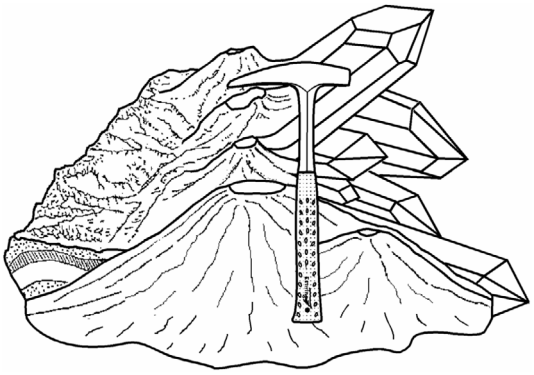


Geocene

Auckland GeoClub Magazine
Number 15, August 2017

Editor: Jill Kenny

Editor – This issue of Geocene has been updated. One image on page 20 has been removed to minimise possible copyright issues. An explanation and reference to the deleted image has been added to its vacant space.

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Geocene is a periodic publication of Auckland Geology Club, a section of the Geoscience Society of New Zealand's Auckland Branch.

Contributions about the geology of New Zealand (particularly northern New Zealand) from members are welcome. Articles are lightly edited but not refereed.

Please contact Jill Kenny <jill.kenny_at_xtra.co.nz> (substitute @ for _at_)

TWO-TIERED SHORE PLATFORM REFLECTS HOLOCENE SEA-LEVEL HISTORY, CARTERS BEACH, WAIKATO WEST COAST

Bruce W. Hayward



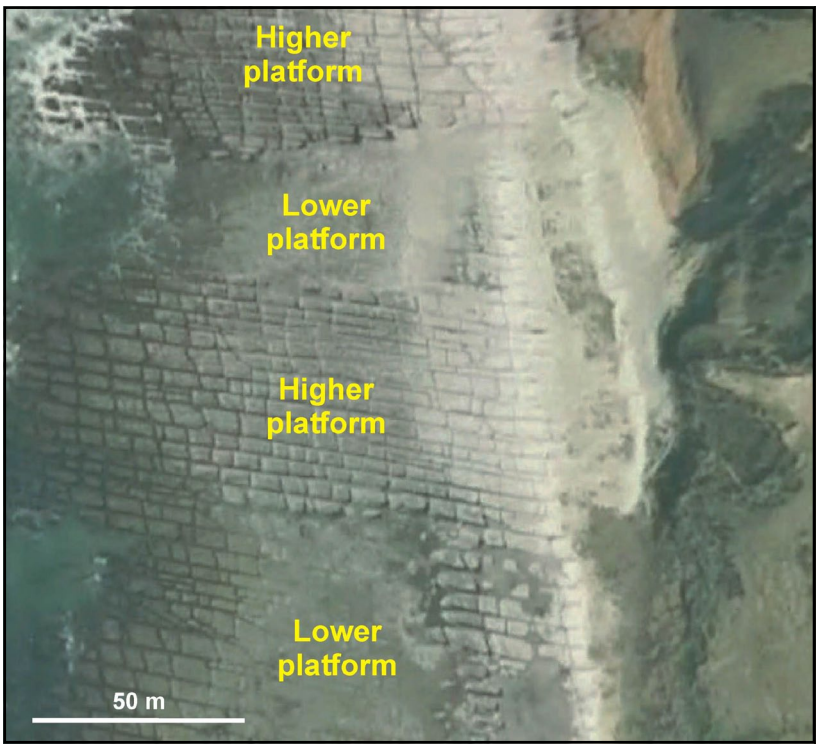


Fig. 1. Left: Location of the two-tiered shore platform at the north end of Carter Beach, 15 km north of Raglan Harbour, Waikato west coast.
Right: Vertical view at low tide of part of the two-tiered shore platform – the reticulate pattern is the higher platform and the smooth pattern is the younger, lower platform that is forming. Both from Google Earth.

In October 2014, a group of Auckland Geoclubbers visited Carters Beach, near Te Akau South on the Waikato west coast (Fig. 1). Access was across private farmland. We walked 1 km north up the beach from the mouth of the stream, to where the beach passed around a point onto a rocky shoreline. At this locality, well-cemented, highly calcareous Te Akatea Siltsone of late Oligocene age is overlain by thin Waitomo Sandstone near high tide level. This in turn is overlain with a slight unconformity by early Miocene Koheroa Siltstone (Fig. 2; Kear, 1966; Edbrooke, 2005).



Fig. 2. Two levels of shore platform cut into massive Te Akatea Siltstone, with bedded Koheroa Siltstone forming the cliffs above.

The intertidal foreshore here, is entirely composed of massive Te Akatea Siltstone that is cut by two sets of joints at right angles to each other. Erosion along these joints has produced a reticulate pattern in much of the higher sloping platform (Fig. 3). Here the intertidal zone has two gently-seaward-sloping platforms eroded into the Te Akatea Siltstone. The lower platform is located at mid-low tide level, whereas the other is 2 m higher and slopes up from mid tide into the supra-high-tidal swash zone. The upper platform is clearly older than the lower one, with the reticulate pattern of joints deeply incised by erosion (Fig. 3). In places the joints have eroded wide



Fig. 3. Two-tiered shore platform at north end of Carters Beach. Note the erosion along the two sets of joints producing the strong reticulate pattern.

gullies, leaving 2 m-high pedestals upstanding on the lower surface (Fig. 4). On the lower tidal platform, the joints have not been eroded out at all. These sloping platforms are not bedding planes, as there is no obvious layering within the Te Akatea Siltstone and the platforms are slightly steeper than the near-horizontal bedding in the Waitomo Sandstone above.

The simplest explanation for this two-tiered shore platform, is that the sloping planes were formed at different times. Both were likely formed by the same erosional process, controlled by the alternating wetting and drying of the rock surface during the tidal cycles. Thus, both platforms likely formed within the same tidal range, with the higher one created when sea level was ~2 m higher than the present level, at which the lower platform is forming. If correct, these shore platforms provide further support for the increasingly accepted model that sea level around New Zealand was 1.5–2 m above present during much of the middle Holocene, 6500–2500 yr ago (Fig. 5).

References

Edbrooke, S.W. 2005. Geology of the Waikato Area. IGNS Geological Map 4.

Hayward, B.W., Grenfell, H.R., Sabaa, A.T., Cochran, U.A., Clark, K.J., Wallace, L., Palmer, A.S. 2016. Salt-marsh foraminiferal record of 10 large Holocene (last 7500 yrs) earthquakes on a subducting plate margin, Hawkes Bay, New Zealand. Geological Society of America Bulletin 128: 896–915.

Kear, D. 1966. Sheet N55, Te Akau. Geological Map of NZ 1:63,360. DSIR.



Fig. 4. 2 m-high, flat-topped pedestals of Te Akatea Siltstone created by erosion along the reticulate jointing pattern. The flat tops are the upper platform level with the base of the pedestals at the level of the lower shore platform.

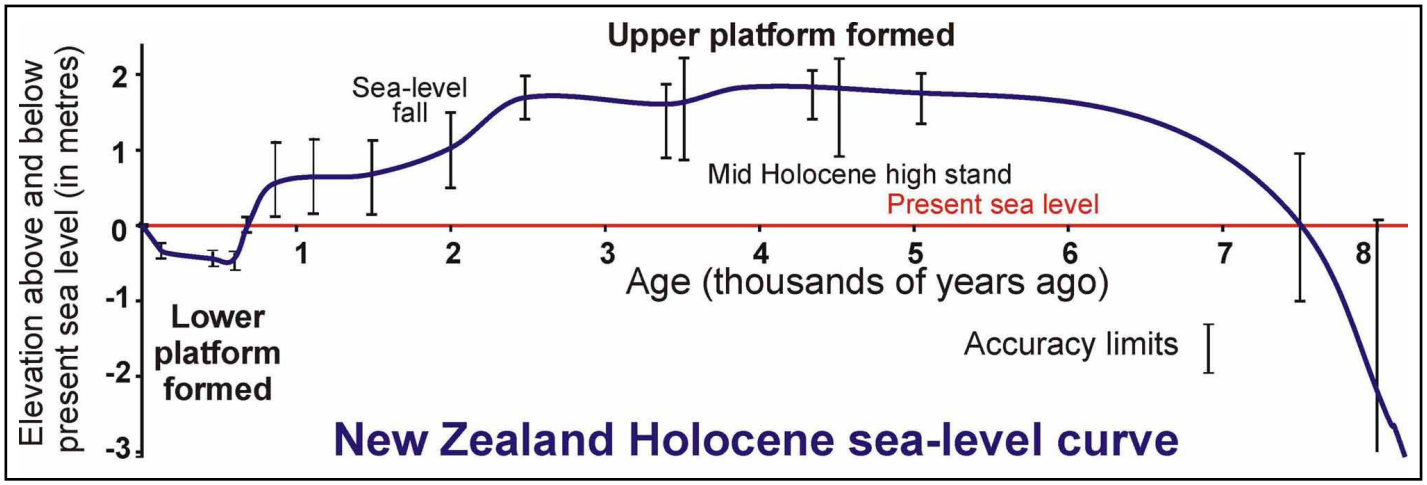


Fig. 5. Current model for sea level around New Zealand during the Holocene (after Hayward *et al*. 2016), showing the inferred times of formation of two shore platforms.

FIRST RECORD OF THE PTEROPOD *CLIO TRIPLICATA* IN NEW ZEALAND (MOLLUSCA, GASTROPODA, EUTHECOSOMATA) PREVIOUSLY KNOWN ONLY FROM THE MIOCENE OF EUROPE

Lyn Hellyar

"***Pteropods: Swimming snails of the sea*** *- The pteropods are a fascinating group of snails that spend their entire lives swimming or drifting in the ocean and never touching the bottom. Pteropoda means wing-foot referring to their muscular foot that has evolved into a pair of wings allowing them to take advantage of the Earth's largest habitat, the open ocean*." Fig. 1.

