki Formation, and is overlain by redeposited volcaniclastic sandstone of Mohakatino Formation. The calcareous facies of Mangarara Formation were mass-emplaced from shallow marine, warm temperate carbonate sources, some to the east but especially from shoal carbonate factories around and upon isolated basement highs to the south (Patea-Tongaporutu High; Fig. 3). The Mangarara Formation is an outcrop analogue for middle Miocene-age carbonate slope-fan deposits elsewhere in subsurface Taranaki Basin (see Fig. 12).

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

The last megasequence comprises the upper Opoitian - upper Castlecliffian Rangitikei Supergroup (Figs. 8, 9). 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, occurring 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; McIntyre & Kamp 1998).

4.3B Wanganui Basin to eastern Taranaki Basin

The cross-section from Santoft–1A to Tuhua-1 (Fig. 9) starts near the modern depocentre of Wanganui Basin, passes north to Parakino-1 in the Wanganui River valley, east across the Patea-Tongaporutu High to Manutahi-1, north along the eastern margin of Taranaki Basin, and crosses the Taranaki Fault between Rotokare-1 and Wingrove-1. 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. 9 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. 8. 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 (Puga-Bernabéu et al. 2009). It is also known in other places on the Tongaporutu-Herangi High (Uruti-1 & 2). During accumulation of the Mount Messenger, Urenui, and Kiore Formations there must have been a very narrow shelf along the cross-section line between Rotokare-1 and Manutahi-1, which widened substantially during accumulation of the Matemateaonga Formation.

4.4 Two phases of Neogene continental margin progradation

Fig. 10 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. 1993; 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 (Fig. 6). 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.

4.5 Stratigraphic architecture between Taranaki and King Country Basins

In the vicinity of eastern Taranaki Peninsula and Wanganui Basin the major stratigraphic units, as described above, accumulated across the boundaries between all three basins (Figs. 2, 3, 11 & 12), 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. 11 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°), 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 (**Stop 10**). 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. 11), 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. 11). The Mahoenui Group is Otaian in age (22-19 Ma) and throughout the King Country region is either a bathyal massive mudstone facies (Taumatamaire Formation) or a flysch facies (Taumarunui Formation). Near Awakino Tunnel, mapping shows that the Taumatamaire Formation clearly onlaps an unconformity cut across the Te Kuiti Group, which it oversteps to onlap basement (Cochrane 1988). The onlap shows that the basin margin subsided differentially during accumulation of Taumatamaire Formation, as indicated by the fanning of dips from 20-5° (Cochrane 1988). The Manganui Fault (Campbell & Raine 1989) lies 3 km to the west of the eroded onlap margin and has the appropriate strike to have acted as the structure controlling the rotation of the block carrying the differentially tilted Taumatamaire Formation. We infer that the Manganui Fault was a high-angle reverse fault at this time, upthrown to the east, with several hundred to 1250 m of displacement.

4.5A 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. 11), and included reverse movement on the Ohura and Pungapunga-Hauhungaroa Faults (Fig. 3) 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. 11).

Mokau Group accumulated during the Altonian to a thickness of about 260 m, mainly northwest of Ohura Fault (Crosdale 1993; Vonk 1999) (Fig. 11). 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. 11). This was followed by the accumulation of Manganui Formation mudstone, initially as a shelfal deposit, but by the middle Altonian as a mid-bathyal succession (King et al. 1993). Moki Formation accumulated as submarine channel and fan deposits on a lower slope to basin floor west of the modern coastline (King & Thrasher 1996) and as channel complexes on a continental slope to the east (Kamp et al. 2004). Hence a complete coastal plain-shoreface-shelf-slope-basin floor linked depositional system developed across the margin between Taranaki and King Country Basins during the Altonian and probably into the mid-Lillburnian (Fig. 4). This depositional system formed over a narrow belt some 35 km wide. We show in Fig. 11 the approximate positions of the shelf-slope break during the Altonian-lower Lillburnian and infer that this break migrated slowly inland (retrogressed). The system had a strong aggradational component during the Altonian-lower Lillburnian and a surprisingly narrow shelf, which will have been controlled by the balance between the rate of subsidence of the underlying basement block and by the rate of sediment flux.

The Altonian marked the start of the collapse (marked subsidence) of the Kawhia Harbour to Taranaki Peninsula sector of the eastern margin of Taranaki Basin. This collapse accelerated during the early-middle Miocene leading at the end of the middle Miocene to the development of a bathyal environment over the eastern Taranaki Basin margin and the King Country region. During the upper Lillburnian, the King Country region underwent marine flooding, possibly in response to emplacement of the subducted slab of Pacific plate beneath the region (Kamp 1999). The basal stratigraphic unit is the Mangarara Formation, which over most of the King Country is a transgressive shellbed. The Otunui Formation is a 100-200 m-thick sandstone to calcareous sandy siltstone, containing a variety of facies typical of an onlapping shoreline through shelf and upper slope succession, including glauconite-rich units (Gerritsen 1994; 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 (Puga-Bernabéu et al. 2009). 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) (Puga-Bernabéu et al. 2009), were sourced partly from areas of carbonate accumulation on the contemporary shelf to the east in the King Country region (Tangarakau Formation, 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/marine settled units, or dominantly as channelised mass-emplaced beds.

Between about 14 Ma (upper Lillburnian) and 11 Ma (lower Tongaporutuan) there was marked subsidence to bathyal (1000 m) basin floor environments of what had previously been land along the eastern margin of Taranaki Basin and in the King Country region (Fig. 11). This subsidence, in the absence of an oversupply of sediment, led to southeastward retrogradation of the continental margin that previously (in the Otaian) had been pinned to the Taranaki Fault. At about 11 Ma, when higher rates of uplift and erosion developed along the Alpine Fault, reflected in high rates of sediment flux, a continental margin wedge comprising Mt Messenger, Urenui, Kiore, and Matemateaonga Formations started to prograde northward into this basin as the progradational part of the Whangamomona Sequence (Figs. 8-11). 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. 11 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.

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5 - FIELD TRIP ROUTE AND STOPS (see Fig. 1)

Day 1

Stop 1 - Hinuera Formation, Hamilton Airport (S15/151669)

Brief stop on Airport Rd at the south end of Hamilton Airport runway at abandoned Winstone's Aggregates Quarry that extracted sand and gravel of the late Pleistocene Hinuera Formation (see section 4.1). Examine quarry road cut in profusely cross-bedded pumiceous and rhyolitic gravelly sands beneath the Hinuera Surface, the last major aggradational surface of the late Pleistocene braided Waikato River system in Hamilton Basin. Having just crossed the modern Waikato River at "The Narrows", compare and explain the contrasting Recent and late Pleistocene fluvial systems.

After Stop 1, join the main Hamilton-Otorohanga highway 3 travelling south on a series of low ridges and hills developed on early-middle Pleistocene terrestrial and pyroclastic deposits of the Tauranga Group (see section 4.1). Good views of the geomorphology and larger-scale geological features of Hamilton Basin and surrounds, mentioned in section 4.1. Nearer Te Awamutu, excellent views to the W-SW of the NW-SE aligned andesitic and basaltic composite cones of Karioi (756 m), Pirongia (959 m), Kakepuku (450 m) and Te Kawa (214 m), all part of the Alexandra Volcanic Group (2.74-1.6 Ma). Away to the east is the andesitic-dacitic cone of Maungatautiri (797 m; 1.8 Ma).

Stop 2 - Waipapa terrane greywacke, Tokanui (S15/153405)

A few km beyond the Tokanui turnoff on highway 3, stop at roadside Osterns Quarry in Mesozoic greywacke basement rocks, here a locally uplifted block of Jurassic Manaia Hill Group within the Waipapa (composite) terrane (Edbrooke 2005). The beds are highly sheared, non-fossiliferous, fine volcanic litharenites, similar to those forming the Pakaroa, Rangitoto and Hauhungaroa Ranges bounding the Hamilton and King Country Basins away to the east and southeast. The Manaia Hill Group extends west from here a further 15-20 km, ending at the major N-S Waipa Fault against the fossiliferous late Triassic-Jurassic Murihiku terrane basement rocks (Fig. 2), to be viewed at Stop 5.

After Otorohanga the generally subdued relief of the Hamilton Basin is replaced by a more rugged topography developed in Tertiary sediments of the Te Kuiti, Mahoenui and Mokau Groups (Figs. 2, 11). Hills are sometimes capped by sheets of columnar-jointed Pakaumanu Group ignimbrites (Fig. 2) sourced from Mangakino caldera between c.1.68-1.00 Ma (e.g., Ngaroma - 1.55 Ma, Ongatiti - 1.21 Ma, Ahuroa – 1.18 Ma, Rocky Hill - 1.00 Ma).

Stop 3 - Otorohanga Limestone and Mahoenui Group mudstone, Oparure (S16/915159)

A few km north of Te Kuiti turn west on to Oparure Rd and travel to McDonald's Lime Quarry, the largest in New Zealand. The quarry exposes at least 60 m of late Oligocene – earliest Miocene (Waitakian, Lw) Otorohanga Limestone, the topmost formation in the Te Kuiti Group (Fig. 13; Nelson 1978; Tripathi 2008; Kamp et al. 2008). A stratigraphic column (C-119) which includes some associated photo images appears as Fig. 14. The Otorohanga Limestone, a bryozoan biosparite or grainstone, typically has carbonate contents above 90% and often near 100%, so it is the preferred unit for extracting high-quality agricultural and industrial lime in the Te Kuiti district. We will briefly note the local stratigraphy and paleoenvironmental setting of the limestones, comment on their pronounced flaggy structure, and discuss the nature and significance of the rapid transition at the top of the limestone up into overlying bathyal mudstones (Taumatamaire Formation) of the early Miocene Mahoenui Group (Figs. 11, 13, 14).

When leaving the quarry roadway after Stop 3 turn north (left) into Oparure Rd and then soon right into Troopers Rd which will take us back to highway 3 well south of Te Kuiti township and near south of Eight Mile Junction where highway 4 goes to Taumarunui. Along Troopers Rd there are good examples of karst landscape features developed in the Otorohanga Limestone, of more rounded hills on Mahoenui mudstone, and common hill-top cappings of the 1.21 Ma Ongatiti Ignimbrite briefly mentioned in the Stop 2 notes. Troopers Rd closely follows the line of the Waipa Fault separating the Waipapa (to E) and Murihiku (to W) basement terranes. The Waipa Fault offsets the Te Kuiti and Mahoenui Group successions so that it has experienced some movement since the early Miocene. At highway 3 turn south (right) towards Piopio (toilets available).

Stop 4 - Wairere Serpentinite – The Dun Mountain–Maitai terrane, Piopio (R17/859932)

In Piopio village turn south off highway 3 into Aria Rd and proceed south through common shallow exposures of Otorohanga Limestone to the road bridge over Mokau River, sited immediately above the Wairere Falls (and Wairere Power Station of King Country Energy). Around and south of Piopio the Otorohanga Limestone is very thin (a few to several m) and alone constitutes the entire Te Kuiti Group, having progressively onlapped a broad basement high in the region (the Piopio High or Threshold) during the earliest Miocene (upper Lw). Note that highly variable and often substantial paleorelief (up to a few 100 m) upon Mesozoic basement rocks was a regionally characteristic feature during accumulation of the Te Kuiti Group between the late Eocene and earliest Miocene (Ab-Lw) throughout the entire Waikato-King Country (South Auckland) area (Nelson 1973, 1978).

Turn left over the road bridge onto Kaitaringa Rd and right into Waitahi Rd, then left into Kohua Rd which leads around to Rorisons RMD serpentinite (and limestone) quarry, extracted as an additive for agricultural fertiliser use since 1945 (Edbrooke 2005). An irregular linear mass of sheared serpentinite, about 700 m long and up to 70 m wide, occurs along the trace of the Waipa Fault which runs N-S through the quarry (Fig. 15). The rocks are correlated with the Dun Mountain Ultramafics Group that includes the early Permian ultramafic rocks of Nelson and Southland. A distinctive linear positive magnetic anomaly known as the Junction Magnetic Anomaly (Hatherton 1967) traces the occurrence of these ultramafic rocks through the North Island. It passes directly through the location of the Wairere Serpentinite body and thereafter closely follows the Waipa Fault, suggesting that the fault represents a terrane suture and the serpentinite mass an outcrop of the otherwise concealed ultramafic rocks of the Dun Mountain-Maitai terrane. The Wairere Serpentinite itself consists of dark blue and green lenses of massive serpentinite separated by pale to dark blue and green sheared serpentinite, all derived from a harzburgite parent (O'Brien & Rodgers 1973, 1974; Edbrooke 2005). Xenoliths of metasomatised gabbro are common, ranging from a few cm to many metres in size, and rodingite is often developed about the margin of the xenoliths.

The serpentinite is in fault contact with Murihiku terrane rocks and overlying Otorohanga Limestone on the west side of the quarry, and with Mahoenui Group mudstone (and possibly limestone) and overlying Mokau Group muddy fine sandstones and carbonaceous beds to the east.

Emplacement of the serpentinite was likely a diapiric process in response to a compressive stress system, possibly close to the time of deposition of the Otorohanga Limestone in the earliest Miocene (Lw), or soon thereafter. Ongoing movement in the Miocene is suggested by local brecciation of the contact Mokau Group sediments. The limestone suffered folding (locally to the vertical) and formation of pinch-and-swell structures, local brecciation and recrystallisation, slickensiding and jointing. Twinned aragonite crystals are common both at contacts and on shear planes within the serpentinite.

Return to Piopio via the same route and turn south again onto highway 3.

Stop 5 - Murihiku terrane "greywacke" and Piopio High, Piopio (R17/855003)

Just south of Piopio stop on roadside opposite the Piopio Quarry to view the stratigraphic succession from bottom to top: west-dipping, well bedded late Triassic (Warepan, Bw) "greywacke" sandstone with occasional interbeds of granite-bearing conglomerate (part of Murihiku Supergroup); thin earliest Miocene (Lw) Otorohanga Limestone (column C-154 and images in Fig. 16); and early Miocene (Po) Mahoenui Group blue-grey mudstone (Taumatamaire Formation). Discuss the evolution of this section, including the Kawhia Regional Syncline, the significance of the unconformities between the three units, and the importance of the Piopio High (or Theshold) on Oligocene sedimentation.

Continue south on highway 3 passing occasional roadside outcrops in Murihiku basement rocks of mainly deeply weathered, well bedded Jurassic siltstones and sandstones, and a gradually thickening succession of Te Kuiti Group units involving Aotea Formation (lower) and Orahiri Limestone (upper) that form impressive bluffs on either side of the Mangaotaki River.

Stop 6 - Aotea Formation - Orahiri Limestone, Mangaotaki Bridge (R17/761957)

Park at off-road bay on roadside opposite the sharp contact between Aotea Formation muddy sandstones and Orahiri Limestone, about half way up the road incline after crossing Mangaotaki Bridge. The Te Kuiti Group here involves basal Waimai Limestone Member on Mesozoic basement overlain by a series of interbedded calcareous muddy fine sandstone and mudstone of Kihi Sandstone Member (both in Aotea Formation, possibly upper Lwh or Ld age), which in turn is separated by a sharp unconformity from overlying Orahiri Limestone (Ld age) which is conspicuously pebbly, glauconitic, phosphatic and macrofossil-rich at its base. Large fossil oysters, diagnostic of the Orahiri Limestone (Nelson et al. 1983), occur in beds up to a few m thick at the top of the cliffs. A stratigraphic column (C-166) and images are shown in Fig. 17. Discuss the nature and significance of the unconformity, and the rapid variations in thickness and character of the Te Kuiti Group in this area.

Stop 7 - Taumatamaire Formation of Mahoenui Group, Mangaotaki (R17/755946)

Near south of Stop 6, park on roadside partway up hill incline to view a road cut in moderately calcareous mudstone of the Taumatamaire Formation. Of early Miocene (mainly Po) age, these mudstones form a prominent thick unit in the landscape through to Mahoenui and beyond. Foraminifera indicate deposition at slope depths (Topping 1978). Although often massive (bioturbated), some outcrops exhibit faint bedding as a result of rhythmic variations in the content of terrigenous silt, suggestive of "mud turbidites". Carbonate concretions, sometimes quite large (up to 1 m), are developed locally in the plane of bedding. A high content of clays (about 45%) in the mudstone, completely dominated by swelling smectite (Nelson & Hume 1977), poses an on-going problem in road construction for civil engineers as a consequence of cyclical wetting and drying and swelling and shrinking of the mudrocks, leading to eventual slope failure. The next couple of km of road beyond this stop has undergone major reconstruction in recent years.

Stop 8 - Mahoenui depocentre overview, Mahoenui (R17/729924)

Pull off highway 3 and park at Totoro Rd junction to view the landscape and geology of the entire Mahoenui depocentre. To the west Murhiku Supergroup basement forms the Herangi Range (High) on the skyline. In front of this, dipping towards us and onlapping the basement rocks, is the Oligocene Orahiri Limestone (plus thin Otorohanga Limestone) with Aotea Formation (sandstone) and Glen Massey Formation (mudstone) out of sight at the foot of the scarp slopes. The central part of the depocentre is filled with early Miocene mudstones of the Taumatamaire Formation. To the S and SE, the Papakauri Plateau forming the skyline is constructed on early Miocene Mokau Group sandstones (Bexley Sandstone). More distant views to the east show the heavily bush-clad country typical of the inland King Country region, underlain by variably eroded late-early to late Miocene formations that were formerly continuous with the Taranaki Basin succession.

Continue south on highway 3 passing through the settlement of Mahoenui, beyond which good roadside exposures of Taumatamaire Formation mudstone with concretions (Mahoenui Group) are seen, and later a prominent dip slope developed on Black Creek Limestone within the Taumatamaire Formation (see Fig. 19, Stop 9).

Stop 9 - Oligocene-early Miocene geology, Awakino Tunnel (R17/618853)

Pull over into roadside park area near north of Awakino Tunnel. The stop looks across to the (now) pine covered dip slope upon the top of the Orahiri Limestone (Ld; locally also a veneer of Otorohanga Limestone, Lw) which dips about 25-30°E towards us (Fig. 18). The Awakino Tunnel just beyond this stop is cut through the Orahiri Limestone. Above the dip slope are Taumatamaire Formation mudstones of the Mahoenui Group (Po) which in this area only include several mainly thin (<few m) discontinuous limestone units, the thickest and most persistent of which is the Black Creek Limestone Member, seen high to the S here and as the dip slope mentioned above (Fig. 19). Taumatamaire mudstone also sits above the Black Creek Limestone and is followed by bush-clad bluffs in Bexley Sandstone (Pl) (Figs. 18, 19)). Note the fanning relationships of all units in the succession, with dips ranging from as much as 35-40°ESE in the Te Kuiti Group formations below the Orahiri Limestone (unseen from here), through 20 to 8°ESE by the level of the Black Creek Limestone, to just a couple of degrees in the topmost Bexley Sandstone (Figs. 19, 20). The situation results from synsedimentary tilting during the Oligocene and early Miocene so that inter- and intra-formational subtle angular unconformities occur through the succession. The driver was differential uplift of the basement Herangi High (Fig. 3).

Discussion points on the Te Kuiti Group: Lithologies and paleoenvironments of the Okoko Subgroup of the Te Kuiti Group suggest a seaway across this area and into Taranaki Basin, whereas the overlying Castle Craig Subgroup units of the Te Kuiti Group suggest structural mobility of the Herangi High associated with reverse movement on the Manganui Fault (Fig. 3). The Aotea Formation (Hauturu Sandstone Member) has an exotic basement provenance and suggests longshore transport from the south hinged to a shoreline along the east of an emergent Herangi High uplifted on the Manganui Fault.

