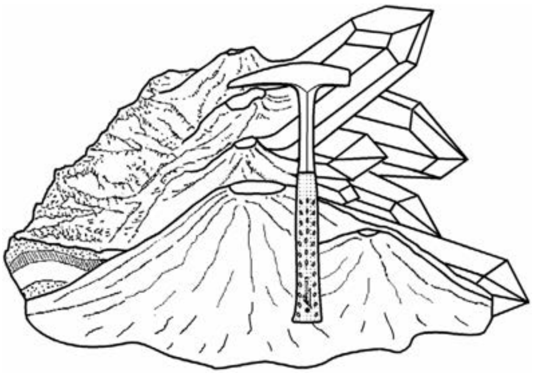

# Geocene


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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.

Please contact Jill Kenny   jill.kenny@xtra.co.nz

## A CURIOUS CASE OF RIVERBED POTHOLES IN WEST AUCKLAND

Michael Coote

Map and photographs by Kent Xie

**Natural rock potholes at Woodside Reserve, Swanson**
During the COVID-19 lockdown period, local exercise was promoted as official government policy. This situation encouraged the authors to look up maps for local walkways, rights-of-way and reserves not previously visited, in order to plan and undertake extended walking tours. On one such walking tour, we arrived at Woodside Reserve off Woodside Road in Swanson, West Auckland. The reserve is accessed on foot via a grassed right-of-way entering between numbers 26 and 30 Woodside Road. Its principal area is a flat, roughly triangular mown grassed area that is bounded along its northern edge by the Swanson Stream. This waterway is obscured from Woodside Reserve by a fringe of mainly native shrubs growing atop a low, soft clay scarp that runs alongside the stream.

Exploring further, we accessed the streambed first via a set of wooden-framed steps that dropped down beside a water level measuring installation, and thereafter via informal tracks cut into the scarp while travelling in a north-westerly direction through the scrub along the stream edge. We found substantial exposed areas of stream bedrock that were strikingly pockmarked with numerous potholes of varying size, depth, diameter and complexity. Some of these potholes were shallow dimple-like impressions; others were narrow, simple, usually vertical cylindrical shafts up to 50 cm deep, and others still were wider complex basins fed into from beneath by two or more underlying, often oblique potholes, totalling up to about 1 m in depth in the biggest example.


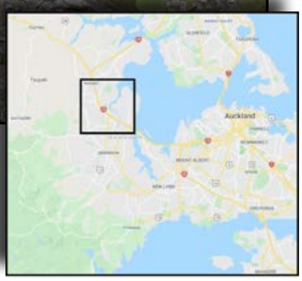

Fig. 1. Near linear distribution of streambed pothole sites in West Auckland.

The majority of the potholes were filled with water, but most were above the water level of the stream. A common feature evident of the potholes was a prominent annular lip of varying degrees of thickness that extended around the full circumference of the pothole mouth and appeared to be composed of a ferrous material like limonite. In some cases, this lip had been worn away, and in a few cases broken up into pieces that had fallen into the pothole. The potholes appeared to be an entirely natural phenomenon, but there were no externally introduced stones found within them that might have ground them out over time as we have observed elsewhere in New Zealand.

The extent of potholed rocks was observed to run downstream from the water level measuring installation towards the beginning of the foundational remnants of the kauri log-holding dam built in the 1850s by William Swanson (Hayward & Diamond, 1975 - dam numbered as 9). We reached the streambed dam site from behind the community gardens, planted out in Woodside Reserve, by walking between two piles of lawn clippings. We crossed inside a broken metal safety fence at the top of the scarp through which entry point access to the streambed was afforded by two informal tracks cut into the bank. Historically, felled kauri logs were stored behind this dam when operational at the head of the Huruhuru tidal inlet and rafted to Auckland for milling.

We found that immediately downstream of the site of the existing dam foundation remnants, the bedrock had been extensively concreted over as part of the original dam works, presumably to prevent the dam from being undermined by stream channel scouring. Accordingly, it was not possible to locate any more potholes from that point onwards, but ferrous seepage inclusions were evident in cracks in exposed rock in that area. We noted a couple of square-cut holes in the exposed bedrock by the dam foundations that were consistent with being man-made as part of dam construction, and this evidence served to underscore that the potholes were not man-made.

Looking down from the broken safety fence at the top of the scarp above the dam site, we noted that there was a mass of potholed rock exposed above the waterline in the middle of the streambed immediately before the dam foundations. Thus, the extent of the potholed rocks within the Swanson Stream by Woodside Reserve would appear to start at the water level measurement installation and stop just before the dam site, but possibly the potholed area was more extensive until modified by the original dam construction. In our judgement, the rock exposed that features potholing is all a single homogeneous piece and set more-or-less at the same level throughout, tilting slightly downwards towards the dam site. This rock formation appears to have become exposed over time due to water action by the Swanson Stream within the confines of a small gorge that is bounded by low cliffs on either side (Figs 2–8). Therefore, we judge that the physical causes of the all the potholes at the site, whatever these causes may be, are the same throughout.

Fig. 2. Steep bluff and deep pool immediately downstream of main riverbed pothole site, Swanson Stream, Woodside Reserve.

Fig. 3. Downstream view with submerged pothole complexes at main riverbed site. The deep pool in Fig. 2 is in the background.

Fig. 4. Mixed pothole types in riverbed rock, Swanson Stream, Woodside Reserve.

Fig. 5. Single-shaft potholes with conspicuous rims in submerged riverbed rock, Swanson Stream, Woodside Reserve.

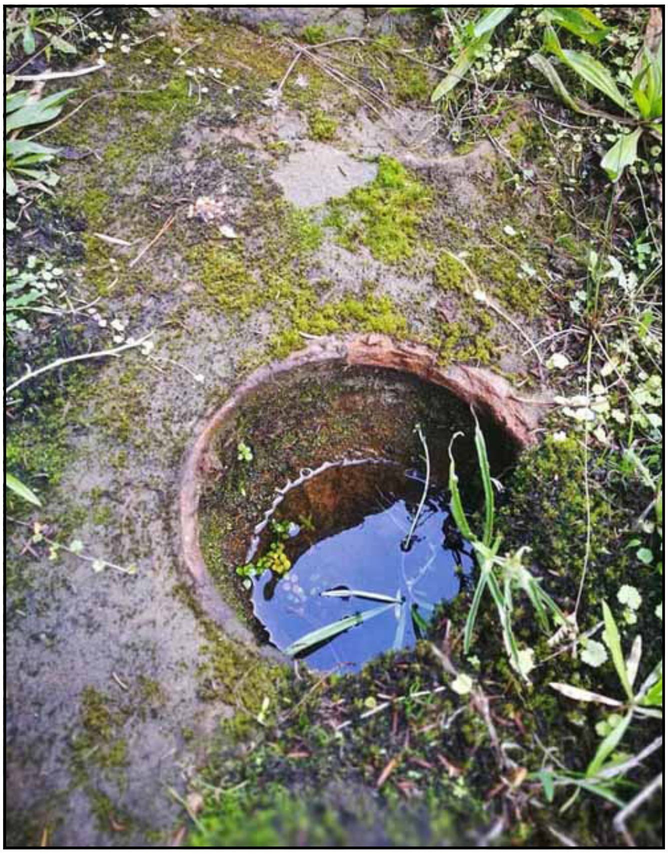

Fig. 6. Single-shaft pothole with conspicuous iron deposit rim in exposed riverbed rock, Swanson Stream, Woodside Reserve.

Fig. 7. Single-shaft potholes in exposed riverbed rock, Swanson Stream, Woodside Reserve.

Fig. 8. Pothole complex in submerged riverbed rock, Swanson Stream, Woodside Reserve.

**Other West Auckland stream sites that display similar potholes**

Two more streambed pothole sites have since been identified northwards of the Woodside Reserve site.

*Lowtherhurst Reserve, Massey*

Site access is via a public concrete path that runs into the reserve at the blind end of the road between numbers 1 and 2 Huruhuru Road. This path follows the lower course of the Rarawaru Stream. The streambed itself is readily accessed by climbing down its banks at certain points where informal tracks have been worn and is also observable from the footbridge that connects the concrete path to the blind end of Redwood Drive in Royal Heights. Following the stream to its tidal terminus leads to a large flattish rock shelf that drops off sharply into tidal mangrove swamp. Much rockbed is exposed in the stream and shows evidence throughout of potholing.

In comparison with the Swanson Stream site, the Rarawaru Stream potholes tend to be smaller, shallower and more eroded in appearance, with only occasional examples displaying the annular lip formation. Many of the Rarawaru Stream potholes are underwater and obscured by a film of mud, but on the final rock terrace before the mangrove swamp there is a swarm of shallow craters of fairly uniform distribution, resembling a lunar landscape. The bedrock of the Rarawaru Stream descends sharply in a series of steps towards the final terrace. Thus, it is not clear if all the Rarawaru Stream potholes belong to the same homogeneous piece of rock as the Swanson Stream examples appear to do, although the effect might be explained by land slumping (Figs 9 & 10).

