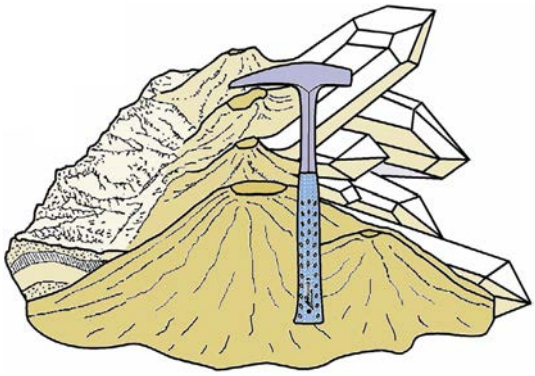


Geocene

Auckland GeoClub Magazine
Number 45, May 2026

Editor: Jill Kenny

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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@xtra.co.nz

HAS THE HOLOCENE SEA LEVEL RECORD IN MIRANDA CHENIER PLAIN BEEN COMPROMISED BY VERTICAL LAND MOVEMENTS ?

Bruce W. Hayward

Introduction

The Miranda chenier plain, along the west shore of the Firth of Thames, is an internationally significant landform as the best example anywhere of a Holocene coastal strand plain accreted by a combination of gravel and shell cheniers (beach ridges) that overlie intertidal mud. The southern two thirds of the chenier plain was created by the accretion of a sequence of shell cheniers over the last 4000 yrs (Schofield 1960).

Jim Schofield's (1960) survey showed that the oldest and most landward shell ridge has its crest and base about 2 m higher than the present day coastal beach ridge. A sequence of eight cheniers (numbered 13 to 6 in **Fig. 1**) aged between 4000 and 1000 years old extends seaward, forming a 2 km-wide plain and the cheniers become progressively lower. There has been considerable debate on how to interpret this. Schofield (1960), Woodroffe *et al*. (1983) and Dougherty & Dickson (2012) inferred that they recorded an actual sea level fall over this period of about 2 m.

Jeremy Gibb (1986) published a seminal paper on New Zealand's Holocene sea level record. He examined data from all around New Zealand and deduced that the most reliable stable coastal sites for recording sea level over the past 10,000 years were at Blueskin Bay, north of Dunedin and Weiti Estuary, just north of Auckland. Based on these, he concluded that sea level reached its present height about 6500 radiocarbon years ago and it has been relatively stable since then "with eustatic fluctuations on the order of a few decimetres" perhaps with a possible low 0.4 m below present at 4500 yrs ago and a possible high 0.5 m above present at 3500 yrs ago. Gibb's (1986) paper became gospel and for the next 30 years was cited by the majority of New Zealand studies that relied on the Holocene sea level curve.

Gibb's conclusions strongly conflicted with the results of Schofield (1976) and Woodroffe *et al*. (1983), which he rejected arguing: "*Schofield (1976) has mapped remnants of undated Pleistocene terraces at 2 to 8 m, 15 to 25 m, 33 m, and 60 to 73 m above their Holocene analogue*". The proximity of these "*to the present coastline suggests that their formation was controlled by interglacial high sea-levels, thus indicating tectonic uplift. In support of this contention there is a general increase in formation height with age of Holocene shoreline features. The data suggest a tectonic uplift of the western Firth of Thames coastline which is at variance with Schofield (1960, 1973), who argued in favour of tectonic stability. On the basis of the evidence, the dated paleosea-levels* [at Miranda] *are inferred to be apparent and not eustatic.*"

In a number of places around northern New Zealand (e.g., Nichol 2002, Hicks & Nichol 2007, Hayward & Morley 2014,

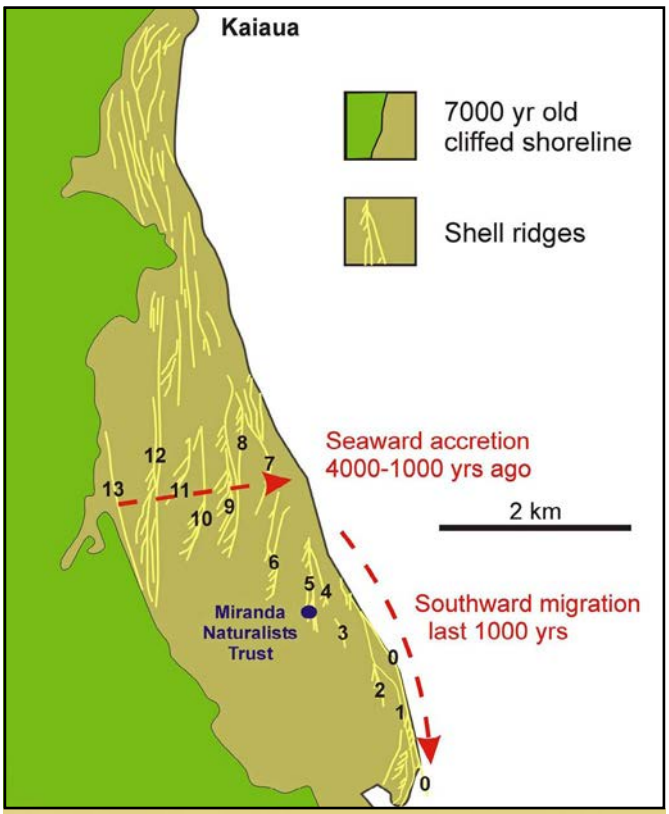


Fig. 1. Map showing the shell chenier ridges mapped and numbered by Schofield (1960) forming the southern half of the Miranda Chenier Plain. Cheniers 13 to 6 accreted onto the seaward edge of the plain between 4000 and 1000 years ago during a period of overall sea-level fall of about 2 m. The subsequent cheniers (1–5) have all advanced southward during the last 1000 years during an interval of relatively stable and more recently rising sea level. Modified from Hayward (2013).

Clement *et al.* 2016, Hayward 2018, 2023) and the South-west Pacific (e.g., Bryant 1992, Nunn *et al.* 2002, Tan *et al.* 2023, Hayward 2024) there is well-dated evidence for sea level being 1.5–2 m above present level around 3,000–5000 years ago and only recently have many workers started to accept that the Miranda chenier plain deposits provide perhaps the best record in northern New Zealand of mid-late Holocene (last 5000 years) sea-level variation in our part of the world.

One has to agree with Gibb (1986), however, that the sequence of coastal terraces up to at least 73 m above present mean sea level cannot be explained by a succession of much higher sea levels, as global sea level has not been higher than about 20 m above present in the last 2.5 million years (**Fig. 2**). The recent availability of Lidar-based 1 m contours for this area (Waikato Regional Council 2026) provides a new tool for investigating the possibility

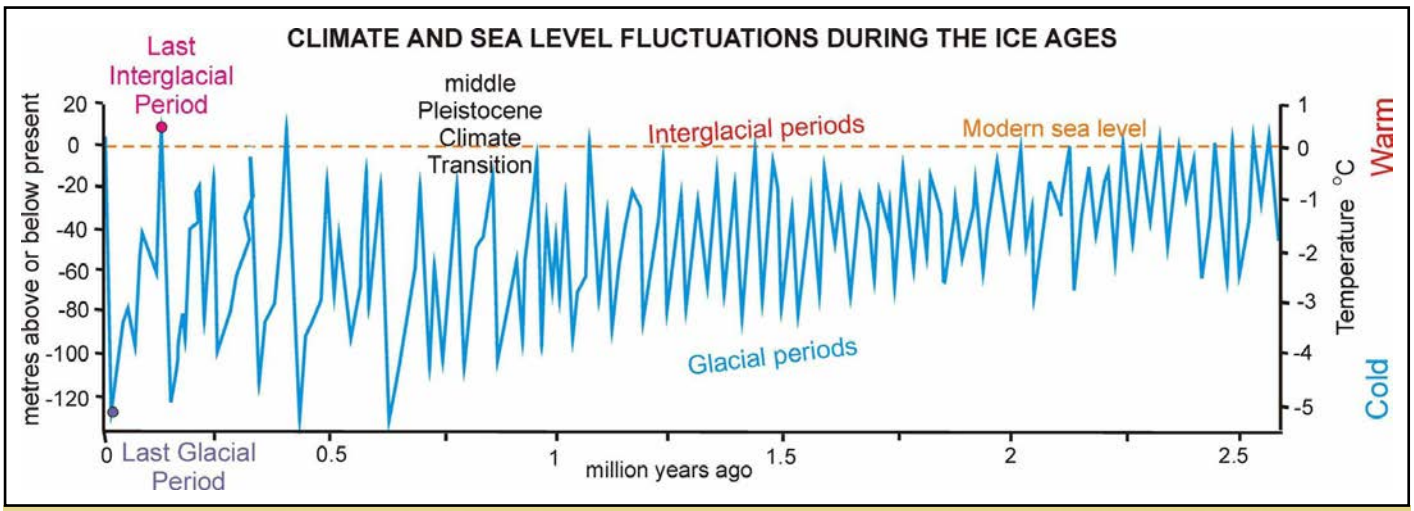


Fig. 2. Global climate and sea level cycles over the past 2.5 million years (Quaternary). Note that in the last 1 myrs, sea level has only been substantially higher (>5 m) than present during the Last Interglacial Period and at about 400,000 years ago. From Hayward (2017).

of tectonic uplift in the late Quaternary (last 125,000 years). It is widely accepted that sea level during the Last Interglacial (MIS 5e, 129,000–116,000 years ago) was somewhat higher than the Holocene, although the precise amount quoted varies widely. Around New Zealand and the Southwest Pacific the elevation during the Last Interglacial is often given in the order of 4–7 m above present (e.g., Chappell 1975, Pillans 1990, Nichol 2002, Cooper & Kostro 2006, Oakley *et al.* 2017, Hayward 2018). Ryan *et al.* (2021) summarised information on the elevation of Last Interglacial sea level around New Zealand based on well-dated and accurately determined sea level indicators and concluded that northern New Zealand may have had higher elevation than southern New Zealand and that work was needed in Northland and southeast South Island to derive an accurate regional sea level curve for New Zealand.

Last Interglacial coastal terraces around Miranda

Along the Miranda coast and south to Highway 25 (Auckland–Thames) the lowest coastal terraces above the chenier plain or Hauraki Plains are all at similar elevations of 9–12 m above mean sea level (MSL) and these are inferred to be from the Last Interglacial highstand of sea level. I illustrate these in three areas where they are well-preserved along a 20 km length of coastal cliffs (**Fig. 3**).

1. Highway 25, Waitakaruru terraces

The most extensive and obvious terrace along the western shoreline is in the south and is crossed by Highway 25 (road to Thames) between the junction with Hwy 2 and the township of Waitakaruru. Driving west across the Hauraki Plains in this vicinity, the land surface is latest Holocene (<1000 yrs) and only 3.5 m above MSL. Hwy 25 passes up a prominent terrace riser (former sea cliff) that can be followed for several kilometres to the south and north (**Figs 4–5**). The eastern edge of the terrace (former top of sea cliff) is 9.5–10 m above MSL and the terrace rises gently to 11 m in most places but (**Fig. 5**) on the widest part rises gently over 1 km distance up to 18 m. This wider part of the terrace may have a component of gently-dipping

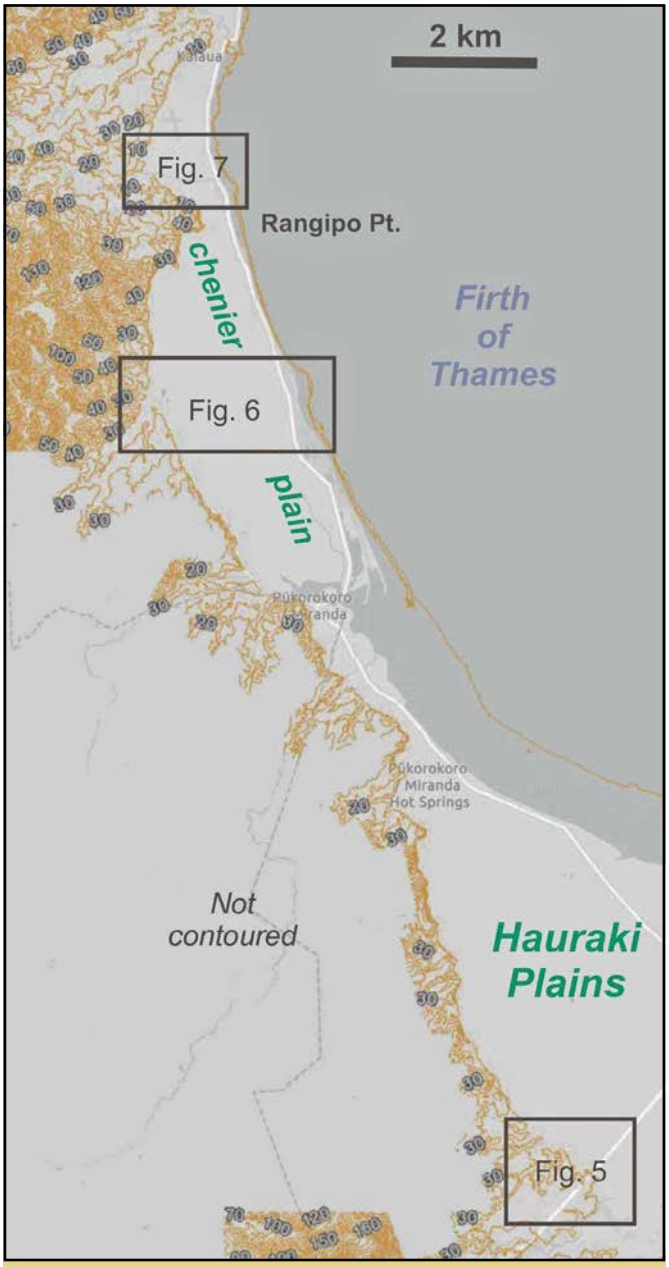


Fig. 3. Location of the three areas studied with well-preserved remnants of the Last Interglacial coastal terrace.

alluvial fan at the mouth of a stream where it flowed out into the intertidal during the Last Interglacial.

Hand-augured cores nearby and the nearest deeper drillhole (15 m) at the junction of Hwys 2 and 25 indicate that this terrace is aggregational (not erosional) and composed predominantly of silt and minor sand and gravel.



Fig. 4. Highway 25 view of 6 m high riser from Hauraki Plains up to the Last Interglacial terrace.

2. Schofield's (1960) transect terrace

Schofield's transect of 13 cheniers across the widest part of the chenier plain (**Fig. 1**) is about 1 km north of Miranda Naturalist Trust centre (**Fig. 6**). The landward end of his transect is close to the mouth of a small stream that has eroded along the Ruaotehuia Fault with greywacke basement uplifted on the north side and Pleistocene sedimentary strata on the south side. There is a well-developed terrace on the south side of the stream and fault but only indistinct terrace remnants at various levels on the north side. The main terrace slopes gently inland from 10 m at the top of the former sea cliff to 13 m above MSL 0.8–1.0 km up valley to the southwest (**Fig. 6**). This gentle slope is likely partly a stream terrace rising inland parallel to the stream bed rise but eroded down to a Last Interglacial sea level base.