The Otorohanga Limestone (Lw, latest Oligocene – earliest Miocene), widespread elsewhere in the northern King Country, is thin or absent here, possibly due to erosion during the early Miocene, reflecting initial uplift due to crustal shortening. This is consistent with a decrease in sedimentation rate upwards through the Te Kuiti Group (70 mm/y, Whaingaroa/Dunphail siltstone; 12.5 mm/y, Aotea sandstone; 8.5 mm/y Orahiri Limestone; Nelson et al. 1994), and the angular unconformity of c.15° between the Orahiri Limestone and the Taumatamaire Formation (Fig. 20).

There is a subtle but important angular unconformity of c.15° between the Orahiri Limestone and the Taumatamaire Formation, representing an earliest Miocene interval of erosion and bevelling of the Te Kuiti Group, followed by subsidence and onlap, such that the Mahoenui Group overstepped the Te Kuiti Group onto basement at higher elevations on the structural high (Fig. 20). Marked synsedimentary tilting occurred on the flanks of the high throughout the accumulation of the Mahoenui Group (Po), resulting in the fanning of dips (Figs. 19, 20). The rate of tilting slowed into the Altonian Stage (Pl) during accumulation of the Bexley Sandstone, but its continuation is evidenced by the overstepping of Bexley Sandstone onto basement west of the most western extent of the Mahoenui Group beds (Fig. 21).

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

The limestones in the Mahoenui Group were sourced from shoreline or shoal facies developed over and adjacent to the tectonically active basement high. The two main limestones are the Awakino Limestone Member (lower) and the Black Creek Limestone Member (upper; Fig. 20). All limestones, thin or thick, thin rapidly to the E-NE (offshore) into background slope mudstone of the Taumatamaire Formation. Some are clearly calc-turbidites and others include hummocky cross-bedding structures, both indicative of redeposition. The limestones are usually distinguished from those in the Te Kuiti Group by their consistently high content of calcareous red algal and (larger) benthic foraminiferal (e.g. *Amphistegina*) grains (Cochrane 1988).

Stop 10 - Orahiri Limestone, Awakino Tunnel (R17/615854)

Driving carefully through the Awakino Tunnel (see Frontispiece A), with the Awakino River alongside, and pull over into the offroad area near beyond the tunnel to examine the sedimentology of the Aotea Formation (Hauturu Sandstone Member) and Orahiri Limestone at the western end of the tunnel entrance and their tectonic significance. A stratigraphic column is reproduced in Fig. 22. These stratigraphic units, and their sedimentology and petrography, are described and interpreted in Nelson et al. (1994).

The Whaingaroa Formation (now referred to Dunphail Siltstone within Glen Massey Formation; Tripathi 2008) is of early Whaingaroan age (34.3–30.0 Ma), c.200 m thick, massive to thin-bedded in its lower part, and composed of calcareous mudstone (45-55% $CaCO_3$). A significant unconformity separates the Whaingaroa and Aotea Formations. It is a sharp burrowed contact, overlain by a bioturbated, glauconitic pebbly sandstone for 0.5 m. The Aotea Formation is c.30 m thick, upper Whaingaroan-Duntroonian in age, concretionary, massive to bedded, calcareous fine sandstone (40-60% $CaCO_3$). At the tunnel it includes a few limestone beds. The sand is quartzofeldspathic and cannot have been sourced from the Murihiku Terrane (Herangi High), but more probably basement to the south. A sharp eroded contact marks the boundary between the Aotea Formation and the Orahiri Limestone, which is c.40 m thick.

The Orahiri Limestone at the tunnel (Fig. 23) comprises three facies: 1. Flaggy limestone beds – sandy, bryozoan-benthic foraminiferal-echinoid skeletal limestone, comprising the lower 8 m of the formation. 2. Oyster beds – large oysters of the tribe *Flemingostreini* Stenzel in a pebbly, micritic, very coarse, bryozoan-bivalve-benthic foraminiferal limestone. This facies dominates in the upper few metres of the formation. The oysters formed as low relief banks in a fully marine tide-swept seaway, probably at inner to mid-shelf depths (Nelson et al. 1983). 3. Limestone-in-limestone beds – interbedded flaggy and "conglomeratic" limestones, the individual beds ranging from 0.5-3.0 m thick, occurring in the bulk of the thickness of the formation in the vicinity of the tunnel (Figs. 23, 24). There are six such beds, interpreted to have been mass-emplaced as debris flows. This facies has a variably micritic matrix, containing highly irregular clasts of dark grey calcareous sandstone and limestone, 1-10 cm in size (Fig. 24), and some well-rounded greywacke and igneous clasts derived from basement. The calcareous lithoclasts are commonly bored (Fig. 25), likely by intertidal pholad bivalves, and calcareous red algae encrust some clasts.

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

Stop 11 - Awakino Limestone Member, Awakino Gorge (R18/591795)

From Awakino Tunnel, proceed south through the Awakino Gorge with roadside exposures mainly in Murihiku basement rocks and occasional glimpses up high on the north side of the road of the overlying Te Kuiti Group rocks (including at Bexley Tunnel). Turn inland (left) at Awakau Rd and travel a short distance to view a roadside outcrop of one of the limestones within the Mahoenui Group (probably the Awakino Limestone Member; Fig. 20). Red algal remains (including rhodoliths) are common in the limestone. Note that further evidence for strongly differential movements of the Herangi High in the Oligocene and early Miocene is shown by the progressive reduction in thickness of the Te Kuiti Group from c.300 m to <15 m and of the Mahoenui Group from >300 m to perhaps also only c.15 m between Awakino Tunnel and Awakau Rd. The Te Kuiti Group is not subaerially exposed south of Awakau Rd.

Return to highway 3 and drive to Awakino Hotel for the evening.

<u>Day 2</u> (NB – Depending on tide times and weather some stops may be interchanged)

Stop 12 - Bexley Sandstone, south end Awakino Gorge (R17/559800)

Travel back towards Awakino Gorge to examine the Bexley Sandstone resting unconformably on steeply dipping Murihiku Terrane of Late Triassic age (Warepan Stage, *Monotis richmondiana*) (Fig. 26). Bexley Sandstone is a transgressive shoreface deposit consisting of well sorted fine sandstone, mainly massive but including intervals with weakly developed low-angle cross- to horizontal-bedding or laminae, and occasional fossil casts. It represents eastward-directed marine onlap of basement during the late-early Miocene (Pl), following cessation of basement overthrusting on the Taranaki and Manganui Faults during the early-early Miocene (Po) (Fig. 21). The facies might be anticipated to occur offshore on basement as far west as the Taranaki Fault.

Stop 13 - Overview Miocene geology, western end of Ladies Mile (R17/547806)

Return towards Awakino with brief stop in off road park area at the western end of Ladies Mile (Fig. 27) to view the geological units exposed in the valley sides and the Waikato Sheet geological map. Note Manganui/Moki Formation in the middle to lower part of the southern hillsides immediately to the left, Mohakatino Formation (brown volcaniclastic sandstone) forming a prominent buttress high up on the left, and thin Mt Messenger Formation at the top of hill and beyond. The trace of the Manganui Fault crosses the valley from right to left, upthrown on the west side, bringing a full thickness of Bexley Sandstone into the bluff outcrop at the end of Ladies Mile. In the vicinity of the Awakino Valley the Manganui Fault has normal throw of Pliocene-Pleistocene age, a reversal of the sense of early Miocene (Po) throw. The prominent hill section at the end of the valley on the south side contains thick (c.20 m) Mangarara Formation calcareous sandstone and limestone as submarine channel complexes above the upper part of Manganui/Moki Formation and below Mohakatino Formation (Puga-Bernabéu et al. 2009). The Mt Messenger Formation is immediately below the line of pine trees at the top of the bluff. On the northern side of Awakino Valley the Bexley Sandstone and overlying Manganui Formation dip southward off the Herangi Range forming dip-slopes.

Note the marked local variation in the thickness of the transgressive Bexley Sandstone (e.g., Fig. 21), thickening eastward into a fault-angle depression on the footwall side of the reverse Manganui Fault. Note also the virtually continuous Altonian – Tongaporutuan section that dips obliquely offshore into Taranaki Basin, which thickens in that direction as the degree of Plio-Pleistocene erosion reduces to the west. Plio-Pleistocene displacement on the Manganui Fault is part of an extensional fault system between the Northern Graben and the Taupo Volcanic Zone.

Stop 14 - Bexley Sandstone to Manganui Formation transition (R17/525818)

Continue towards Awakino and about midway between the petrol station and Awakino Hotel, park on the river side of highway 3 to walk an excellent roadside section across the contact zone between the shoreface sands of the Bexley Sandstone (Pl; Mokau Group) and the overlying deep-water (slope) muds and turbidite beds of the Manganui Formation (here also Pl). A concretionary shell bed marks the contact. A schematic stratigraphic column is reproduced in Fig. 28.

Stop 15 - Manganui/Mangarara/Mohakatino Formations, Awakino Heads (R17/511808)

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

Fig. 29 shows a simplified stratigraphic log from King et al. (1993) and Fig. 30A illustrates the section. The upper part of the Manganui Formation is (dangerously) well exposed in a cave/bluff at the inland end of the section. This is overlain by channelised Mangarara Sandstone. A 20-50 cm-thick channelised conglomerate (concretions) bed with a volcaniclastic matrix overlies Mangarara Sandstone. Mohakatino Formation (Purupuru Tuff) comprises thin to medium bedded volcaniclastic succession 8 m thick. It is has a Marine Oxygen Isotope Stage 5e (last interglacial) ravinement surface cut across it. Late Quaternary terrace deposits of the Rapanui Formation overlie the ravinement surface.

The Manganui Formation is a pale grey massive mudstone facies, with sticks of solitary coral (*Truncatoflabellum* sp.) scattered within it, jarosite and occasional phosphate nodules and conchoidal fractures. The part of the formation exposed is of middle to late Altonian age, and the sediments accumulated at mid-bathyal depths (c.1500 m) (King et al. 1993). The Manganui Formation is well exposed in the hill country to the east of highway 3 where it is about 200 m thick, and includes a variety of facies, including thin turbidite facies, channelised beds of mass-emplaced siliciclastic very fine sandstone, and large wavelength (50 m) wavy concretionary siltstone channel facies high in the succession. The channelised sandstone facies would be regarded as Moki Formation in eastern Taranaki Basin well records. This would include the Mangarara Sandstone channel at Awakino Heads and the more carbonate-rich (i.e. limestone facies) beds in the section above Ladies Mile. At low tide, examples of these channelised beds are exposed in the river bed at Awakino Heads.

Fig 30B illustrates the upper part of the Manganui Formation and the transition to Mangarara Sandstone. A subtle normal fault with more than 4 m of throw offsets the Manganui Formation, down-faulting the uppermost part to the west. In this block we can observe the transition from

Manganui Formation into Mangarara Sandstone. The lower part comprises 1.5 m of very glauconitic siltstone. The glauconite occurs mainly as rounded pellets and angular coated siltstone grains. This is overlain by a 10 cm-thick calcareous redeposited bed, followed by 2 m of laminated siltstone, which is cut into by a 2.5 m-thick channelised deposit of Mangarara Sandstone. Further along the outcrop the Mangarara Sandstone comprises two or three sedimentation units. Mangarara Sandstone at Awakino Heads is glauconitic, gritty, shelly muddy sandstone with abundant foraminifera. In the steep section at the western end of Ladies Mile there are channelised beds of calcareous sandstone that grade upwards into limestone.

We interpret the upper Manganui – Mangarara succession as having accumulated on a paleo-continental slope. The mudstone facies represent background hemipelagic slope sedimentation, and the calcareous sandstone and limestone represents submarine channel fill and upper fan facies. The carbonate material, chiefly large benthic foraminifera and algal fragments, will have been sourced from a narrow shelf to the east, or from the south along submarine portions of the Patea-Tongaporutu High. The glauconite would have been sourced from near the shelf-slope break and incorporated into the debris flows as they passed over the shelf edge and down the paleo-slope channels. The unconformity at the top of the Mangarara Sandstone at Awakino Heads represents the base of another submarine channel, where submarine erosion at slope depths has removed sedimentary section of late Clifdenian through to Waiauan age, some 3 m.y. of time (Figs. 11, 29). The Purupuru Tuff, being the on land equivalent of the lower part of the Mohakatino Formation accumulated at lower slope depths, and the beds accumulated as sedimentation from tephra fallout, and as mass-emplaced debris flows or sandy debris flows sourced from the collapse and erosion of the contemporary Mohakatino Volcanoes in northern Taranaki Basin. The conglomerate at the base of the Purupuru Tuff contains concretions, some pholad-bored (having passed through an intertidal zone), that were probably sourced out of older Neogene beds (e.g. Mahoenui Group) exposed to the east, and deposited as a submarine channel fill. The clast-supported conglomerate may have been infiltrated by andesitic volcaniclastic sand soon after deposition. The unconformity between the Rapanui Formation and older beds formed a few metres above present sea level by wave erosion during the end of the last interglacial sea-level rise. Most of the present elevation of this surface has been achieved through tectonically-driven uplift since about 125 ka.

Stop 16 - Mt Messenger Formation, Pahaoa Hill (R18/513799)

The highway 3 drive south between Awakino and Mokau exposes fine examples of the Mt Messenger Formation in the high bluffs east of the road. We will not have time to ascend to these exposures but provide the following notes for the section above the Mokau village water works known as Pahaoa Hill (Fig. 31; farm owner David Black). The Mt Messenger Formation is of lower Tongaporutuan age in this section (King et al. 1993; M.P. Crundwell, personal communication, 2003). It rests conformably on the Purupuru Tuff, both units having accumulated on a lower continental slope to basin floor. The base of the Mt Messenger Formation here at Awakino and to the north (Waikawau) is sand-dominated, by contrast with a mud-dominated base to the formation inland to the southeast around Tahora (Kohu Member). This raises an issue about the definition of the Mt Messenger Formation and differences between on land mapping approaches to stratigraphy versus a definition more restricted to sandstone facies, as identified from wireline records in Taranaki Basin exploration holes.

Amalgamated yellow-brown siliciclastic sandstone beds form a prominent unit at the base of the hill section. The beds are well sorted fine sandstone and probably accumulated as sandy debris flows, forming a basin floor fan. Overlying beds are siliciclastic mudstone (hemipelagic sedimentation) or individual or amalgamated redeposited sandstone beds. Higher up in the section in the road cutting (Fig. 32) the bedding comprises interbedded siliciclastic sandstone and mudstone, and andesitic volcaniclastic sandstone and mudstone. The contrasting provenance of the sediments reflects the concurrent activity of the andesitic volcanoes in northern Taranaki Basin, supplying sediments semi-radially into the basin from the volcanic centres, and the bottom sets (Mt Messenger Formation) of the continental margin prograding into the basin from the south, being sourced from erosion of the continental collision zone across the Alpine Fault.

Stop 17 - Rapanui Formation, Seaview Motor Camp (R18/509794)

Park on ocean side of road just past the entrance to the Seaview Motor Camp to view the roadside section through coastal deposits of the late Quaternary Rapanui Formation. Here the Rapanui deposits rest unconformably (a major sequence boundary) on late-early Miocene (upper Pl) Manganui Formation mudstone, seen at the north end of the exposure at road level. A thin conglomerate lies above the unconformity followed by about 2 m of trough cross-bedded and planar bedded gravelly sand and 4 m of low-angle cross-laminated sand, all of beach-foreshore origin. Above this are c.5 m of cross-bedded aeolian sand (dunes) and a 3 m cover of Taranaki-derived tephra. The light colour of the black (iron) sands in the section is due to weathering. The sedimentary deposits represent the highstand systems tract associated with Marine Isotope Stage 5e (125 ky BP).

Stop 18 - Mt Messenger/Mohakatino Formations, Mokau River mouth (R18/510770)

Brief stop at Mokau (toilets here) to view the section exposed on the south side of the Mokau River mouth (Fig. 33). Several SW-NE striking normal faults displace the section in the vicinity of the river mouth. The major fault passes to the north of the Mokau Heads, up-throwing the Purupuru Tuff (Mohakatino Formation) on the south side of the estuary. Another subparallel fault to the SW follows the road through the gut as it comes down to the estuary, down-throwing Mt Messenger Formation relative to Purupuru Tuff. An array of associated small faults displaces Mt Messenger Formation to the SW of this second fault. The main cliff, draped by an expansive metal mesh due to cliff collapse, comprises Ferry Sandstone Member of the Mt Messenger Formation. This is the sand-dominated lower part of the formation. In the hill to the south above the road bridge a mudstone interval is the Tawariki Mudstone Member, and this is overlain by younger sandstone packets that probably represent basin floor fan deposits.

Stop 19 - Mt Messenger Formation sandstone, Mohakatino River bridge (R18/505736)

Continue south and stop in off road car park on the north side of the Mohakatino River bridge. Across the road is a 25 m thick package of amalgamated sandstones, typical of those at several horizons in the Mt Messenger Formation, and here in the lower part of that formation. The individual sandstone units are thick bedded (up to a few m), fine- to medium-grained sandstones with internal structure that is massive or planar bedded overlain by convolute bedding. They are interpreted as sandy debrites deposited in a basin floor fan setting. Thin mudstone, sometimes drawn up into flame structures, may occur between the sandstone beds. These thick bedded sandstones are equivalent to the better quality sands in the subsurface lower Mt Messenger Formation beneath peninsula Taranaki, and are a prime target for hydrocarbon exploration.

At this site the sandstone package sits on hemipelagic grey mudstones which include darker thinly bedded tephric layers. Preservation of the tephras in the mudstones but not the amalgamated sandstones highlights the much slower sedimentation rates associated with the former compared to the redeposited sandstones. Consider where to place the sequence boundary in such sections.

Stop 20 - Mt Messenger Formation sandstone, Tongaporutu River mouth (Q18/486642)

Brief stop (toilets on south side of river) to view the Tongaporutu River estuary, and a very thick sandstone bed, considered to have accumulated on a lower continental slope as a basin floor fan (King et al. 1993, 1994) (Fig. 34). The boundary between the lower and upper Tongaporutuan Stage (Fig. 4) lies at about the stratigraphic level of the sediments exposed in the cliffs around the estuary (King et al. 1993). The immediate road cutting above the Rest Area exposes very well a 30 m-thick section of amalgamated sandstone beds in a basin floor fan which also crops out on the southern side of the estuary (Sequence No 1 of King et al. 1994). Some of the individual sandstone beds are many metres thick. The base of this bed is well exposed in the cliff above the road some 50 m down the road towards the road bridge. In the base of it is a huge mudstone raft 1 m high and several m long, which is completely enclosed in sandstone. This raft has been ripped up from the underlying mudstone and is graphic evidence for the dense viscous flow character of the bed prior to its deposition.

Continue south on highway 3 and just beyond Ahititi School turn left (east) into Okau Rd (which leads inland through rugged bush country to Ohura and Taumarunui).

Stop 21 - Mt Messenger Formation thin-bedded sandstone, Okau Rd (R18/515578)

At this stop there are well exposed medium to thinly bedded sandstone beds and associated mudstone (Fig. 35). Subhorizontal echinoderm (*Scolicia*) burrow traces are common. We infer redeposition from turbulent flows, but the depositional setting (?channel overbank/levee) is uncertain and discussion is invited. The more prominent and thicker sandstone beds are examples of sandy debris flow deposits, as distinct from classical turbidites, which are deposited out of a more fluid medium.

