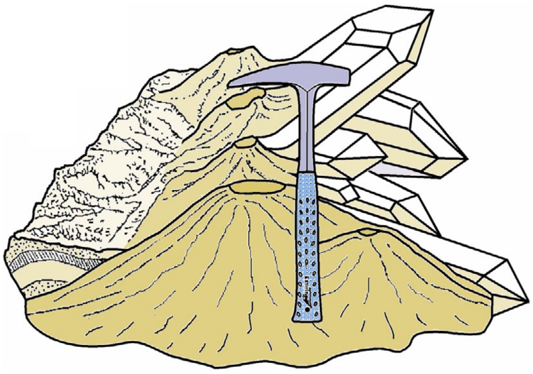

# Geocene

**Auckland GeoClub Magazine**
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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.

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# REQUIEM FOR A DOOMED ICONIC ROADCUT: SLIDE MOVEMENT IN THE MIOCENE WAITEMATĀ BASIN

Bernhard Spörli

This is a memorial for a landmark often admired by geologists on their way through the Miocene Waitematā Group basin, travelling to and from the region north of Auckland (Fig.1). It is a road cut opposite a pull-out on State Highway 1 near the Puhoi River that for some time served as a toll ticketing site for the Johnstone Hill tunnel (Fig. 2). The rock exposures occasionally became overgrown, but road workers would free them up again. The visitors could gaze at them, but few dared to go across for a close up examination, because of the traffic hazard. Now that the new Northern Motorway bypasses the old State Highway 1, things have become quiet; weathering and plant growth are taking over again, probably forever. Let this be a fond record of the spectacular geology visible when conditions were best, and a celebration of layering and folding in the Waitematā Group sediments.

The tracing in Fig. 3 only covers the lowest bench of the road cut, as the higher parts have always been too weathered and overgrown for reliable analysis. The cut exposed a typical Waitematā Group sequence of alternating sandstones and mudstones. There are at least eight folds. They lean to the left (south), and many are almost isoclinal, i.e., the beds on their opposing flanks or 'limbs' (Fig. 4) are almost parallel. This indicates a large amount of crunching up. If, hypothetically, one laid out one single bed going through all the folds, an initial bed length of 137 m would have been reduced to 60 m (= 44%), that is to a bit less than one half of its original length by the

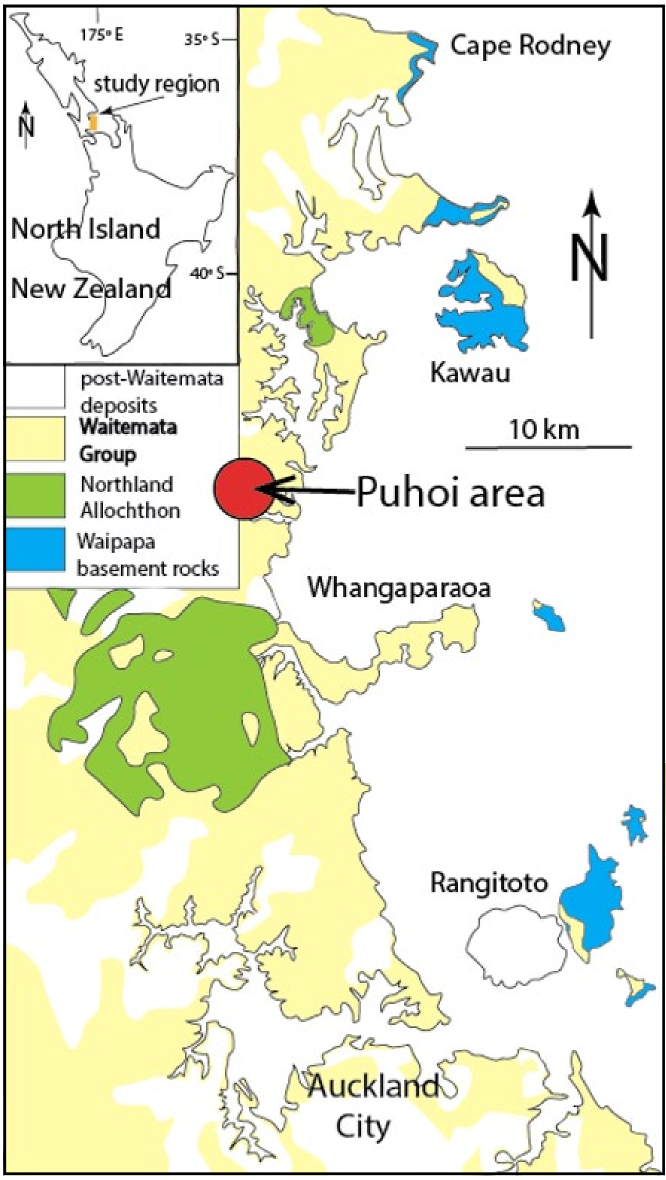


Fig. 1. Map of the Waitematā basin, its geological framework, and location of the Puhoi area. Modified after Hayward 2017, p.91.

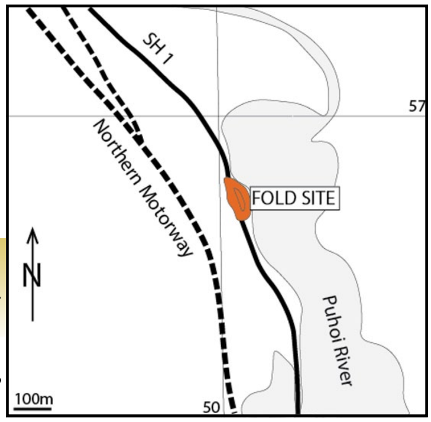


Fig. 2. Location of the road cut in the Puhoi River area. Numbered straight lines are from NZMS 260, Sheet R 10 grid.

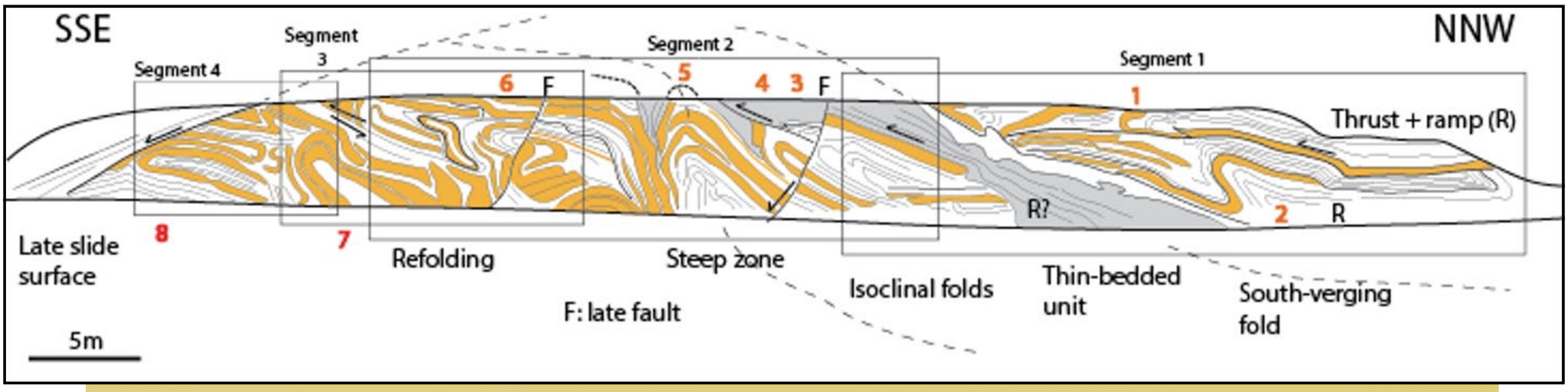


Fig. 3. Tracing of geology in the road cut from photographs (including Figs 6–9). Prominent sandstone beds are shown in gold. Arrows indicate fault movement. Dashed lines are hypothetical projections of main structural features beyond the boundaries of the exposure. Rectangles delineate Figs 6–9 (segments 1–4 in the text). Main folds are numbered in red.

folding. Because of unaccounted-for folds and thrusts, the actual reduction may have been even greater.

Before we go further, it is necessary to explain a few basic expressions, especially about folds (Fig. 4) and thrust faults (Fig. 5) that will be useful in the up-coming descriptions. Note that both of these figures are schematic and simplified. In actual exposures, **fold axes**, **axial planes** and **thrust faults** are often not that straight, so that the term **'axial surface'** is sometimes used for bumpy axial planes in folds. The intersection of an axial surface with a rock face is called the **axial trace**. Furthermore, structural geologists distinguish between **'fold axis'**, a statistical geometric characteristic of a fold (there are methods of determining these), and the closely related **'fold hinge'**, which is the physical line around which a layer in a fold is bent most sharply (like in the spine of a book). Thus a fold with many layers may be assigned only one fold axis, but will have as many hinges as there are layers. Folds can intersect with topography at any angle. Best for interpretation is the cross section, at a right angle to the fold axis. At the other extreme, **longitudinal sections** provide less information and are most often seen on geological maps. Thrust faults (Fig. 5) are low angle reverse faults (also see Spörli *et al*. 2022) that cause shortening and upward repetition of units.

Finally, geologists record the orientation of tilted planar features, such as bedding or faults, as the **"strike and dip"**. The **strike** is the azimuth of a horizontal line on the

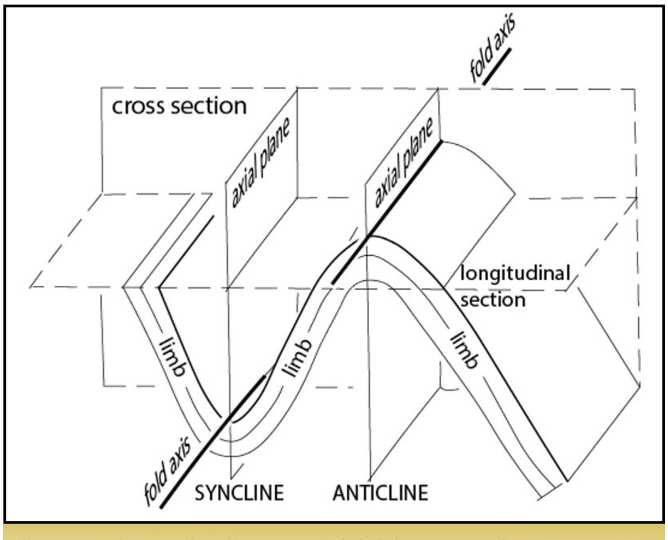


Fig. 4. Schematic diagram of fold nomenclature.