3. Rangipo Rd. terraces

3.5 km north of Schofield's transect, in the embayment north of Rangipo Point, the chenier plain widens out again

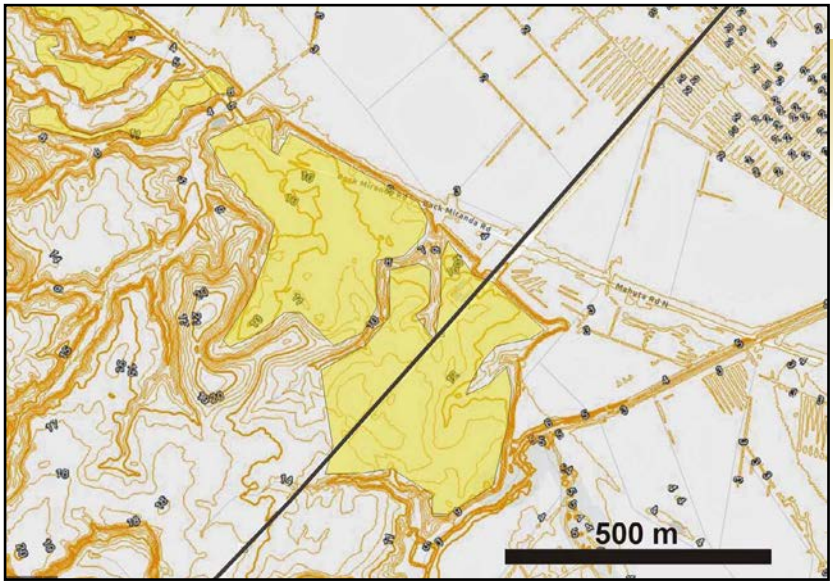
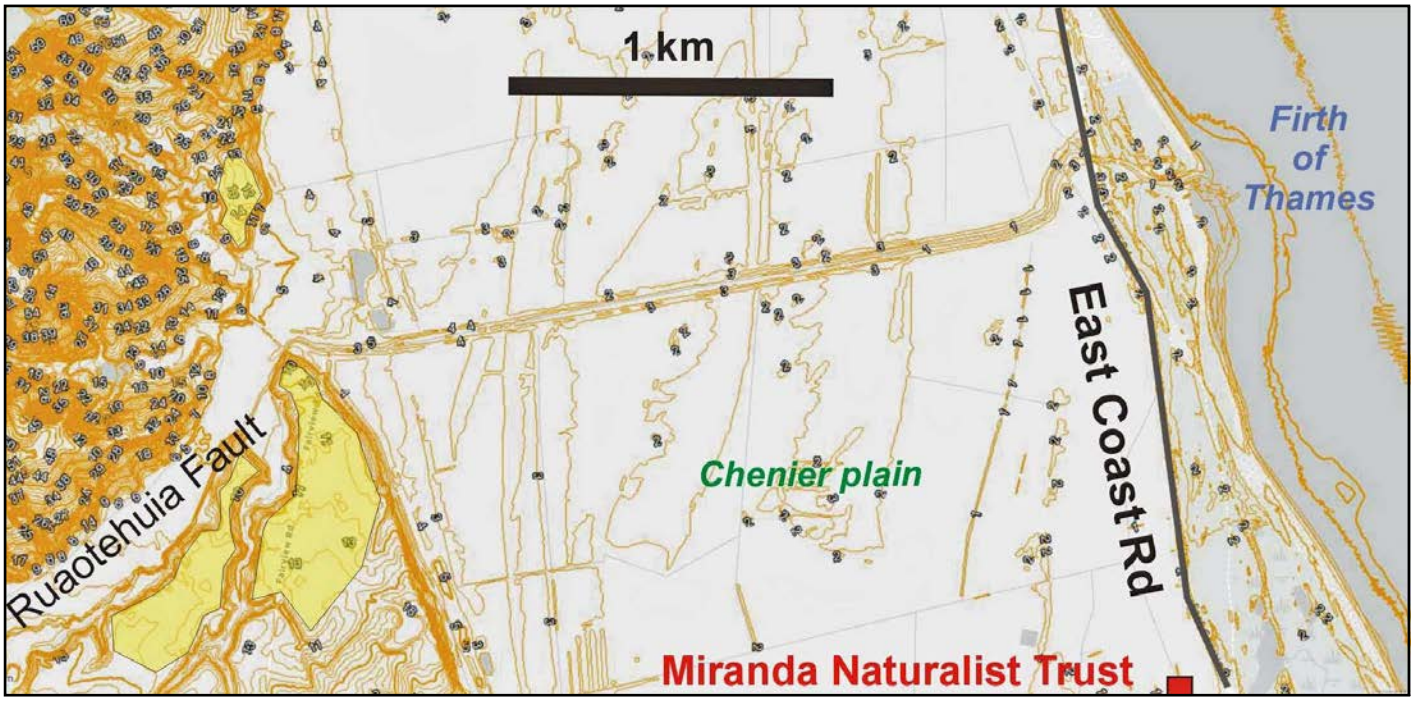


Fig. 5. Contour map (1 m apart) of area 3–5 km southwest of Waitakaruru, where Highway 25 (solid black line) passes south-westwards up a 6 m high riser and across the Last Interglacial terrace (yellow). Basemap from Waikato Regional Council (2026).

Fig. 6. Contour map (1 m apart) of area extending 2.5 km northward of Miranda Naturalist Trust centre on East Coast Rd in the vicinity of the widest part of the chenier plain where Schofield (1960) measured his transect of 13 cheniers. The Last Interglacial terrace is coloured yellow. Basemap from Waikato Regional Council (2026).



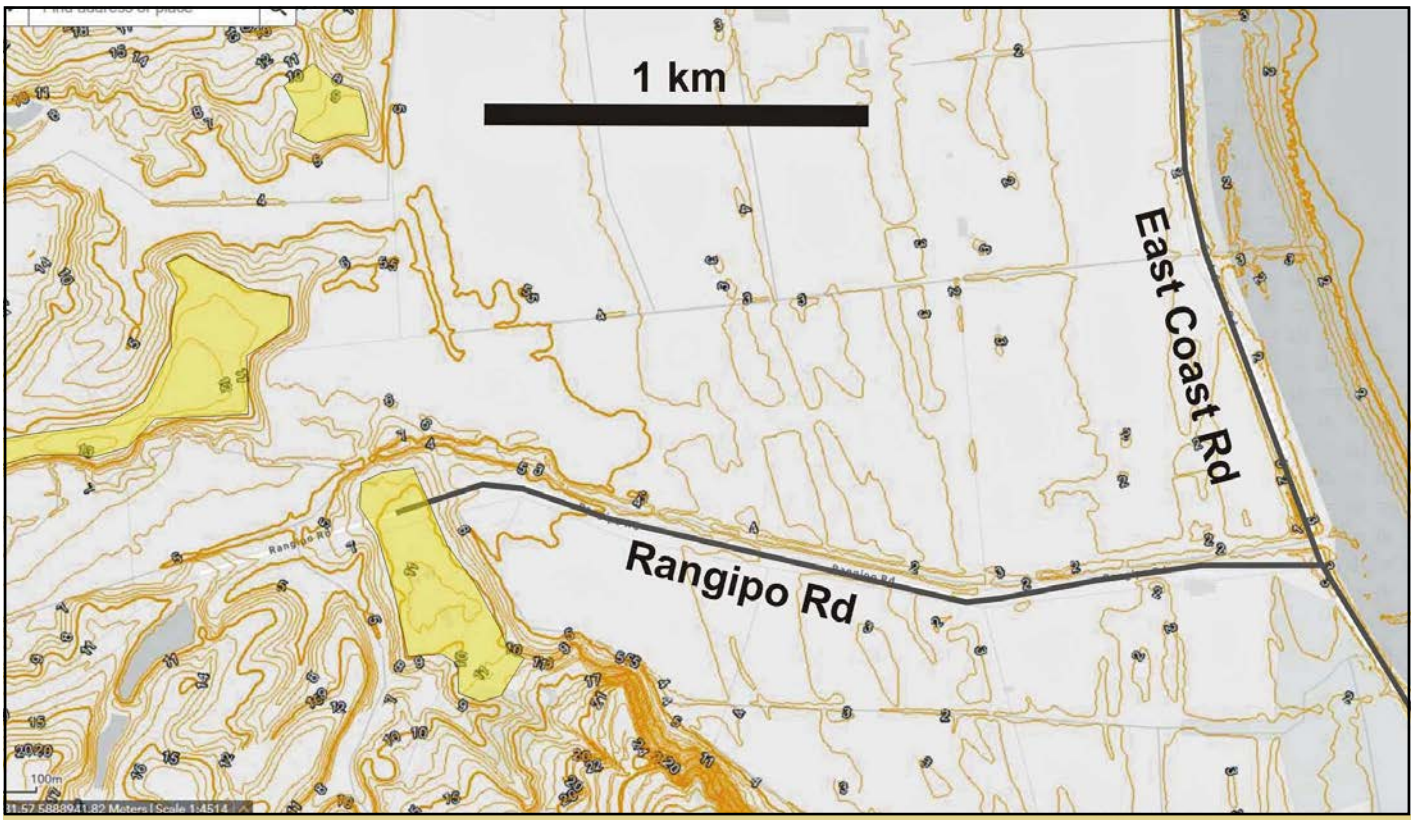


Fig. 7. Contour map (1 m apart) of area 3.5 km north of Schofield's transect (Fig. 6), in the vicinity of Rangipo Rd. The landward end of the road rises up onto a Last Interglacial terrace (yellow), at an elevation of 9–11 m above MSL. Basemap from Waikato Regional Council (2026).



Fig. 8. View west along landward end of Rangipo Rd (right) showing abrupt riser from chenier plain (5 m above MSL) to Last Interglacial terrace (9–11 m above MSL).

and is nearly 2 km wide and rises to 5 m above MSL (2.5 m above the modern beach ridge). At the landward end of Rangipo Rd, the road rises abruptly up the former sea cliff to a terrace that rises gently over 600 m from 9–11 m above MSL (**Figs 7–8**). Across the stream valley to the north are two other flat terraces, each 9–12 m above MSL (**Fig. 7**). Where these terraces exist they are once again in an area of soft Pleistocene sedimentary strata and most likely have been eroded down to the Last Interglacial sea level base, 120,000 years ago.

Discussion

Given that all three areas of coastal terrace along 20 km of Miranda shoreline are at the same elevation, it is logical to conclude that all were created at the same time when sea level was at this relative level, undoubtedly during the Last Interglacial period (129–116,000 years ago). If they have been displaced vertically, then the whole 20 km stretch has experienced the same amount of displacement. Downthrow seems highly unlikely but could there have been some uplift?

The seaward (clifftop) edge of each terrace is ~9 m above MSL today. Since most terraces slope gently up to ~11–12 m, it seems reasonable to infer that these sloping terraces were formed in the upper half of the intertidal, as tidal mud flats similar to what is present along this coast today. If there has been no uplift, then at the peak of the Last Interglacial sea level would have been 9 m above present. This is at the very upper end of quoted global (far field) values for the peak Last Interglacial sea level (e.g., Hearty *et al*. 2007). Far field refers to a long way away from where there was ice on land during the last glaciations. The weight of the ice depressed the land and since its melting, these nearfield regions have been rebounding (glacial isostacy) – hence they are unreliable for studying the actual global sea level record.

The Last Interglacial high sea level stand is reported to have lasted 13,000 years (129–116,000 years ago) and some overseas studies suggest that sea level may have varied by 6–10 m during this period (e.g., Hearty *et al.* 2007) with the highest sea level during the latter part of

this period. In my discussions I use the hypothesis that the terraces being studied were formed during the highest sea level stand, possibly over-printing lower sea level related features.

A Last Interglacial sea level 9 m above present is at least 2 m higher than almost all previous New Zealand field-based estimates, which are in the range 4–7 m. On stable Great Barrier Island, a Last Interglacial beach indicates a sea level 4–6 m higher than now (Hayward 2018). Up the Tamaki Estuary in Auckland there are a number of inferred Last Interglacial coastal terraces at Point England (9–11 m above present, and some lower), at St Kentigern's College (9–13 m above present), and at Highbrook in part eroded into Pukewairiki tuff ring (at 8–10 m above present).

There are two end-member options to explain the above:
a. The Great Barrier elevation is actual and the Miranda–Tamaki Estuary elevations have all experienced 2–4 m of uplift since the Last Interglacial.
b. Sea level around northern New Zealand was indeed 9 m above present.

There can be no doubt that the Hunua Ranges were already partly uplifted when the Puketoka Formation fluvial sediments were deposited around Mangatangi in the late Pliocene, 3–3.7 myrs ago. At Puketoka Trig these fluvial conglomerates are 120 m above MSL today and were probably deposited at no more than 20 m above MSL back then. Thus there has been at least 100 m of uplift in the area to the west of Miranda in the last 3 myrs and possibly even more to the north where the Hunua Ranges are nearly 700 m above MSL. If all the uplift at Puketoka was evenly spread (unlikely) over the past 3 myrs, it equates to 3 m per 100,000 yrs. This is uncannily similar to the rate of uplift that could explain the elevation of the Miranda Last Interglacial terraces.

Conclusion

If we accept that there was 2–4 m of uplift along the Miranda coast in the last 120,000 years (option a), and if uplift has been at a roughly constant rate (it does not have to be and may have been episodic during earthquake ruptures), then there could have been 10–20 cm of uplift in the last 5000 yrs since the oldest part of the chenier plain started forming. This is well within error of the estimated mid Holocene sea level elevation of about 2 m above present at Miranda at that time. This pretty much confirms the belief of Schofield (1960) that sea level was that much higher than present at that time and fell progressively to reach the present level or slightly lower by 1000 yrs ago (Dougherty & Dickson 2012). Hopefully this puts to bed Gibb's (1986) much quoted hypothesis that sea level around New Zealand, and certainly in the north, was not much different than now throughout the mid–late Holocene (last 6500 years or so).