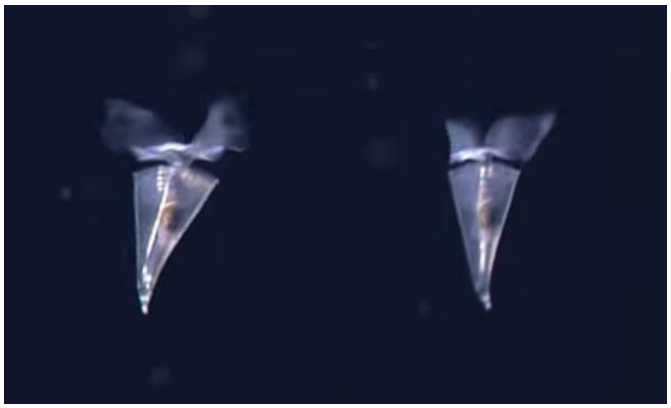


Fig. 1. Screen grab of two segments in a YouTube video, showing how a pteropod uses its winged feet to move through the water.

In late 2016, three species of Euthecosomata (Pteropoda) were recorded (Janssen & Hellyar, 2016) from the Taumaranui Formation (Mahoenui Group) (Nelson *et al*. 1994). These were initially found during a Geoclub trip in April 2016. The specimens were collected by the author at Herlihy Bluff (Fig. 2) on State Highway 43, southwest of Tauramanui.

The strata at Herlihy Bluff are thinly bedded (10–20 cm-thick beds) turbiditic sandstones and mudstones (Kamp *et al*. 2004). The under-sides of the sandstone slabs have ripples, load casts or flute marks. Fossils are mostly occasional foraminifera and leaf and wood fragments.



Fig. 2. Herlihy Bluff, River Road, State Highway 43, 6–7 km southwest of Taumaranui.

Large falling blocks from the towering bluff are contained by a metre-plus-high stop bank, used to create a trench at the base to protect passing traffic. One slab hammered from a large fallen block had some small triangular shapes that rang a bell from some research that I had done previously on planktonic gastropods.

Viewing them in the field through a 10x loupe was inadequate, so there was a wait until my microscope could be used. They were not well preserved, having thin shells of aragonite, a form of calcium carbonate that is ~50% more soluble than calcite. A possible identification as *Clio pyramidata* had been suggested, but that didn't quite work for me – there was a subtle difference, but I didn't have the expertise to know what it was. So on advice from Dr Richard Willan in Australia, to whom I'd shown the images, I contacted Arie Janssen in Leiden, The Netherlands. The slab was couriered to Arie, but a definite identification was still not possible because of the poor preservation.

So, in June I went back to Tauramanui. Day one: I drove out to the bluff. The fog lifted at lunchtime, but I found the ground still wet with water lying in pools behind the stop bank. The blocks of material free of the pools had a fine layer of mud over them, and the ground in places was ankle-deep in soft sticky mud.

After three hours hammering, I had one block with specimens in three slabs (Fig. 3).

Day two: More of the same conditions, plus a rock fall some metres away gave cause for a slight elevation in heart rate, but another three hours hammering revealed no more specimens. The body called a halt.



Fig. 3. The three slabs (including little one to right of hammer) of fossiliferous rock found at Herlihy Bluff, June 2016.

I despatched the latest slabs to Arie – and relief – an email of congratulations. The elusive *Clio* was *triplicata* Audenino, 1899 (Figs 4, 5), plus two other records. One other *Clio* sp. and a Limacinidae sp. recorded in open nomenclature due to poor preservation. Specimens are now housed in the Naturalis Biodiversity Center, Leiden, The Netherlands and GNS Science, Lower Hutt, New Zealand.

Full details are published in the New Zealand Journal of Geology and Geophysics (Janssen & Hellyar, 2016).



Fig. 4. Triangle-shaped pteropods on the first slab I found at Herlihy Bluff. A probable specimen of *Clio triplicata* is about 7 mm left of rusty spot on top rim of the slab. Scale bar is 10 mm.

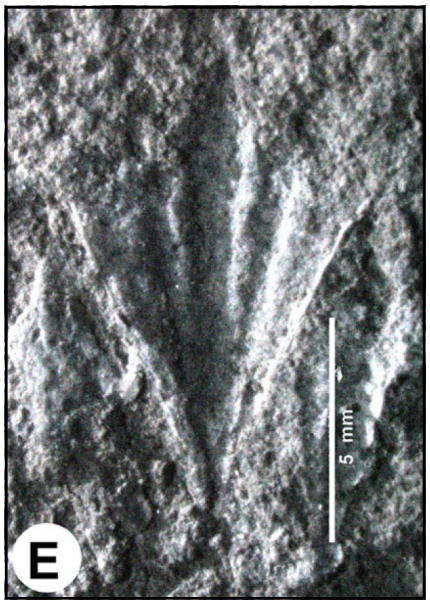


Fig. 5. Cast of dorsal side of *Clio triplicata* from Janssen & Hellyar, 2016, Fig. 3. Scale bar is 5 mm. Photographer Eduard F. de Vogel.

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

Youtube video extract - https://www.youtube.com/watch?v=3-40RU3iSkA Published on Nov 11, 2015

Thanks are due to many people, acknowledged in the published paper.

Grateful thanks for support must be given here to Bruce Hayward, Alan Beu, and of course Arie Janssen, who was incredibly patient.

I would be interested in seeing any collections of fossil or modern pteropods, from anywhere.

Lyn Hellyar. Orewa Auckland.
email: lynetteh@clear.net.nz

QUIZZES

Know your volcanoes - a lot easier if you were on the 2016 GeoClub field trip to Northland.
Match photos 1 – 5 with volcano names A – E.
(Answers on last page)

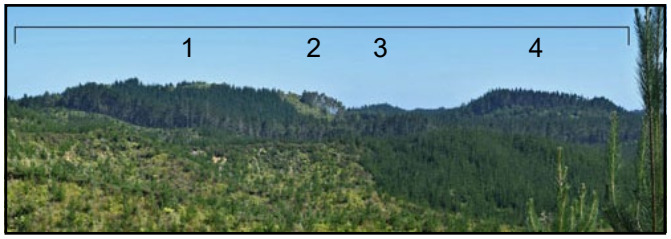
1.



2.



3.



4.



5.



Possibilities to choose from:-

A Hikurangi dacite dome, Whangarei Volcanic Field
B Opuawhanga dacite dome, Puhipuhi Volcanic Field
C Putahi rhyolite dome, Kaikohe Volcanic Field
D Te Ahu Ahu basalt volcano, Kaikohe Volcanic Field
E Te Puke basalt volcano, Bay of Islands Volcanic Field

Where is this basalt karst?
(Answer on last page)



Possibilities to choose from:-

a Lake Manuwai, Kerikeri
b Stoney Knowe, Helena Bay
c Stony Batter, Waiheke Island
d Ti Point, Leigh
e Wairere Boulders, Hokianga

QUATERNARY FOSSIL FORESTS AND SEQUENCE OF LIGNITES/PALEOSOLS AT BAYLYS BEACH, NORTHLAND

Bruce W. Hayward, Ian Geary, Paul Williams, Brent V. Alloway and Alastair Jamieson

Summary

In January 2017, a well-preserved fossil forest was exposed for the first time in a lifetime beneath the sands at the mouth of Chases Gorge, Baylys Beach but is now once again buried and hidden. This forest occurs within the upper part of the oldest of four lignite lenses that occur in a sand dune-dominated sequence that forms a 2–3 km-wide coastal belt along the west side of this part of the North Kaipara Peninsula. Here, the exposed 65 m-thick sequence contains four periods of lignite lenses that accumulated in former interdune or valley floor lakes or swamps. Each lignite is underlain by a podzolised fossil soil that developed under forest during times of stabilised dunes. Podzolisation may have resulted in perched groundwater tables that developed the lakes and swamps at elevations higher than sea level. Each lignite and sometimes forest remains is buried by sand – wind-blown at higher levels at least. Two additional podzolised soil horizons are recognised in the middle of this sand sequence, thus creating six cycles of sand accumulation, stabilisation, forest establishment, podzol soil development, followed by water ponding in depressions. High interglacial sea levels may have influenced the groundwater table that led to widespread lignite swamps during the two oldest, lowest sediment cycles. Sea level fall at the end of warm interglacial periods is inferred to be responsible for excess sand on the beach that blew inland to bury the swamps, forest and podzolised soils on four occasions, the last probably in the middle Holocene (~4000 yrs ago).

Introduction

In November 2016, 28 Geoclubbers visited Baylys Beach, on the west coast out from Dargaville, for 45 mins and saw several lignite lenses within the Quaternary sand sequence in the cliffs just north of Chases Gorge. Unfortunately the tide was well in and the wind blowing up sand, so we missed some of the more interesting highlights that could have been seen on a better day with a lower tide. In January 2017, the first two authors (BWH, IG) spent two low tides on the beach looking for fossil fruit and seeds in lignite lenses, collecting tephra samples and getting a feel for what was present. On this occasion the beach sand was particularly low around Chases Gorge mouth and locals told us they had not seen so little sand in at least the last 50 years. This note provides photos and a short description of two low tide reefs with in-situ fossil stumps of forest trees that had not previously been seen in a lifetime. In April 2017, all the authors except IG, spent a day examining the cliff sections and especially lignite lenses and tephra exposures during a middle-of-the-day low tide. BVA's 4-wheel-drive vehicle enabled us to examine a section of coast extending 7 km south of Baylys Beach to Mahuta Gap and 8 km north to Moremonui Gully (Fig. 1). Unfortunately the sand had returned and the two low-tidal reefs with fossil forest were once again completely buried beneath the beach.

