Dynamic New Zealand, Dynamic Earth: Auckland 2017
Annual Conference of the Geoscience Society of New Zealand

Field Trip 6
Saturday 2 December – Sunday 3 December 2017

Fossil highlights of Auckland

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Bibliographic reference:

Hayward, B. and Geary, I. (2017). Fossil highlights of Auckland. In: Brook, M. (compiler). Fieldtrip Guides, Geosciences 2017 Conference, Auckland, New Zealand. Geoscience Society of New Zealand Miscellaneous Publication 147B, 37 pp.

ISBN: 978-0-9922634-3-0

ISSN (print): 2230-4487

ISSN (online): 2230-4495

http://www.gsnz.org.nz

Caption for cover page:

Takapuna Reef fossil forest. Mould of the straight trunk of an un-tapered kauri tree that had collapsed into the upper parts of the flow and may have been rafted along by it.

FOSSIL HIGHLIGHTS OF AUCKLAND

Sat 2 December and Sun 3 December

Leaders Bruce W Hayward[1] and Ian Geary[2]
[1]Geomarine Research and [2]Department of Geology, University of Otago

Saturday 2nd Dec

Low tide East Coast 12.40 PM 0.6 m.
Low tide west coast 3.50 PM 0.5 m.

9 AM Leave Auckland University
Drive from Auckland University to Lake Pupuke end of Northcote Rd

AUCKLAND VOLCANIC FIELD

The Auckland Volcanic Field is an intra-plate field of 53 small monogenetic basalt volcanoes (Fig. 1) that have erupted in the last 200,000 years (Hayward et al., 2011; Leonard et al., 2017; Hopkins et al., 2017; Hayward, 2017a). All except Rangitoto are believed to have erupted on land into a forested landscape. The eruptions usually started off wet with magma interacting with ground water to produce phreatomagmatic eruptions of base surges and ash clouds. Later many eruptions became dry with Vesuvian fire-fountaining producing scoria cones and the effusion of basalt lava flows. These eruptions would have buried some of the nearby forest and set fire to others. In Auckland there are two excellent examples of fossil forests that were killed and buried by the local volcano.

STOP 1. 9.30-10 AM Pupuke Volcano - Northcote Rd volcanic sequence
Visit to set the scene for stop 2, as we wait for the tide to drop. Ar-Ar dating of Pupuke Volcano gives an age of 190,000-196,000 years (Leonard et al., 2017) making it one of the oldest volcanoes in the field (along with Onepoto).
Northcote Rd to Takapuna Fossil Forest (end of The Promenade)

STOP 2. 10.30 AM-Noon Takapuna Fossil Forest (Middle Pleistocene)
(toilets near reef carpark)

Here at Takapuna Reef and along the coastal walkway towards Milford is the best example in New Zealand of the remains of a forest that has been preserved in a lava flow. Takapuna Reef contains the basalt moulds of the lower portions of over 200 trees created by a lava flow passing through the standing forest to a depth of ~1 m (Hayward and Hayward, 1995). The hot lava from Pupuke Volcano cooled and congealed around the lower trunks of the trees creating the moulds. The roof of the lava flow also solidified and remains in some places forming arches between adjacent tree moulds. The still molten lava inside the flow then drained out and carried away much of the lava flow roof that probably collapsed into it. There is evidence in some places for a second pulse of lava flow passing through the forest to a depth of ~50 cm and creating outer moulds around the earlier ones and leaving more cooled solidified basalt in between. Unlike most Auckland volcanoes, Pupuke Volcano appears to have started with dry lava flow and scoria eruptions and later water got into the vent and generated phreatomagmatic eruptions of ash. The lava flow at Takapuna reef and beyond was buried by at least 5 m of ash cover which seems to have protected the flow and fossil forest from weathering until it was exhumed by marine erosion in the Late Holocene.

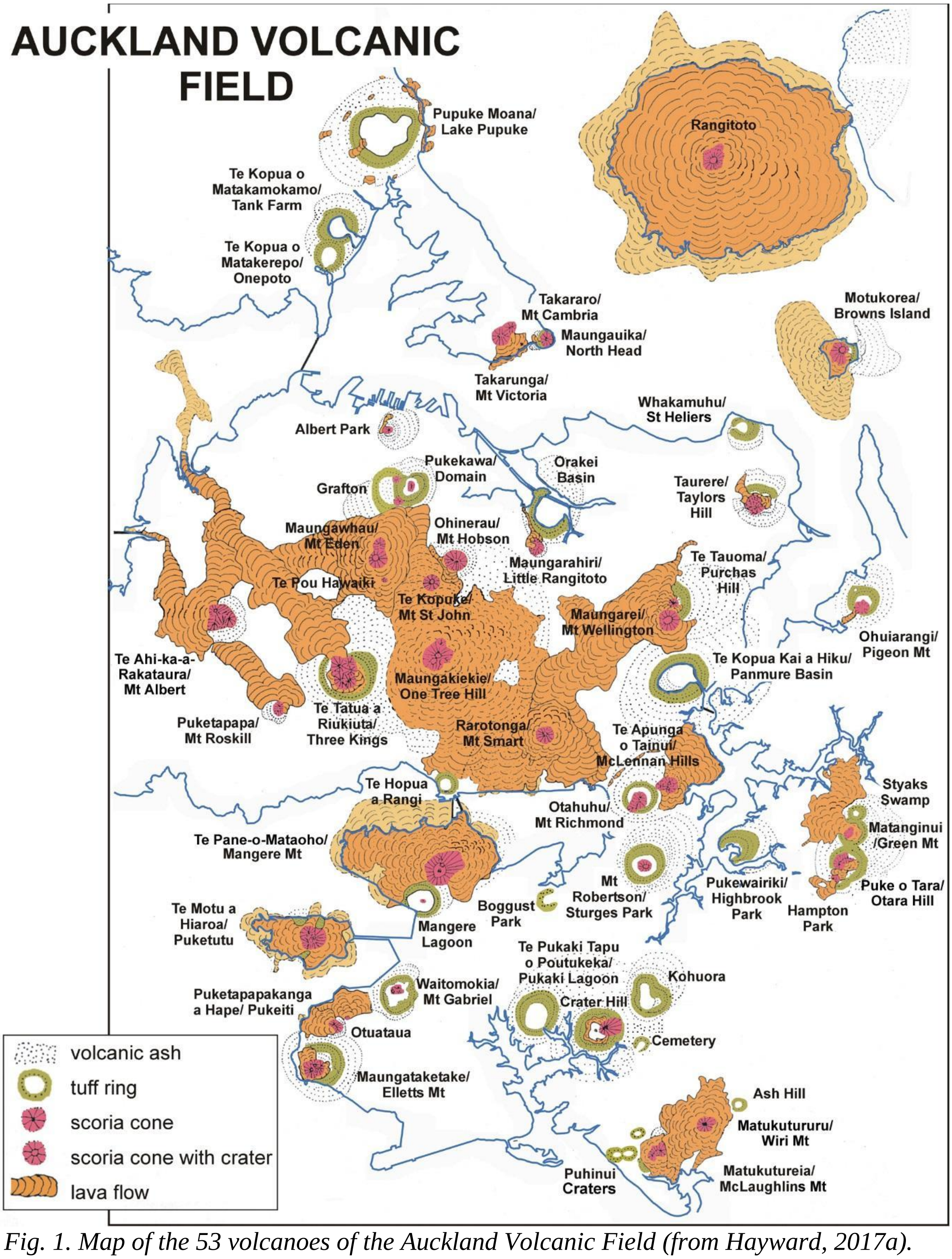


Fig. 1. Map of the 53 volcanoes of the Auckland Volcanic Field (from Hayward, 2017a).

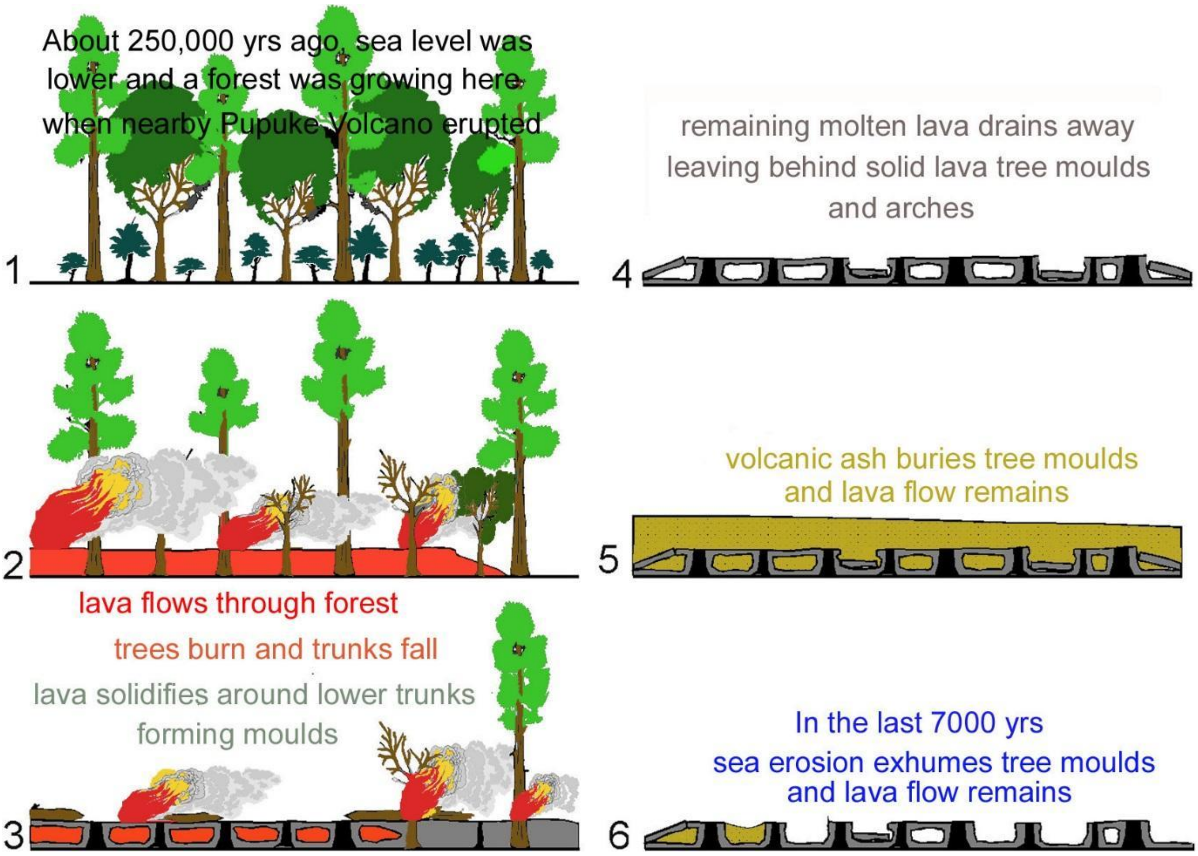


Fig. 2. Cartoons showing how it is envisioned that Takapuna fossil forest was formed. Diagrams by Hugh Grenfell (from Hayward et al., 2011).

In the reef there are a few moulds of the horizontal trunks of trees that presumably collapsed into the flow and were rafted along within its upper parts.

We will walk along the rough walkway towards Milford to see the moulds of several in-situ 1-1.5 m diameter kauri tree trunks and the moulds of numerous trunks and branches in the upper part of the flow. Other features will include pahoehoe lava flow surfaces, gas blisters and small lava caves with lava stalactites and stalagmites and segregation veins within the basalt (Allen and Smith, 1991; Hayward et al., 2011).