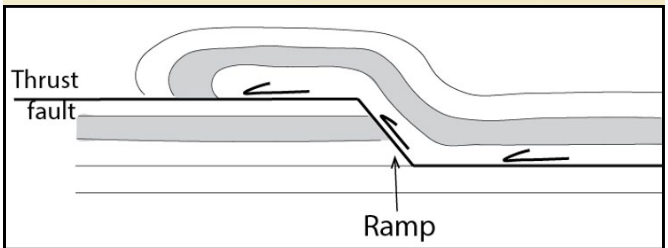


Fig. 5. Schematic diagram of a thrust fault with a ramp. Arrows show movement on the fault, causing repetition of beds.

plane, while the **dip**, at a right angle to the strike, is the angle of maximum inclination. Reflecting the downward-looking bias of geologists: if **"a bed dips to the south"**, it goes down into the earth in that direction.

We are now ready to celebrate these beautiful structures in more detail, with a selection of the best photographs taken over the years (Figs 6–9), and proceeding from north to south. Please also refer to Fig. 3 to keep track of the overall structure.

**Segment 1: South-verging fold, and thrusts** (Fig. 6)

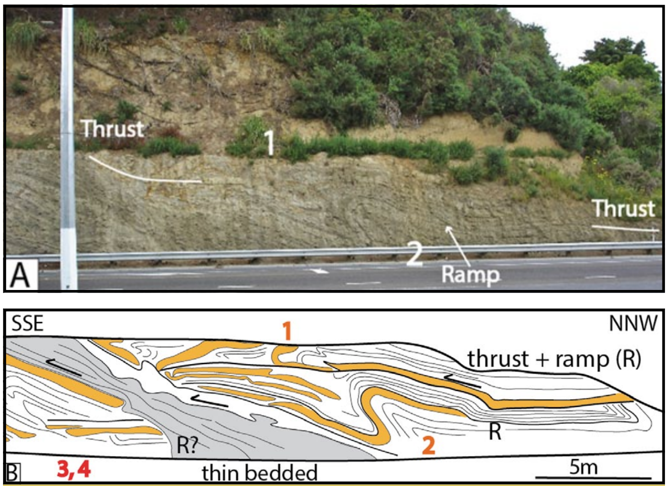


Fig. 6 A: photo; B: tracing of segment 1 in Fig. 3. Numbers identify major folds. Arrows indicate movement on thrust faults. Fold No. 1 above a thrust fault, and the south-verging fold No. 2 below it. Grey: sequence of thinner-bedded sandstones and mudstones. Note the weathering and overgrowth detrimental for geological analysis in the level above the first bench. In Figs 7 & 8, the weathering is also prominent in the first bench.

This is the least complex of the four segments. At the bottom of the northern end, fold 2 is a classic asymmetric fold: The gently north-dipping long limbs of a syncline/anticline couple are connected by a shorter limb that dips more steeply to the north. Because of this 'lean', this asymmetric structure is called a **"south-verging fold"**. Above this fold is a shear plane overlain by a distinctive continuous sandstone layer with a pointed southern termination that is associated with even more strongly south-verging fold 1, the northernmost or highest folds in the in the road cut, indicating that is a thrust fault. This fault has a ramp (see Fig. 5) in its northern part (R in Figs 3 & 6B) that allows the thrust to step to a higher level southward. All these structures strongly suggest transport of material from north to south.

Near the southern end of this segment, there is a distinctive darker grey sequence of much thinner-bedded sandstones and mudstones, which has thrust-like shear planes at its top and bottom. The bottom fault of these two has developed another possible ramp structure that cuts off the sheared core of the next fold to the south.

**Segment 2: Isoclinal fold and steep zone** (Fig. 7)

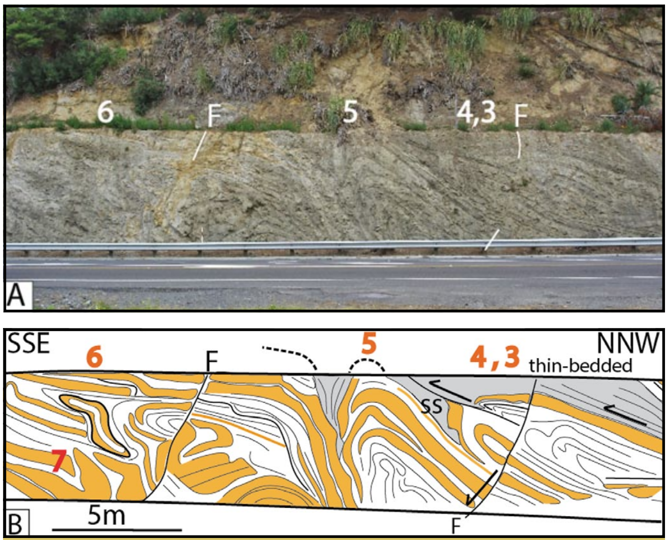


Fig. 7 A: photo; B: tracing of segment 2 in Fig. 3. Numbers identify major folds. Note the impressive fold No. 5, marking the steep zone of the fold stack. ss: sigmoidal sandstone body indicating top-to the-south thrusting on the dark fault line at its top. This thrust is displaced upward towards the north by one of the two late faults (= F). In A, the the southern late fault is marked by a yellow zone of post Miocene weathering.

Because of the overlap with Fig. 8, we will here only discuss the northern half of this segment, reserving comment on the southern half for segment 3.

An isoclinal fold (part of double fold No. 3, 4) is the first structure that we see as we enter this segment from the north. Note the parallelism of its limbs. However, this fold can only be considered to be truly isoclinal if its fold axis is at a high angle to the outcrop face. Should the fold axis be sub-parallel to the face, we would be dealing with a longitudinal section (see Fig. 4) and then would not know much about the angle between its limbs.This fold is dropped down to the south by a late normal (extensional) fault (for a definition also see Spörli *et al.* 2022 p. 8), as is the thrust at the top of the fold. The top-to-the south sense of movement of this thrust is nicely illustrated by the streaking out of a sandstone body in the frontal hinge area of the isoclinal fold (ss in Fig. 7B).

The thin-bedded sequence mentioned in segment 1 is also present here, and is folded around anticlines and synclines (also see Fig. 7B, dotted line), rising out of the road cut further south.

The most impressive fold (No.5) of the entire road cut is just north of the centre of this segment. This anticline contains four traceable sandstone layers that wedge out laterally. This may be due to primary sedimentation, but could also be caused by shearing out during pre- or syn-folding deformation. The steep dip of the fold's axial plane that contrasts with the much lower northward dips on either side marks one of the two most drastic changes in the overall structure of this exposure. The cause of this steepening will be discussed later. But note how the syncline immediately to the south is tightly squeezed, and it southern limb bends over, but also cuts off, the adjacent lower dip structures.

**Segment 3: Refolding** (Fig. 8)

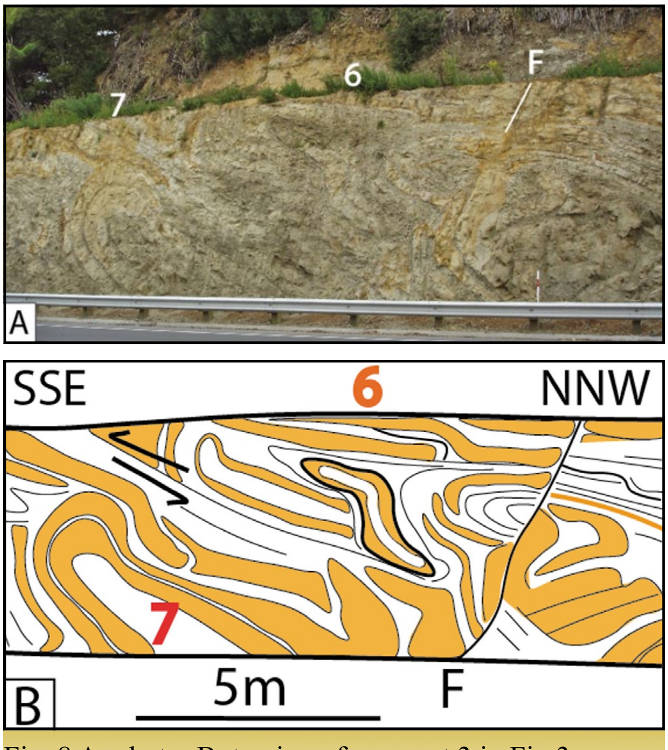


Fig. 8 A: photo; B: tracing of segment 3 in Fig 3. Numbers identify major folds. Arrows show sense of movement on thrust fault. Note the sigmoidally refolded Z-shaped fold below the number 6, and the northwards bending of the southern tips of folds 6 and 7. F marks the southern steep late faults also shown in Fig. 7. To the bottom right of this fault are the 'blocky' sandstones mentioned in the text. Irregular yellow colouration in the cut is post-depositional weathering. Less weathered rocks are grey.

In the northern part of this segment there is another late fault like the one in segment 2. Although markers to determine its offset are not as clear, it likely to be a normal fault like the one in segment 2.

Some of the sandstone beds in this segment are clearly thicker than elsewhere and react to the folding in a 'blockier' style.

Apparently isoclinal folds are also present here, and two of them have their southern hinge areas bent northward. In the structure immediately north of the upper isoclinal fold, beds form a closed 'loop' pattern that has been distorted into an open 'Z' shape – a typical example of refolding of an earlier structure. This may have originated as the longitudinal section through a previously formed fold with a curved fold hinge.