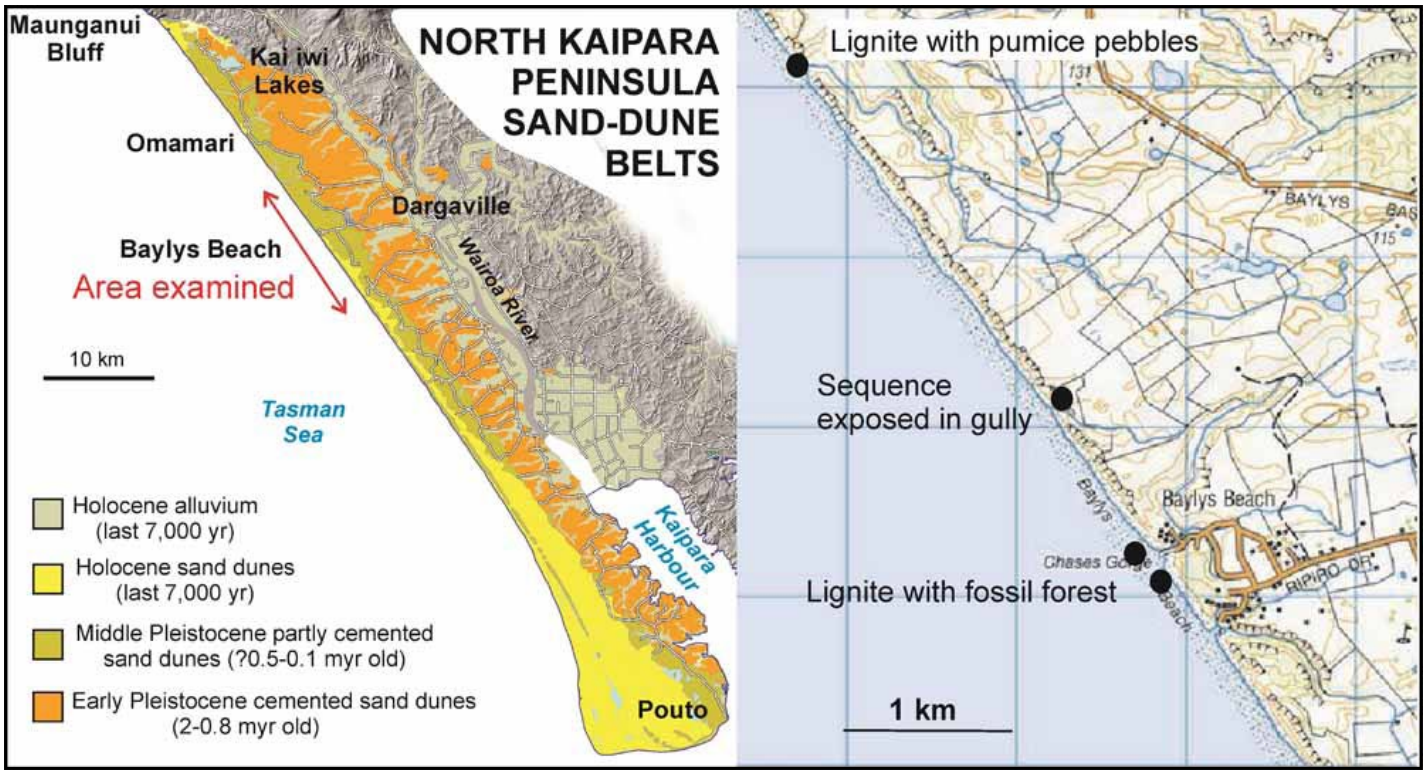


Fig. 1. Left. Map showing the mapped distribution of different sand belts forming North Kaipara Peninsula, from GNS QMap database (Edbrooke and Brook, 2009).
Right. Map showing location of lignites and fossil forests referred to in this note.

Previous work

Although the general nature of the North Kaipara sand barrier with interspersed lignite beds was known from as early as the mid nineteenth century, it was Rick Richardson who first attempted to better understand its architecture and age in his MSc thesis in 1975. He recognised three belts of sand between Dargaville and the west coast (Richardson, 1985) and placed the 2–3 km-wide (youngest) coastal belt in his undifferentiated Hawera fixed dunes unit. More recently Steve Edbrooke and Fred Brook (2009) included this area in their 1:250,000 geological map and separately mapped this 2–3 km-wide coastal strip of sand and lignite deposits as a single unit (Fig. 1). They inferred it to be "older parabolic dunes" of early-middle Pleistocene age (placed in their Kariotahi Group) plastered on the west side of an older backbone of Awhitu Group sands. In some places they mapped a thin cap of weakly consolidated to loose Holocene sand dunes on the top of the cliffs.

Dallas Mildenhall *et al*. (1992) summarised the lignite settings and palynoflora of all the west coast sand deposits from Maunganui Bluff to south of Port Waikato. They recognised two different environments for accumulation of the organic-rich deposits within the west coast dune systems. The first they called dune paleosols and interdune deposits, which consist of thin sand-dominated organic-rich paleosols that may be traced for hundreds of metres or more. The second they called dune-impounded lake and stream delta deposits, typified by those at low levels around Baylys Beach. They infer that these thick, laterally-impersistent lignite lenses accumulated in shore-parallel, dune-impounded lakes and stream deltas. They inferred the lignites and paleosols accumulated in well-watered interglacial environments.

Bill Harris (1953) was the first to have studied the palynology from any of the lignites. He recognised a cool, beech-dominated pollen flora overlain by a warmer pollen flora in the lignite lens exposed in the lower cliff, 200 m south of Chases Gorge. The setting and palynology around Baylys Beach was summarised in David Pocknall and Roger Tremain's (1988) field guide. They concluded a Castlecliffian or Nukumaruan age (2.4–0.34 Myr) based on "the lack of extinct pollen types". Dallas Mildenhall (in Richardson, 1985) studied the palynology of a number of the lignites around Baylys Beach and concluded "a Castlecliffian or younger age and a climate similar to the present" (ie. younger than 1.6 Myr).

Murray and Grant-Mackie (1989) reported on the palynology of a 40 m-thick sequence of carbonaceous and sand units at Rototuna, near the south end of North Kaipara Peninsula. The lower two thirds of the sequence contained kauri-podocarp-hardwood palynofloras considered to indicate a warm wet climate, whereas palynofloras from above a prominent tephra were dominated by podocarp-hardwood-beech considered to be from a cooler climate. They inferred early Pleistocene ages. Recent geochemical work (Newnham *et al*., in press) has shown the tephra is late Pleistocene Rotoehu Tephra (~50,000 yrs old) making the sequence (or at least its upper part) much younger than thought and deposited during the Last Glacial (MIS 3–2). Dallas Mildenhall *et al*. (1992) summarised all the palynology in the west coast lignites and placed the lignites in the lower cliffs around Baylys Beach in the Awhitu Group with a Nukumaruan age (early Pleistocene, 2.4–1.6 Myr).

Geological Setting

This section of coast has been mapped as a 2–3 km-wide belt of sand dunes of inferred middle (?early) Pleistocene age (~780,000–125,000 yrs) that was added on to the west side of an older North Kaipara sand barrier (Edbrooke and Brook, 2009). Because many of these sands are not strongly cemented, the 40–60 m-high coastal cliffs are a mix of steep vegetated and unvegetated sand slopes interspersed with sections of more vertical cliff-face exposures. In some places small, modern stream valleys have cut down right through the sequence and flow out to the coast through gaps/gorges in the cliffs. They may have small, sand-filled estuaries/deltas extending up their lower reaches that sometimes pass into vegetated freshwater swamps with flax, raupo and other plant communities.

The lower 15–20 m of the cliff faces expose a mix of subhorizontally-bedded sands (water-laid, probably beach or shallow subtidal) and dune-bedded sands (subaerial wind deposits). If some of these are marine deposits then they suggest relative sea level was at least 15–20 m higher than present when deposited. The highest that sea level has been above present during warm interglacials in the last 1 Myr has been ~10 m during MIS 11 (~400,000 yrs ago). Thus some subsequent uplift is likely, unless the deposits are much older than 1 Myr. The upper 30–40 m of the cliff sections are less well exposed and were not examined in detail, but include cross-bedded sand dune deposits and more massive sand units. No obvious water-laid sands were seen in these upper parts.

About 5% of the deposits exposed in the cliffs is composed of black lignite lenses that are more compacted than most of the sands and therefore often form prominent cliff faces. These lignites appeared to be more common at lower levels and intertidally, but thinner lignite lenses were observed in places higher in the cliffs all the way to the top (see later). The lignite lenses as observed in the cliffs were 5–200 m across and up to 8 m thick in the middle in some of the lower units. They appeared to be small valley-fill deposits. The raupo-flax swamps in the small modern valleys that cut the sequence are possibly modern analogues of the environments in which these thick lignites accumulated. A distinctive cream-coloured tephra bed (5–12 cm thick) occurs in many of the lower lignite lenses extending at least 8 km north and 400 m south of Baylys Beach. If it is just one airfall event from a caldera eruption in the centre of the North Island, then many of the lignite lenses just above high tide level

were deposited at the same time. The presence of small rounded pumice pebbles (Fig. 2) on the sandy edges of one of these lenses (3.5 km north of Baylys Beach) suggests that they were washed in from the sea into a high-tidal estuary at the mouth of a small stream and that relative sea level must have been close to the present at that time (i.e. an interglacial warm period).



Fig. 2. Small rounded pumice pebbles in sandy lignite indicate that it accumulated in a valley-mouth swamp at about storm surge height. Locality 3.5 km north of Chases Gorge.