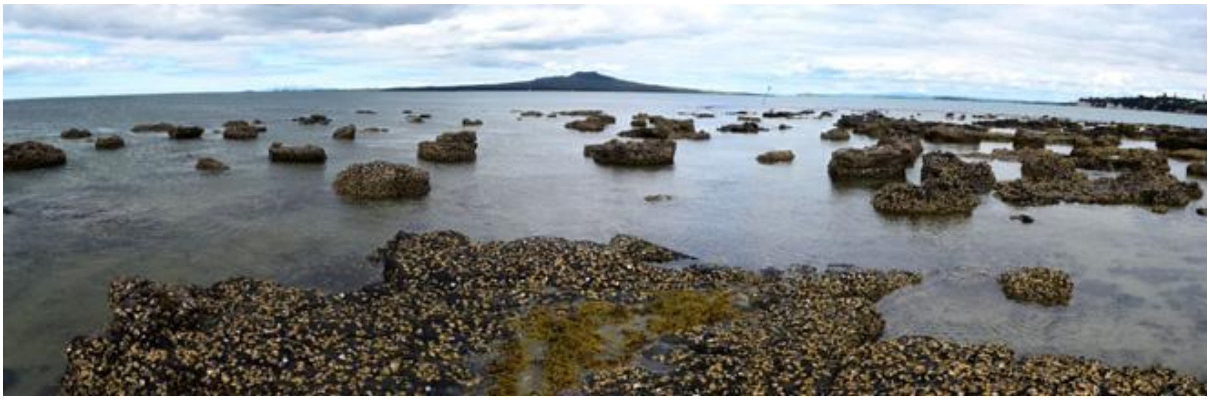


Fig. 3. Mid tide showing many of the basalt tree moulds of Takapuna Reef fossil forest.

Fig. 4. Mould of the straight trunk of an un-tapered kauri tree that had collapsed into the upper parts of the flow and may have been rafted along by it.

12-12.45 PM Drive from Takapuna to Muriwai 42 km, 45 mins

12.45-1.15 Lunch (provided) at Muriwai (Maori Bay carpark and toilets)

The Maori Bay carpark is located in the old quarry that worked the north end of the internationally significant Maori Bay pillow lava flow (Hayward, 1976a, 1979). Quarrying was halted in the mid 1970s as a result of a campaign by locals assisted by GSNZ.
The volcaniclastic sedimentary rocks forming the cliffs for several kilometres south of Muriwai were deposited about 17 Myr ago (middle Altonian) on the lower north-eastern submarine slopes of the large Waitakere Volcano.

The Maori Bay lava flow sits conformably on a deep-water sequence of volcaniclastic sandstone and mudstone containing sparse macrofossils and trace fossils (Powell, 1935; Hayward 1976b, 1976c; Hayward and Buzas, 1979). A 2 m thick bed of volcanic conglomerate (debris flow deposit) contains rare macrofossils (including rare reef coral heads) from a shallow marine tropical environment (Hayward, 1976c, 1977a). The tide will be too high and we will not have time to examine this section close up.

If we have time we may take the tourist track to Otakamiro Pt to view the gannet colony and the Maori Bay cliffs from a distance.

Fig. 5. Maori Bay cliffs contain an early Miocene pillow lava flow overlying deep-marine volcaniclastic sedimentary rocks.

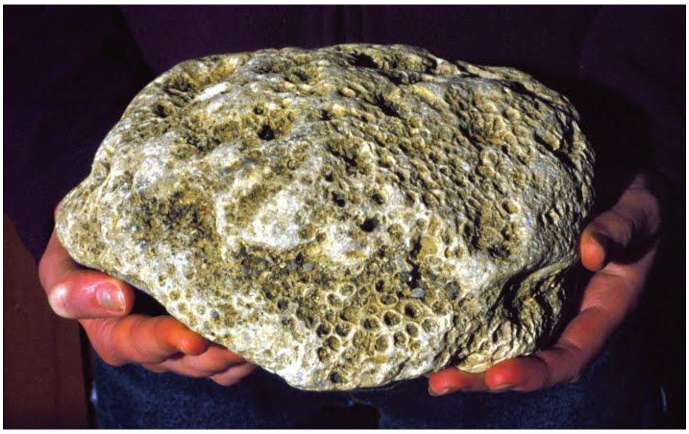


Fig. 6. The best example of a fossil reef coral head to come out of the volcanic conglomerate debris flow deposit at south end of Maori Bay.

STOP 3. 1.15-1.45 PM Muriwai moa foot prints (Early Pleistocene)
We will turn right out of Maori Bay and drive uphill to park in Ngatira Rd and walk up Waitea Rd (watch out for cars - wear reflective jackets).

This road cutting exposes Early Pleistocene weakly cemented sandstone that was deposited as part of a coastal sand barrier (Kaihu Group) that stretched northwards from here as the South Kaipara Peninsula. Nearby a white rhyolitic tephra within the sequence has been identified by glass shard chemistry as Potaka Tephra with an age of ~1 Myr (Claessens et al. 2009). The sequence sits on an unweathered undulating unconformity of Early Miocene Waitakere Group rocks at elevations of 40-105 m ASL - suggesting there has been considerable uplift in the last 1-2 Myrs. This road outcrop is 60-70 m above sea level.

The road cutting contains horizontally bedded sands with numerous sedimentary and other features made more clear by laminae of rusty-orange oxidised black sand within the quartz-dominated sands (Hayward, 2016a). Beneath the horizontally bedded unit there is cross-bedded dune sand, but the horizontal bedded unit appears to have been deposited in a wet/watery setting. Some flaser bedding is suggestive of sand ripples, perhaps developed on the edge of a dune lake. In addition to the sedimentary features there are some unusual vertical compressional traces, reminiscent of the dinosaur footprints discovered by Greg Browne at Whanganui Inlet, NW Nelson, a few years ago.

In these compressional features one can see laminae that have been depressed downwards and compressed and in places broken and displaced downwards. These are consistent with some form of heavy object landing in wet sand and then being removed. There is no evidence to suggest that large boulders falling off a cliff could have been responsible. Therefore the most likely cause seems to be a large animal walking along the damp sand at the edge of an un-vegetated dune lake (there is no peat or carbonaceous deposits). In the Early Pleistocene the most obvious candidate is one of the larger species of moa. Close examination of the best exposed part of the cliff shows evidence of perhaps 6 or more “moa footprints” (Hayward, 2016a). Do you agree that this is the most likely interpretation of these features?

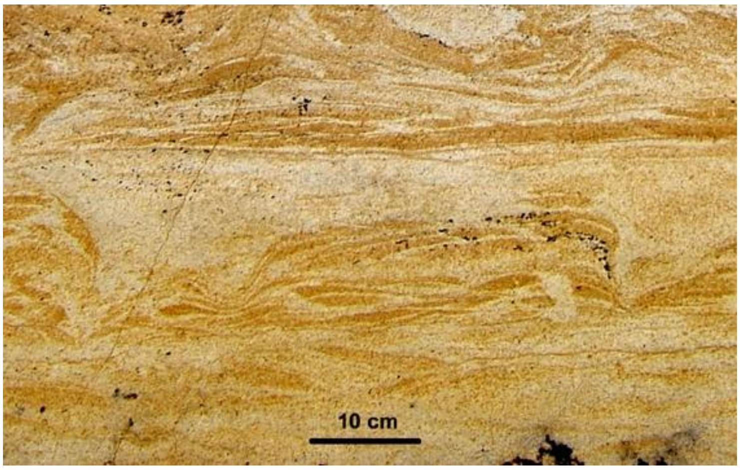


Fig. 7. Compressional "moa footprints" seen in cross-section in Early Pleistocene weakly cemented sandstone (Kaihu Group). Note also the flaser sand lozenges suggestive of ripples.

STOP 4. 2-4.30 PM Bartrum Bay Early Miocene deep-water body and trace fossils

We will drive down a long, narrow, steep private road and park at end. From there we walk down through private property (permission has been obtained from the owner), down wooden steps over low cliffs and further along a private walking track. We will detour through the flax and descend a steep slippery slope to a small creek bed with a 20 m boulder clamber to the back of Bartrum Bay beach. This descent (and ascent) is the most difficult on the trip and not suitable for those who are physically challenged. If you feel you cannot go on, please tell the trip leader and we may suggest that you enjoy the views for an hour or so while we are down on the coast. If you are diffident we promise that your efforts will be rewarded with some spectacular geology and fossils.

After spending an hour or so at Bartrum Bay we will re-ascend the slippery slope and then pick up the private track again and descend down steps cut in rock to the shore platform between Bartrum and Powell bays and from there walk into Powell Bay. The return trip will be back up the same track to the vehicles.

Note that Bartrum and Powell bays are named after geologist/palaeontologist Prof John Bartrum, University of Auckland, who published on an enigmatic fossil from here (Bartrum, 1948) shortly before his death; and for Dr Baden Powell, malacologist and palaeontologist at Auckland Museum, who described new fossil molluscs from the shore platform south of Powell Bay (Powell, 1935).

On the descent into Bartrum Bay we will have excellent views of a 8 m-diameter lava pillow with feeder dike that was intruded into these near seafloor sedimentary rocks (Early Miocene, middle Altonian, ~17 Myr).

Fig. 8. View from descent to Bartrum Bay showing basaltic andesite pillow with feeder dike intruding the volcaniclastic sedimentary strata. People for scale.

At Bartrum and Powell bays, the cliffs are made of volcaniclastic sedimentary rocks mapped in two formations. The older Nihotupu Formation is finer-grained, well-bedded volcanic mudstone and sandstone containing lower bathyal (1000-2000 m) fossil foraminifera (Hayward, 1976a; Hayward and Buzas, 1979; Hayward and Triggs, 2016). The younger Tirikohua Formation contains coarser and thicker bedded volcaniclastic grits, sandstones and elsewhere conglomerates, that unconformably overlie and fill submarine canyons and channels eroded in the Nihotupu Formation. The two formations appear to be middle Altonian with the older Nihotupu Formation possibly deposited at greater depths than the Tirikohua Formation. The Tirikohua Formation clearly contains sediments that would be regarded as more proximal to source than the Nihotupu, but this may more be a product of more direct downslope transport of coarse volcanic detritus in subaqueous mass flows than a result of geographic distance from source.