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

Stop 22 - Otunui Formation and volcaniclastic interbed, Okau Rd (R18/574547)

Brief stop to view a 4 m-thick interval of andesitic volcaniclastic sandstone facies within Otunui Formation (Fig. 36). These beds are compositionally similar to the Purupuru Tuff of the Mohakatino Formation at Awakino Heads. However, at this site the volcaniclastic beds are demonstrably of Waiauan (late-middle Miocene) age. Hence they are the lowest stratigraphic occurrence in the on land record of the products of northern Taranaki andesitic volcanism. The beds are considered to have been mass-emplaced, the flows either having ridden part way up the contemporary slope from the northwest, or to have been emplaced down the slope, having accumulated higher up as airfall into the sea. We favour the former explanation as the volcaniclastic beds are not particularly mixed with siliciclastic mudstone.

This outcrop is also amongst the most western occurrence in outcrop of the Otunui Formation, here a diffusely dm-bedded muddy fine sandstone that shows characteristic burrow mottling. The formation does not occur in the Mohakatino River valley to the N/NW, where correlative beds (Moki Formation) are slope channel complexes with a finer-grained mudstone matrix than occurs in Otunui Formation. We infer accumulation of the lower parts of Otunui Formation in outer shelf to upper slope environments, possibly under eustatic control, whereas the Moki Formation accumulated on a mid- to lower continental slope (Fig. 11).

Travel back to north of the Tongaporutu bridge crossing on highway 3 and enter an off road car park on the ocean side.

Stop 23 - Mt Messenger Formation, Kawau Pa site (Q18/492697)

Depending on weather and tide state, we will view the coastal section that includes the "Jamroll" and other slump features in the Mt Messenger Formation, and proceed by track through bush down to coastal cliffs at Kawau Pa where there are superb outcrops of both the amalgamated basin floor sandstone and hemipelagic mudstone facies in the formation (see Frontispiece B), previously viewed (from a distance) at some other stops. Time permitting, participants can explore the exposures as they wish, noting perhaps the tephric layers in the mudstones, the sharp and sometimes highly irregular base of the amalgamated sandstone packages, consideration of sequence boundary placement and systems tracts in the record, observation of complexly slumped/deformed sections nearby, and consideration of the significance of these units to hydrocarbon exploration in offshore Taranaki Basin.

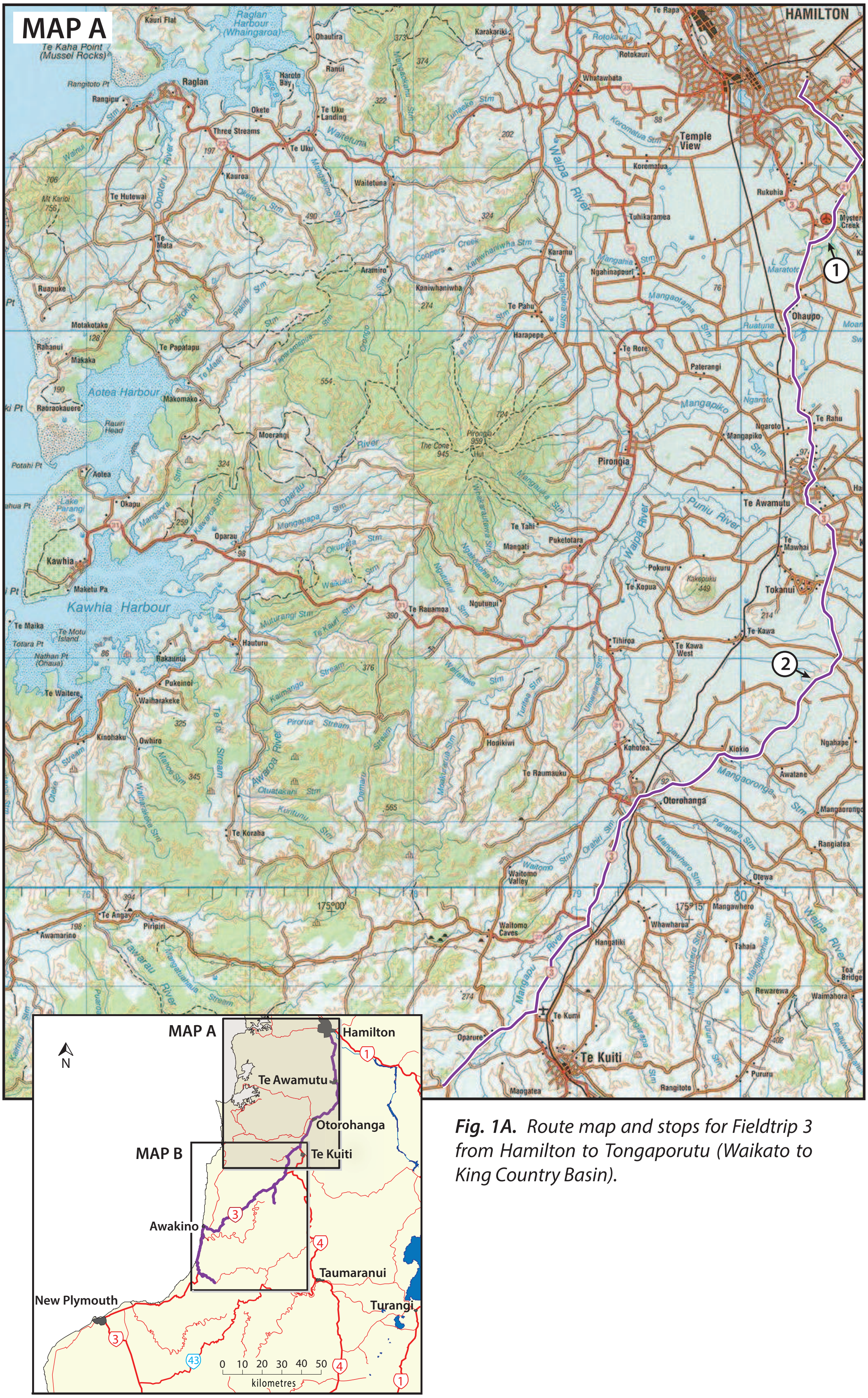
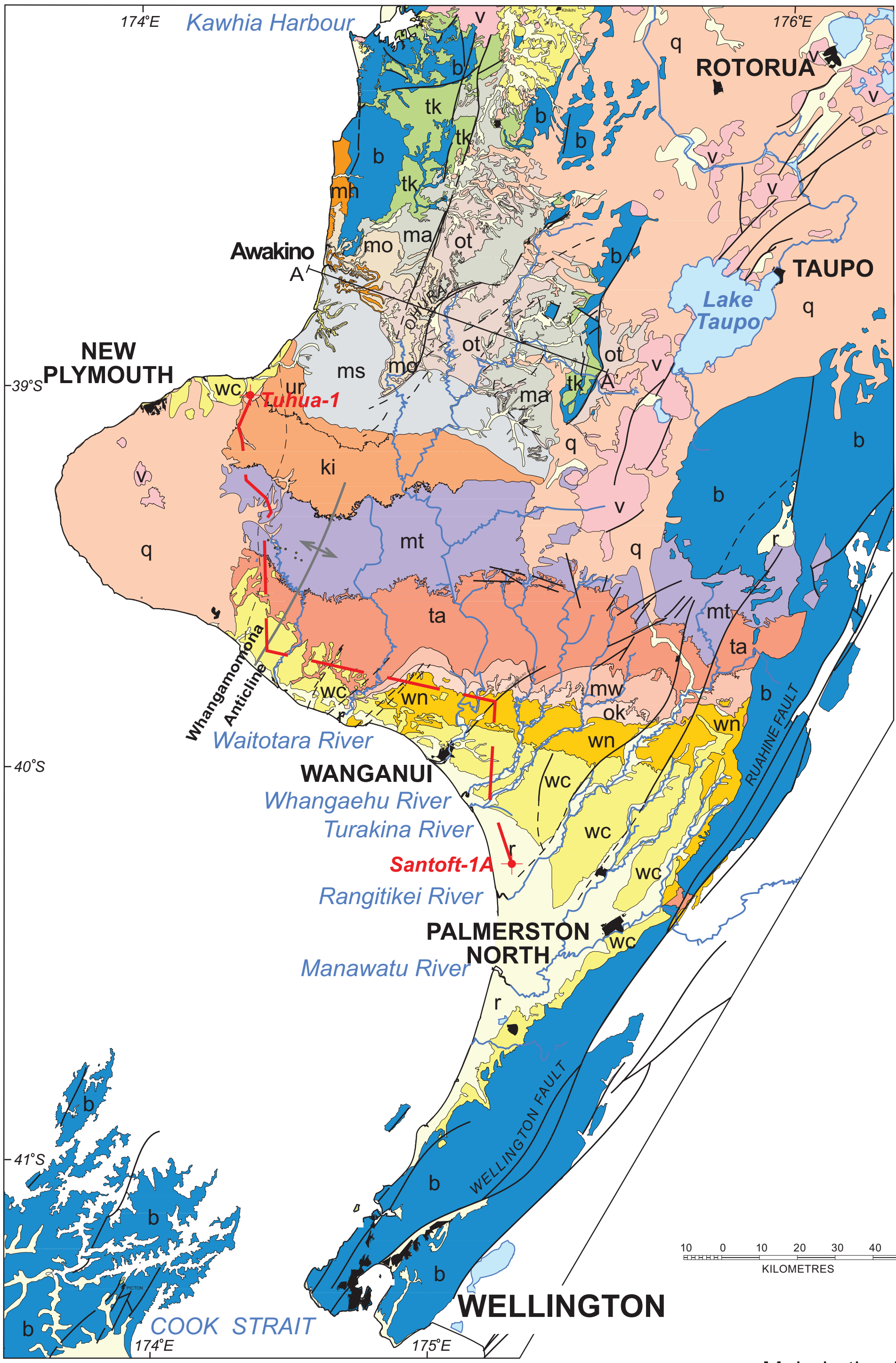


Fig. 1A. Route map and stops for Fieldtrip 3 from Hamilton to Tongaporutu (Waikato to King Country Basin).

Fig. 1B. Route map and stops for Fieldtrip 3 from Hamilton to Tongaporutu (Waikato to King Country Basin).



q	Quaternary volcanics	ok	Okiwa Group	mh	Mohakatino Fmn & Moki Fmn
v	Volcanic rocks	mw	Mangaweka Mudstone	ot	Otunui Fmn
r	Recent deposits	ta	Tangahoe Group	mo	Mokau Group
wc	Castlecliffian strata	mt	Matemateaonga Fmn	ma	Mahoenui Group
wn	Nukumaruan strata	ur + ki	Urenui Fmn + Kiore Fmn	tk	Te Kuiti Group
		ms	Mt Messenger Fmn	b	Basement

Fig. 2. *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. 6). Cross-section line A-A' is the basis for the chronostratigraphic panel in Fig. 11. From Kamp et al. 2004 (Fig. 1).*

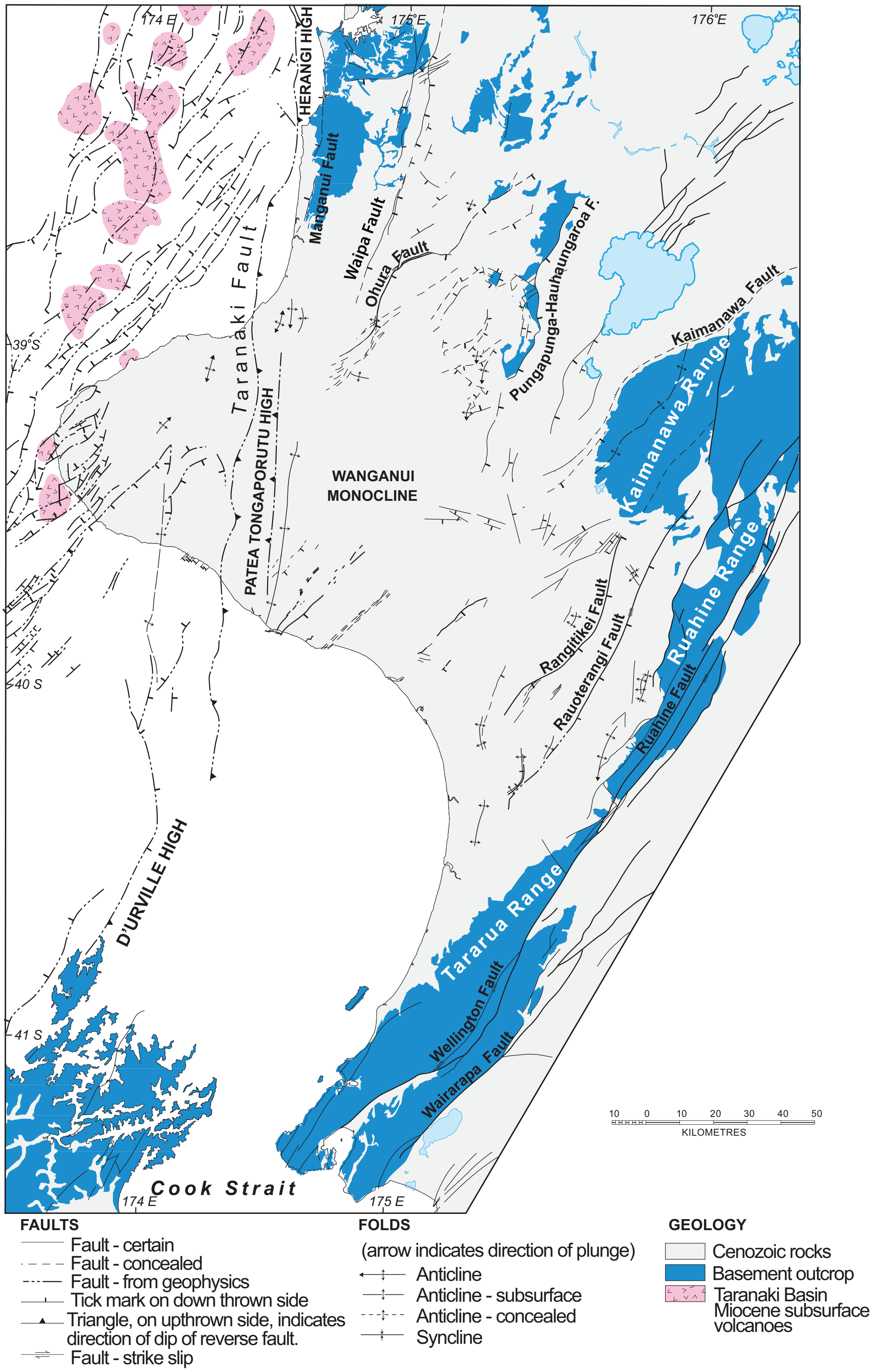


Fig. 3. Map of western North Island showing the major geological structures and the distribution of basement. While many of the structures are of Pliocene-Pleistocene age, some date back to the early Miocene and may not be currently active. From Kamp et al. 2004 (Fig. 2).

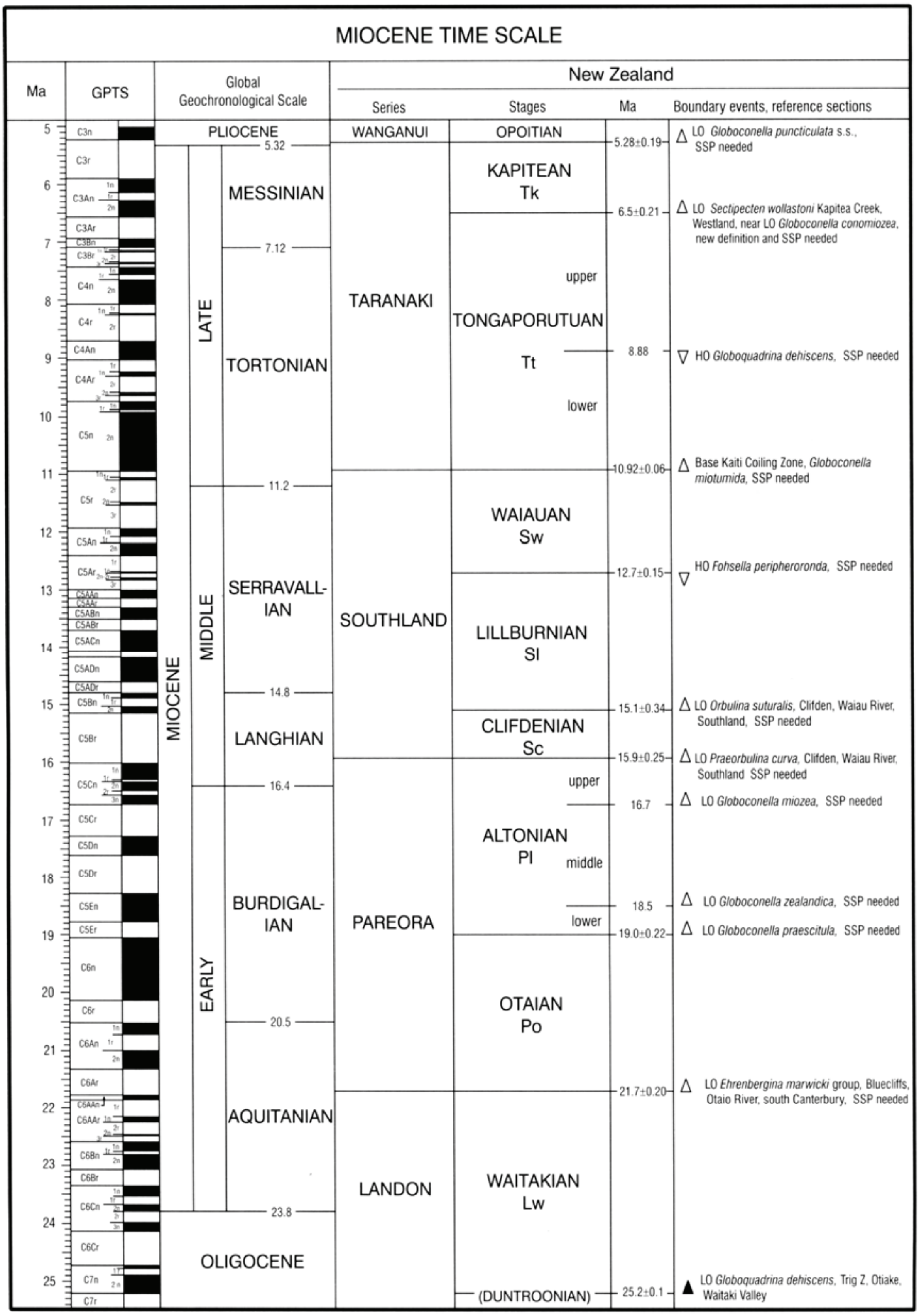


***Fig.4. Miocene** time scale showing the age of New Zealand Stages. From Crundwell et al. (Fig. 12.1) in Cooper (ed.) (2004).*

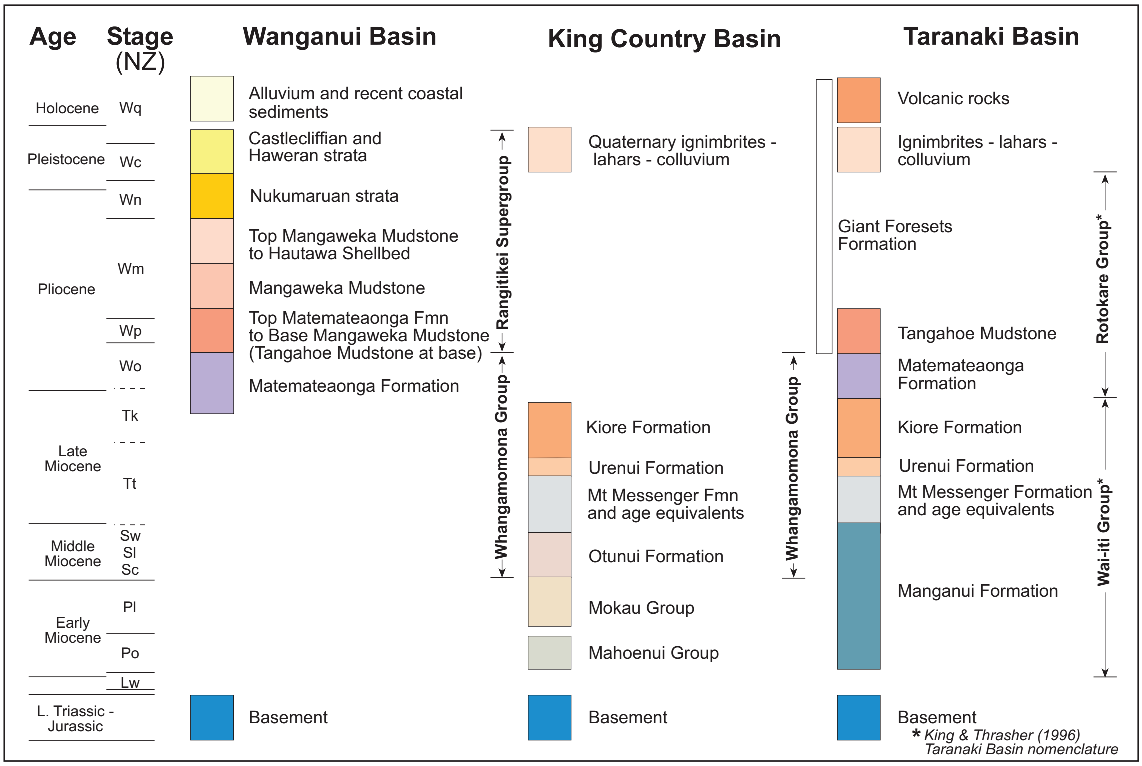


Fig. 5. The major Neogene stratigraphic units in each of Taranaki, King Country, and Wanganui Basins, and their age. The Moki and Mohakatino Formations, which occur within Manganui Formation in Taranaki Basin, are not shown. From Kamp et al. 2004 (Fig. 3).

