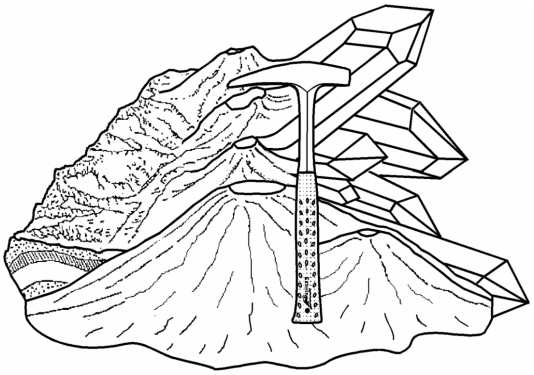


Geocene

Auckland GeoClub Magazine
Number 19, April 2019

Editor: Jill Kenny

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

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

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

AN AMATEUR'S REDISCOVERY AND STUDY OF TĀKOU (RED OCHRE) PITS AT TĀKOU, BAY OF ISLANDS, NORTHLAND

Chris Booth and Nora Rameka

Ed - This article is based on a talk Chris gave last December to the New Zealand Archaeological Association, co-authored by local kuia, Nora Rameka.

Tākou (Fig. 1), about 15 km north of Kerikeri, is part of the whenua within the rohe of hapū Ngāti Rēhia in the Bay of Islands, Northland. In other words, the area of tākou (red earth) is found in the lands owned by the extended families of Ngāti Rēhia, a subtribe of the Ngāpuhi iwi of Northland.

The families of Ngāti Rēhia continue to retain ahi kā (continuous occupation) on behalf of all hapū of Ngāpuhi, because they are able to trace their lineage back to the primary ancestors who lived on this land ever since the coming to Tākou of the great migratory waka, Mātaatua,



Fig. 1. Tākou Bay, north of the Bay of Islands, with the Purerua Peninsula, which forms the northern enclosure to the Bay of Islands, in the far distance.



Fig. 2. The modern namesake of Mātaatua, Mātaatua II, at Waitangi, built by Hekenukumai Busby. Note the red paint which would originally have been made from red ochre and shark oil.

approximately 700 years ago. Tākou River is the final resting place of this legendary waka (Fig. 2).

The following research is not that of a scientist, but of an artist who has a great interest in archaeology. This discovery and subsequent study of tākou pits at Tākou started with an epiphany, and wonderfully ends with the insight coming true!

It began in 2017, when my brothers and I re-connected with the Booth Whānau collection (over 3000 artifacts collected and catalogued from predominantly exposed surfaces, from 1956 to about 1975), which was recently accessioned into Te Kongahu Museum of Waitangi. In the process of transferral, all the artifacts were revisited in detail by the Booth Whānau (4 boys). Amongst the artifacts were what appeared to be a pestle and mortar with kokowai (red ochre with shark oil pigment) stains and lumps of kokowai (Fig. 3).

Significantly, these artifacts prompted my epiphany - the sudden recollection of a conversation made at Tākou Bay 61 years ago. In 1957, when my twin brother, John, and I were 8 years old, our family were shown red ochre pits adjacent to Otaha Road, by Mr Robinson, the sole teacher at Tākou Bay School (7 km away and long since closed). Otaha Road runs through Tākou land.

Regrettably, my family couldn't recall that conversation with Mr Robinson all those years ago. Nor did I meet anyone locally who knew anything about red ochre pits in the area. There were no red ochre mine sites in



Fig. 3. Red ochre grinding stone artifacts plus lumps of kokowai artifacts (prepared from cooked and ground red ochre nodules). Note: the dark stains on the back of one of the red ochre grinding stones could be shark oil from the users hand.

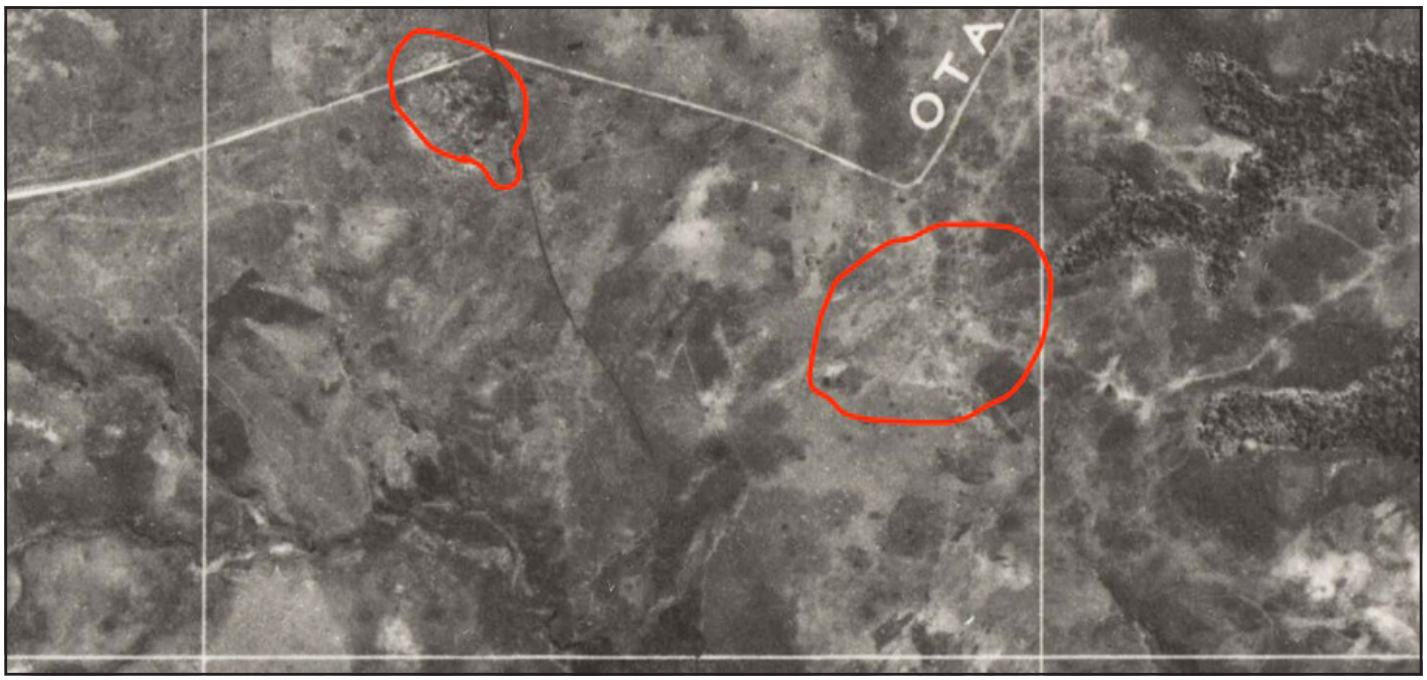


Fig. 4. 1951 aerial photograph of the area where I remembered tākou pits to be (circled in red).

the reference material that I consulted (Tregear, 1904; Hindmarsh, 1996; Gröning, 1998; Anon, undated), nor did Heritage New Zealand have any site records anywhere in the wider region.