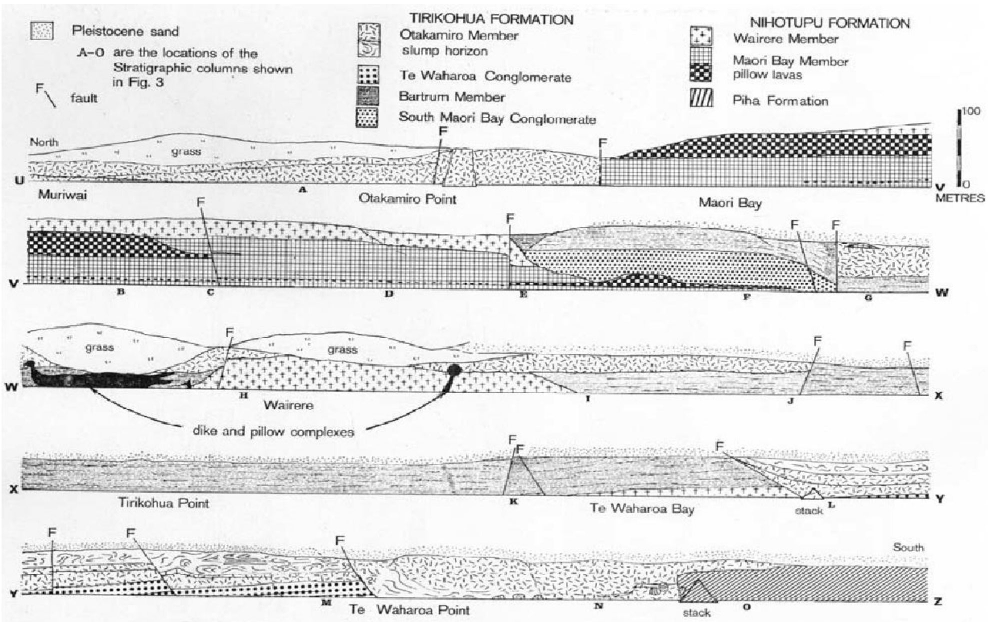


Fig. 9. Sketches of cliff section south from Muriwai (U). Powell and Bartrum Bay are located on either side of Wairere (section W-X). From Hayward (1976a)

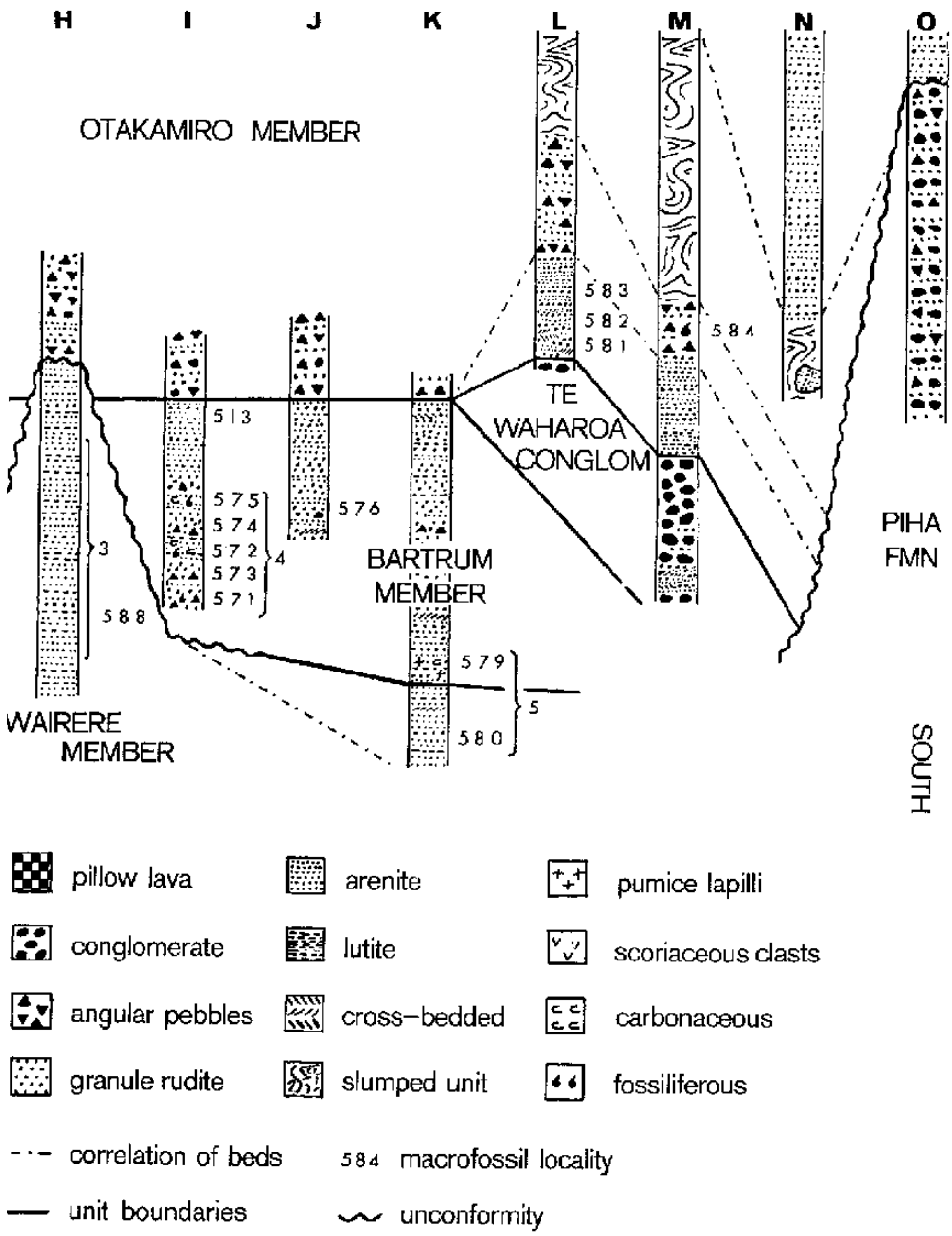


Fig. 10. Stratigraphic columns of cliff sections from Powell Bay (H) southwards. Bartrum Bay section is I. Fossil record numbers shown are pre-metric and should be in the range Q11/f7001-7999. From Hayward (1976a).

In the lower part of the cliff on the south side of Bartrum Bay is the erosional wall of a 1 km-wide, up to 100 m deep submarine canyon. The wall is intensely burrowed (Hayward, 1976c; Gregory and Campbell, 2005) showing that the sedimentary rocks were stiff and compacted but not cemented at the time of the canyon's formation. This is one of the very few places in the world (?only) where a trace fossil assemblage can be seen in the wall of a bathyal submarine canyon. Burrows include one of the few records in New Zealand of the ichnogenus *Rhizocorallium* as well as large vertical burrows clearly made by deep-water crustaceans.

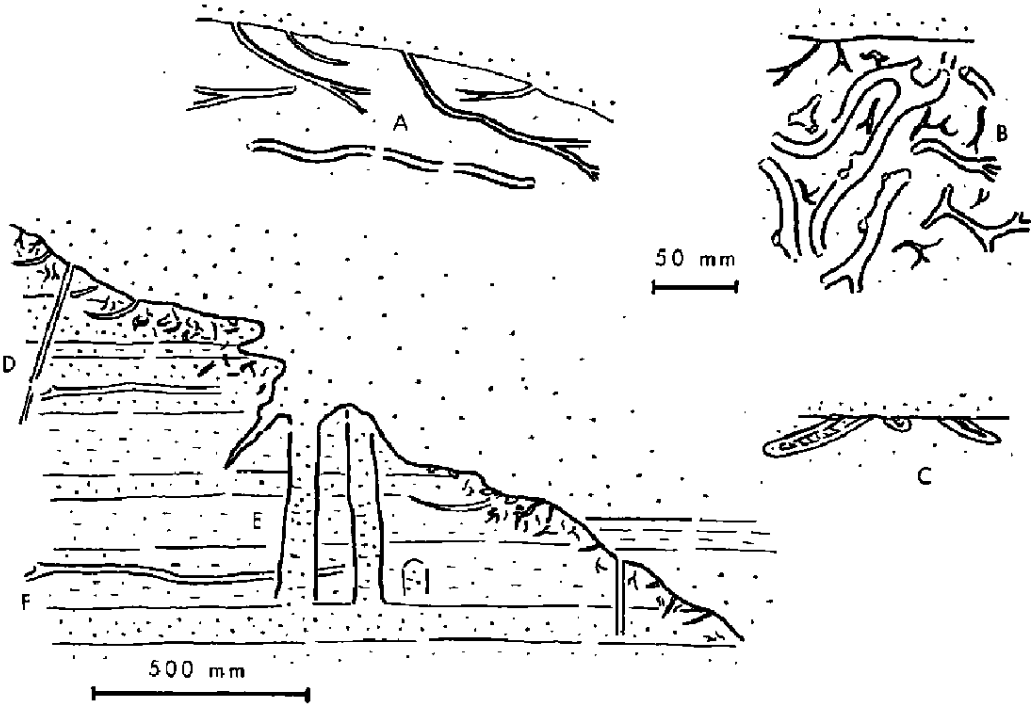


Fig. 7. Submarine canyon wall ichnocoenosis sketched from photographs. □A. Gently curved, inclined, branching burrows. □B. Intertwining branching burrows. □C. *Rhizocorallium* ichnosp. □D. *Tigillites* ichnosp. C. □E. *Tigillites* ichnosp. D. □F. Large horizontal branching burrows.

Fig. 11. Sketches of burrows from Early Miocene submarine canyon wall at Bartrum Bay (from Hayward, 1976c).

Fig. 12. Vertical crustacean burrows in wall of submarine canyon, now eroded away. (Hayward, 1976c).

Fig. 13. Low angle wall of the submarine canyon exposed on south side of Bartrum Bay, 2016.

Fig. 14. Cliffs on south side of Bartrum Bay (north side of Tirikohua Pt) are composed of 1-2 m-thick coarse sandstone beds that fill this part of the submarine canyon.

In the cliffs on the south side of Bartrum Bay (Fig. 14) a series of 1-2 m-thick, volcaniclastic sandstone beds fill this part of the submarine canyon (Tirikohua Formation, Bartrum Member, middle Altonian, Early Miocene). These appear to be a series of proximal turbidites that were deposited on the canyon floor on the lower slopes of the Waitakere Volcano before reaching the Waitemata Basin proper. The sandstones contain numerous trace fossils including the mud-lined open burrow networks of ichnotaxon *Ophiomorpha nodosa.* Note the increased bioturbation in the carbonaceous horizons near the tops of the sandstone beds. Can you see any escape traces made by organisms trying to burrow to the surface out of the sand that may have transported them down the canyon?

These sandstone beds contain scattered macrofossils, often filled with recrystallized calcite. The most interesting is an unusual segmented tubular fossil that was first collected here in the 1940s by Auckland geologist Professor Bartrum (Fig. 15). He was so perplexed by its features that he published a picture of it in the international Journal of Paleontology (Bartrum, 1948), calling for suggestions as to what it might be, from the palaeontologists of the world. There is no record that there was any response. In the 1970s more specimens (Fig. 17) were found at the same bay, which now bears Bartrum's name. By more careful examination, it became apparent that there was an outer tube with the shape of a segmented fossil body inside (Hayward, 1977b). Both the tube and the external shape of the segmented body have been accentuated by later growth of calcite inside them. Hayward (1977b) postulated that these are extremely rare examples of the fossilised soft bodies of polychaete sabellid fan-worms preserved inside their parchment tubes (Fig. 16). Perhaps the only examples in the world of the fossilised soft bodies of polychaete worms in rocks deposited in the last 100 Myr. These worms were described and named *Archesabella bartrumi* Hayward, 1977. All the specimens found to date come out of several mass-flow beds of coarse volcanic sand that are inferred to have flowed as a sediment slurry down a submarine canyon on the side of the Waitakere Volcano, about 17 Myr ago. Judging by the number of fossil tubes with and without segmented bodies inside them, it appears that thousands of these fan worms were caught up in these submarine sediment slides as they flowed down the slopes. When the slurry came to a standstill, the fan worms were buried within the 1-2 m-thick beds. They had retreated to the innermost parts of their parchment tubes (Fig. 15), which filled with sediment, trapping the dying worms inside. The fine sediment that entered the tubes preserved the external segmented shape of the soft-bodied worms as moulds, which have later been lined or filled with secondary white calcite crystals.