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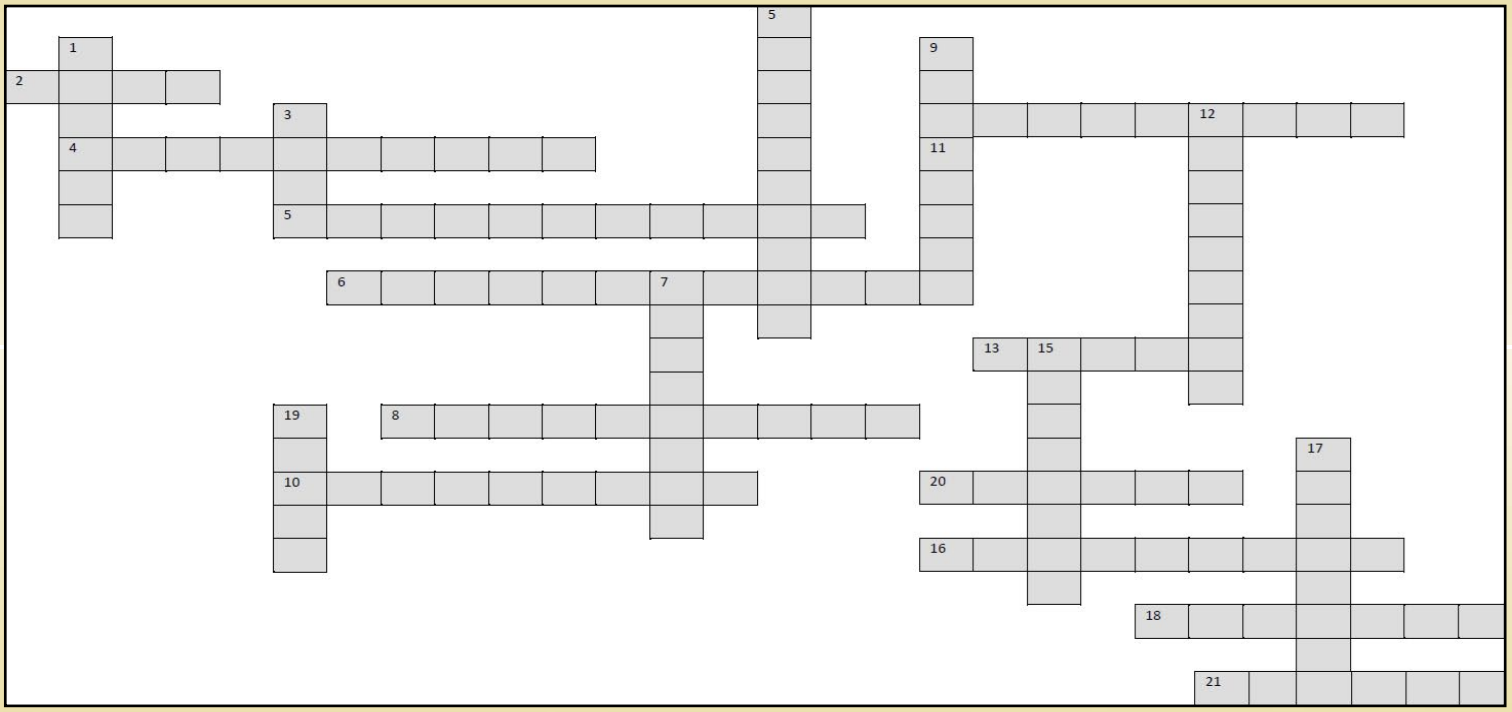
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THE NEW ZEALAND GEOLOGY CROSSWORD
Rock types, epochs and structural features of the Shaky Isles

Wendy Goad

(Answers on last page)



ACROSS CLUES

2. Compacted volcanic ash.
4. Rock formed from the deposits of high-temperature pyroclastic flows.
5. The epoch associated with the “Ice Ages,” preceding the Holocene.
6. Coarse-grained sedimentary rock containing cobbles and pebbles.
8. A large block of rock moved far from its origin, like the Northland variety.
10. The “muddy” sandstone forming the backbone of NZ’s mountain ranges.
11. Sedimentary rock with remains of shelly organisms; famous at Waitomo.
13. A fracture in the Earth’s crust where movement has occurred.
16. A massive body of intrusive igneous rock formed within the crust.
18. Coarse-grained intrusive rock found in the South Island.
20. Dark, fine-grained volcanic rock common in the Auckland volcanic field.
21. Volcanic rock with a composition between andesite and rhyolite.

DOWN CLUES

1. Porous, frothy volcanic rock that can float on water.
3. Acronym for New Zealand’s national geological map series.
5. The current period of the Cenozoic Era, covering the last 2.6 million years.
7. A major geological terrane found in both Waikato and Southland.
9. The current geological epoch, starting ~11,700 years ago.
12. A rock deposit from an underwater sediment flow or gravity current.
15. Volcanic rock typical of stratovolcanoes like Ruapehu or Taranaki.
17. Processes related to structure and large-scale movement of the crust.
19. Molten rock located beneath the surface.

GEOLOGICAL PHENOMENA IN MOEAWATEA VALLEY, SOUTH TARANAKI

Michael K. Eagle

Introduction

Formed by the Whenuakura River and Moeawatea Stream, Moeawatea Valley, South Taranaki, is flanked by a main north–south ridge known to be an historic travelling route for Māori journeying between the Taranaki and Whanganui regions. Access to the remote valley is by Moeawatea Road – a single, unmetalled track (i.e. a paper road) across high hills (with views of Mt Taranaki), eventually winding down to the Moeawatea Valley 70 km northwest of Waverley. The 'papa' (farmers' name for the soft, blue-grey mudstone of the Tangahoe Formation) track is generally unsuitable for non-4WD vehicles, especially during the winter wet season, when the road is impassable for days on end. It is for this reason that the road is usually steel barrier-barred and padlocked by the South Taranaki District Council from 1 June to 31 October, thereby preventing year-round visitation.

As part owner and sole Director of Rewi Alley Moeawatea Trustee Limited, I have spent over twenty years maintaining listed Historic Place Category 2 Rewi Alley's Whare in Moeawatea Valley in the lee of that ridge. Consequently, many excursions in the immediate area have been spent investigating the geological phenomena found there.

From the southern coastal margin of the Waverley hinterland and its uplifted marine and river terraces, the inland hill country from north of Kohi to Moeawatea Valley and beyond (**Fig. 1**) rises to a dissected upland consisting of narrow ridges with steep, sloping valley sides and deeply entrenched streams. The skyline displays concordant summit heights considered by Naish *et al*. (2005) to be remnants of an extensive, exhumed coastal marine erosion surface. All the hillside slopes are at the same angle, so that the ridges, spurs and valleys are symmetrical in cross-section.

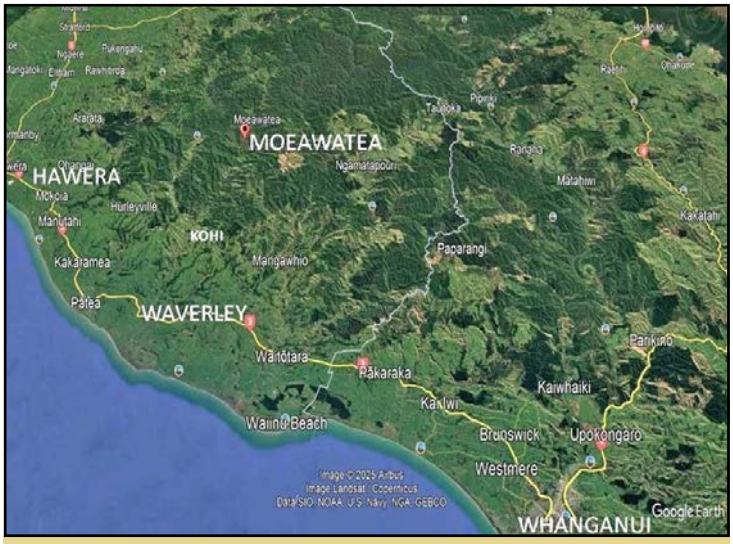


Fig. 1. Terrain topographical map showing inland hill country in which Moeawatea Valley is located and its geographical relationship to Hāwera, Waverley, and Whanganui (Google Earth image: 2021).

Younger strata in Moeawatea Valley belongs to the Rangitikei Supergroup that mainly consists of early Pliocene to Pleistocene marine sediments, but also sporadic minor terrestrial deposits. It was deposited in transgressive–regressive sequences (deepening and shallowing cycles) in the Taranaki and Whanganui Basins.

The Tangahoe Formation is the basal unit of the Rangitikei Supergroup (Naish *et al*. 2005) and signifies a significant phase of basin filling, showing progradation of shelf deposits with distinct sequences of siltstones, sandstones and shellbeds crucial for understanding the regional geology. It is approximately 270 m thick and is characterised by shallow-marine depositional sequences, which reflect cyclical changes in sea level driven by Pliocene glacio-eustasy (expansion and contraction of Antarctic ice sheets. In Moeawatea Valley, each sequence is typically composed of three vertically stacked parts: a basal suite of lag and/or shellbed deposits, an aggradational siltstone succession, and a progradational sandstone layer. These strata indicate a depositional environment that varied cyclically in places in water depth from sub-tidal to inner-shelf and middle/outer shelf to upper slope conditions, often corresponding to individual 40,000-year glacio-eustatic sea-level cycles.

In the Moeawatea Valley, the Tangahoe Formation overlies older Matemateonga Formation, which is an early Pliocene continental shelf succession of the mid Miocene to early Pliocene Whangamomona Group. Tangahoe Formation is a mid Pliocene (Waipipian Stage) continental slope and shelf succession. It is in turn covered by younger Pleistocene sediments. The Tangahoe Formation in Moeawatea Valley is a grey, sandy marine mudstone in places rich in marine fossil faunas, the composition of which indicates different paleoenvironments. Interpretation of deposition is shallow water wave and/or current-influenced sedimentation associated with the development of ravines and marine flooding surfaces within transgressive system tracts. Induration of the grey sediment by overburden burial and leached cementation prior to natural exhumation has locally consolidated fossil deposits. Tangahoe Formation above that stratification is a well sorted, fine to medium grained, grey-brown sandstone, usually semi-consolidated, barren to sparsely fossiliferous, rarely bioturbated, with metre-scale cross-bedding (sometimes with sinuous ripples indicating paleo-current direction).

Septarian concretions

Paragenesis refers to the sequence in which minerals form and are associated within a rock deposit (from Greek para "beside" + genesis "origin"). Paragenesis aids in understanding the geological history, formation conditions (e.g. temperature, pressure, fluids), and the relationships between minerals, necessary for deciphering depositional conditions, tectonic and metamorphic events, and rock evolution. During the concretion process, minerals crystallise out of supersaturated ground water in the spaces between

particles in a porous sedimentary rock and cement them together. Concretions can be massive and structureless, or they might preserve fossils or internal sedimentary structures such as cross-beds. They are geochemical archives for pore-water chemistry and burial diagenesis in clastic sediments (composed of pre-existing rock fragments or clasts) (Wikipedia 2025).

Carbonate concretions are a common feature of the Tangahoe Formation. They are often observed partially exhumed in the sandstone and mudstone as spherical or ovoid bodies of rock protruding from natural outcrops noticeably cemented harder than the host rock. In Moeawatea cliff sections, though often homogenous, some sedimentary beds and sedimentary structures (e.g. occurring in the middle of the formation) can be traced right through concretions, indicating that the concretion clearly formed after sediment deposition.

Septarian concretions occur at many horizons within the Tangahoe Formation. They record the passage of generations of pore fluids, the first of marine origin and the last still present in cavities, and exhibit multiple generations of cements that include body, fringe, and spar phases (Yoshida *et al*. 2018). A septarian concretion located in the Whenuakura River near the eastern (right-hand) bank at the ford crossing (39°33' 43"S; 174°38'22.25"E; **Fig. 2**), now concreted over as a subsurface vehicle crossing, was both large and interesting. This concretion had at one time been eroded from a nearby high cliff. In its down-slope gravity fall it had cleaved into two nearly equal halves. Radial cracks were unusual in that they tapered inward instead of normally tapering as they extend outward (pers. obs.). Additionally, there was no evidence of the usual concentric cracks running parallel to the concretion's surface. Septarian concretion cracking is attributed to the dewatering and syneresis (shrinkage) of the centre. Even after the distal, outer layers have become a cement-hardened shell, the central interior of the concretion often remains soft for a time. A difference in stiffness between the interior and exterior created the necessary stress for the internal material to initially fracture. The concretion's radial cracks, subsequently infilled, partially or completely by minerals that form *in situ* within sediments or sedimentary rock (rather than being weathered from elsewhere and transported) were precipitated from pore fluids percolating the host sediment. Leaching by chemical dissolution has occurred, partially robbing the radial cracks of infill (Marshall & Pirrie 2013). Another atypical characteristic is that the radial cracks in the Whenuakura River concretion reach the peripheral surface and do not remain contained within the cemented outer layer (pers. obs.). Many septarian concretions of the Tangahoe Formation in Moeawatea Valley contain fossils or the partial remains thereof, in various states of preservation and completeness.

Gold

While manually digging a septic tank repository in the Moeawatea Valley, the author made a surprise find of gold at a shallow depth of only 1.8–2.0 m. The small, abraded cobbles discovered appear broken-off a larger igneous rock that obviously did not originate in the Neogene sedimentary Whanganui Basin. The specimens seemed characteristic of down-river mineral assemblage 'float' specimens encountered previously by the author when panning for gold in 1998 near Tākaka in the northern South Island.

The small, abraded cobbles containing gold discovered in the Moeawatea Valley appear to be similar to the Paleozoic Sam's Creek gold deposit near Tākaka (**Fig 3**). If the Moeawatea Valley specimens originated near Tākaka, how did they get there? That is a distance of over 200 km. Buried at such a shallow depth at Moeawatea, could they have been carried from Upper Tākaka by the Tākaka River, deposited into the coastal sea of the time, transported by marine bottom currents and long-shore drift, deposited in



Fig. 2. A large, eroded septarian concretion of the Tangahoe Formation near the eastern (right-hand, true left) bank of the Whenuakura River farm ford crossing showing peripheral radial septaria (image: 2019).



Fig. 3. Sam's Creek entering the Takaka River, Northwest Nelson, in the vicinity of a Palaeozoic microgranite dyke intrusion associated with stockwork vein mineralisation including gold (Image courtesy of M. Fitzgerald).

shallow waters in the area that is now Moeawatea, and then subjected to uplift and erosion? In the Whanganui Chronicle (2020) Vince Neall postulates that certain Waitotara ventifacts of a particular rock type only from the Tākaka Valley "were pushed by the sea along a 'marine bench' 120,000 years ago ... during an ice age." Alternatively, could they have migrated to the Moeawatea area attached to floating tree roots? Grapes (2026) describes examples of South Island rocks washed up on Wellington beaches possibly transported there by floating trees.

Molluscan macrofossils

Powell (1937) noted that "communities" of "dominant" and "subdominant" molluscs could be recognised in the Pleistocene Whanganui section. Subsequently, Fleming (1953) applied derived benthos associations to the Pliocene and Pleistocene marine fossils exposed between Waverley Beach and Whanganui. But paleontological and modern detailed numerical analysis has shown that marine benthic paleocommunities are not disparate entities, but instead grade into one another (Beu & Maxwell 1990, Hendy & Kamp 2004). In Moeawatea Valley, basal, poorly indurated, grey Tangahoe Formation is overlain by poorly consolidated, blue-grey sandstone containing shallow water Waipipian shellbeds that seem to be species groups sharing similar paleoecological conditions at different paleogeographical locations. Fossil localities in Moeawatea Valley appear to be paleocommunities resulting from local differences in environment (**Table 1**). Molluscan specimens are poorly to moderately preserved, mainly as disarticulated, rarely complete, broken and abraded shells.



