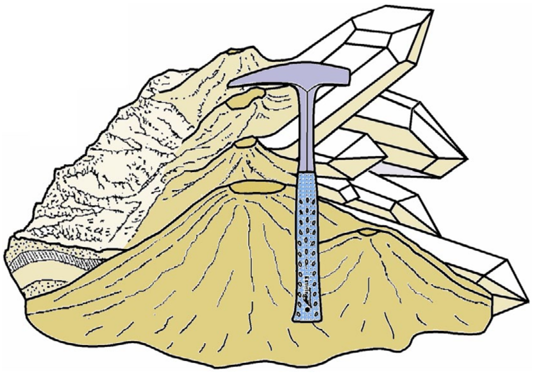

Geocene

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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.

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MORE MOA TRACKS IN CROSS-SECTION ON KAIPARA SOUTH HEAD

Bruce W. Hayward, Willo M. Stear

Geoclub has held 3 trips to the eastern shore of Kaipara South Head in the last 3 years, all focussed on examining the Pleistocene sandstone sequence in which moa tracks (footprints) were first found on loose sandstone slabs by fishers in 2022 (Hayward 2022, Thomas *et al*. 2025). The first trip was to see the actual footprints now reposited in the iwi's humidity-controlled storeroom at Woodhill (Thomson & Hayward 2024), followed by a visit to Mosquito Beach to see where the blocks had been dislodged from out of the cliff and then later collected for safe-keeping (Figs 1 & 2). Our second trip, in April 2024, was to Omokorito Bay, from where we walked northwards towards Te Kawau Pt (Figs 1 & 2). Another set of moa tracks was found along this section of coast in mid-2024 (Thomson & Hayward 2024). So, in early 2025, Geoclubbers returned to Omokorito Bay and walked southwards beyond Pararaha Pt looking for more moa tracks. Only one possible imprint in oblique cross-section was found and photographed by one of the 2 authors (WMS). This was at the high tide level on Pararaha Pt (locality 1, Fig. 2B). Moa tracks in cross-section had previously been recognised by one of us from similar rocks above Muriwai (Hayward 2016). The 2 authors of this note returned in April 2025 and, with more time available, re-examined all the potential low cliff and high tide exposures between Te Kawau and Pararaha points. This note records what was found.

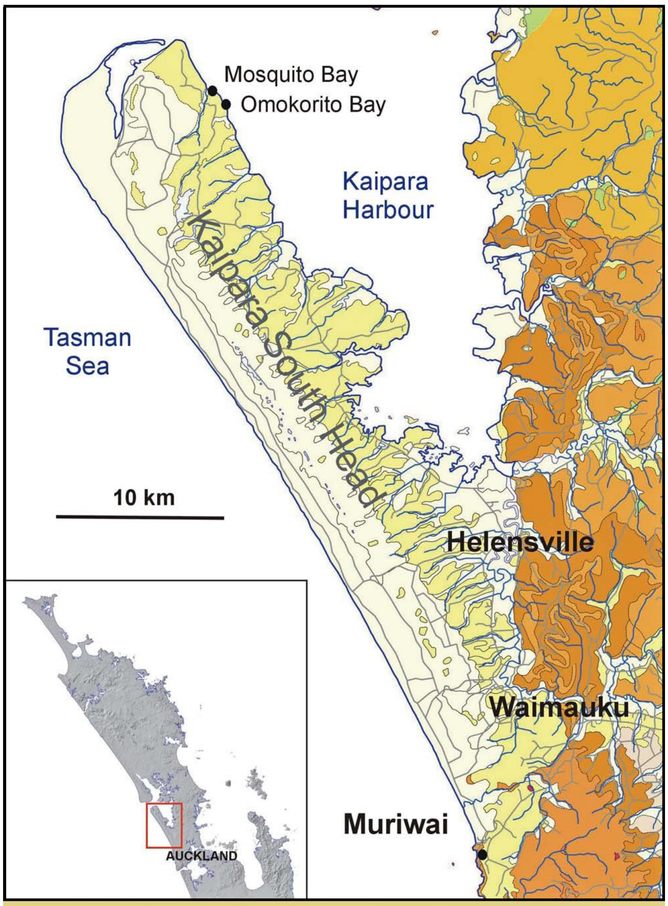

Fig. 1. Map of South Kaipara Peninsula sand barrier showing locations of previous moa track discoveries (black dots) and the location of Omokorito Bay, where the present observations have been recorded. Darker yellow represents the outcrop of Pleistocene sandstones and light yellow of Holocene sand.

Recognising tracks in cross-section

Tridactyl moa tracks preserved in plan view on a bedding plane surface are easily recognised by the 3 front-pointing toes with claws and round ball behind them where the toes meet the tarsus (Fig. 3). The bedding plane surface on which the track maker had walked will display a mould-like depression (epirelief) with this distinctive shape. The upper surface (counter plane) will usually have the sand attached that filled the depression, forming a positive cast (hyporelief) in the shape of a 3-toed track on the underside of the overlying sandstone bed.

Only occasionally, and usually after severe storms, do the relatively poorly lithified Pleistocene sandstones of the South Kaipara Peninsula slip from the cliff faces as slabbed blocks, but when they do, the blocks often split open along bedding planes, providing the opportunity to look for tracks in plan view. The most common exposures of these rocks are in the cliff faces and sloping high tide

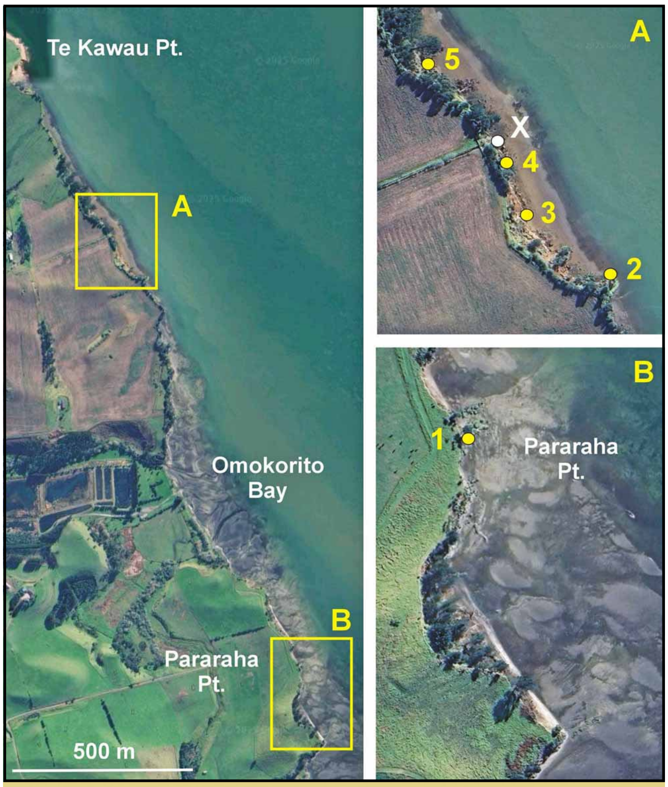

Fig. 2. Google satellite photos of the coast north and south of Omokorito Bay where moa tracks have been recognised in cross-section (1–5) and where tracks were found in plan view on a bedding plane (X) in mid-2024 (Thomson & Hayward 2024).

platforms, where plan views of tracks cannot be seen. Profile views of tracks in cross-section, however, are occasionally visible in the cliffside exposures and on the intertidal platforms. In many places, the surfaces of the outcrops in these settings are obscured by vegetation or fungus growth, loose sand, or secondary mineral overgrowth. The proportion of the lower cliffside sections that are fresh enough to see clear track and sedimentary structural detail is low.

A factor that makes it tricky to recognise tracks in cross-section is the strong secondary development (weathering) of the rusty hydrated iron oxide mineral, limonite. This usually takes the form of wavy subparallel lines (akin to liesegang rings) that often cut across the primary bedding but sometimes also follows it. Several wavy layers with well-developed mammillary limonite clusters occur within the sequence, in places following primary sedimentary horizons, but elsewhere also crosscutting them. But a feature that greatly assists in the recognition of tracks and sedimentary structures in these rocks is the presence of iron (titanomagnetite) particles in the sandstone layers, often occurring as dark laminae interbedded with lighter coloured layers contained lesser amounts of iron.

To recognise tracks in cross-section requires a freshly exposed, clean sedimentary profile, preferably with limited development of secondary limonite lines running through it. We use 2 main attributes to distinguish tracks from other soft sediment deformation features, such as water-expulsion (liquefaction) structures, erosional hollows or swales and burrows. These are:

1. a depression showing downwards bending of the underlying layers (laminae) and compression (thinning) of them beneath the depression;
2. sometimes the presence of a steep side to the depression where the laminae can be seen to have been broken through by a downwards force.

Liquefaction features may be highly variable, but normally show features that correspond to upwards movement of interstitial water and its corresponding upwards breakage of strata and injection of sediment from beneath. Sometimes, liquefaction can be associated with track formation, caused by water pushing upwards around the track depression as the track maker stood on the saturated sand. Erosional hollows or swales and burrows lack evidence of compression of the layers beneath them.

A vertical, eroded cross-section through a 3-toed and ball tridactyl track can be at any angle and thus can take a wide range of shapes. It might be a section through a single toe impression or of 2 and, rarely, 3 toes. Where more than 1 toe depression is visible there will usually be a saddle in between. The width and depth of the track in cross-section also depends on the angle of the section with respect to the track outline and will seldom be as wide as the maximum dimension of the track. The track depression can be crisply preserved where it was made in stiff, wet sand that was later filled by wind-blown sand.

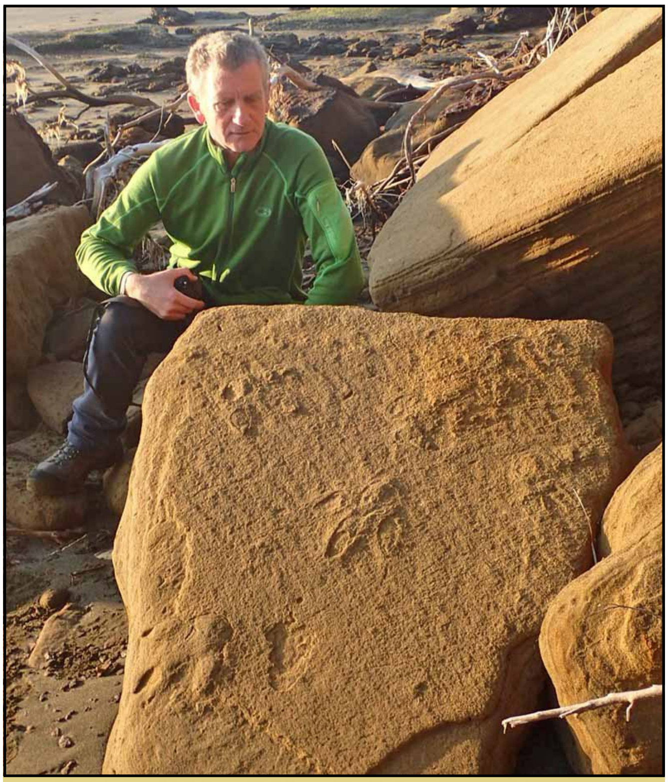

Fig. 3. One of the blocks with moa tracks found between Omokorito Bay and Te Kawau Pt in mid-2024 (Thomson & Hayward 2024). It shows the 3 toes and ball of the moa foot shape in hyporelief preserved as a cast (filling) on the lower surface (counter plane) of sandstone that was deposited on top of the track depressions.