**Segment 4: Late slide surface** (Fig. 9)

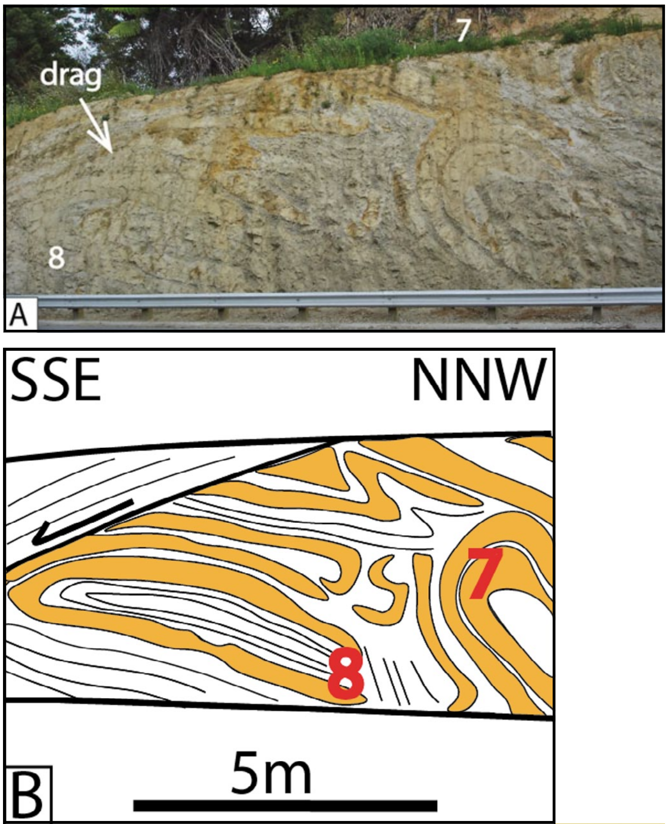


Fig. 9 A: photo; B: tracing of segment 4 in Fig 3. Numbers identify major folds. Arrow shows movement on the slide surface. 'drag' identifies the lower limb of the middle isoclinal fold that is bent down by movement on the slide. Fold No. 8 is the southernmost and lowest fold in the sequence. The irregular yellow colouration in the cut is post-depositional weathering. Less weathered rocks are grey.

Here at the southern end of the road cut, **we have the second drastic change in overall structure** – the folds are abruptly cut off by a sequence of southward dipping straight beds. Something like that can have two possible explanations – either it is a sedimentary unconformity (i.e., the folded beds were eroded, and the straight beds then deposited on them), or it has a tectonic (deformational) cause – the contact is a fault. Support for the second interpretation is available – there are two isoclinal folds with very low dip axial planes adjacent to this contact. The lower limb of the upper fold, instead of being truncated by the overlying beds, bends into parallelism with them, i.e., it is dragged down along it by movement of the overlying sequence (see 'drag' in Fig. 9A). In addition, the axial plane of the underlying fold 8 (Figs 3 & 9) is bent down with a similar sense of dragging, as are all the remaining beds underneath down to road level. All of this indicates movement with a down-to-the south component of the overlying sequence of straight beds. Note that this does not exclude the sedimentary explanation. We could be seeing a little piece of the sloping side of a submarine channel along which some sliding has taken place.

Within this segment, there is another, local, steepening of axial planes (but less prominent than in segment 2). The prominent fold 7 (Figs 3 & 9) displaying it (involving two adjacent sandstone beds) has its top hinge bent to the north, an indication of refolding.

**What does it all mean?**

It is well known that the Waitemata Group basin was formed in the Miocene, when a new subduction system became established under New Zealand (Ballance 1974, Hayward 1993, 2017, Mortimer *et al*. 2017, Sutherland *et al*. 2020), and which involved the emplacement of the Northland Allochthon (Ballance & Spörli 1979, Isaac *et al*. 1994, Kenny 2008, 2013), suggesting a special regime that must have been associated with heightened tectonic activity in this mostly deep water oceanic basin. This is undoubtedly expressed by the numerous exposures of contorted beds in the Waitemata Group (Spörli 1989, Spörli & Rowland 2007). The road cut we are celebrating features one of these manifestations. When we see such an exposure, the questions are always: What was driving the deformation and when after the deposition of the beds (i.e., at what depth in the pile of sediments) did it happen? What can we read in respect of this out of the contortions in this doomed road cut?

Seismic profiling on continental margins of the oceans has produced a wealth of data on basins of this kind (e.g. Joanne *et al*. 2013, Bache *et al*. 2014, Mahanjane & Franke 2014, Butler *et al*. 2015, Sobiesiak *et al*. 2018). They often contain complex drainage networks of submarine channels. Deformation ranges from (less often preserved) squeezing and crushing of sediments between harder blocks, to more commonly seen higher level sliding on slopes. Some of the latter include not only very shallow, small syn-sedimentary mass movements (e.g. Strachan 2008), but also deeper-seated displacements that can affect laterally gigantic sediment slabs (e.g. Joanne *et al*. 2013). Down-slope movement in gravity-controlled slide masses often creates an extensional headwall detachment dominated by normal fault swarms bottoming out in a basal low angle shear (Sobiesiak *et al*. 2018). In contrast to that, the downslope end or toe of a slide slab, where the movement ceases, is a site of fold and thrust shortening above the basal detachment.

It is obvious that in the main part of our road cut with its folds and thrusts, we are dealing with the structures at the toe of a slide mass that had been moving in a general southerly direction. The sandstone beds are remarkably continuous, and regular in their thickness. They also are not much thickened in the fold hinges and thinned in the limbs. At the scale at which we are observing, there is no evidence of sand mobilisation such as sandstone dikes or irregular protrusions from the sandstone beds. This indicates that by the time of the deformation, the sediments had acquired a certain amount of strength. The preservation of ramps on the thrusts also requires a certain stratal strength. This is also supported by the 'blocky' deformation of the thickest sandstone beds. The conclusion from these observations is that we are seeing deformation at a certain depth within the slide mass and not up near the sea floor. On the other hand, we have no indication how far below the road the basal shear plane (detachment) for these fold structures would be.

At this point we can consider the origins of the steepening in the fold stack mentioned in segment 2 (Fig. 7). It can be regarded as a flexure that verges north (dashed lines in Fig. 3), in the opposite direction to the south-verging fold 2 of segment 1 (Fig. 6). We can only speculate about the causes for this flexure. One cause could be that the mass sliding southwards received a northward push by some obstacle in the slide path. The northward bending of folds in segment 3 (Fig. 8) could also be part of this. The push could also have come later, during movement on the late slide surface at the southern end of road cut (Figs 3 & 9). A more local reason could be that the resistance of the fold knot of thicker beds in segment 3 (Figs 7 & 8) has 'braked' the prominent fold No. 5, steepening it during southward movement. A fourth possibility would be movement of the whole fold assembly over a larger ramp hidden below the road.

The late slide surface at the southern end represents another slide unit that moved later. In contrast to the folds in the main part of the exposure, we are here further back, near the extensional head wall of a mass movement, with the two late faults in segments 2 and 3 either representing outliers of the same system or formed later. This manifests the sequential formation and interference of two different slide masses.

**Acknowledgements**
I thank Jill Kenny for her critical advice and expert formatting of this article, and my wife Hanni for her help in the field.

With this we end the interesting structural insights that this doomed exposure with its aesthetically pleasing features has bequeathed us.

Fig. 10: State of the road cut on 26 May 2023.The new yellow scars at the top were caused by Cyclone Gabrielle.

***R.I.P.***

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# Is there gold in them there hills? Mystery over find

**Mike Dinsdale**

A foreign company doing secret earthworks to look at a possible tunnel or bypass for the Brynderwyns may have discovered gold.

Private equity firm Primeiro de Abril, from Brazil, has been carrying out secret work on land at the Brynderwyns, about 50km south of Whangārei, on behalf of an unknown overseas company that is keen to build an alternative route to bypass the Brynderwyns, which are prone to closures due to slips during heavy rain.

Recent works at the site may have uncovered what is believed to be a previously unknown gold seam that has the potential to be worth billions of dollars, Advocate sources say.

It remains to be seen - and further testing could confirm – if it is financially viable to mine gold from the site, with a number of other factors having to be taken into consideration, given the Government has imposed a ban on any new mining or exploration consents.

Last week, a representative of the group, Yúrén Jié, met with representatives of Whangārei District Council to discuss the issue, but given the sensitivity of the subject the council is not revealing any details at this stage.

For now though, it's understood that the company is also making representations to the Government to see if it can get the mining ban overturned and potentially start a Northland gold rush.

One other impediment to any gold extraction at the site is that it's yet to be determined if it's pure gold, or fool's gold - also known as pyrite.

Of equal importance is that the rare native Hochstetter frog has been discovered on the site. The frogs are endangered and their protection could prevent any mining.

Looking forward, the group will need to do further work at the site to find out just how much gold there is and whether it could be extracted cost effectively, if consent was given.

Such a find though could see a new gold rush occur and while the land is a mixture of public and private land there could be a big pay day for ratepayers, with the seam suspected to be mostly under the public land.

Business leaders are staying tight-lipped about the prospects at this stage, waiting for the group to come back with more information.

As of edition time yesterday Primeiro de Abril was refusing to discuss the find with the *Northern Advocate*, referring all the *Advocate*'s questions to its spokesperson.

Yúrén Jié said commercial sensitivity meant that no more details can be released at this stage, but promised that the Northland community would be kept fully informed of any plans to develop the site as they were finalised.

Article that appeared in the Northern Advocate, 1 April 2023.

# MATUKUTŪREIA/McLAUGHLINS MT EXPLOSION CRATER AND TUFF RING ARC HYPOTHESIS PROVEN

Bruce W. Hayward

## Introduction

Auckland Geology Club has had two field visits to Matukutūreia/McLaughlins Mt Reserve, the southernmost volcano in the Auckland Field (Fig. 1), in the last two decades. We climbed the pyramidal remains of the quarried scoria cone and explored the extensive lava flow field and pre-European stonefield gardens to the south. On both occasions, we also examined a half-moon shaped pond and surrounding low arcuate ridge to the southwest of the maunga. Half of this is in the public reserve and half in private land (Fig. 2). This pond and arcuate ridge (Figs 3–4) have always been inferred to be an explosion crater surrounded on one side by a low tuff ring with later toes of lava flows having advanced part way into the pond on the cone side (e.g., Kermode 1992, Kermode *et al*. 1992, Hayward 2009, 2019, Hayward *et al*. 2011).

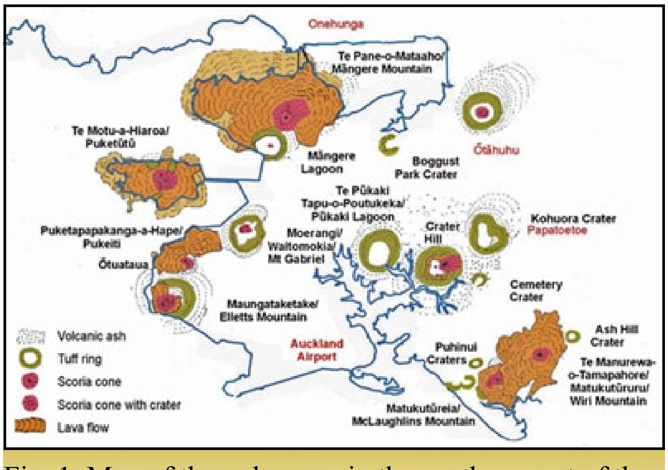


Fig. 1. Map of the volcanoes in the southern part of the Auckland Volcanic Field with Matukutūreia/McLaughlins Mt the southernmost. Modified from Hayward (2019).