Fig. 4. Moeawatea Stream sandstone shellbed near Syd Hughes's Hut, Makowhai Station, Moeawatea (last entry in **Table 1**). Photo is 0.6 m wide.

The basal, poorly indurated, grey sandstone commonly contains the following inner-shelf marine molluscs:

BIVALVIA:
Glycymerita (Manaia) manaiaensis (Marwick, 1923);
Crassostrea ingens (Zittel, 1864);
Phialopecten marwicki (Beu, 1970);
Phialopecten ongleyi Marwick, 1965;
Mesopeplum (Borehamia) crawfiordi (Hutton, 1873);
Pteromyrtea dispar (Hutton, 1873);
Miltha neozelandica Marshall & Murdoch, 1921;
Purpurocardia purpurata (Deshayes, 1854);
Pratulum quinarium (Marwick, 1944);
Mactra (Maorimactra) chrydaea (Suter, 1911);
Zenatia (Zenatraria) waipipiana Beu, 1966;
Dosinia crebra (Hutton, 1873).

GASTROPODA:
Maurea hawera Oliver, 1926;
Zethalia russelli Marwick, 1965;
Zefallacia lawsi Marwick, 1948;
Stiracolpus huttoni (Crossman, 1912);
Pelicaria canaliculata (Zittel, 1864);
Struthiolaria incrassata (Powell, 1931);
Pelicaria zelandiae Marshall & Murdoch, 1920;
Polinella obstructa (Marwick, 1924);
Polinices waipipiensis (Marwick, 1924);
Austrofusus (Austrofusus) pagoda (Finlay, 1924);
Austrofusus (Austrofusus) pliocenicus (Powell, 1931);
Euthria pangoides Beu, 1973;
Amalda (Baryspira) oraria (Olson, 1956);
Lamprodomina neozelanica (Hutton, 1885);
Alcithoe gatesi Marwick, 1926;
Zemacies prendrevillei Marwick, 1928.

Table 1. Notable Waipipian shellbed/molluscan macrofossil localities in Moeawatea Valley.

Locality	Latitude	Longitude	Fossil Record Number
Moeawatea Road cutting (lower valley)	39°34'06.95"S	174°38'31.39"E	R21/f0044
Whenuakura River (now beneath concrete ford)	39°33'44.77"S	174°38'22.57"E	R21/f0045
Moeawatea Stream (down from Rewi Alley's shearing shed)	39°33'25.03"S	174°38'25.57"E	R21/f0046
Moeawatea Road cutting (on way to Campbell's Whare)	39°32'47.43"S	174°38'47.41"E	R21/f0047
Mathews Stream (natural fiord at start of western farm track)	39°30'59.99"S	174°39'48.25"E	R21/f0048
Nirvana western farm track	39°30'48.29"S	174'38'51.50"E	R21/f0049
Nirvana western farm track further west	39°30'29.72"S	174°40'02.87"E	R21/f0050
Moeawatea Stream near Syd Hughes's Hut, Makowhai Station **(Fig. 4)**	39°30'22.67"S	174°40'06.66"E	R21/f0051

The overlying weakly consolidated, blue-grey sandstone contains a diverse marine macrofauna that live in the breaker zone in modern New Zealand coastal environments (Beu & Maxwell 1990). The fossils suggest an unprotected, high-energy in-shore setting of 0–10 m often with coarse grained shell lags and hash. Representative molluscan species include:

BIVALVIA:
Lutraria grandis (Hutton, 1873);
Maorimactra chrydaea (Suter, 1911);
Scalpomactra scalpellum (Reeve, 1854);
Dosinia greyi Zittel, 1864;
Tawera errans Marwick, 1927.

GASTROPODA:
Zethalia russelli Marwick, 1965.

Ichnofossils

This facies occasionally has ichnofossils (trace fossils) that include the following burrow ichnogenera: *Conostichus, Diplocraterion, Ophiomorpha, Palaeophycus* and *Planolites* (**Fig. 5**). *Conostichus* and *Diplocraterion* are found primarily in shallow marine environments. *Ophiomorpha, Palaeophycus* and *Planolites* are considered eurybathic and facies-crossing marine trace fossils, meaning they can exist across a wide range of depths and sedimentary conditions from shallow, innershelf to deep-water environments, such as continental fans and distal offshore coastal shelves.

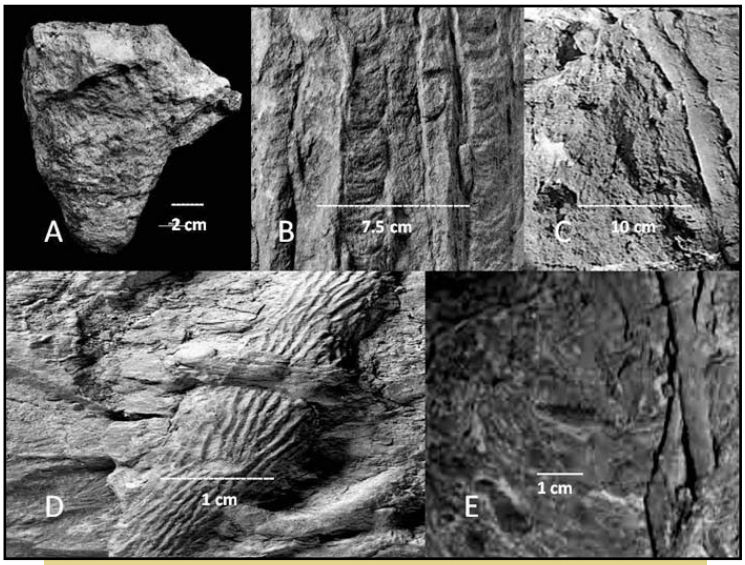


Fig. 5. Examples of Tangahoe Formation ichnogenera: A. *Conostichus*; B. *Diplocraterion*; C. *Ophiomorpha*; D. *Palaeophycus*; and E. *Planolites*).

Echinodermata macrofossils

In 2019, a shallow natural ford of the Whenuakura River south of historical Rewi Alley's Whare (**Fig. 6**), afforded access from Moeawatea Road to an adjacent farm. Across the ford, on the true right bank of the river, immediately to the left of the stock/vehicle farm track leaving the river, at location 39°33'43.06"S 174°38'21.72"E, fossil specimens of the sand dollar *Fellaster zelandiae* were exposed in a weathered sandstone bed; Fossil Record File No. R21/f0052 (**Figs 7–9**).



Fig. 6. Lower Moeawatea Valley showing Rewi Alley's Whare in relation to the Whenuakura River ford (oblique Google Earth image: 2024, facing north). In the distance (upstream), the Whenuakura River forks to the left and the Moeawatea River forks to the right.

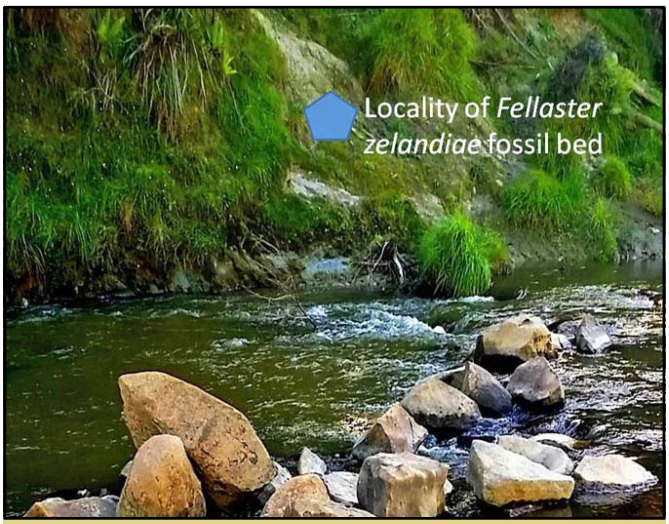


Fig. 7. Whenuakura River western (true right) bank fossil bed locality of the sand dollar *Fellaster zelandiae* prior to the natural ford being concreted over to upgraded stock/vehicle farm access (image: 2019).

Fellaster zelandiae possess a high Mg-calcite solid endoskeleton, 80–120 mm in diameter, bio-mineralised to withstand wave energy. Modern *Fellaster zelandiae* have a distinctive flattened purple-grey segmented, disc-shaped test (shell) covered with fine spines. They are a marine, mobile invertebrate living infaunally in a soft substrate, feeding by algal grazing or detrital chewing at sublittoral depths. To date, the Whenuakura River bank locality is the only record of *Fellaster zelandiae* in Moeawatea Valley. Modern *Fellaster zelandiae* occur across a broad latitudinal range (35°–48°S), and manages to live in a temperature range of 5–24°C. It occurs as fossils at various locations across New Zealand, with notable concentrations in Pliocene marine sediments, particularly in the Whanganui region.



Fig. 8. Fig. 8. Present day Whenuakura River fiord concreted crossing laid over the localities of the fossil *Fellaster zelandiae* bed and large, cleaved Tangahoe Formation septarian concretion (oblique Google Earth image: 2024, facing north).



Fig. 9. A. *Fellaster zelandiae* exoskeleton complete and B. disarticulated fragments (all minus spines); C. an arm stereom, part of the mouth skeletal structure of Aristotle's Lantern from Whenuakura River ford locality.

Summary

Remote Moeawatea Valley as detailed, retains a variety of interesting marine, Cenozoic geological phenomena, most of which are overlain by Holocene terrestrial deposition. Access is difficult, but well worth it when you get there. The septarian concretions are spectacular, the macrofossils interesting and the gold find was exciting and unexpected.

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HOLOCENE SUB-FOSSIL-BEARING CONCRETIONS, HOKIANGA HARBOUR, NEW ZEALAND

Seabourne Rust

Hokianga Harbour in western Northland is, at 11,500 ha, New Zealand's fourth-largest harbour, a headland-enclosed estuary with Pleistocene sand dunes at the entrance (**Fig. 1**). This most recent version of the harbour was formed by the drowning of a river valley system during sea-level rise after 12,000 years ago (Hayward 2017).

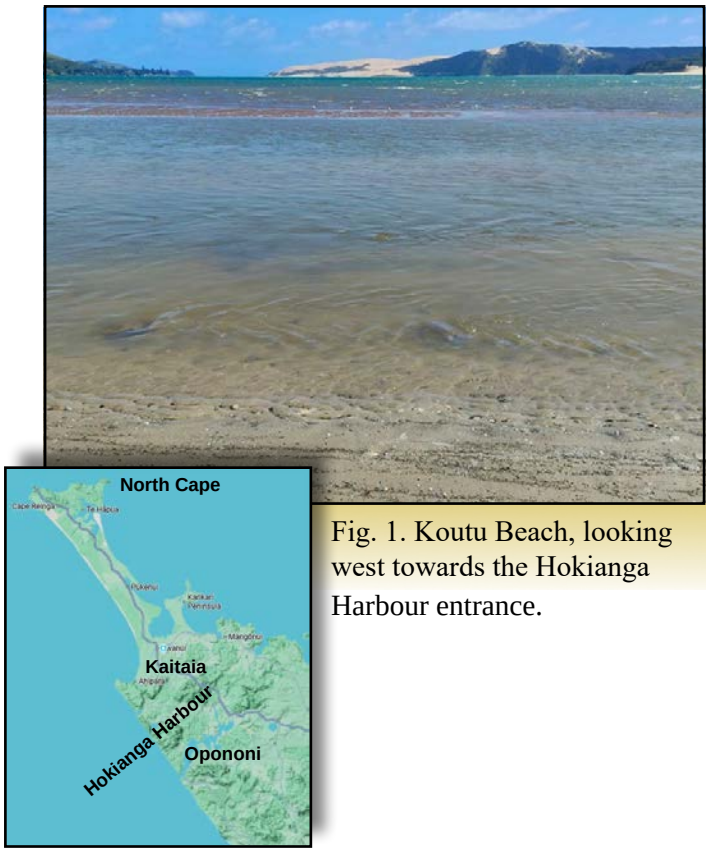


Fig. 1. Koutu Beach, looking west towards the Hokianga Harbour entrance.

On occasion, when the tide is low and recent sand movement has revealed underlying strata, we find in patches along the lower to middle harbour shoreline (for example Koutu Beach) curious isolated pieces of pale grey, well cemented, fine-grained, calcareous sediment (readily dissolves in acetic acid). These concretionary bodies often occur in unusual shapes and many contain subfossil shells and woody material (**Fig. 2**). They appear to have washed ashore, perhaps after being eroded out of Holocene deposits exposed nearby underwater.

Subfossil remains in these samples include recent species of bivalves – namely cockles/tuangi/littleneck clams, *Austrovenus stutchburyi* (many still articulated and retaining some colour), and pieces of wood. Some tubular concretions may have originally formed around twigs/plant material, now eroded away, while others perhaps represent cemented molds around burrows (**Figs 3 & 4**). Many of the concretions have since been bio-eroded and bored into by marine invertebrates.

Very similar concretionary deposits were noted in the Waitematā Harbour by Bartrum (1917), as well as recent subfossil crabs, turritellid gastropods, etc. occurring in the muddy concretions from Otago Harbour, found washing ashore at Aramoana Beach from harbour dredging (Benson & Finlay 1950, also personal obs.). Despite resembling Cenozoic fossils, the matrix of some of these samples has been found to contain recent foraminifera (e.g. Benson & Finlay 1950).

Nelson & Grant-Mackie (1980) noted a bone of the moa *Anoimilopteryx didiformis* (Owen), found contained in tidal flat deposits from 7500–6500 years ago beneath downtown Auckland city, had carbonate concretionary growths about its articular ends. They suggested that the concretions, which are younger than about 6500 years BP, were formed by precipitation of microgranular, relatively low-magnesian (6–8 mol% $MgCO_3$) calcite cement within pore waters of the sandy mud enclosing the bone, probably associated with bacterial decomposition of associated organic matter.

Evans (1985) suggested that shelly concretions (of similar appearance to **Fig. 2**), irrelevant of age, with protruding fossils that appear mantled by the cementing



Fig. 2. Two concretionary samples found at Koutu Beach, the one above is tubular and bioeroded, the other containing sub-fossil bivalves.

sediment, indicate incomplete early stages of diagenetic cementation. They may then be eroded or sometimes reworked into later sedimentary deposits.

Bioturbation can be fundamental in early diagenetic processes (e.g. Gonçalves-Aquino *et al*. 2025). In particular, burrows can create permeability conduits through sediment, as well as zones of oxidation, dissolution, precipitation, mucus impregnation and compaction. Therefore, they are essentially initiating concretionary diagenesis in the immediate region – so called 'diagenetic halos' or 'halo burrows' (see Bromley 1990). Grenfell & Hayward (1995) provided an Auckland example of crustacean trace fossils that may represent casts of burrows analogous to some of the tubular concretions.