*Moire Park, Royal Heights*
Site access is from the carpark at the head of Manutewhau Track opposite 90 Moire Road. Following the formal gravel track down to the Manutewhau Stream and walking along informal streamside tracks, an area of stream bedrock can be found which displays potholes that are underwater and filmed over with mud. These potholes were visually inspected from the streambank but not physically accessed for further investigation (Figs 11 & 12).

**Checking further south for streambed potholes**
Observations were made at Henderson township of the exposed rocky streambeds at Opanuku Stream (Henderson's old mill site, Sel Peacock Drive) and Oratia Stream (Falls Park). Some potholes were evident at these sites, but they were infrequent and appeared to be caused by erosional breakage and abrasion of the bedrock. At the mill site some were square and obviously man-made for the purposes of mill construction. In some cases, stones could be seen in the potholes that appeared to be externally introduced. These potholes are not closely similar to those observed at the three sites in Swanson Stream, Rarawaru Stream, and Manutewhau Stream.

**Speculations**
As hobby geology enthusiasts, we do not have the expertise to pose any scientific hypotheses on the origin and formation of the streambed potholes described. We can only speculate as amateurs on the origins of the streambed potholes found at Woodside Reserve, Lowtherhurst Reserve, and Moire Park. In our observations, these potholes have not originally been formed by abrasive erosion, although many now show an eroded state. The best, least degraded examples are to be found in Swanson Stream at Woodside Reserve.

Fig. 9. Pot hole complex at Rarawaru Stream (tributary of Henderson Creek), Lowtherhurst Reserve.

Fig. 11. Submerged pothole bed, Manutewhau Creek (tributary of Henderson Creek), Moire Park.

Fig. 10. Submerged "Craters of the Moon" pothole bed near tidal estuary terminus of Rarawaru Stream (tributary of Henderson Creek), Lowtherhurst Reserve.

Fig. 12. Another submerged pothole bed, Manutewhau Creek, Moire Park.

The common presence of a ferrous deposit annular lip on the top of these potholes (found also occasionally at Lowtherhurst Reserve), combined with lack of externally introduced abrasive material such as stones within them, plus their highly variable size, shape and depth, suggest an originating chemical reaction of some kind at certain points within the bedrock that has been critically aided or induced by water.

Whether this suspected water-caused potholing effect was originally submarine when the supporting bedrock was sunken below sea level, and has subsequently been exposed by uplift onto land and terrestrial erosion effects, or instead fresh water-sourced, occurring once the bedrock was exposed directly to rainfall and spring-fed drainage from the Waitakere Ranges, is unknown to us. We did note the bluish colouration characteristic to the waters of the Swanson, Rarawaru and Manutewhau streams, and the ferrous intrusions in bedrock cracks and deformations at the Swanson Stream site as possible chemical influences. We also suspect that it is the same band of bedrock that extends northwards in a line from Woodside Reserve, through to Lowtherhurst Reserve, and on into Moire Park that is prone to potholing from the same unknown causation throughout (Fig. 1), and that there may be other examples within this line of uncertain full extent.

Geologist Bruce Hayward has described these mysterious potholes as possibly being "liesegang rings in reverse, i.e. oxygen-laden water penetrating the sandstone from the water-filled holes over hundreds of years". In our view, this case of the curious potholes is ripe for scientific examination, perhaps for a post-graduate geology thesis, and we look forward to reading papers published thereon. In any event, the three sites described are all worth visiting for their intrinsic merits, and the Woodside Reserve site throws in the added bonus of the old kauri log holding dam remnants. We would urge caution when directly accessing the pothole-studded rocks as they are mossy, muddy, and slimy, and accordingly a slipping and falling hazard.

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# GRANITE FLUTING, BASINS AND TAFONE ON SOUTHERN STEWART ISLAND

Lee Sawyer, Ken Smith & Bruce W. Hayward

Karst landforms are produced by the partial solution of rocks by slightly acidic water. The rocks are generally those containing carbonates, like limestone, marble and dolomite. In nature, rainwater by itself is usually not acidic enough to dissolve these rocks but when it passes through soil, it dissolves carbon dioxide, forming weak carbonic acid and becomes sufficiently acidic to slowly dissolve carbonate rocks, given sufficient time (e.g. Kenny & Hayward, 2010).

Non-calcareous rocks are more resistant to solution or don't dissolve at all and seldom are known to produce karst-like landforms. A well-known New Zealand example of an exception to this generality is the basalt karst features, sometimes called pseudokarst, which can be seen to have developed on basalt boulders that have sat exposed at the surface for thousands of years in parts of northern New Zealand, Norfolk Island and Hawaii (e.g. Hayward and Kenny, 2011; Hayward, 2015). There are many records of the weak development of karst-like features on granite and quartzite overseas (e.g. Migon & Dach, 1995; Wray, 1997; Twidale & Vidal Romani, 2005) but we do not know of any records from New Zealand. Most of this karst developed on non-calcareous rocks is found in humid tropical climates and writers used to infer that these warm conditions are a requirement for the solution of these rocks, but it has now been shown that similar landforms occur in arid and cold environments (even Antarctica), although maybe not always as commonly (e.g. Twidale & Bourne, 2003; Twidale & Vidal Romani, 2005).

In the summer of 2018/2019 the first two authors sailed on their yacht from Auckland to Stewart Island and return. The furthest south ventured was into Port Pegasus (47.2°S) on the southeast coast of the island (monthly mean temperature range 7–18°C). This is one of the least visited and remote places in New Zealand. There are no inhabitants and it is surrounded by virgin forest all within Rakiura National Park. The forest comes right down to the water's edge. Most of Stewart Island is eroded out of massive granite and this is true for the land surrounding Port Pegasus. We also sailed into Patterson Inlet on Stewart Island (46.9°S) which, away from Oban at its entrance, also has natural forest extending right down to the shoreline within Rakiura National Park.

We noted and took photographs of three unusual karst-like features in the granite surrounding Port Pegasus and Patterson Inlet (Figs 1 & 2):

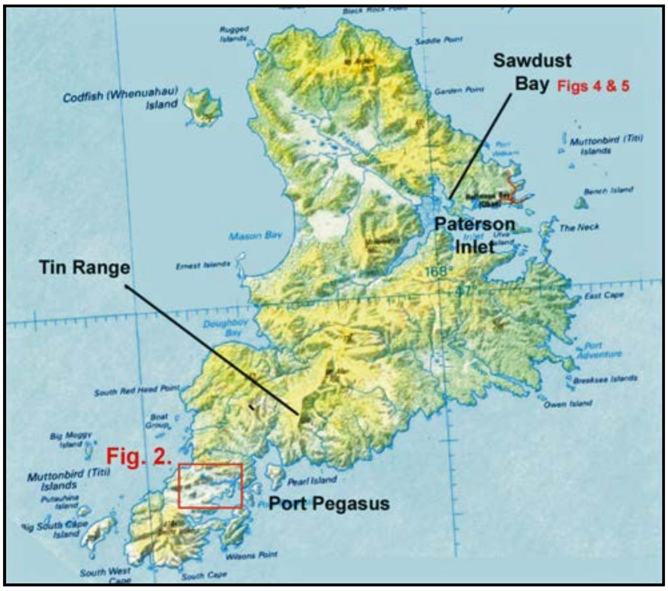


Fig. 1. Stewart Island map showing location of places visited and mentioned in the text, including the location of shoreline fluting in figures 4 and 5.

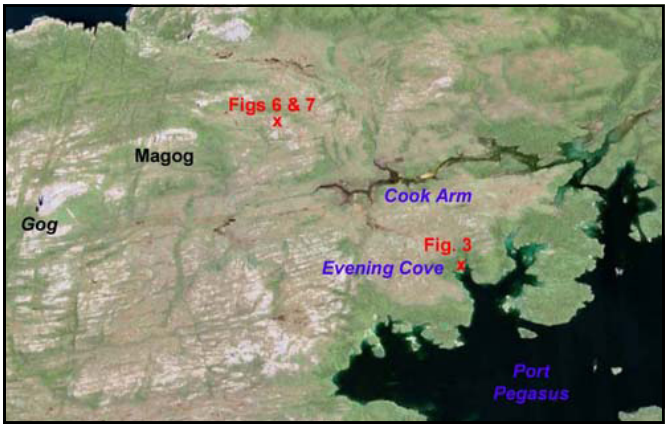


Fig. 2. Google Earth image of part of southern Stewart Island showing the location of fluted granite on the foreshore of Port Pegasus (Fig. 3) and of granite boulders with basins and tafone (Figs 6 and 7) on the ridge leading up to Magog from Cook Arm.