How could I find out if this open cast mine still existed? Were there any early aerial images?

With advice from my brother John, I focused in on a 1951 aerial photograph from the Alexander Turnbull Library and there, with huge relief, I found that my epiphany was correct! Right there beside Otaha Road were the pits! And they appeared to be extensive (Fig. 4).



Fig. 5. Google image of the area within the left red circle in Fig. 4. The pits within the right red circle have been destroyed.

But did evidence of them still exist today? I was very doubtful. To my incredulousness, however, a Google Earth image, showed me that they did! In fact, Otaha Road ran right through the north western tip of them.

In 2018, I investigated a nearby road cutting, and sure enough found samples of red ochre. These I took to Tewarihi Hetaraka, Te Tai Tokerau Tohunga Whakairo, who commented that this was a very high grade of red ochre. He also enlightened me as to the correct name for the ore, tākou, and kokowai for the ground up red ochre mixed with shark oil.

Armed with this strong evidence, I shared my knowledge with the leader of Ngāti Rēhia, Nora Rameka, friend and assistant for this article. Did she know about these pits? No. But she was excited and encouraged me to continue my investigations, as did Heritage New Zealand archaeologist, James Robinson. Did anyone else know about them? I visited the oldest resident, Mēeke Puru, born in Tākou Bay 84 years ago. He knew nothing about them, although he did recollect his Dad using kokowai to paint his boat, but he was unsure where the tākou came from. Mēeke left Tākou Bay when he was about 5 years old to go to school elsewhere, and never returned to live until recently.

Nora recalls the stories told by kaumatua, Wiremu Paora, of how Tākou got its name. There is a red rock in the Tākou River that was chipped for the tākou (red ochre) to be used for special purposes. Thus, the recognition of the kokowai pits is exciting because it relates the use of red ochre back to the rock in the river and the naming of the whole area.

I contacted Geoff Lodge, the farmer of the land containing the pits. He met Nora, Tewarihi (Tohunga Whakairo), my

daughter Lena Huia (armed with her camera) and me at his farm gate, right beside what should be the pit area. Within the first 50 m of the paddock, there before us was a static, waving sea of troughs and mounds - pits and spoil heaps (Fig. 6). I couldn't believe how well preserved the site was. The farmer, who has been farming here for 30 years, said he knew that there must have been some sort of mining activity going on there, because it looked like pits and spoil heaps. But what for? He was unaware of it being mined so long ago for red ochre. Geoff can only be applauded for never having modified this precious, pre-European contact site.



Fig. 6. View of troughs and mounds from ground level.

A few days later, when the sun was just rising, and the shadows emphasised the terrain, another friend photographed the paddock with his drone (Fig. 7). Then, with permission from Nora Rameka and farmer Geoff, we took several 5 cm-diameter geotechnical core samples, up to 2 m deep, from all over the site and around the perimeter (Fig. 7, superimposed on photo; Figs 8–11).



Fig. 8. Auger sampling.

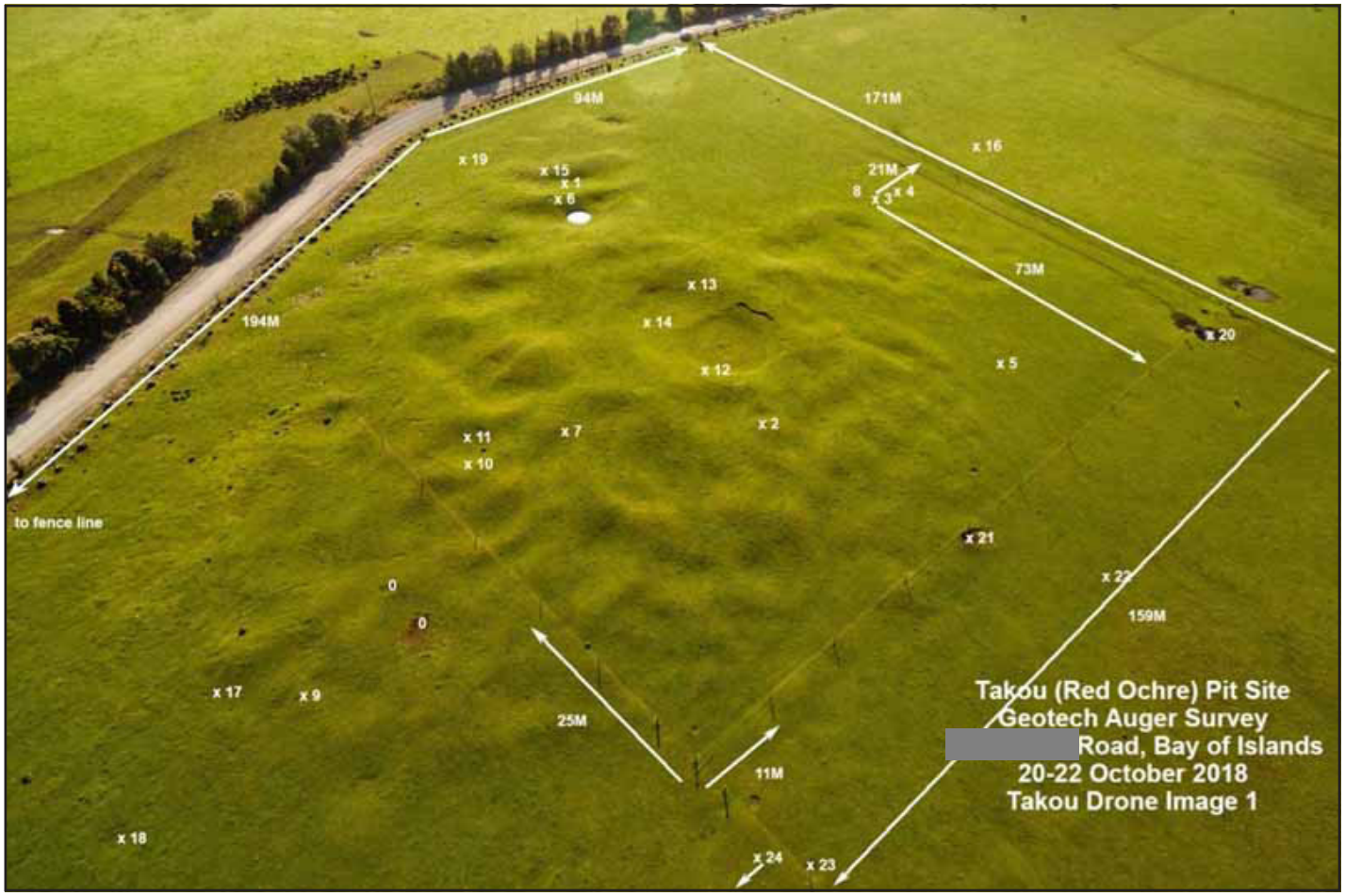


Fig. 7. Drone view of the site, with geotechnical auger survey superimposed. Road number masked for site protection.