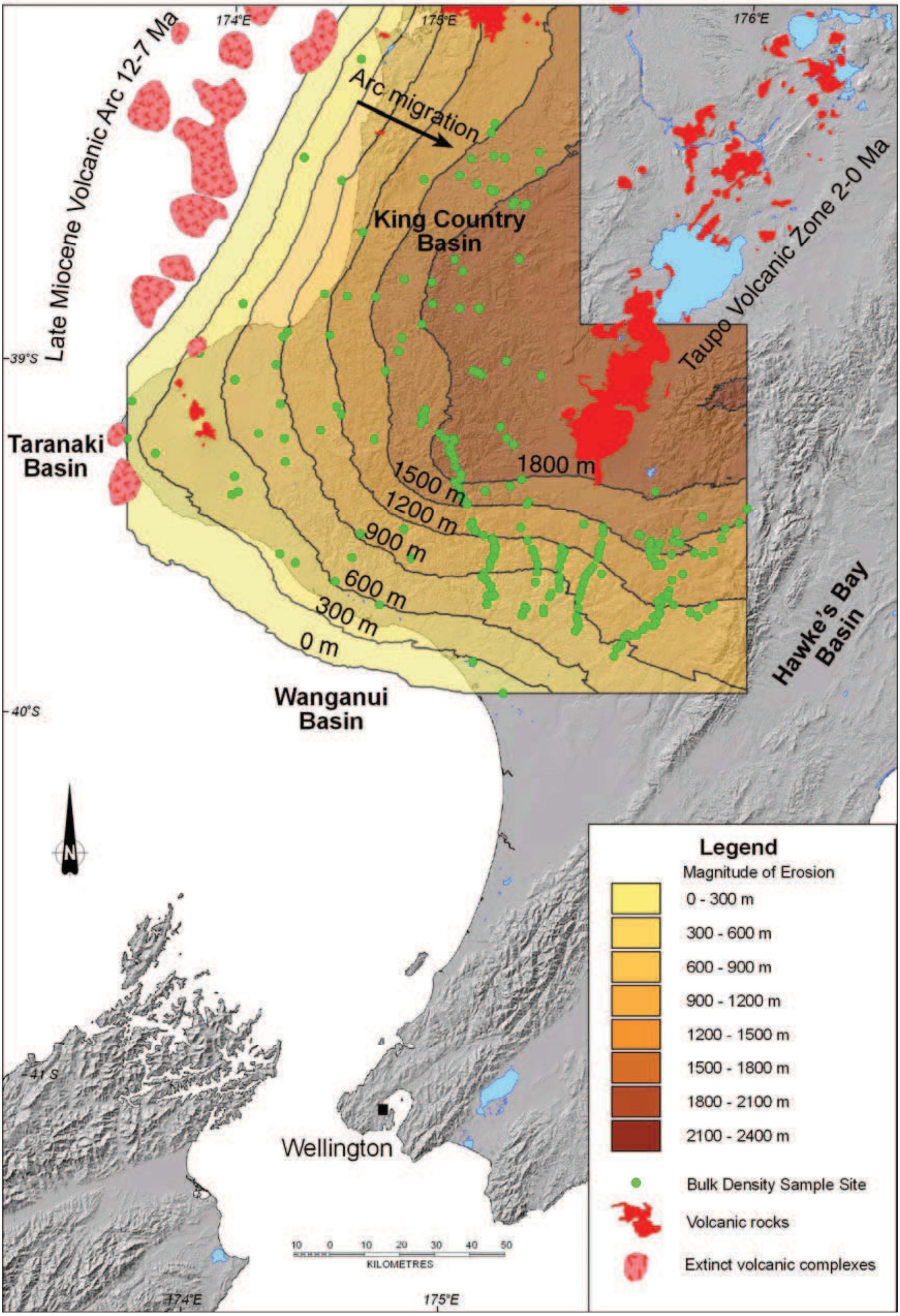


Fig. 6. *Map showing the magnitude in 300 m contours and pattern of Pliocene-Pleistocene erosion over central North Island derived from mudstone bulk density data. See text for discussion. From Kamp et al. 2004 (Fig. 4).*

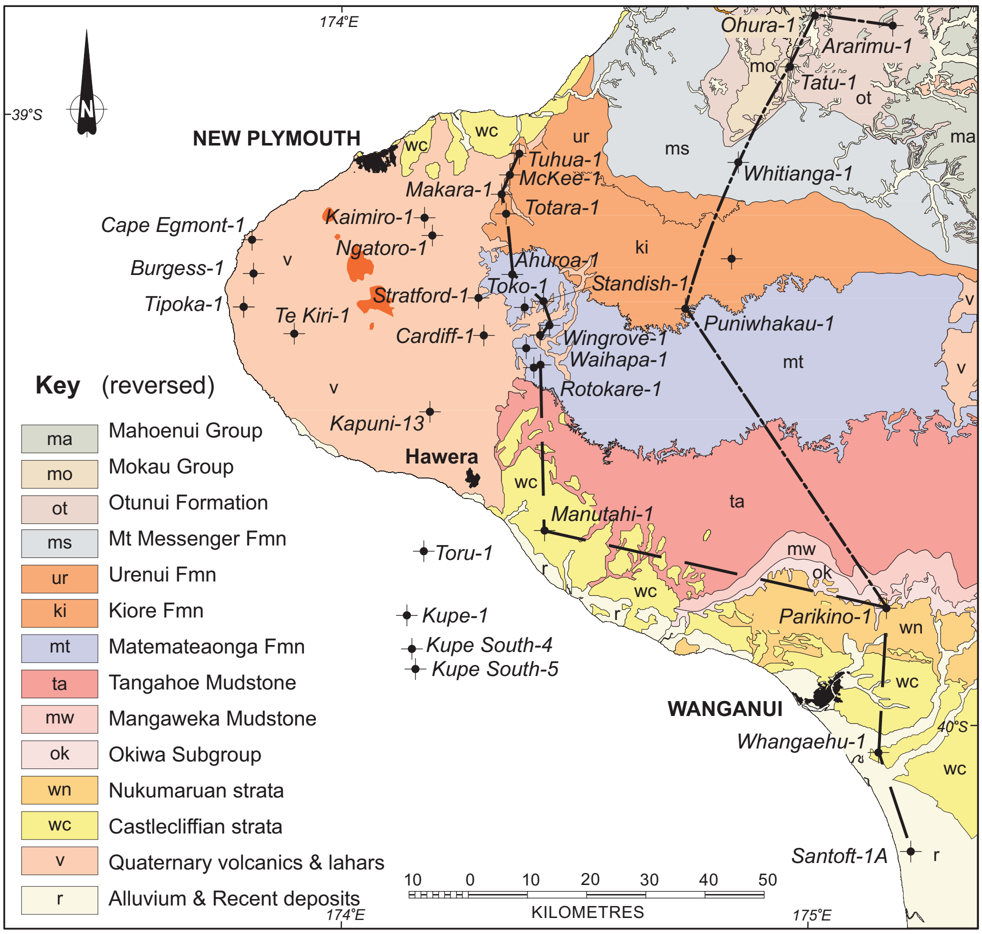
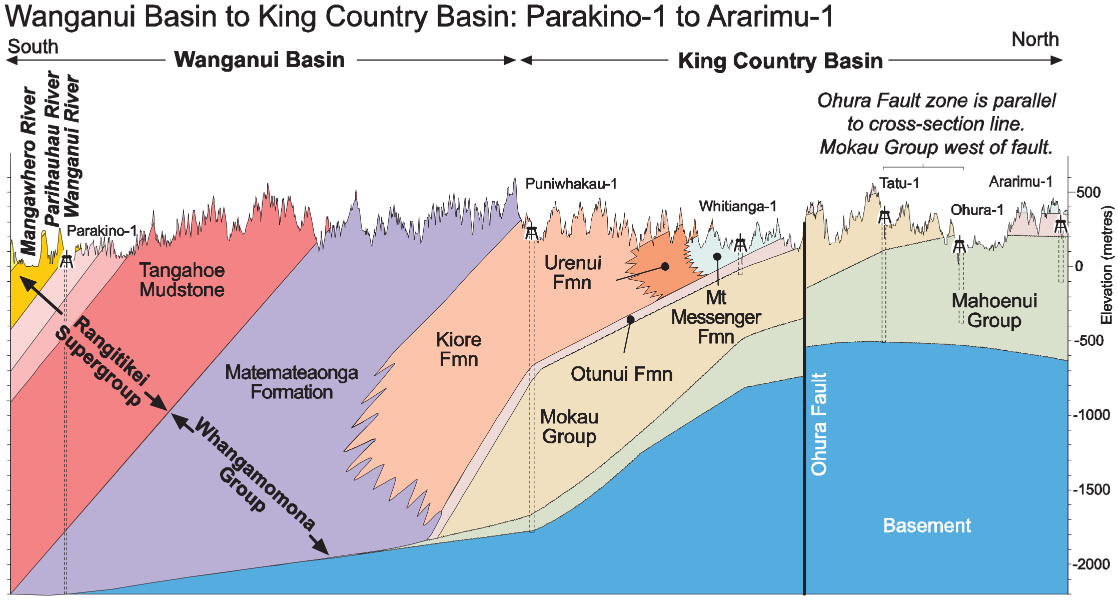


Fig. 7. Geological map of central-western North Island, including Taranaki Peninsula, showing the location of key hydrocarbon exploration holes and the line of two cross-sections illustrated in Fig. 8 & 9. Modified from Kamp et al. 2004 (Fig. 5).



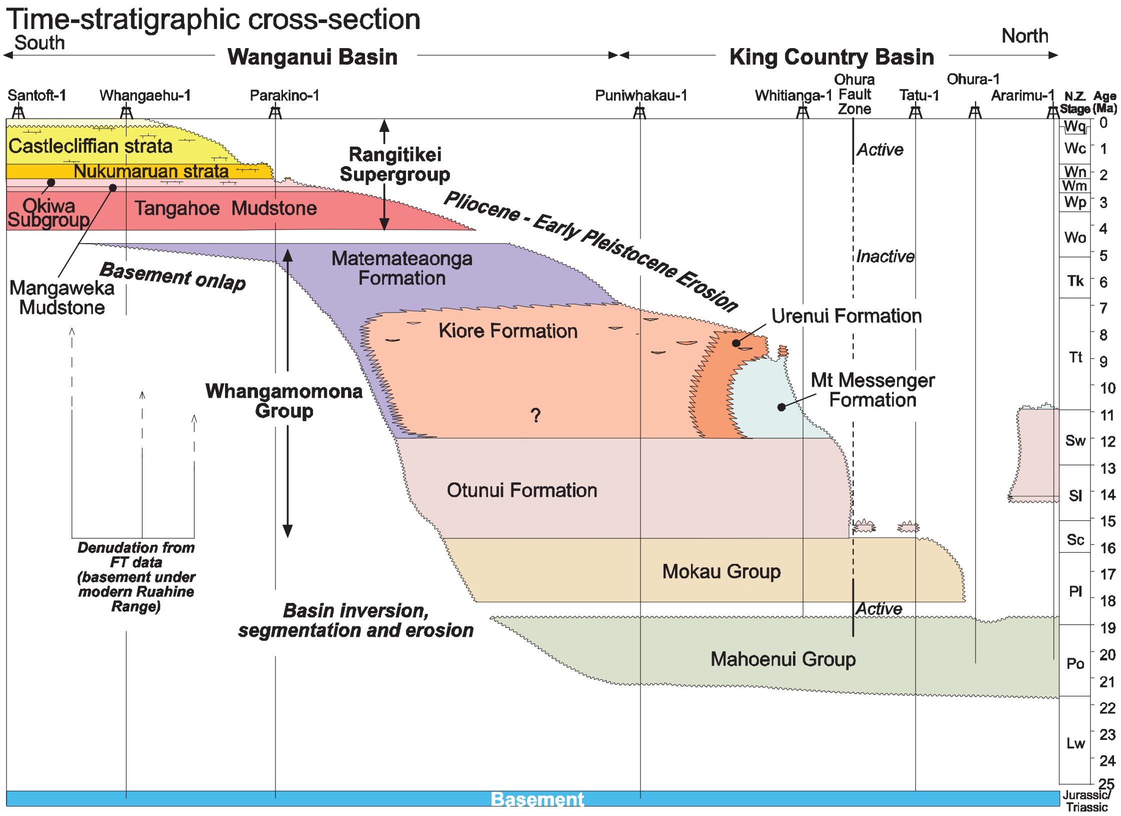
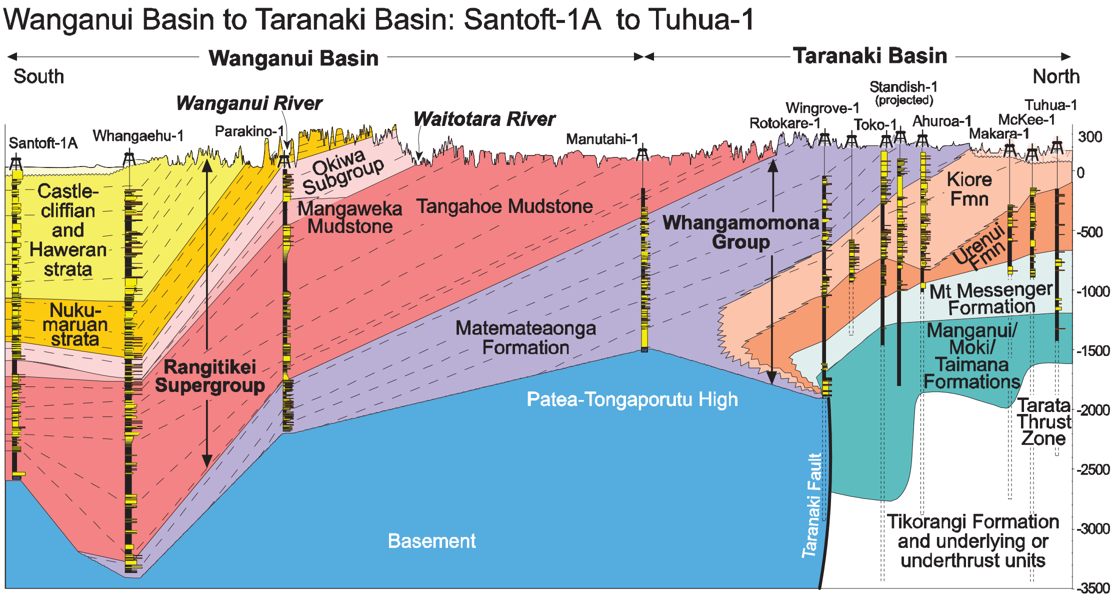


Fig. 8. *Wanganui Basin to King Country Basin (Parakino-1 to Ararimu-1) stratigraphic panel built up from well-to-well correlations, and related time-stratigraphic cross-section. The timing of denudation of basement underlying the present Ruahine Range, determined from apatite fission track analysis, is also shown. From Kamp et al. 2004 (Fig. 6).*



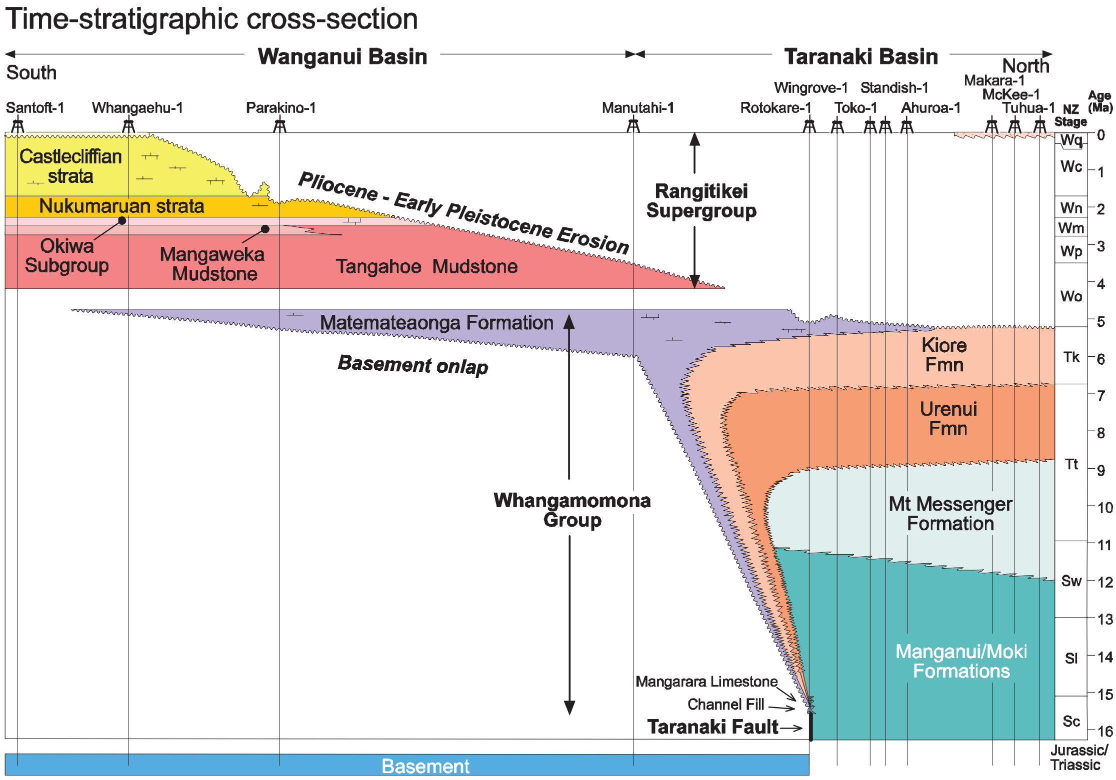


Fig. 9. Wanganui Basin to Taranaki Basin (Santoft-1A to Tuhua-1) stratigraphic panel built up from well-to-well correlations, and related time-stratigraphic cross-section. From Kamp et al. 2004 (Fig. 7).