**1. Fluted granite**

In many places around the edge of Port Pegasus and Paterson Inlet, rainwater runoff percolates down to the inlet through the thick peaty soils, picking up tannins on the way and giving the water in some of the more sheltered arms a brown tea colour. At times weak tannic acid can reduce pH of water to below 7. As we navigated around the shore in our inflatable dinghy, we noticed several places where solid granite rock was overlain by dark peaty soil just above high tide level (e.g. Fig. 3). Water was seeping out of the peat and draining down over the rock into the sea. In two places the 30–50 cm wide belt of bare rock between the base of the soil and mean high tide level was fluted with a series of rounded vertical flutes about 20 cm across and 10 cm deep (Figs 3 & 4). Elsewhere we saw places where the flutes were less regular but extended over a wider supratidal zone of about 1 m width (Fig. 5).

Fig. 3. Section of shore in Evening Cove, Port Pegasus, at high tide showing dark layer of peat (under dead tree) overlying a 30 cm belt of fluted granite (down to water level).

Fig. 4. Section of shoreline in Sawdust Bay, Paterson Inlet, at low tide showing 30-50 cm wide belt of dark-stained fluted granite below the vegetation and above the intertidal zone.

Fig. 5. Section of shoreline at Sawdust Bay (Paterson Inlet) during mid tide, showing a 1 m wide belt of irregular vertical flutes through the granite above high tide level.

How were these flutes formed? There is insufficient water pouring over these rocks, even during heavy rain, to envisage mechanical erosion. The observed trickle of tannin-coloured (acidic) water out of the peat and down some of the flutes provides all the evidence we need to conclude they were made by some form of acid-water hosted weathering or solution of the rock. Others who have studied granite fluting ("granitkarren") overseas have sometimes inferred the fluting was initiated when under the soil (Logan, 1849; Twidale & Bourne, 2003). In our examples, the association of the flutes with a steep eroding shoreline precludes any chance that the fluting began underground.

Dodge-Wan & Nagarajan (2016) studied fluting on granite boulders in Borneo and concluded that large feldspars were fragmented and mechanically weathered by abrasion in the flutes that was enhanced by the presence of moist mosses. They rejected the notion of solution. Scholz (1947) on the other hand, like us, concluded that the granite flutes he was studying were due to "solvent action of downward trickling solutions charged with organic acids derived from soil-filled basins on the upper parts of the residual boulders." Most workers steer a middle course and believe the flutes are produced by a combination of chemical and mechanical processes, but there is also debate about the relative role, if any, of moisture and the associated vegetation (Twidale & Vidal Romani, 2005). Can we claim that these are examples of granite karst in New Zealand or not?

**2. Granite "armchair basins"**

While anchored in Port Pegasus we undertook two inland forays. One into the Tin Range (Fig. 1) to look at remnants from the historic tin mining venture from the 19th century (e.g. Petchey, 2006). The second foray was more of a bush crash from Port Pegasus up towards one of the two prominent granite tors – Magog (Fig. 2). Once we climbed up onto a ridge crest the going was a bit easier as the bush was less dense subalpine scrub. On the ridge top we came across several large rounded granite boulders sitting on solid granite bedrock. These are clearly core stones that have weathered out of the granite massif by weathering along wide-spaced joint sets while underground and later exhumed by erosion. This area in southern Stewart Island is today above the bush line in subalpine scrub and grasses. It may have been fired by humans in previous centuries and could have had slightly higher vegetation cover during the slightly warmer Early to Mid Holocene (~11,000–5000 years ago). For most of the time in the last 2 million years or so, this area has been a lot colder than today with abundant snow and maybe thick winter ice cover. These boulders on the ridge crest have been eroded out and survived the harsh glacial conditions. We infer that the detailed features we describe were probably formed in the ~18,000 years since the end of the Last Ice Age (MIS 2).

Two of these large boulders caught our attention (example 2 "armchair basins" and example 3 "tortoiseshell rock").

The first is a large saucer-shaped boulder of granite about 3 m x 2 m in size (Fig. 6). The smoothly rounded underside of the boulder was balancing on the solid rock beneath and rocked when pushed down on one end (https://vimeo.com/379407387). What attracted our attention most, however, was the fact that the whole upper surface of the boulder was excavated into a series of rounded basins, each 30–50 cm wide and of similar depth, separated by sharp peaked ridges (Fig. 6). We were immediately struck by the similarity of these basins to those on top of large basalt karst boulders that we had seen with Geoclub in northern New Zealand (Hayward & Kenny, 2011; Hayward, 2012). There the basins on top of the basalt boulders have been inferred to have been dissolved out by weakly acidic humic acid that formed in humus around the roots of plants that grew on the boulders under a forest canopy. We find it hard to envisage this Stewart Island boulder existing beneath high forest with shrubs and monocots growing on top as clearly happened with the basalt boulders in northern New Zealand, even during the slightly warmer parts of the Holocene.

A wide variety of enigmatic rock basins have been recorded in granite surfaces overseas, particularly in Australia (e.g. Twidale & Vidal Romani, 2005; Timms, 2013; Twidale & Bourne, 2018). These workers have classified the rock basins into a number of types and those on top of our boulder would be placed in their "armchair basins" category. Armchair-shaped basins have a water overflow flute developed downslope. They note that this kind usually form on slopes of 20–30°, which could have been the situation around the top of our original boulder. Most of the rock basins discussed in the literature formed on extensive flat or gently sloping granite surfaces and few on top of small boulders like ours. The main debate about the origin of these basins is how the initial small indentation was formed in the featureless granite. Once there is a depression that collects and retains water, there seems to be general agreement that growth and deepening of the basins occurs by etching which decays the rock's minerals (other than quartz). If all the water in the basin evaporates, the decayed remains of the minerals in the bottom of the basin may be blown away by the wind or bounced out over the overflow by heavy rain. By this proposed mechanism the granite does not actually dissolve into the water like limestone.

Another option, similar to the proposed process for the basins on top of basalt boulders in northern New Zealand, could have involved the growth of subalpine plants on top of the fairly flat-topped boulder with gradual accumulation of humus and peat around their roots. Could the acidic waters in this root mass have progressively etched out the basins? We speculate that with probable European firing and clearing of much of the land around Port Pegasus in an attempt to establish sheep farming, the vegetation that may have been growing on top of our boulder was likely killed and the soil that had been bound by its roots was washed and blown out of the basins. If this hypothesis is correct then one could say that the rock minerals were etched or partially dissolved away and the armchair basins are an example of granite karst.

**3. Granite tafone or "tortoiseshell rock"**

Also during our excursion towards Magog, we came across another unusual granite boulder that was about 2 x 1.5 m in size and concavo-convex in shape (Fig. 7). Most of the inside of the boulder has been hollowed out, with the original rounded convex outside of the upper part of the boulder still present. In a few places there are small circular "windows" linking the inside with the outside. This kind of small landform is known elsewhere around the world in granite boulders and is placed in the landform type called tafone (Twidale & Vidal Romani, 2005). Tafone (plural = tafoni) is an Italian word meaning perforation or window. In geomorphology it refers to a

Fig. 6. The large rocking granite boulder capped with "armchair basins" on a ridge crest above Cook Arm, Port Pegasus, Stewart Island.

Fig. 7. Our "tortoiseshell boulder" on a ridge crest above Cook Arm, Port Pegasus is an example of tafone that has excavated out the inside of this granite boulder.

shallow cavern partly enclosed by the preservation of a hood or visor and commonly occurs on the underside of boulders, like this one.

Exactly how tafone is formed is hotly debated but the excavation is generally agreed to occur subaerially and is not believed to be influenced by any variation in the original chemistry or texture of the original massive, homogeneous granite (Twidale & Vidal Romani, 2005). The flakes that break off inside the tafone are generally fresh which rules out chemical weathering or solution as the erosive process. Freeze and thaw of moisture inside the tafone has been suggested as a way to shatter the inside surface – but it is generally pretty dry inside and this process is not well supported by researchers (Twidale & Vidal Romani, 2005). Crystal growth of various salts is often cited as a mechanism to disintegrate rock and produce tafone. This seems quite probable in coastal areas and where there is a lot of salt in the vicinity but it also requires moisture for the salt to crystallise out of. Our conclusion and that of the literature seems to be that we don't exactly know how these tortoiseshell rocks well away from the coast were excavated.

It can be noted that often the inside of the excavated tafone parallels the convex shape of the outside of the boulder, which suggests that somehow the outer 5–20 cm of the originally homogeneous granite boulder is more resistant to erosion than the excavated inside. It seems that the outside of the boulder is case-hardened, possibly as a result of secondary precipitation of iron-oxide at the weathering front when this core stone was under the soil.

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# EVIDENCE FOR TUFFS AT MANGAWHAI HEADS

Garry Carr

Early Miocene Pukekaroro dacites outcrop around Brynderwyn and along the coast north of Mangawhai (Fig. 1). Inland the dacites are “mainly tuffs with thin flows” but on the coast they are “dacite flows associated with two small domes” (Edbrooke and Brook, 2009). But north of Mangawhai near the arch (close to where the clifftop walkway descends to the shore) there are a few mostly small boulders (cobbles) on the beach that are clearly tuffs. The clifftop walkway can be seen on the map (Fig. 2) but extends further north than can be discerned and descends to the coast close to the yellow X marked on the image. It is in this area that tuff boulders can be found.

