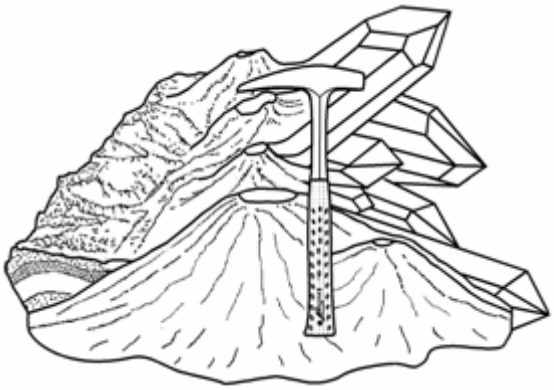


Geocene

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Geocene is a periodic publication of GeoClub, 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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LATE CRETACEOUS SHARK VERTEBRAE (CHONDRICHTHYES) FROM KOUTU BOULDERS, HOKIANGA, NORTHLAND.

Seabourne Rust

Abstract

Several vertebral centra of a shark are described from the Late Cretaceous (?Haumurian Stage) concretionary 'Koutu Boulders' within the Punakitere Sandstone, in the Hokianga district, Northland, New Zealand.

Introduction

The fossil record of chondricthyan material from New Zealand consists mainly of isolated teeth, with the notable exception of rare death assemblages from the Cenozoic (e.g. Gottfried & Fordyce 2001). In the New Zealand Late Cretaceous some 12 species (11 genera) of chondricthyan fishes have been recognised, largely by the work of Davis, Chapman and Keyes (see King et al. *in* Gordon, 2009). They constitute a mostly cosmopolitan fauna including extinct mackerel sharks, chimera, dogfish and sawsharks, represented predominantly by isolated teeth. Fossil shark teeth are usually well preserved, being hard enamel, in contrast to much of the cartilaginous skeleton, and tooth morphology forms the basis of most taxonomic studies. However occasional ossified vertebrae are also known to occur in New Zealand strata (e.g. Grant-Mackie 1982). Although somewhat limited in taxonomic information, the specimen described here represents the first initial record of a fossil vertebrate from the locality and adds to the expanding record of vertebrates from the Cretaceous of Northland (e.g. Grant-Mackie et al. in press, Grant-Mackie et al. 2011; Sachs & Grant-Mackie 2003 etc).

Locality

The fossil was discovered on a stretch of Hokianga Harbour shoreline known as the 'Koutu Boulders' for its large spherical concretions, some five kilometres northeast of Opononi, in the Hokianga region of Northland (North Island, New Zealand). Photos of this area may be accessed online (see Rust 2012).

The specimen was collected by S. Rust & D. Yanakopulos on 19 February 2013 as an isolated piece from an outcrop of Late Cretaceous (Maastrictian = Piripauan–Haumurian) Punakitere Sandstone (Hay 1960, Isaac et al. 1996), exposed at low tide, in the vicinity of the southernmost group of large (>1m diameter) concretions, between Koutu and Kauwhare Points on the southern shoreline of Hokianga Harbour (Fig. 1). Details of the locality are recorded in New Zealand Fossil Record File database (www.fred.org.nz), with the registration number O06/f0125 ; the map reference is NZMS 260 O06/485 373.

Geological setting

Much of Northland is covered by a significant succession of allochthonous Cretaceous and early Cenozoic strata that formed originally as a passive margin to the north-east. The Northland Allochthon was emplaced as active subduction proceeded in the area during the early Miocene. Across northern Northland these structurally complex sequences have been mapped as large thrust sheets, later deformed by regional uplift, faulting and folding (Isaac et al. 1996).

In the Hokianga area an allochthonous sedimentary sequence of Late Cretaceous and Paleocene quartzose sandstone and siliceous mudstone (included in the Mangakahia Complex) overlies Cretaceous Tangihua Complex rocks of the Waima Range. Locally the Late Cretaceous Punakitere Sandstone is dominated by bedded or concretionary quartzofeldspathic sandstone and mudstone with minor conglomerate. The regional distribution and lithology of the formation have been documented by Hay (1960), Isaac et al. (1996) and others.

Systematic paleontology

Phylum VERTEBRATA
Class CHONDRICHTHYES
Subclass NEOSELACHII
Order LAMNIFORMES?