If the track was made in less firm or saturated sand, including in shallow water, or was quickly covered by the incoming tide, then the shape and fill of the depression will likely be more imprecise and blurred and the track fill massive to chaotic.

Lithofacies units present

Three lithofacies units are recognisable in the cliffs between Pararaha and Te Kawau points. They are essentially flat lying, although in places they undulate slightly and can be followed for the full 2 km distance. The contacts between these 3 units are often unclear or appear to interfinger. The 2 lower units are the same as described and illustrated in the cliffs 100–400 m to the north of Te Kawau Pt at the south side of Mosquito Bay (Hayward 2022). A detailed description is not repeated here.

Lower unit: Several thick beds (2–3 m thick) of planar cross-bedded and low-angle, lateral accretion, cross-bedded sandstone are overlain by flat-lying sandstone beds often displaying herring-bone bedding, flaser bedding and hummocky crossbedding with evidence of deposition by strong bidirectional currents. Localised slump folding is present in the foreset beds and burrows typical of shallow marine or intertidal organisms (*Skolithos*, *Scolicia*) are scattered throughout. This unit is inferred to have accumulated at or just below low tide level in a flood-tide delta setting where 2- to 3-m high, subtidal, migrating sand banks were deposited by strong incoming tidal currents. Sand on the flat-lying sections of the lower foreshore intertidal or shallow nearshore seabed was deposited by strong reversing tidal currents usually associated with estuary and harbour entrances (Hayward 2022). This is the main unit seen in fresh exposures today in the upper tidal zone and base of the cliffs in this study.

Middle unit: This unit varies in thickness (up to 2–3 m) and consists of near flat-lying, laminated sandstone with minor lensing and wedging of layers, but largely lacking evidence of strong current movement. It is inferred to have been deposited in the middle and upper intertidal zone on a beach, presumably as the abundant sand supply accumulated on top of the lower foreshore deposit beneath. The middle unit is usually observed a few metres up in the cliffs from the modern beach and is seldom able to be examined closely in a fresh face except where blocks have fallen out onto the beach.

Upper unit: This unit is not present in the relatively low cliffs of southern Mosquito Bay but is present in most of the cliffs in the current study, albeit often obscured by vegetation and slips. It consists primarily of 1–10 m-thick, cross-bedded sandstone beds, sometimes with flat-lying topsets beds in between. Exposures are seldom accessible or fresh enough for detailed examination, but no evidence of water deposition have been seen (e.g. marine burrows, slumping, strong current bedding). We infer these sandstone units to be terrestrial sand dunes that were deposited on top of the subtidal and intertidal sands of the lower and middle units, as more sediment accumulated on the beaches and was blown up as dunes, possibly as sea level was falling after the high stand sea level when the lower 2 units were deposited.

Fig. 4. Oblique cross-sectional view through a 30 cm-wide moa track at locality 1. Note the 3-pointed digit depressions of the toes and the depression produced by the ball. Scale is 10 cm.

The newly discovered probable moa track localities

1. Pararaha Pt, 36°28’22”S 174°16’10”E (Figs 4 & 5)
This single, 3-toed print is the only one recognised to date south of Omokorito Bay. It was found in a low-angle, oblique section on a high-tide platform. It occurs within the upper part of the uppermost planar cross-bedded bed in the lower lithofacies unit. The erosive cut of the cross-bedded sandstone has produced a section that provides a near-plan view of the 3 large toes and ball depression and gives a maximum span of ~30 cm. Two of the toe depressions have sharp points produced by the moa’s claws. The track has clearly pierced some of the underlying sand layers and compressed others beneath the depressions. The infill of this track consists of dark laminae that follow its shape, probably representing wind-blown sand. This is the crispest and best preserved of the newly recognised tracks.

2. 36°27’41”S 174°15’51”E (Figs 6 – 11)
At least 8 depressions with attributes of moa tracks in profile were recognised along 10 m of high tidal exposure in the base of cliffs on a small promontory located 750 m north of Omokorito Bay carpark. They all occur within the upper 50 cm of 2 m high foreset beds in a 2 m-thick, cross-bedded sandstone at the top of the lower unit (Fig. 6). The 2 tracks at the end of the promontory each show 2 depressions (= toes) separated by a high saddle (Figs 7 & 8). Neither is crisp and both have a rather disrupted infill (Fig. 8). Five metres further, on the north side of the promontory (Fig. 9) at locality 2a, there is a concentration of putative tracks (Fig. 10) all located within a narrow stratigraphic profile, but not all at the same stratigraphic level, meaning that they were not all made at the same time. All show evidence of downwards pressure and compression of laminae, including some breakage through laminae. Another 5 m further on, there is a 5 cm-deep depression within a finely laminated section also containing several marine/intertidal burrows (Fig. 11).

Fig. 5. Locality 1, south of Omokorito Bay where the most impressive moa track was found (Fig. 3).

Fig. 6. Locality 2. The tracks (Figs 6 & 7) occur in the upper 0.5 m of the lower cross-bedded unit (arrowed) just below the flat-lying, herringbone-bedded unit. Photo width 4 m.

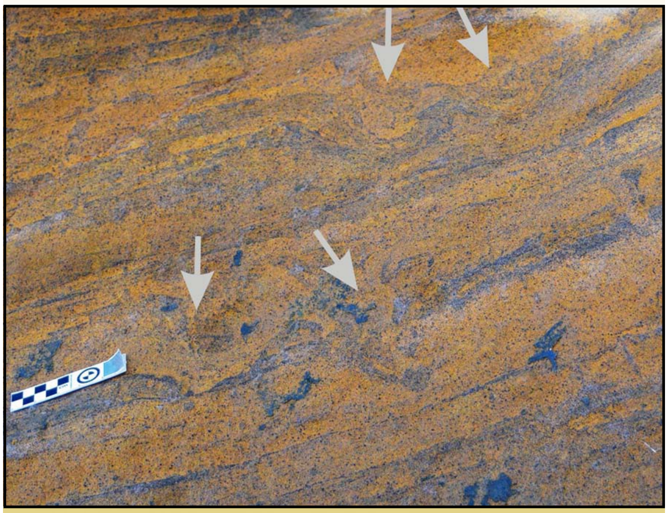

Fig. 7. Two inferred track depressions at different levels in the upper part of the foreset beds at locality 2. Note both depressions have 2 deeper parts (arrowed) separated by a saddle. A short, straight, marine invertebrate burrow can be seen in the middle right of the photo.
Scale is 10 cm long.

Fig. 8. Locality 2 tracks. Enlarged version of the 2 tracks of Fig. 7.

Fig. 9. Locality 2a, 5 m west of locality 2 (Fig. 6) showing the planar cross-bedded unit beneath the flat-lying herringbone-bedded unit. More track depressions are present near the hiking pole in the upper part of the cross-bedded unit.

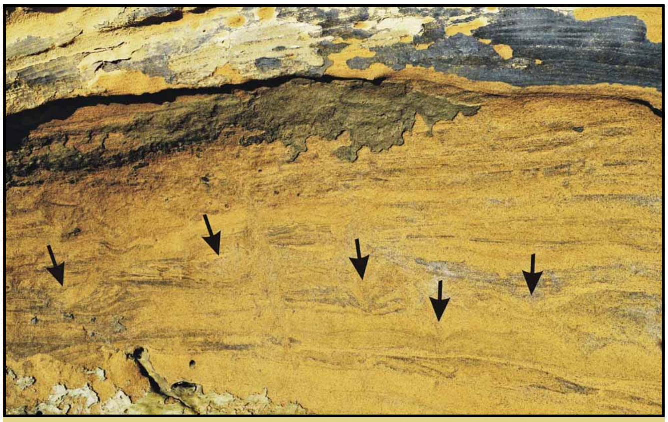

Fig. 10. Some of the numerous depressions (arrowed) inferred to be moa tracks, with broken and downwards compressed laminae at locality 2a. Photo width 1 m.

Fig. 11. Probable moa track (arrowed) at locality 2a, with several straight steeply inclined invertebrate burrows also present. Photo width 35 cm.

3. 36°27’39”S 174°15’48”E (Figs 12 & 13)
A single depression, inferred to be a moa track, was found in a loose boulder at the back of the beach (Fig. 12). The depression (and boulder) was orientated upside down, but examination of the sedimentary layering within the boulder clearly showed soft sediment compression of the underlying layers (Fig. 13). The boulder was derived from either the lower or middle unit.

4. 36°27’38”S 174°15’48”E (Figs 14 & 15)
The largest loose block of sandstone lying at the foot of the cliffs (just 20 m south of the mid-2024 moa track find) is 2 x 4 m in size and not easily accessible for examination. The surface facing the modern beach is a bedding plane that has suffered considerable erosion by the rain over at least a year. Along the top there are 3 unusual depressions on the surface, 2 with double lobes (Figs 14 & 15) that do not appear to have been caused by rain erosion and are quite possibly the weathered remnants of tracks. This surface could conceivably be the same as that which contained the moa tracks found in mid-2024 (Fig. 3). We admit that these 3 depressions are the least convincing of the recognised moa tracks and it is even possible that, if they are indeed tracks, they may have been registered by some other species of small track maker.

Fig. 12. Fallen boulder (upside down) with inferred moa track (Fig. 13) at locality 3.

Fig. 14. Locality 4. Three imprecise depressions (arrowed) occur in the bedding-plane surface of this large block that has fallen out of the cliff above. Photo width 5 m.

Fig. 13. Close-up of Fig. 12 showing the upside-down depression with compressed layers beneath inferred moa track.

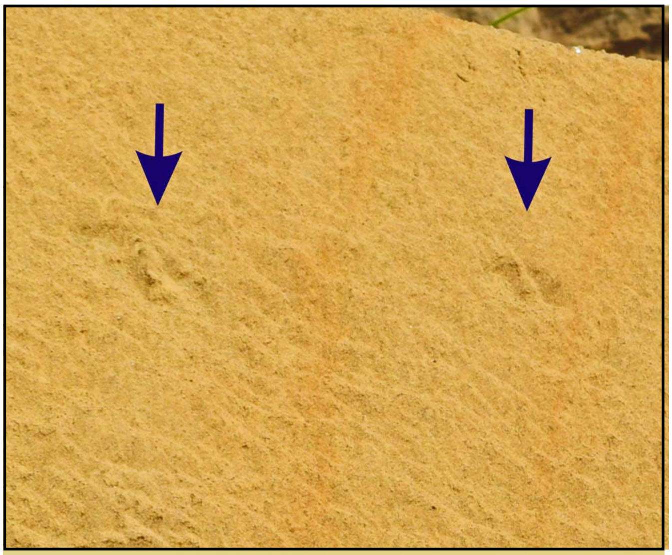

Fig. 15. Close-up of Fig. 14 showing 2 of the track-like depressions.

5. 36°27'30"S 174°15'42"E (Fig. 16)

Further north, another dislodged boulder at the back of the beach has landed on its edge with the bedding orientated vertically. Within the limonite-enhanced bedding there is an obvious depression with compressed layers beneath, but no broken laminae. Despite this, we infer the feature to be a vertical section through part of the ball of a moa track.