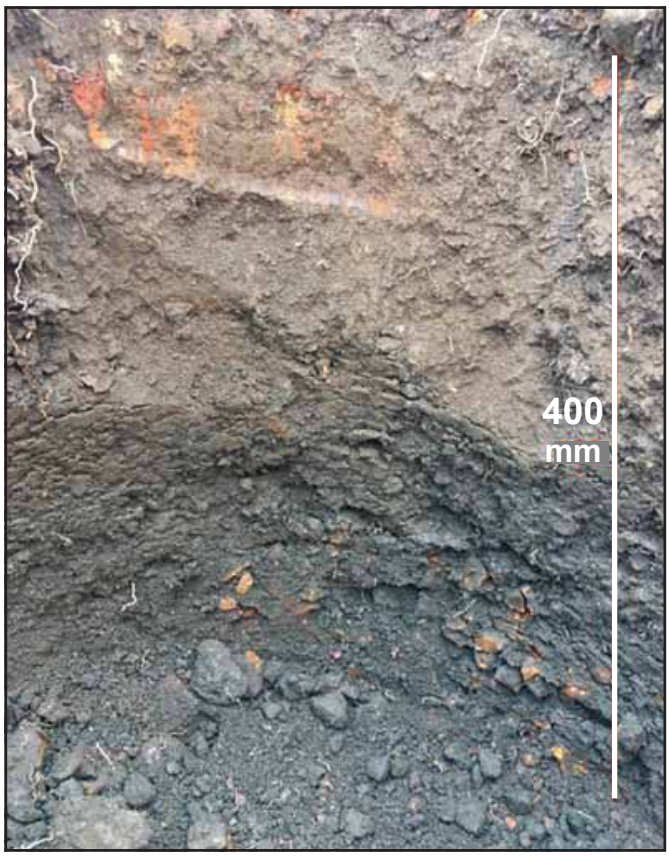


Fig. 9. Site 8 during the drilling of a 100 mm-diameter hole using auger and crowbar. Chris, Magnus and Lena Huia eventually drilled to 900 mm. This passed through 150 mm of brown topsoil with minimal ochre, 200 mm of black soil and 550 mm of hard noduler strata mixed with black soil. They eventually hit flattish, small, white-coated pebbles.



Fig. 10. The finished 100 mm-diameter red ochre nodule hole, showing the flattish white-coated pebbles (in Lena Huia's hand) from the bottom of the hole.



Fig. 11. Typical tākou nodules collected from the drill holes.

It appears from our sampling that the full extent of the mined area has been exhausted of all tākou, and yet samples taken just outside the mine area show dense nodules of tākou, which at one site is 550mm thick.

Our research shows that pits are much less well defined in the south and southwest of the area, indicating that mining probably began there and moved towards the north and northeast, where the pits and spoil heaps are quite well-defined. It is likely that the pits were filled in as they moved north and northeast. There also appears to be evidence of small shallow pilot(?) pits to the southwest and west. In addition, big chunks of tākou seem to have been dumped, as they can be seen in exposed and semi-exposed areas beyond the southern boundary.

My daughter, Lena Huia, and I brought some of the tākou nodules home, ground them up to powder using stone tools, and successfully made paint by mixing the powder with olive oil (Fig. 12) - that was our substitute for the shark oil originally used for making kokowai (red ochre paint).

This exciting rediscovery of the red ochre pits raises many questions:

Does the extent and the intensity of the pit area mean that tākou must have once been famous for its high quality kokowai production, thus honouring its high-profile name? To date we are unable to prove that it was traded because, according to the expert mineralogist/anthropologist, Andy Mcalister (University of Auckland), red ochre is generally too difficult to differentiate from one source to another because it is made up of mostly iron with little or no variation in chemistry (the nodules are slightly attracted/repelled by a magnet). But retired geologist, Dr Ross Ramsay, has suggested that Mössbauer analysis (Wikipedia) may well be able to make this differentiation.



Fig. 12. My daughter, Lena Huia Booth, mixing tākou with olive oil to make red ochre pigment (kokowai).

Why were the mines sited here and not somewhere else in the vast areas of iron stone country in the district? Was it because of exceptional quality, particular concentration, or proximity to the village where the ore was taken for processing? There is a large, crystal clear spring nearby - did this have some bearing?

Why does no one else remember these pits? In 1930–40s, on the north side of Tākou, was a village where many whānau lived. In the 1940s, a religious prophet, Rapana, arrived in the area and many of the Tākou whānau followed him to Te Tii Mangonui and then to the cities for work. Their descendants only came back in recent times.

Considering as a conservative guesstimate, there were at least 1000 tonnes of tākou mined from these pits, that was a huge amount of kokowai - a lot of paint!

All cultures have used body paint and still mostly do. Kokowai was used to adorn, decorate and preserve. Pre-European Maori, Aboriginal and Peoples of Oceania were no exception.

The information we had gained from the red ochre pit site was given to regional archaeologist, James Robinson, who has now officially registered it with Heritage New Zealand. Therefore, the site can no longer be modified or interfered with in any way.

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Acknowledgements

I wish to thank my assistant and photographer, my daughter, Lena Huia Booth and my co-researcher, kuia Nora Rameka of Ngāti Rēhia.

Thanks also to professional consultants:

James Robinson, Northland Regional Archaeologist, Heritage New Zealand;

Tewarihi Hetaraka, Te Tai Tokerau Tohunga Whakairo (Ngati Wai, Ngāpuhi) - specialist Northland carver;

Andy Mcalister, artist, anthropologist, University of Auckland.

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Editor

Chris Booth is a renowned Northland sculptor who has lived in this area for most of his life and shares a deep engagement with Mana Whenua, the Maori people of the area. He is best known for his extraordinary monuments all over the world. Here are just four from the North Island. Thanks to Google Maps Street View for these images.

Rainbow Warrior Memorial at Matauri Bay





'*Te Whiringa O Manoko*' in Kerikeri Domain

'*Gateway*' at the Victoria St entrance to Albert Park, central Auckland





'*Nga Uri o Hinetuparimaunga*' at the entrance to Hamilton Gardens.

HOW WAS THE CLEARY ROAD HILL BUILT ON THE CREST OF PANMURE BASIN TUFF RING?