Fig. 1. Dacite lava between Mangawhai Heads and Bream Tail, eastern coast of Northland.


Fig. 2. Google maps image of the coastline just south of Bream Tail. Dacite outcrops on the coast from near the bottom of the image up to the point beside the yellow X on the image.

Numerically there are far fewer tuff boulders than lava boulders. Presumably tuffs are present in the steep hillside and cliffs lining the coast here, but unlike the lavas are poorly exposed, and seem to be absent on the shore platform. Slips and rockfalls over time could have transported these boulders on to the beach. Poor exposure is probably due to the lavas being more resistant to weathering compared to the tuffs. I have not ventured up the cliffs to have a closer look for exposures of tuffs in place. Significantly, the tuffs are found close to the margin of the dacite exposures on the coast.

Figures 3–8 are photos of various tuff boulders all found in relatively close proximity to each other. They show a considerable variety of tuffs and hence several eruptive events, probably over a short period of time, that can be inferred from this one centre.

Fig. 3 (above) and Fig. 4 (below). Bedding with some very fine grained material and coarser grained layers. Dark angular fragments of what appear to be greywacke are also present.

Fig. 5. Tuff here appears to be a flow deposit with a high proportion of fine material with altered larger fragments of what could have been pumice along with angular dark fragments of greywacke.

Fig. 6. Fragments that have been extensively altered with white rims formed round original clasts in the tuff.

Fig. 7. Bedding with some very fine grained material and coarser grained layers, similar to Figs 3 and 4.

Fig. 8. A rock with large rounded fragments of what appear to be flow-banded lava and may be a sedimentary deposit eroded from the lava dome. Other material is considerably finer and of different character, possibly altered pumice.

One boulder of breccia (Figs 9, 10, following page) has been noted in the breakwater, which extends from near the surf club out toward Sentinel rock at the entrance to Mangawhai Harbour. This breakwater was originally built in the 1860s (Mabbett, 1977) and the rock was apparently quarried from the dacite lava exposed nearby (blast holes are present in the outcrop). The breccia boulder has been broken into several pieces by storms since first observed. There is no outcrop in the vicinity of anything like the breccia boulder found in the breakwater.

The boulder contains angular fragments, some quite large, of a variety of lithogies including what appear to be volcanic fragments (bombs?), sandstone and limestone (fizzed with acid) reminiscent of lithogies within the Northland Allochthon. In my view this breccia is likely to be associated with the volcanism producing the local dacites. However, due to the location of this boulder and no sign of where it originally came from, it probably should be discounted since its origin cannot be verified.

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Figs 9 and 10. Parts of a boulder from the breakwater at Mangawhai Heads. The boulder is a breccia containing a variety of lithologies.

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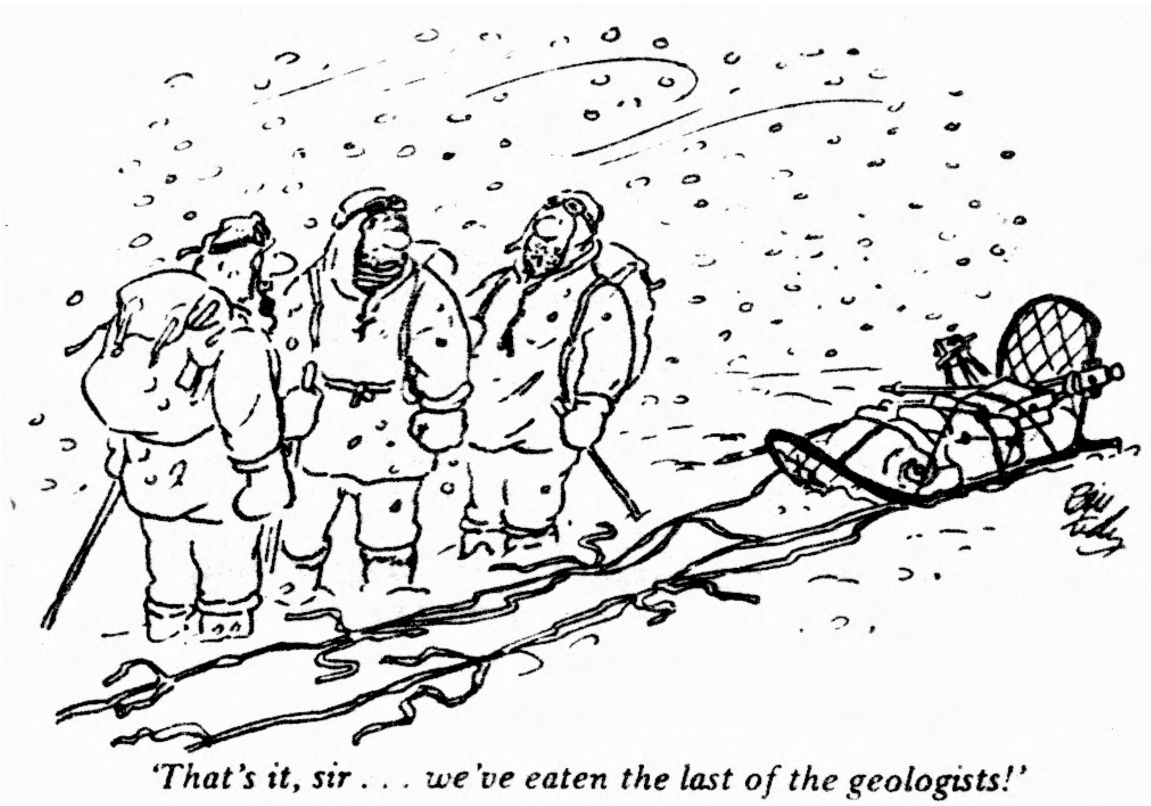

# EXHUMED LAVA CAVE AT KERIKERI, NORTHLAND

Bruce W. Hayward

In recent decades I have often stated that lave caves in New Zealand are only found in the young Auckland Volcanic Field (e.g. Hayward, 2017). The occurrence of several lava bridges in Northland have been documented for over 40 years at Titoki and Onekura Rd, Pungaere (Heming, 1979; Hayward, 1996). These tunnels may have initially developed by erosion and solution along lava caves within basalt lava flows but now there is no evidence left of any original cave at these two localities.

In November 2016, 30 members of the Auckland Geology Club visited the historic Edmonds Ruins – the basalt stone remains of a nineteenth century stonemason's house (Challis, 1993) in Edmonds Rd on the south side of Kerikeri Inlet. The house was built on and out of a young lava flow from Te Puke Volcano (Kermode *et al*., 1992; Fig. 1). Following that visit we decided to look for fresh exposures of the young lava flows in the vicinity and drove down to the edge of the Kerikeri Inlet at the end of Kerikeri Inlet Rd (Fig. 2). Access was not easy as the tide was in. We scrambled along a rough track through the long grass and scrub and reached a tiny embayment in the basalt lava flow with several dinghies pulled up on shore.

From a fly-over I had made in 2015, I knew this part of the shoreline of Kerikeri Inlet had numerous relatively fresh and well-preserved lava flow-fingers extending into the tide waters (Figs 3 & 4), rather similar to the southern, uneroded sheltered shoreline of Rangitoto Island in Auckland. This embayment consisted of a narrow, elongate gut that cut through the lava flow to a tiny shingle beach (Fig. 5) used by locals for landing their dinghies and kayaks at high tide.

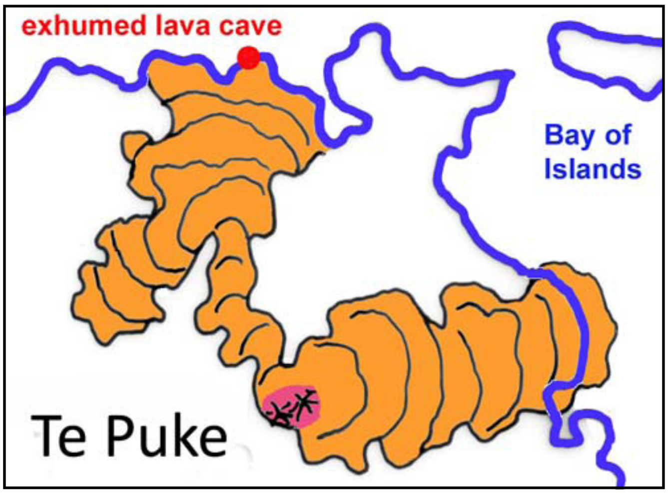


Fig. 1. Sketch map of the extent of lava flows from Te Puke Volcano, halfway between Waitangi and Kerikeri, showing the location of the exhumed lava cave.


Fig. 2. Google Earth image, 2004, showing location of exhumed lava cave on the basalt foreshore 50 m from the end of Kerikeri Inlet Rd.

Fig. 3. Oblique aerial of part of the southern shoreline of Kerikeri Inlet close to the end of Kerikeri Inlet Rd (left among houses). The exhumed lava cave is just out of the picture to the left.