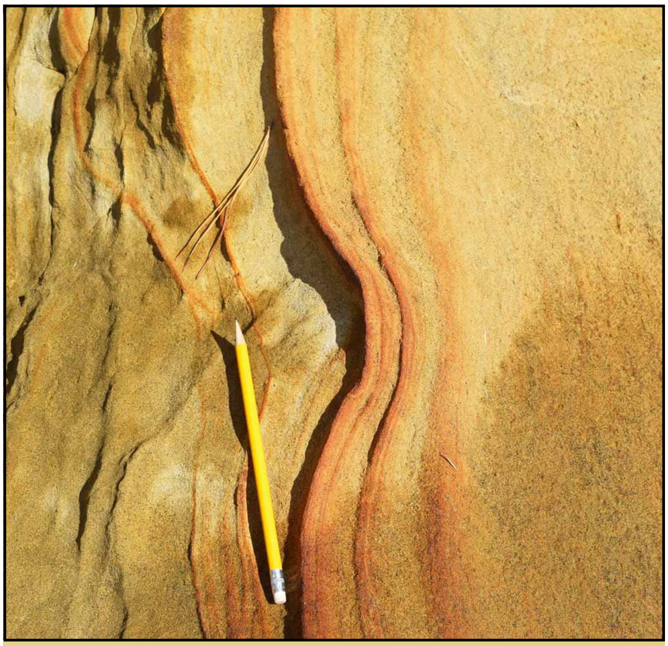

Fig. 16. Locality 5 is a fallen boulder with bedding tilted to vertical. The depression with compressed layers beneath (on right) is inferred to be a possible moa track.

Discussion

No tracks have been recognised so far in the upper unit, in part because it does not occur at an elevation where fresh faces are exposed. It is likely that few tracks would have been preserved within the terrestrial sand dunes because of the mobile nature of the dry sand and the absence of rapid cementation after deposition of the sand.

The 3-dimensional tracks on bedding planes found in fallen blocks at Mosquito Bay (Thomas *et al*. 2025) and north of Omokorito Bay (Hayward *et al*. 2024) are derived from the middle unit. The inferred middle or upper intertidal beach setting for the deposition of this unit makes it the most likely for the preservation of well-defined tracks. The possible scenario for this is that moa left tracks in firm, damp sand near the top of the beach. Before the tide rose and destroyed them, dry sand of a slightly different composition from above the high tide mark was blown in, filling and burying them.

Most of the depressions seen in cross-section in the present study and inferred to be moa tracks occur in the lower unit, and the outlines of many of them are not particularly crisp and well-defined. This suggests that the substrate was not as firm when the track maker stood on the sand, which may have been saturated by sea water or was rapidly immersed by the in-coming tide. This is consistent with the sedimentologically-based inference of a lower foreshore environment. Some of our recently discovered tracks occur in the upper 50 cm of the foreset beds of a 2 m-thick unit interpreted to be an aggrading sand bank (e.g. localities 1 & 2). A sand bank of this height is unlikely to have been deposited while advancing in the intertidal zone. More likely, the top of the bank was probably only partially exposed at low tide level as it advanced and built out into 2 m-deep water. If this is correct, then the tracks may have been made by moa wading into the shallow sea water during spring low tide, implying that the registering of these tracks was subaqueous.

This study records the recognition of up to 13 additional moa tracks in the Pleistocene sandstones around Omokorito Bay in the vicinity of where 3-dimensional tracks had previously been discovered. This concentration of moa tracks at the northern end of Kaipara Peninsula reflects the environments in which the exposed sedimentary rocks were deposited and is not necessarily an indication of any increased numbers of moa in the area at the time. It is also highly unlikely that all the recognised tracks were made by a single moa during a short period of time (although this is theoretically possible). The lower and middle units in which the tracks occur extend over at least 3 km and were not deposited within a short period of just a few years. It does seem probable, however, that these 2 units were formed during a single interglacial period of high sea level sometime around 1±0.5 myrs ago (Hayward 2022). An interglacial high stand of sea level with <5 m of elevational change during that period would have spanned less than 8000 years and thus this would have been the maximum time span within which all these moa tracks were created.

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EDGERLEY AVE WATERCARE TUNNEL, UNDER SOUTHERN MOTORWAY, EPSOM, AUCKLAND

Peter Crossley

Hunua 4 is a 32 km-long pipeline that connects Watercare's reservoirs at Redoubt Rd in Mānukau to the central city water storage tanks at the top of Khyber Pass in Grafton (Water New Zealand Project 2016). It is part of a larger scheme that pipes water from the Hunua Ranges to central Auckland. The final 3.5 km section, from Market Rd (Remuera) to Khyber Pass (orange in the top left map of Fig. 1), was constructed by McConnell Dowell using state-of-the-art trenchless technologies to install the pipe almost entirely below the road or motorway corridor (McConnell Dowell undated). The tunnel is a concrete lined, 2.55 m ID (inside diameter) concrete pipe that is hydraulically rammed into the tunnel dug with a rotating boring machine.

During the excavation for the final section (Market Rd to Khyber Pass, Fig. 1), 4 voids were encountered and surveyed on 4 separate occasions in 2019 and 2020 by the author using photogrammetry, described below, and Chirag Jindal using a 3D laser to measure precise distances (see end of article). The following are some of the observations from this work.

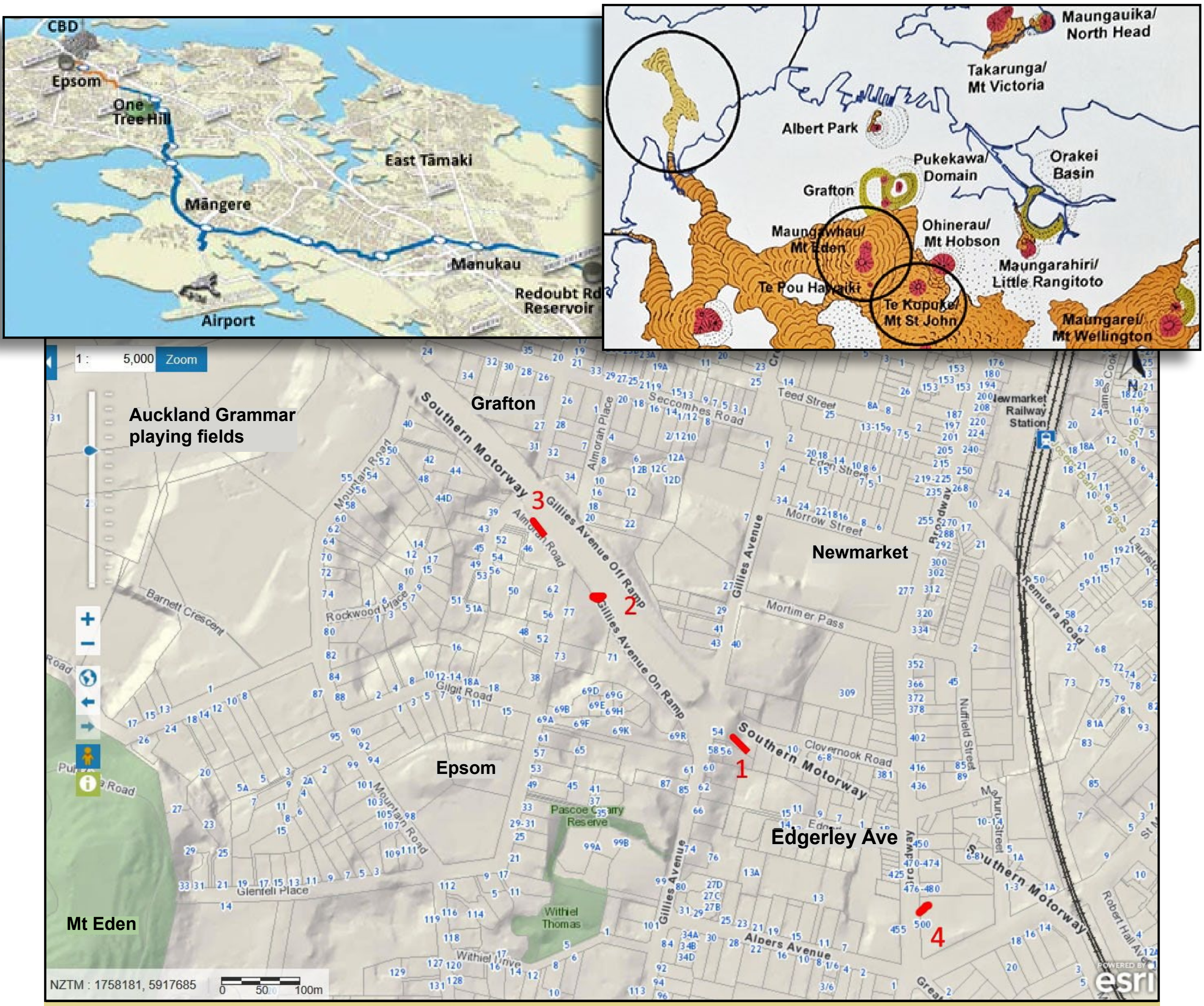

Fig. 1. Main map shows positions of the 4 voids along the Hunua 4 tunnel route in the vicinity of the Southern Motorway in the Epsom/Newmarket/Grafton area.
Left small map roughly indicates the route of Hunua 4 pipeline from Redoubt Rd reservoir in Mānukau to Khyber Pass in Grafton, modified from a Watercare brochure (Water New Zealand Project 2016). The final section, which contains the 4 voids, is in the top left corner, coloured orange.
Right small map is modified from part of figure 9.71, Auckland Volcanic Field (Hayward 2017). Black circles show Meola Reef in yellow colour and Mt Eden and Mt St John in red (cones) and orange (lava flows).

Entry to the tunnel was from the Edgerley Ave works. The first void (1) was encountered about 60 m in from the access shaft and the second (2) at 370 m under the Gillies Ave motorway on ramp. Void 3 is another 100 m further, under 46 Almorah Rd. Number 4 was encountered in the opposite direction, under Broadway, almost under the Alpers Ave interersection. Numbers 1, 2 and 3 are approximately 20 m below the surface and number 4 about 6 m.

Lava flows

Mt St John predates Mt Eden. Its main lava flow travelled down a valley to beyond Western Springs, continuing into the Waitematā River valley to become Meola Reef when sea level rose (Fig. 1, top right map). Mt Eden's flow rode over the top of the Mt St John lava with a more viscous lava that solidified into conspicuous columnar-jointed lava lobe 'buttresses'. This can be seen in the Mortimer Pass road cutting and the Auckland Grammar School playing fields. From maps of the flows (Hayward & Carr 2014, Hayward *et al*. 2014, Kenny 2014), it appears likely that voids 1 and 4 are in the Mt St John flow and 2 and 3 voids are low in, or below, the Mt Eden flow.

Detail of the voids

While we were afforded every help, safety requirements precluded us from exiting the pipe to properly survey the extent of the voids. In any case, except for voids 1 and 3, which had been encountered by rocks falling from the roof and piercing the pipe, the voids 2 and 4 could only be seen through several small 200 mm-diameter portholes in the grinding face while it was turned off and fuses removed! I could just stretch though 2 of them to get stereo photos.

Surveying details

The images displayed were generated by photogrammetry. This involves taking up to several hundred overlapping photos from different positions to generate a 3D image, or point cloud. This can then be meshed and textured to form 3D photographic models that can be manipulated on a computer screen. The images of the pipe and voids are as seen from *within the surrounding rock*, just as an Xray scan would be studied.