Fossil Forests

The best example of a fossil forest was seen in January in intertidal reef exposures within 200 m either side of Chases Gorge. Although separated at the time by 200 m of beach sand, it seems likely that they are part of the same fossil forest. Just to the north, the exposure covered an area of 80 x 20 m with numerous stumps with roots still in place in a brown sandy soil that passed up into lignite (Figs. 3–5). The largest stump (Fig. 5) was nearly 1 m in diameter and stood 1–1.5 m high above the soil. By our April visit it was completely buried. The lignite at this locality contained numerous large lumps (up to 10–15 cm across) of golden kauri gum (Fig. 6).

About 200 m south of Chases Gorge, a 0–2 m thick lens of lignite can be seen in the lower cliffs and in January this continued out across the beach as a reef of 2 m-thick lignite (Fig. 7). At the seaward edge there were numerous, planed off stumps and roots still in growth position embedded in the upper part of the lignite (Fig. 8), which at this locality contained abundant kauri cones and leaves (e.g. Fig. 9). Near the base of this lignite lens in the reef exposure near high tide at the foot of the cliff, the lignite contained numerous leaves of beech (*Nothofagus fusca*), rimu (*Dacrydium cupressinum*) and other broadleaf plants (e.g. Fig. 10). This appears to be the lignite studied by Harris (1953) in which he recorded a change from dominantly *Nothofagus* beech pollen at the bottom to a flora with influxes of kauri, tanekaha and totara. This change in both the palynology and leaves is suggestive of climate warming during deposition of this lignite.



Fig. 3. Fosilised in-situ stumps of forest trees exposed by natural sand removal in Jan 2017, 100 m north of Chases Gorge mouth (cars).



Fig. 4. Fossil forest at low tide, 100 m north of Chases Gorge, Jan 2017.



Fig. 5. Largest tree stump and roots exposed by low beach sand levels 100 m north of Chases Gorge, Jan 2017.



Fig. 6. Lump of kauri gum in peat soil around fossil tree stumps at low tide 100 m north of Chases Gorge, Jan 2017.



Fig. 7. Sloping edge (due to compaction) of 2 m-thick lignite, 200 m south of Chases Gorge. In Jan 2017 the lignite reef, seen here, extended 50 m seaward of the cliff, but in April 2017 was under the beach sand again.



Fig. 8. In-situ tree stump in top of lignite 200 m south of Chases Gorge, seen Jan 2017.



Fig. 9. Male kauri cone, parts of female kauri cones and leaves are seen in a number of lignite lenses, like this one 500 m south of Chases Gorge.



Fig. 10. Fossil beech (*Nothofagus fusca*) and other leaves are present in several lignite lenses, such as this one 6 km south of Chases Gorge.

Other less spectacular examples of in-situ tree stumps were seen in and around the edges of several other younger lignite lenses. The youngest lignite in the cliff section studied (below) contained stumps and roots of probable kauri up to 1 m across and a similar sized kauri stump was seen eroding out of a lignite at the base of the cliff, about 400 m north of Chases Gorge, although it did not appear to be in growth position.

Sand and Lignite Sequence

A small gully eroded through the 60 m-high cliffs, ~1 km north of Chases Gorge (Fig. 1), provides continuous exposure through the entire sequence at this locality. It contains four paleosol/lignite horizons separated by units of massive and dune-bedded sand (Fig. 11). The lowest 10 m at the gully mouth is hidden by sliding sand, but 50 m away near high tide level is a fifth carbonaceous unit, a lignite lens containing the distinctive cream tephra (Fig. 12). At Chases Gorge a thin lignite, containing the tephra, occurs 3–5 m above high tide in the lower cliffs. It is separated by 3–6 m of sand from a sixth, and lowermost carbonaceous unit, which was exposed intertidally in Jan 2017 and contains the fossil forest described above (Fig. 13).

The two lowest carbonaceous units are lignite lenses (Fig. 13), each up to 2–3 m thick and containing plant remains and wood that indicate forest colonisation. The third and fourth youngest units (in the gully exposure) are thin sandy carbonaceous horizons that are best described as paleosols (Fig. 11). The fifth (second-youngest) unit is another 2–3 m-thick lens of lacustrine/swamp lignite. The youngest unit is up to 1 m-thick lignite lens containing remains of a mature ?kauri/podocarp forest in its lowest parts (Fig. 14). It is overlain by ~2 m of wind-blown sand of probable Holocene age. This youngest lignite accumulated in a shallow valley/interdune depression between rounded dune ridges that are 3–5 m higher than the depression.

Each carbonaceous unit/lignite is abruptly overlain by sand – presumably wind-blown in most instances. Each carbonaceous unit is underlain by a moderately cemented whitish, sand horizon (weakly-developed silcrete) (Figs 7, 13), often with iron-staining and an irregular limonite hard-ground pan (Fig. 14) running through the lower part of the 1–5 m thick cemented sand. The cemented sand and limonite hard ground are inferred to be the results of podzolisation soil development beneath a podocarp/kauri forest.

Interpretation

The presence of several levels of in-situ fossilised tree stumps indicate that the coastal sand sequence that has accumulated here was stabilised and colonised by forest on a number of occasions, before being overwhelmed, killed off and buried by sand, mostly wind-blown.

The observed 65 m-thick sand sequence, north of Chases Gorge, contains six organic-rich horizons, each overlying

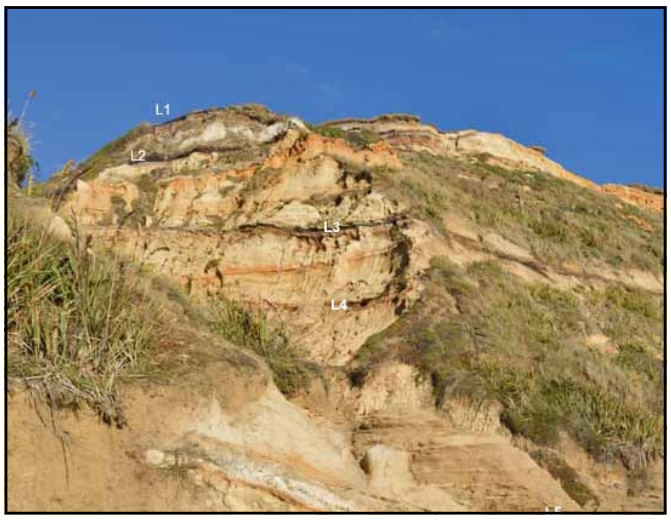


Fig. 11. Gully cut exposure through 60 m sand sequence, ~1 km north of Chases Gorge, exposes two paleosols (L3, L4) and higher up two lignite lenses (L1, L2).



Fig. 12. 12 cm thick cream rhyolitic tephra (above scale's head) within lower part of a 6 m-thick lignite lens, exposed 4 m above high tide just north of the gully sequence.



Fig. 13. Low tidal exposure of podzolised layer overlain by lignite lens (left foreground) with in-situ fossil forest, just north of Chases Gorge mouth (top right), in Jan 2017. A thinner lignite, with tephra horizon (not visible in photo), can be seen in the low cliffs, 3-5 m above the level of the beach lignite. These are the two oldest lignites in the sequence studied at Baylys Beach.



Fig. 14. Youngest lignite with large tree branches and stumps at the base, overlying a thin podzol with irregular limonite pan and overlain by 2 m of wind-blown sand. At the top of the cliff section in gully north of Chases Gorge. Lignite and overlying sands are inferred to be Holocene in age.

a well-developed, podzolised soil. Some workers have postulated that the lakes and swamps that the lignite accumulated in were a result of raised water tables associated with interglacial high stands of sea level. This might have played a part in the lower two lignites in the succession we studied, especially as we have observed water-laid sands around them and pumice pebbles in one correlative lignite (Fig. 2). Indeed the greater abundance of lignite lenses in the lower cliffs relative to the higher cliffs could very well be a result of groundwater levels influenced by interglacial high sea levels.

Raised groundwater levels associated with high sea level stands clearly do not explain the two highest and youngest lignites at 45–60 m above present-day sea level. Thus we infer that where the podzol developed in a depression or valley, no matter what its elevation above sea level, the podzol may have reduced permeability, creating a perched water table that allowed water to collect and a swamp or dune lake to form. Where the podzol developed on a ridge, no lignite accumulated, only organic-rich sandy soil layers.

How much time is represented?

The 65 m-thick sequence contains six periods of sand dune stability with vegetation colonisation and paleosol/podzol development followed in at least four instances by swamp/lake formation and lignite accumulation. In each instance the lignite accumulation or paleosol has been buried by subsequent moving sand – clearly wind-blown in the upper parts and either wind-blown or by beach encroachment in the lower parts. It is highly speculative to infer the amount of time represented by the sequence – wind-blown sand dunes and beach sands can accumulate very rapidly. Lignite accumulation in a swamp can also be relatively rapid (~1 m compacted thickness per 1000 yrs). How long it takes to develop a podzol beneath forest is less well known and most time may be represented by these hiatuses in the sequence of accumulation.

The sequence could be interpreted as six sediment accumulation cycles. But what is the driver of the cycles? Possibly the climate cycles. As one hypothesis, we suggest that climate cycle-driven sea-level fluctuations controlled the supply of sand to this coastal belt. When there was excess sand accumulating at the back of the beach, it was blown inland and invaded the vegetation-covered fixed dunes and buried the lakes, swamps, forests and shrub-lands with moving sand dunes. The coast at these times could have been hundreds of metres away to the west. We see this process occurring today at the south end of North Kaipara Peninsula, where moving sand is still invading forest stands in some places.