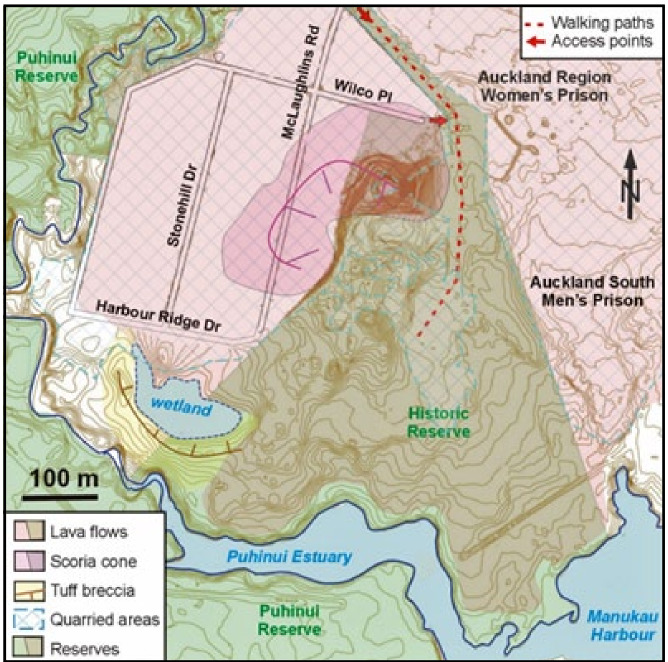


Fig. 2. Present day map of Matukutūreia/McLaughlins Mt volcano, extent of scoria cone, lava flows and location of inferred early explosion crater and tuff ring arc (modified from Hayward, 2019).

Fig. 3. 1952 oblique aerial photo from the south, prior to quarrying of the scoria cone (upper) showing the arcuate ridge (tuff ring) margining a lunate pond-wetland (explosion crater) in the foreground.

Fig. 4. Part of a Geoclub group visiting the eastern parts of the wetland and surrounding tuff ring arc in the public Historic Reserve in 2009. View from the east.

Our interpretation was strongly influenced by the landforms. It would be extremely difficult to produce such a smoothly arcuate and relatively smoothly rounded ridge on the Manukau lowlands by any means other than as a tuff ring. It was shapes like this on the 1 m contour Lidar that allowed me to recognise the additional volcanic craters on the lowlands a decade or so ago (Hayward *et al*. 2011). With such a smoothly arcuate tuff ring on one side, it is extremely difficult to visualize how material could have been explosively erupted out of the crater only in one direction, and in all other similar features around Auckland there is a matching arcuate tuff ring ridge on the opposite side, or as a circular structure. There is no suggestion whatsoever of any explosively erupted material or heap on top of the lava flows on the north side of the crater, which led us to infer that the crater predated the lava flows, and the tuff ring on the northern side was overtopped and hidden beneath the flows. The margin of the pond/wetland on its north side is irregular and smoothly digitate - a shape consistent with the toes of lava flows have advanced into and partly filled the crater from the north side. Trying to explain the origin of this unusual edge by any other process is difficult.

**Protection of the Matukutūreia explosion crater and tuff ring arc**

Because of this most plausible hypothesis for the origins of the pond depression and arcuate ridge, it was included in the mapped extent of the scheduled Matukutūreia Volcano Outstanding Natural Feature (ONF) in the Auckland Unitary Plan. This scheduling was to protect features from loss of their geoheritage values as a result of subdivision or development and effectively meant that no significant earthworks or dense building could be permitted on the land by council.

**Hearing on development proposal for part of the tuff ring arc**

In 2018, the development company that owned the land decided to dispute the extent of the mapped ONF in the hope that they could reduce its size and turn it into industrial subdivision. At the Council hearing on the matter in 2020, an expert volcanology witness, contracted by the owner, argued that the pond was a one-shot explosion (phreatic) crater that had mantled the surrounding arcuate ridge with a thin deposit of massive tuff breccia, that could be seen in a stream bank exposure (Fig. 5). The witness inferred that this deposit was not a landform-forming deposit and the arcuate ridge was not a tuff ring nor of volcanic origin. The only aspect of the landforms that related to the volcano was inferred to be the explosion crater (pond). The hypothesis presented was that magma had risen up into shallow ground, heating ground or surface water and causing a single steam eruption, which blew out mostly young sedimentary material but also blocks of existing lava flows. Thus, the inference was that the deposit post-dated most or all of the Matukutūreia eruption.

On behalf of the Geoscience Society of New Zealand, I disputed some of this and said that the existing hypothesis of Kermode and myself seemed the most obvious and likely. The Council's geoheritage expert sided with the applicant's young steam eruption theory and so the hearings committee allowed the ONF to be reduced in size, cutting off the northwestern end from any protection, but retaining the pond-wetland and most of the arcuate ridge.

**Subsequent earthworks**

In late 2022, the developer undertook earthworks on the site (Figs 6–8) that have dramatically altered the shape of the land between the northwest end of the pond and Puhinui Stream. In so doing, a 4 m-high cutting was made through and along the northwestern end of the arcuate ridge (Figs 5, 7). Examination of this cutting shows that it is composed of a 4 m+ thick massive deposit of tuff breccia (Fig. 8), thereby proving that the arcuate ridge is a constructional feature created by one or more phreatic eruptions from the explosion crater. The deposit is essentially the same as that exposed in the stream bank to the south and consists of angular blocks of early Miocene Waitemata Sandstone and rare blocks of basalt lava "floating" in a light grey, ash-sized matrix composed predominantly


Fig. 5. 2018 oblique aerial photo looking north over the explosion crater wetland margined by the arcuate tuff ring with the pyramidal quarried remains of the Matukutūreia scoria cone beyond (top). The recent industrial subdivision developed on the floor of the old quarry can be seen bordering the northern part of crater. The 2022 earthworks have levelled the lower left portion of the photo, including a slice through the west end of the arcuate tuff ring (X). The stream bank exposure of massive tuff breccia of phreatic explosive origin is marked Y. Note the fence line passing right through the crater wetland with Historic Reserve on the right and private land on the left.

Fig. 6. Panorama looking east over the still impressive, explosion crater pond/wetland and remaining part of the arcuate tuff ring, cleared of vegetation on the private portion in 2022.

Fig. 7. View south along the 2022 cutting, which provides a long window into the heart of the western end of the arcuate ridge that surrounds the explosion crater (pond). The cutting has weathered soil and midden on top, overlying a massive (4 m+) thick deposit of tuff breccia, produced by one or more large explosive steam eruptions.

Fig. 8. The freshest part of the 4 m-high cutting through the arcuate ridge. Note the lack of any bedding and the massive nature of the deposit. Angular blocks of Waitemata Sandstone "float" within the light grey, ash-sized, lithic matrix composed predominantly of disaggregated Pleistocene sediment. The largest sandstone block (left) is 1.5 m across.

of disaggregated Pleistocene sediment (that underlies the site at shallow depth). The composition of the lower part of the tuff ring is unknown. In geological terms, the deposit would be called "lithic tuff breccia" as the erupted particles are composed of previously formed rocks. Thus, the arcuate rim around the south side of the crater, being made of lithic tuff breccia, can legitimately be referred to as a tuff ring arc, even although it may not have included a primary magmatic component in the eruption. Most of Auckland's tuff rings have units of phreatic tuff breccia interbedded with the more layered deposits of magmatic base surge and ash fall eruptions (e.g., Hayward 2021).

**Depth of crater throat**

The presence of large and small blocks of fresh, angular Waitemata Sandstone in the tuff breccia deposit (Fig. 8) can only be explained by some of the explosive blast that ejected them occurring at depth within Waitemata Sandstone in the throat of the crater. Unfortunately, there are no deep boreholes within 1 km of the explosion crater recorded in the NZ Geotechnical Database. A shallow borehole (70126), located 400 m to the southeast, and another 400 m due east (68171) both were stopped while still in Pliocene-Pleistocene soft sediment at 10 m below sea level. The nearest borehole to intersect the top of the Waitemata Sandstone is on Prices Rd (82602), 1.5 km north of the crater. Here, the top of the Waitemata Sandstone is 42 m below MSL. In the other direction, 1.8 km to the east, a borehole (67809) intersected Waitemata Sandstone at 9 m above MSL. The present wetland floor of the Matukutūreia crater is 8 m above MSL. The above borehole logs indicate that the Waitemata Sandstone thrown out of the crater must have come from at least 20 m below the present crater floor, but unlikely to have been as deep as 50 m below. This implies that it was magma that heated groundwater at depth, and not a surface lava flow, that caused the steam eruption or eruptions that built the tuff ring rim.

**Conclusion**

Kermode's (1992) hypothesis - *that the pond and arcuate ridge around its southern side, located to the southwest of Matukutūreia, was produced by phreatic (and possibly also phreatomagmatic) eruptions presumably associated with or being the early phases of eruption of this volcano* - is correct. After the eruption style became drier the scoria cone was built by fire-fountaining and lava flows poured out towards the south, with the digitate toes of one or several flows reaching and partly entering the pond or wetland in the small crater. This could, conceivably, have resulted in the phreatic tuff breccia deposits seen in the stream bank and large blocks of lava scattered over the surface of the tuff ring arc, but not the construction of the tuff ring arc itself. The possibility that this crater was older than, and not related to, the eruption of Matukutūreia itself cannot be ruled out. Another possibility is that it was coeval with the three small phreatic and phreatomagmatic eruptions that produced Puhinui craters, 500 m away to the west (Hayward *et al*. 2011). The one certain thing is that this crater and tuff ring arc predate the lava flows from Matukutūreia.

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# SOUTHERN KAIMAI RANGE EXPLORATION

Willem Aalderink

In mid-March, 2023, a long weekend was used to further explore the secrets hidden under the Mamaku Ignimbrite or exposed in the streams and rivers in the Ngatuhoa area in the southern Kaimai Ranges (Fig. 1).