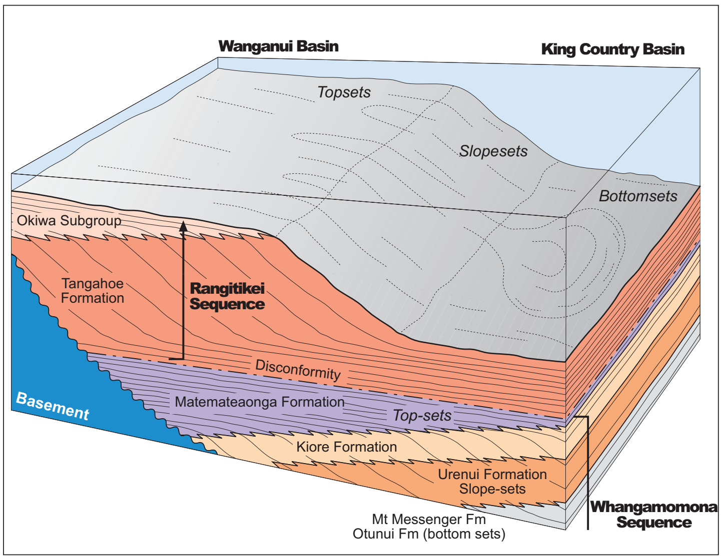


Fig. 10. *Schematic block diagram showing the occurrence of two continental margin wedges representing the Whangamomona and Rangitikei Sequences, each having prograded northward through central-western North Island during the late Neogene. North is to the right. From Kamp et al. 2004 (Fig. 10).*

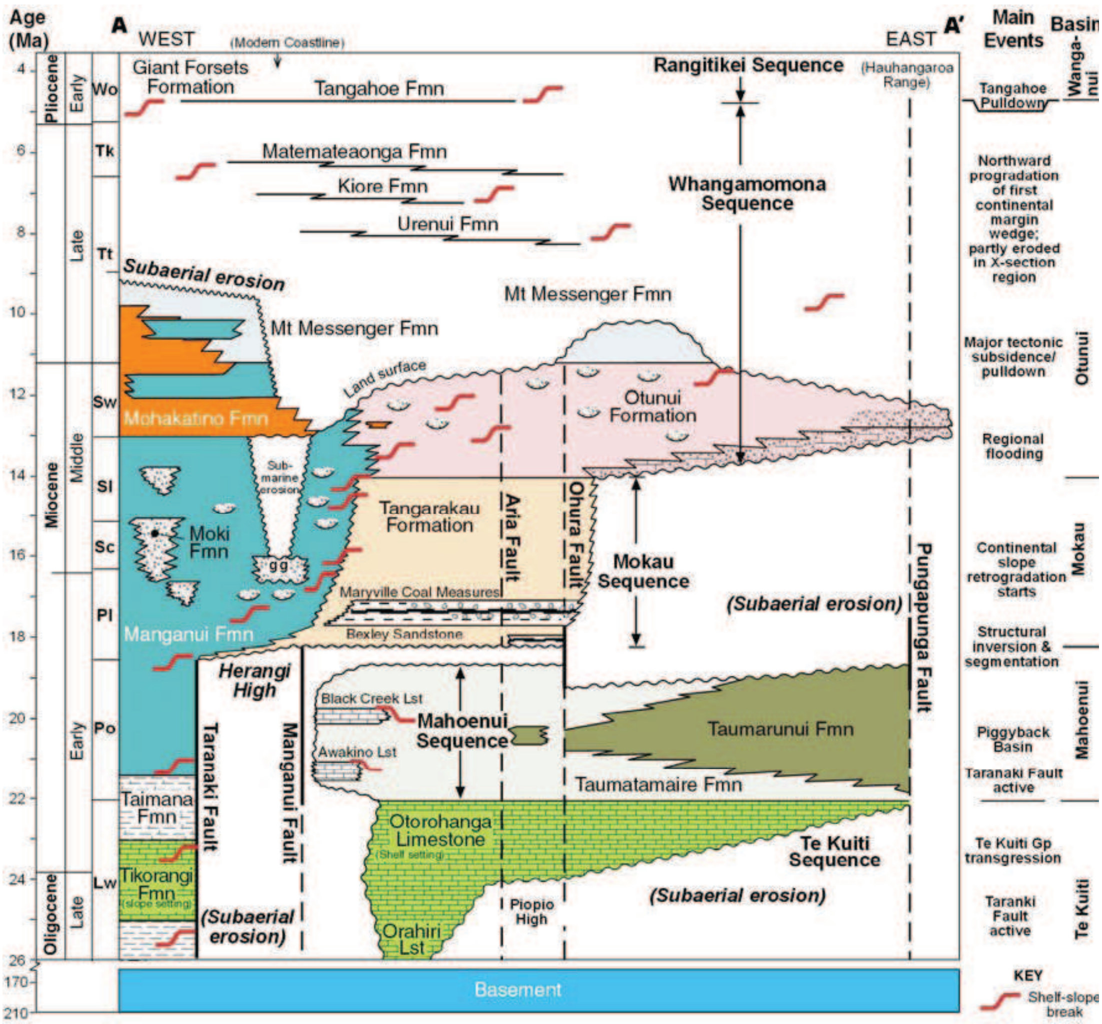


Fig. 11. *Chronostratigraphic panel representing the relationship between formations and 2nd order sequences of Cenozoic age cropping out in a cross-section between Awakino Heads in eastern Taranaki Basin and Waitui Saddle on the Hauhungaroa Range along the eastern margin of the King Country Basin (line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

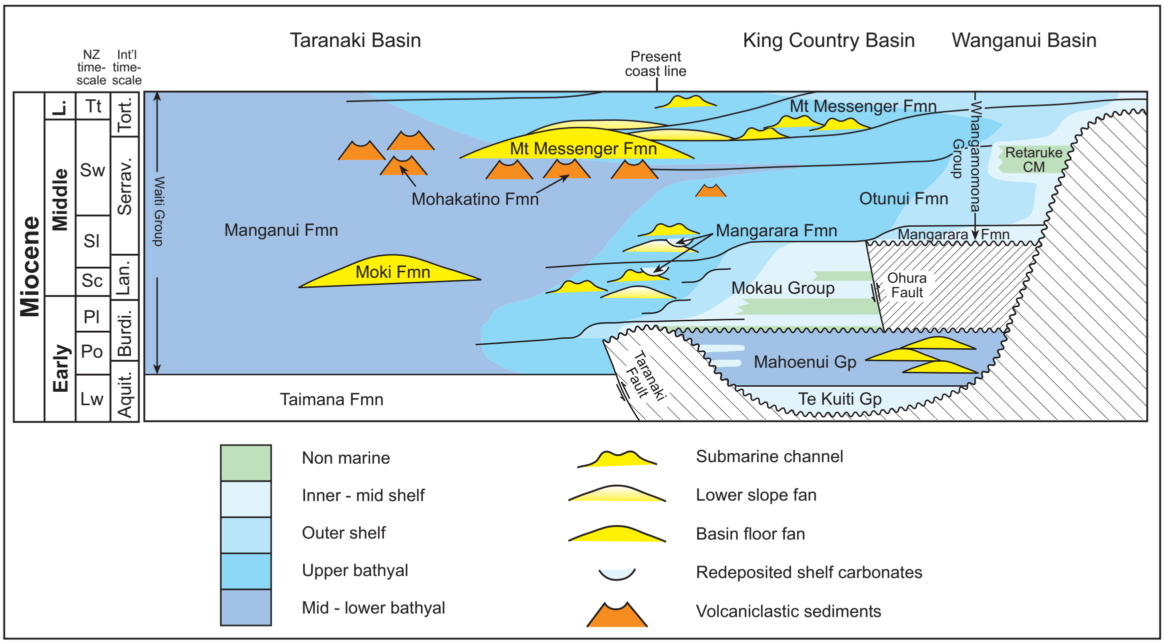


***Fig. 12.** Time-space stratigraphic panel for early and middle Miocene deposits and their inferred depositional settings in a roughly east (King Country Basin) to west (Taranaki Basin) section across the western North Island coastline. From Puga-Bernabéu et al. 2009 (Fig. 2).*

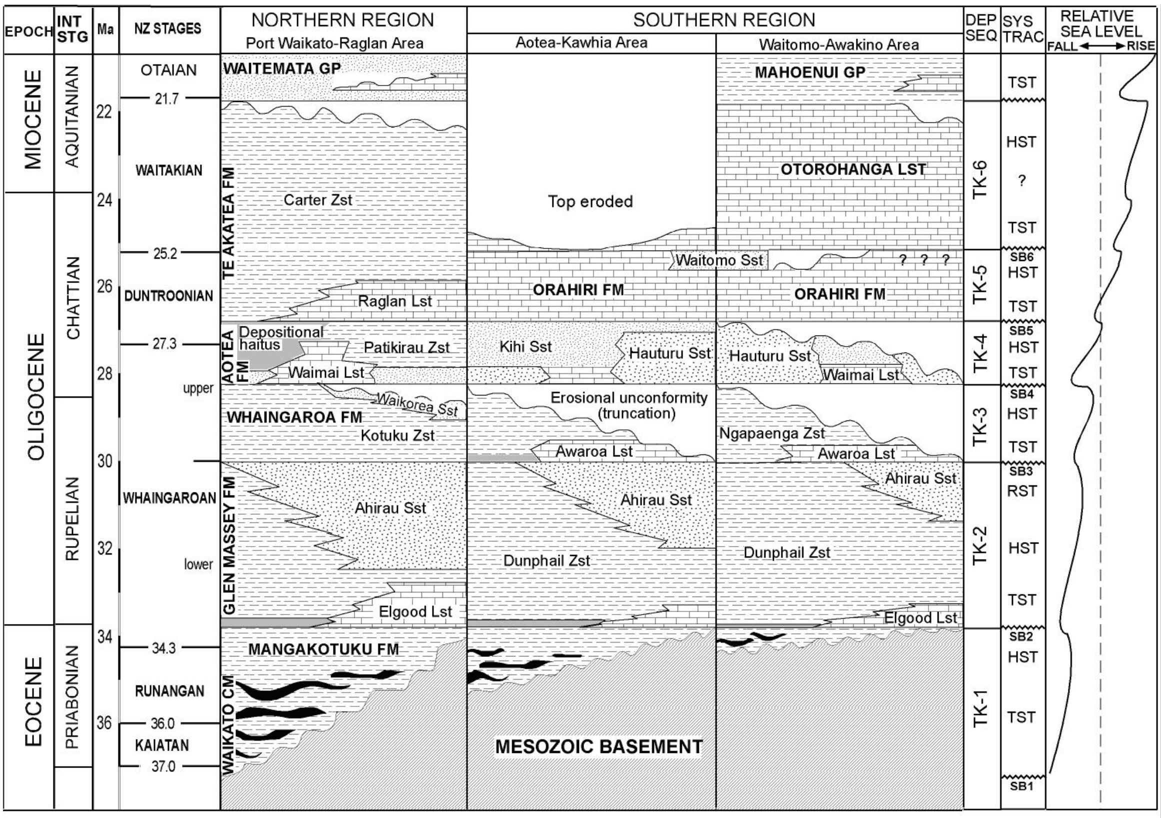


***Fig. 13.** N-S lithostratigraphic nomenclature for formations in the Te Kuiti Group between the Waikato and King Country Basins. From Tripathi (2008).*

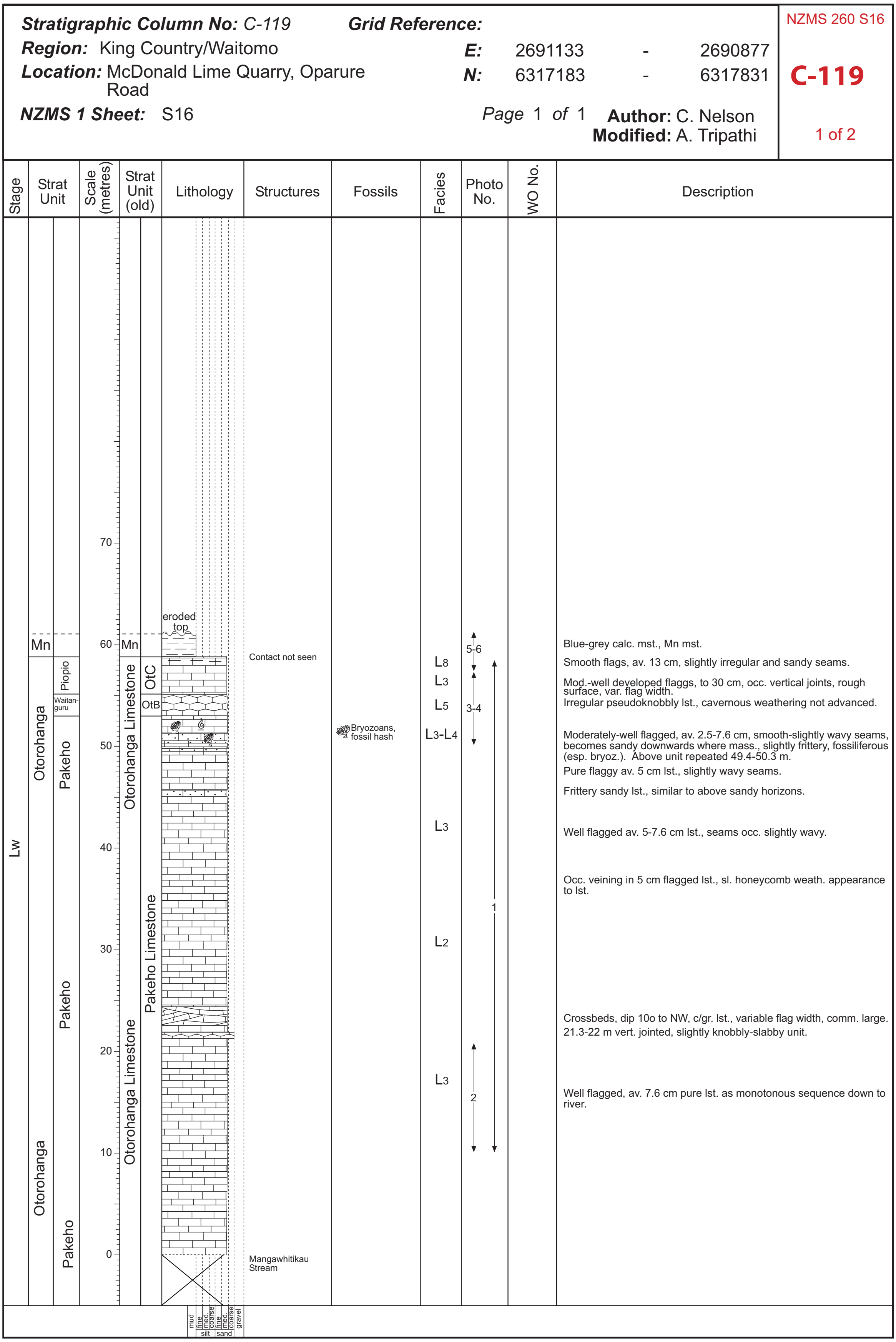

Stratigraphic Column No: C-119
Grid Reference:
Region: King Country/Waitomo
E: 2691133 - 2690877
Location: McDonald Lime Quarry, Oparure Road
N: 6317183 - 6317831
NZMS 1 Sheet: S16
Page 1 of 1
Author: C. Nelson
Modified: A. Tripathi
NZMS 260 S16
C-119
1 of 2
Stage
Strat Unit
Scale (metres)
Strat Unit (old)
Lithology
Structures
Fossils
Facies
Photo No.
WO No.
Description
Lw
Mn
Otorohanga
Piopio
Waitan-guru
Pakeho
Otorohanga Limestone
OtC
OtB
Pakeho Limestone
eroded top
Contact not seen
Bryozoans, fossil hash
Mangawhitikau Stream
L8
L3
L5
L3-L4
L3
L2
L3
5-6
3-4
1
2
70
60
50
40
30
20
10
0
mud
silt
fine
med
coarse
sand
gravel
Blue-grey calc. mst., Mn mst.
Smooth flags, av. 13 cm, slightly irregular and sandy seams.
Mod.-well developed flaggs, to 30 cm, occ. vertical joints, rough surface, var. flag width.
Irregular pseudoknobbly lst., cavernous weathering not advanced.
Moderately-well flagged, av. 2.5-7.6 cm, smooth-slightly wavy seams, becomes sandy downwards where mass., slightly frittery, fossiliferous (esp. bryoz.). Above unit repeated 49.4-50.3 m.
Pure flaggy av. 5 cm lst., slightly wavy seams.
Frittery sandy lst., similar to above sandy horizons.
Well flagged av. 5-7.6 cm lst., seams occ. slightly wavy.
Occ. veining in 5 cm flagged lst., sl. honeycomb weath. appearance to lst.
Crossbeds, dip 10o to NW, c/gr. lst., variable flag width, comm. large.
21.3-22 m vert. jointed, slightly knobbly-slabby unit.
Well flagged, av. 7.6 cm pure lst. as monotonous sequence down to river.

Fig 14 A.