Description

The specimen (Figs 2, 3, 4) consists of two adjoining vertebral centra, with a piece of the articular wall from a third centrum also attached. Each calcified centrum has concave articular faces with ring like 'annuli' visible, central regions are somewhat obscured by matrix. Numerous radiating lamellae are visible laterally, connecting the articular cones. The vertebrae are not evenly circular and exhibit some taphonomic distortion probably due to compaction. Centrum height is 60 mm, diameter (width) is 55 mm. Vertebral length is ~ 25 mm. Paired foramina are prominent on the dorsal and ventral surfaces, which would have supported the basidorsal and basiventral cartilages of the neural and haemal arches respectively. These foramina, some 12 mm in length, are 22 mm apart dorsally, and 12 mm apart ventrally (i.e. interforaminal width of Kraig 2008).

Discussion

Systematic interpretation of this specimen (or any shark from isolated vertebral centra) is severely limited; teeth tend to provide more useful taxonomic information. Cook et al. (2011) provide some data on several Late Cretaceous lamniform shark species, including *Archaeolamna kopingensis, Cretoxyrhina mantelli*, and *Squalicorax* spp. however it is unclear whether the Koutu specimen represents any of these. The specimen (and other fossils from the locality) are undergoing further study and will be the subject of a future research article.

Estimation of the original total length of this shark is difficult without knowing the total number of centra in the vertebral column, which varies between species (see Cook et al for example). If we use the formula suggested for *Carcharodon angustidens* by Gottfried and Fordyce (2001) based on maximum vertebral width (MVW) whereby total length (m) = 0.22 + 0.058(MVW mm) we obtain a result of 3.41 m. This is only to be considered as a highly speculative minimum length estimate as it is unlikely the largest centra of the shark are represented in this specimen.

The ring like 'annuli' or dark-light band couplets weakly visible on the articular faces of each centrum are interpreted to represent growth cycles of progressive mineralisation. These often (but not always) correspond to yearly seasonal cycles, and are sometimes used to determine the ages of modern sharks.

Palaeoecology

The Mangakahia Complex of the Northland Allochthon includes a clastic flysch association thought to have been deposited in outer shelf to bathyal depths (Hayward, Brook and Isaac 1993). The source of the Punakitere Sandstone itself was probably somewhat shallower on the shelf; the substrate was sandy and gravelly, with some shell (*Inoceramus*) debris. The matrix surrounding the specimen is well cemented medium- to coarse-grained sandstone.

Sedimentary structures at the locality indicate some deposition from turbidites and gravity flow mechanisms (Isaac et al. 1996). Casts of burrows and other trace fossils are relatively common, as are fragments of *Inoceramus*. Other local fossils include some rare bony fish remains (isolated bones and scales), these may be suggestive of possible prey for the shark.

Acknowledgments

Jack Grant-Mackie provided welcome support throughout this study and kindly reviewed an early copy of the article. Neville Hudson provided access to University of Auckland collections. Diane Yanakopulos has been an invaluable assistant in the field.

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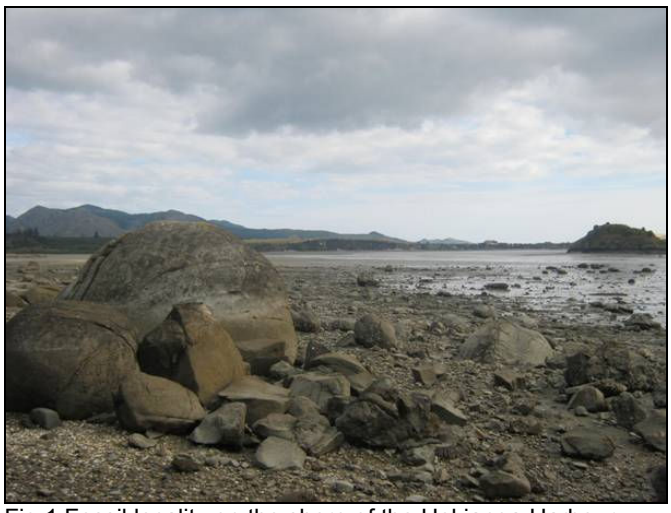


Fig.1 Fossil locality on the shore of the Hokianga Harbour, concretionary Punakitere Sandstone ‘Koutu Boulders ‘ in the foreground, Mahena Island and Koutu Point in the distance.