Void 1 (Figs 2–4) is a 'genuine' lava tube formed from lava draining out of a fluid flow. This can be seen from the surface of the cave being a smooth surface. It would have been like a basalt pipe within a scoriaceous matrix. It is 20 m below the surface of the flat area of Edgerley Ave. Previously unrecorded caves had been found in this area near the surface, but had been discounted as being of no interest by an archeologist.

The orientation indicated the void was almost parallel to the pipe. This indicated that it was likely to be in the Mt St John flow and it would not be a big problem for tunnelling.

Fig. 2. Void 1 showing refluxed roof of a natural lava tube. The floor is the pipe roof.

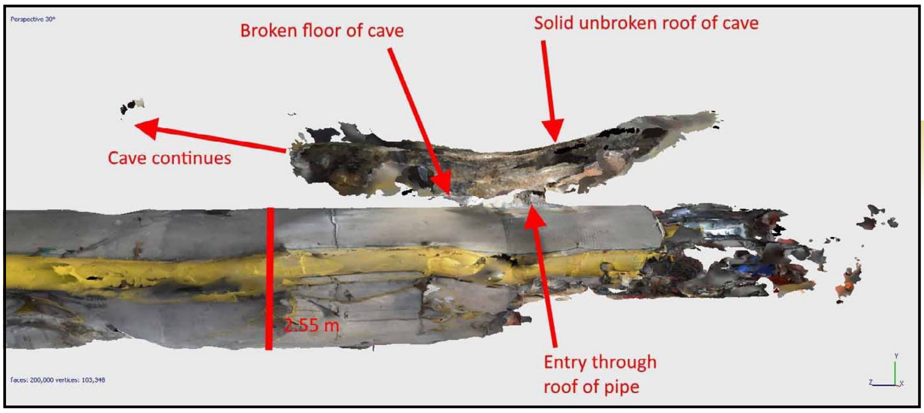

Fig. 3. Photogram side view of void 1, including pipe. Hundreds of overlapping photos have been used to generate a photogrammetric 3D image, called a Photogram.

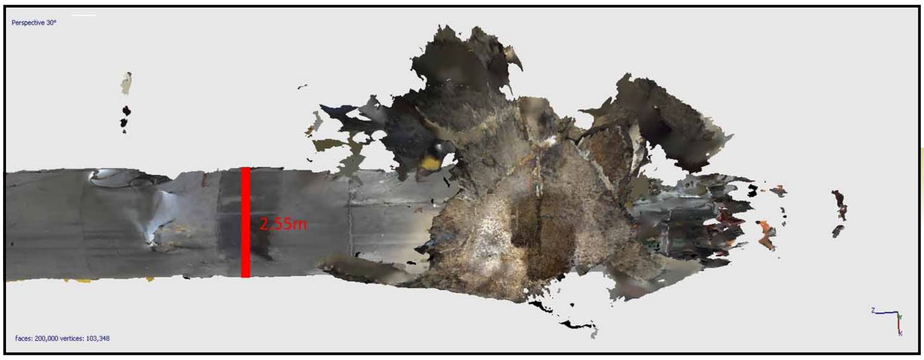

Fig. 4. Photogram plan view of void 1.

The second, void 2 (Figs 5–8), is very different. We could only see a small part of it through the grinding face, but sufficient to see that it was composed of hard rock (basalt), similar to the Mt Eden exposures. It was very fractured, and the void appeared to be formed by spalling upwards as the grinder moved the rock away underneath. It is beneath the Gillies Ave onramp. This indicates a very different problem to the encounter of a lava tube. It indicates to me that it is the Mt Eden flow, which is much harder and more massive than the flow originally encountered. But it is probably the lower surface, which could be more fractured.

Fig. 5. Void 2 - solid basalt boulder in grinder.

Fig. 6. Void 2 - shattered basalt on floor.

Fig. 7. Void 2 - shattered rock ceiling.

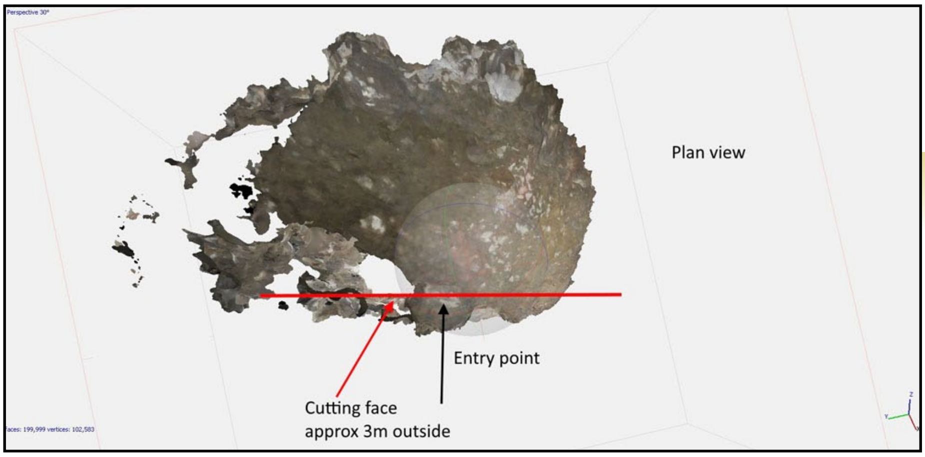

Fig. 8. Photogram cut through pipe and void. The plan view is roughly 3–5 m round.

Void 3 (Figs 9–13) was formed by a rock falling and smashing through the roof. It appeared to extend in both directions along the tunnel. We were allowed to get our upper bodies outside the tunnel, but no further. This allowed a good view, but the scanning of the walls created many 'shadows' behind boulders. We did not see any glazed cave walls, only semi welded scoria. The void appeared to follow the tunnel. I could not tell if it was a real lava cave or just an artifact of the unconsolidated rock spalling down onto the tunnel roof and being conveyor-belted away when the pipe was driven forward. The tunnel is about 20 m below the surface and underneath the edge of the motorway by 46 Almorah Rd.

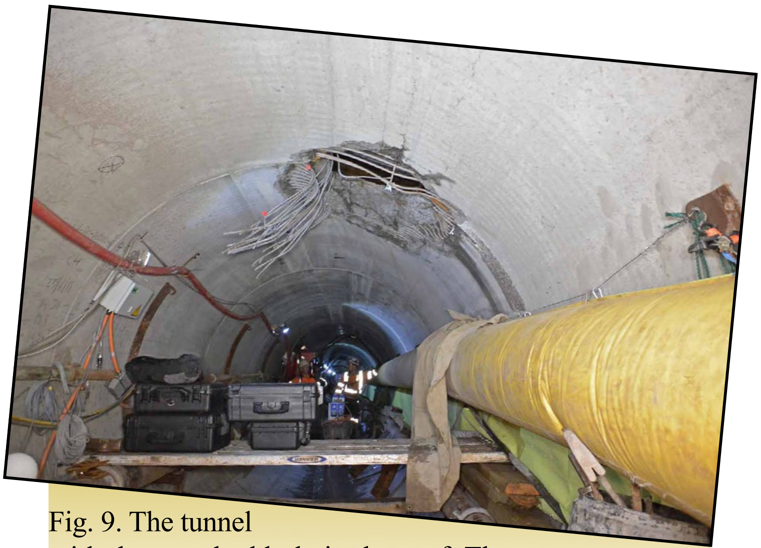

Fig. 9. The tunnel with the smashed hole in the roof. The diameter of the tunnel is 2.55 m. For scale: a worker is just visible in the background in a jacket with bright strips.

Fig. 10. Looking along the passage on top of the concrete tunnel.

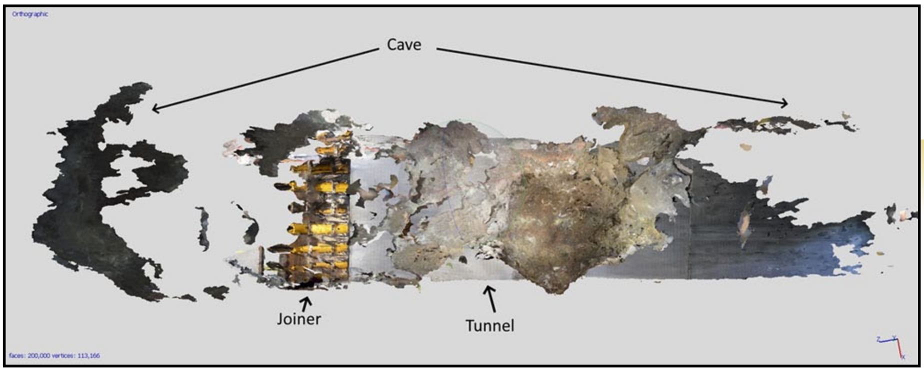

Fig. 11. Edgerley 3 photogram plan view.

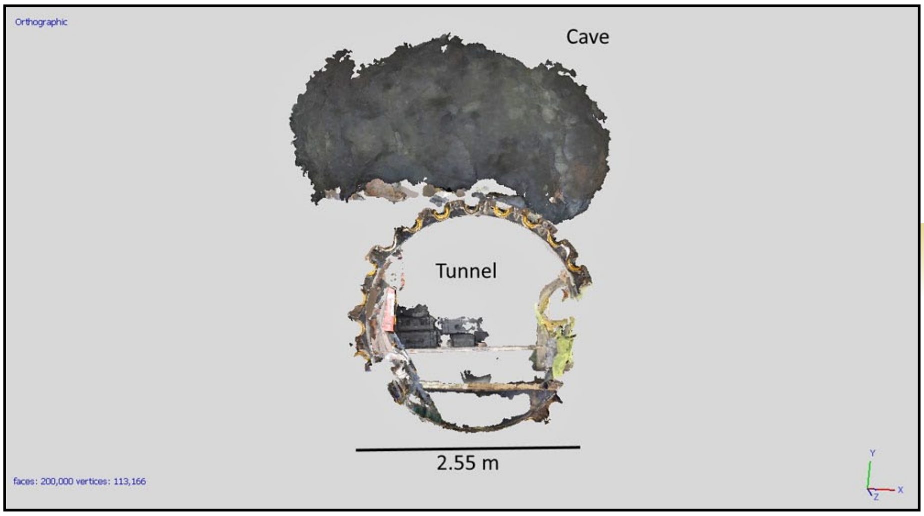

Fig. 12. Edgerley 3 photogram end view.

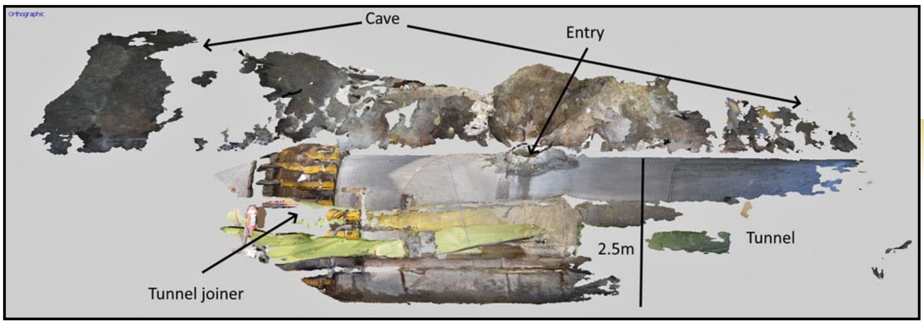

Fig. 13. Edgerley 3 photogram side view.