Fig. 3. A tubular concretion, probably cemented around the mold of the burrow of a shrimp (the trace fossil "*Thalassinoides*"), with abundant evidence of tiny 'polydorid' worm borings on the exterior.



Fig. 4. Specimen in **Fig.3** showing cross section at break, note asymmetric halo of cementation around tubular burrow.

It seems probable that Holocene burial of the Hokianga Harbour shell and plant material (perhaps by several metres of sediment), bioturbation and the resulting localised early diagenesis might have occurred during the filling of the harbour over the last high-stand period of sea-level, with these concretionary bodies only to be subsequently eroded out after sea-level fell post 3000 years ago. This type of sub-fossil-bearing sedimentary structure is probably quite common in the drowned valley harbours of New Zealand, and can form relatively quickly in geologic terms!

Dedication

This article honours the memory of long-term Koutu Beach and Hokianga resident John Hunia, who passed away in February 2026.

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A BASALT SILL ASSOCIATED WITH PUPUKE VOLCANO, AUCKLAND

Bruce W. Hayward[1] and Harry Follas[2]

Because of their young age, little of the plumbing beneath any of Auckland's volcanoes has been exposed by erosion of overlying erupted volcanic deposits. The one exception is on the south side of Te Motu a Hiaroa/Puketutu Volcano, where a narrow sill-dike basalt tongue can be seen in the intertidal zone where it has intruded through and beneath a few metres of Pleistocene rhyolitic sediment and thin overlying tuff (Hayward & Muirhead 2026).

Elsewhere, there are several instances of quarries that have been excavated sufficiently deep to expose shallow intrusive dikes through the scoria cones, e.g., Eden Gardens quarry, Maungawhau/Mt Eden (Hayward 2019, p. 119); Te Pou Hawaiki (Bartrum 1928); Borough Council Quarry, Maungarei/Mt Wellington (Bartrum & Searle, 1948); Ōtuataua Quarry (Hayward 2019, p. 278); Matukutūruru/ Wiri Mt (Hayward & Fraser 2025).

To our knowledge, no intrusions have been recorded previously associated with Pupuke Volcano (**Fig. 1**). Dated at ~190,000 years old, Pupuke Volcano is considered to be the oldest volcano in the Auckland Volcanic Field (Hayward 2019, Hopkins *et al*. 2021). Unlike all other Auckland volcanoes, Pupuke seems to have had limited initial wet explosive (phreatomagmatic) eruptions, with the main early phase of eruption consisting of effusion of lava flows in all directions from a central vent (Lake Pupuke) possibly associated with some fountaining producing a small central scoria cone (Hayward 2023). This early phase of dry eruptions was followed by wet explosive eruptions, creating a much wider explosion crater and building a 10–20 m high tuff ring around it. This unusual switch from dry to wet (rather than the reverse) has been attributed to the possible damming of Wairau Valley and diversion of the stream into the Pupuke Volcano vent (Hayward 2019). The shape of Lake Pupuke led Heaphy (1860) to infer it was formed by two craters – a main central crater and a smaller one in the northeast. This has been supported by the geophysical identification of two magnetic anomalies (basalt plugs) beneath the lake (Nunns & Hochstein 2019).

While undertaking site investigations for a proposed multi-storey apartment development at 112 Kitchener Rd, Milford in 2022 (**Figs 2, 3**), engineering geologists working for Geoconsult supervised and logged the coring of a number of boreholes. The boreholes were located on the Pupuke tuff ring at 15–18 m above mean sea level (MSL). The shallower boreholes encountered tuff overlying basalt lava at 7–9 m above MSL (**Fig. 4**), as expected from our understanding of the Pupuke sequence in many other places with the tuff overlying basalt flows. Moving slightly downslope away from Pupuke crater (Lake Pupuke) the lava flow/s appear to wedge out and were not identified

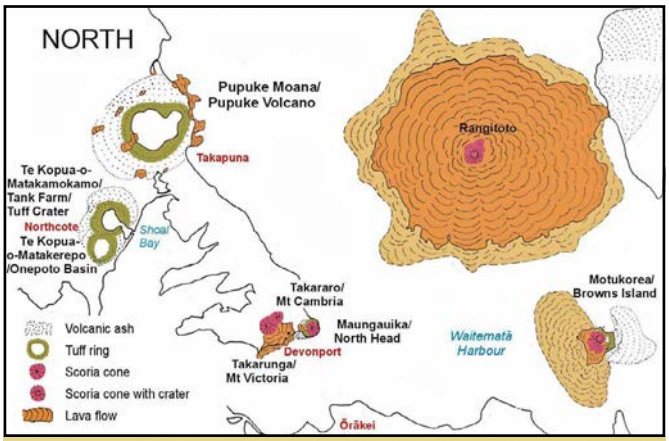


Fig. 1. Map of the northern volcanoes in the Auckland Volcanic Field showing Pupuke Volcano in the northwest (modified from Hayward 2019).

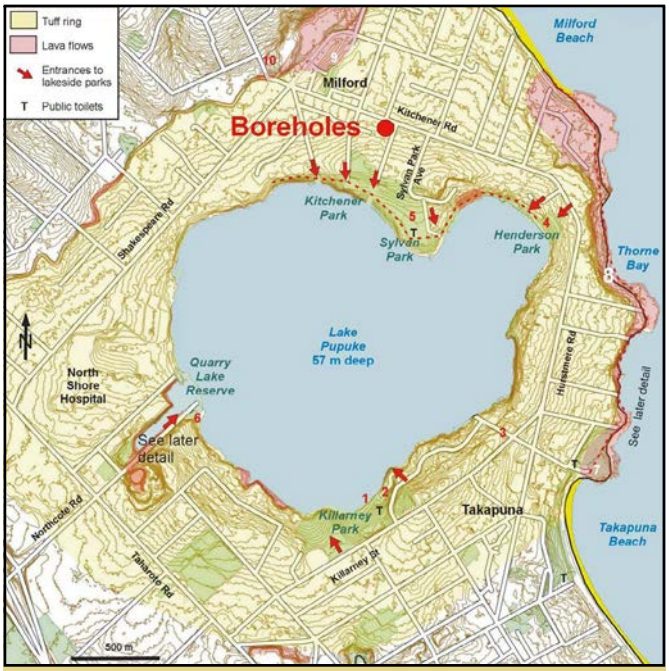


Fig. 2. Location of boreholes at 112 Kitchener Rd, Milford.



Fig. 3. Location of boreholes in Milford on the Pupuke Volcano tuff ring.

[1] Geomarine Research, 19 Debron Ave, Remuera, Auckland, b.hayward@geomarine.org.nz
[2] Engineering geologist, Northcote, Auckland

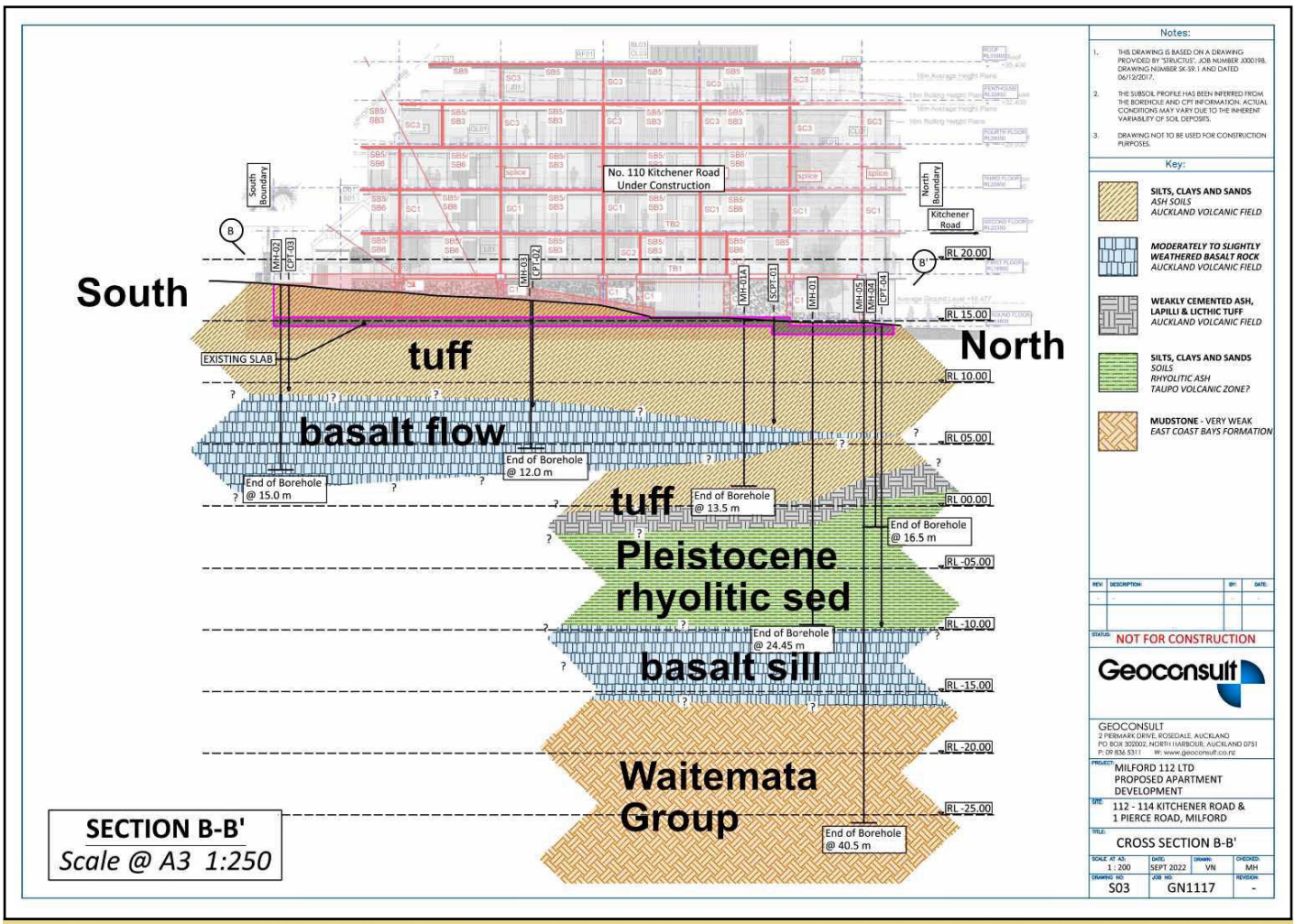


Fig. 4. South (left) to north compiled cross-section beneath the Kitchener Rd development site, based on the sequences encountered in the cored boreholes (vertical lines labelled MH). Published with permission of Geoconsult.

in boreholes near the Kitchener Rd northern boundary of the development site (**Fig. 4**). Beneath the flow/s the deeper boreholes encountered ~5 m of tuff and lapilli tuff, somewhat more than has been recorded beneath the basalt flows elsewhere at Pupuke.

As expected, the lowest tuff overlay 8–10 m of light-coloured rhyolitic sediment and clay (Tauranga Group) of probable early-mid Pleistocene age (1.5–0.5 myrs) – the same as encountered elsewhere beneath the Pupuke Volcano flows and sometimes exposed beneath the sand at adjacent Takapuna Beach (**Fig. 5**, Hayward 2015). Usually these Tauranga Group sedimentary rocks unconformably overlie an eroded surface of Waitematā Group sandstone and mudstone (early Miocene). The surprise came when the deepest boreholes encountered 6 m of fresh basalt beneath the rhyolitic sediment before passing down into the expected Waitematā Group rocks. This cannot be a basalt flow and has to be basalt lava from Pupuke Volcano that has intruded as a sill (here 6 m thick) along the contact between the harder Waitematā Group sedimentary rocks and the overlying softer rhyolitic sediments. At this site the basalt sill was at 10–16 m below MSL (**Fig. 4**).

The shear strength of the cored rocks was measured in each borehole and the engineering geologists were surprised at the hardness and high shear strength of several dry horizons within the Tauranga Group rhyolitic sediments. We infer that these are porcellanite that have been baked by the



Fig. 5. Massive light-coloured rhyolitic silt and clay with scattered pieces of wood and stumps in-situ, exposed from beneath sand on Takapuna Beach in 2014.

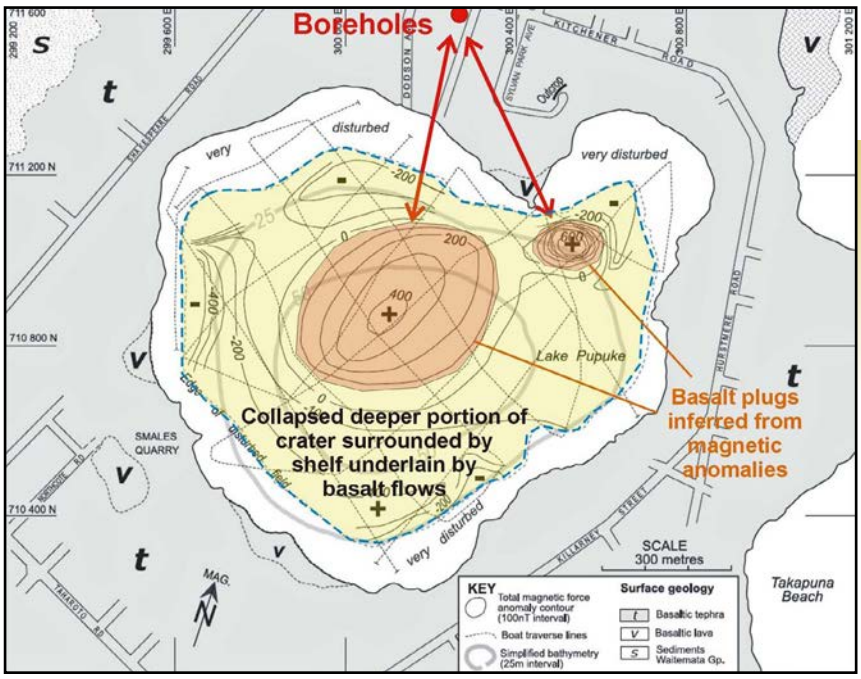


Fig. 6. Map of Lake Pupuke showing contours on magnetic anomalies with positive anomalies underlain by inferred basalt plugs in orange. The magnetic contours also pick out the collapsed steep edge of the crater (yellow). The two possible magmatic conduit sources of the basalt sill are shown with red arrows. Background map and magnetic data from Nunns & Hochstein (2019).

high temperatures around the sill and beneath the flow. Similar baked porcellanite, sometimes with miniature polygonal contraction columns, occurs in 1–5 m diameter lumps of this material that have been rafted along inside the upper parts of a flow exposed around Northcote Rd end on the southwestern side of the lake (Hayward 2020, **Fig. 2**).