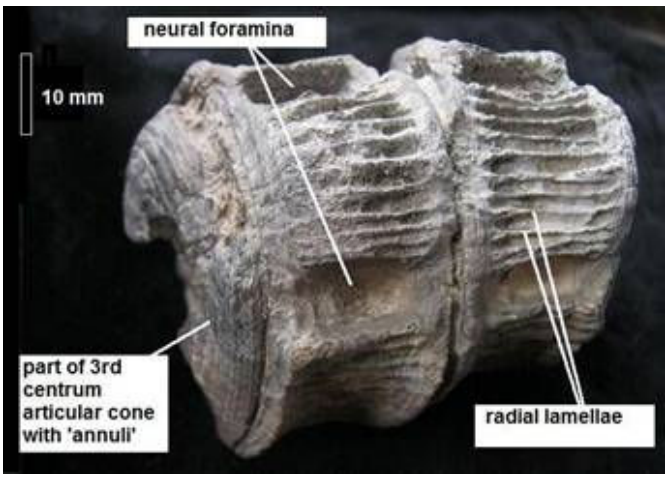


Fig.4 Specimen showing some morphological features.



Figs 2, 3 Specimen (oblique dorsal and anterior views), scale in mm.

PARAKAI QUATERNARY NOTE
Michael Eagle

'Palm Springs' is a commercial geothermal hot pool complex opened as 'Springside' in the early 1960's located 46 kilometres from Auckland and is presently being renovated on Parkhurst Road, Parakai, Rodney District (Fig. 1). The Parakai geothermal field (managed by the Auckland Council) is of regional significance and in the 1860's possessed a natural hot pool with other hot springs rising through several local creek beds. These no longer exist. The geothermal field is centred on the Parakai Reserve, gazetted in 1883. The geothermal field is only 800 metres in diameter and extends just north of Springs Road to Parakai Avenue. The Parakai Geothermal field is the largest and hottest thermal water resource in the Auckland region, exceeding that of Waiwera to the east and Miranda to the south-east.



Fig.1. Locality map of Palm Springs

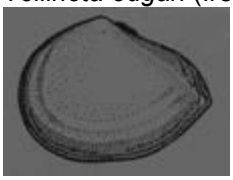
The Parakai geothermal field bore production temperatures range from 65ºC at the centre of the field to 45 ºC at the margin with c.700m³/day (near its limit) being drawn for commercial and domestic consumption. The Geopreservation Inventory notes that the former hot springs disappeared due to increased well production, and the situation described herein suggests that the resource is still highly vulnerable to exploitation.

The carbon-filtered geothermal water used by Palm Springs, is naturally expressed at c.65ºC but is manually temperature controlled to range in various pools between 34-41ºC. The geothermal mineral water contains fluctuating amounts of calcium, magnesium, sodium and potassium compounds. At the beginning of 2013 the original 76 metre deep bore initially drilled in the early 1960's, refurbished 1980's failed due to borehole and subterranean sump/pump corrosion. A new 75 mm dia. bore with 190 mm dia. upper casing (Fig. 2) sunk to the same depth failed to obtain the required flow-rate to sustain commercial use, so was continued to a depth of 150 metres where an acceptable hydrothermal volume was realised.

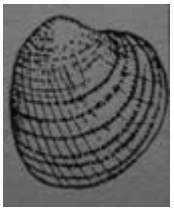

Fig. 2. Palm Springs new geothermal pool complex, Parkhurst Road geothermal bore-head, Parakai.

Whilst drilling through the uppermost homogenous gley soil (a soil characterised by iron and manganese compounds that are subject to periodic water-logging because of a permeable c-horizon) a number of Quaternary strata were encountered, being (surface down): black carbonaceous detrital peat at surface to 0.3 m; then coarse, alluvium to 4.6 m, followed by light grey fluviatile sediment to 52.3 m; and dark grey, fossiliferous, shallow marine, coarse sandstone sediments to 150 m. Fossil specimens (taxonomy of Maxwell 2009 (molluscs) and Mah *et al.* 2009 (echinoderms)) recovered from the 150 m level are:

MOLLUSCA
BIVALVIA
VENEROIDA
TELLINIDAE
Tellinota edgari (Iredale, 1915)



VENEROIDEA
VENERIDAE
Austrovenus stuchburyi (Gray in Wood, 1828)