While exploring the area where a tunnel for the Kaimai hydro scheme was built, I picked up a rock that looked somewhat different from the usual ignimbrites found in the area. I tried to break it in half with my rock hammer, but it was too hard. I assumed it was a piece of Waiteariki Ignimbrite (Prentice *et al*. 2020), or if lucky, a piece of rhyolite from a dome I expect to be present somewhere below this area. I didn't get to have a good look until after I got home and could use a fist hammer and big chisel to break the rock. I was blown away by what it revealed (Fig. 2). It certainly was not 'plain' Waiteariki Ignimbrite or any of the other ignimbrites present in the area. It was something I had only seen in pictures on my screen while reading up on the many rock types that can be found. The rock I found resembled most a gabbro, but that was 'not possible'. There are no reports of gabbro ever having been found in the Kaimai area. Further examination of the rock with a hand lens (10x magnifier) showed a mixture of crystals and minerals, with the majority resembling plagioclase and brown crystals. The matrix was virtually non-existent, but the visible part was creamish-grey. After an extensive search on the internet, the brown crystals appear to be hornblende, which is a component of many volcanic rocks. The number of brown crystals is somewhat puzzling, but further analyses may shed some light on that.

During a meeting of the Auckland Geoclub in April, some much better qualified people provided their opinion and the consensus was that the rock was andesite. Further analyses might be required to confirm the nature of the brown crystals and the sample's composition, as it might turn out to be a dacite. The designation of 'andesitoid' (Mindat.org undated) might be fitting for the time being.

I am not aware that andesite or dacite have been found at this elevation in the southern Kaimai Range, so it represents an exciting development in the understanding of the volcanic processes that took place prior (or perhaps even following) the Waiteariki eruption c. 2.1 Ma (Prentice *et al*. 2020).

Part of the rock is currently at Waikato University for examination. Hopefully they can determine the type of rock and perhaps an indication of the history of its 'creation'. It is scheduled for thin sections to be made in May/June, 2023. *[Editor: No results by publication date.]*

An interesting aspect is the similarity in colour between this andesitoid rock and Waiteariki Ignimbrite, collected near where the andesitoid rock was found. Both rocks were wettened to better show the colours (Fig. 3).

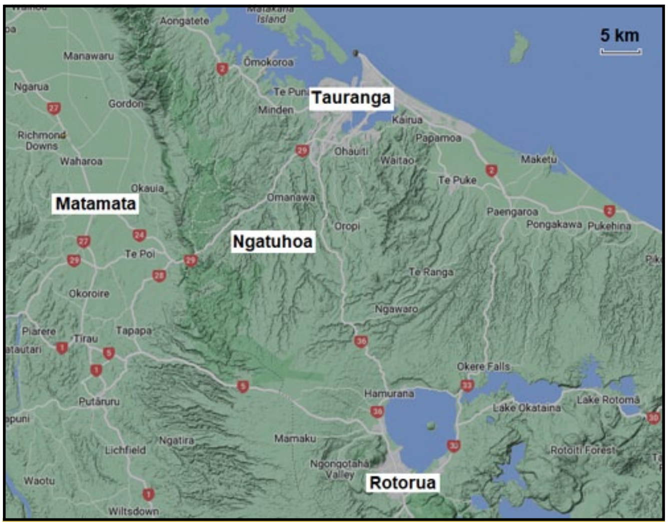


Fig. 1. Location of the Ngatuhoa area in the southern Kaimai Ranges, south of State Highway 29 between Matamata and Tauranga.

Fig. 2. Unusual rock, temporarily classified as 'andesitoid' (Mindat.org undated), found near Opuiaki River in the Ngatuhoa area of the southern Kaimai Ranges (Fig. 1).

Fig. 3. Wettened andesitoid rock behind typical Waiteariki Ignimbrite.

During the same weekend, I also explored the tailings dumped following the tunnel boring and digging of the hydro tunnel between the Opuiaki River and the Ngatuhoa Stream. The history of this project is very interesting and might be the subject of a future contribution. Before they started the tunnel boring, holes were drilled to establish the hardness of the rock below.

It appears some errors of judgement were made, as the tunnel boring machine had to be ditched for manual digging of the tunnel (I assume with the use of explosives), because the rock was too hard. This might be further indication of a rhyolite dome hiding under the surface. During an email exchange with the engineer who worked on the project, he stated that the area was a geological minefield and that it was partly thixotropic (see the reference to my cave project in the last paragraph).

Many observations were made that provided a better understanding of the process involved with developing the hydro scheme.

Previously, a few years back, I found a piece of rhyolite lava in that area, and I was hoping to find further evidence of rhyolite, likely from a lava dome that didn't reach the surface or was subsequently covered by the deposits from the Waitearki eruption. I was lucky. A big piece rhyolite rock was just waiting for me to come along and pick it up. The rock previously found did not show hydrothermal alteration, but this rhyolite rock clearly showed evidence of hydrothermal alteration (Fig. 4).

For a researcher, finding a rock near a stream, and at the bottom of the tailings from the hydro tunnel, is not clear evidence that this rock came from the digging of the tunnel. Luckily, I don't require that kind of certainty of the source. I infer that the rhyolite rock came from the hydro tunnel diggings. Future finds and exploration might discover further evidence of the presence of a rhyolite dome. It appears that the latest find came from deeper in the tunnel. The hydrothermal alteration might be related to the cave I have been exploring for some time. The cave is filled with clays (possibly including smectite, montmorillonite) most likely generated in hydrothermal processes. It is far too early to draw conclusions, but in every visit to this area, I make a little bit of progress in assembling the puzzle relating to the forming of the inferred Omanawa Caldera (Prentice *et al*. 2020) and subsequent volcanic processes. In the case of the andesitoid rock, it might even provide information on volcanic processes that happened long before the Waiteariki eruption.

Fig. 4. Hydrothermally altered rhyolite.


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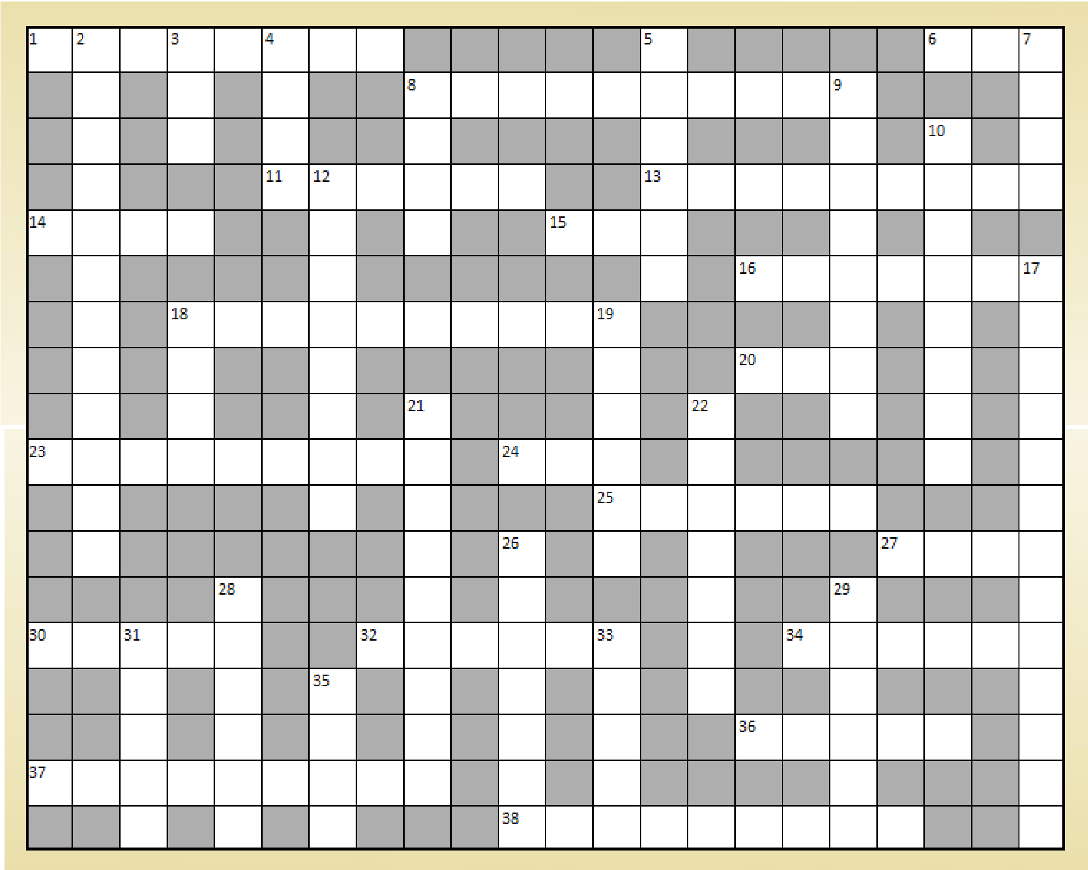
## GEOLOGICAL CROSSWORD




ACROSS
1 A measure of empty spaces within a rock (8)
6 Metal with the symbol Sn (3)
8 A middle rank of coal (10)
11 Has rings around it (6)
13 Large plates of these fossils are found on western Motutapu (9)
14 Active Sicilian volcano (4)
15 Mohs hardness number for talc (3)
16 Mid ocean ridge island (7)
18 One of the main components of greensand, giving it its colour
20 Chronological time span (e.g. Mesozoic) (3)
23 Process of creating sausage-like stretched structures in deformed rock (9)
24 90 degrees from strike (3)
25 Jill's role in this publication (6)
27 Another word for vein in mining terminology
30 A toxic bloom (5)
32 Lavas before they reach the surface (6)
34 A weak earthquake only detected by sensitive seismometers (6)
36 Together with $CO_2$ and energy, a product of mixing oxygen and glucose (5) [ This is not as hard as it sounds! It's a liquid. ]
37 Impermeable rock that acts as a barrier to the flow of groundwater (9)
38 Tsunami from this volcano might have reached the Red Sea in biblical times (9)