Bruce W. Hayward

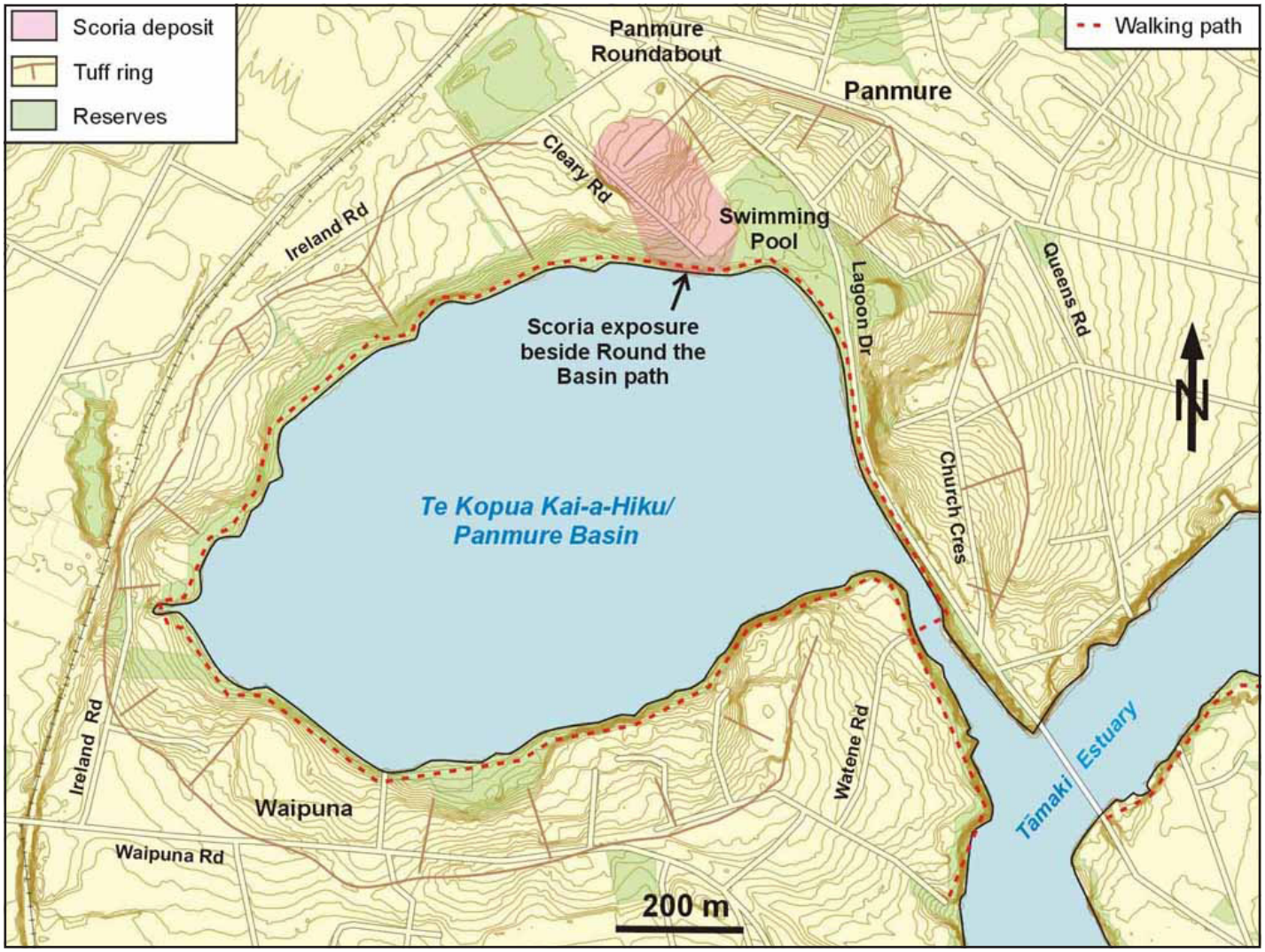


Fig. 1. Map of Panmure Basin crater and surrounding tuff ring showing the location of the scoria deposit (pink) in the vicinity of Cleary Road.

Cleary Road, which runs down from Ireland Road to the back of the Panmure Swimming Pool complex, goes up and over a small hill (26 m ASL) that rises 5–7 m above the level of the crest of the Panmure Basin tuff ring in this vicinity (19–20 m ASL) (Figs 1, 2). In a driveway cutting to number 8 Cleary Road, we used to be able to see scoria exposed near the hill's surface. This led me to speculate (Hayward *et al*., 2011, p. 173) that - "the hill from Cleary Road to Panmure Roundabout was probably built … by wind-blown scoria from fire-fountaining in the basin." Supporting evidence for this hypothesis came from a 4 m-high bank of bedded fine scoria exposed beside the Round the Basin Walkway at the bottom of Cleary Road (Fig. 3; Hayward *et al*., 2008, p.3), and the fact that scientific drilling in the sediments that fill Panmure Basin in 2008, cored into the top of a scoria cone that had been buried by lake and marine sediment and is no longer visible.

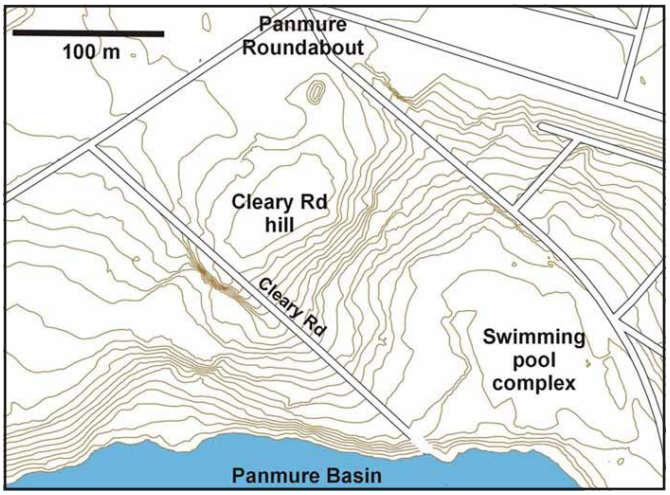


Fig. 2. Contour map of the northeast sector of the Panmure Basin tuff ring showing the Cleary Road hill. Contours in 1 m intervals.

During the Auckland Heritage Festival in October 2018, I led a guided field trip around the volcanoes of the eastern part of the isthmus, starting from Panmure Basin. I arrived early and so wandered down the driveway of number 10 Cleary Road on the southwestern side of the small hill (Fig. 4). The hill had been cut into and the bank (18–23 m ASL) was partly retained, partly covered in vegetation and partly exposed the rock sequence. To my surprise, I discovered that the lower 3 m of the cutting (18–21 m ASL) was composed of bedded tuff (Figs 5, 6) that was overlain by bedded scoria (Fig. 7) in the upper 2 m (>21 m ASL). Thus it would seem that the Cleary Road hill consists of a 2–3 m-thick layer of scoria draped over the crest of a small natural high point on the crest of the basin's tuff ring.