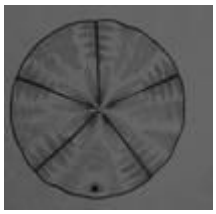
GASTROPODA
SORBEOCONCHA
CERITHIOIDEA
BATILLARIIDAE
Zeacumantus lutulentus (Kiener, 1841)



MURICOIDEA
BUCCINIDAE
Cominella (*Joespha*) *quoyana* A. Adams, 1854



ECHINODERMATA
CLYPEASTEROIA
ARACHNOIDIDAE
Fellaster zelandiae (Gray, 1855)



The low diversity of species may reflect the small sample obtained, or the decalcification and leaching of fauna, or both. Most of the specimens collected were of the gregarious bivalve *Austrovenus stuchburyi*. However, the molluscs and echinoderm recovered are characteristic of an estuarine sandy tidal flat that was probably part of an embayed coastline partially open to the sea. Although all of the species constitute present-day endemic fauna, they also appear in Haweran and Castlecliffian geologic stages at (for example) the type localities (see: Beu and Maxwell 1990) and in the Te Piki Member, Te Piki, Cape Runaway (see: Richardson 1997) in the North Island. Because of these occurrences and the fossils stratigraphic position, a tentative Haweran Stage (Pleistocene, 340,000 ybp) age is assigned to the fossils. A Late Quaternary landscape at the Parakai bore site suggests that after inter-tidal/sub-tidal deposition, a later, deeper transgressive incursion of the sea, perhaps caused by sediment loading and the effects of a near-shore current regime, buried the earlier near-shore coarse sand deposits under more sediment as over-burden. In time, these incremental deposits rose ahead of sediment loading to become shallower, eventually building sandbanks that were later covered by fluviatile deposits, and even later by a water catchment area that included shallow, fresh-water swamps. The carbonaceous layer uppermost indicates that the swampy catchment area was eventually infilled by silt and vegetation, further stabilised by dendritic drainage into a developing Kaipara River, finally emptying into the Kaipara Harbour. It is suggested that detrital accumulation and natural drainage aided the formation of a terrestrial prograding accretionary prism to buffer the present-day 100 year flood-plain from further marine incursion.

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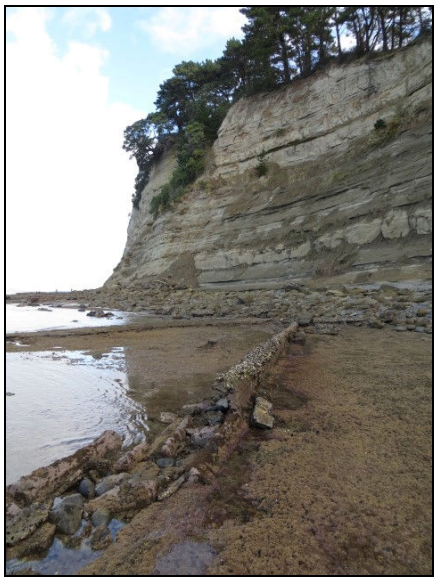
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CLASTIC DYKES
Peter Scott

Dykes are defined as rocks which are intruded vertically, usually through the bedding plane of the country rock. Igneous dykes are caused by rising magma cutting the strata. The magma may force its way up a line of weakness or previously made crack. However there are non-volcanic clastic dykes, which have different modes of formation.

The sandstone dykes at Emu Point at the southwestern tip of Motutapu Island are fine features (Figs 1, 2). There is a network of dykes varying in width from 30 cm to 3 cm wide and up to 30m long approximately aligned NE/SW, exposed by erosion on the wave cut platform of Waitemata Group sandstones in Emu Bay. The NE seaward end of the largest dike is visible as is the top which penetrates into the cliff. There is no appearance of dykes in the cliff above the top of the exposed dykes. Is that the limit of upward intrusion or has it been removed by the deposition of beds above this level?





Figs 1, 2. Views of the dyke from opposite directions.

Emu Bay geology is worth the trip. Basement greywacke is exposed and the active Motutapu Fault has formed a rocky stream gully where middens indicate Maori occupation. The beach by the stream mouth is covered with greywacke cobbles unlike the rest of the bay which is a wave cut platform, rocks and sand. There is a series of faults across Emu Point with traces of possible scarp slopes on the cliff top. In the cliff close to the dykes are traces of carbonised plants and lenses of what appears to be pumice or particles of ignimbrite.