Theoretically, when sea level falls, excess sand is deposited on the beaches and this would be the time when the paleosols and lignites would have been buried. When sea level rises, coastal erosion occurs and there is no sand being blown inland. Thus maybe when sea level was low, during glacial periods, and the coast was many kilometres out to the west, the Baylys Beach coastal dunes were stabilised and vegetated and podzolisation occurred. This situation would have continued during sea level rise as the coast migrated eastwards towards its present position. The main time of excess sand on the beaches would have been in the latter part of an interglacial period when sea level began to fall as the climate began to cool and the coast was still not too many kilometres distant.

This scenario is supported by the palynology and plant remains in the oldest lignite seen intertidally around Chases Gorge. The lower part of the lignite has a beech-dominated flora suggestive of a cooler (?glacial) flora that passes up into a kauri-rich warmer (interglacial) flora that was killed by the mobilised sand as sea-level started to fall.

Is each sediment cycle the same length then as a climate cycle (100,000 yrs each for last 700,000 yrs)? Maybe some sediment cycles were faster and were influenced by the sea-level fluctuations associated with climate perturbations (?stadials-interstadials) within the larger cycles.

What age?

We do not know, yet. Hopefully detailed studies of the tephra's chemistry and its correlation with tephra of known age to the south or offshore will answer this question. It appears highly likely that the uppermost lignite and fossil forest (Fig. 14) was killed and buried by wind-blown sand in the middle Holocene as sea-level began to fall about 4,000 yrs ago. Thus this young kauri-dominated forest was probably early Holocene in age (~12,000–4000 yrs old). The paleosol beneath it probably developed during the Last Glacial, but it is far more speculative to infer whether this youngest paleosol was formed only during the glacial MIS 2 stadial (30,000–12,000 yrs ago) or the whole cooler part (MIS 4–2) of the larger climate cycle (~80,000-12,000 yrs ago). Maybe the second youngest lignite formed during the Aurora Interstadial (MIS 3, 61,000–43,000 yrs ago).

At present we consider it too speculative to equate each paleosol/lignite with one glacial-interglacial period and we must wait until we know the age of the tephra. The presence of a significant erosional or non-depositional hiatus, of more than one climate cycle in duration, within the sequence cannot be excluded either at this stage.

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OLD LIMONITE WORKINGS IN OKAIHAU, BAY OF ISLANDS AREA

Don Mackereth

Brief Overview of Limonite

Limonite is an iron ore consisting of a mixture of hydrated iron oxide-hydroxides in varying composition. The generic formula is frequently written as $FeO(OH) \cdot nH_2O$ with a hardness on the Mohs scale of 4 to 5.5. Names such as “brown iron,” “brown hematite,” “bog iron,” and “brown ochre” have been used by miners to relate limonite to its potential uses. The use of these names has declined significantly, and the name “limonite” is now used (Fig. 1).

Limonite is not a true mineral but a mixture of similar hydrated iron oxide minerals. Most limonite is made up of **goethite** (chemical FeO(OH)), hydrated iron oxide. Massive goethite and limonite can be indistinguishable.

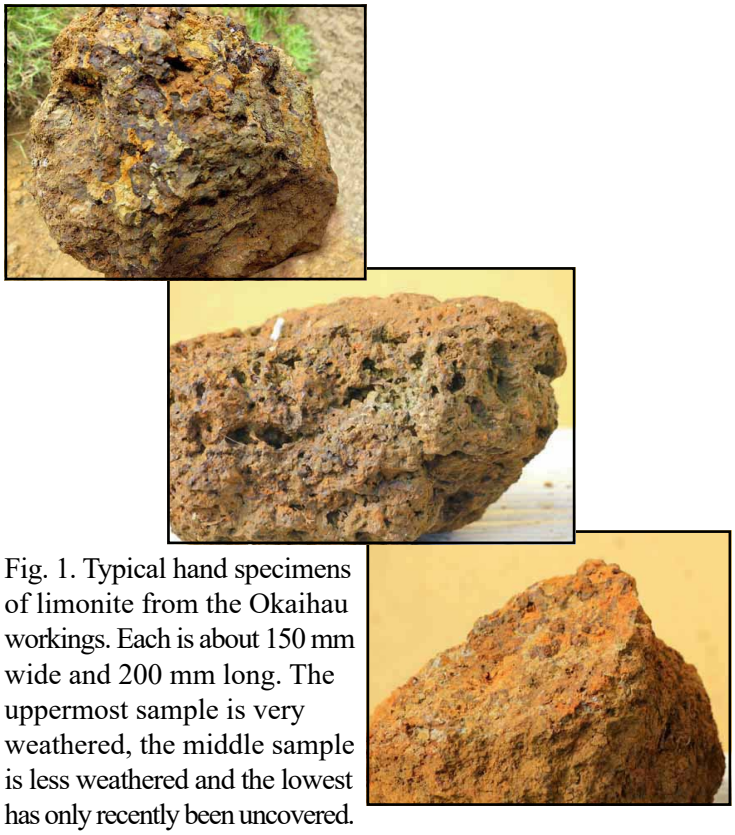


Fig. 1. Typical hand specimens of limonite from the Okaihau workings. Each is about 150 mm wide and 200 mm long. The uppermost sample is very weathered, the middle sample is less weathered and the lowest has only recently been uncovered.

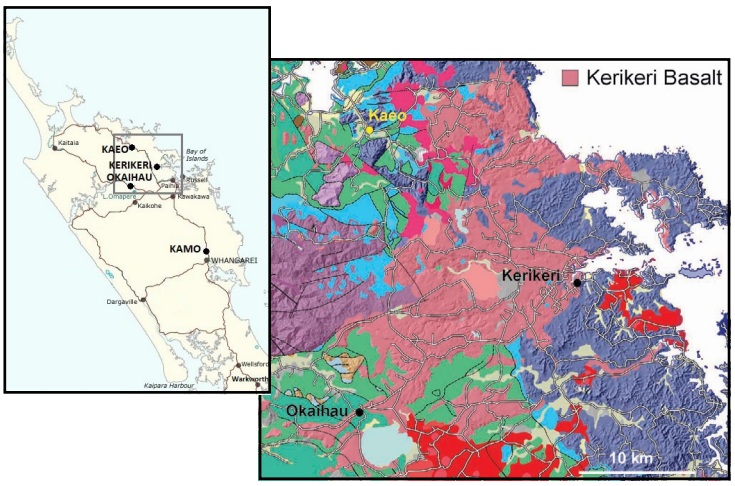


Fig. 2. Geology map of the Okaihau/Kerikeri area based on the Whangarei QMAP (Edbrooke & Brook, 2009).

Limonite forms mostly in or near oxidized iron and other metal ore deposits, and as sedimentary beds. It has been known to pseudomorph other minerals such as pyrite (FeS_2, iron sulfide), meaning it replaces a crystal of pyrite with limonite but keeps the shape of the pyrite crystal.

In Northland, small limonite deposits occur near Kaeo, Okaihau, Kerikeri and Kamo (Fig. 2). These deposits appear to have been formed from leaching of ferrous iron from Kerikeri Basalt by carbonated surface and ground waters, with its subsequent deposition on the surface of existing ferric hydroxides.

Brief History of the Okaihau Limonite Workings

Early geological exploration by McKay (1900) indicated that Okaihau iron-ore “certainly exceeds one and may be several square miles in extent.” Similar lesser deposits also exist in the same district (Park, 1903).

The deposit near Okaihau, situated on Waiare Road, 200 m west of the site of the present Far North District Council Waste Transfer Station (pers. comm. Bill King, Okaihau, on whose property the old workings remain) (Fig. 3), was worked intermittently up until 1961, producing



Fig. 3. Location of the old limonite workings, with the township of Okaihau lower left.
Photograph source: Google Earth.

a combined total of 39,111 tons, most of which was processed into powdered limonite by passing the raw material through a jaw crusher and then, in early years, through a grist stone, and in later years a hammer mill.

Production figures available as recorded in the annual "Mines Statement" by the Hon P.C. Webb Minister of Mines at the time, showing the mass and value of limonite produced per year from Okaihau.

1940	663 tons	value	£1838
1942	959 tons	value	£2773
1944	1893 tons	value	£5442
1945	2568 tons	value	£7882
1950	2441 tons	value	not given

The open cast mine and processing plant at Okaihau (Fig. 4) was operated by the Nicholson family with most of the limonite going to Taupo by rail in bagged form for agricultural purposes. This was trucked from the workings to the Okaihau rail head by A.J. Rowsell Ltd of Okaihau. The excavation of the opencast mine measures approximately 100 by 50 metres with a maximum depth of about 3 m.

It was noted that during the mining operation the immediate area surrounding the limonite works was covered in a thick yellow dust and this dust caused chronic respiratory problems for the workers at the mine (pers. comm. Colin Thomas, Okaihau). The Okaihau deposit today is less than 1 m, though some 60,000 tons containing 60% Fe_2O_3 remain (Williams, 1974).



Fig. 4. The Okaihau limonite workings as they appear now. The lower photograph shows 2 concrete portals where crushing machinery was once mounted.

Another deposit found, but not commercially worked, at Potaetupuhi Bush on the Okaihau - Kerikeri Road, towards the Kerikeri end [*Editor's note - probably Wiroa Road*], "consisted of small patches of high grade limonite (average analysis of 43.1% Fe) that extended over a total area of 4 ha" (Bell & Clarke, 1909). The exact location of these deposits are at present unknown.

The deposit near Kamo was also intermittently worked, producing 26,165 tons of ore up until 1961. This deposit contains between 10 and 36% Fe_2O_3 and may be an exhumed fossil laterite (laterite is the iron-rich red clay that has been indurated, which basically means naturally baked). According to Williams (1974), similar buried deposits could yet be discovered elsewhere in the region.

Uses of Limonite

Limonite has been used as a low-quality iron ore and colouring pigment throughout the world for thousands of years. When Europeans arrived in New Zealand the Maori were found to be making extensive use of "kokowai" (maroon) - that is to say limonite or brown ochre (qv), mixed with shark oil - as a predominant colouring agent. Solid chunks of limonite were ground on a flat but rough-surfaced rock to produce the powder.