NZMS 260 S16

C-119

2 of 2

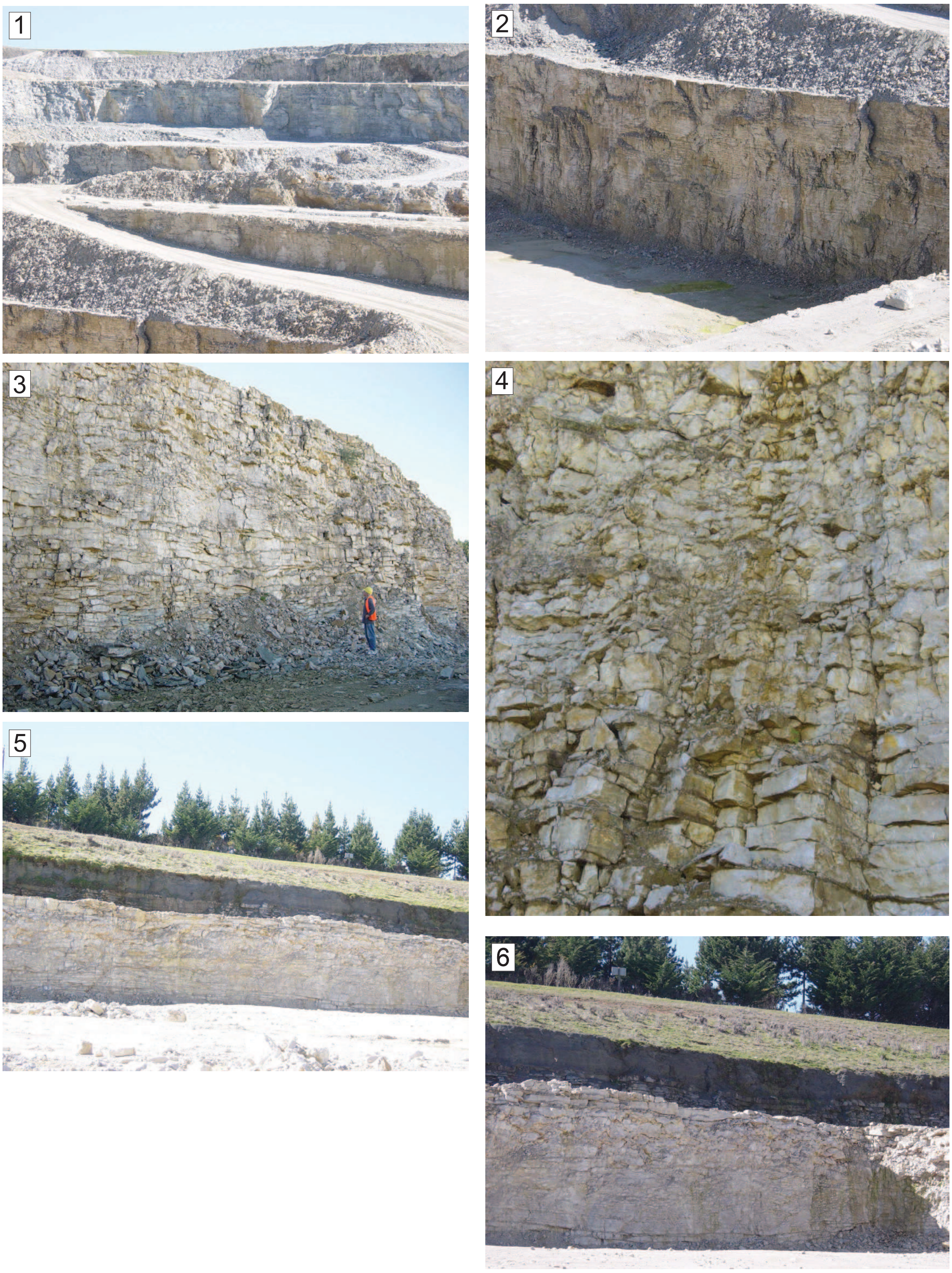


Fig 14 *B.*

Fig. 15. *Looking north into the Wairere Serpentinite Quarry along the trace of the Waipa Fault, with bounding Otorohanga Limestone (Lw) on left and Mahoenui/Mokau Group (Po/Pl) mudstone and sandstone on right.*

Stratigraphic Column No: *C-154*
Region: Te Kuiti
Location: Pio Pio Quarry, SH3
NZMS 260 Sheet: R17/845004

Grid Reference:
E: 2684500 -
N: 6300400 -

Page 1 *of* 1 **Author:** C.S. Nelson

NZMS 260 R17

C-154

1 of 2

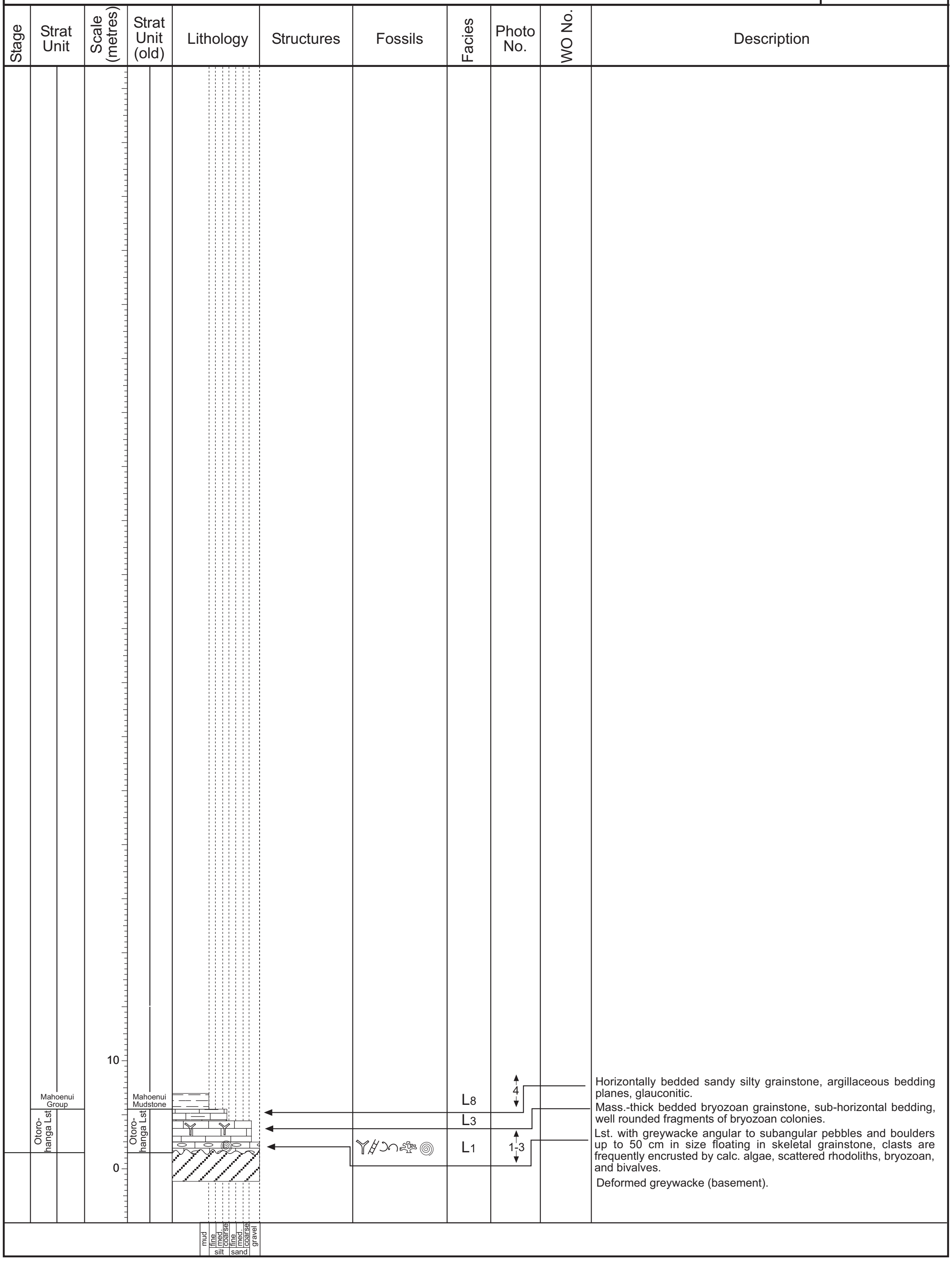


Fig 16 A.

NZMS 260 R17

C-154

2 of 2

Fig 16 B.

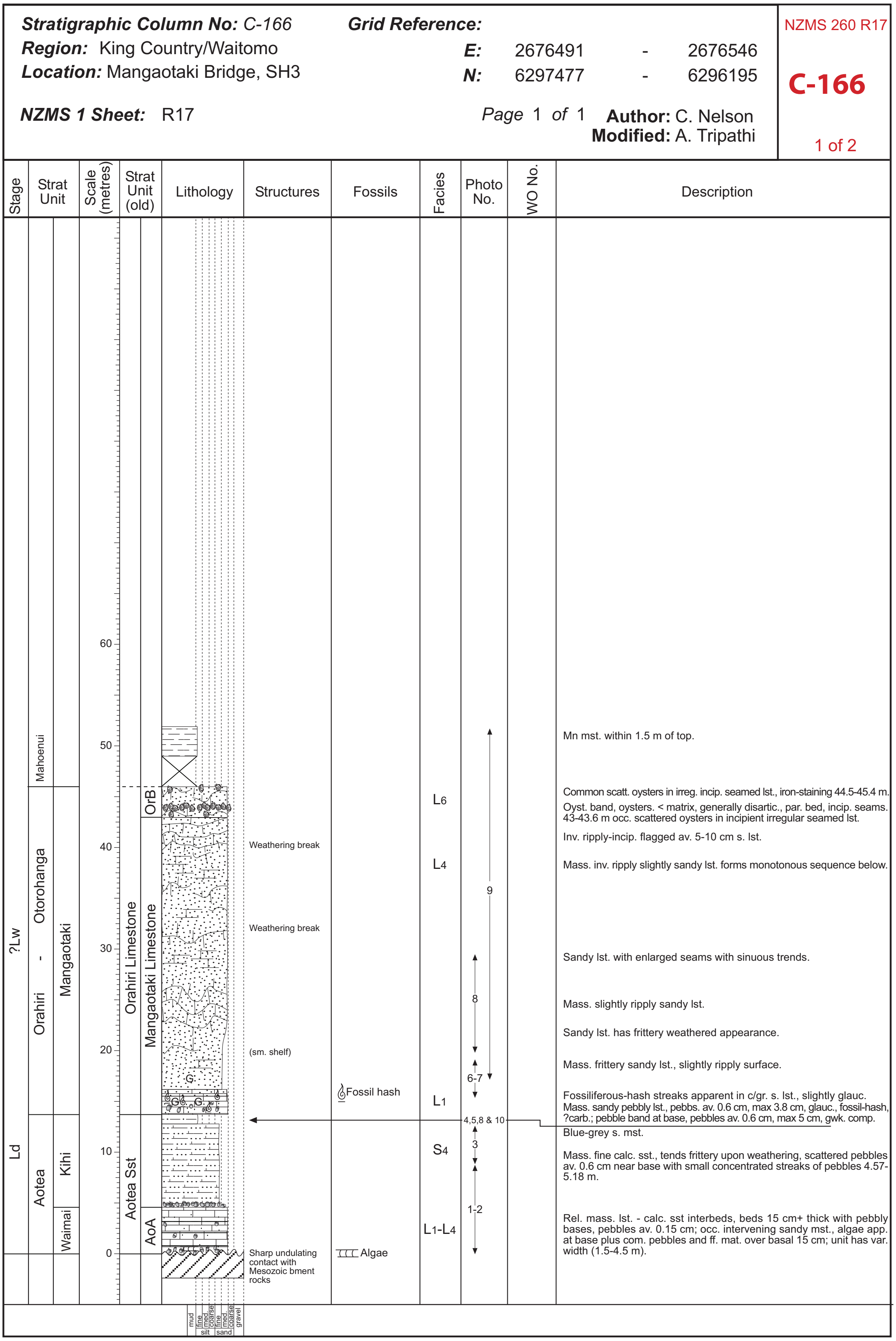

Stratigraphic Column No: C-166
Region: King Country/Waitomo
Location: Mangaotaki Bridge, SH3
NZMS 1 Sheet: R17
Grid Reference:
E: 2676491 - 2676546
N: 6297477 - 6296195
Page 1 of 1
Author: C. Nelson
Modified: A. Tripathi
NZMS 260 R17
C-166
1 of 2
Stage
Strat Unit
Scale (metres)
Strat Unit (old)
Lithology
Structures
Fossils
Facies
Photo No.
WO No.
Description
?Lw
Ld
Mahoenui
Orahiri - Otorohanga
Mangaotaki
Aotea
Kihi
Waimai
OrB
Orahiri Limestone
Mangaotaki Limestone
Aotea Sst
AoA
60
50
40
30
20
10
0
Weathering break
Weathering break
(sm. shelf)
Sharp undulating contact with Mesozoic bment rocks
Fossil hash
Algae
L6
L4
L1
S4
L1-L4
9
8
6-7
4,5,8 & 10
3
1-2
Mn mst. within 1.5 m of top.
Common scatt. oysters in irreg. incip. seamed lst., iron-staining 44.5-45.4 m.
Oyst. band, oysters. < matrix, generally disartic., par. bed, incip. seams. 43-43.6 m occ. scattered oysters in incipient irregular seamed lst.
Inv. ripply-incip. flagged av. 5-10 cm s. lst.
Mass. inv. ripply slightly sandy lst. forms monotonous sequence below.
Sandy lst. with enlarged seams with sinuous trends.
Mass. slightly ripply sandy lst.
Sandy lst. has frittery weathered appearance.
Mass. frittery sandy lst., slightly ripply surface.
Fossiliferous-hash streaks apparent in c/gr. s. lst., slightly glauc.
Mass. sandy pebbly lst., pebbs. av. 0.6 cm, max 3.8 cm, glauc., fossil-hash, ?carb.; pebble band at base, pebbles av. 0.6 cm, max 5 cm, gwk. comp.
Blue-grey s. mst.
Mass. fine calc. sst., tends frittery upon weathering, scattered pebbles av. 0.6 cm near base with small concentrated streaks of pebbles 4.57-5.18 m.
Rel. mass. lst. - calc. sst interbeds, beds 15 cm+ thick with pebbly bases, pebbles av. 0.15 cm; occ. intervening sandy mst., algae app. at base plus com. pebbles and ff. mat. over basal 15 cm; unit has var. width (1.5-4.5 m).
mud
silt
sand
gravel

Fig 17 A.

NZMS 260 R17

C-166

2 of 2

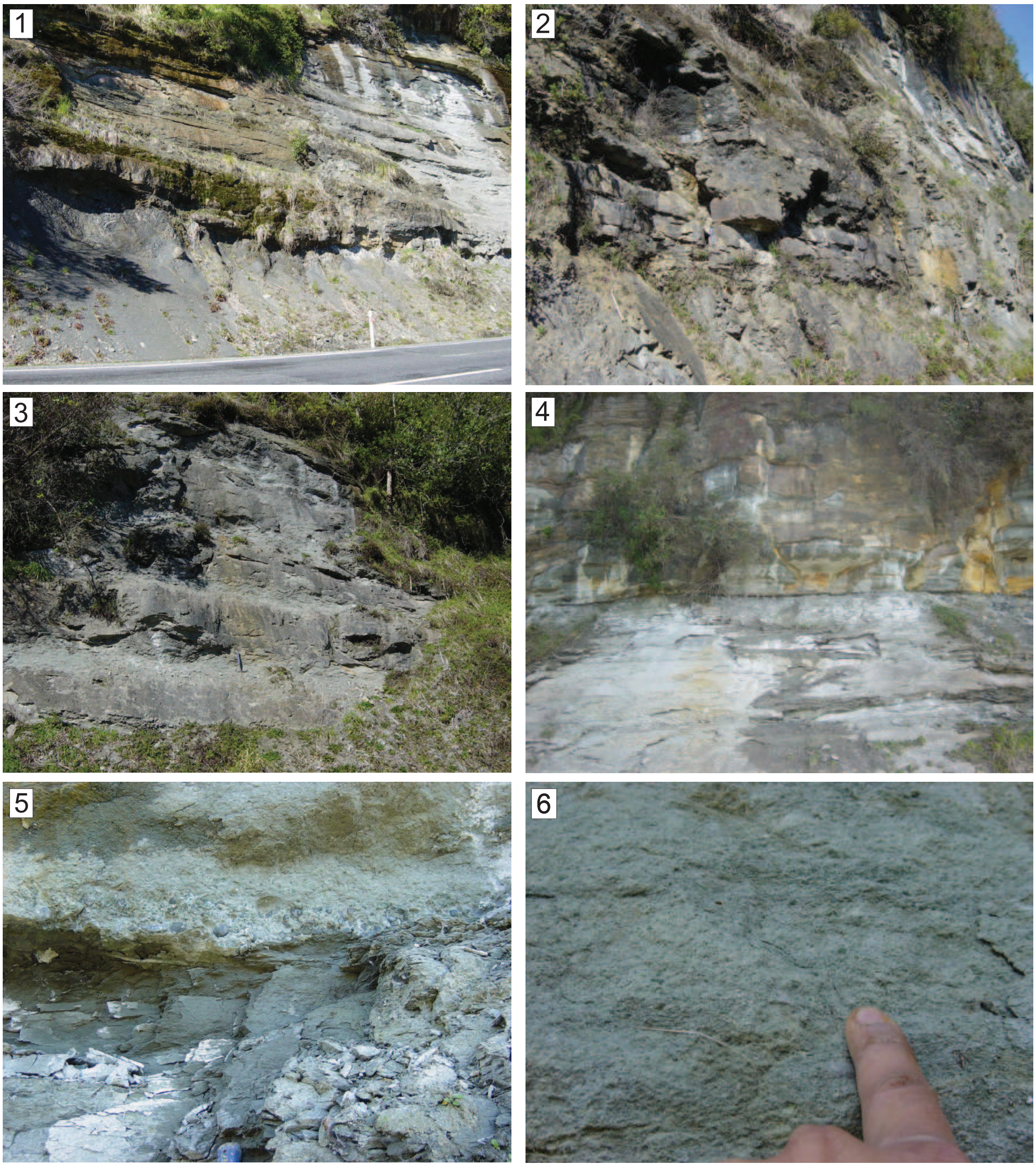


Fig 17 B.

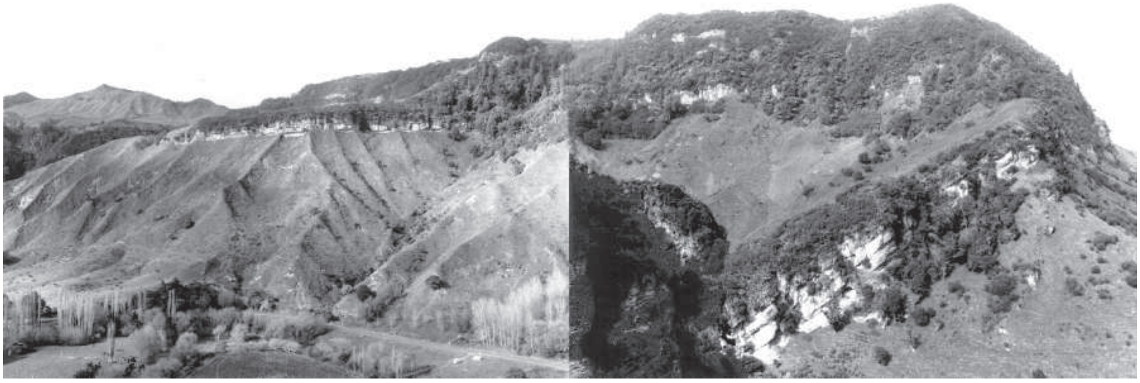


Fig. 18. *Photo composite of the hill section on the southern side of the Awakino Tunnel, northern end of Awakino Gorge. Fig 19 shows the wider geological setting of this photo. From Kamp et al. 2004 (Fig. 11).*

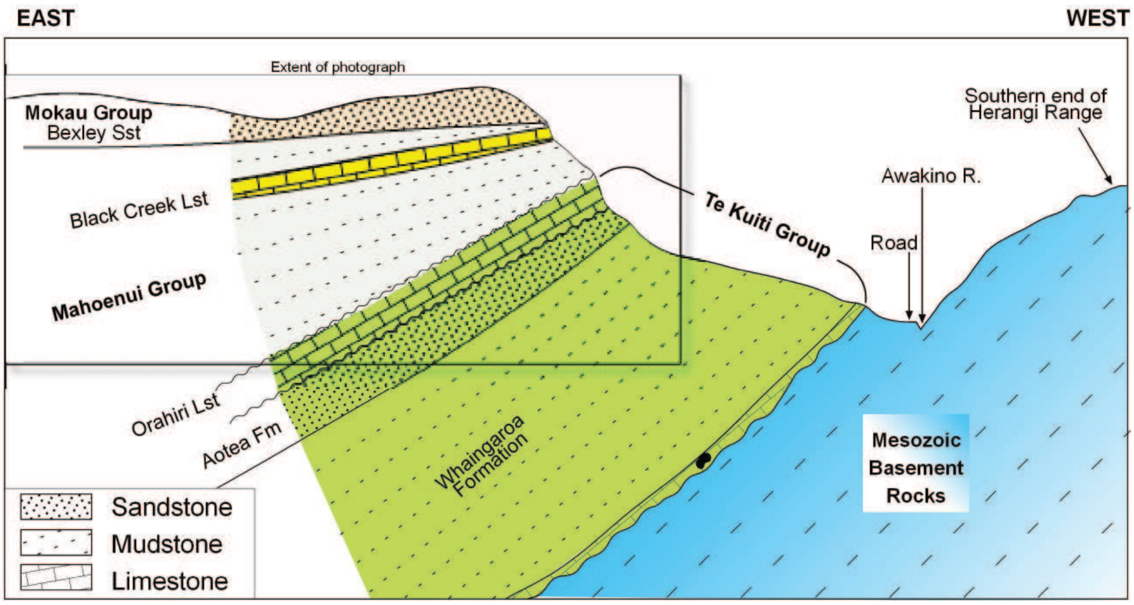


Fig. 19. *Sketch illustrating the stratigraphy and structure of the Te Kuiti, Mahoenui and Mokau Groups in relation to basement at the northern end of Awakino Gorge. The inset box shows the approximate extent of the photo composite illustrated in Fig. 18. From Kamp et al. 2004 (Fig. 12).*