Fig. 3. Bedded fine scoria exposure beside the Round the Basin Walkway, near the end of Cleary Road.



Fig. 4. Google Earth view of Cleary Rd where it goes over the crest of the small hill, showing the location of scoria exposure beside the driveway to number 8 and the larger exposure (white rectangle) in the artificial bank beside number 10 Cleary Road.



Fig. 5. Lower part of the bank exposure at number 10 Cleary Road showing bedded tuff, with an unconformity (top right) and lithic bombs sitting in impact depressions (centre).



Fig. 6. Part of the bank exposure of bedded tuff at number 10 Cleary Road showing small keystone fault set displacing some layers. Note the light-coloured sedimentary blocks of Pleistocene and Lower Miocene country rock that had been blasted out of the Panmure Basin vent.



Fig. 7. Bedded scoriaceous lapilli tuff near the transition from explosive wet eruptions to dry fountaining, number 10 Cleary Road.

In the exposure, there was an unconformity where the earlier tuff was horizontally-bedded, having been deposited on the flat crest of the growing tuff ring. Clearly, some of this crest on the basin side, had slumped back down into the crater before further bedded wet tuff was deposited unconformably over the sloping slump scarp (Fig. 5). The tuff itself had features that indicated some was deposited by explosive blasts that threw small blocks of lithic (sedimentary) country rock out of the vent. Where they landed in the soft ash, they had sometimes created impact depressions (Fig. 5). Cross-bedding in several layers suggested deposition by base surges. Differential compaction during drying and lithification of the tuff, and maybe some further slight downhill slumping, had created several sets of small keystone faults with minor displacement of the tuff layers (Fig. 6).

Above the middle of the bank exposure, the bedded tuff becomes more basaltic and scoriaceous (Fig. 7) and transitions upwards into more massive scoria lapilli deposits. This transition records the drying out of the vent, as it switched from wet phreatomagmatic eruptions to dry fountaining style that produced the small scoria cone now buried inside the basin. Thus, this newly-recognised bank exposure is the only one now that records some of the later history of the eruption of Panmure Basin.

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PSEUDO-RETICULITE (BASALT FOAM) IN THE AUCKLAND VOLCANIC FIELD

Bruce W. Hayward

In August 1995, Les Kermode led 45 Geoclubbers around the volcanoes of the Tamaki Estuary catchment. When we visited Otahuhu/Mt Richmond on our last stop, he showed us several 10–20 cm lumps of highly vesicular scoria (Fig. 1) that were lying loose on the eastern slopes above the bowling club (now closed). The rock was very low density with vesicles having a distinctive polyhedral cellular structure. A polyhedron is a 3-dimensional shape having many plane/flat surfaces, usually more than six. In this setting, on the slopes of the Mt Richmond scoria cone, it would appear that this foam was one of the last products that fountained out from a nearby vent.



Fig. 1. A block of basalt foam (pseudo-reticulite) from the grass-covered slopes of Otahuhu/Mt Richmond scoria cone. Photo 15 cm across.

For many years after that I did not see anything as vesicular or distinctively polyhedral anywhere else in the Auckland Volcanic Field, but on a 2013 Geoclub trip to Maungarei/Mt Wellington, I noticed a layer of similar solidified basalt foam between two lava flows (Fig. 2) high up in the old quarry cutting beside the track that leads down from Gollan Rd into the new suburb of Stonefields. This cutting intersected the youngest flows that spewed out from the bell-shaped surge chamber (Te Rua a Potaka - see Hayward *et al.*, 2010, p.164) near the western foot of Mt Wellington's scoria cone. Here the solidified foam clearly formed the upper part of a lava flow.



Fig. 2. Basalt foam layer between two lava flows in track cutting at end of Gollan Rd, Mt Wellington. Photo 15 cm across.

In 2018, while leading an Auckland Heritage festival trip around the east Auckland Isthmus volcanoes, I noticed that the in-situ upper surface of the lava flow in Maungarei Stonefields reserve (Tidey Rd) was also covered in a thin-layer of the same frothy polyhedral scoria (Fig. 3). It can be seen throughout the several hectare reserve as the upper part of the solid lava flow and also as many loose rocks that have been heaped up into stone heaps (Figs 4–5) by the pre-European Maori as part of their cultivation activities. This location is no more than a few hundred metres from the Gollan Rd track (Fig. 6) and this could be part of the same lava flow where I had previously observed the scoria foam, although it possibly emanated from a vent a little further south than the surge chamber.

This particular Auckland rock type is highly distinctive and unusual. It is a kind of lava froth /foam and is superficially similar to an even lower density basaltic rock named reticulite (Wentworth and Williams, 1932) that has sometimes erupted from Kilauea Volcano in Hawaii and is also known as basalt pumice or thread-lace scoria. The Hawaiian reticulite has similar polyhedral cellular structure but the walls between the cells are not fully formed and may be narrow and translucent glassy brown in colour. The term pseudo-reticulite was coined by a group of Swiss and United Kingdom scientists in 2011 (Pistone et al., 2011) and seems the most appropriate name for these frothy Auckland rocks. They define the term for a rock "with a high content of bubbles (85 vol%), showing a polyhedral cellular network".



Fig. 3. Basalt foam (pseudo-reticulite) in-situ on the top of a lava flow, Maungarei Stonefields Reserve. Photo 25 cm across.

Studies by Mangan and Cashman (1996) on a suite of scoria through to reticulite rocks from Kilauea Volcano, led them to conclude that "basaltic foams evolve through an initially disordered, closed cell, spherical state to a well-ordered, open-celled, polyhedral state as the vesicularity rises from ~75% to 98%. The structural changes occur rapidly (<10 seconds) in the conduit and fountain in response to an intense vesiculation burst." "The observed runaway rate of bubble production indicates strong supersaturations (of gas) at the onset of nucleation. We speculate that the rise in the speed of the magma, as it reaches the level where significant volatile exsolution begins, determines the intensity of the vesiculation burst."



Fig. 4. Maungarei Stonefields Reserve with numerous stone heaps with Maungarei/Mt Wellington behind.



Fig. 5. One of the stone heaps in Maungarei Reserve showing heaped up loose blocks of pseudo-reticulite from the surface of the underlying flow.

Thus, it would seem that occasionally, similar conditions of rapid magma rise and high supersaturation with volatiles has occurred in at least two volcanoes in the Auckland Field. Vesiculation has not reached the high levels that produce Kilauea's reticulite, but has been sufficient to produce a well-ordered, polyhedral structure with ~85% vesicularity, for which the term pseudo-reticulite seems most appropriate or, if you prefer a simpler term, then basalt foam. As previously described, this might have been erupted from fountaining eruptions on Mt Richmond, but the fountaining accompanied lava flow extrusion from Mt Wellington.