I suggest the sandstone dykes were injected into cracks from below into reasonably consolidated horizontally-bedded Waitemata sandstone and are possibly water expulsion features. The main dyke sticks up out of the shore platform by up to 0.6 m. It has a distinct cross-section, hooked due to increased wave erosion and rock abrasion on the side facing seawards. I took 5 samples from detached pieces and one sample from the dyke which appeared to be the same composition as the detached samples. The dyke is made mainly of grey sandstone which under a lens showed shell fragments and small dark particles which may be carbonised organic material. There is a halo of lighter weathered rock 3cm deep around the detached fragments. The rock is quite friable and uncemented, and internally structureless with no evidence of flowing or layering.

The area around the east end of Motutapu is active tectonically (Motutapu Fault with recent earthquake epicentres within 500 m) and Rangitoto, which erupted 600 yrs ago, is close by, so it is possible that the dykes could have been associated with these and be relatively young.

The dykes that we saw at Flaxmill Bay, Mercury Bay, Coromandel Peninsula, are in a volcanic area and were probably formed in the ignimbrite by a combination of tectonic and volcanic action. These dykes have vertical stratification (variations in colour and texture) of clasts within them and they appear to have the same layers repeated on either side becoming younger from the outside in towards the centre of the dyke. It is suggested that here a crack formed and there were repeated liquefaction episodes depositing material on top (inner side) of previously deposited material adhering to the crack sides. The centre of the main dyke is filled with coarser rock which shows horizontal layering and grading which suggests the deposit fell from above into the open crack. However it was formed, it is a spectacular and rare formation.

Dykes are features which are often obvious due to differential erosion, colour and structure. Aesthetically, they often result in photogenic features such as caves and jetties. Scientifically, they can bring up underlying rocks as inclusions in the cooled magma, which provides valuable insight into their source and formation. For me, dykes (igneous or sedimentary) are often the highlight of field trips and generate good natured debate and conjecture!

UNDERSTANDING MAUNGAWHAU / MOUNT EDEN VOLCANO

Bruce Hayward and Garry Carr

In May 2013 the Auckland Geology Club ran a field trip to Mt Eden attended by about 20 members. One goal of the trip was to try and determine just how many volcanic vents or overlapping scoria cones were involved in the construction of the highest volcano on the Auckland Isthmus, Maungawhau/Mt Eden. Another goal was to try to determine the origin of the knolls around the lower slopes of the mountain – were they rafted scoria mounds or something else?

Maungawhau's scoria cone is approximately 800 m long in a north-south orientation and 400 m wide. Its highest point is 195 m above MSL at the southern end of the volcano on the southern crest of the single bowl-shaped crater on the mountain. Mt Eden volcano has been dated as erupting 28,000 years ago, about 500 years after the eruption of nearby Three Kings Volcano (Lindsay *et al*., 2011), which produced vast quantities of scoriaceous tuff that mantled all the surrounding area.

How many scoria cones form Mount Eden?

Some archaeologists and geologists (e.g. Searle, 1962) have suggested that Mt Eden was composed of four overlapping scoria cones because, prior to the construction of water reservoirs on the northern end of the crest, the mountain's profile had four clear high points (Fig. 1), each of which had been defended positions in the Maungawhau pa. The two southernmost high points are on either side of the crater and clearly were erupted from this single vent and are part of only a single cone (Fig. 2). Most commonly cited has been the opinion of Searle (1964) and Kermode *et al*. (1992) that Mt Eden is formed by three overlapping scoria cones. We speculate that this interpretation was based on the observation that two high points were associated with the southern scoria cone and the other two crestal high points were scoria mounds erupted from separate vents.



Fig. 1. Profile of Mt Eden from the east showing four high points along its crest, photographed in the 1860s. Note the distinctive secondary hill off the south (left) end on which The Pines apartment complex is now built (see later).