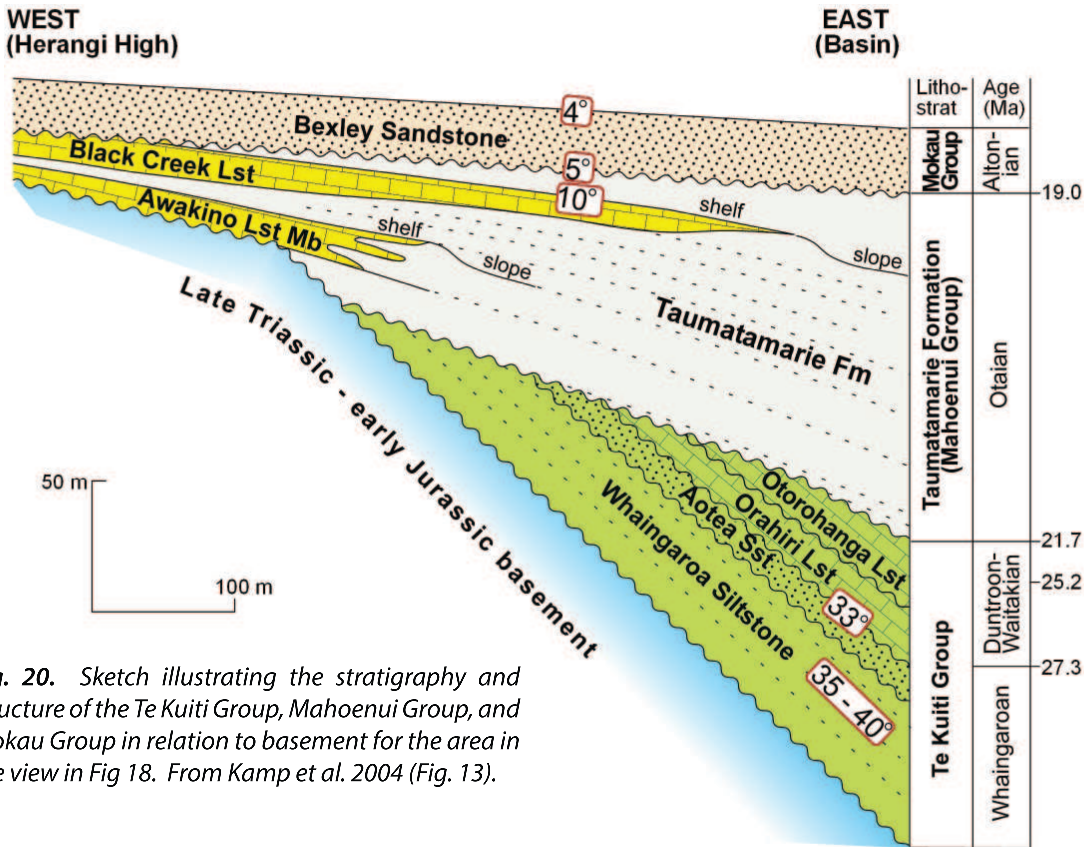


Fig. 20. *Sketch illustrating the stratigraphy and structure of the Te Kuiti Group, Mahoenui Group, and Mokau Group in relation to basement for the area in the view in Fig 18. From Kamp et al. 2004 (Fig. 13).*

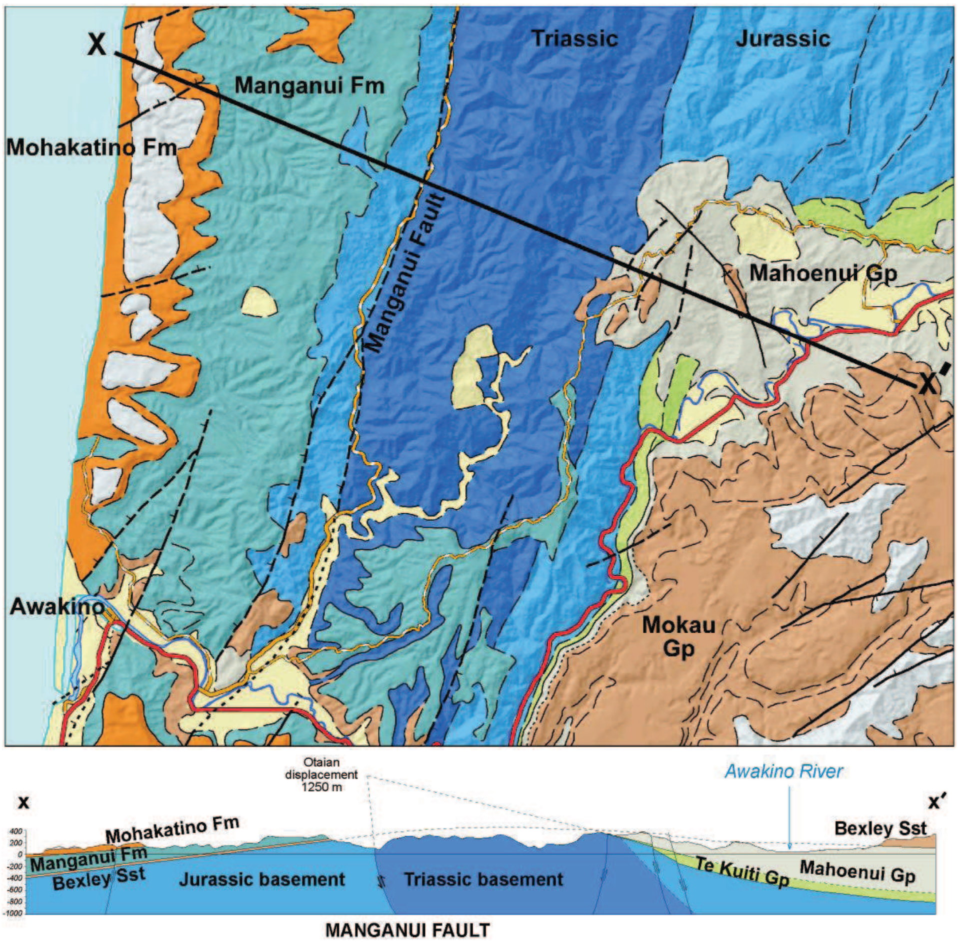


Fig. 21. *Geological map and cross-section of the southern end of the Herangi Range. Based on map in Edbrooke (2005).*

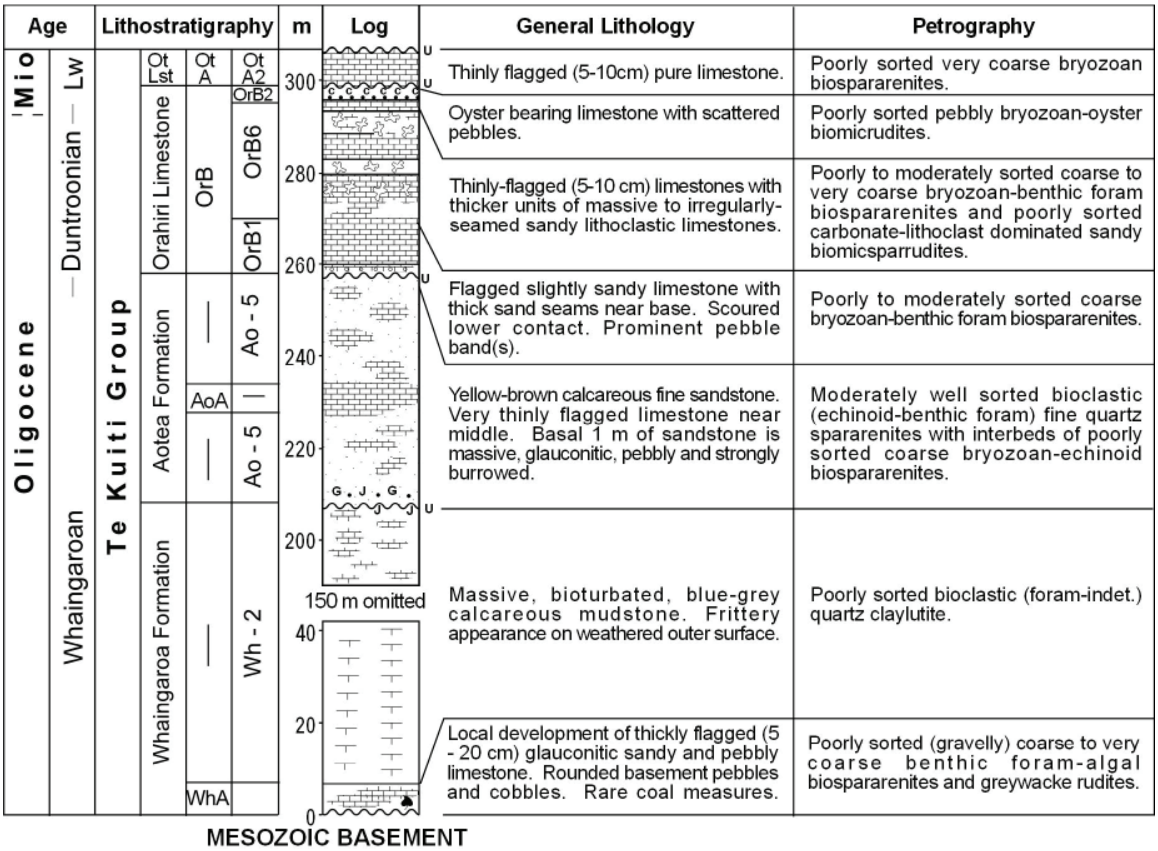


Fig. 22. *Stratigraphic column for the Te Kuiti Group at Awakino Tunnel. From Nelson et al. 1994 (Fig. 4).*

Fig. 23. *Orahiri Limestone at Awakino Tunnel. The recessive beds in the cliff above the tunnel entrance are a succession of redeposited beds containing lithoclasts (Limestone-in-limestone Beds).*

Fig. 24. *Close-up of a fresh outcrop of a redeposited bed within Orahiri Limestone at Awakino Tunnel containing pholad-bored lithoclasts (Fig. 25). From Nelson et al. 1994 (Fig. 5A).*

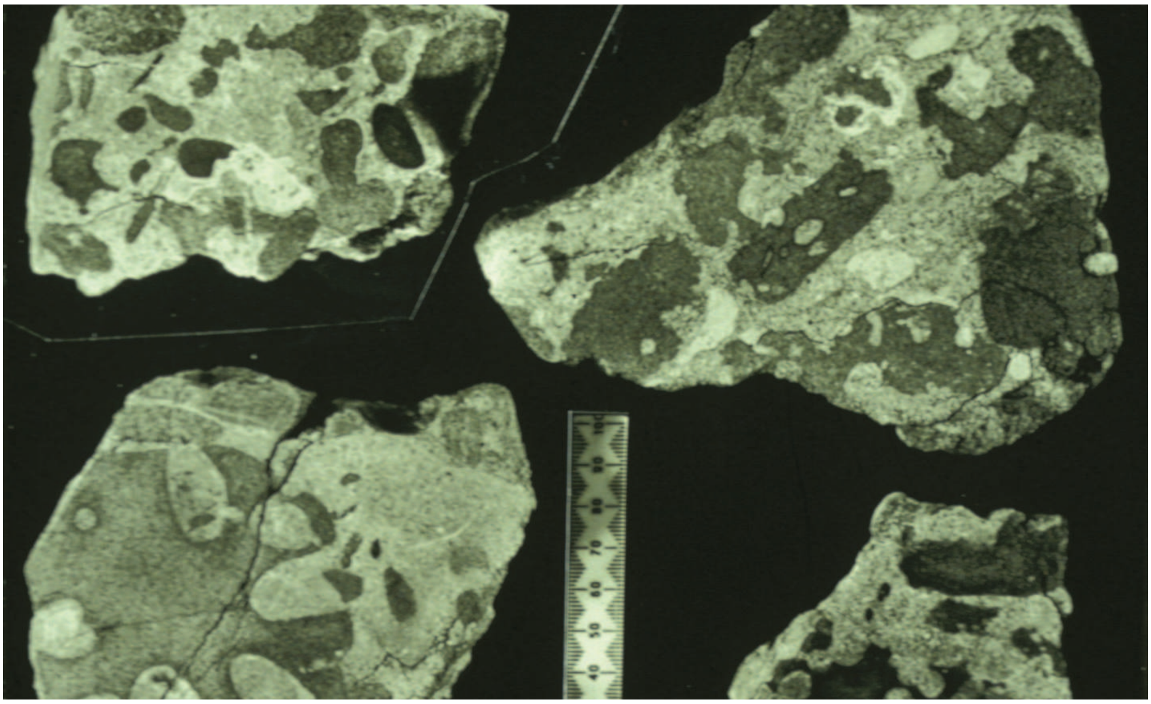


Fig. 25. *Cut slabs of samples from redeposited beds within Orahiri Limestone at Awakino Tunnel, showing pholad-bored lithoclasts. From Nelson et al. 1994 (Fig. 6).*

Fig. 26A. *Brown weathered Bexley Sandstone (Pl) on irregular relief (top of grassed face) on late Triassic Murihiku terrane basement at the SW end of Awakino Gorge.*

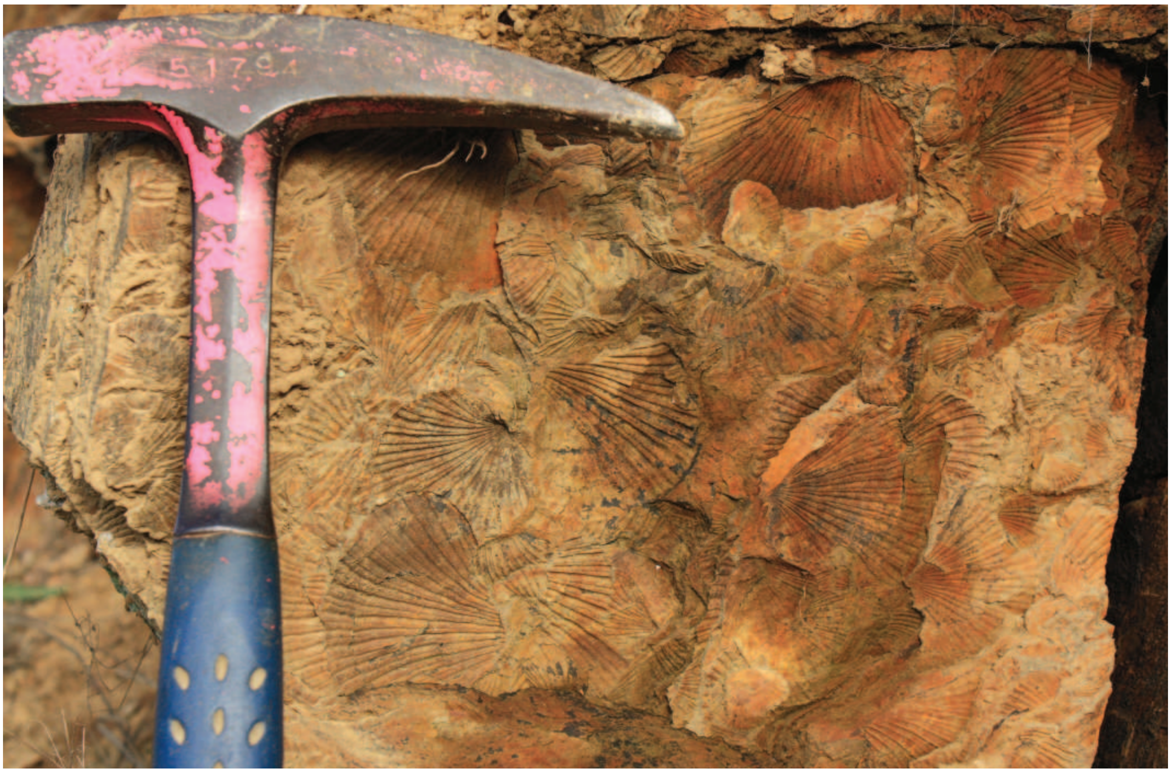


Fig. 26B. *Late Triassic (Warepan Stage, Bw) Monotis richmondiana fossil casts in the steeply E dipping Murihiku basement siltstone beneath the Bexley Sandstone seen in Fig. 26A.*

Fig. 27. *Photo panorama split into two segments (A-A' and A'-A'') looking east to west at the hills on the southern side of Ladies Mile, lower Awakino Valley.*

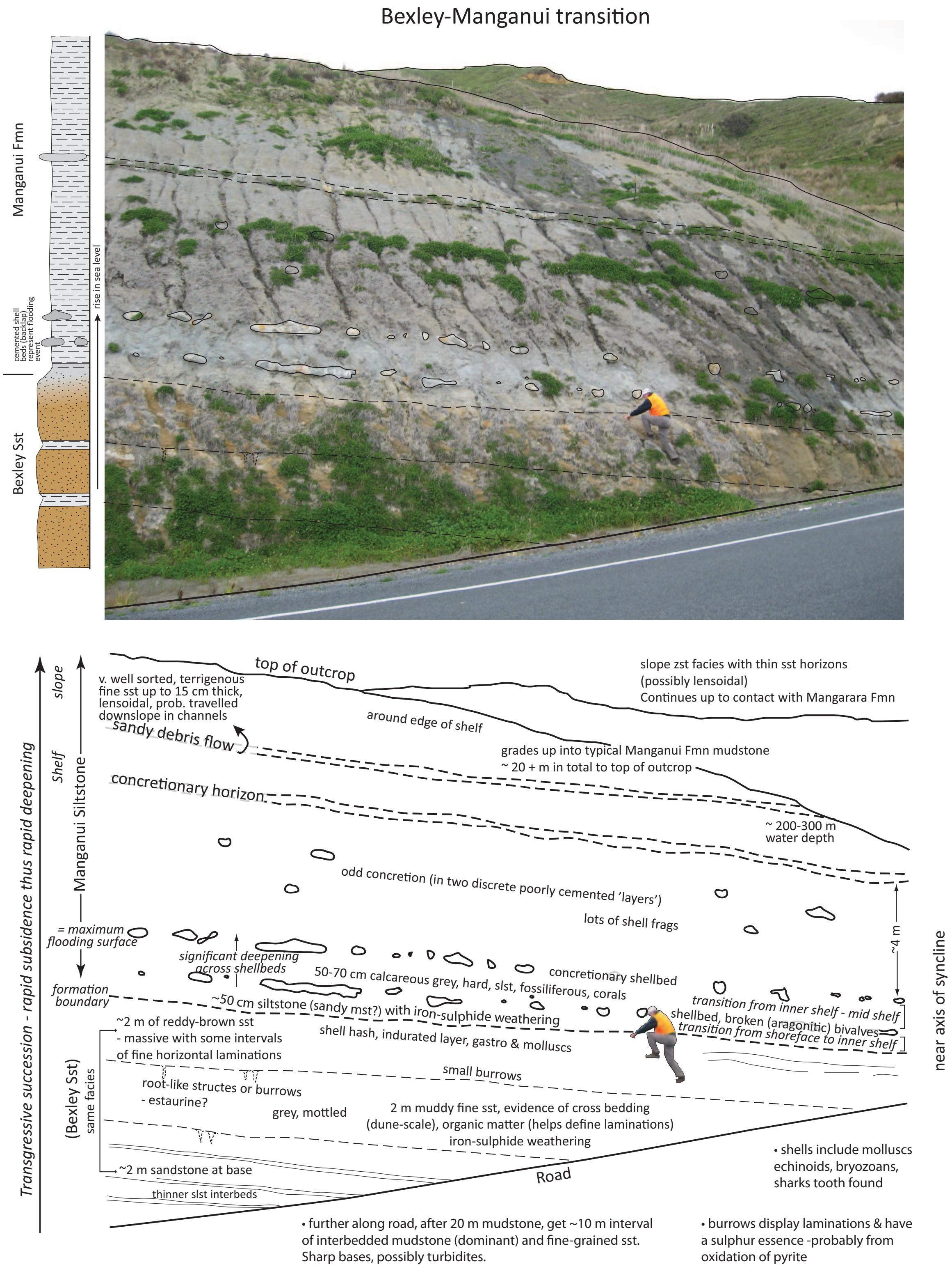


Fig. 28. *Sketch stratigraphic section across the Bexley Sandstone to Manganui Formation transition near Awakino (compiled by Dr Rochelle Hansen, University of Waikato).*