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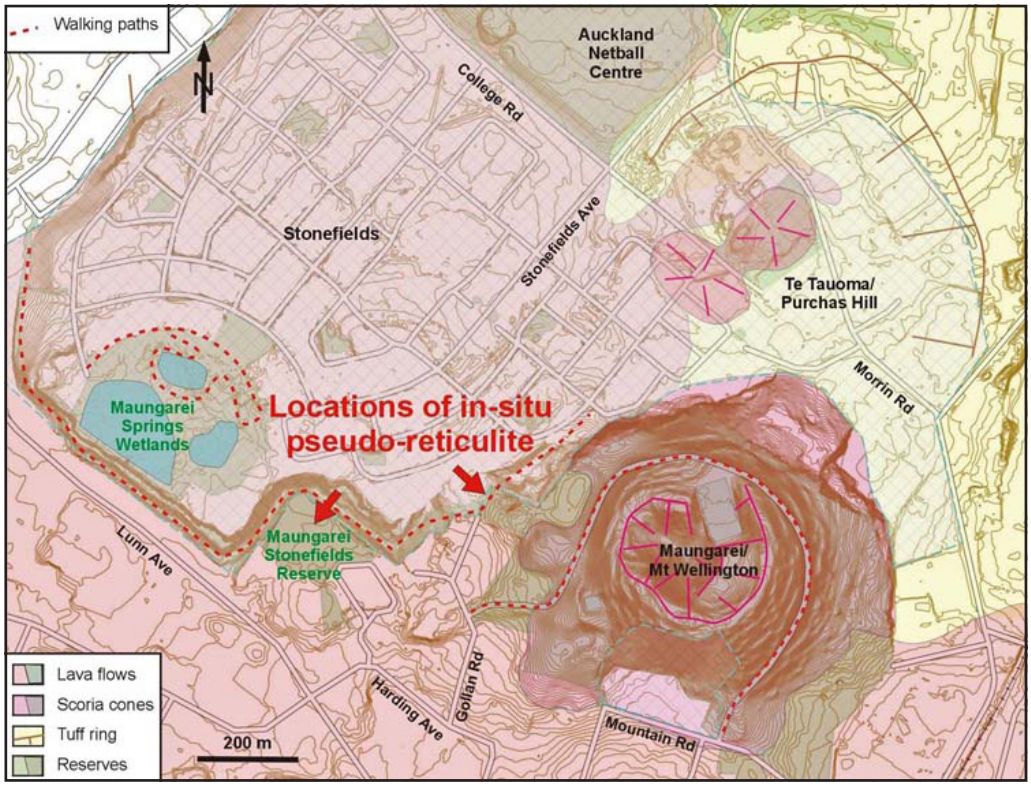


Fig. 6. Map of the Maungarei/ Mt Wellington area showing the location of the in-situ basalt foam (pseudo-reticulite).

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A WALK ON A BEACH, MANGAWHAI HEADS, PART 2

Garry Carr

Geoclub has visited Mangawhai Heads surf beach and coast on at least two occasions. This is part 2 of a photo essay of the rocks along the coast line. In Part 1 (Carr, 2016), we examined the volcanic rocks by the Mangawhai surf club and exposed along the shore to the northwest.



Fig. 1. As we walk past the start of the Mangawhai Clifftop walkway, rocks are exposed in the lower part of the beach and the high "cliffs" that border the beach. The rocks are entirely different in character, to those described nearer to the surf club – they are typically dark grey and quite angular, in contrast to the light grey more rounded shapes of the volcanic rocks encountered earlier. These rocks are much older. The gap in the hills behind the beach is believed to mark the position of a fault uplifting the hills to the northwest, exposing these much older rocks (Carr, 2016, centre of Fig. 2).



Fig. 2. A close-up view shows the rock is dark grey with lighter coloured, discontinuous bands in places, crossed with white veins. The dark grey argillite is extensively deformed (sheared) and contains broken chunks of lighter coloured sandstone.



Fig. 3. Another view of this rock. The rock has been deformed and the very dark, fine-grained material has deformed easily, whereas the lighter-coloured and coarser-grained material has not deformed so easily and has broken into discrete bits. The original sediment probably consisted of thinly-bedded sandstones and mudstones and has been deformed and metamorphosed to pumpellyite-actinolite grade. White veinlets are formed from metamorphic minerals crystallising from fluids squeezed out of the original sediments, as well as from the breakdown of hydrated minerals such as clays. Based on the mineralogy, these rocks have, in the past, been buried to about 12–15 km depth.



Fig. 4. Some of the spectacular folding and deformation visible at the start of the walk round the rocks.
Coin for scale.



Fig. 5. As we move along the coast the beds are thicker and predominantly sandstones without the extreme deformation seen earlier. The rocks are more often brown coloured.



Fig. 6. Tar from a spill some time ago (perhaps from the Niagara, a ship that foundered after hitting a mine in World War 2). Broken shell material and gravel have stuck to the tar.



Fig. 7. In other greywacke sequences in Northland and Auckland, pillow lavas can be found. The shapes and colour here are suggestive of pillow lavas.

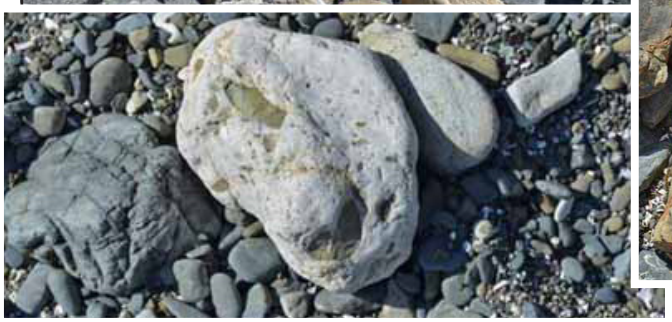


Fig. 8. Cherts are present in the sequence and are typically light grey in colour. The author has found 2 red chert pebbles on the beach, but no red cherts have been found in place on the foreshore (photo of one in Fig. 9). This sequence is similar to that found in other exposures of the Waipapa Terrane in Northland and Auckland (see Hayward, 2017, for a description of Waipapa terrane accretionary wedges).



Fig. 9. The modern beach deposits contain many pebbles derived from the rocky foreshore along with shell debris.









Figs 10–13. As we move further along the coast, we encounter another change, with light coloured calcareous rocks and boulders (some very large) on the beach. Some contain greywacke grit and gravel along with barnacle fossils. These rocks are much younger and are basal Waitemata group rocks that formed as the Waitemata Basin started to subside about 22 million years ago - a time gap of perhaps 120 million years. These rocks do not crop out at beach level, but do so higher up the cliff.