Edgerley 4 Tunnel Cave (Figs 14–17)
This cave could only be seen through the small holes in the grinding face of the boring machine. Views back along the outside of the pipe therefore entailed some contortion to point the camera.

Inspection by eye indicated a lava tube, i.e., a cave formed within a solid skin of basalt by flowing lava. These usually follow a lava flow radially away from a volcanic vent. They can be several hundred metres in length but are commonly only a few tens of metres in Auckland.

This cave was measured at about 5–6 m wide and 1–2 m high. The furthest extent along the passage could not be seen or measured, but is at least 20 m The pipe appears to intersect the cave at about 45 degrees to the flow. The cross section is a squashed hemisphere. It appears to be stable.

This cave is remarkably similar to the first void we investigated and may be part of that flow.

A sample of rock was taken for later analysis.

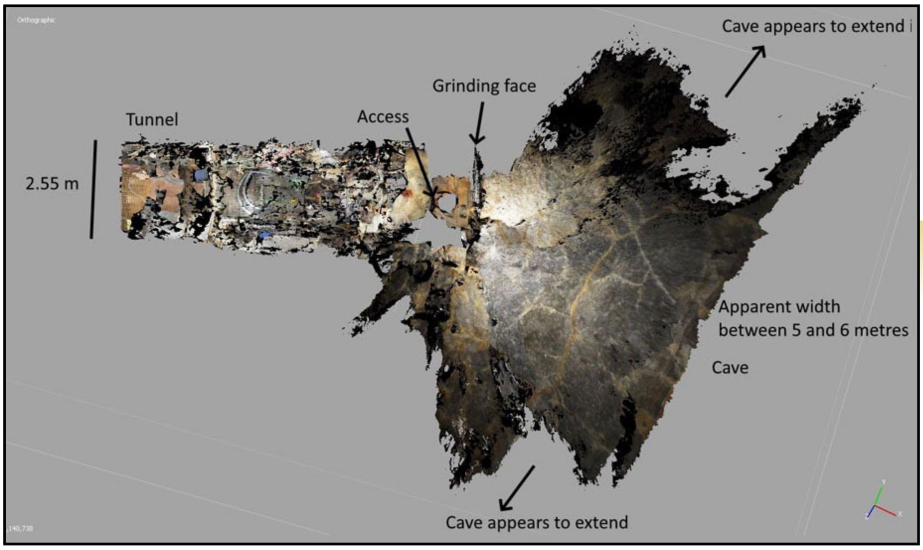

Fig. 14. Edgerley 4 photogram plan view.

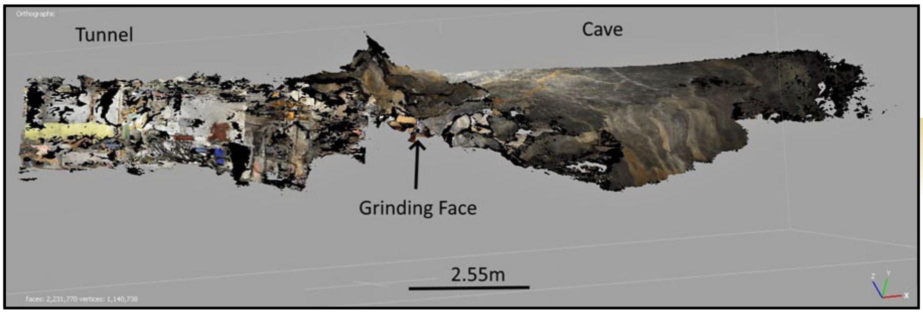

Fig. 15. Edgerley 4 photogram side elevation.

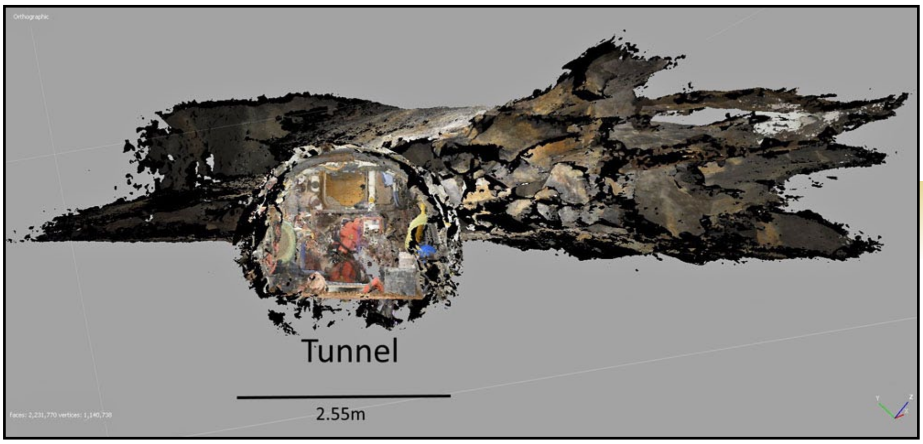

Fig. 16. Edgerley 4 photogram end view.

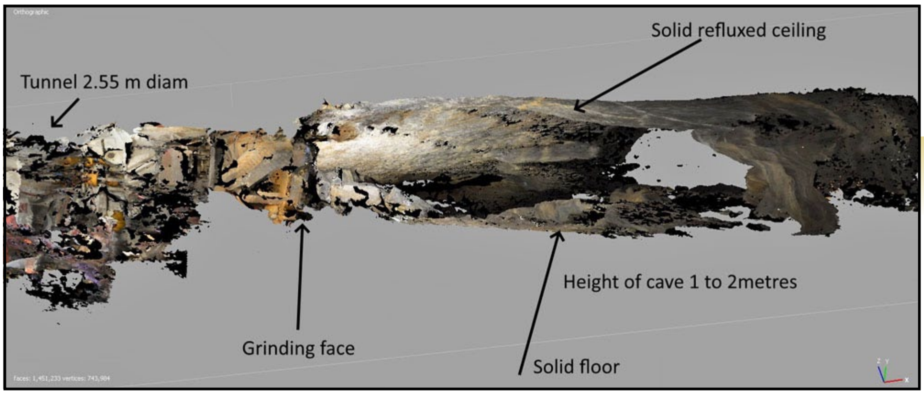

Fig. 17. Edgerley 4 photogram side elevation cut away.

Discussion

Which volcano? Mt Eden has in general solid, sometimes columnar, basalt, e.g., the old prison quarry, the motorway cutting, Withiel Drive boulders and Mortimer Pass. Apart from Mortimer Pass, which has a special shear cave, Mt Eden has produced no tube caves. The Ashton and Tarata tube caves, I suspect, are Te Pou Hawaiki. Mt Hobson and Mt St John have so far not revealed any caves, so they are unknown quantities.

The tunnel has skirted just ouside the Mt Eden flow scarp, down Broadway between Mt St John and Mt Eden until Edgerly Ave, where it turns left under the edge of the motorway towards Mountain Road.

So, the tunnel roughly follows the path of the flow from Mt St John towards Meola Reef. The flow must have been a big one.

Hence I postulate –

Edgerley 4 is a true cave that is 6 m deep, came from Mt St John (or One Tree Hill?) and is covered by a little ash.

Edgerley 1 is a cave at 20 m deep, which is under Edgerley Ave. It is still Mt St John lava but covered by Mt Eden volcanics.

Edgerley 2 is caused by spauling from semi welded basalt.

Edgerley 3 is back to loose scoria, but being deep at 20 m, is under the Mt Eden flow.

If I had only been able to get out of the tunnel, I could have caved all the way to Mt Albert!

Acknowledgements

Thanks to Watercare Sevcies Ltd for allowing Chirag and me the opportunity to investigate the tunnel.

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The business end of the tunnel looking at the grinding face. The author's colleague, Chirag Jindal, is setting up his lidar scanner below a hole in the roof that a naughty rock made and we had to survey through.

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BRONZED LATE PLIOCENE TO EARLY PLEISTOCENE MOLLUSC CASTS IN THE MANUKAU HARBOUR

Lori Dale

On a perfect autumn day on the Weymouth beachfront, bordering the Manukau Harbour, near Waimai Avenue, Manurewa, Auckland, 2 very accessible small (4 m x 4 m) exposures of fossil-bearing sediment were explored (Fig. 1).

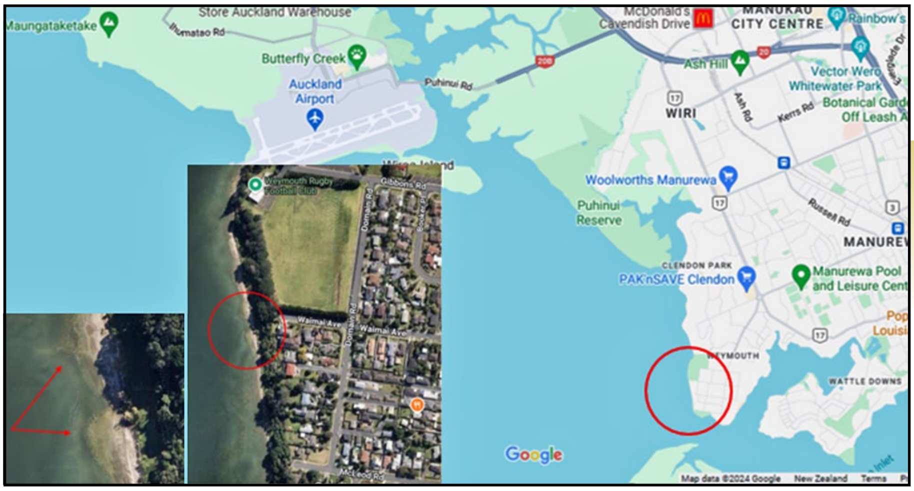


Fig. 1. Map of Manukau Harbour, Auckland, New Zealand.
Insets: Locations of 2 fossil exposures on Weymouth Beach accessible from Waimai Avenue, Weymouth (Google 2024).

The shell casts and moulds

In one assemblage, plucked off the side of the exposure, a bronze-coloured cast separated cleanly from the encasing mud (Fig. 2). The detail on the cast showcased 2 adductor muscle scars, a rounded umbo, and a delineated hinge ligament, revealing the inner life of this multimillion-year-old mollusc. On the underside of the assemblage were a number of distinct shell moulds, with full ornamentation visible (Fig. 3).

Shell Composition

It is usual to find brown-stained fossil moulds around the Weymouth Beach coastline, coloured by Fe2+ iron oxidation (Hayward & Geary 2017, Hayward 2022, Thomson & Hayward 2025). But it is less usual to find casts, especially one that exhibits a shiny bronze colour.

Fig. 2. Bronze-coloured mollusc cast 7cm x 5cm (pers. obs.).

Fig. 3. Decalcified darker Fe^{2+} shell moulds (pers. obs.).

The colour may be suggestive of pyrite 'permineralisation', which occurs in marine sediments saturated with iron sulphides (Wikipedia 2025). Over millenia, it appears the shell might have become decalcified and the outer layer microscopically replaced with pyrite, resulting in a thin patina of bronze $Fe^{+}S_2$ (or more correctly Fe^{2+} $[S_2]^{2}$) (Gasdia-Cochrane 2023).