Fig. 15. Original specimen of an unusual tubular fossil collected from Bartrum Bay by Prof Bartrum. It is the holotype of Archesabella bartrumi *Hayward, 1977. Length 15 cm.*

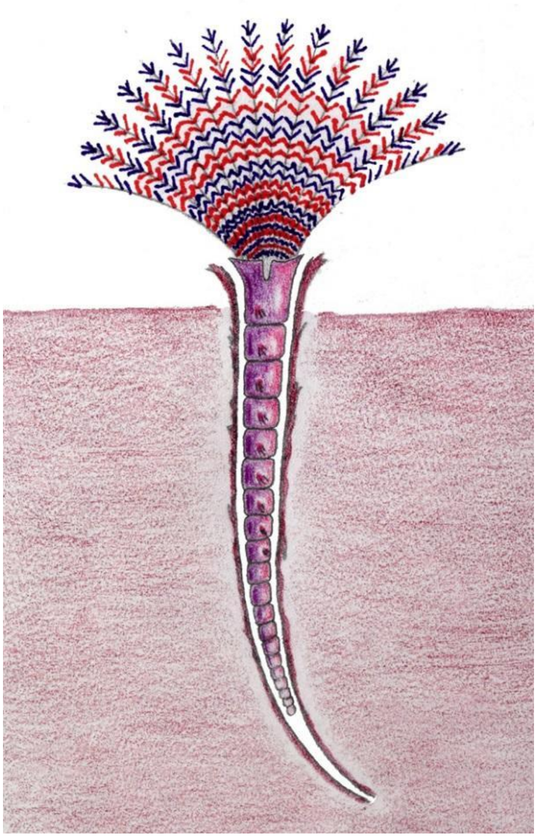


Fig. 16. Interpretative reconstruction of one of the many Archesabella *tube worms that were living in the source sediment prior to being transported down the submarine canyon in a turbidity current, buried and fossilised. Drawing by the Late Margaret Morley.*

Fig. 17. One of many fossil Archesabella *seen in the volcaniclastic sandstones at Bartrum Bay. Length of fossil 8 cm.*

In addition to the numerous inferred sabellid worm fossils, these canyon-filling sandstone beds contain a number of other macrofossils (Powell's 1935 fossil locality D) (Fig. 18), such as the pteropod *Vaginella depressa*, cephalopod *Aturia cubaensis*, *Monilea grantmackiei* Hayward, 1981, *Lucinoma taylori* (Powell, 1935), and solitary deep-water coral *Stephanocyathus* (Hayward, 1976b).

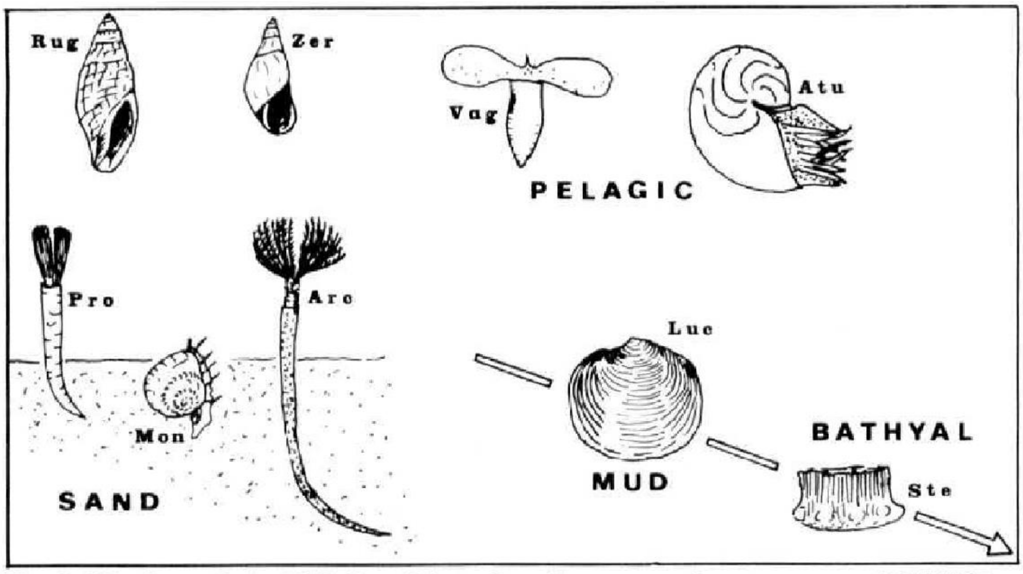


Fig. 9. Members of the Tirikohua Point submarine canyon thanatocoenoses (N41/f571 – f575). Inhabitants of a mid – neritic granular or coarse sand biotope around the top of the canyon are the annelids *Protula* (Pro) and *Archesabella* (Arc) and gastropods *Monilea* (Mon), *Rugobela* (Rug) and *Zeradina* (Zer). Probably picked up by the passing subaqueous mass flow were the mud dweller *Lucinoma* (Luc) and bathyal coral *Stephanocyathus* (*Odontocyathus*) (Ste). The remains of the pelagic molluscs *Vaginella* (Vag) and *Aturia* (Atu) are very common.

Fig. 18. Sketches of fossils found in the canyon-filling sandstones at Bartrum Bay (from Hayward, 1976b).

Powell Bay and Wairere headland

The shore platform and headland between Powell and Bartrum Bays (formerly referred to as Wairere) is composed of thin-bedded volcaniclastic sandstones and mudstones of the Nihotupu Formation (Wairere Member, Altonian, Early Miocene). These are the older sedimentary rocks, deposited at lower bathyal depths, that underlie and have been eroded into by the submarine canyon. Further exposure of the coarse volcaniclastic sandstone fill of the canyon and of a gently dipping section of canyon wall (with trace fossils) can be seen in the lower cliffs on the north side of Powell Bay (Figs. 19, 20). The headland between the two bays seems to exist because of the more erosion-resistant Bartrum Member rocks which here appear to form a secondary high between two eroded channels in a larger canyon.

The shore platform and high tide cliffs between the two bays is Powell's (1935) fossil locality C and has yielded a sparse macrofauna of lower bathyal molluscs and rare corals (Figs 21, 22). It is the type locality of ten mollusc species (Powell, 1928, 1935, Hayward, 1981). The macrofossil species list includes (Hayward, 1976b):

Gastropoda
Astele boileaui Marwick, 1931
Austrotoma cf. *clifdenica* Powell, 1942
Echinophoria multinodosa (Powell, 1928) Type locality
Echinophoria toreuma (Powell, 1928) Type locality
Gemmocolus gemmatus (Powell, 1935) Type locality
Gymnobela carinaria Powell, 1935 Type locality
Monilea grantmackiei Hayward, 1981 Type locality
Bathytoma mitchelsoni Powell, 1935 Type locality

Gemmula kaiparaensis (Marshall, 1918)
Comitas fusiformis (Hutton, 1877)
Echinoturris finlayi (Powell, 1935) Type locality
Bivalvia
Lucinoma taylori (Powell, 1935)
Myrtea maoria Powell, 1935 Type locality
Thyasira bartrumi Powell, 1935 Type locality
Thyasira motutaraensis Powell, 1935 Type locality
Nemocardium cf. *patulum* (Hutton, 1873)
Nucula sp.

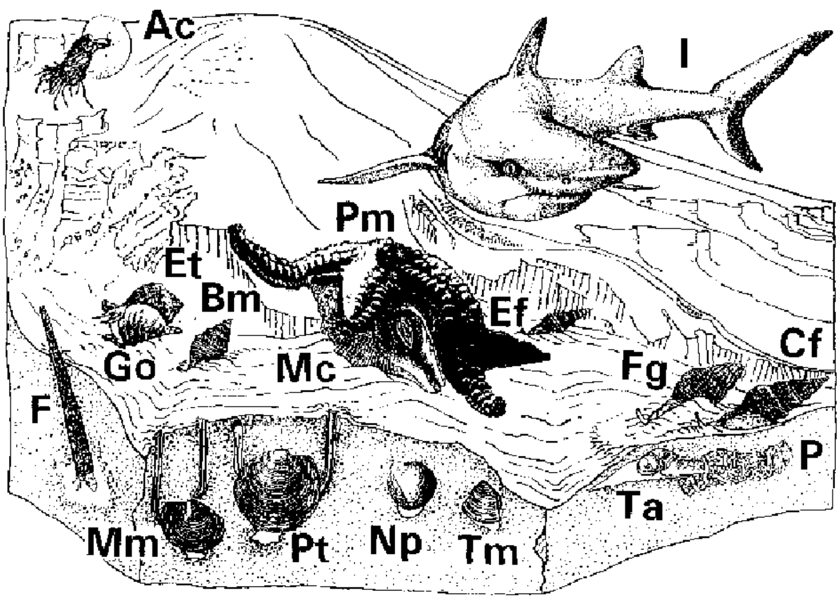
Scaphopoda
Cadulus delicatulus Suter, 1913
Dentalium mantelli Zittel, 1864
Dentalium ecostatum Kirk, 1880
Laevidentalium pareorense (Pilsbry & Sharp)

Scleractinia
Oculina virgosa Squires, 1958
Trochocyathus powelli Squires, 1962

Echinodermata
Pseudarchaster motutaraensis Eagle, 1999 Type locality

Fig. 19. Gently dipping submarine canyon footwall exposed in cliffs on north side of Powell Bay. Well-bedded Nihotupu Formation below and more massive Tirikohua Formation above.

Fig. 20. Trace fossil assemblage in the wall of the submarine canyon on north side of Powell Bay.



Eagle—New Miocene starfish 555

Fig. 10 Schematic drawing of the outer shelf to mid-bathyal mid-Altonian thanatocoenosis (800–2000 m) at Powell Bay, of which *Pseudarchaster moututaraensis* n. sp. is a member. No scale implied. Ac, *Aturia cubaensis*; Bm, *Bathytoma mitchelsoni*; Cf, *Comitas fusiformis*; Ef, *Echinoturris finlayi*; Et, *Echinophoria toreuma*; F, *Fissidentalium solidum*; Fg, *Falsicolus gemmatus*; Go, *Gemmula* cf. *orba*; I, *Isurus* sp.; Mc, *Marshallena carinaria*; Mm, *Myrtea maoria*; Np, *Nemocardium patulum*; P, polychate sp.; Pm, *Pseudarchaster motutaraensis*; Pt, *Pteromyrtea motutaraensis*; Ta, *Taniella motutaraensis*; Tm, *Thyasira motutaraensis* (Mollusca after Beu et al. 1990).

Fig. 21. Schematic reconstruction of the mid-lower bathyal fauna from Wairere Member between Powell and Bartrum Bays. By Eagle (1999).