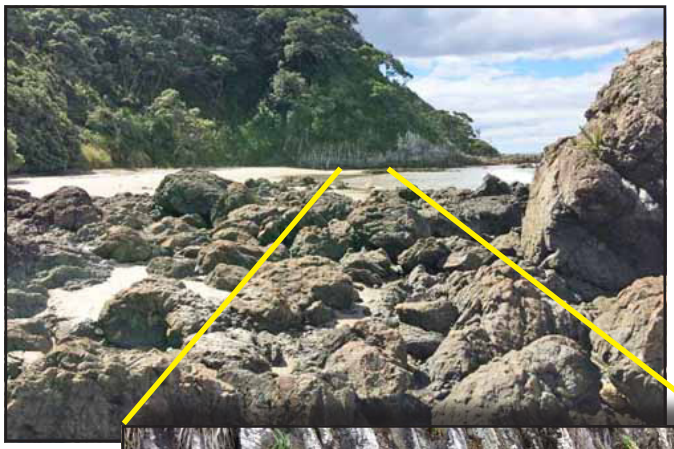


Fig. 14. Greywacke rocks outcrop until this point at "Paradise Bay". On the far side of the bay, a spectacular outcrop of columnar-jointed dacite is exposed. Flow banding is visible where the waves have removed softer portions of the rock. The light grey dacites outcrop from here, along the coast, all the way to the locality where the Mangawhai clifftop walkway descends to the coast (at Fig. 18).



Fig. 15. A close-up photo of the dacites seen in the distance in Fig. 14.



Fig. 16. A view back across “Paradise Bay”. A slip on the right of the of grassed area carried down boulders of typical Waitemata Group rocks - siltstones and sandstones - just as we would find in Auckland.



Fig. 17. The only variation in the light grey, fairly massive, dacitic volcanic rocks are the occasional tuffaceous boulders as shown here on the boulder beach.



Fig. 18. The arch excavated in the jointed dacitic rocks where the Mangawhai Clifftop Walkway descends to the coast. Low tide is required to walk through the arch without getting wet feet.

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AN EXPLANATION FOR THE ORIGIN OF THE TRIANGULAR TUFF RING REMNANTS AT PUKETUTU VOLCANO

Bruce W. Hayward

Puketutu Volcano/Te Motu a Hiaroa is unique in the Auckland Volcanic Field because it has three triangular-shaped remnants of its tuff ring forming part of the land surface (Firth, 1930; Searle, 1959; Kermode, 1962) - two on the north side and one on the south (Figs 1, 2). A fourth, more irregular and flatter, tuff ring remnant has been identified in the eastern part of the island (Fig. 3). Otherwise Puketutu Volcano is fairly typical of many of Auckland's small basalt volcanoes, having a complex of scoria cones built inside the initial explosion crater (marked by the tuff ring remnants), with extensive lava flows having welled out from around the base of the scoria cones.

As is the case elsewhere, the tuff ring remnants are easily distinguished from the remainder of the volcano because of their smooth, relatively stone-free surfaces. The extensive

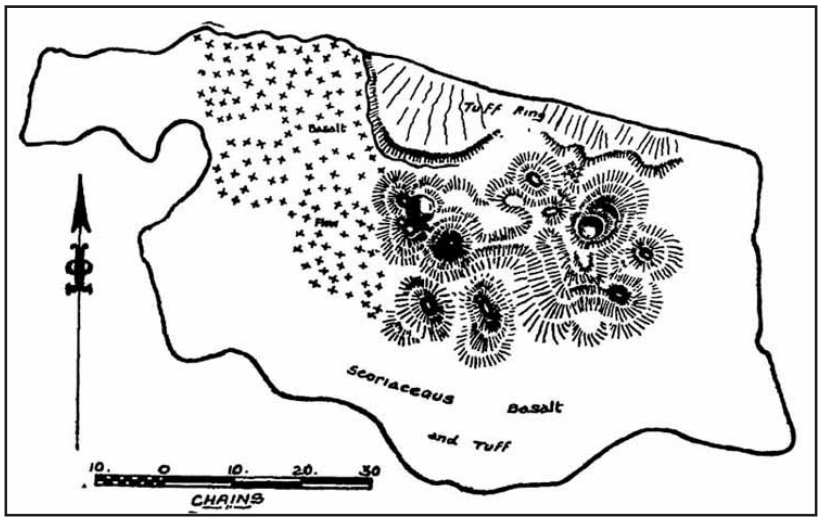


Fig. 1. Sketch of the geology of Puketutu Volcano by Cyril Firth (1930) showing two areas of remnant tuff ring on the north side. The map orientation is that published by Firth; maybe he has used magnetic north as the vertical axis.

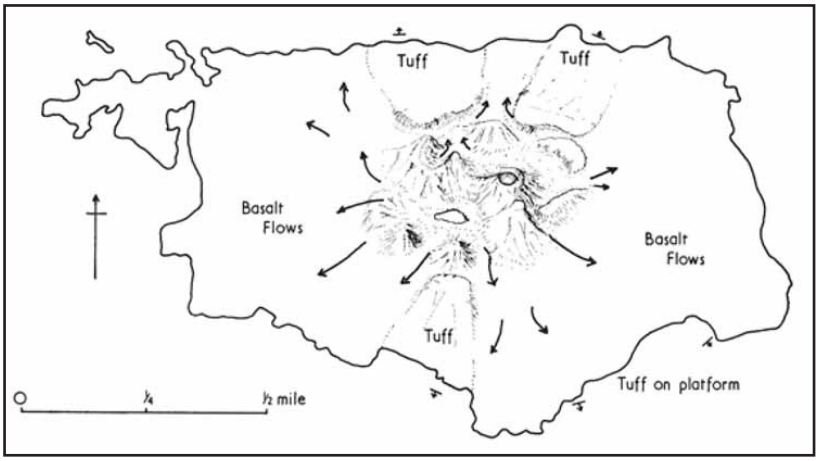


Fig. 2. Sketch of the geology of Puketutu Volcano by Ernie Searle (1959) clearly showing the three triangular remnants of tuff ring.

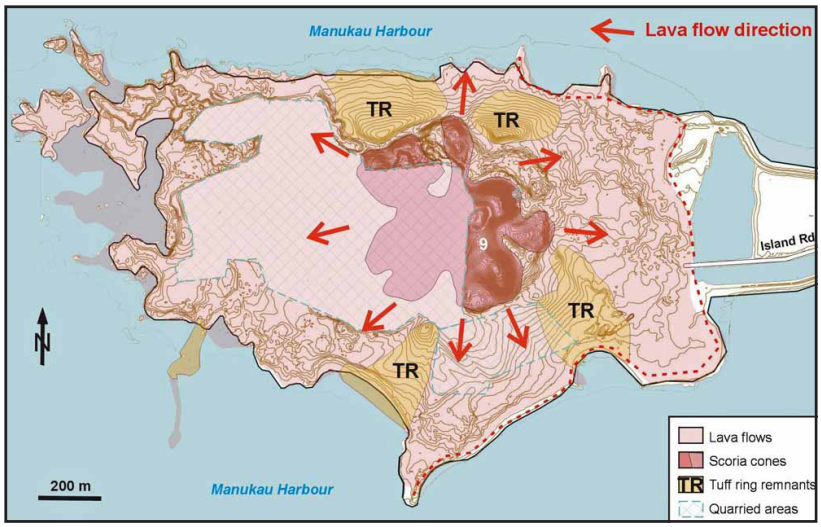


Fig. 3. Modern map of the geology of Puketutu Volcano (Hayward, 2018) showing four areas of triangular tuff ring remnants.