This was used to paint their large war canoes and the carvings of meeting houses. Ochre prevented the drying out of the wood in canoes; later, missionaries estimated that it would last for 30 years. It was also roughly smeared over the face, especially by women, to keep off insects.

Later, limonite was used as an absorbent in the purification of coal gas, as a colouring agent in bricks, in improving cement and as a fertiliser, mostly because of its cobalt impurity and as an agricultural stock lick to relieve "bush-sickness".

Brief Overview of the Interaction of Limonite and Bush Sickness

The central North Island is covered by rhyolitic ash and ignimbrite deposits. At the surface the dominant deposits are Taupo Tephra, erupted ~232 AD from the Taupo Caldera and Kaharoa Tephra, erupted ~1314 AD from Mt Tarawera. This material is rich in silica, but has very low metal element concentrations, in particular iron, selenium, copper and cobalt.

Leo Fanning (1933) discusses the importance of limonite as quarried in Okaihau to the agricultural industry - "... in particular the central North Island where an area between two million and three million acres of tephra ash, to where death kept court for grazing cattle and sheep."

At first it was thought that the animals had absorbed poison from the pastures. Veterinarians were unable to diagnose any diseases, and it was thought that some property of the soil was responsible. Analytical techniques of the day (1900) were too insensitive to show what this might be, but trial and error showed that iron ore from some, but

not all sources provided relief. Later research, directed under Mr. B. C. Aston, concluded the trouble was traced to a deficiency of iron in the soil (later proved to be incorrect) - “It has been demonstrated that the health of animals and mankind requires about 0.004 % of iron in the body—and this need was lacking in the pumice country.” In 1934, Grimmett and Shorland (senior chemists at the Department of Agriculture’s chemical laboratory) found that the limonite which gave the best results contained significant amounts of cobalt.

“By 1935, Australian scientists (J.P. Filmer and E.J. Underwood) confirmed that the problem was in fact a lack of cobalt, which was responsible for health problems encountered. The Cawthron / DSIR group were quick to apply the findings and showed trace amounts of cobalt at a rate of one milligram per sheep per week cured the South Island version of bush sickness.” Ross Galbreath, (1998). “Cobalt acts as a catalyst in the assimilation of iron into the haemoglobin, the red blood corpuscles, of sheep and cattle.” (West, 1978).

The necessary iron for stock was usually supplied in a mixture of finely ground limonite and salt, compressed into “licks,” and left on the pastures, dispensed into water of drinking troughs or sprinkled on hay or ensilage.” (Fanning, 1933). The iron content of limonite did have an effect on the rhyolitic tephra soils by assisting in conditioning those soils through microbe action so as to allow an agricultural soil horizon to establish.”

Conclusion

Commercial mining of limonite in New Zealand as a source of iron is no longer undertaken. Limonite deposits are usually too small and too impure for use in modern metallurgy. In the field of agriculture, cobaltised super phosphate fertiliser, which has been developed, has been applied to the affected area ever since, at a rate of a few grams per hectare, and has resulted in the addition of about 250,000 Ha of productive farmland to New Zealand’s stock. The introduction of this cobaltised super phosphate fertiliser was responsible for the sudden closure of both the Okaihau and Whangarei mines in 1961, as they were no longer economic viable entities.

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AN INVESTIGATION INTO THE ENVIRONMENT OF DEPOSITION OF UPPER NUKUMARUAN / LOWER CASTLECLIFFIAN–AGED SANDSTONE FROM FINNIS ROAD, POHANGINA, MANAWATU

Wendy Goad

Introduction

In June 2011, I made an on-site inspection of a section of Upper Nukumaruan/Lower Castlecliffian-aged unconsolidated sands at Finnis Road near Pohangina village in the Manawatu. This report sets out the results of that investigation and then discusses the likely sedimentary environments operating at the time of deposition.

Location

The study section is exposed on the southern side of Finnis Road, Pohangina, Manawatu, North Island, New Zealand. The first study station was located approximately 750 m from the edge of the Pohangina village at 40^0.10'2.65"S/175^0.47'10.27E at an elevation of 161 m asl (Fig. 1).

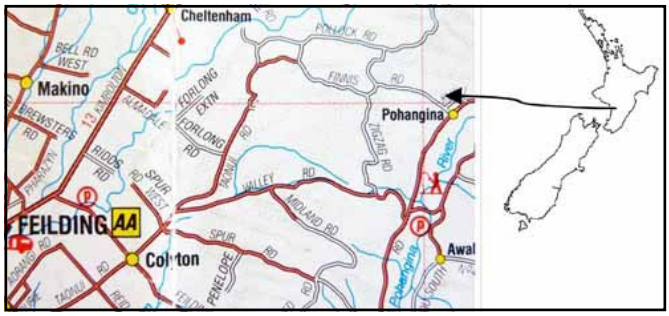


Fig 1. Location of study site.

Geologic setting

The study section is part of the greater Whanganui Basin. The Basin is a "… a broadly elliptical foredeep situated behind the Australia-Pacific plate boundary. The Pliocene–Pleistocene subsidence and basin formation is attributed to lithospheric loading in combination with compressional downwarping …" (Naish & Kamp, 1997) associated with subduction at the plate boundary. During the late Quaternary, the basin sediments have been uplifted at rates of 0.3–0.5 m per 1000 yrs in the vicinity of the modern coastline, and at rates of 1–3 m per 1000 yrs adjacent to the axial ranges (Pillans, 1986). Gently dipping strata are exposed within incised river valleys in the Manawatu region (pers. obs.) such as those in Finnis Road (Fig. 2).

Methodology

From the first exposure near the base of the hill, a total of 10 stations were measured, over a distance of 136 m, uphill along Finnis Road, using a Jacob's staff and abney level.

The bank is vegetated, necessitating clearance with a shovel and digging out of debris to expose the full height (ca. 1.5 m) of each station.

Stratigraphic Log

A stratigraphic column was completed based on observations made at each station.

Clast Morphology

- **Sand:** Seven sand samples were taken. Each sample was oven-dried overnight, weighed, then sieved for 10 minutes, using a series of sieve sizes and a mechanical shaker. The samples were weighed by grain size. Grain size classifications were made as per Udden-Wentworth Grain-Size Scale.

  Lithology & Colour: Sub-samples were assessed using a hand lens and the proportion of the main lithologies present visually estimated. Colour was assessed using the Munsell colour system.

  Sorting (grain size distribution): Visually assessed using the chart contained in the Geological Society of New Zealand Field Wallet (2005).

- **Pebbles/Cobbles**
  Form: A random sample of 40 pebbles and cobbles were measured and the ratios Ds/Di and Di/Dl were plotted on a Zingg Diagram and a histogram.
  (Editor: Ds, Di and Dl are abbreviations for the short, intermediate and long axes of pebbles. Classification of pebble shape is determined as Ds/Di, the flatness ratio, and Di/Dl, the elongation ratio).

  Sphericity and Roundness: A sub-sample of 22 similar-sized clasts was assessed using visual comparison against a Powers Sediment Rounding and Shape Chart.

  Surface features: These were not assessed.

  Imbrication: No imbrication was obvious



Fig 2. Station 1 of the Finnis Road section.

Size: The range of sizes of 35 clasts was plotted using the Di axis measurement. The five largest clasts (cobble sized, i.e. >65 mm) were excluded from the analysis as they would skew the results. Clast size classifications used the Udden-Wentworth Grain-Size Scale.

Sorting: All 40 clasts were used in this assessment.

Sedimentary Structures
Each sampling station was visually interrogated for evidence of primary and secondary structures. Sketches and photographs were taken of each structure type identified.

Fossils
No macro-fossils nor ichnofossils were observed in this section. The presence of micro-fossils was not investigated.

Results
Clast Morphology: The erosion, transport and deposition of clasts impacts on their morphology leaving clues that can be used to glean information about those processes and the depositional environment.

- **Sand**: The sorting of a grain population is a measure of the range of grain sizes present and the magnitude of the spread of these sizes around the mean size (Boggs, 2006). A visual estimate of sorting arrived at a "well sorted" classification, whilst grain size (given the writers concern regarding bias in sample selection outlined above) shows a predominance of the 3 phi (fine) faction; figure 3.3 of Boggs (2006, p.58) interprets this as 'well-sorted'.

  The roundness of sand grains is largely controlled by their lithology (Boggs, 2006). Quartz comprises between 20 and 50% of the lithology of the sand grains – hard resistant material not easily rounded, indeed, examination with a hand lens showed the grains to be predominantly very angular to angular. By contrast the pumice sand, a relatively soft, easily worked material, is assessed as rounded to well-rounded. The greywacke faction of each sample ranges from sub-angular to rounded. The titanomagnetite gains range from sub-rounded to well-rounded.

  Fifty-four percent of the sand (by weight) falls into the 'fine' grain category, 2.5 – 3.5 phi, with 32% in the medium/coarse category. Unfortunately the results for this data are skewed by the preferential selection of the coarser faction at each sample station. The very fine sand/silt/mud categories are under-represented (pers. obs.).

- **Pebbles:** The lithology of the sample pebbles reflects that found in today's nearby axial ranges, i.e. greywacke, jasper and argillite, suggesting a relatively 'local' source.

  Sixty-three percent of the pebbles are categorised as rounded, 59% as spherical. In respect to grain shape, 60% are classified as blades and/or rollers; 57% fall into the coarse/medium pebble size, i.e. 8–35mm.