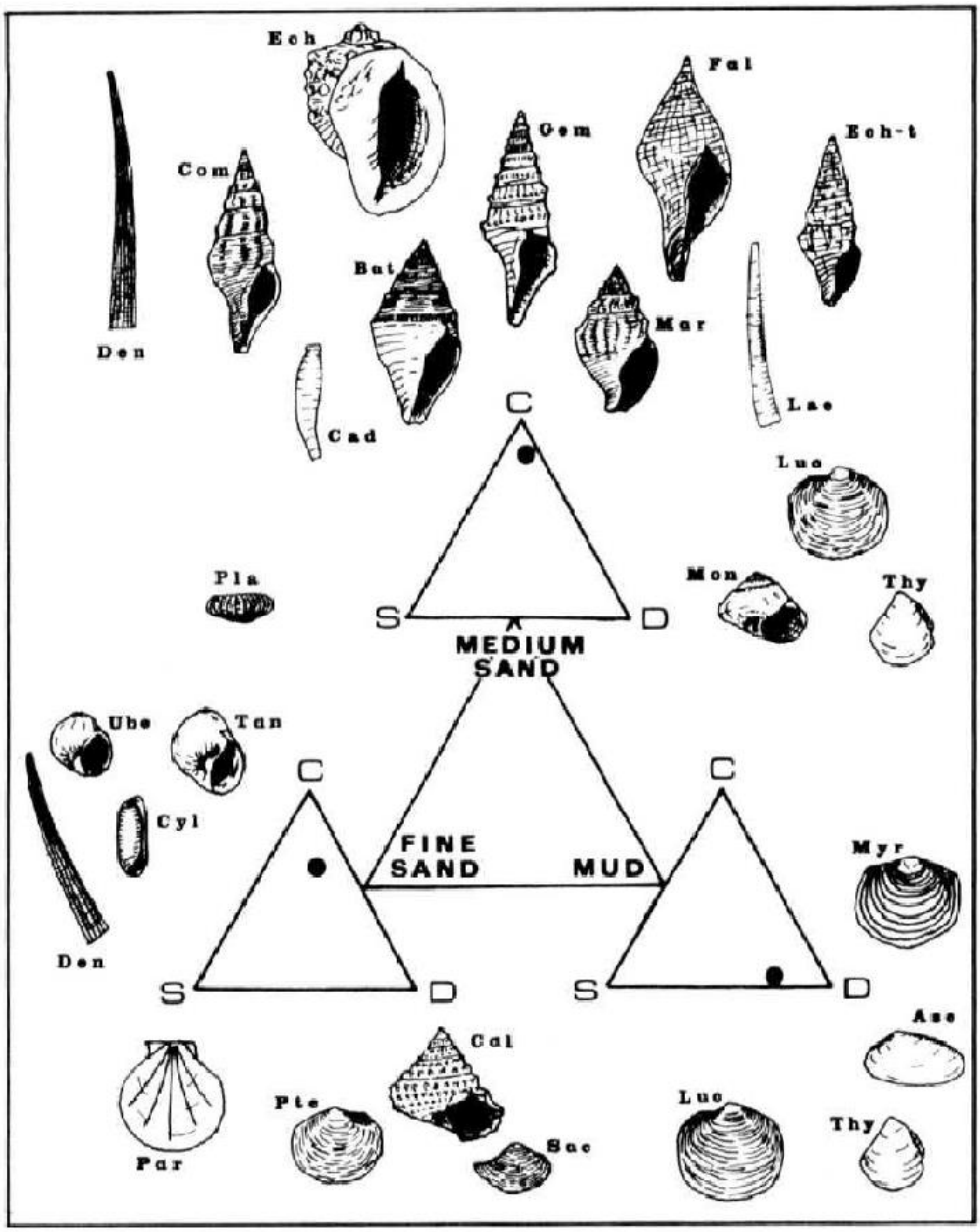


Fig. 10. Dominant members of the mid – lower bathyal undisplaced biocoenoses from Maori Bay. Mud biotope (N41/f2) – *Myrtea* **(Myr)**, *Ascitellina* **(Asc)**, *Lucinoma* **(Luc) and** *Thyasira* **(Thy).**

Fine sand biotope (N41/f589, part f1) – *Saccella* **(Sac)**, *Calliotropis* **(Cal)**, *Pteromyrtea* **(Pte)**, *Parvamussium* **(Par)**, *Dentalium* **(Den)**, *Cylichnania* **(Cyl)**, *Uberella* **(Ube)**, *Taniella* **(Tan).**

Medium sand biotope (N41/f3) – *Cadulus* **(Cad)**, *Dentalium* **(Den)**, *Laevidentalium* **(Lae)**, *Trochocyathus* (*Platycyathus*) **(Pla)**, *Comitas* **(Com)**, *Echinophoria* **(Ech)**, *Bathytoma* **(Bat)**, *Gemmula* **(Gem)**, *Marshallena* **(Mar)**, *Falsicolus* **(Fal)**, *Echinoturris* **(Ech-t)**, *Lucinoma* **(Luc)**, *Monilea* **(Mon)**, *Thyasira* **(Thy).**

Trophic level composition, using number of individuals, is plotted for each biotope. (D = deposit feeders, S = suspension feeders, C = carnivores).

Fig. 22. Sketches of many of the lower bathyal fossil molluscs that have been recovered from Maori Bay (lower) and from Wairere Member between Powell and Bartrum Bays (upper half - medium sand biotope, N41/f3).

Fig. 23. Specimen of Echinophoria toreuma *(Powell, 1928) from Wairere Member, south end of Powell Bay.*

Drive Muriwai to Auckland University 41 km, 45 mins
5.30 PM Return to Auckland University

Sunday 3rd Dec

Low tide East Coast 1.30 PM, 0.5 m
Low tide West Coast 4.30 PM, 0.3 m

9 AM Leave Auckland University.
Auckland to Ponga Rd 45 km, 45 mins

STOP 5. 9.45-10.45 AM Drury Late Eocene fossil leaves and freshwater mussels

The Drury Coalfield is at the northern end of the Hunua Ranges. In the 1850s, the fathers of Auckland were looking for a nearby source of coal to power the township. The Rev Guyon Purchas was shown some black coal in Symonds Stream by local Maori and the Provincial Council sent out a call for a geologist to come and assess the resource as a potential godsend for the then capital of New Zealand. They heard that there was a young geologist on an Austrian frigate, the Novara, that was planning to visit Auckland. So they asked the Novara expedition leaders if Ferdinand Hochstetter might have a look at the Drury coal while here. This was the very first thing he did and he wrote a reasonably favourable report. Over the years many small mines were open but only a small amount of coal was recovered (Kear, 1959). The single, up to 2 m thick seam, was commonly displaced by faulting and lost underground.

Hochstetter (1859) collected and described fossil leaves from two of a number of localities of mining interest in the Drury Hills and also recorded the presence of freshwater mussel fossils. Unger (1864) described and named 7 species of leaf from Hochstetter's leaf collections from localities that are no longer exposed. Penseler (1930) recorded leaves from further south in the Waikato Coal Measures and updated Unger's identifications from Drury. The leaf flora is currently the subject of a modern review of Australasian Eocene floras by John Conran and others. Palynological studies indicate that the Drury coal measures span the boundaries between the two subzones of the Late Eocene-Early Oligocene *Nothofagidites matauraensis* biozone (Ar-eLwh) (Edbrooke et al., 1994).

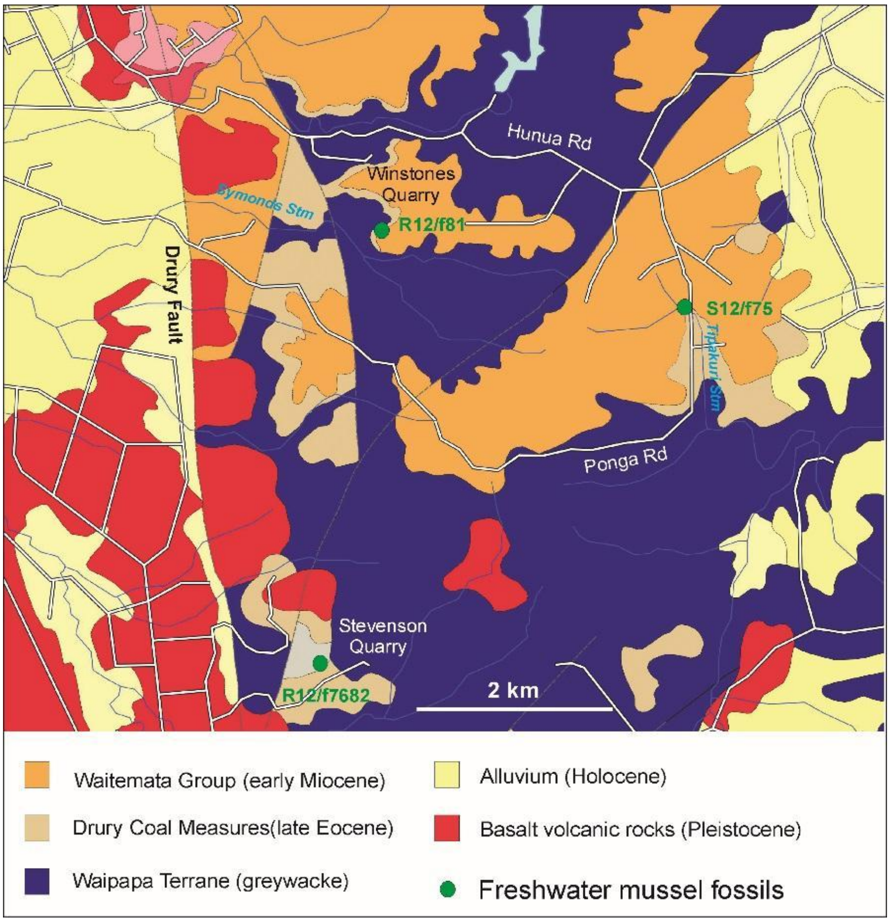


Fig. 24. Location of Late Eocene fossil freshwater mussels and leaves in the Drury Coal Field. Geology from GNS Science QMap.

Tipakuri Stream exposure

This involves a short scramble down a sloping bank under forest to the small stream bed. There is room for only three people on the exposure at once for those happy to get wet feet.

This recently discovered fossil locality (S12/f75) occurs in a massive grey mudstone of unknown thickness (5 m+) that is inferred to overlie the coal seam (in road cut). This same lithology containing similar leaf and freshwater mussel fossils (Hayward, 2017b) has been collected from localities 3 and 5 km away to the west (Fig. 24). This mudstone probably accumulated in a freshwater lake or lakes.

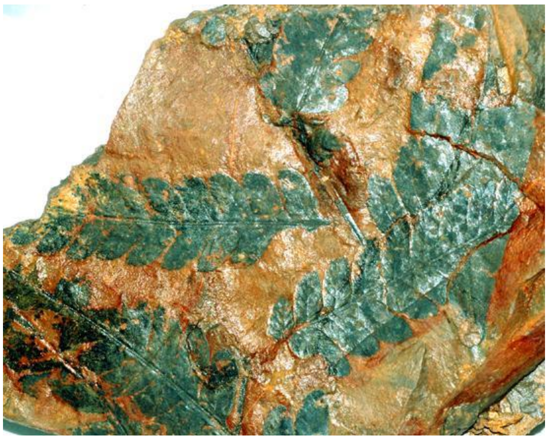


Fig. 25. Fossil fern from Tipakuri Stream exposure of Waikato Coal Measures (S12/f75).

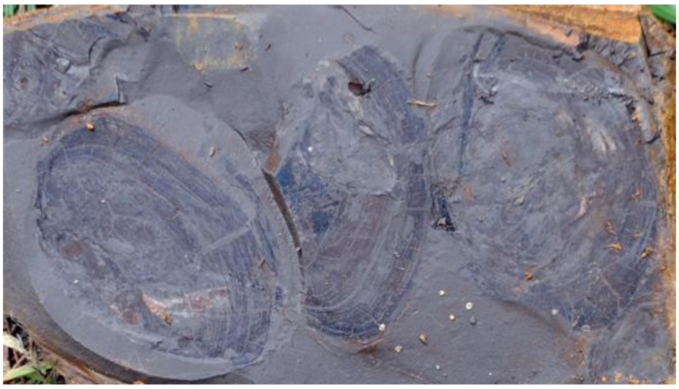


Fig. 26. Fossil impressions of an undescribed freshwater mussel from the Tipakuri Stream exposure (S12/f75).