Fig. 4. View west over the southern side of Puketutu Volcano showing the smooth grassed triangular area of tuff ring remnant between rougher fields with pre-European heaps of stone and stone alignments. Photo Geoff Fairfield 1930s.



Fig. 5. View west over the north side of Puketutu Volcano showing the two tuff ring remnants (foreground and middle right) with smooth slopes to the north and triangular apices to the south (left). Photo Geoff Fairfield 1930s.

lava flow surfaces were rubbly and rock-covered, and were more easily distinguished from the triangular tuff ring remnants prior to the clearing of stones by the Kelliher family to make stone walls, as seen in the aerial photographs by Geoff Fairfield in the 1930s (Figs 4, 5).

In addition to having smooth surfaces, each of the three triangular remnants is gently sloping outwards away from the centre of the volcano, and they are clearly remnants of the outer slopes of the tuff ring. Each slopes up from a wide base at sea level to an acutely-angled apex close to the foot of the central scoria cones (Figs 6, 7). The apices of each is at 18.5 m elevation on the south side of the island and at 18 and 24.5 m on the north side.

As far as I can discover, no-one has ever bothered to try and explain why the three tuff ring remnants have the same distinctive, outwardly sloping triangular shape. The likely explanation can be seen in the map outline of the crest



Fig. 6. 1960 vertical aerial photo showing the central part of Puketutu Volcano just as quarrying was starting. The three triangular areas of smooth tuff ring remnant are clearly visible when you know where to look.



Fig. 7. 2018 view looking south, over the central northern side of Puketutu Volcano, with the northern two triangular tuff ring remnants still clearly visible (in the grass). Photo Bruce Hayward.

of a number of other tuff rings that surround explosion craters in Auckland (e.g. Panmure Basin and Crater Hill). In places, the crest and inner wall of the tuff ring forms a series of scallops that mark where sections of the still wet tuff ring have slid down into the crater, leaving these arcuate or scalloped scarps. It would seem that similar slumping of the tuff ring back into the explosion crater occurred during the eruption of Puketutu. This appears to have resulted in the crest of the tuff ring having a scalloped shape (Fig. 8), with high points at the apices between the scallops and low saddles over the crest in the deepest parts of the slump scarps.

Following the wet phreatomagmatic phase of eruptions that built Puketutu tuff ring, dry fountaining eruptions from a number of central vents within the explosion crater built up a complex of small scoria cones. Degassed lava welled out from around the bases of these cones and flowed into the remaining explosion crater filling the narrow moat between the tuff ring crest and the scoria cones with molten lava. The outwelling continued and lava poured over the lowest parts of the tuff ring crest (Fig. 9), which on the northern and southern sides were the low points in the slump scallops. These lava flows flowed on down and out below today's sea level, creating the distinctive triangular shapes of the tuff ring remnants that were not overwhelmed by lava. The crest of the tuff ring to the west and east appears to have been lower than parts in the north and south, and thus the lava flowed completely over these portions and they are now hidden from view.

The two northern tuff ring remnants are still in good condition (Fig. 7), whereas the southern one has recently been desecrated by Watercare who have built a high road metal dump on top of it, possibly as a stock pile of material to use in their solid waste disposal reclamation in the old quarry.

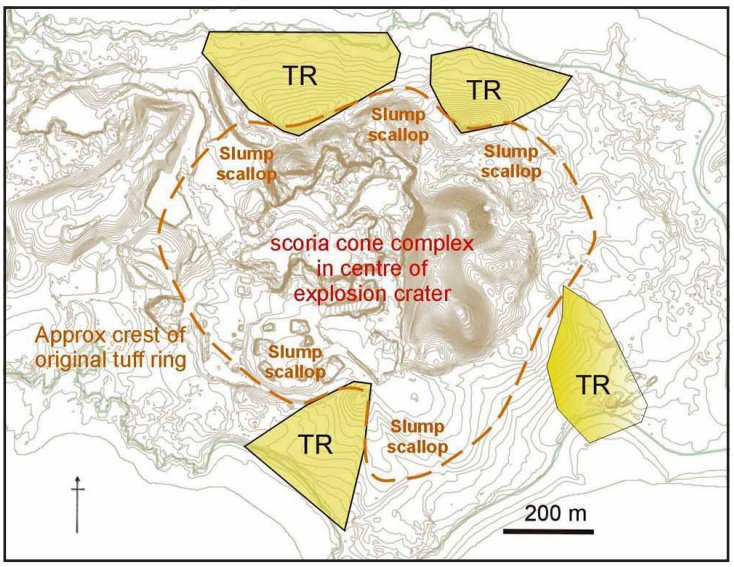


Fig. 8. Modern contour map of central Puketutu island showing tuff ring remnants (TR) and approximate location of the scalloped crest of the tuff ring based in part on the groundwater survey carried out by Watercare in 2008 using borehole data.

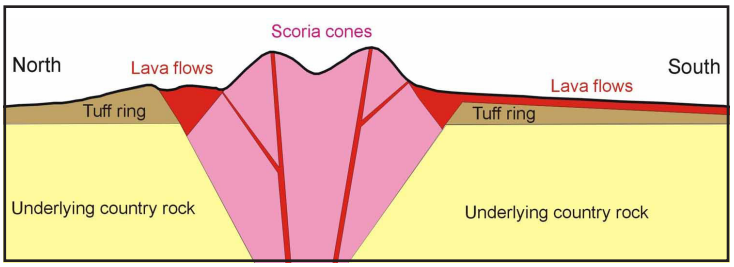


Fig. 9. North-south generalized cross-section through Puketutu Volcano showing a tuff ring remnant on the north side not overtopped by lava flows whereas the tuff ring has been overtopped on the south side. Note the moat between the scoria cones and the tuff ring is filled with basalt lava (red).

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CORRESPONDING AUTHORS' CONTACT INFORMATION

Chris Booth	Guest contributor,	**chris@chrisbooth.co.nz**
Garry Carr	Geoclub Member,	**garry@thecarrs.net.nz**
Bruce W. Hayward	Geomarine Research, Geoclub Member,	**bw.hayward1@gmail.com**

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