The sill must have been intruded from one of the two magma-filled conduits at the time of eruption of Pupuke Volcano and to have travelled at least 500–600 m underground to where it was intersected in the Kitchener Rd boreholes (**Fig. 6**). We cannot determine which of the two conduits the sill was sourced from. This is only the second sill we know that has been recognised so far in the Auckland Volcanic Field. The other is the extremely narrow and shallow sill also intruding for at least 600 m and baking overlying Pleistocene rhyolitic sediment (and tuff) at Puketutu Volcano (Hayward & Muirhead 2026). The large, rafted block of tuff overlying 1 m of partly baked rhyolitic sediment, enclosed within a thick basalt flow and exposed in the wall of the old Mt Wellington Quarry (Hayward 2024) would seem to have originated from another sill (from Maungarei/Mt Wellington Volcano) intruding along the contact between Waitematā rocks and the soft Tauranga Group.

Acknowledgements

We thank Marco Holtrigter of Ground Investigation for arranging permissions from the developer and Geoconsult for the publication of figure 4.

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FIRST RECORD OF A MIOCENE CHIMAEROID (HOLOCEPHALI: CHIMAERIFORMES) FROM NEW ZEALAND

Tayin Patel

Abstract
A fragment of a chimaeroid mandibular tooth plate is reported from the Waiwiri Phosphatic Cast Bed of Otaian (early Miocene) age at Waikawau Beach, Waikato. It represents the only reported Miocene chimaeroid material from New Zealand to date.

An introduction to chimaeroids

Often referred to as "ghostsharks" or "rabbitfish", chimaeroids (Order Chimaeriformes) are cartilaginous fishes (Class Chondrichthyes) typically characterised by bulky heads, large pectoral and pelvic fins, large eyes, long tapering tails, and two dorsal fins, the first preceded by a sharp spine. They diverged early from their sister group, the elasmobranchs (sharks and rays; **Fig. 1**), first appearing in the fossil record during the Devonian (~400 million years ago).

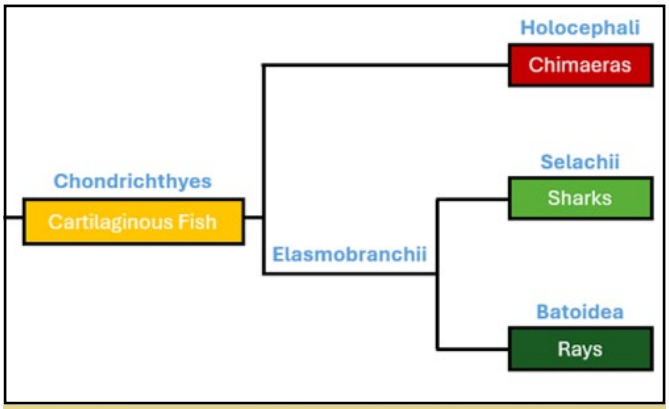


Fig. 1. A simplified phylogenetic tree shows the relationship between chimaeras (Holocephali) and sharks and rays (Elasmobranchii).

Chimaeroids are primarily deep-water inhabitants, most commonly found along continental slopes at depths of 200–2000 m, with relatively few extant species occurring in shallower waters. Exceptions include the members of the genus *Callorhinchus*, such as New Zealand's own makorepe or reperepe (elephant fish), *Callorhinchus milii*, which reaches approximately 1 m in length (**Fig. 2**). Some extinct taxa, such as those within the genus *Edaphodon*, are thought to have attained lengths of up to 3 m.

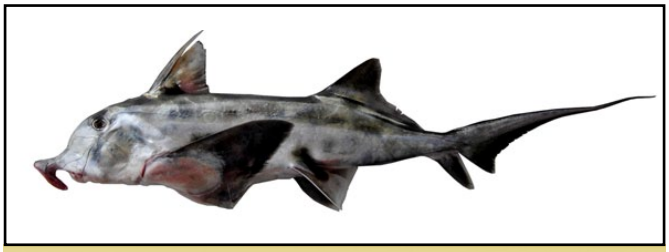


Fig. 2. An extant New Zealand chimaera, *Callorhinchus milii* (Makorepe/elephant fish) (Source: Talley's 2026).

Unlike sharks, which possess rows of replaceable teeth, chimaeroids have six large, continuously growing tooth plates arranged in three pairs: one pair on the lower jaw (mandibular) and two pairs on the upper jaw (vomerine and palatine) (**Fig. 3**). These plates form a beak-like crushing and grinding apparatus specialised for their durophagous diet, which includes hard-shelled prey such as molluscs and crustaceans.

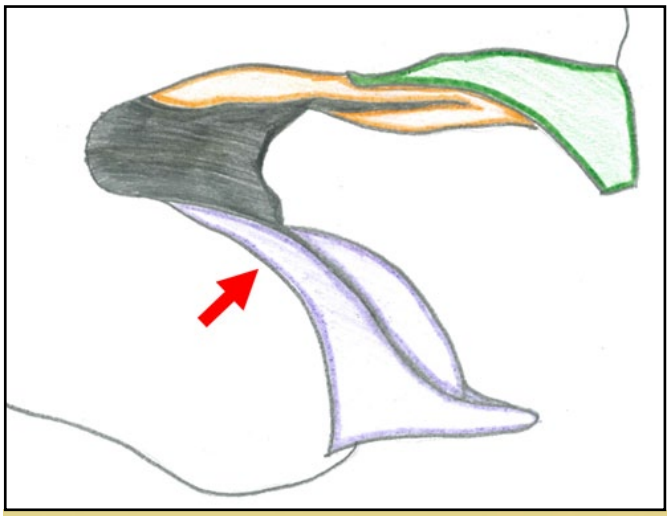


Fig. 3. The life positions of tooth plates in the mouth of a modern chimaeroid: mandibular (purple), vomerine (green), and palatine plates (orange). A red arrow indicates the approximate position of the tooth fragment discussed in this article. Redrawn and modified from a photograph of specimen LDUCZ-Z2465, Grant Museum of Zoology and Comparative Anatomy, University College of London.

Within these tooth plates, tritors – pads or ridges on the occlusal (biting) surfaces – form the main sites of prey crushing during feeding. They are composed of a dense, hypermineralised tissue called whitlockin, unique to chimaeroid dentitions.

Because chimaeroids possess cartilaginous skeletons, like sharks, their fossil record is limited largely to the most durable elements. Isolated tooth plates, therefore, dominate, with only rare occurrences of fin spines and egg capsule trace fossils. This preservation bias means that taxonomic classification relies heavily on tooth plate morphology, particularly the number, arrangement and geometry of tritoral pads (Stahl 1999). More recent work has expanded this approach to include structural composition revealed through cross-sectional analysis (Popov *et al.* 2020).

The chimaeroid fossil record in New Zealand

Globally, chimaeroids reached their greatest diversity during the mid-Cretaceous in shallow intercontinental seas of

the Northern Hemisphere (Popov & Machalski 2014). But the Southern Hemisphere record is sparser, and the New Zealand record is largely restricted to the Late Cretaceous. Popov & Terezow (2018) revised approximately 100 New Zealand specimens, revealing greater taxonomic diversity than previously recognised.

The oldest record of chimaeroids in New Zealand is represented by *Chimaerotheca reperepe* (Gottfried & Fordyce 2015), an impression of an egg capsule from Southland dating to the Late Triassic (Warepan or Otapirian stage).

In the Santonian (Piripauan; 86.5–83.6 Ma), the assemblage is represented solely by *Ischyodus thurmanni* (Newton 1876, Chapman 1918). By the Santonian–Maastrichtian interval, the fauna expands to include *Callorhinchus hectori* and representatives of the genera *Elasmodes, Stoidolop, Elasmothorax* and *Lebiodon*. Maastrichtian strata (Haumurian; 72.1–66 Ma) further yield *Callorhinchus hectori*, *Elasmodes* sp., *Ischyodus* sp. and *Elasmodus* sp. This includes *Elasmodus kawai* (Popov & Terezow 2018), originally described as *Edaphodon kawai* (Consoli 2006), from the middle Campanian to middle Maastrichtian (Haumurian; 77.8–69 Ma) of the Chatham Islands.

The Paleocene contrasts with Late Cretaceous Southern Hemisphere chimaeroid assemblages, being characterised by members of the genus *Callorhinchus* (Buchanan *et al*. 2007), rare representatives of *Ischyodus* and diverse specialised representatives of *Edaphodon* (Popov & Terezow 2018).

Globally, chimaeroid diversity declined following the Late Cretaceous, with a further reduction from seven to four fossil genera between the Eocene and Pliocene (Popov *et al*. 2020). The latter part of this decline, particularly during the Oligocene–Miocene, has been attributed to paleogeographic fluctuations - such as the reduction of shallow shelf seas - and climatic changes at the end of the Paleogene (Schopf 1980, Popov *et al*. 2020). As a result, the Cenozoic chimaeroid fossil record is relatively sparse globally.

In New Zealand, the fossil record for this interval is especially limited, so much of our understanding relies on Australian assemblages. Sediments from Victoria and Tasmania preserve three taxa: *Ischyodus sweeti* (synonymised from *Edaphodon sweeti* and *Ischyodus mortoni*; Chapman & Pritchard 1907; early Miocene to Pliocene), *Edaphodon mirabilis* (latest Miocene to Pliocene), and *Callorhinchus* sp. (Popov 2011). Popov & Takeuchi (2011) note that Southern Hemisphere chimaeroid assemblages – dominated by *Callorhinchus* and Ischyodus, are distinct from Northern Hemisphere faunas, and that both genera can be traced back to the Southern Hemisphere before the Miocene.

More recent Neogene records in New Zealand include mid-Pliocene (Waipipian; 3.82–2.9 Ma; Clowes *et al*. 2026) remains of indeterminate chimaeroids reported from the Māngere Shellbed of the Ōtāhuhu Formation (Hayward *et al*. 2023), as well as two indeterminate chimaeroid taxa and *Callorhinchus milii* from Hawera, South Taranaki (McKee 1994).

Identification

The specimen is a fragment of the right mandibular tooth plate of a chimaeroid, and likely represents less than 20% of the original element. It retains a portion of both the medial and posterior outer tritor (**Fig. 4**) and exhibits well-preserved whitlockin (**Fig. 5**). The fragment was collected in April 2025 from a fallen boulder at the southern end of Waikawau Beach, Waikato, North Island, New Zealand.

Material. Auckland War Memorial Museum specimen [MA62674], from locality R13/f7078C (FRED - Fossil Record Electronic Database).

Tooth Plate Terminology Abbreviations: iod = intertritoral osteodentine, **mt** = medial tritor, **pot** = posterior outer tritor

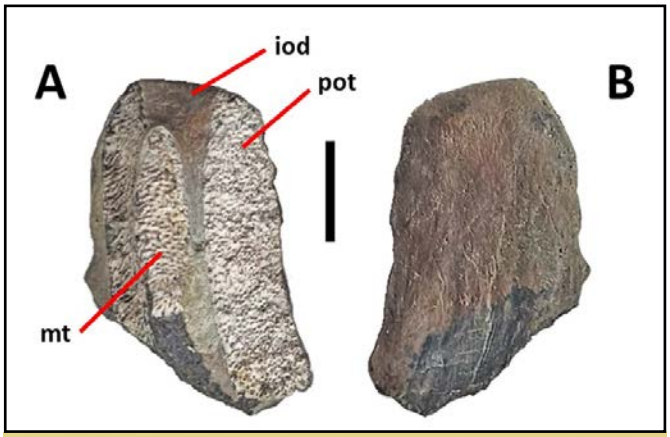


Fig. 4. Distal fragment of the right mandibular tooth plate of *Edaphodon* cf. *sweeti* from the Waiwiri Phosphatic Cast Bed.
(A) Occlusal view (biting surface) and
(B) labial view (outer side). Scale bar = 1 cm.



Fig. 5. Oblique internal view of the medial tritor showing exceptional preservation of whitlockin. A dense network of tubular rods (compact whitlockin) is visible, demonstrating that the tritoral tissue forms a deep, three-dimensional, hypermineralised structure specialised for wear resistance.

Evgeny Popov, a chondrichthyan palaeontologist specialising in holocephalians, tentatively identified the fragment as ***Edaphodon* cf. *sweeti***.

Edaphodon sweeti (Chapman & Pritchard 1907) is known from the earliest early Miocene (Aquitanian; 23.9–21 Ma) deposits of Tasmania and from late Miocene to early Pliocene deposits in Victoria, Australia (Fitzgerald 2004), consistent with the stratigraphic age of the present specimen. Although the species has since been reassigned to *Ischyodus sweeti* (Popov 2011), the original designation (*E. sweeti*) is retained here for consistency with the broader literature and for ease of comparison with previously described material.

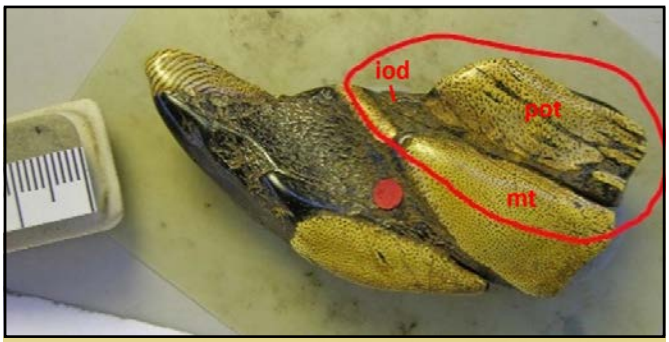


Fig. 6. Comparative mandibular plate of *Edaphodon sweeti* from the syntype MV 9111 (Museums Victoria, Melbourne, Australia).

The fragment differs slightly from the syntype material (**Fig. 6**) with regard to the shape of the right margin of the medial tritor, particularly expressed in the shape of the intertritoral osteodentine corridor between the medial and posterior tritors (**Fig. 5**). But chimaeroids are known to exhibit a high degree of intraspecific (within a species) variation in individual tooth plate morphology, as observed in populations of extant taxa (Stahl 1999), and such variation cannot be assessed from a single fragment.

Given the fragmentary nature of the material and these minor morphological differences, the specimen is conservatively referred to ***E.* cf. *sweeti***, with "cf." (confer) denoting resemblance to, but not definitive assignment to, the species.

Locality

The Waiwiri Phosphatic Cast Bed (Hayward & Brook 1984) is a thin, glauconitic horizon of Otaian age (early Miocene, 21.1–18.64 Ma; Clowes *et al*. 2026) exposed in coastal cliffs south of Port Waikato. It represents the uppermost unit of the Kawau Subgroup (**Fig. 7**), the basal subgroup of the Waitemata Group, and lies conformably between the Otangaroa Member and the Waikawau Sandstone of the Meremere Subgroup. Both the Otangaroa Member and the Waiwiri Phosphatic Cast Bed are members of the Tipakuri Sandstone Formation.

The basal portion of the bed comprises green calcareous sands and silts (Collins & Stolberger 2025). The abundance of glauconite indicates low-energy conditions and reduced sedimentation rates. The upper portion is heavily bioturbated and overlain by a horizon rich in phosphatic nodules, along with abundant internal moulds (steinkerns) of molluscs from which the unit derives its name.