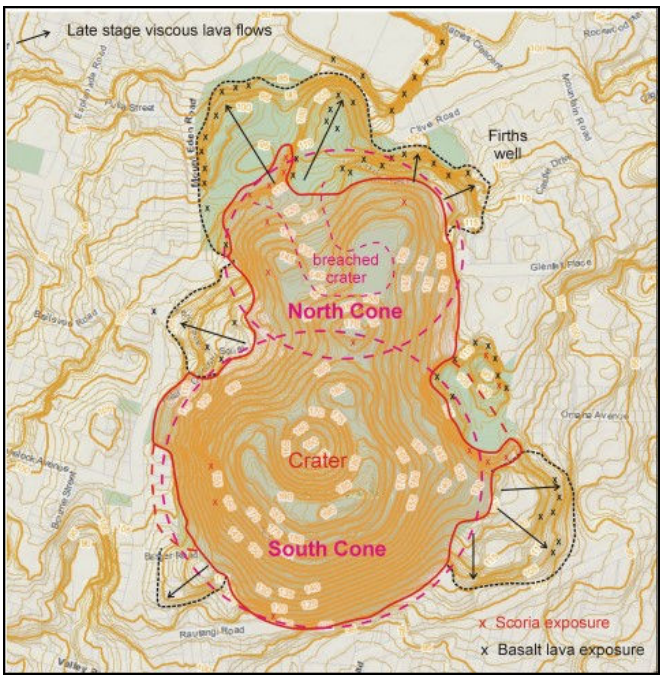


Fig. 2. 1m interval contour map of Mt Eden scoria cones showing locations of scoria (red crosses) and basalt lava exposures (black crosses), inferred discharge locations of lava (black arrows) and the inferred extent of two scoria cones with the breached crater to the north.

Independently the two authors of this note had previously examined the shape of Mt Eden's elongate cone and concluded that it was more probably formed by just two, slightly overlapping cones. The field trip set out to look at the evidence. A close look at the latest LiDAR contour map of Mt Eden cone (Fig. 2) shows that near its base it has a waisted elliptical plan. The southern end has a near circular plan corresponding to the scoria cone built up from lava fountaining from the existing crater. A similar, but less regular, subcircular plan is recognisable forming the northern half of the elongate cone. This suggests two scoria cones (Fig. 3), but if this is correct where is the crater from the northern cone? The crestal area/depression between the two main northern high points of the cone is now filled with buried, flat-topped water reservoirs which have hidden/destroyed the original topography. It is likely to have been a flat to gently-sloping depression that may have already been modified by pre-European Maori earthworks.

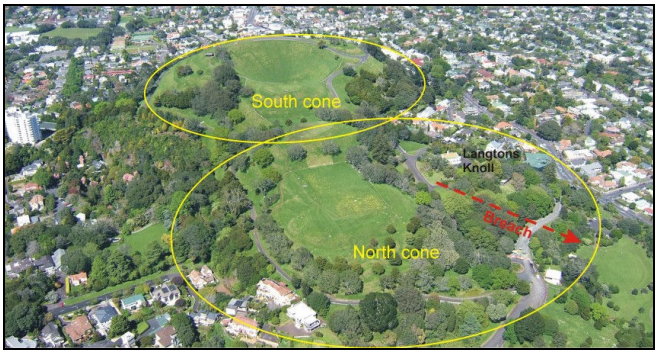


Fig. 3. Aerial view from the north over Maungawhau/Mt Eden showing the extent of the two inferred scoria cones that form it.

We speculate that this was the location of the original fountaining-crater that built the northern cone. It possibly was active earlier than the southern cone and its crater may have been partly filled by scoria erupted later from the southern centre (but see later).

It is interesting that the southern cone has two high point scoria mounds on the crater rim – one on the south side and one on the north. If we are correct about the northern cone with a central crater then it too had two high point scoria mounds on the crater rim – one on the south side (170 m ASL) and one on the northeast (153 m ASL). These must have been produced by unidirectional fountaining of frothy scoria possibly driven by two successive wind directions. It is tempting to hypothesise that this might indicate that the latter parts of both scoria cones were formed by lava fountaining from their craters at the same time. There is additionally a lower high point (145 m) on the west side of the northern cone where a building (formerly Langtons Restaurant) is sited (Fig. 2).

Further examination of the recently available LiDAR contour map of the crest of the northern part of Mt Eden shows a crude, perched U-shape depression in the vicinity of the bus carpark [not labelled] (Fig. 2). This depression slopes down towards the north suggestive of a small breached horseshoe-shaped crater (Fig. 3). The lip of this "breached crater" is quite high on the scoria cone however, at ~115-120 m above MSL (Fig. 2). If this is a breached crater then usually it would have been breached by lava coming up the vent pushing through the loose scoria on one side and rafting it away with the outpouring flow.