Fig. 4. View east along the southern shore of the Kerikeri Inlet with its numerous lava flow toes showing the location of the small exhumed lava cave.

Fig. 5. The small exhumed lava cave at high tide in 2016.

Closer examination revealed that this 1.5 m wide by 6 m long gut had the structure of a small, de-roofed lava cave that had been exhumed by marine erosion. The western side around the head of the gut still retained the curved-over edge of the roof of the cave and the head of the embayment was the hollow of the cave now almost completely filled with fine basalt beach gravel. Thus this seems to be the first recorded occurrence of a lava cave still retaining some of its identifiable shape in a Northland basalt lava flow. An appropriate term for it could be an exhumed lava cave. Dictionary meanings of “exhume” include “to bring to light” and “expose something that was formerly buried”. There is no reason why more, possibly larger and more complete lava caves may exist inside the young lava flows of Te Puke Volcano.

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# A RECORD OF THE DISTINCTIVE BRYOZOAN GENUS *RETELEPRALIA* FROM THE EARLY MIOCENE WAITIITI FORMATION OF NORTHLAND, NEW ZEALAND

Seabourne Rust

**Overview of local geology & paleoecology**

In the banks of the present-day Taita Stream near Waimamaku, South Hokianga, Northland (Fig. 1), the Waitiiti Formation outcrops as a shallowing-up, north-dipping section, largely obscured and deformed by recent slumping and mass movement, adjacent to the Waima Range (Wakefield, 1977; Evans, 1994; Hayward, 1993). We have been studying the Taita section, in an effort to record macrofossil distribution and diversity, (Rust & Yanakopulos, 2011, 2012), with results recorded on the New Zealand Fossil Record File (FR# O06/f0121).

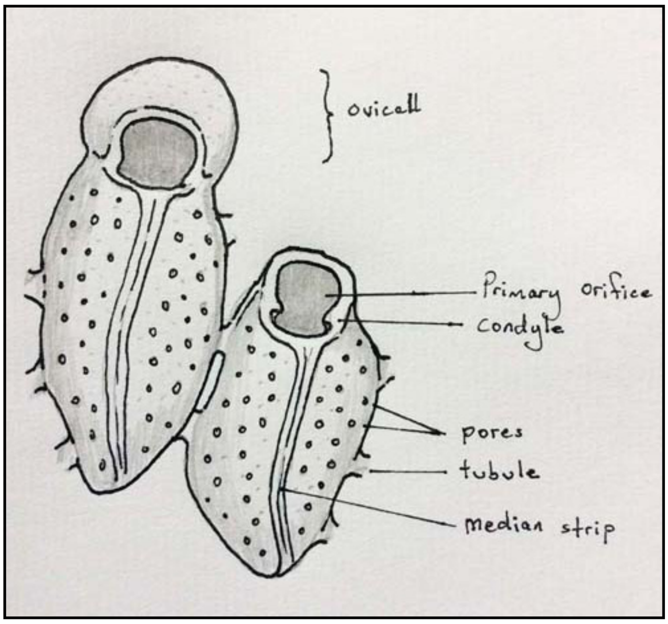
The Waitiiti Formation in the Taita Stream consists of poorly-bedded grey mudstone with scattered macrofossils (mainly small mollusca), passing upward into layered mudstone and fine sandstone, with some coarser lenses or channel-fill deposits of larger lithic fragments, rhodoliths and occasional worn macrofossils. The studied assemblage comes from the uppermost 50 m of the Waitiiti Formation section, where lithic fragments often show signs of bioerosion and are commonly encrusted by a well-preserved attached epifauna. These rocks may represent part of the original 'bedrock' of an Early Miocene shallow shoal or perhaps euphotic-mesophotic zone 'reef', which once existed on the western fringes of proto-Northland, covering an area being progressively uplifted, to eventually form the Waima Range. Locally the rocky seafloor developed a significant rhodolith habitat that supported a diverse, bryozoan-rich epifauna (e.g. Rust, 2019; Rust & Yanakopulos, 2012). This is the subject of ongoing study by S. Rust & D. Gordon, who have identified close to a hundred cheilostome bryozoan taxa from the Waitiiti Formation (Gordon, pers.comm. 2018).


Fig. 1. Location and Waitiiti Formation outcrop on the banks of Taita Stream, South Hokianga.

However, these reef edge rocks and their associated shallow (euphotic zone) biota were later eroded and incorporated/mixed into slightly deeper shelf settings. Thus we interpret the assemblage as a 'displaced thanatocoenesis', a number of which are found in other comparable Miocene basin-filling strata of northern New Zealand (cf. Hayward, 1976; Hayward & Triggs, 2016). Microfossil analysis by Hayward (1993) indicates eventual deposition of the upper Waitiiti Formation at mid-shelf depths and has confirmed an Early Miocene age (Otaian NZ Stage).

**A notable bryozoan**

Some of the most distinctive fossil encrusting bryozoans found at the locality are colonies of the cheilostome *Retelepralia*. These are recognisable due to the prominent median strip on the frontal wall or shield (Di Martino & Taylor, 2012; Gordon & Arnold, 1998).




Fig,. 2. *Retelepralia* sketch.

**CLASS GYMNOLAEMATA**

ORDER CHEILOSTOMATA
Family Cheiloporinidae (Bassler, 1936)

**Genus *Retelepralia*** (Gordon & Arnold, 1998)
Type species: *Lepralia mosaica* Kirkpatrick, 1888

*Retelepralia* sp. cf. *mosaica*

**Material**
Relatively rare at the Taita Stream locality as patch-like colonies encrusting hard surfaces.

**Description**
Colonies encrusting, multiserial, unilaminar (Fig. 2). Autozooids generally rhomboidal, longer than wide, typically 0.65–0.80 mm long x 0.5–0.60 mm wide, separated by deep furrows in between short tubular processes that connect the adjacent zooids.

Convex frontal shield, finely granular, covered by evenly spaced round pseudopores with a median strip of smooth calcification averaging 0.02 mm wide. This extends distally to form a smooth rim around the orifice.

Primary orifice bell-shaped, 0.15 mm x 0.12 mm wide, with a small pair of proximally-directed lateral condyles. The rim of the orifice is slightly raised but lacks oral spines.

No avicularia. Ovicells (brood chambers) are present in some zooids, these are inflated, hyperstomial, globular, approximately 0.36 mm in length and 0.44 mm wide. The ovicell surface is granular apart from a thin gymnocystal lip and lacks pores.

**Remarks**
*Retelepralia* has a wide but sporadic record of distribution in space and time. The Recent species *R. mosaica* is known from Mauritius and from the shelf waters of north eastern Australia and along the Norfolk Ridge (Gordon & Arnold, 1998). Interestingly, fossil species of *Retelepralia* are also known from the Late Oligocene of Borneo, and the Miocene of France and Morocco (see Di Martino & Taylor, 2012). The Waitiiti Formation fossil species is similar in size and the morphology of the zooids and ovicells to *R. mosaica*. However, given the currently known distribution, this may represent a rather cryptic species (Di Martino & Taylor, 2012). These fossils are certainly the first recorded occurrence of the genus from New Zealand; an addition to the diverse bryozoan fauna from the Miocene of Hokianga.

**Acknowledgements**
Many thanks to Dennis Gordon for taking the SEM images and identification of the Taita specimens plus taxonomic advice, Paul Taylor and Emanuela Di Martino for helpful comments, and also Diane Yanakopulos for her assistance in the field.