The deposit represents a prolonged starvation interval associated with rapid tectonic subsidence in the southern Waitematā Basin during the early Miocene (Ricketts *et al.* 1989). This interval is marked by an abrupt transition from shallow coastal sediments to outer shelf–upper bathyal facies. As basin subsidence outpaced sediment supply, clastic input was reduced, resulting in a condensed, time-averaged deposit.

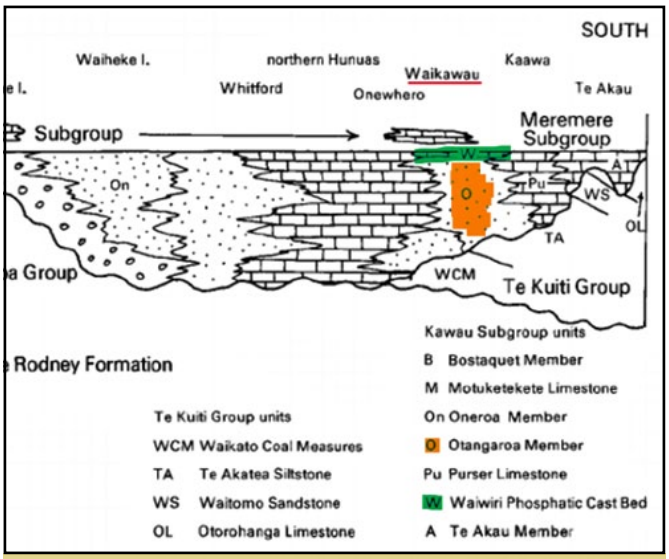


Fig. 7. Schematic stratigraphic section showing the member relationships within the Kawau and Meremere subgroups (Waitematā Group) (Hayward & Brook, 1984).

Paleoecology of the Waiwiri Phosphatic Cast Bed

Diverse foraminiferal assemblages (41 species) characterised by an abundance of *Bolivina reticulata*, a lack of *Amphistegina* and a high planktic proportion (75%) suggest sheltered, lower oxygen, fine-grained offshore conditions (Hayward 2004). While the Modern Analogue Technique (MAT) estimated a depth of 150 m, Adjusted Paleobathymetry (ADP) suggested depths exceeding 500 m, placing deposition between the outer shelf (100–200 m) and upper bathyal zone (200–600 m).

The associated vertebrate and invertebrate assemblage further supports an offshore depositional setting. Vertebrates - including hexanchid (*Notorynchus*), sand tiger, and sharpnose sharks, rays, teleost fishes, and a marine turtle (*Lepidochelys*; Buckeridge 1981) are present. The benthic invertebrate fauna, dominated by bivalves, gastropods, and corals, is consistent with a shallow outer shelf environment (generally <200 m depth; Collins & Stolberger 2025).

The occurrence of a benthic durophagous chimaeroid within a shell-rich phosphatic horizon is not inconsistent with the interpreted outer shelf to upper bathyal depositional setting.

What's next?

This identification represents a rare Cenozoic record of chimaeroids in New Zealand, bridging a substantial gap between the diverse Late Cretaceous–Paleocene assemblages and the Pliocene record. It highlights the limited resolution of the current fossil record for this group during the Cenozoic.

The scarcity of material from this interval likely reflects a combination of preservational and publication bias, as well as a broader global decline in chimaeroid diversity through the Cenozoic. This interpretation is supported by their occurrence in coeval Australian deposits.

The Waiwiri Phosphatic Cast Bed demonstrates good preservational potential, suggesting that additional material may yet be recovered from this unit and other Cenozoic deposits. Further discoveries and re-examination of existing collections will likely refine the taxonomy and improve understanding of chimaeroid diversity in New Zealand.

Acknowledgements

I thank Evgeny Popov (Saratov State University, Russia) for identifying the specimen and sharing his expertise, and Thomas Stolberger (University of Auckland, New Zealand) and Bruce Hayward (Geomarine Research, New Zealand) for their guidance and valuable input during the preparation of this article.

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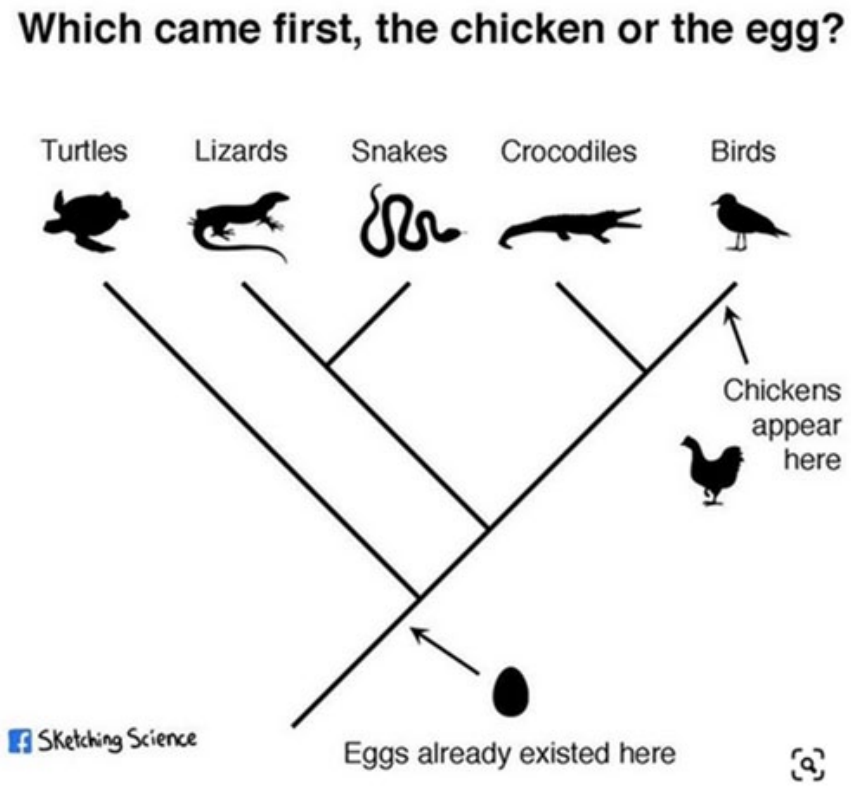
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STORY IN A LIMESTONE COBBLE FROM THE PARNELL GRIT AT WAIWERA BEACH, NORTH OF AUCKLAND

Bruce W. Hayward

Introduction

When I last visited Waiwera Beach (**Fig. 1**) with Auckland Geology Club in 2004, I picked up a cobble of limestone on the cobble beach just below the Parnell Grit bed in the cliffs (**Fig. 2**). It had eroded out from the lower conglomeratic part of this Parnell Grit bed. I have been looking at the cobbles of coarse bioclastic limestone that occur sporadically within the lower parts of the Parnell Grit in this part of the Auckland region for many years, always examining them for clues as to where the limestone may have come from. By far the majority are straight limestone with no inclusions.

This time I had found a cobble that seemed to contain rounded pebbles that answered my questions as to source, at least in part. In the past, others (e.g. Ballance & Gregory 1991, Allen 2004) have seen these limestone cobbles and inferred they were pieces of Oligocene Whangārei Limestone from the in-situ basement sequence of Waipapa

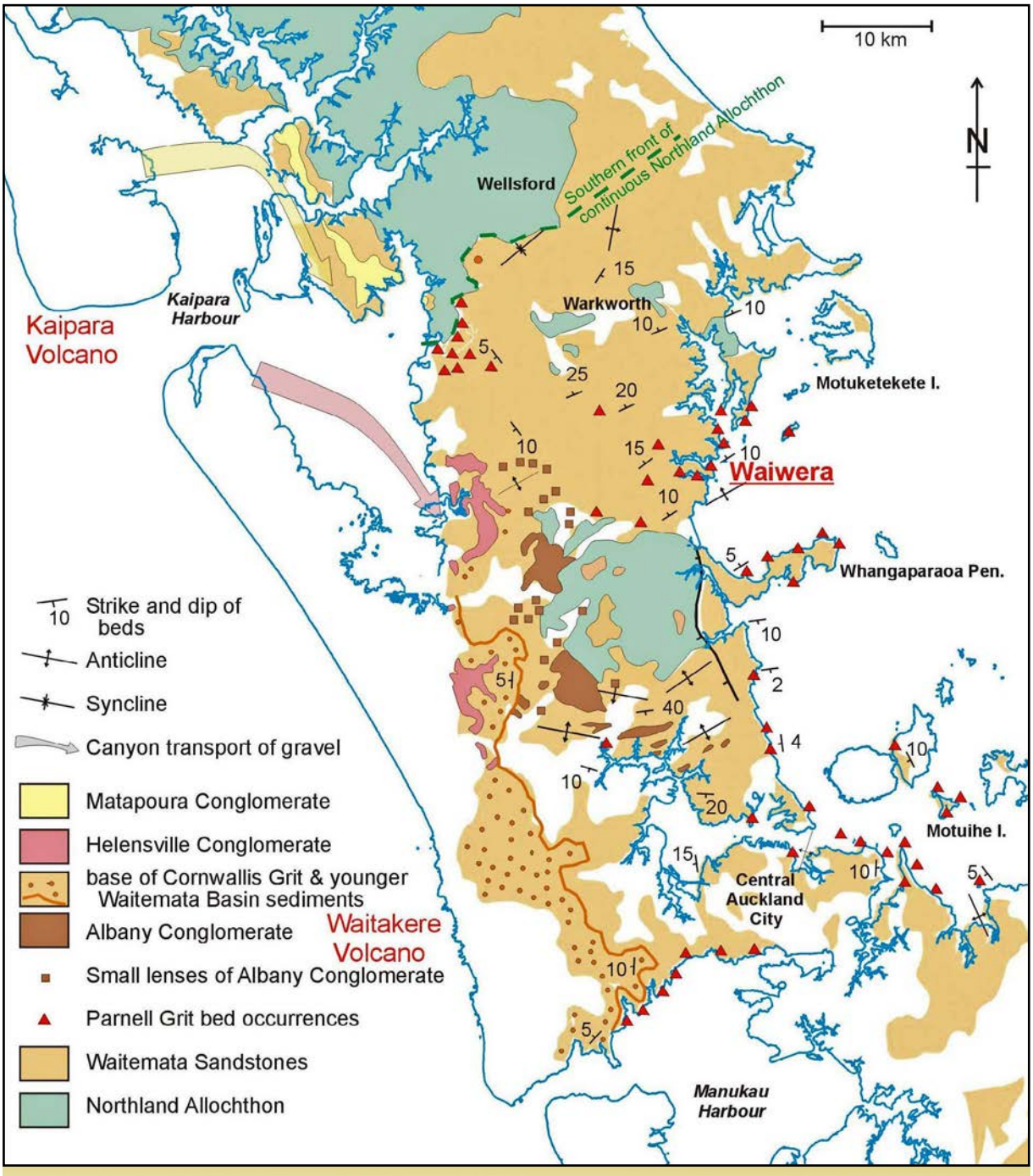


Fig. 1. Schematic geological map of most of the Auckland region showing the outcrop distribution of the Parnell Grit beds (red triangles) and other formations, members and features of the early Miocene Waitematā Group (modified from Hayward 2017).

Group greywacke overlain by late Eocene–Oligocene Te Kūiti Group rocks (Isaac *et al*. 1994). Another possibility, albeit less likely, would seem to be that this limestone is a transported cobble from the early Miocene basal Waitematā Group limestone (Papakura Limestone) that has small outcrops today at Motuketekete and Motuihe islands (**Fig. 1**) (Hayward & Brook 1984). Both of these potential sources occur in close proximity and overlying basement greywacke. At the time of Parnell Grit emplacement, basement and any Te Kūiti Group rocks were more likely exposed east of Northland and Auckland than to the west, if at all (e.g., Isaac *et al*. 1994, Hayward 2017).

Parnell Grit

This term applies to beds of volcaniclastic boulder and cobble-bearing, pebbly, sandy grit that occur in a few places within the Waitematā Group flysch (alternating sandstone and mudstone) around Auckland (Ballance 1974, Ballance & Gregory 1991, Allen 2004). The unit was first noticed and described by Hochstetter (1864) and raised to member status within the Waitematā Group by Ballance (1976). Although the lower parts of some deposits are conglomeratic and the upper parts of some thick beds are coarse sandstone, the dominant grain size is granule (2–4 mm across) and therefore the most appropriate and commonly-used name for these individual beds is Parnell Grit. Parnell Grit beds have been inferred to have been deposited by subaqueous volcaniclastic gravity flows that flowed down into the 1000–2000 m deep Waitematā Basin from terrestrial and/or shallow marine settings on the flank of island volcanoes (Ballance & Gregory 1991, Allen 2004).

Description of limestone cobble

The cobble is held in the University of Auckland collection (Cat. no. PAU69014). It is 10 x 8 x 6 cm in size and rounded to subrounded in shape (**Fig. 3**). About 95% by volume is limestone composed of strongly cemented broken and whole shells of bivalves and bryozoa. Other bioclasts may be present but are not identifiable in the somewhat recystallised limestone without thin sectioning it. Scattered through the limestone are small rounded to well-rounded pebbles (5–15 mm diameter), mostly composed of finely vesicular basalt or extremely fine grained (aphyric) basalt (**Figs 3–4**). One of the pebbles has a 1 mm-thick coating of calcareous algae. Also presence are scattered angular granule-sized ferromagnesian crystals.

Provenance of limestone

Basal portions of the Oligocene Whangārei Limestone and Papakura Limestone often contain small pebbles of the basement greywacke rock that the limestone had been deposited upon or near to. Thus the presence of greywacke pebbles would likely have helped clinch the provenance of this limestone as probably coming from the east or northeast. The presence of small pebbles of basalt and ferromagnesian crystals in my limestone cobble both indicate that the limestone originally accumulated as a shell deposit on the submarine flanks of a basalt volcano. The composition of the Waiwera cobble is similar to limestone "crusts", up to 1–2 m thick, that have been reported today on the moderately shallow (200–800 m) submarine flanks of a number of volcanic islands in the Caribbean and Mediterranean sea (e.g., Tucker *et al*. 2020): "*These crusts are hardgrounds composed of mixtures of volcaniclastic debris and bioclastic material, in most cases cemented by calcite, in the form of coatings around grains*



Fig. 2. Lower conglomeratic part of the Parnell Grit bed at Waiwera overlying thin-bedded sandstone and mudstone (flysch) of the Waitematā Group. The limestone cobble was found on the beach at the foot of this cliff.



Fig. 3. Limestone cobble containing small, rounded pebbles of basalt and fragments of bivalves and bryozoa, from Waiwera Parnell Grit.
(University of Auckland collection, Cat. no. **PAU69014**)



Fig. 4. Crystalline and vesicular basalt pebbles cemented in the limestone cobble from Waiwera Parnell Grit. The right-hand pebble has a thin coating of calcareous algas (rhodolith). Width of photo 4 cm.

and pore-filling spar … The carbonate crusts are attributed to seawater circulating within the surficial sediment, in some cases mixing with hydrothermal fluid driven by geothermal and volcanic processes."