  The pebble beds appeared to be moderately sorted to this observer; no imbrication was evident. A review of the photos taken of the beds shows the grading to be somewhat jumbled; it cannot be categorically classified as either normal or reverse. No obvious erosional contact between the bottom of the pebble beds and the sediment below can be identified. It is reasonable to assume that the pebbles and sand were emplaced together, probably during a flood or a small turbidity current off a channel wall, with the sand masking any erosion of the beds below. Whilst from this distance it is difficult to ascertain whether the sand immediately above the pebbles was syn-depositional, my proposition is that it was - that a mixed flow of pebbles and sand was emplaced together, the clay perhaps being a rip-up clast entrained into the flow of pebbles and sand.

Sedimentary Structures: In so much as they reflect the environmental conditions prevailing around the time of deposition, sedimentary structures are useful for determining sediment transport and deposition mechanisms (Boggs, 2006).

The sedimentary structures at Finnis Road, e.g. flaser bedding, reflect deposition in water, either marine and/or fluvial, rather than being aeolian in origin. The primary, or syn-depositional structures identified include planar and wavy laminae, cross-bedding, flaser bedding, and scour-and-fill structures. Post-depositional structures include flame and ball-and-pillow structures, another de-watering structure comprising a broken-up mud bed, at least one erosional bed boundary, mottling and a liesegangen band.

No biogenic structures nor paleosols were identified.

Discussion
The section on Finnis Road comprises unconsolidated sandstone, with minor mud/siltstone, of Upper Nukumaruan / Lower Castlecliffian age. A precise age was not ascertained, however, the Rewa pumice marker bed lies below the Finnis Road beds (J. Palmer, pers. comm.) thus the section cannot be older than 1.29 Ma (Pillans *et. al.,* 2005). Palmer also intimated that the 10 stations investigated represented ca. 280 kyrs.

Whilst some of the parent material for the pumice sand likely arrived at the deposition site as airfall, it is probable, given the distance from the likely sources (central North

Island and Taranaki), that the bulk has been carried to the coast by rivers (e.g. the Whanganui). The sediment has then moved to the deposition area by longshore sediment transport mechanisms (littoral drift). These are also the likely transport methods for the titanomagnetite sand from the Taranaki and Taupo Volcanic Zone volcanoes. Long distance transport tends to result in well-rounded clasts. It is also noted that well-sorted sediment (little variation in the grain size distribution) also reflects long transport. The Finnis Road samples are predominantly rounded and well sorted, supporting a hypothesis of long distance transport from source to deposition.

These transport methods suggest that the depositional environment for the Finnis Road section was either coastal or shallow lower shoreface/inner-shelf. Masselink & Hughes (2003) point out that longshore transport processes deposit sediment in low-energy zones and an example that may apply to the Finnis Road section is that of a large bay protected by headlands (Fig. 3). Fleming (1953), writing about the general period in which the section was deposited, notes - "..sediment was so abundant … bay-bars enclosed estuaries and harbours".

The scenario of deposition on the lower shore-face of a sheltered bay (not necessarily enclosed by a bay-bar) is reinforced by comments from Boggs (2006) that in this environment "… deposits form under relatively low-energy conditions and grade seaward into open-shelf deposits. They are composed dominantly of fine to very fine sand, but may contain thin, intercalated layers of silt and mud. Sedimentary structures can include small-scale cross-stratification and planar, nearly horizontal laminated bedding". This is an accurate description of the sediments of the Finnis Road section.

Boggs (2006) goes on to say that parallel laminae result from changing depositional conditions causing variations in grain size, clay content and mineral composition. At Finnis Road heavy-mineral (titanomagnetite) black sand contrasts with light-mineral (pumice) sands. Laminae of the heavy black sand are common at each station, whilst at station 5 a distinctive 10 mm-thick lamina of black sand is laterally extensive for some 27 m.

Ripples form under low-flow conditions - too much turbulence and ripples are eroded away, as is demonstrated by cross-bedding, which is eroded ripple foresets. Ripples can form under either uni- or bi-directional currents thus they would not be at odds with the sheltered bay scenario.

Flaser bedding of varying thickness, and by association, ripples, occur at stations 1, 2 & 3. Flaser bedding is a drape of mud over ripples formed in sand. Flasers form when a current of sufficient velocity to form ripples alternates with quiet periods which allow mud to settle out of suspension. As noted by Boggs (2006) an ideal environment for formation of flaser bedding is near-shore shallow water.

Mud/silt also occurs as a 10 cm-thick bed towards the bottom of station 3, as large clasts at the top of station 4 (a mud bed broken up during de-watering of underlying beds?), and as a significant component of the lower beds at station 7 (pers. obs.) There are also thin planar silt beds scattered throughout the section.

The provenance of the mud is unlikely to be re-activation of sediment during a transgressive period - any mud present would be resuspended and carried seawards. It is more likely that during interglacials, sub-aerial erosion processes were active on the hinterland and during flood events a river(s) in the vicinity of the deposition site carried fine sediment, plumes of which were carried beyond the river mouth, settled out in the low energy marine environment proposed above and demonstrated in the example in Fig.4.

The lack of any biogenic structures at Finnis Road has already been noted. Boggs (2006) notes that very few species live in the nearshore shelf zone and what structures they may create are often lost due to the reworking of the sediment. Therefore, the sandy sediments from this zone are dominated by physical structures such as cross-bedding.

Two thin (1–4 pebble thickness) beds of moderately sorted, rounded, spherical coarse/medium sized (8–35 mm) pebbles with a blade and/or roller grain shape are present at stations 1 and 2. As with the sand, the shape of the individual clasts is indicative of longshore transport, assessed in this paper as being primarily fluvial (i.e. a river). No imbrication was obvious so the likelihood of the beds being a form of armouring of the

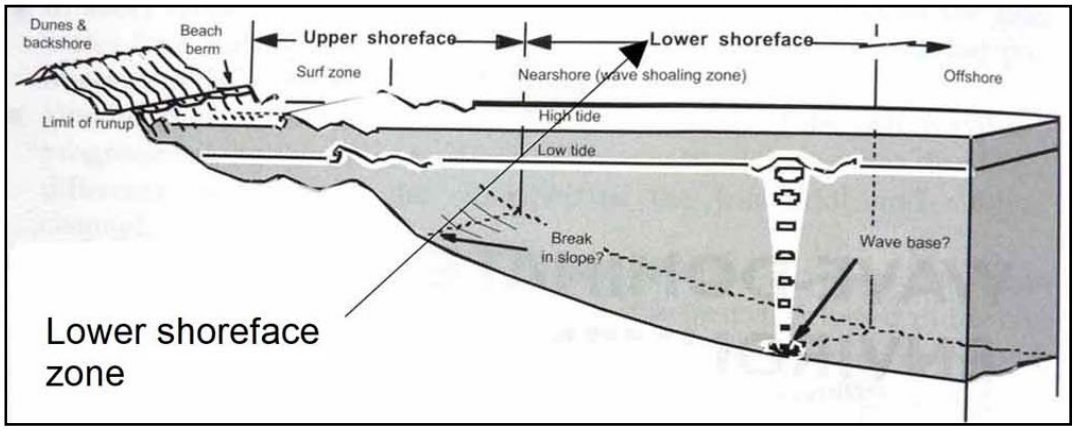


Fig 3: Diagram to illustrate the near-shore depositonal environment (source: Masselink & Hughes 2003).

Editor – Image removed for copyright reasons.
The image was an oblique aerial photo of Clarence River mouth. Other photos of the sediment plume can be found on the internet.

Fig 4. Sediment plume from the Clarence River, near Kaikoura, South Island, being carried seawards and north by longshore processes (photo: D.L. Homer, GNS Science).

sediment surface is unlikely. The possibility of the gravel being a lag deposit emplaced within a channel is remote given the lack of sorting and that in several places the bed is only one clast thick.

Rapidly deposited sediment from a single transport event is often poorly sorted, whereas frequently re-worked and re-deposited sediment tends to be well sorted (Masselink & Hughes, 2003). The minor degree of pebble sorting identified at Finnis Road could result from differential primary transport of the pebbles; the somewhat chaotic nature of the bed, especially at station 2, appears consistent with a sudden, single secondary transport event that moved the pebbles to their present resting site.

The lack of obvious disturbance of the beds below and the matrix-supported nature of the pebbles, suggests that a mixed flow of pebbles and sand was emplaced as one sudden event. The nature of that event is unknown, but this observer would conjecture that the pebbles have been emplaced elsewhere by fluvial transport (perhaps from a river similar to the extant Pohangina). A slump, possibly on a large scale laterally, has occurred in those sediments (as described in Strachan, 2008). In the course of movement of the slump, sandy sediments have been entrained along with the pebbles; the deposit at Finnis Road is the distal end of the slump. The entrained sand has softened the placement of the pebbles and masked any erosion of underlying beds formed in similar sand.

Conclusion – the Environment of Deposition

It is the writer's hypothesis that the Finnis Road section was laid down in a near-shore environment, beyond all but major storm-wave base, but still in relatively shallow water (<50 m), within a large sheltered bay analogous to today's Poverty or Hawke bays. With the exception of the pebbles and silt, the sediment has been carried down the coastline from the north by long-shore processes. Once those currents have entered the bay, they have lost much of their traction ability, allowing the sand to settle on the sea floor. Tides moving in and out of the bay have been sufficient to rework the sand, to form ripples and to agitate the sediment so as to winnow out the heavy and light minerals, forming the light and dark laminae observable today.

During inter-glacials, increased rainfall, in contrast to the relatively arid glacial periods, has resulted in rivers being able to entrain silt, especially during flood events and carry it beyond the river mouth as a plume of suspended sediment. In the relative quiet waters of the bay this fine sediment has settled out, forming flaser and planar bedding on the seafloor. At times that amount of fine sediment has been sufficient to form sandy/silt/clay beds.