Pyrite is a relatively common mineral, with any pyrite in this area possibly devolving from the organic decay central to permineralisation. Or potentially it has been carried from the gold-bearing Coromandel Peninsula to Weymouth by the Late Pliocene Clevedon River up to 3.5 mya when the sea level was 10–25 m higher than now (Hayward *et al.* 2006, Ballance 2017). Minor pyrite has also been reported from the West Auckland region at the Te Henga Mine in the Waitākere Ranges, bordering the Manukau Harbour, and at some Coromandel-facing east coast beaches from Cheltenham Beach to Waiwera (Mindat 2025).

Supporting the pyritisation theory, a yellow mineralisation was observed throughout the assemblage, suggestive of sulphur, though most closely resembling jarosite, a sulphate mineral sometimes developed on Plio-Pleistocene sediments around the shores of the Manukau Harbour (pers. obs.) (Fig. 4). Somewhat detracting from this theory, nary a single cuboid pyrite crystal could be found, though the pyrite might have been finely dispersed throughout the sediment.

Fig. 4. Yellow, sulphurous-looking deposits - likely to be jarosite - found especially around moulds and casts (pers. obs.).

Alternatively, the bronze colouration might be due to humic acid leaching from the soil when the region was forested (Hayward & Hayward 1995, Hayward *et al*. 2011).

Identifying the strata

The age of the fossiliferous layers present at Weymouth includes Miocene (at least 5.33 mya), Pliocene (5.33–3 mya) and Pleistocene (3 million to 11,700 years ago) (Moore & McKelvey 1971) (Fig. 5).

The sedimentary mud layer these casts and moulds were located in most likely corresponds to the Late Pliocene to Early Pleistocene Tauranga Group, Tamaki Formation.

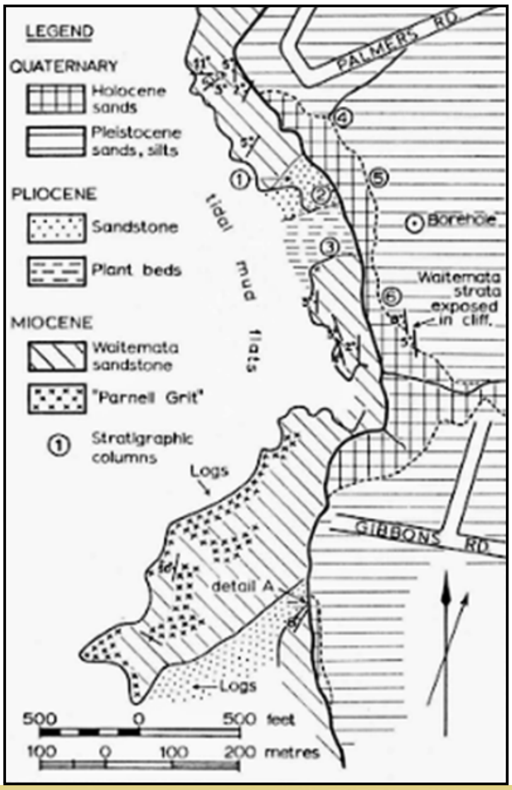


Fig. 5. The fossiliferous exposures lie just south of this graphic (Moore & McKelvey 1971).

These Tamaki Formation exposures have possibly been uplifted by the Manurewa Horst, a horst of low-lying land to shallow water, oriented NE to SW and located in the vicinity of Weymouth to Waiuku (Berry 1986, Hayward *et al*. 2023). For reference, the Wiri Fault lies less than 200 m to the NE of this exposure (Kenny *et al*. 2012).

Identifying the cast and moulds

With a Late Pliocene to Early Pleistocene time frame, the bronzed bivalve cast appeared at first most likely a *Paphies porrecta* – the precusor to today's tuatua (Beu & Raine 2009). But viewing of *Lutraria* shell images in the fantastic shell database for South Auckland fossil shells – thanks to the Watercare Interceptor project, work done by the Auckland Museum, and dozens of avocational volunteers – might also suggest the extinct *Lutraria solida* or *Lutraria grandis* (Māngere Kaawa Formation fossils 2022, Hayward *et al*. 2023) (Fig. 6).

The assemblage moulds have been matched with their closest likenesses (Fig. 7).

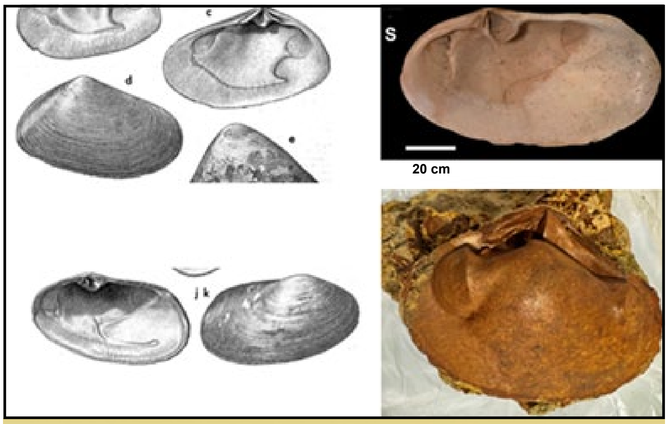
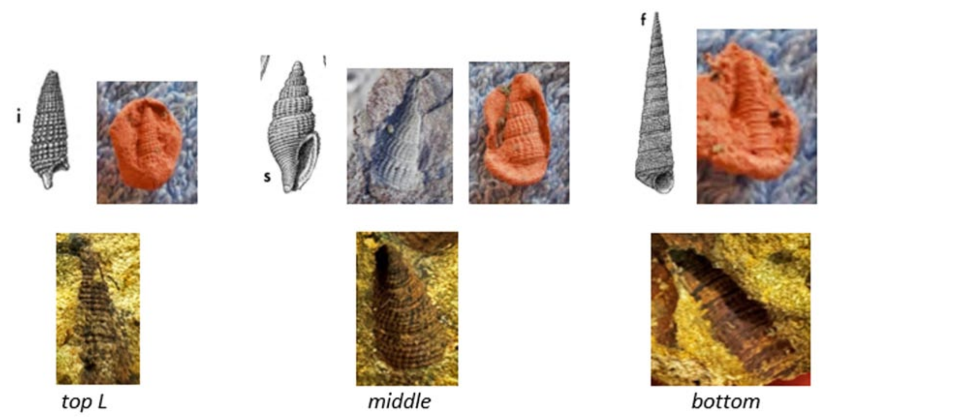


Fig. 6. Candidates for the bronzed bivalve cast: top left image is *Paphies porrecta* and bottom left is *Lutraria solida*, both from Beu & Raine (2009). Top right photo is *Lutraria grandis* from Auckland Museum MA166556, scale 2 cm. Bottom right photo is the cast for comparison (also refer back to Fig. 2, left photo).



Position in assemblage	**Potential name**
top L:	i. *?Taxonia suteri,* or *?Taxonia tesserata,*
middle:	s.*?Antizafra pisanopsis*, or *?Zeacumantus (?luculuntus)*, or *? Pyrazus ebininus*
bottom:	f. *?Zeacolpus (Zeacolpus) vittatus,*

Fig. 7. Candidates for the moulds: Top row - i, s & f (Beu & Raine 2009); the remainder (Hayward & Geary 2017).

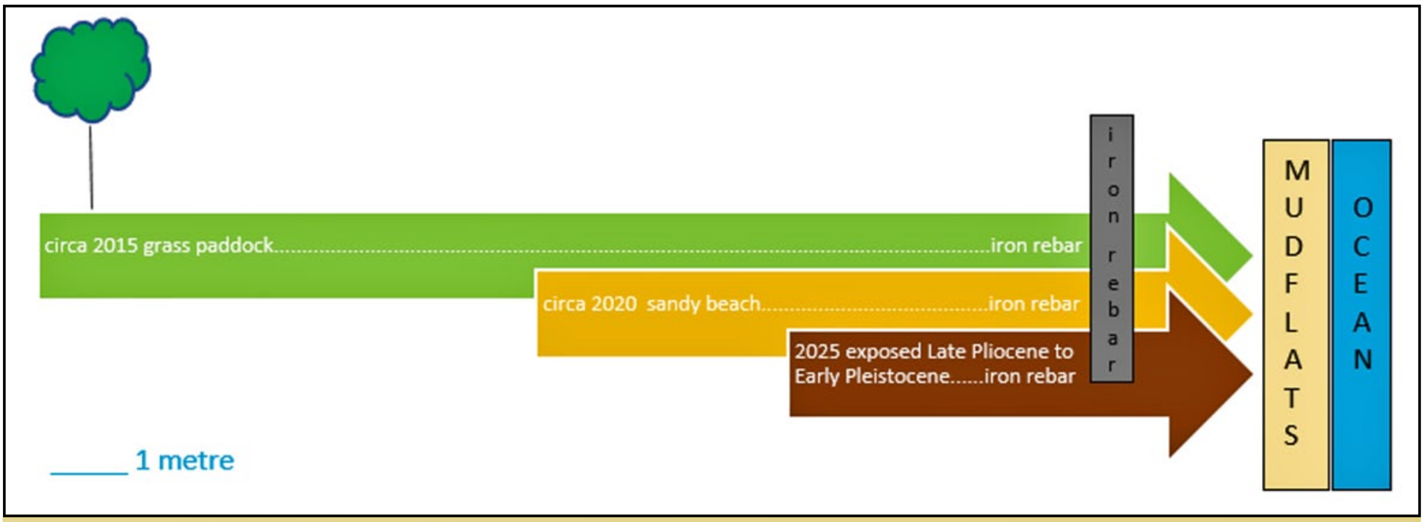


Fig. 8. Author's depiction of erosion over the past decade showing relatively recent exposure of the potentially pyritised Tamaki Formation deposits at Weymouth Beach, in relation to prior fencing rebar post (see Fig. 9).

Hayward *et al.*'s (2023) seminal report on fossils found at the Interceptor's Māngere Wastewater Treatment Plant notes that – "several in situ, double-valved specimens of the extinct, deep-burrowing, filter-feeding otter shell *Lutraria grandis* were found in Tamaki Formation (at 22.6–16 m)". Also noted nearby in the Tamaki Formation were *Taxonia tesserata* (in sheltered slightly brackish tidal flats) and *Zeacumantus lutulentus*, common gastropods that thrived in the shallow waters of the Tamaki Formation (Hayward *et al*. 2023). These 3 molluscs are all likely candidates for the cast and moulds in the assemblage. It would appear fairly safe to say the shells in this Weymouth Beach assemblage lived in a Late Pliocene to Early Pleistocene, Tamaki Formation coastal estuary tidal environment around 3–2.4 mya.

Erosion

Finally, how long have these Tamaki Formation, sulphur-bearing, possibly pyritised, small beachside fossil deposits been exposed? Locals anecdotally tell of marked erosion along the shoreline, asserting 6–10 m of grassy bank and sandy beach have been eroded away and overrun by the mudflats and ocean over the past decade (pers. obs.) (Fig. 8).

Iron rebar

Supporting locals' tales of erosion is a lump of material, highly attracted to a magnet, found poking out of the fossil layer near the edge of the sand/fossil boundary (…finally, a meteorite?). After 45 minutes levering the lump out, the base revealed the telltale signs of a triangular metal rebar fencepost (Fig. 9).

The top of the rebar post had either been struck by lightning or blowtorched by human hand to prevent injury to walkers on the beach. What once marked the end of a grassy paddock now marks a fossil deposit from 3–2.4 mya. And, though locals have lost grassy bank and sandy beach areas, on the plus side, more fossils have been exposed. You cannot fail to find a fossil, and the odd fencepost, in these small, but mighty, fossil deposits.