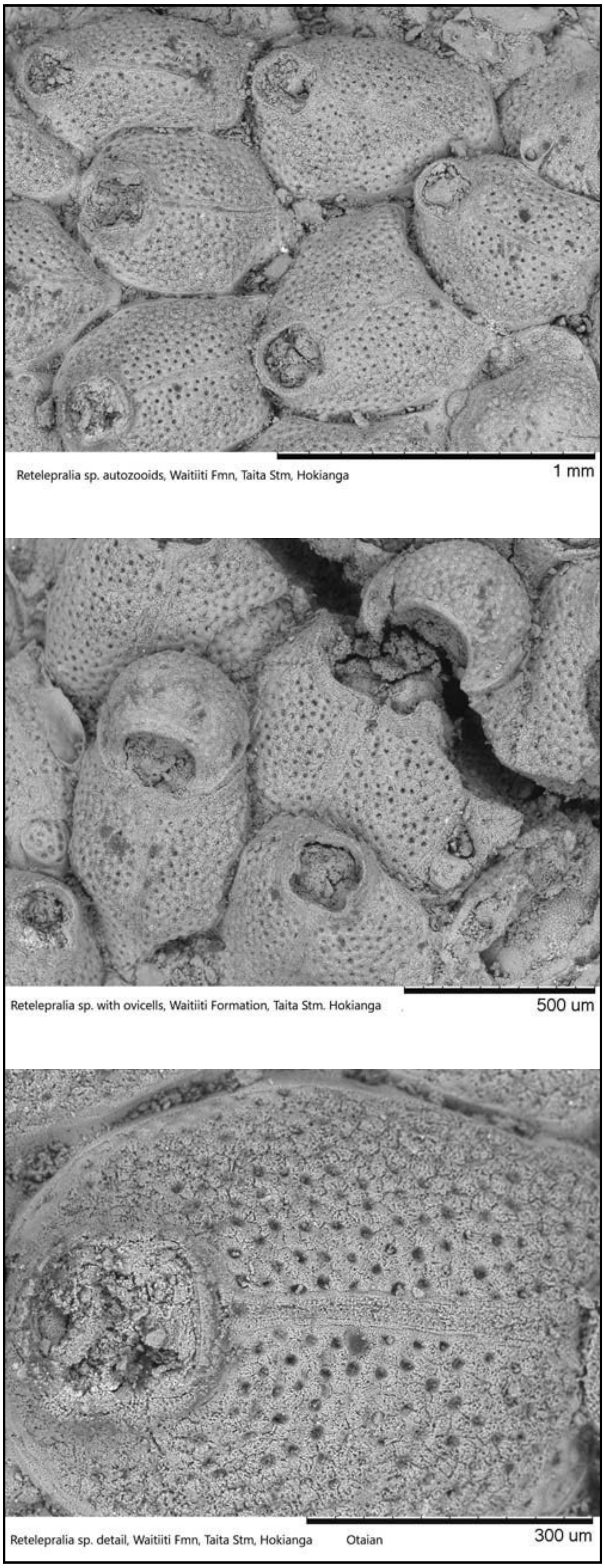



Fig. 2. SEM images of Retelepralia from the Waitiiti Formation showing: top- autozooids; middle – two maternal zooids with ovicells; lower – details of median strip of frontal wall and primary orifice.

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## IHUMATAO ROAD END FOSSIL FOREST

Bruce W. Hayward & Maureen Burke

In September 2019, an Auckland Geology Club field trip visited Otuataua Stonefields and circumnavigated Maungataketake Volcano on the Manukau Lowlands (Fig. 1). As we were returning to the cars, some of us took a short cut across the sand flats near the end of Ihumatao Road and one of the authors (MB) noticed an in-situ fossil tree stump sticking up out of the sand. This locality is 1.5 km around the coast to the northwest of the well-known Ihumatao Fossil Forest at the end of Renton Road (Hayward & Hayward, 1995; Marra *et al.*, 2006). We remember the late Les Kermode mentioning on a previous Geology Club trip that there were several fossil tree stumps in the vicinity of the end of Ihumatao Road end, but cursory searching had only ever turned up one (probably number 17, Fig. 2).

As this fossil locality is not documented anywhere, the first author decided it was time to do this, so that visitors or researchers would have no difficulty in finding it in the future. Using the GPS Test app on a smartphone, the locations of all apparent tree stumps (wood grain oriented vertically) and larger fallen logs were recorded with a software-claimed accuracy at the time of ± 1–2 m (Table 1). These locations were computer plotted and overlain on a google earth satellite image of the site (Fig. 2). The edge of the in-situ tuff shore platform was mapped using GPS points and the google earth image (Fig. 2), and indeed the location of all features appears to be close to the claimed accuracy.

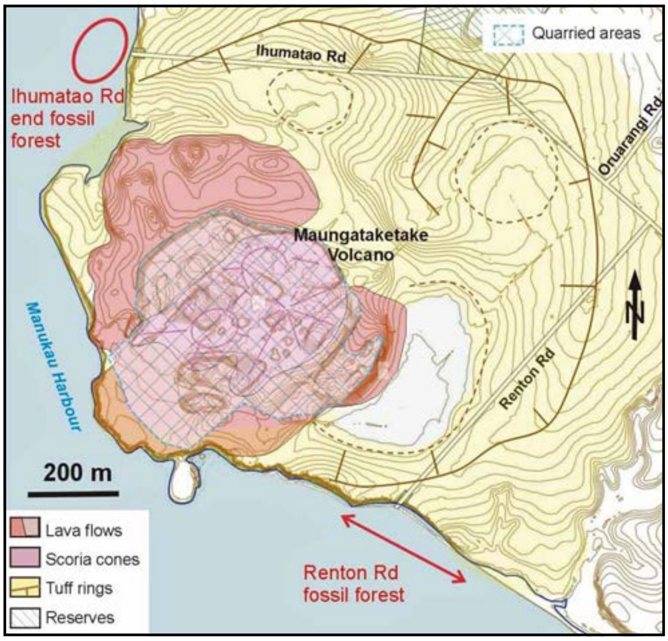


Fig. 1. Map of Maungataketake Volcano showing the location of Ihumatao Rd end fossil forest and also the better exposed Renton Road fossil forest (modified from Hayward, 2019).

It is not surprising that these fossil tree stumps have not been documented previously as they are easily overlooked and quite obscure, especially when compared to their well-exposed counterparts at the end of Renton Road (e.g. Hayward, 2019). In the foreshore at the end of Ihumatao Road, just below high tide level, there is a near-flat, eroded shore platform made of case-hardened tuff (hard on the outside), ranging between 0 and 60 m wide and extending out beyond the narrow shell beach and mangrove fringe (Fig. 2). The shore platform passes seaward and northward into a muddy sand flat with loose boulders of tuff and basalt scattered over it (Fig. 3). Digging into the sand, one finds it is only 2–10 cm thick and generally overlies relatively soft dark brown peaty soil that extends underneath the tuff. This was clearly the forest floor at the time of eruption of nearby Maungataketake Volcano. The eruption has been dated by Ar–Ar dating at ~90,000 years ago (Leonard *et al*., 2017).

In the low cliffs at Renton Road it is possible to see the stumps of a number of relatively small trees that have been killed and buried by the first base surge eruptions of tuff from Maungataketake (e.g. Hayward & Hayward,

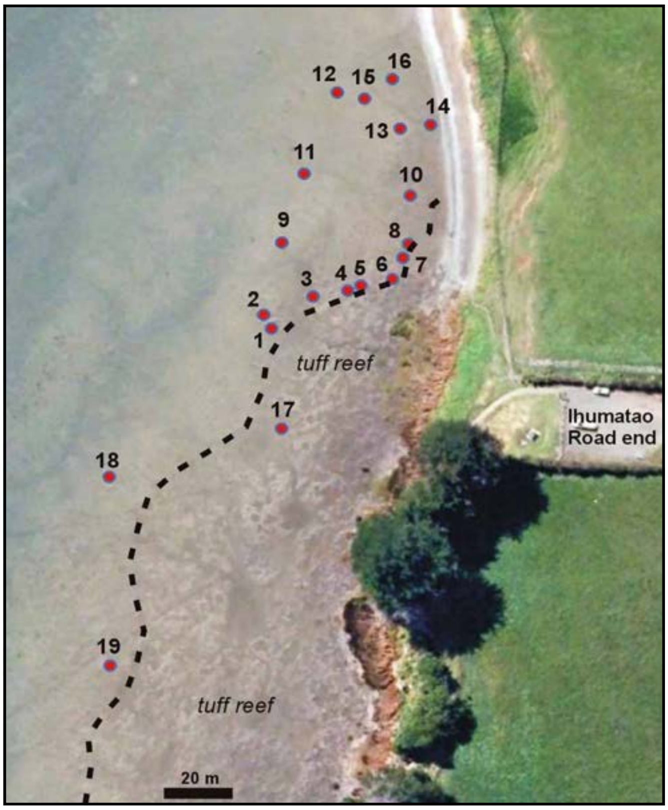


Fig. 2. Google earth image of the foreshore at the end of Ihumatao Road showing the extent of tuff reef and the GPS located fossil tree stumps and logs that protrude above the level of the sand flat around the edge of the reef, with only one tree stump (17) extending up through the tuff.