DOWN
2 Chaotic and mixed heterogeneous material formed by slumping or gravity sliding (12)
3 Valuable metal deposit that can be mined (3)
4 Atoms or molecules with net positive or negative charges (4)
5 Type of ornament on the outside of shells (6)
7 Monstrous loch (4)
8 Colour of the amphibole glaucophane (4)
9 Important information on a map, together with a north arrow (5,3)
10 Planes that are at 90° angles in pyroxenes and 120° in amphiboles (8)
12 A plain composed of material deposited by running water (8)
17 Unconformity where erosion has occurred between parallel strata (13)
18 Alluvial prize (4)
19 For emergency treatment of an allergic reaction during a field trip (6)
21 A . . . . . . . . . material allows liquids or gases to pass through it (9)
22 Rupture of this fault in 1891 was felt in Auckland. Named after Port . . . . . . . (7)
26 Not so quiet vents in offshore Bay of Plenty (7)
28 Swiss word for turbidite (6)
29 Old and stable part of the continental lithosphere (6)
31 Taxonomic rank between family and species (5)
33 Limestone metamorphosed by heat (5)
35 Isolated seamount and coral atoll east of Tonga (4)

(Answers on last page) Return to contents page

# GEOLOGY OF MOTU KAIKOURA, AOTEA/GREAT BARRIER

Bruce W. Hayward

**Summary**
Motu Kaikoura is part of the eroded remnants of the middle Miocene West Great Barrier andesite stratovolcano that erupted between 15 and 12 million years ago as part of the Coromandel Volcanic Arc. The majority of the volcanic rocks consist of thick massive beds of volcanic breccia and stratified volcanic breccia. The former were probably deposited by debris flows coming down the steeper sides of the volcano and the latter by more water-rich (40–90% water) hyperconcentrated flows, both of which were probably generated by rainstorms and/or earthquakes between eruptions. These breccias are interbedded with andesite lava flows, mostly 2–20 m thick and some contained within small paleovalleys. A few thin flows interfinger with red-oxidised breccias that were created by fragmentation of the flows as they were moving and cooling. A 200 m-wide andesite intrusion with beautifully-developed columnar jointing intrudes the sequence and forms the West Point of the island.

**Introduction**
When a Geology Club field trip visited Great Barrier Island for a few days in 2018, we took a special chartered boat trip from Whangaparara north into Port Fitzroy to look at the rocks and coastal landforms along this remote section of coast. As we entered Port Fitzroy, we sailed through Man of War Passage with Great Barrier on the starboard side and Motu Kaikoura on the port. Several years later, in 2023, I had the opportunity, at the invitation of the Motu Kaikoura Trust to visit and document the geology and geoheritage of this lovely island. The island is being transformed into a near-predator free nature reserve. Rats were completely removed about a decade ago, but managed to reinvade from the adjacent Great Barrier Island and are now being kept at low numbers by trapping and baiting.

Motu Kaikoura is the largest island off the coast of Aotea/Great Barrier, sitting across the entrance to Port Fitzroy (Fig. 1). The island is 185 m high, 4 km east–west and 3 km north–south with a triangular outline on the map.

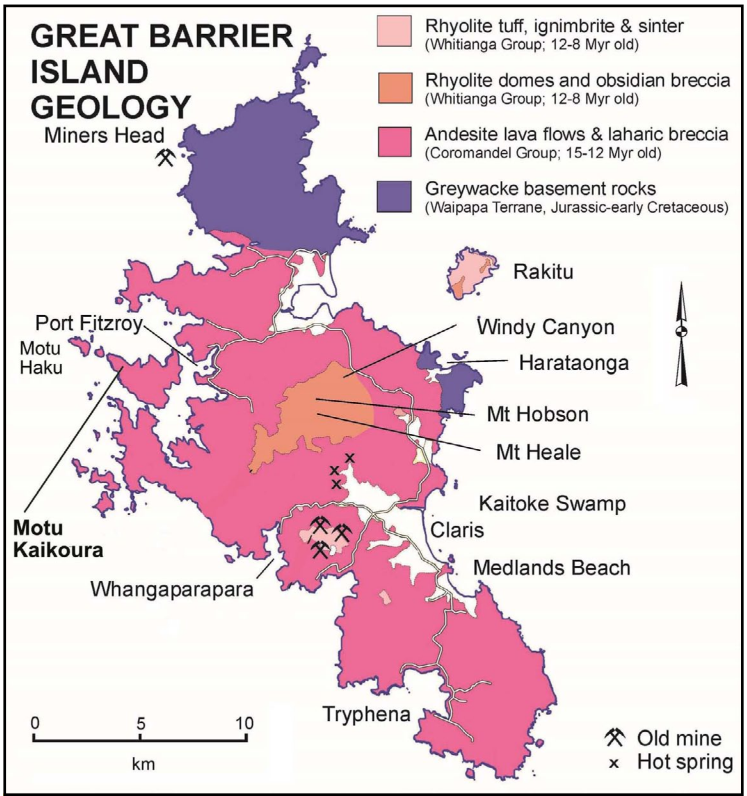



Fig. 1. Location of Motu Kaikoura across the seaward side of Port Fitzroy. Map shows the generalised geology of Aotea/Great Barrier Island (from Hayward 2017).

**Geology of Motu Kaikoura**
Motu Kaikoura is made of rocks of the Coromandel Group, all of which erupted in the middle Miocene between 15 and 12 million years ago (Edbrooke 2001, Moore 2001, Hayward 2017). On Motu Kaikoura, these comprise andesitic tuff breccia, andesite lava flows and an andesite intrusion (Fig. 2).

*West Point intrusion*
The West Point of Motu Kaikoura is composed of a 200-m-wide, 80-m-high body of andesite lava cut by numerous, spectacular, mostly columnar cooling joints (Figs 3–4). The intrusive contact with the volcanic breccia is well exposed in the cliffs on the northeastern side where the contact strikes near north-south and is subvertical (Fig. 4). The stratified breccia has been dragged up to a 30° tilt away from this contact. On the southern side of the intrusion, the contact is less clear and partly

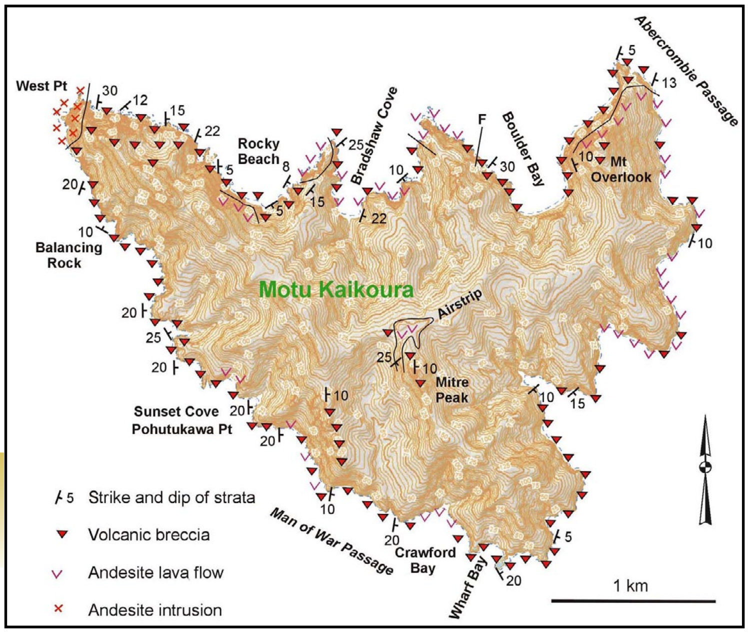



Fig. 2. Simplified geology map of Motu Kaikoura showing the distribution of lava flows, volcanic breccia and the West Point intrusion, and the attitude of the bedding in the stratified breccia sequences.

Fig. 3. West Point is composed of the partially eroded remnants of an andesite intrusion, which was probably a small shallow magma chamber at one time during the eruption of West Great Barrier Stratovolcano.

Fig. 4. Eastern intrusive contact of columnar-jointed West Point intrusion with breccia.

obscured by scree and vegetation but appears to slope at 40° to the southeast.

Within the intrusion, there are a number of zones parallel to the intrusive contacts, each comprised of parallel sets of subhorizontal to gently dipping columnar joints. These zones are interpreted as multiple periods of intrusion and cooling within and along the edge of the intrusion. One of the contacts between two of these zones on the southern side has a highly unusual texture of subvertical ridges and gauges (Fig. 5), that might have been produced as semi-solid lava was intruded alongside earlier solidified andesite.

There is no sign that this intrusion extends far in a northwest direction as it is not present on adjacent Nelson Island. The West Point intrusion is the only intrusion recognised on Motu Kaikoura and indicates that this was close to one of the conduits up which magma moved to erupt and form the volcano. There is another possible andesite intrusion

Fig. 5. Unusual vertical ropey texture, or gauges, within West Point intrusion.

Fig. 6. Block of deformed, baked, thin-bedded mudstone within inferred intrusion on the south side of Motu Haku, west of Motu Kaikoura.

forming the southeast portion of nearby Motu Haku Island. It contains a 5 m-wide raft of highly folded and cooked (cemented) thin-bedded mudstone (Fig. 6), which must have been ripped from the side of the conduit that passed through soft, relatively unconsolidated sediment and was carried upward within the “intrusion”.

*Andesite lava flows*

Lava flows comprise about 20% of the rocks on the island and can be seen in the sea cliffs and shore platforms in various places right around the island (Fig. 2). These rocks are medium grey when fresh but weather to shades of red and purple. Andesite is usually erupted from subduction-related volcanoes in a volcanic arc that parallels the collisional boundary between tectonic plates. In this case the West Great Barrier Stratovolcano erupted as part of the Coromandel Volcanic Arc above the zone of subduction of the edge of the Pacific Plate beneath the Australian Plate (Hayward 2017).

Many of the lava flows are 3–20 m thick and rather massive, often with steep columnar cooling joints oriented perpendicular to the flow’s top and bottom. A few of these flows have zones where close-spaced (5–20 cm thick) planar cooling joints are present (Fig. 7). All flows appear to be conformable within the sequence of volcanic breccia, although in several places along the northern coast of the island, their shape suggests they flowed down paleovalleys on the slopes of the volcano and cooled and solidified as thick lenses within these valleys. In many places, the exact geometry of the flows cannot be determined by the limited amount of exposure, especially on the more sheltered eastern shore of the island.

In a few places on the northern side of the island (especially in the cliffs on the eastern side of Bradshaw Cove), there are thin tongues and lenses of lava flow within red-oxidised angular breccia (Fig. 8). The clasts in these breccias are all of the one composition and texture, and the same as the interlensing flows. They are interpreted to be autobreccia formed by the lava flows shattering and breaking up as they moved along and solidified.