Roadside coal exposure

We will drive 500 m along the road to view a road cut through the Eocene coal seam containing sparse lumps of fossil amber. Reflective jackets should be worn in case a car comes along.

Fig. 27. Ponga Rd road cut through coal seam and inset fossil amber.

Ponga Rd to Beachlands 36 km, 45 mins

Auckland in the Late Pliocene

There are a few clues to the geography of the South Auckland Region in the Late Pliocene (~4-3 Myr). Exposures of Puketoka Formation s.s. (Hayward & Grenfell, 2010) at Puketoka, Kidds Beach, Karaka Pt and Whitford (Fig. 28) contain conglomerate with boulders, cobbles and pebbles of quartz reef, flow-banded rhyolite and silicified wood that must have been sourced from the Coromandel Volcanic Zone (Battey, 1949; Hayward et al., 2006; Hayward & Mauk, 2011). These indicate that the Hauraki Rift had probably not started foundering at this time. It was probably land with rivers flowing west from the Coromandel Range over the Rift and through down-faulted half grabens in the basement greywackes to the sea in the Manukau Lowlands area. Red chert (jasper) probably eroded from the Waiheke Island-north Hunuas area of Waipapa Terrane greywacke and is found as abundant pebbles at Kidds Beach and in lower densities at Karaka Pt, Weymouth and Beachlands (Fig. 28). Sediments and fossils, of inferred Late Pliocene age, that accumulated in fluvial, estuarine and harbour flat environments occur in the half grabens or on the Manukau Lowland. Two of these localities (Beachlands, Weymouth) will be visited today, making use of the low tides that on the west coast are three hours later than on the east coast.

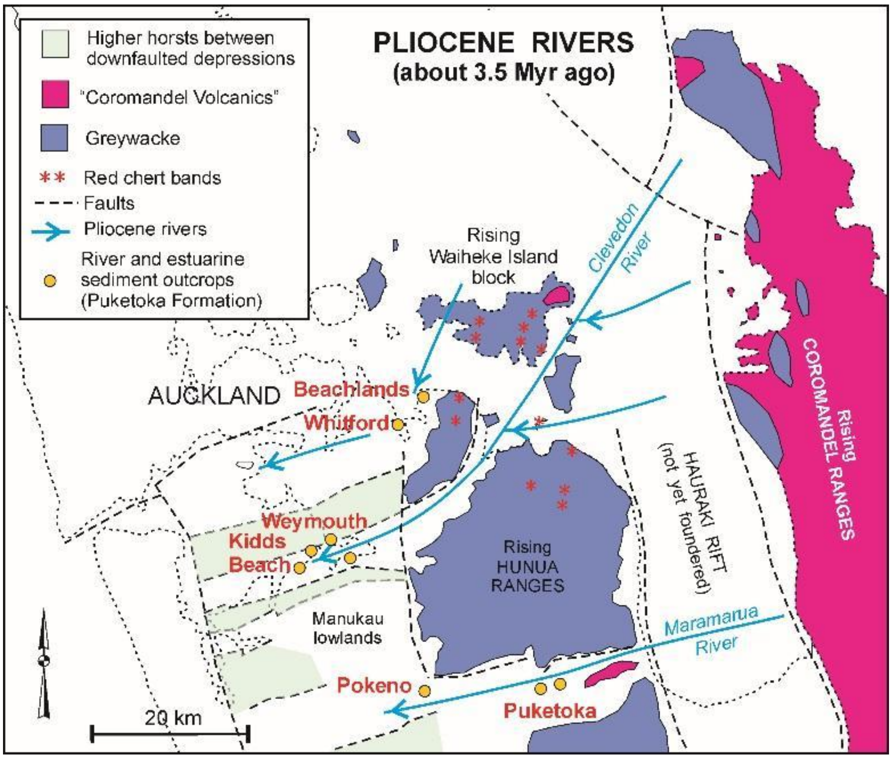


Fig. 28. Skeletal geological map with inferred Late Pliocene rivers and main localities where rocks and fossils of this age can currently be seen. From Hayward (2017a).

STOP 6. 11.30 AM-12.45 PM Beachlands Pliocene estuarine and fluvial plant fossils

Beachlands is a coastal eastern suburb of Auckland (Fig. 28) with early Miocene, probable Pliocene and Quaternary aged sediments that each yield some insight into the floras of their time. Here we will walk around the coast examining Pliocene and some Miocene rocks and their plant fossil component. Take care near cliffs as we will be walking around a coast that experiences slipping and block fall. Also take care walking on exposed shore platforms because these are frequently coated in modern silt and therefore slippery.

Early Miocene sedimentary rocks

Like much of Auckland's eastern coastline, a dominating feature at Beachlands is cliffs of Waitemata Group (Otaian, early Miocene) sandstone and siltstone that bound beaches and form extensive shore platforms and reefs (Glading, 1987; Tejakusuma, 1998; Edbrooke, 2001) (Fig. 29). The uplifted, faulted and deformed deep marine sedimentary rocks of the Waitemata Group here belong to the East Coast Bays Formation with sandstone turbidites and thin overlying beds of mudstone (Ballance, 1976; Tejakusuma, 1998). A thin (0.5 to 20 cm) woody carbonaceous horizon is found atop most turbidites (Tejakusuma, 1998), which at Beachlands also yields occasional seeds (Figs. 29, 30). These seed fossils are well preserved and several types are currently recognised, including small 'cones' of Casuarinaceae and very rare specimens attributable to Malvaceae.

Fig. 29. Dipping Waitemata Group sediments forming the cliff and shore platform at Beachlands (younging to the right). The plastic container sits on top of a woody carbonaceous horizon where plant fossils can be found.

Fig. 30. A 2 cm fruit/seed found within the Waitemata Group at Beachlands.

Pliocene sediments

Puketoka Formation sediments at Beachlands were deposited within a patchwork of paleovalleys incised into the Waitemata Group (Glading, 1987; Tejakusuma, 1998; Hayward, 2017a). The age of Puketoka Formation sediments here is a little uncertain. Palynology indicates a Miocene age (pers. comm., Dallas Mildenhall, 2015) but these age-diagnostic pollen and spores are probably reworked from the Waitemata Group. The Puketoka Formation sediments of Beachlands could be similar in age to those of Weymouth (late Pliocene, ~3-4 Ma) with which they share many similarities. The inferred depositional environments at Beachlands are varied and include fluvial and estuarine/muddy river sediments with abundant fossil plant material that has been organically preserved as wood (logs, branches, stumps and roots), leaves, fruits (and seeds and cones), amber, pollen, spores and mosses (Fig. 31, 32, 33). Note that while most fossils are organically preserved, some wood specimens are silicified (usually poorly).

Numerous fossil fruit taxa are recognised and those presently identified suggest a flora highly discordant to that of modern northern New Zealand. Only a few fossil fruit taxa found here are recognised as possibly ancestral to New Zealand's modern species (e.g. *Elaeocarpus*, *Prumnopitys* and *Passiflora* specimens). Conversely some taxa clearly share affinities with groups that are currently distributed in Australia, New Caledonia/Papua New Guinea (e.g. Menispermaceae, Vitaceae, *Brassospora*-type *Nothofagus* and locally extinct taxa of *Elaeocarpus*). Interestingly, many types share as yet uncertain affinities (Fig. 31). Also of interest are the diverse fossil mosses that are found here (Fig. 32). Moss fossils are not commonly documented and only two other instances of their preservation are recorded from New Zealand (see Thorn, 2001; Mays et al., 2015).

Other fossils of note include bracket fungus basidiocarps, many of which belong to Ganodermataceae (Fig. 33). Woody bracket fungi are one of the more commonly preserved types of fungal macrofossils owing to their more durable composition, although they are still rarely encountered as fossils with just one other specimen reported from New Zealand (see Penseler, 1930). Microfossil arthropod remains such as mites (Acari) and fragments of beetle exoskeleton are also sometimes found.

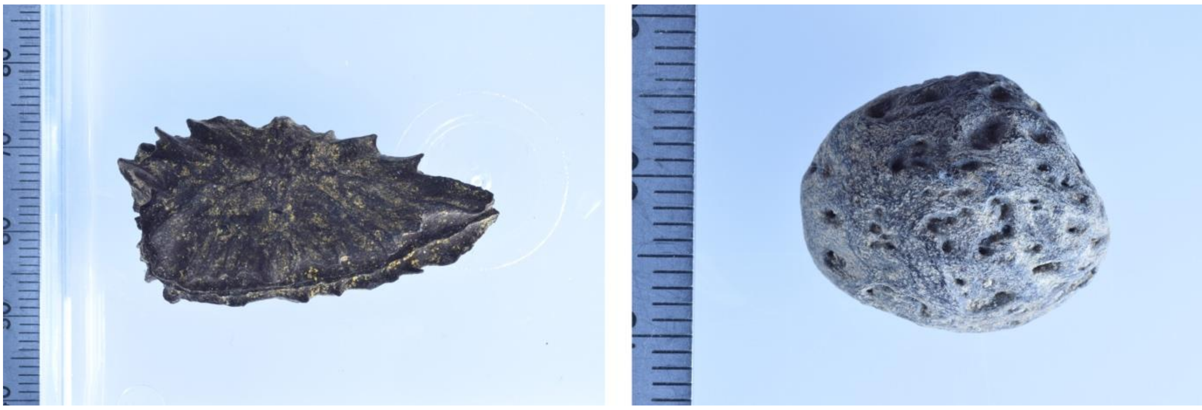


Fig. 31. Two Pliocene fossil fruits/seeds collected from Beachlands (scale: notches on ruler are mm).

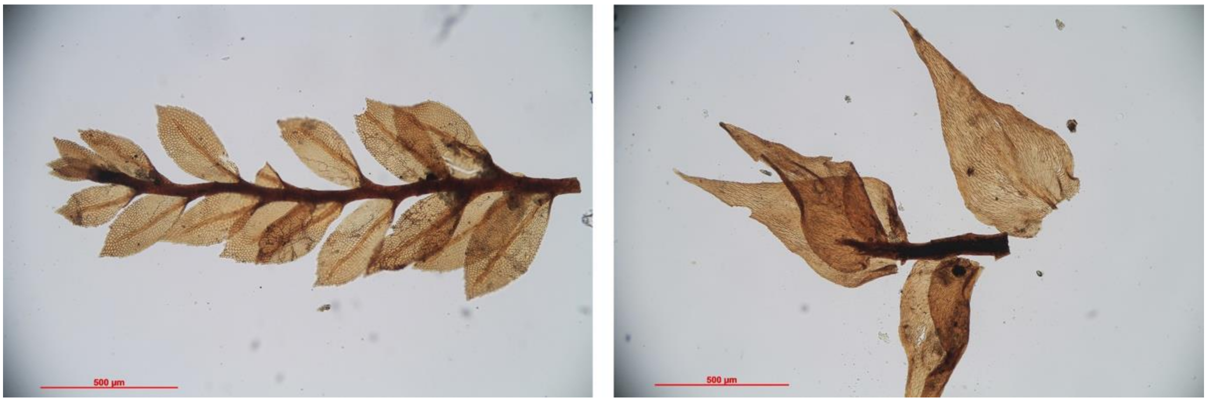


Fig. 32. Two Pliocene fossil mosses collected from Beachlands (0.5 mm scale bars).