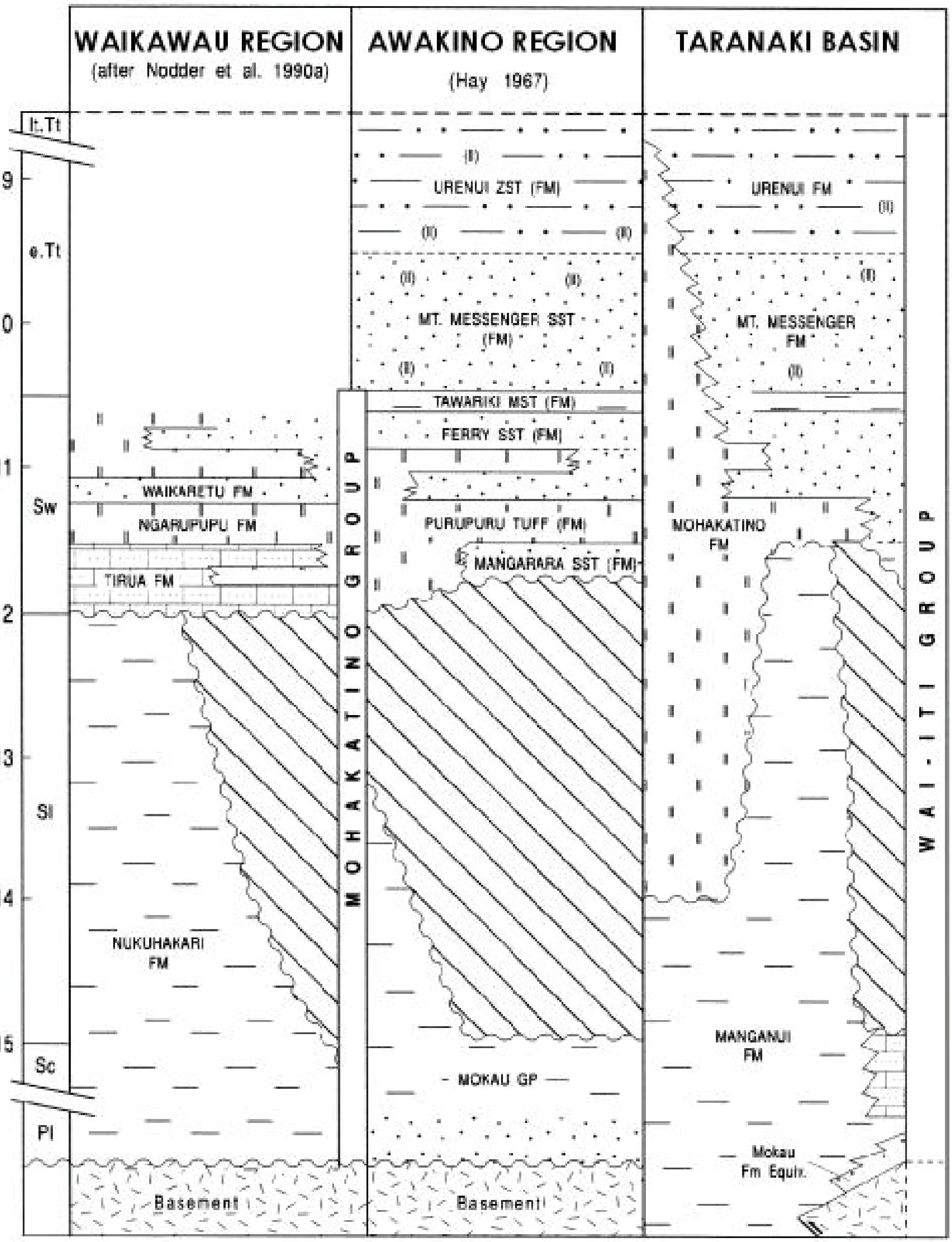


Fig. 29. Miocene time-stratigraphic logs for the Awakino region in relation to the Waikawau area to the north along the King Country coastline and offshore parts of Taranaki Basin. Mangarara Sandstone is shown for Awakino as being of Waiauan (Sw) age, but King et al. (1993) noted it contains Clifdenian (Sc) microfauna. From King & Thrasher (1996).

Fig. 30A. *Awakino Heads section showing the extent of Manganui Formation, Mangarara Sandstone, Purupuru Tuff (Mohakatino Formation) and Rapanui Formation. Note the channel occurrence of the Mangarara Formation, which is equivalent to the Moki Formation.*

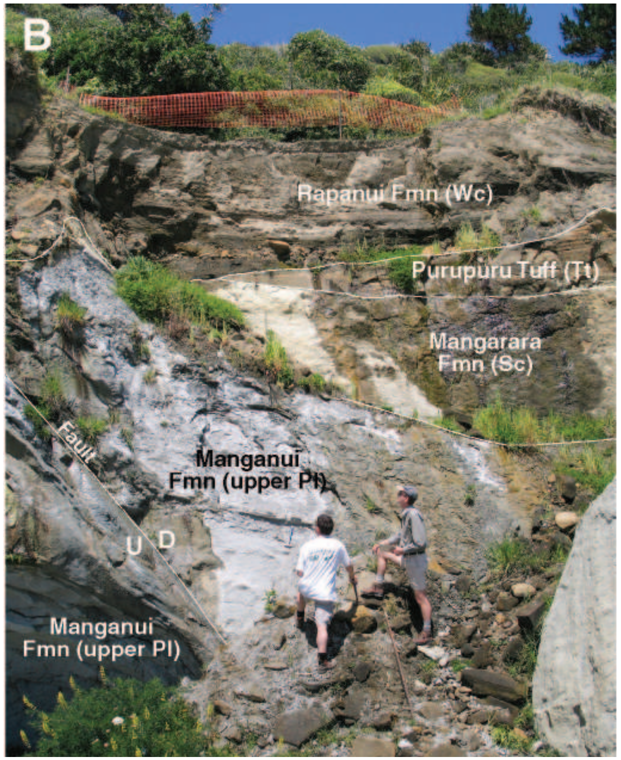


Fig. 30B. *Close-up of eastern end of Awakino Heads section. Note the 10 cm thick redeposited carbonate bed below the Mangarara Sandstone channel. The 1.5 m-thick mudstone bed below this thin carbonate bed includes abundant glauconite pellets and angular glauconite-coated mudstone clasts. Pl, Altonian; Sc, Clifdenian; Tt, Tongaporutuan; Wc, Castlecliffian.*

Fig. 31. *Mt Messenger Formation at Pahaoa Hill, showing amalgamated sandstone beds in the lower part of the section, which are interpreted as paleo-basin floor fan deposits, and overlying siliciclastic sandstone and mudstone beds (turbidites) with intercalated andesitic volcaniclastic beds, best viewed in cuttings along the upper part of the farm track at left (see Fig. 32).*

Fig. 32. *Intercalated siliciclastic sandstone and mudstone beds with andesitic volcaniclastic beds (Mt Messenger Formation) in the farm track shown in Fig. 31. The volcaniclastic sediments were sourced from late Miocene andesitic volcanoes in northern Taranaki Basin, much like modern day Mt Egmont/Taranaki seen here in the background.*

Fig. 33. *View of south head of Mokau River showing Ferry Sandstone Member (Mt Messenger Formation) in the main cliff and upthrown Mohakatino Formation beds at the South Heads.*

Fig. 34. *Tongaporutu River mouth and estuary viewed from the Rest Area adjacent to highway 3 north of the road bridge exposes the thick sandstone (Mt Messenger Formation) seen on the roadside at Stop 20*

Fig. 35. *Medium- to thin-bedded Mt Messenger Formation exposed on Okau Road.*

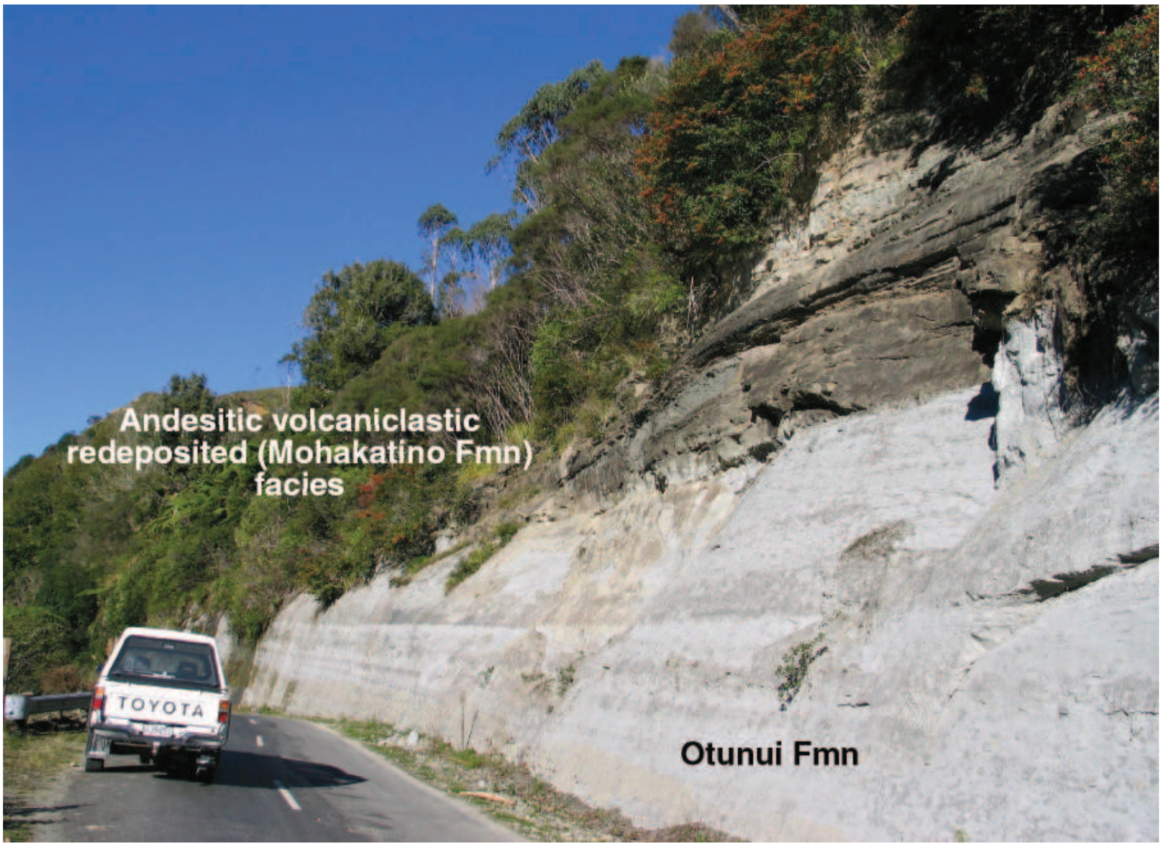


Fig. 36. *Otunui Formation at Okau Road that includes a thin interbedded unit of volcaniclastic Mohakatino Formation.*

Stop specific potential hazards and mitigation for Fieldtrip 3 (Oligocene-Miocene sedimentary record, eastern Taranaki Basin margin)

These Stop specific notes supplement the Health and Safety information given on page 3.3, which must be read. Approximate grid references for Stop sites are shown on page 3.4.

Contact name on trip: Cam Nelson, mobile 027-5182249; Peter Kamp 027-5544341

Emergency Hamilton contacts:

Adrian Pittari (GSNZ Conference Convenor): 021-02538762

Sydney Wright (Earth Sciences Office): 07-8384024, home 07-8550588

Margaret Nelson: home 07-8543483, mobile 027-2111301

Emergency agency: Phone 111

Healthline: Phone 0800 611116

First aid: Vans carry appropriate first aid kits

Illness: Advise trip leaders immediately if any health or other problems arise during the trip

Drinks: No alcohol or recreational drugs during the scheduled field trip programme

Smoking: No smoking in vehicles during the trip

NOTE – *At road side stops hi-vis large cones will be placed some distance either side of the stop site, along with road marshals wearing fluoro vests and hard hats to advise road users of a field party ahead*

Stop 1: Hinuera Formation, Hamilton Airport

Hazard: Traffic

Mitigation: Parking off-road at gateway of disused quarry site; do not wander back on to main road; wear fluoro vests, hard hats and solid footwear

Stop 2: Waipapa terrane greywacke, Tokanui

Hazard: Falling rock debris (although we will not enter the main quarry site); quarry traffic

Mitigation: Follow instructions of Robert Crighton (Osterns Quarry Manager); keep well away from cliff/quarry faces; use geological hammers appropriately and wear safety glasses; wear fluoro vests, hard hats and solid footwear; remain in tight group and allow any passing quarry traffic the right-of-way.

Stop 3: Otorohanga Limestone and Mahoenui Group mudstone, Oparure

Hazard: Falling rock debris (although we will only observe actively quarried faces from afar); quarry traffic

Mitigation: Follow instructions of Darcy Maddern (McDonald's Quarry Manager); keep well away from cliff/quarry faces; use geological hammers appropriately and wear safety glasses; wear fluoro vests, hard hats and solid footwear; remain in tight group and allow any passing quarry traffic the right-of-way

Stop 4: Wairere Serpentinite, Piopio

Hazard: Falling rock debris (although we will only observe the active quarry from afar); quarry traffic

Mitigation: Follow instructions of Pierre Stockman (Rorison's RMD Quarry Manager) or Jason Phillips (Quarry Foreman); keep well away from cliff/quarry faces; use geological hammers appropriately and wear safety glasses; wear fluoro vests, hard hats and solid footwear; remain in tight group and allow any passing quarry traffic the right-of-way

Stop 5: Murihiku terrane "greywacke" and Piopio High, Piopio

Hazard: Traffic

Mitigation: Do not wander on to main road; wear fluoro vests; line up along roadside quarry fence to view and discuss the geology from afar (Kirsty Reeves Quarry contact)

Stop 6: Aotea Formation – Orahiri Limestone, Mangaotaki Bridge

Hazard: Traffic; falling rock debris

Mitigation: Remain in off-road park area; do not wander on to main road; cross road only if instructed; remain attentive of roadside sloping cliff face; wear fluoro vests, hard hats and solid footwear; use geological hammers appropriately and wear safety glasses

Stop 7: Taumatamaire Formation of Mahoenui Group, Mangaotaki

Hazard: Traffic

Mitigation: Unless instructed, remain in parked vehicles pulled off-road; if leave vehicles do not cross road until instructed; wear fluoro vests

Stop 8: Mahoenui depocentre overview

Hazard: Traffic

Mitigation: Remain in off-road park area; do not wander back on to main road

Stop 9: Oligocene-early Miocene geology, Awakino Tunnel

Hazard: Traffic

Mitigation: Remain in off-road park area; do not wander out on to main road

Stop 10: Orahiri Limestone, Awakino Tunnel

Hazard: Traffic

Mitigation: From large off-road park area just west of the Tunnel we will walk back under firm instruction to the Tunnel entrance; must not wander on to main road; at Tunnel remain behind the metal barrier road wall; wear fluoro vests and solid footwear

Stop 11: Awakino Limestone Member, Awakino Gorge

Hazard: Traffic

Mitigation: Little traffic expected but be wary; do not wander out on to road; wear fluoro vests

Stop 12: Bexley Sandstone, south end Awakino Gorge

Hazard: Traffic

Mitigation: Park vehicles well west (at least 50 m) of the roadside outcrop; await instructions for road crossing and walk along fence line of wide grass verge to outcrop; wear fluoro vests, hard hats and solid footwear; use geological hammers appropriately and wear safety glasses

Stop 13: Overview Miocene geology, western end of Ladies Mile

Hazard: Traffic

Mitigation: Remain in large off-road park area; do not wander back to main road; wear fluoro vests

Stop 14: Bexley Sandstone to Manganui Formation transition

Hazard: Traffic

Mitigation: Park on wide off-road verge and await instruction for crossing road; do not wander on to main road; remain in single file line on wide verge to observe outcrop

Stop 15: Manganui/Mangarara/Mohakatino Formations, Awakino Heads

Hazard: Sea state/tide level (Thurs HT 1100, LT 1715; Fri HT 1140, LT 1750); slippery coastline rocks and track; falling rock debris

Mitigation: Be vigilant of the tidal situation (instruction will be given); wear fluoro vests, hard hats and solid footwear; stay out of the undercut bluff/cave; walk unhurriedly at your own confident pace; use geological hammers appropriately and wear safety glasses

Stop 16: Mt Messenger Formation, Pahaoa Hill

Hazard: Traffic

Mitigation: Time could dictate only a short off-road park view stop of section, possibly inside a farm entrance gateway; remain by vehicles; do not wander back on to main road

Stop 17: Rapanui Formation, Seaview Motor Camp

Hazard: Traffic

Mitigation: An off-road park view stop; do not wander on to main road; cross road only under instruction

Stop 18: Mt Messenger/Mohakatino Formations, Mokau River mouth

Hazard: Traffic

Mitigation: Parking in off-road rest area; do not wander on to main road; pay attention to any other vehicle movements in the rest area

Stop 19: Mt Messenger Formation sandstone, Mohakatino River bridge

Hazard: Traffic; falling rock debris

Mitigation: Parking in off-road rest area; do not wander on to main road; cross road only under instruction; remain back form bluff face; wear fluoro vests, hard hats and solid footwear; use geological hammers appropriately and wear safety glasses

Stop 20: Mt Messengar Formation sandstone, Tongaporutu River mouth

Hazard: Traffic

Mitigation: Parking in off-road rest area; do not wander on to main road; we will walk down roadside a short distance and group behind the roadside wall barrier; wear fluoro vests and solid footwear

Stop 21: Mt Messenger Formation thin-bedded sandstone, Okau Rd

Hazard: Traffic

Mitigation: Park off roadside on this light traffic road; remain by vehicles until instruction given to cross road to view outcrop; wear fluoro vests and solid footwear; use geological hammers appropriately and wear safety glasses

Stop 22: Otunui Formation and volcaniclastic interbed, Okau Rd

Hazard: Traffic

Mitigation: Park off roadside on this light traffic road; remain by vehicles until instruction given to cross road to view outcrop; do not wander on road; wear fluoro vests and solid footwear; use geological hammers appropriately and wear safety glasses

Stop 23: Mt Messenger Formation, Kawau Pa site

Hazard: Traffic; falling rock debris; slippery coastline rocks and bush track; sea state/tide level (Thurs HT 1100, LT 1715; Fri HT 1140, LT 1750)

Mitigation: Park in large off-road park area; wear fluoro vests, hard hats and solid footwear; walk unhurriedly at your own confident pace; use geological hammers appropriately and wear safety glasses; keep well back from steep cliff faces; pay close attention to tidal/sea state situation