Fig. 7. Platy-jointed andesite flow (foreground) beneath stratified laharic breccia in cliffs on east side of Bradshaw Cove.

Fig. 8. Thin, grey lava flow tongues interfingering with red-oxidised autobreccia that was erupted very close to this location and emplaced while hot. The overlying cream- and buff-coloured volcanic breccias were deposited by cold flows of debris coming down the volcano's slopes.

*Volcanic breccia*

Approximately 80% of the rocks forming Motu Kaikoura (and much of nearby Great Barrier Island) are volcanic breccia of andesitic composition. Most of the breccia contains angular to subangular cobbles and pebbles of a limited variety of colours and textures "floating" within a matrix of sand-sized ash. Boulder-sized clasts are also sometimes present (Fig. 9). Technically, most units could be called tuff breccia. Some of the beds have a lighter-coloured matrix and contain pebbles of cream devitrified pumice (erupted andesite froth). In several places there is a distinct thin bed (0.2–0.5 m thick) of dark coloured tuff lacking larger clasts, which was probably deposited as an airfall deposit of volcanic ash.

There are two kinds of bedding or stratification within the volcanic breccia, each of about equal volume (Fig. 10).

Fig. 9. Volcanic breccia containing a 4 m raft of andesite lava that is inferred to have been swept down the volcanic slopes in the cold debris flow that deposited the breccia.

Fig. 10. Well-bedded volcanic breccia forming the lower half of the cliff at the east end of Rocky Beach. Several dark beds may be airfall volcanic ash deposits. The upper half of the cliff is composed of a thick bed of massive breccia, lacking bedding.

One kind consists of thick beds of massive breccia with no obvious stratification or sorting, with clasts of all sizes distributed randomly throughout. Several of these thick beds contain subrounded rafts of andesite lava flow that have been picked up by the passing lahar and rafted along within it (Fig. 9). The second kind of unit is well stratified breccia with distinct bedding, usually expressed as layers of different sized clasts that were deposited sequentially on the volcano's slopes by the passing lahars.

The term lahar is used here for any mass flow, other than normal stream flow (which would usually result in more rounded clasts) on the slopes of a volcano. Other definitions include: "A lahar is a violent type of mudflow or debris flow composed of a slurry of pyroclastic material, rocky debris and water" (Wikipedia). Both kinds of volcanic breccia described above can be deposited by a passing lahar. These lahars may occur during eruptions or at any other time by the collapse of unstable lava, breccia and ash on the volcano's steeper slopes. It often involves water (rainfall during storms, crater lake break out), but not always. In technical terms, the more stratified deposits are often deposited from hyperconcentrated flows (containing 5–60% sediment mixed with water), whereas the more massive deposits were more likely deposited by debris flows or debris avalanches (with less water).

Most of these lahars would have originated on the steeper slopes (10–25°) of the stratovolcano cone and would have deposited the volcanic breccias on gentler slopes further down, on either the lower slopes of the cone or on the gently sloping ring plain (both dipping at 0–10°).

*Structure*

The strike and dip of the bedding within the breccia (and occasionally at the base or top of the flows) is shown on the geological map (Fig. 2). With one exception (within an inferred paleovalley), all strata slope in a general easterly direction (mostly with a strike of between 160 and 040° and a dip of 5–30° to the northeast, east or southeast). As noted above, dips of up to 10° are possibly from the original slope on which the breccia was deposited, but dips of >15° are likely to include a component of later tectonic tilting. There are no obviously water-laid sediments on Motu Kaikoura, which would have originally been deposited horizontally. Thus, we cannot be sure how much and what direction a component of later tectonic tilting might have been. It seems probable that the original volcano slope was to the east and the main cone was located out to the west, as inferred by Moore (2001). If the original slopes were in the range 0–10°, then the rocks of Motu Kaikoura have probably been tilted an average 10–15° east in the western and central parts of the island and maybe none at all in the east part.

**Acknowledgements**

I am grateful to Mike Lee and the Trustees of Motu Kaikoura for the invitation to undertake this study. I am particularly grateful to the two rangers, Clint and Jacinda Stannard and their family, for their hospitality and help while on Motu Kaikoura, and especially for transporting me to and from and around the island to study the rocks and coastal landforms.

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# AN UNUSUAL FOSSIL FIND AT CASTLECLIFFIAN ONEPUHI FOSSIL BEDS, RANGITIKEI RIVER, MANAWATŪ-WHANGANUI REGION

Glenys Stace

On our way to Palmerston North, we discovered we had time to call in to the Onepuhi fossil beds. I hadn't been to Onepuhi since Kelvin Stace, Mike Eagle and I went there in 1996. I was interested in finding out how the river had treated the site and if any more sediment had been revealed. We didn't intend to stay overnight, which had been possible in the past, but the camping paddock no longer existed and it was only just possible to park close to the river. Recent massive floods had impacted on the river bank, and where large iron railing and wire had been installed, they were out of kilter, but they were still there.

The track along the river bank was overgrown but passable and the cliff that is the Onepuhi beds was still very much as I remembered it. There were good fossils at every level and a large block that had fallen down made collecting easy.

Auckland Museum has a good collection of Onepuhi fossils and a detailed description of the paleo-environment, a species list and faunal associations were published in Poirieria* ( Eagle & Stace 1997).

Fig. 1. Original position of the fossils within an oyster shell (upper photo) and close-up (lower photo). A dental pick for scale in the upper photo.

As I began to scrape loose sand out of the fossils we were collecting, I paused over an oyster shell with an unusual pattern of a shell inside it (Fig. 1). On further examination I was unable to identify it (Fig. 2). Echinoid is the first word that comes to mind. *Fellaster zelandica* and *Echinocardium cordatum* are the only ones I can find recorded from that site and I am sure it is neither of those.

**Does anyone recognise this pattern?**

**Reference**

Eagle MK, Stace G. 1997. Onepuhi Fossil Beds, Rangitikei River. *Poirieria* 20: 26–34.

* Poirieria - the magazine of the Auckland Shell Club (Auckland Institute and Museum, Conchology Section) www.biodiversitylibrary.org/bibliography/117415#/summary

Fig. 2. Prepared fossils. Dorsal aspects (upper photo) and ventral aspects (lower photo). An ordinary sewing pin for scale, length 25 mm.

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# THE GEOLOGY RESPONSIBLE FOR THE RECENT SLIPS ON MAUNGAKIEKIE/ONE TREE HILL

Bruce W. Hayward

In March 2023, a Geoclub field trip visited Maungakiekie/One Tree Hill to inspect the recent slips that had occurred there and exposed information about the volcano's history. This followed heavy rain storm events a few weeks earlier. On 27th January, Auckland was hit by a "weather bomb" or "atmospheric river" that dumped a city record of 240 mm of rain on the city in 24 hours. A few days later, on 1st February, a further drenching occurred. Many low-lying parts of Auckland were flooded and numerous coastal cliff slips were brought down by the usual culprits - the roots of large pohutukawa trees at the top of the cliffs could no longer hold the weight of the trees as the soil and weathered rock at the top of the cliff lost its strength when water-logged. The most unusual occurrences, however, were land slips on the steep slopes of Maungakiekie/One Tree Hill scoria cone.

This was only the second time in living memory that landslips have occurred here, and on the previous occasion there was only one slip in the vicinity of the water reservoirs, and there was some debate as to whether a pipe leak may have been implicated. In early 2023, Maungakiekie had 15 discrete landslips, whereas a quick inspection of most of the other cones of Auckland showed that this was mostly a Maungakiekie phenomenon, with one other obvious slip on Mt Albert's northern slopes and two small slips on the northern slopes of Mt Hobson. In an endeavour to determine why this was so, I spent several hours inspecting and mapping (Fig. 1) the Maungakiekie slips on 10th February, after 9 days of drying.

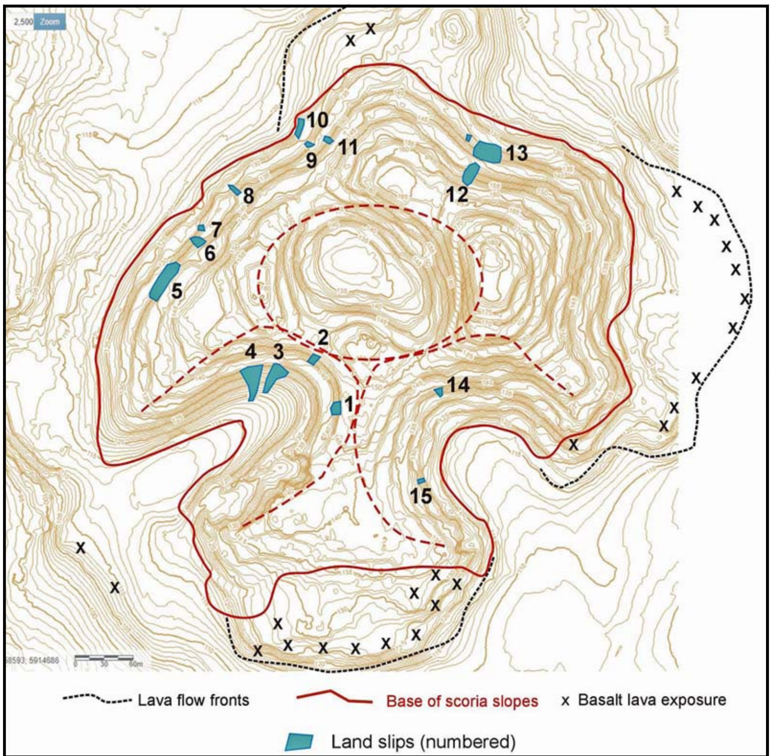


Fig. 1. Map showing the location and extent of numbered landslips on Maungakiekie cone.

**Distribution**

The slips are most widespread on the northern and western slopes and all occur between 145 and 120 m above sea level on the steep (naturally 30°) slopes of the scoria cone. Nine occur on the outer slopes and six on the walls inside the two southern breached craters (Figs 1–2). No slips are present where there are obvious lava flow fronts where viscous lava oozed out from the lower slopes of the cone, mostly around the southern, eastern and northwestern sides (Hayward 2015).

**Nature and stratigraphy exposed in the slips**

All slips appear to have occurred where there are no trees on the slopes, except slip 9 (Fig. 3), which started above a large tree and has slipped around it, exposing scattered tree roots. The depth of all slips is shallow, typically the top

Fig. 2. The two largest slips (3-4) in the southwestern breached crater. Note how slip 3 (right) has started slipping at the top, just below the edge of the terrace above.