Fig. 33. Your leader (Ian Geary) holding a large bracket fungus basidiocarp fossil collected from the Pliocene sediments of Beachlands.

Quaternary sediments

Overlying the inferred Pliocene Puketoka Formation sediments [unconformably?], are Pleistocene sediments attributed to the Puketoka Formation by Glading (1987), Tejakusuma (1998) and Edbrooke (2001), but here placed in the Tauranga Group. ss. These sediments are associated with mid-Pleistocene tephra (~1-1.2 Ma) that can be dated or correlated by analysing their volcanic glass component (Tejakusuma, 1998). Plant fossils such as wood and leaves have been observed from these sediments (Firth, 1930; Glading, 1987; Tejakusuma, 1998; pers. obs., Ian Geary).

An interesting feature exposed near the wharf at Sunkist Bay, Beachlands, is the relatively young Beachlands Fault that offsets Miocene and Quaternary sediments, including a pre-Ongatiti tephra (pre-1.2 Ma; Tejakusuma, 1998; Alloway et al., 2004, Hayward, 2016b) (Fig. 34).

12.45-1.15 PM Lunch (provided) (toilets at Sunkist Bay)

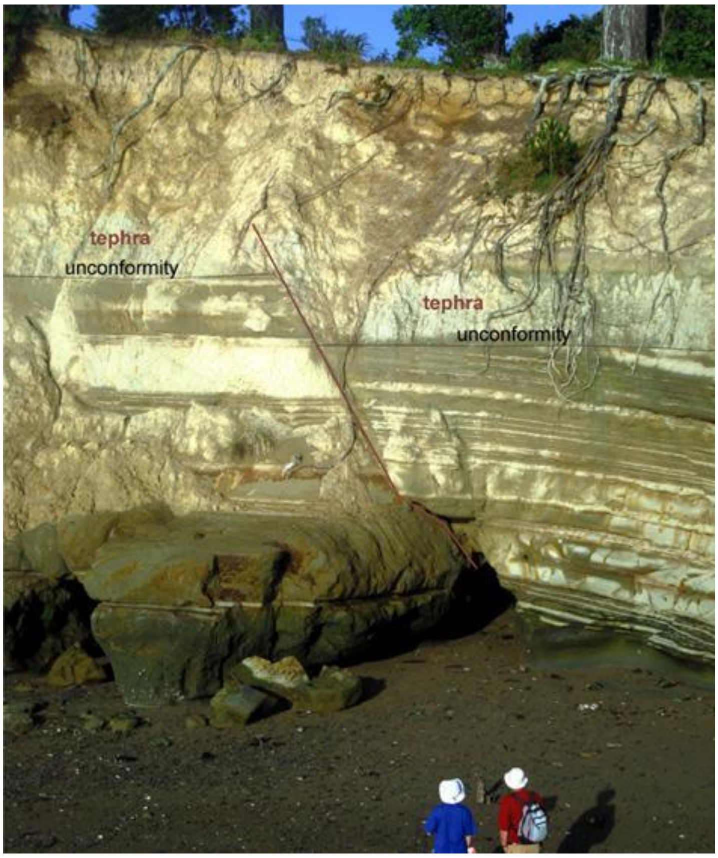


Fig. 34. Beachlands Fault (viewed from Beachlands wharf, Sunkist Bay) provides evidence for Late Quaternary tectonism in Auckland. It displaces a pre-Ongatiti Tephra (Tejakusuma, 1998; Alloway et al., 2004; Hayward, 2016b).

1.15-2.00 PM Beachlands to Weymouth 31 km, 40 mins
End of Roys Rd (toilets)

STOP 7. 2.00-3.30 PM Weymouth Pliocene estuarine shell and plant fossils

Weymouth is a coastal, southern Auckland suburb situated approximately 21 km southwest of Beachlands (Fig. 28). Weymouth, like Beachlands, has extensive Pliocene (Puketoka or Kaawa Formation) and Quaternary sediments (Tauranga Group), which unconformably overly Waitemata Group (Miocene) sedimentary rocks (Moore & McKelvey, 1971; Edbrooke, 2001) (Fig. 35). At Weymouth the Pliocene sediments yield not only a well preserved, diverse fossil plant assemblage, they also yield an associated mollusc macrofauna that can be used for biostratigraphic correlation (Moore & McKelvey, 1971). Depositional environments here include sheltered estuarine, intertidal and near shore paleoenvironments, yielding common and identifiable fossils (Figs. 35, 36, 37, 38). Walking around the coast we will examine the Pliocene fossil plant flora and mollusc macrofaunas from sites previously documented by Moore and McKelvey (1971) and from several new sites.

Fig. 35. Carbonaceous Pliocene sediments unconfomably overlying a weathered Waitemata Group surface.

Fig. 36. A preserved Pliocene mud crack surface. Sediment infill has been bioturbated and yields an associated macromollusc fauna.

Pliocene sediments
Fossil mollusc fauna

The molluscs from these sediments have been completely dissolved (decalcified) and are preserved as moulds (Figs. 37 right, 38 right). To most easily visualise the shape and ornamentation of these molluscs, casts (positive impressions) can be made using plasticine and modelling clay (Fig. 39). Intricate ornamentation has often been preserved allowing correlation of some specimens to those of named species known to have occurred in the Pliocene, such as those of the Kaawa fauna and the Otahuhu Brewery well fauna. A number of different assemblages occur here, inferring a variety of preserved paleoenvironments. Moore and McKelvey (1971) provided a fauna list with 21 mollusc morphotypes recognised (identified by Jack Grant-Mackie). The molluscs were correlated to the Kaawa beds of Port Waikato and provided support for a late Pliocene age (Waitotaran, Ww = Wp-Wm in modern usage). Age diagnostic taxa identified from Weymouth included *Mactra* c.f. *discors* (?Wo-R, Opoitian to Recent), ?*Crassostrea ingens* (Ww), ?*Venericardia* aff. *purpurata* (Ww-R), ?*Tawera duobrunnea* (Ww), *Modiolaria* c.f. *impacta* (Ww-R).

The present authors, with help from Alan Beu, have identified differing, but complementary mollusc faunas from other sites at Weymouth that include these additional age diagnostic taxa: *Maoricardium spatiosum* (Sl-Wm, Lillburnian to Mangapanian) (Fig. 37 right), *Eumarcia kaawaensis* (Wo-Wp, Opoitian to Waipipian), *Barytellina crassidens* (Wp-Wn, Waipipian to Nukumaruan), ?*Lutraria solida* (Wp-Wn), ?*Zefallacia lawsi*/turritellid (Wp), *Bassina katherinae* (Wp-Wm) and *Dosinia powelli* (Wp). These taxa are indicative of a late Pliocene age that is consistent with the Waitotaran age of Moore and McKelvey (1971), but more specifically these taxa indicate a likely Waipipian age (3.6-3.0 Ma) and correlate more closely with the fauna of the Otahuhu Brewery well than that of the Kaawa beds of Port Waikato (pers. comm., Alan Beu, 2017).

Fig. 37. Pliocene macromollusc shell bed at Weymouth (left) and the remains of a decalcified mould of Maoricardium spatiosum *(right).*

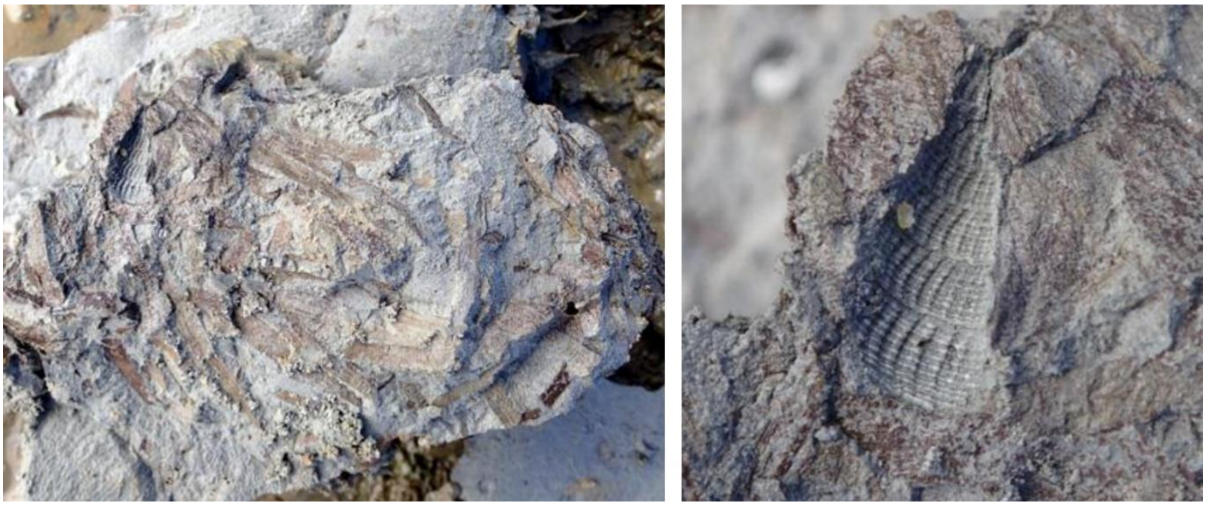


*Fig. 38. A bed of Pliocene sea grass leaves (left) and detail of an associated mollusc mould, possibly ?*Zeacumantus *(right).*

Fig. 39. A selection of clay casts made from the Pliocene macromollusc fossils of Weymouth. Clockwise from top left: Pyrazus ebeninus *or ?*Zeacumantus, *?*Buccinulum, Taxonia tesserata, *?turritellid,* Dosinia powelli, Struthiolaria *(scale: notches on ruler are mm).*

Fossil plants

Plant fossils are common, with well preserved, organic specimens of wood (logs, branches, stumps and roots), leaves, fruits (and seeds and cones) (Fig. 40), amber, pollen, spores and mosses collected from these sediments (Fig. 35). A diverse assemblage of fossil fruit taxa has been recognised although only a few morphotypes share affinities with New Zealand's modern flora (e.g. *Prumnopitys* and *Elaeocarpus*). Many of the fruit taxa presently identified share affinities to groups that are currently distributed in Australia, New Caledonia/Papua New Guinea (e.g. Menispermaceae, Casuarinaceae, *Brassospora*-type

Nothofagus, and locally extinct taxa of *Elaeocarpus*). A diversity of exquisitely preserved fossil mosses are also found in these sediments.

Beds of fossil sea grass (identified by John Conran) are found in some areas at Weymouth where they are sometimes associated with fossil molluscs, such as ?*Zeacumantus* (Fig. 38).

Opalised wood/fruit fossils are found in overlying sediments where they are thought to represent organic material reworked from the lower Pliocene sediments that later became opalised (Moore & McKelvey, 1971).

Moore and McKelvey (1971) provide an appendix (by Dallas Mildenhall) listing and interpreting the pollen and spore taxa from carbonaceous Weymouth sediments. A Waitotaran age was inferred by Dallas, based on the dominance of *Brassospora*-type *Nothofagus* and presence of *Eugenia* [*Syzygium*] pollen.

Fig. 40. Two Pliocene fossil fruits/seeds collected from Weymouth (scale: notches on ruler are mm).