Fig. 9. Highly magnetic triangular iron rebar farm fencepost … not a meteorite (pers. obs.).

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DAVID KEAR'S OFTEN OVERLOOKED 1961 MAP OF THE BAY OF ISLANDS – KAIKOHE VOLCANICS

Bruce W. Hayward

The late David Kear (1923–2019) (Fig. 1) was District Geologist in the Otara (Auckland) office of the New Zealand Geological Survey 1958–1965 (Nathan *et al*. 2019) when he was instructed to assist Bob Hay in compiling the North Cape sheet (Kear & Hay 1961) of the survey's flagship programme at the time – a complete series of geological maps covering all of New Zealand at a scale of 4 miles to the inch. Soon afterwards he was sent north again to the area inland of Kerikeri to join a joint NZ Geological Survey–NZ Soil Bureau sampling and drilling field campaign in March–April 1960 to assess the quantity and richness of recently discovered bauxite (Kear *et al*. 1961).

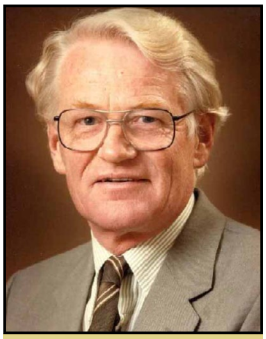

Fig. 1. Dr David Kear CMG FRSNZ

When compiling the 4-mile map for the Bay of Islands-Kaikohe Volcanic Field, the corners of 3 existing maps were brought together from the mapping of Bell & Clarke (1909), Ferrar (1925) and Hay (1960). None of these had identified individual volcanoes (volcanic centres) on their maps, but Kear & Hay (1961) used asterisks to show the location of what was labelled in the legend as "volcanic vents". Twenty-five asterisks are shown in the area that would now be included in the field at large. Three vents are shown at Te Puke (now recognised as a line of 4 small scoria cones) and 2 vents at Puketona/Puketutu (now recognised as a cluster of up to 7 small cones) (Hayward 2017, 2019). For the first time, eleven vents are recognised and shown within the older, weathered basalts that lack well-preserved scoria cones.

In 1958–59 bauxite was recognised in the soils of the Kerikeri basalt plateau by soil scientist Dr Leslie Denis Swindale (1928–2022) (Swindale 1960). Because of the widespread interest in the possibility of commercial bauxite deposits in New Zealand, a drilling and analytical programme was rapidly formulated to be undertaken jointly by NZ Soil Bureau (Leslie Swindale and Charles Sutherland) and NZ Geological Survey (David Kear and Barry Waterhouse). The field work took the form of drilling 53 holes to depths of 2–20 ft using a portable hand rig.

David Kear had an enquiring mind and was not one to be happy for very long mindlessly drilling holes with their locations determined by a 700-yard grid (Kear *et al*. 1961). His interest in the original arrangement of the basalt volcanoes of the Bay of Islands – Kaikohe Volcanic Field, both old and young, had clearly begun during the 4-mile mapping in 1958–59. The weeks stationed in the area during the bauxite programme gave Kear the opportunity to pursue his enquiries and develop his ideas on the locations and ages of eruption of the volcanoes. Results of the bauxite programme were published in a hurry (Kear *et al.* 1961) because of the interest in them, but half of the resulting stand-alone DSIR Information Series booklet (58 pages) was taken up by Appendix 1 (28 pages) by Kear alone (Kear 1961) on the age, structure and sequence of basalts in the "Bay of Islands Volcanic Zone".

On the second page of this paper, Kear (1961) presents a map (Fig. 2) captioned "Geology of the Kerikeri basalts of the Bay of Islands Volcanic Zone, showing the presumed order of eruption of the several volcanic centres." To my knowledge this map has never been referenced in any detail since that time and his mapping and identification of all the older centres has not been taken up (e.g., Edbrooke & Brook 2009, Hayward 2017). I suggest this is mostly because the paper was published in a one-off publication with a mineralogical title ("Bauxite deposits in Northland") that gives no hint of David's insightful work inside. In this article I highlight the existence of this often-overlooked map by Kear, which deserves to be known, utilsed and maybe slightly improved.

Fig. 2 occupies all of the next page.

Horeke Basalt Formation

On his map, Kear (1961) divides the Kerikeri basalts into older and younger formations (Horeke and Taheke respectively) largely based on their level of weathering and erosion. In the older Horeke Basalt Formation (Fig. 3) he maps and names 15 Members (volcanic centres) and numbers them in his inferred age order from 1 (oldest) to 15 (youngest). For 3 of these centres (Martin, Taiare and Omapere), he has labelled their location on the map as uncertain. He has also been unable to infer volcanic centres for lava flow remnants in the west, around Horeke, that were mapped by Alan Mason (1953).

In most instances, I infer that he has identified the volcanic centre as the topographically highest point of

Fig. 3. View south from Puketi Rd across the high plateau ridges made of eroded, older (Horeke) basalt flows erupted from the Okaihau centre (Kear, 1961) of the Bay of Islands-Kaikohe Volcanic Field.

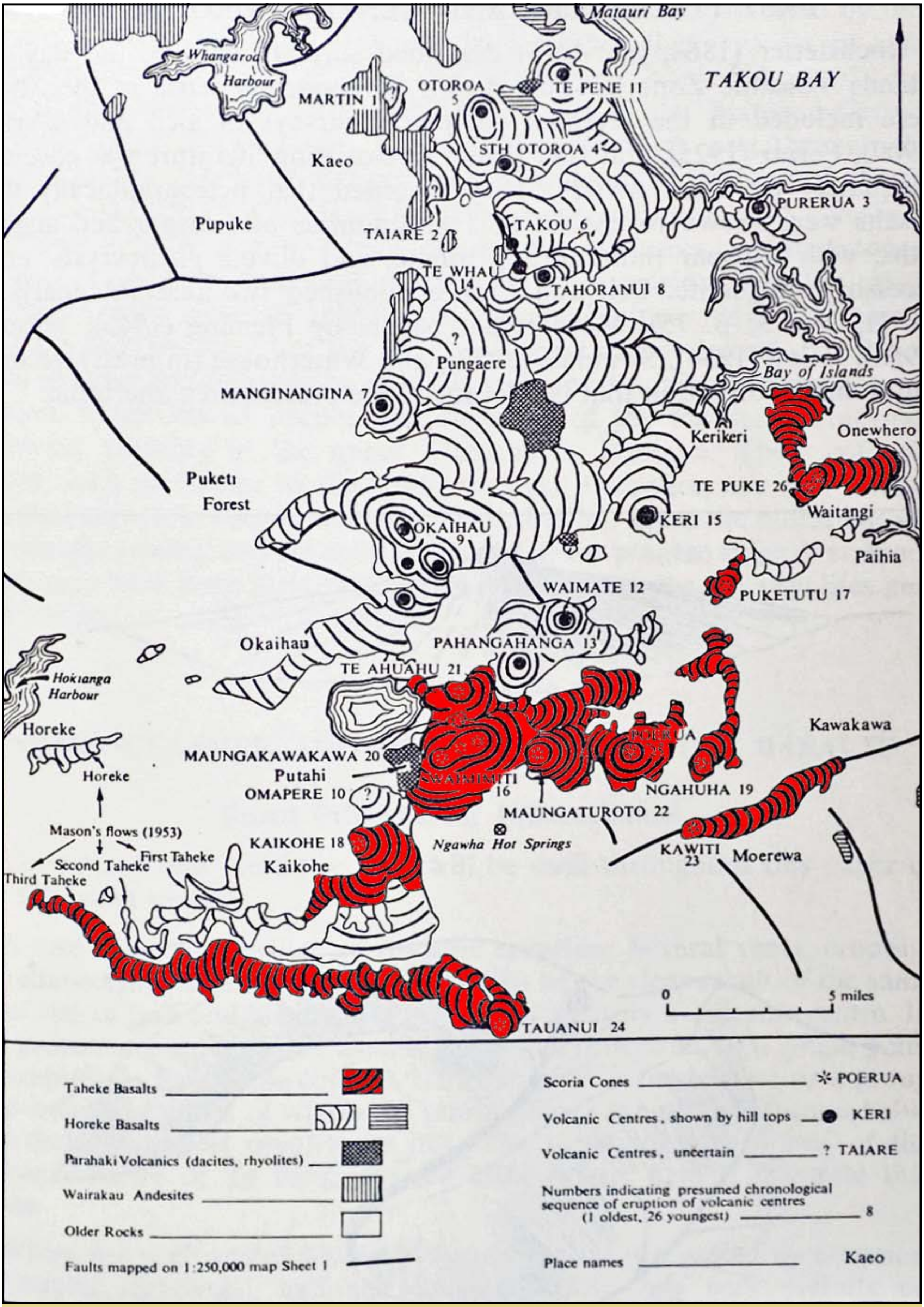

Fig. 2. Kear's (1961) "geological map of the Kerikeri basalts of the Bay of Islands Volcanic Zone". The young volcanic rocks (<360,000 years old) of the Horeke Basalt Formation have been coloured red.

an extensive lava flow (e.g., Manginangina, Fig. 4). This would not have been particularly simple back then, as the topo maps available had contours at 100 ft intervals and were not particularly accurate. Looking at his map, I think he did a magnificent job with maybe only a few tweaks or changes possibly necessary with the better-known extent of the weathered basalts (Edbrooke & Brook 2009) and the much improved and more closely spaced contours now available.

Taheke Basalt Formation

In the younger Taheke Basalt Formation, Kear (1961) maps and names a further 11 Members (volcanic centres) and numbers them in his inferred decreasing age order from 16 to 26 (Table 1) and indicates that these are the

Fig. 4. Manginangina has been inferred by Kear (1961) to be the source volcano (dated at 7 million years old) for lava flows inland from Kerikeri.

Table 1. Kear (1961)'s recognised 26 "members" (volcanic centres) "of the Kerikeri Group in the Bay of Islands in assumed order of eruption with the youngest at the top". Numbers refer to inferred eruption centres (oldest to youngest) and also correspond to the numbers on Kear's (1961) map (Fig. 2). Ages in brackets are K-Ar dates from Smith *et al*. (1993) and Ar-Ar ages* from Shane (undated).