Fig. 3. Slip 9 is the only that has occurred near any tree, with some roots exposed by the slipping, which has started above and beyond the tree.

Fig. 4. Slip 1, in the southwest crater wall, is an example of the kind of slips that have occurred on Maungakiekie, with failure of the rise between two terraces and only the upper 0.5–1 m of regolith failing and flowing down the slope, with its toe extending across the lower terrace.

Fig. 5. Slip 6 shows the over-steepened nature of the slope that failed and the shallow depth of regolith that has flowed down slope, like a carpet of grass and topsoil developed in the terrace fill.

Fig. 6. Shell midden has been exposed and come down in most of the slips, here photographed in slip 1.

0.5–1 m of the ground (rarely up to 1.5 m) (Figs 4–5). The material that has slipped, or flowed, is the long grass and its root zone plus some of the underlying soil and shell midden (Fig. 6). Almost always the top of the slip is at the outer edge of a man-made terrace and from there the slip extends down the slope (riser between terraces) for 5–10 m, often stopping at the back of the next terrace down (Fig. 4). Examination of several of the better-exposed scarps at the back of slips 1, 2, 6 and 14 (Figs 7–9) showed the following stratigraphy (sequence of deposits, from bottom to top): >1 m thickness of slightly weathered hard, impermeable, clayey tuff (ash) with dipping 1–3 cm

Fig. 7. Close up view of the upper scarp of slip 1 showing weathered fine tuff at the base, overlain by darker red-brown soil in the middle, overlain by terrace fill containing lumps of tuff dug out from the back of the terrace above by pre-European Māori.

Fig. 8. Stratigraphy exposed in slip 2 with obvious beds of harder coarse tuff within finer tuff (all erupted from Three Kings Volcano) in the lower part of the scarp. This is overlain by a darker red-brown soil and at the top the lighter terrace fill.

Fig. 9. Slip 7, on the western slopes, has exposed the freshest bedded Three Kings tuff (lower right) overlain by ref-brown soil and then lighter brown terrace fill.

thick beds of hard, coarse volcanic ash (Figs 8–9); overlain by 0.3–0.6 m of dark red-brown soil (Figs 7, 9). This soil is overlain by 0.3–1.5 m of massive, cobbly soil containing angular cobbles, pebbles and granules of the underlying tuff (Fig. 7). This layer was thickest at the top of the slips near the terrace edge and thinned downslope. It was capped with abundant shell midden and modern soil.

**Interpretation of the stratigraphy**

None of the slips penetrated deep enough to encounter loose or weathered Maungakiekie scoria (erupted about 60,000 years ago) that the cone is largely made of. Thus, everything exposed in the slips is a later addition. The bedded tuff is clearly Three Kings ash that was erupted about 28,000 years ago and is known to bury most of the One Tree Hill lava flow fields, and was thought to possibly also mantle the steeper slopes of Maungakiekie (Hayward *et al.*, 2011). This ash was erupted wet, and as it dried out on the cone's slopes, it hardened into the rock we call tuff. The majority of slips are on the western slopes of the cone facing Three Kings and this may suggest that the wet ash was plastered more thickly on this side of the cone by base surges. In some places (e.g. the steep lava flow faces around the eastern and southern sides of the maunga), most of this ash possibly was washed/eroded off the cone soon after eruption, but clearly this did not happen everywhere. The thick, dark-red soil on top of Three Kings tuff is inferred to be the soil that developed beneath native forest on the cone's slopes in the 27,000 odd years between Three Kings eruption and forest clearance by pre-European Māori. The massive, mixed cobbly layer is fill that was dug from the back of each terrace and deposited over the edge at the front of each terrace as they were cut into the naturally smooth slopes of the cone and the shell midden was dumped over the top of this by the Māori occupants.

**Inferred cause of the slips**

A combination of factors has contributed to the slips. The unprecedented heavy rainfall water-logged the softer surface layers on the steep slopes and they failed. The material to fail was mostly fill that had been excavated from the back of the terrace above and used to build out the front of terrace by pre-European Māori, but also included some of the underlying soil. The above conditions occur on all the other cones where slips did not occur, or only rarely did so, but the one difference is that Maungakiekie was blanketed by thick volcanic ash from Three Kings, much of which did not wash off the steep slopes and instead hardened there into tuff. Near the surface, this tuff has weathered into fine hard, impermeable clay, which the rain water does not easily penetrate, unlike the loose scoria of the other cones. Te Kopuke/Mt St John and Ohinerau/Mt Hobson are also known to have been mantled with Three Kings volcanic ash, but being more distant would have received less ash than Maungakiekie, and likely a lot less still remains on the slopes of these two cones.

Thus, the rain water-logged the upper loose soil layers, mostly of fill, and rain water could not penetrate deeper because of the Three Kings tuff. The grass roots held much of the water-logged soil together as it flowed and rolled downslope over the top of the hard Three Kings tuff.

**References**


Hayward BW 2015. Understanding Maungakiekie/ One Tree Hill Volcano - source of its lava flows. *Geocene* 12, 16–21.

Hayward BW, Murdoch G, Maitland G 2011. Volcanoes of Auckland: The Essential Guide. Auckland University Press.


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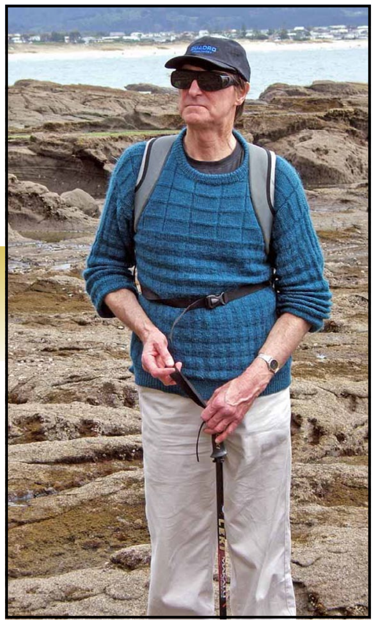
## MEMORIES OF DOUG DENIZE, GEOCLUB MEMBER 1992–2012

Bruce W. Hayward

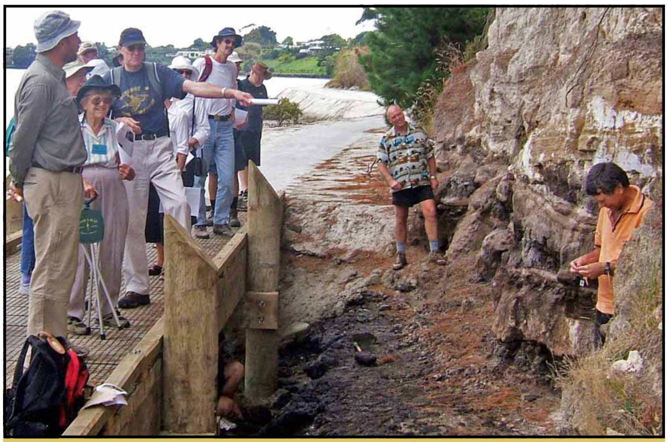
Doug Denize attended the inaugural meeting of Geology Club and became a foundation member from its establishment in 1992. He was one of a group of geoenthusiasts who attended Les Kermode's University extension geology class at that time and were sufficiently motivated by Les to come along. Doug spent one year (2008) on the Geoclub committee but, his main contribution to our activities was a regular attendee of monthly meetings and field trips. He would always help ready the lecture theatre and tidy up afterwards, and he always participated in discussions of the geology when on the outcrop. In 2003, he prepared and gave a very competent short lecture to Geoclub on the minerals magnetite and ilmenite. He often examined rocks in detail with his hand lens to get a better understanding of their composition and origins.

In January 2005, Doug gave us and himself a fright when he blacked out while resting after climbing most of the way up the steep clay track out of Mercer Bay, south of Piha. Fortunately, Margaret Morley was on hand to check his vital signs and declare that we probably did not need to summons a rescue helicopter. After sufficient rest, we gently shepherded him the rest of the way back to the cars. The trip had been advertised as "Moderately hard, only suited to those who are reasonably fit, not afraid of heights or clambering down steep rocky slopes (not dangerous but quite a climb back up)." Obviously, Doug, and we, had not considered that this was beyond his capabilities at the time. After doctor checkups, Doug continued to attend our meetings and most of our field trips for many more years.

Doug worked for many years for Douglas Pharmaceuticals in Henderson. He passed away at his home in December 2012 and has been missed by many of us ever since.



Doug Denize at Omaha, 2005.



Doug Denize (pointing) at St Kentigerns cliff section, Tamaki Estuary, 2007.

Doug Denize (right) at Lake Ohia, Northland in 2003, with fellow Geoclubbers (from left): Kath Prickett, Warren Spence, Helen Holzer and Shungo Kawagata.

Doug Denize having lunch on the side of Loop Rd, Waiotapu, with fellow Geoclubbers in 2005. From left: Kath Prickett, Helen Holzer, Margaret Morley, Doug Denize, Rhiannon and Peter Daymond-King.

Doug Denize crossing the mouth of Kaiwahata River on the Wairarapa coast, 2006. Hugh Grenfell (right) gives encouragement

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## GEOLOGICAL CROSSWORD ANSWERS

ACROSS

1 Porosity
6 Tin
8 Bituminous
11 Saturn
13 Barnacles
14 Etna
15 One
16 Iceland
18 Glauconite
20 Era
23 Boudinage
24 Dip
25 Editor
27 Reef
30 Algal
32 Magmas
34 Tremor
36 Water
37 Aquiclude
38 Santorini, in the southern Greek Islands (the Red Sea parted for the Israelites, then the tidal wave engulfed the Egyptians who were trying to catch them)

DOWN

2 Olistostrome (a mélange is different - investigate)
3 Ore
4 Ions
5 Ribbed
7 Ness
8 Blue
9 Scale bar
10 Cleavage (also in rocks, e.g. schistose cleavage, along which the schist breaks apart)
12 Alluvial
17 Disconformity (also check out noncontormity)
18 Gold
19 Epipen
21 Permeable
22 Waikato
26 Rumbles (SSW of the Silents, some of many submarine volcanoes of the southern Kermadec Arc)
28 Flysch
29 Craton
31 Genus
33 Skarn
35 Niue

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