Other fossils

As at Beachlands, a number of well preserved fossil bracket fungus basidiocarps, oribatid mites and arthropod remains have also been collected from here.

Beachlands and Weymouth comparison

Despite differing depositional paleoenvironments, many similarities can be drawn between the fossils found at Beachlands and Weymouth:

- Each locality yields a taxonomically diverse plant flora, sharing few affinities with modern New Zealand taxa
- A full range of plant parts have been preserved (e.g. leaves, wood, fruit, pollen) yielding a more complete picture of present taxa. For example, Lauraceae are known only from leaf fossils here and likewise Vitaceae are only known from seeds
- Rarely found fossil groups such as bracket fungi and mosses are common at both localities
- There is a high taxonomic overlap with many fruit and moss taxa being found at both localities

Weymouth to end of Renton Rd 14 km, 25 mins

STOP 8. 4 PM-5 PM Ihumatao Fossil forests (Middle and Late Pleistocene)

In the foreshore and low cliffs at the end of Renton Rd are the fossil remains of two forests, one that grew on top of the other (Hayward and Hayward, 1995). The older forest is of tree stumps in-situ and fallen trunks of large kauri trees that were preserved waterlogged in swamp peat. They are now being exhumed in the beach at mid tide and the base of some of the cliffs to the north. The kauri forest of unknown age was established on fresh rhyolitic sediment of unknown age. Marra et al. (2006) used OSL dating of the overlying phreatomagmatic succession to infer that this older forest was of late MIS 7 age (~150 ka). Hayward and Hayward (1995) had inferred that there could be a time break between the kauri forest which was clearly killed by swamp establishment and fossilised in the resulting peat accumulation. Measurements on the orientation of kauri logs in the swamp show a dominance of NE-SW orientation (Fig. 41) consistent with felling of dead standing trees during the dominant strong SW winds of this region (Hayward and Hayward, 1995).

At a later date a second mixed conifer forest became established on the somewhat drained peat swamp. This forest was blown over, decapitated, killed and buried by initial phreatomagmatic (base surge) eruptions from nearby Maungataketake Volcano. OSL ages of 140±14 and 170±23 ka were obtained from the base of the basaltic tuff sequence (Marra et al., 2006). In the past four radiocarbon samples were collected from this site by various researchers which yielded diverse ages ranging from 31±1 ka to 43.600±1.4 ka 14C yrs BP (Grant-Taylor and Rafter, 1963; Polach et al., 1969). In addition basaltic material was dated at 74±15 ka BP (McDougall et al., 1969) using the K-Ar technique and at 38±1.9 ka BP using the thermoluminescence technique (Wood, 1991). Marra et al (2006) also obtained radiocarbon ages for both the kauri and mixed conifer trees of >55 ka BP. Thus it is generally accepted that both forests are older than the limits of radiocarbon dating. Recently, Leonard et al. (2017) obtained Ar/Ar age for Maungataketake eruption of 86-92 ka BP.

Trunks, logs and leaves of the younger forest are preserved in the lower parts of the up to 10 m thick basaltic tuff sequence forming the cliffs and represent tree material that was blown or stripped from the standing forest (rimu, miro, kauri, tanekaha, hinau) (Hayward and Hayward, 1995) by early base surge eruptions (Augustin-Flores et al., 2014). Beetle and pollen assemblages indicate a northern conifer forest growing adjacent to a wetland on or near a coastal plain (Marra et al., 2006). The pollen record shows forest compositional changes, in particular a period of *Agathis australis*-dominance (early forest) between two phases of *Dacrydium cupressinum* dominance. Concomitant developments in the wetland flora may have been linked to changes in groundwater conditions as sea level fluctuated across the coastal plain. Despite overall similarity to the modern flora and fauna, both beetle and pollen assemblages include elements that are found today at higher elevations in the region, indicating that slightly cooler climate conditions existed (Marra et al., 2006). Wood is preserved in the lower parts of the thicker tuff sequence where it was permanently water-logged below ground water level. Higher in the sequence and out to the east where the tuff is thinner the wood has rotted away leaving branch and trunk moulds.

A wave-cut terrace 1 m above present MHW at the southeast end of the cliffs was interpreted by Marra et al (2006) to be of Last Interglacial age (MIS 5e, 120-130 ka) but has always been regarded by the present writer (Hayward) as being formed during the Middle Holocene highstand (~6-2 ka).

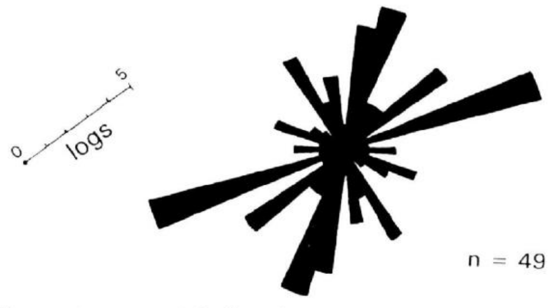


Fig. 41. Rose diagram showing the dominant orientation of kauri logs preserved in the peat swamp at Ihumatao (Hayward and Hayward, 1995).

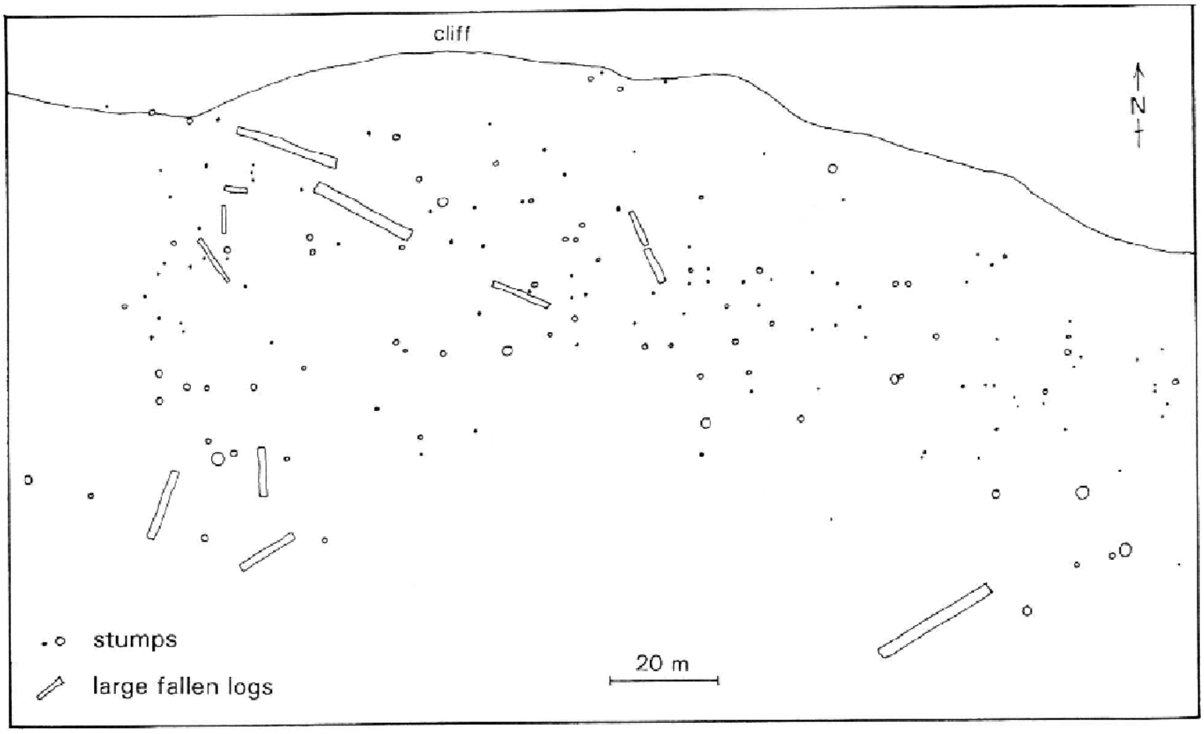


Fig. 42. Map of the Ihumatao foreshore showing the location of in-situ kauri stumps and fallen logs preserved in the swamp peat. (Hayward and Hayward, 1995).

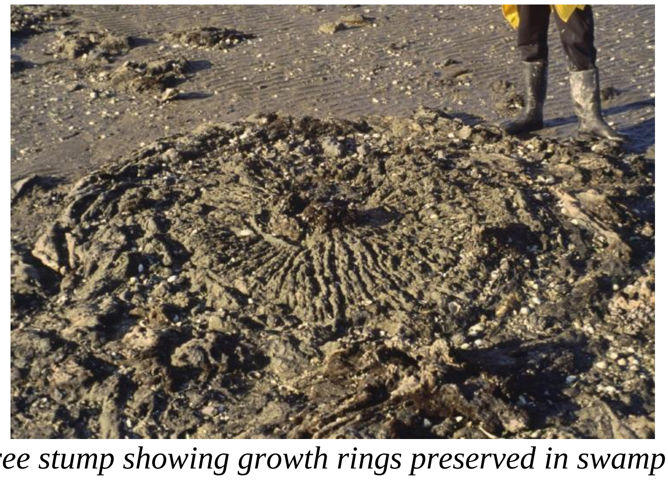


Fig. 43. Kauri tree stump showing growth rings preserved in swamp peat, Ihumatao.

Fig. 44. Fallen trunk of large kauri that was preserved in the swamp peat at Ihumatao.

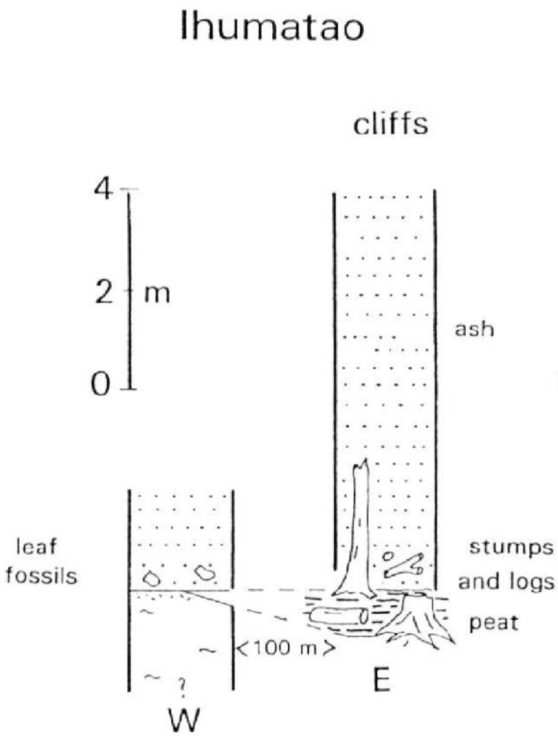


Fig. 45. Simplified stratigraphy showing the relationship between the two fossil forests at Ihumatao (Hayward and Hayward, 1995).

Fig. 46. Excellent example of a standing tree that was knocked sideways and decapitated by early base surge eruptions from Maungataketake Volcano before being buried by tuff.

Fig. 47. Fossil rimu leaves are most common in the basal layers of tuff from the Maungataketake eruption.

Fig. 48. Tanekaha leaves from basal Maungataketake tuff.

Fig. 49. Kauri leaf from basal Maungataketake tuff.

Renton Rd to Auckland Airport domestic terminal, 5 km, 10 mins
5.20 PM Auckland Airport domestic terminal drop off
Airport to Auckland University 24 km, 30 mins (Waterview tunnel, port off ramp)
6 PM Return to Auckland University

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