Table 1. List of fossil in-situ tree stumps and fallen logs (with dimensions) that can be seen in the foreshore at the end of Ihumatao Rd. Their GPS locations are given, and the numbered features are shown on Fig. 2.

| Number | Feature type | Size | Latitude | Longitude |
|---|---|---|---|---|
| 1 | tree stump in peaty soil | 12 cm diameter | 36.988978° S | 174.743852°E |
| 2 | tree stump | 10 cm diameter | 36.988943° S | 174.743830°E |
| 3 | splayed roots | 70 cm diameter | 36.988896° S | 174.743969°E |
| 4 | tree stump | 10 cm diameter | 36.988881° S | 174.744067°E |
| 5 | fallen log | 60 cm long | 36.988868° S | 174.744104°E |
| 6 | tree stump | 10 cm diameter | 36.988851° S | 174.744193°E |
| 7 | angled tree stump | 30 cm diameter | 36.988797° S | 174.744223°E |
| 8 | fallen log | 40 cm diameter | 36.988761° S | 174.744238°E |
| 9 | angled fallen log in peat | 25 cm diameter | 36.988758° S | 174.743881°E |
| 10 | tree stump | 6 cm diameter | 36.988637° S | 174.744243°E |
| 11 | 2 fallen logs | 35 and 50 cm x 1.5 m long | 36.988581° S | 174.743944°E |
| 12 | tree stump | 12 cm diameter | 36.988373° S | 174.744037°E |
| 13 | 2 fallen logs in peat | 30 cm x 1.5 m each | 36.988466° S | 174.744215°E |
| 14 | splayed roots of stump | 40 cm diameter | 36.988456° S | 174.744300°E |
| 15 | tree stump | 50 cm diameter | 36.988389° S | 174.744114°E |
| 16 | tree stump | 10 cm diameter | 36.988339° S | 174.744193°E |
| 17 | tree stump extending up through tuff | 10 cm diameter | 36.989234° S | 174.743880°E |
| 18 | fallen log in peat | 30 cm x 2 m long | 36.989358° S | 174.743394°E |
| 19 | tree stump | 10 cm diameter | 36.989842° S | 174.743397°E |

1995; Hayward, 2019). Most of these decapitated tree stumps are rooted into the top of a lens of black peat that contains the preserved, water-saturated stumps and fallen trunks and branches of a somewhat older, predominantly kauri forest with much larger diameter stumps and logs (Hayward, 2017, p. 283). The in-situ tree stumps measured at the end of Ihumatao Road are relatively small (Table 1) and stick 10–15 cm up above the top of the peat or 5–10 cm out of the sand (e.g. Fig. 4) and are most probably remains of trees that were living when nearby Maungataketake erupted. Several tree sites (3, 14) consist of a splay of roots (e.g. Fig. 5) that appear to be eroded out of the top of the "soil" and are also probably from trees that were killed and buried by the erupted tuff. Only one tree stump and circular mould (17)

Fig. 3. View from the north across the mid-tidal muddy sand flat at the end of Ihumatao Road with scattered boulders of tuff and basalt mixed in with occasional fossil tree stumps and logs. The tuff reef is in the distance in front of the large trees.

Fig. 4. The top of a 10 cm-diameter, partly eroded in-situ tree stump (number 6) protrudes from the mid-tidal sand flat at the end of Ihumatao Road.

Fig. 5. The preserved splay of roots (no. 3) in-situ and exposed through the mid-tidal sand flat at the end of Ihumatao Road.

can be seen sticking up through the lower 10–20 cm of tuff (Fig. 6) and this was clearly a living tree at the time of the eruption.

The six recorded fallen logs at the end of Ihumatao Road (e.g. Fig 7) all occur out beyond the edge of the tuff shore platform and do not extend more than 5–10 cm above the level of the sand. Undoubtedly there are many more, not currently visible, buried beneath the sand. It is not possible to be sure whether these are branches and trunks that were felled by the earliest base surge or whether they are the exhumed tops of older logs that had been preserved in the peaty soil. Fallen logs and branches of both ages can be seen in Renton Road fossil forest. The tuff exposures from Maungataketake have been studied in detail by Brand *et al*. (2014) and Agustín-Flores *et al*. (2014) and both have inferred the style and strength of these phreatomagmatic eruptions. Brand *et al*. (2014) in particular, used the character and thickness of the initial base surge deposits and the diameter of the decapitated tree stumps at Renton Road to infer the speed and strength of the early base surges. They inferred initial, near-vent, base surge speeds of 65 m per second and base surge thicknesses (extending above the ground) of 60 m. They concluded that the run-out distances for the base surges was about 4 km, with complete destruction expected within 500 m and partial destruction and decapitation of trees out to about 2 km from the vent (Brand *et al.*, 2014). The Renton Road fossil forest is 500-700 m from the nearest vent, whereas the Ihumatao Road end fossil forest is 700–900 m from the vent in the opposite direction (Fig. 1). Thus, while we cannot test the hypothesis because of the amount of erosion, it is likely the in-situ tree stumps at Ihumatao Road end were also decapitated by the initial base surges from the Maungataketake eruption.

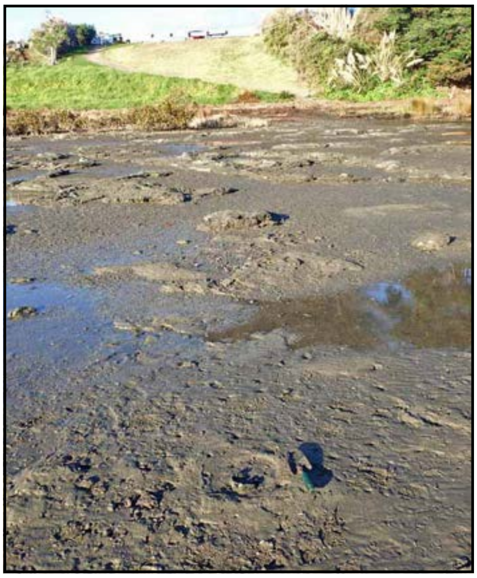

Fig. 6. View of the only in-situ tree stump (foreground, number 17, beside trowel) that was found protruding up through the lower layers of the eroding tuff reef. The parking area at the end of Ihumatao Road is in the background.

Fig. 7. Two fallen logs (number 11) protruding above the sand flat surface may have been preserved from an older forest or the trees that were felled by the base surge eruptions.

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# RAFTS OF PLEISTOCENE SEDIMENT IN PUPUKE VOLCANO LAVA FLOWS

Bruce W. Hayward

On a number of occasions over the past 25 years, Auckland Geology Club field trips have visited the Pupuke Volcano sequence in the road cuttings and quarries around the end of Northcote Road, Takapuna (Figs 1 & 2). Over this period, the exposures became more and more weathered and progressively obscured by vegetation growth. On the most recent visits, the exposures had been improved by extensive vegetation clearance by the council and by the owners of the disused Smales Quarry as they have been planning for the site to be subdivided and developed.

On our first Geoclub visit in the mid-1990s, leader Les Kermode took us into the disused Smales Quarry. Near the middle of the pit and in its floor, we noted the presence of a small patch of perfectly formed, small (~1 cm diameter) hexagonal columns of a cream-coloured, hard porcellanite. We concluded that these were formed by baking of a light-coloured clay that had accumulated between lava flows from Lake Pupuke. I have never been able to re-find these perfect columns on subsequent visits. Now, with the much clearer exposures in the Northcote Road cuttings (Fig 3) and in the walls of Smales Quarry, I decided maybe it was an opportunity to look more closely for the origin of this porcellanite. The light-colouring suggested that maybe this was a rhyolitic tuff that had been erupted from the centre of the North Island between eruption of several of Pupuke Volcano's lava flows. If it was, then maybe it could be identified from its geochemistry and be used to test the 190,000-year-old age currently assigned to the volcano (Hopkins *et al.*, 2017; Hayward and Hopkins, 2019). If it was mud that had accumulated in a pond between flows, this would suggest that there had been a number of years between flows and give an indication of the longevity of the eruption.

The cutting on the south side of Northcote Road, along the side of the old Smales Quarry, exposes two 1–3 m thick basalt lava flows separated by an irregular and impersistent rubbly zone (Fig. 3). In one place, a small hornito has been over-topped by the second flow (Hayward, 2009). In several places, the scree along the foot of this 2–4 m high cutting contains a significant amount of light-coloured porcellanite fritter amongst the weathered basalt soil and scoria from above. This porcellanite fritter can be traced