The coarse fraction of the river sediment (pebbles and cobbles) was deposited elsewhere but a slump occurred in those deposits. The slump has entrained sand and rip-up clasts of clay as it moved. The distal end of the slump was emplaced at Finnis Road, forming the allochthonous pebble beds observable today.

An alternative scenario for the source of sediment for the Finnis Road section is that of transgression, with pre-existing sediments being reworked towards the new shoreline. Given the age range for the section the transgression(s) could have been due to higher sea levels resulting from glacial eustacy (from ice cap melting during an interglacial), tectonic subsidence of the Whanganui Basin, or a combination of the two. The sorting of heavy and light minerals by swash and backwash would also operate in this environment. This concept of transgression does not make the sheltered bay scenario redundant nor the pebble emplacement scenario set out above.

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LATE EOCENE FRESHWATER MUSSEL FOSSILS FROM THE DRURY COAL MEASURES

Bruce W. Hayward

Freshwater mussels are thin-shelled bivalves that live in the surface sediment on the floors of freshwater lakes, ponds and sometimes streams. Occasionally their shells or the shape of their shells are found preserved in mudstones that accumulated in these freshwater environments. Often they are accompanied by numerous fossil leaves. Fossil freshwater mussels are found in sedimentary rocks in New Zealand extending back in age as far as the Late Cretaceous (about 70 myrs ago; McMichael, 1957). Living in New Zealand today there are three endemic species of freshwater mussels (genus *Echyridella*). The modern species can grow up to 10 cm long and in perfect conditions live for at least 35 years. They filter feed on detrital matter suspended in the water.

In northern New Zealand fossil freshwater mussels have been found in sedimentary rocks that accumulated in several Miocene volcanic lakes in the Coromandel Volcanic Arc (Medlands Stream on Great Barrier Island and Wainora Stream, Kauaeranga Valley) (Hayward, 1973). They have also been recorded from Pleistocene dune lake peaty sediment on the coast of Awhitu Peninsula (Barter, 1976).

I remember that in August 1972 Jack Grant-Mackie took a small group of graduate students (including me) to Stevensons Quarry on the uplifted side of the Drury Fault (Fig. 1), southeast of Drury, and collected fossil leaves and several large freshwater mussels from massive mudstone of the late Eocene (Runangan stage) Drury Coal Measures (R12/f7682). The Eocene sedimentary rocks were overburden on top of the targeted greywacke aggregate and had been stripped off and shunted aside as large blocks that we worked on. Today this area has been quarried away and backfilled and no Eocene is exposed in the modern quarry faces. I recalled that the shape of the mussel fossils was higher and larger than those I was familiar with from the Miocene of Coromandel and modern New Zealand.

In Dec 2014 I received a request from Daphne Lee at Otago University to assist her and Australian paleobotanist John Conran locate and collect late Eocene fossil leaves from the Drury Coal Measures. On a reconnaissance field trip I ruled out any likelihood of finding exposed Eocene at Stevensons Quarry, but from across the fence Winstones' Hunua Quarry looked a possibility. I also recalled from some 1979 and 1992 fieldwork I had

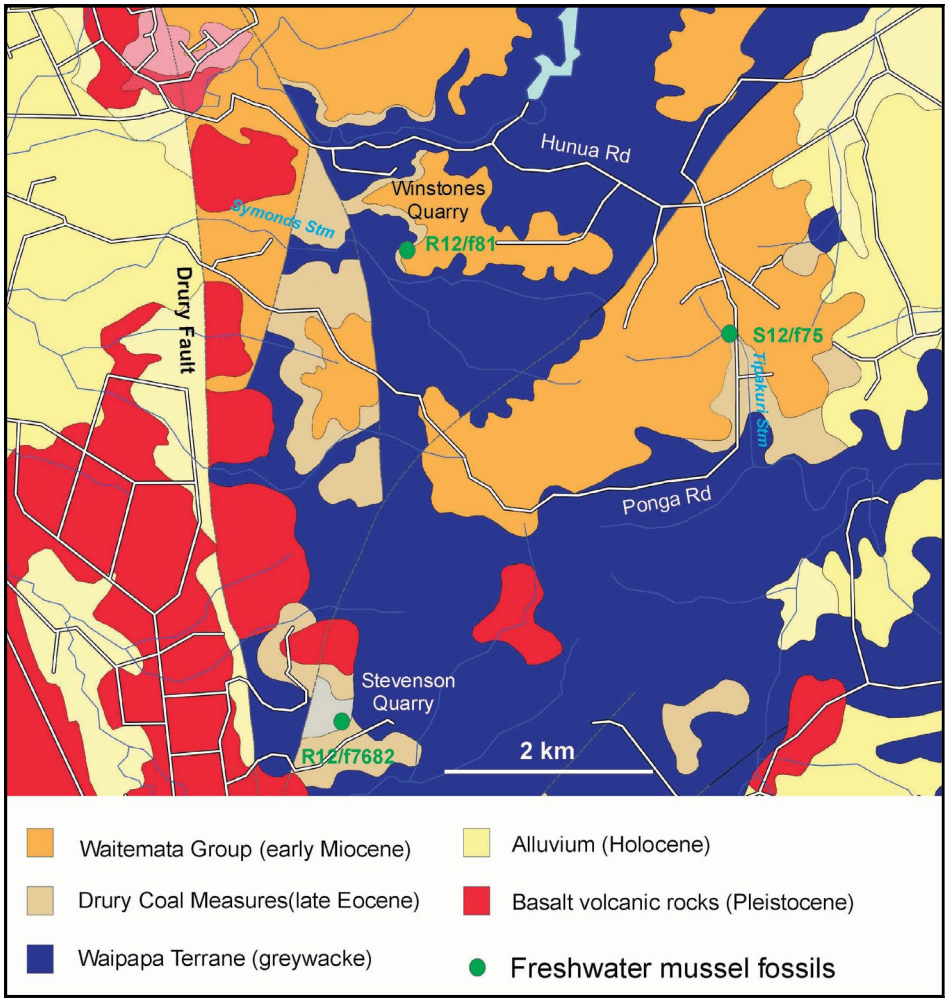


Fig. 1. Localities where freshwater mussel fossils have been found in late Eocene Drury Coal Measures mudstone. Geology derived from GNS QMap.

done that there was a 50 m length of stream outcrops of massive late Eocene sedimentary rock exposed just above the road bridge in Tipakuri Stream. I traversed the section looking for any signs of fossils and in one place near the top of the section turned up some quite well preserved leaves and a level rich in freshwater mussels (Figs 1–2). A few days later in Feb 2015 I took Daphne, John, and NZ paleobotanists Liz Kennedy and Ian Geary to the Tipakuri site (S12/f75) where leaves were collected and more freshwater mussel fossils seen. In May and Dec 2015 I took groups from Auckland Geoclub to visit this locality and sample some of the Tipakuri Stream fossil leaves and freshwater mussel fossils (Figs 3–5).



Fig. 2. Location of Tipakuri Stream fossil site.

The freshwater mussel fossils all occur within a 20 cm-thick level in the massive mudstone with leaf fossils more widely distributed within a 1 m thickness of mudstone. All the mussel shells are dissolved away and preserved as impressions. The majority have high umbos and a suboval outline (Figs 3–4), but a few are more elongate (Fig. 5) and may indicate the presence of two species. Most valves are single but several articulated pairs that had not broken apart but were flattened out like a butterfly were present (Fig. 5).

In August 2015 I received notification from Winstones Quarry that they had excavated some excellent fossil leaf horizons in the Symonds Creek watershed out the back of their active quarry (Fig. 1). I made three trips there (R12/f81) between August and November 2015 to collect leaves with Hugh Grenfell, Heidi Schlumpf and later Liz Kennedy. While collecting leaves, we saw several fossil freshwater mussels, but they were hard to collect intact. Thus freshwater mussel fossils have been found in three places in the same sedimentary rock type in the late Eocene Drury Coal Measures. The sediment in which they occur at all three sites is a massive (no bedding) grey-brown, weakly carbonaceous mudstone with scattered leaf fossils. I infer this accumulated in an



Fig. 3. Two broken specimens of late Eocene fossil freshwater mussels in mudstone from Tipakuri Stream, northern Hunua Ranges. Photo by Warren Spence.



Fig. 4. Three separate valves of large freshwater mussels in the same plane of late Eocene mudstone from Tipakuri Stream. Width of photograph 25 cm.



Fig. 5. Two articulated fossil valves of one, more elongate, freshwater mussel from late Eocene mudstone, Tipakuri Stream. Width of photograph 12 cm.

open water lake or lakes surrounded by forest. The thin coal beds in the field appear to be at a lower stratigraphic level and presumably accumulated in a much shallower, vegetated peat swamp.

Until now the only published record I can find of New Zealand Paleogene (Paleocene-Oligocene) fossil freshwater mussels is of a small species named *Velesunio huttoni* McMichael, 1957, from the Oligocene of Ohai, Southland (McMichael, 1957). The more oval Drury specimens have similar outlines to this and could be conspecific, although the Drury ones are larger.

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QUIZ ANSWERS

Know your Northland volcanoes.

1 = C Putahi rhyolite dome, Kaikohe Volcanic Field, with Lake Omapere in foreground
2 = B Opuawhanga dacite dome, Puhipuhi Volcanic Field, northeast of Whangarei
3 = E Te Puke basalt volcano, Bay of Islands Volc Field, a line of 4 small cones
4 = D Te Ahu Ahu basalt volcano, Kaikohe Volcanic Field, with Lake Omapere in background
5 = A Hikurangi dacite dome, Whangarei Volcanic Field, north of Kamo - a very distinctive shape

Where is this basalt karst?

A stream draining into **Lake Manuwai**, north of Kerikeri, accessible from the end of Onekura Road.

Here is a photo of the karst surrounding a beautiful sheltered inlet on the edge of Lake Manuwai itself.