		Age in Ma = millions of years	Age in yrs; myrs = million years
Taheke Basalts			
26.	Te Puke	(0.14 ± 0.06 Ma; 0.075 ± 0.012 Ma*)	(140,000 ± 60,000 yrs; 75,000 ± 12,000 yrs*)
25.	Pouerua	- -	
24.	Tauanui	(0.06 ± 0.05 Ma; 0.043 ± 0.01 Ma*)	(60,000 ± 50,000 yrs; 43,000 ± 10,000 yrs*)
23.	Kawiti	(0.19 ± 0.07 Ma)	(190,000 ± 70,000 yrs)
22.	Maungaturoto	(0.36 ± 0.06 Ma)	(360,000 ± 60,000 yrs)
21.	Te Ahuahu	(0.28 ± 0.02 Ma)	(280,000 ± 20,000 yrs)
20.	Maungakwakawa	- -	
19.	Ngahuha	- -	
18.	Kaikohe	(1.27 ± 0.06 Ma)	(1.27 myrs ± 60,000 yrs)
17.	Puketutu/Puketona	(0.10 ± 0.06 Ma)	(100,000 ± 60,000 yrs)
16.	Waimimiti	- -	
Horeke Basalts			
15.	Keri	(3.46 ± 0.29 Ma)	(3.46 myrs ± 290,000 yrs)
14.	Te Whau	(4.02 ± 0.43 Ma; 3.02 ± 0.18 Ma)	(4.02 myrs ± 430,000 yrs; 3.02 myrs ± 180,000 yrs)
13.	Pahangahanga	(1.4 ± 0.6 Ma)	(1.4 myrs ± 600,000 yrs)
12.	Waimate	(2.01 ± 0.24 Ma)	(2.01 myrs ± 240,000 yrs)
11.	Te Pene	(5.04 ± 0.2 Ma)	(5.04 myrs ± 200,000 yrs)
10.	Omapere	- -	
9.	Okaihau	(1.33 ± 0.11; 2.70 ± 0.15 to 3.56 ± 0.45 Ma)	(1.33 myrs ± 110,000 yrs; 2.70 myrs ±150,000 yrs to 3.56 myrs ± 450,000 yrs)
8.	Tahoranui	- -	
7.	Manginangina	(7.2 ± 0.2 Ma)	(7.2 myrs ± 200,000 yrs)
6.	Tako	- -	
5.	Otoroa	(4.48 ± 0.3 Ma)	(4.48 myrs ± 300,000 yrs)
4.	South Otoroa	- -	
3.	Purerua	(4.61 ± 0.28 Ma; 3.98 ± 0.26 Ma)	(4.61 myrs ± 280,000 yrs; 3.98 myrs ± 260,000 yrs)
2.	Taraire	- -	
1.	Martin	- -	
Not shown			
X1.	Lower Waitangi valley	(1.87 ± 0.18 Ma; 1.85 ± 0.09 Ma)	(1.87 Ma ± 180,000 yrs; 1.85 Ma ± 90,000 yrs)
X2.	Horeke	(2.67 ± 0.11 Ma; 2.84 ± 0.15 Ma)	(2.67 Ma ± 110,000 yrs; 2.84 Ma ± 150,000 yrs)

centres with existing scoria cones remaining. He labels as Waimimiti a line of 3 cone symbols, which today we recognise as 3 separate centres – Te Pua andesite, Waimimiti crater and Tarahi scoria cone (Fig. 5). In the south, he only maps Tauanui scoria cone (Fig. 6), whereas today we also recognise a separate cone named Hanganui. Today, we also include as volcanic centres in the field, Putahi rhyolite dome (Fig. 7) and a recently recognised eroded tuff ring at Kawiti (May 2000).

Kear (1961) noted that there appeared to be a migration of volcanic activity from north to south through time with all the Taheke centres in the southern part of the field.

Fig. 5. Tarahi is an undated, rounded scoria cone that may be part of either the Taheke or Horeke Basalt formations.

Fig. 6. Tauanui Volcano has been dated at 43,000–60,000 years old and is the source of a long lava flow (Fig. 2).

Fig. 7. Putahi rhyolite dome is inferred to be part of the younger Bay of islands-Kaikohe Volcanic Field.

Subsequent studies

Most subsequent workers have deliberately ignored Kear's 2-fold subdivision of the Kerikeri Volcanic Group in the Bay of Islands–Kaikohe area (Kear 1961, Kear & Hay 1961, Kermode *et al*. 1992) and preferred to unite them all as one continuous volcanic field. Some of us, however (e.g., Hayward 2017), have found it useful to informally recognise this 2-fold subdivision as the "Older" and "Younger" Kaikohe–Bay of Islands Volcanic Fields, based on the presence or absence of recognisable scoria cones and little eroded, fresh lava flow fields.

In 1961, Kear (1957) had recently proposed a scheme for recognising the relative ages of volcanoes based on their degree of weathering and erosion. In his 1961 study he extended his criteria still further for inferring the relative ages of the Bay of Islands basalt volcanoes and their sequence of eruption. Not only did he include the erosional stage and extent of weathering of the cones and lava flows, but also the relationship of flows to sea level along the coast, to river terraces, and the amount of soil development.

In 1961, the radiometric methods we now have available for dating basalt rocks did not exist and so Kear (1961) had no good means for calibrating the age of his sequence of eruptions. This did not stop him from inferring, however, that his older formation (Horeke Basalt) erupted "from the upper Pliocene or lower Pleistocene to the upper Pleistocene" and his younger Taheke Basalt Formation "from the upper Pleistocene to upper Holocene". Kear's Holocene date came from observations by Wellman (pers. comm.) of well-preserved basalt bombs from Te Puke Volcano occurring in coastal deposits at Onewhero that he had had radiocarbon dated at between 1200 and 1800 years old (Kear,1961). Lava flows from Te Puke occur along the south coast of Kerikeri Inlet and also as islands within it (Fig. 8) and appear to have been emplaced when sea level was lower (pre-10,000 years ago) (consistent with more recently acquired radiometric dates, Table 1).

Fig. 8. Motupapa and Rahui islands in Kerikeri Inlet are made of basalt flows that appear to have been erupted when sea level was lower than today.

In more recent decades Smith *et al.* (1993) obtained numerous K-Ar dates for basalts in this field and Phil Shane (undated) acquired 2 Ar-Ar dates. These dates have been assigned to Kear's (1961) volcanic centres in Table 1. These indicate that Kear's (1961) age calibration of the time of eruption of these volcanoes was rather too young, with the Horeke Basalt centres now known to have erupted in the Late Miocene to Early Pleistocene (7–1.3 Ma) and all the dated Taheke Basalt centres, except Kaikohe Hill centre, erupted in the Middle and Late Pleistocene (0.36–0.04 Ma). Maybe the more weathered Kaikohe and the Waimimiti-Te Pua-Tarahi centres should be shifted into the older Horeke group (all older than 1 Ma) with the Taheke centres much younger and considered to be in a dormant part of the field that is likely to erupt again some time.

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THE FIRST EXPLANATION IS NOT ALWAYS THE BEST – NUMBER 2

Bruce W. Hayward

This is my second note in a possible series (the first being Hayward 2020) as I continue to discover geological features that at first seem best explained in one way but on later reflection or collection of more observations, turn out to be way off the mark.

In 2024, a Geoclub field trip visited Omokorito Beach and the Pleistocene sandstone deposits in the cliffs to the north as far as Te Kawau Pt (Fig. 1). On that occasion, I noticed an unusual, rounded cobble (~30 cm across) of laminated, rusty Pleistocene sandstone within marine rusty Pleistocene foreset beds just above high tide level at Te Kawau Pt (Figs 2 & 3). The level of induration and iron-sand weathering (rust coloured) of the cobble and host rocks was similar. The laminated cobble also had

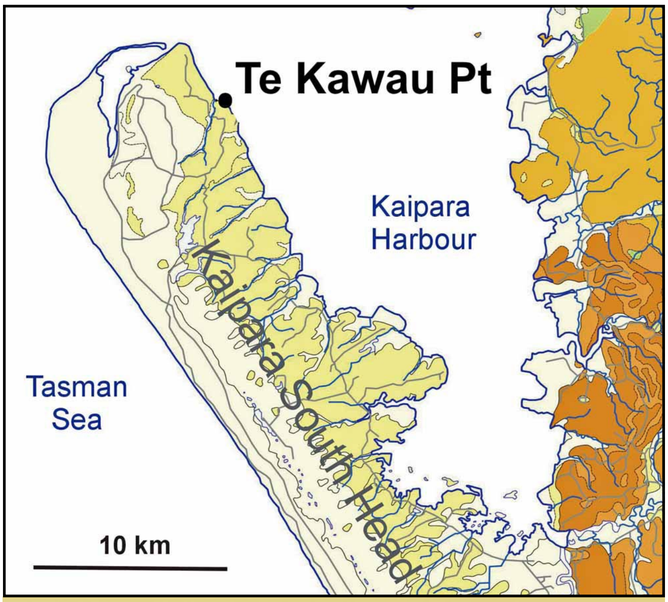

Fig. 1. Location of Te Kawau Pt on the Kaipara Harbour side of the South Kaipara Peninsula.
Dark yellow = Pleistocene sandstone; light yellow = Holocene sand dune belts.

Fig. 2. Rounded cobble in foreset Pleistocene sandstone bed above high tide level on Te Kawau Pt.

Fig. 3. 30 cm-wide, laminated cobble of Pleistocene sandstone with trace fossil burrows seemingly within the host cross-bedded Pleistocene sandstone at Te Kawau Pt.

marine burrow trace fossils in it (Fig. 3), which were not present in the host rocks at this locality.

I was extremely surprised to see such a cobble within the sequence as I had not seen anything similar anywhere else in these Pleistocene sandstones. At the time, I thought the cobble had to have been eroded out of an older marine (interglacial) Pleistocene sequence close-by and presumably altitudinally above the host cross-bedded unit. I postulated the presence of a cliff nearby that the cobble had fallen out of and been rounded as it was transported down the face of the advancing subtidal sand bank. How unusual, I thought, as I took a photograph and moved on.

I returned to Te Kawau Pt in April 2025 and immediately went looking for my cobble within the foreset beds and yes, it was still there and not eroding away fast. I sat down and had lunch at the spot as I once again pondered how this relationship came to be. By now I was more familiar with the local sequence and was aware that laminated, burrowed, rust-weathered sandstone identical to the cobble sat only a couple of metres above the cross-bedded unit in the low cliff above.

Then the "penny dropped". Could it be that I had been deceived and that the cobble is not actually within the foreset beds? I looked closely at the contact. It certainly looked remarkably convincing that the host sandstone was around the cobble and the cobble certainly was not loose on the surface. I looked around and found several other cobbles of the same lithology sitting loose on the surface, with 1 cobble (Fig. 4) also seemingly eroding out of the cross-bedded unit. With this one, I managed to prise it out of the "host" sandstone and discovered it had a flat underside and had worked itself into the underlying

Fig. 4. Another laminated sandstone cobble nearby, sitting flat on the sloping high tide platform but not as deep-seated as the first cobble (Fig. 3). Photo width 40 cm.

unit by just a few millimetres (Fig. 5). Elsewhere in a number of places along the shoreline, I had noticed that the gentle rocking and jostling by waves and wind often allowed branches and even sandstone blocks to erode themselves into the soft host sandstone of the high-tide shore platform and this was clearly the real explanation for my original observation. This jostling had initially eroded the base of both cobbles flat, so they sat snuggly on the high tide platform and then they had jiggled themselves into the underlying, maybe slightly softer unit. A similar process has been described for Oligocene sedimentary rocks near Raglan (Nelson & Hood 2016).

The cobble had fallen out of the low cliff above and landed just above high tide level on the tilted platform of the slightly older (not younger) foreset beds. Over the months or years, the cobble had become more rounded and had

Fig. 5. When I prised the second cobble loose, it was clear its base had been abraded flat, and the cobble itself had wiggled itself several millimetres into the host sandstone. The darker colour is where the cobble had been sitting. Photo width 40 cm.

gently eroded itself several millimetres to a centimetre into the underlying host sandstone. Further wave and wind erosion of the host rock had left a raised rim of host rock around the embedded cobble, giving the realistic impression that the cobble was actually within the cross-bedded unit. Once again, I recognised that the first explanation of an unusual geological feature is not always the best or correct one.

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