The rounded pebbles in the Waiwera cobble and the calcareous algal coating over one of the pebbles indicates that some of this material spent time in the high energy photic zone, probably shallower than 50 m. Unfortunately, the cobble does not answer the question of where the source volcano was.

Provenance of volcanic pebbles

The finely vesicular, crystalline and fine-grained basalt pebbles in the Waiwera cobble appear similar to the larger volcanic cobbles and pebbles in the lower part of the Parnell Grit, but this has not been checked with thin-section study nor geochemistry. Day (1986), Smith *et al*. (1989) and Shane *et al*. (2010) all noted that the dominant volcanic cobbles and pebbles in this and other East Auckland exposures of Parnell Grit are composed of an unusual high-Al, low-Si basalt that Shane *et al*. (2010) stated had affinities to an oceanic island basalt and was not calc-alkaline typically occurring in subduction-related volcanic arcs, such as the western and eastern belts of the early Miocene Northland Volcanic Arc (Smith *et al*. 1989).

The Waitematā flysch at Waiwera and elsewhere is biostratigraphically well-dated as Otaian Stage (21.1–18.64 myrs – Clowes *et al*. 2026). The deep-water flysch beds must have been deposited in the latter half of the Otaian Stage (<20 myrs) to allow for Waitematā Basin subsidence from sea level to 1000–2000 m during the Otaian before its deposition (e.g. Hayward 2004). Shane *et al*. (2010) obtained an Ar-Ar age of ~20 myrs on three separate basalt clasts from the Waiwera Parnell Grit, which, if correct, indicates that the deposit was sourced from a contemporaneous or recently active basalt volcano. Remnants of an early Miocene volcano with this basalt composition are not exposed on land today.

Geophysical (aeromagnetic, seismic) evidence of buried volcanic/igneous rocks that have not been sampled occurs in two possible source areas (**Fig. 5**):

1. Beneath the sea floor to the northeast between Whangārei Heads and surrounding Hen Island (Thrasher 1988). This area has outcropping eroded remnants of the calcalkaline andesite Taurikura stratovolcano of early Miocene age (Isaac *et al*. 1994). Thus it seems unlikely, but not definite, that the buried igneous rocks of this area are all calcalkaline and not the likely source volcano for the Parnell Grits.
2. The large Kaipara Volcano and a number of smaller ones occur to the northwest beneath the seafloor west of Northland and have been inferred from their seismic stratigraphy to have been mostly active between 22 and 19 myrs (Herzer 1995). Thus the Kaipara Volcano seems the most probable source of the basalt in the Parnell

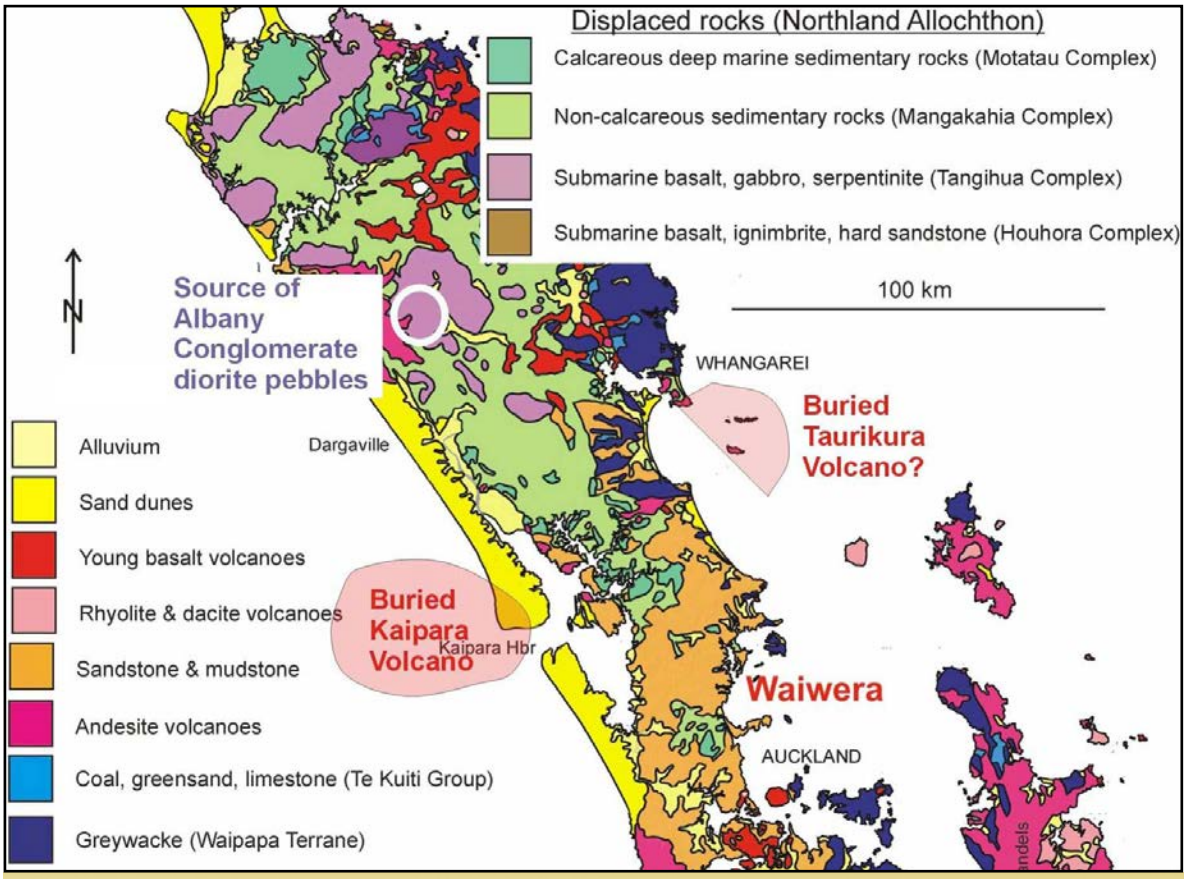


Fig. 5. Simplified geological map showing the location of two possible source volcanoes (buried Kaipara and Taurikura volcanoes) for the basalt in the Waiwera Parnell Grit. Also circled in white is the location of the Tangihua Complex block composed of plutonic rocks and probable source of the diorite pebbles in the Albany Conglomerate. (Modified from Hayward 2017).

Grits, but the possibility exists that the source lies hidden beneath the Northland Allochthon or the Taurikura Volcano (Whangārei Heads, Hen Island).

Provenance of plutonic pebbles

Scattered pebbles of microdiorite and metasomatised basalt (Clast Type 3 of Shane *et al*. 2010) occur in the Waiwera and a number of the other Parnell Grit beds (e.g., Ballance 1974, Allen 2004). These are identical in composition, size and rounding to the dominant clasts in the Albany Conglomerate which outcrops today inland to the west and southwest of Waiwera (**Fig. 5**, Schofield 1989). The pebbles are sourced from the Tangihua Complex ophiolites of the Northland Allochthon (Isaac *et al.* 2004) with the plutonic component likely sourced from the only plutonic block of Tangihuas north of Dargaville (Isaac *et al*. 1994).

Hayward (1982, 1993) hypothesised that the Albany Conglomerate, now located southwest and west of Waiwera, was part of a giant subseafloor slide that may have displaced it up to 50 km to the south after the Waiwera Parnell Grit was deposited. This strengthens the hypothesis that the volcaniclastic gravity flows came from the Kaipara Volcano, or somewhere nearby in the west or northwest, and may have picked up Albany Conglomerate pebbles enroute. But we cannot exclude the unlikely possibility that Albany Conglomerate existed to the north or northeast in the early Miocene and has subsequently been uplifted and eroded away.

Discussion

Ballance (1974) mainly relied on the presence of the distinctive Albany Conglomerate pebbles in the Parnell Grits to infer they flowed into the basin from volcano/es in the northwest or west. This direction was accepted by Smith *et al*. (1989), Ballance & Gregory (1991), Hayward (1993) and Isaac *et al*. (1994). Allen (2004) and Shane *et al*. (2010) argued that the different geochemistry of the basalt clasts in the Parnell Grit occurrences (including Waiwera) implied a different source direction, possibly from a volcano in the north or east.

The heavy mineral composition of the Waiwera Parnell Grit (Hayward & Smale 1992, sample 44) is dominated by clinopyroxene and magnetite and is essentially the same (their Group 1a) as that in Pakiri facies sandstones that outcrop north of Waiwera as far as Pakiri (**Fig. 6**). It is possible that the Pakiri volcaniclastic turbidites and the Parnell Grits were sourced from the same basalt volcano or volcanoes (e.g., Isaac *et al*.1994, fig. 5.23).

Conclusions

The sporadic lumps of limestone in the Parnell Grit at Waiwera are not derived from either the Oligocene Whangārei Limestone or the early Miocene Papakura Limestone. The presence of rounded basalt pebbles and angular pyroxene crystals indicates that the limestone accumulated and was cemented on the submarine flanks of a contemporaneous early Miocene basalt volcano. The location of this source

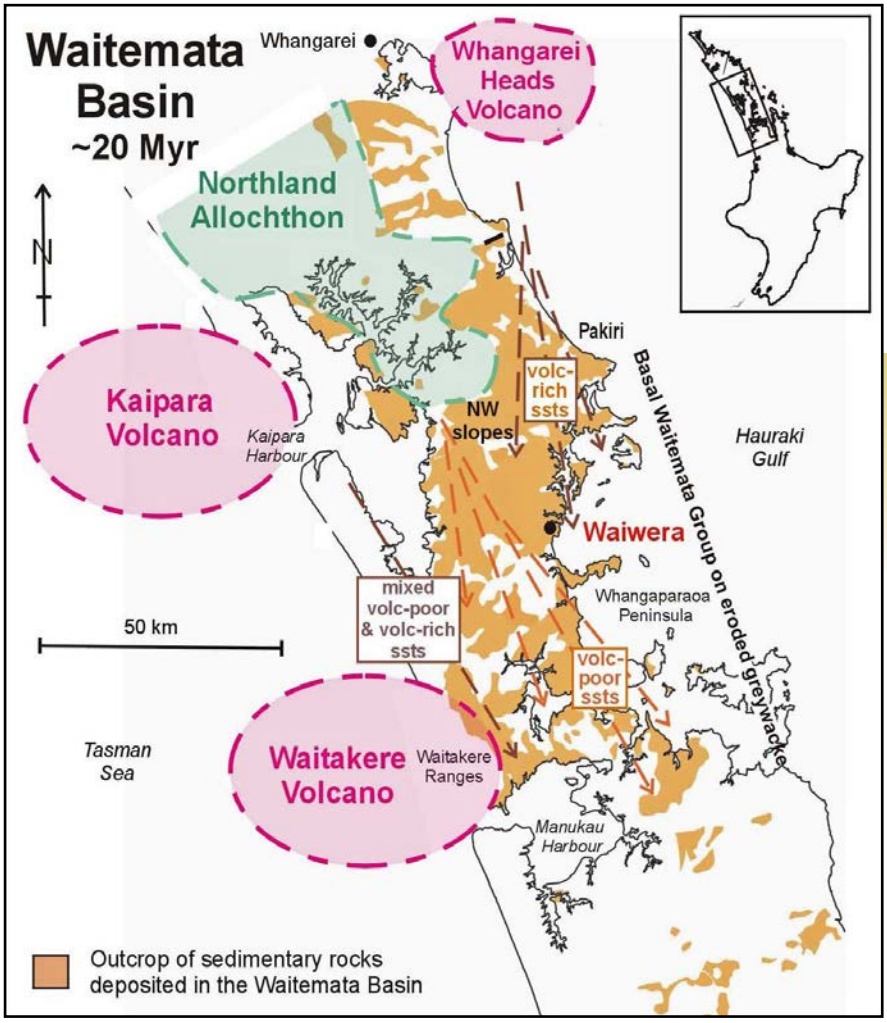


Fig. 6. Schematic map showing outcrop distribution of the volcanic-rich (Pakiri) facies, volcanic-poor (East Coast Bays) facies and mixed (Blockhouse Bay) facies of the Waitematā Group flysch and their relationship to the three known large volcanoes of the time (Early Miocene) (modified from Hayward 2017).

volcano remains elusive. It was unlikely to be in the south, but could have been anywhere between northwest and northeast. The completely buried Kaipara Volcano to the northwest is the most probable source because of the presence of Albany Conglomerate pebbles(from the west to northwest) and lack of what was previously inferred to be Whangarei Limestone (from the north to east).

Postscript

On a more recent visit to Waiwera, I discovered a 25 cm diameter cobble in-situ in the Waiwera Parnell Grit (**Fig. 7**) consisting of subangular to rounded basalt pebbles and cobbles in a coarse sandy matrix cemented together by calcite – a larger and more volcanic-rich version of the original limestone cobble.



Fig. 7. Two cobbles in the Waiwera Parnell Grit. A volcanic clast on the left and a pebbly limestone on the right containing subangular and subrounded pebbles of basalt. Width of photo 50 cm.

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CORRESPONDING AUTHORS' CONTACT INFORMATION

Michael K. Eagle	Geoclub Member,	**docrock50@aol.com**
Wendy Goad	Geoclub Member,	**wendymikeclark@gmail.com**
Bruce W. Hayward	Geoclub Member,	**b.hayward@geomarine.org.nz**
Tayin Patel	Geoclub Member,	**pateltayin@gmail.com**
Seabourne Rust	Geoclub Member,	**seabourne.rust@gmail.com**

CROSSWORD ANSWERS

ACROSS

2. **TUFF**: Rock made of compacted volcanic ash.
4. **IGNIMBRITE**: Rock formed from high-temperature pyroclastic flows.
5. **PLEISTOCENE**: The "Ice Age" epoch.
6. **CONGLOMERATE**: A coarse-grained sedimentary rock.
8. **ALLOCHTHON**: A large block of rock moved far from its original site.
10. **GREYWACKE**: Hard, dark sandstone forming the New Zealand mountain ranges.
11. **LIMESTONE**: Sedimentary rock common in Waitomo.
13. **FAULT**: A fracture in the crust (e.g., the Alpine Fault).
16. **BATHOLITH**: A very large mass of intrusive igneous rock.
18. **GRANITE**: Coarse-grained intrusive rock often found in the South Island.
20. **BASALT**: Fine-grained volcanic rock common in Auckland.
21. **DACITE**: Volcanic rock between andesite and rhyolite in composition.

DOWN

1. **PUMICE**: Porous volcanic rock that can float.
3. **QMAP**: The national geological map series of New Zealand.
5. **QUATERNARY**: The current period of the Cenozoic Era.
7. **MURIHIKU**: A major geological terrane found in the Waikato & Southland.
9. **HOLOCENE**: The current geological epoch (last 11,700 years).
12. **TURBIDITE**: Deposit from an underwater sediment flow.
15. **ANDESITE**: Volcanic rock typical of Mt. Ruapehu.
17. **TECTONIC**: Relating to the processes that shape the Earth's crust.
19. **MAGMA**: Molten rock beneath the surface.

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