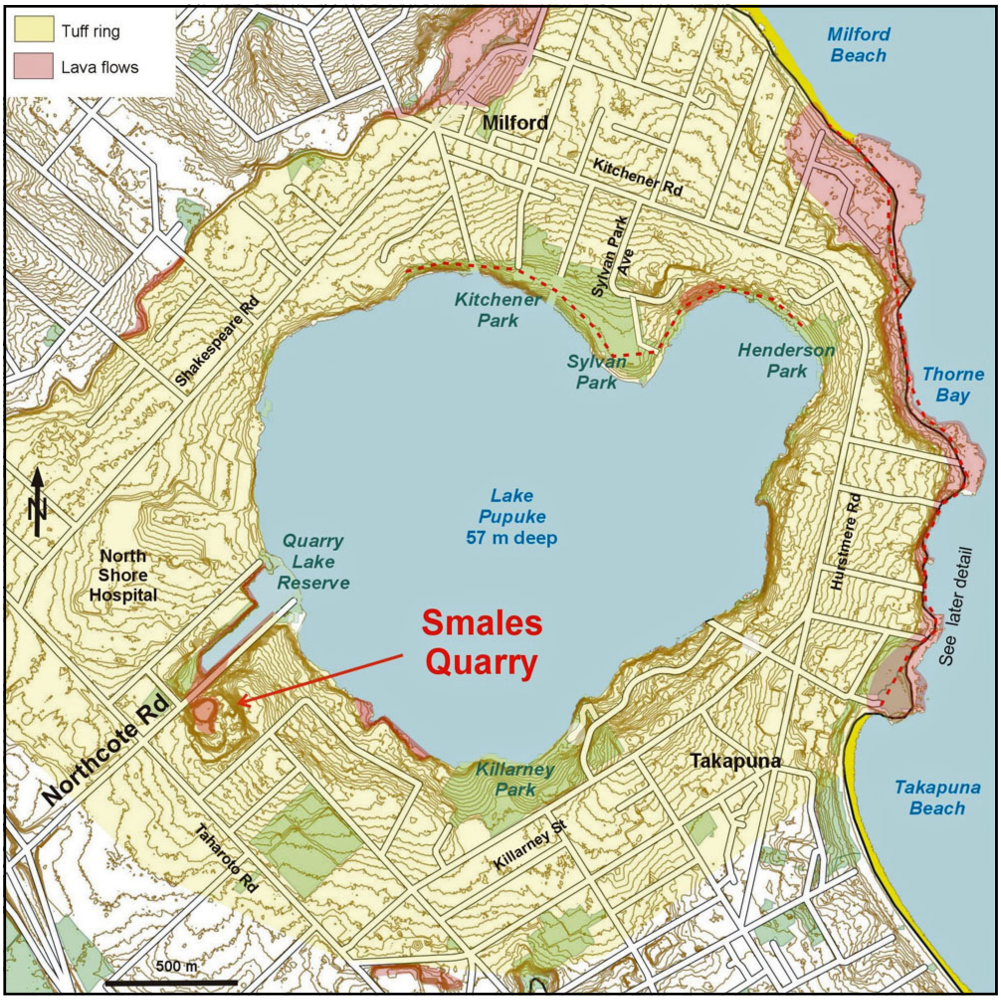


Fig. 1. Map of the extent of Pupuke Volcano with Lake Pupuke occupying the late phase explosion craters. The study site in Smales Quarry and adjacent road cuttings at the end of Northcote Road is indicated. Map modified from Hayward (2019).

Fig. 2. Oblique aerial view from the southwest over Smales Quarry and Quarry Lake Reserve with the end of Northcote Road in between, 2009.

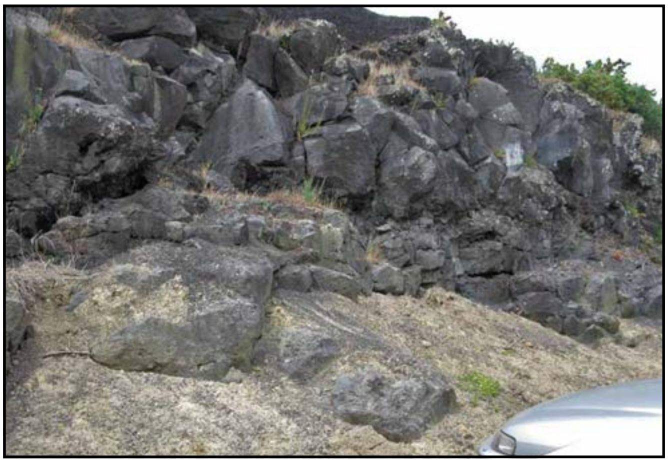

Fig. 3. Part of the road cutting through two basalt flows on the southeast side of Northcote Road, when freshly cleared of vegetation in 2010.

up into the cutting to several irregular pods (0.3–1 m diameter) of partially baked sediment within the basalt flows (Figs 4 & 5). The sediment is not a rhyolite ash fall layer draped between the two flows, but instead consists of 2–3 pods located close to the inter-flow boundaries but within the flows.

In 2010 and 2019, the owners of Smales Quarry invited me in to assess their proposals on how they might protect the geoheritage features in the younger scoriaceous tuff exposed higher in the sequence in the old quarry faces (e.g. Hayward, 2010). While there, I was given the opportunity to examine the lava flow walls that underlay the pyroclastics. The deepest part of the quarry had been dug through a 6 m thick basalt flow with large vertical columnar jointing in the lower part (Fig. 6). This is presumably the same flow as was quarried in the elongate and now flooded quarry (Quarry Lake Reserve) on the opposite (north) side of Northcote Road (Figs 1 & 2). For many decades the lower 4 m of the Smales Quarry pit has been full of water (e.g. Figs 2 & 4), but during my visit in 2019 it had been drained and the vertical columns in the lower portion were clearly visible (Figs 6 & 7). These would have been submerged when seen by Nemeth *et al*. (2012) who inferred the massive basalt in the upper part of the flow was a “dark basalt plug indicating that the quarry .. likely .. excavated an initial magmatic vent”. The owners informed me that the drained floor in the deepest part of the quarry was the base of the basalt, confirming that it is indeed a flow and not a plug.

The 6 m-thick flow passes upwards into the irregular thinner flows that are exposed in the Northcote Road


Fig. 4. Vertical air photo of Smales Quarry before the lake in the deepest part was drained. Red crosses indicate locations where light-coloured rhyolitic sediment pods/rafts can be seen within the basalt lava flows.

Fig. 5. 50 x 30 cm pod of partly baked cream-coloured sediment (inside rectangle) near the top of the upper basalt flow in the Northcote Rd cutting.

Fig. 6. Large vertical columns of basalt from the base of the 6 m-thick flow in the bottom of Smales Quarry when it was drained in 2019. Note that the light-coloured rock above, with the weak horizontal jointing, is the upper part of the same basalt flow that has been stained on the surface by bleached dead algae that lived in the lake water.

cutting. Above that there are the scoriaceous pyroclastic deposits. In several places along the southern walls of the small quarry there was cream-coloured frittering sediment in the scree. Once again, this sediment could be traced back to irregular pods or blocks within the upper part of the thickest flow or within the two upper flows (Figs 7–9). The largest block was at least 5 m wide and 2 m thick in the cutting (Figs 7 & 8). It was hard but not strongly baked to porcellanite, especially away from its edges.

The sediment has clearly been ripped up and carried along by the lava flows, the heat of which has baked the outside of the sediment rafts, with the finest layers baked to a hard white porcellanite, sometimes with fine columnar structures (Fig. 10). These rafts of sediment are the same rhyolitic silts that fill a wide Pleistocene paleo-valley that underlies much of the nearby depression from Shoal Bay through to Takapuna Beach (Searle, 1959; Kermode, 1992; Hayward, 2015). Thus these rafts provide evidence that much of the Pupuke Volcano is probably also underlain by Pleistocene rhyolitic silts that were probably 3–5 m thick beds of alluvium reworked from rhyolitic tephra erupted from the centre of the North Island (Searle, 1959). There is no evidence to indicate whether these rafts were ripped up as the flow passed over them, or whether they were ripped from the walls of the vent and incorporated into the flow as the lava was emerging from the throat. I prefer the latter explanation as the most likely as there is no evidence of weathering or soil development in the rafts that might be expected if excavated as the flow passed over the surface.

Blocks of the underlying country rock, including similar Pleistocene sediment such as this, often occur in phreatic and phreatomagmatic deposits blasted out by the initial "throat-clearing" eruptions of many of Auckland's volcanoes, but rafts of country rock caught up, carried along and partly baked by lava flows is highly unusual. I only know of examples elsewhere around the coast of Rangitoto Island (Grant-Mackie and Cook, 1990; Hayward, 2017). At Rangitoto, the lava flows are inferred to have ploughed into the soft seafloor sediments (Late Pleistocene and Holocene), pushed them along with some blocks being forced upwards, where they can now be seen intertidally within the basalt flows. On Rangitoto, some of these

Fig. 7. Photo inside the deepest part of Smales Quarry in 2019 when lake was drained showing the 6 m-thick lava flow (upper part of previously submerged portion stained white on the surface by the dead algae in the water). The largest raft of partly baked rhyolitic sediment (Fig. 8) can be seen within the basalt flow to the right of the blue hose (top left of photo).

Fig. 8. Closer view of the largest raft of rhyolitic sediment (Fig. 7) with dark basalt clearly visible above and below, showing it cooled and solidified around the shape of the raft.

Fig. 9. Hard white baked porcellanite raft within a basalt flow in the south face of the disused Smales Quarry, 2019.

Fig. 10. Close-up view of the pseudo-columnar shrinkage joints within the hard white porcellanite raft (Fig. 9).

included sediment blocks are baked and others are not, similar to what is seen on a smaller scale here at Pupuke Volcano.

These observations rule out the possibility that the porcellanite is a baked rhyolitic ash layer within the Pupuke lava flows, or that it is a rhyolitic mud that accumulated in ponds between eruption of the flows. Instead, it is a rare example of soft Pleistocene sediment rafts that have been ripped from the volcano's throat and carried along and baked within the top of the basalt flows.

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## CORRESPONDING AUTHORS' CONTACT INFORMATION


| | | |
|---|---|---|
| Garry Carr | Geoclub Member, | **garry@thecarrs.net.nz** |
| Michael Coote | Geoclub Member, | **mcmarquis@gmail.com** |
| Bruce W. Hayward | Geoclub Member, | **b.hayward@geomarine.org.nz** |
| Seabourne Rust | Geoclub Member, | **seabourne.rust@gmail.com** |
| Ken Smith | Geoclub Member, | **kennlee@orcon.net.nz** |


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