Tahaki Reserve, just below the "lip of the breached crater", is an old scoria quarry. Examination of the overgrown quarry faces below the lip show that basalt lava has spilled down over these northern scoria slopes consistent with the breached crater hypothesis. The coast to coast walkway ascending the northern side of Mt Eden on the east side of Tahaki Reserve quarry passes through small outcrops of basalt lava rock up to a small natural bench at 125 m above MSL. Above this height only scoria is present. It would appear that basalt lava must have come up inside the throat of the scoria cone and broken out at this elevation, which corresponds with the approximate elevation of the middle of the sloping floor of the perched "breached crater". Thus the height of the lava on the northern slopes is also consistent with the hypothesised breached crater of the northern cone. It is interesting to note that Hochstetter's (1864) map (Fig. 4), made before any quarrying, shows a lava flow coming down the northern scoria slopes giving the impression of possible breaching.

What are the knolls around the lower slopes of Mount Eden?

Later in our field trip we looked around the eastern side of Mt Eden, in Eden Gardens and into the grounds of The Pines apartment complex on a mound off the southeast corner of Mt Eden (Fig. 1).



Fig. 4. Part of Hochstetter's (1864) map showing the Maungawhau/Mt Eden area and the southern cone and crater and the northern part of the cone with three high points and a northern lava flow suggesting the breaching on the northern slopes.

In both places, exposures of solid basalt lava extended up to elevations of 120 m above MSL, which is closely similar to the elevation lava is inferred to have risen inside the vent of the northern scoria cone. At Eden Gardens we saw exposures of lava flow overlying and baking scoria forming part of the lower slopes of the cone. We also saw a 0.5-1 m thick dike of basalt intruding the scoria (Fig. 5). This may be one of the feeders for the lava flows that appear to emanate from this location and show that they were extruded late in the eruptive history of the volcano. The knoll on which "The Pines" apartment complex stands also appears to be another location where viscous lava rising up inside the conduit to the southern cone pushed through the scoria and was extruded at the surface. In the grounds of The Pines there are exposures of the steep face of the cooled lava flow front with textures of fissured and twisted basalt on their surfaces (Fig. 6).



Fig. 5. This 50 cm rib of basalt lava just inside the gate of Eden Gardens is part of a dike where the loose scoria on either side of it has been removed by quarrying before the area was turned into gardens. This dike can be traced westwards under the café building and can be seen intruding scoria in the former quarry face. The dike may have fed some of the lava that flowed out from the lower slopes of the Mt Eden scoria cone in this vicinity.



Fig. 6. The fissured and twisted texture on the surface of this basalt exposure in the gardens of The Pines on the southeastern side of Mt Eden was probably produced on the steep front of the viscous lava flow just as it was congealing and coming to a stop late in the eruptive history of the volcano.

Could it be that lava rose up inside the conduits of both the southern and northern cones to an elevation of ~120-125 m at the same time late in the life of the volcano and pushed through the sides of their scoria cones and poured out as viscous lava flows from a number of different places? Earlier outpourings of lava flows appear to have been more fluid and may have spewed out from lower down on the slopes of the cones while they were still growing.

There is one further spot on the east side of the northern cone (above Castle Drive) where viscous lava appears to have pushed out at ~120 m ASL. On the west side of the southern cone there are two further bulges (Batger Rd and Hillside Cres) that undoubtedly correspond to outpourings of viscous lava from elevations close to ~120 m ASL. There are exposures of in-situ basalt lava at 120 m ASL in road cuttings at the junction of Hillside Crescent and Percy St (Fig. 2) that confirm that this protuberance is formed by expelled lava. The Hillside Cres bulge lies west of the junction between the two cones and directly in line with the low (163 m ASL) saddle on the rim of the southern cone crater (Fig. 7). This saddle has possibly collapsed into the passage through which the lava was flowing out and stopped at an early phase of a crater breaching before the complete scoria rampart was rafted away (as suggested by Searle, 1962) We infer that the same process was more advanced on the north side of the northern cone, producing the fully breached crater in the vicinity of Tahaki Reserve. Langtons knoll on the western side, could be scoria that was rafted a short distance to the northwest on top of the outflowing lava.

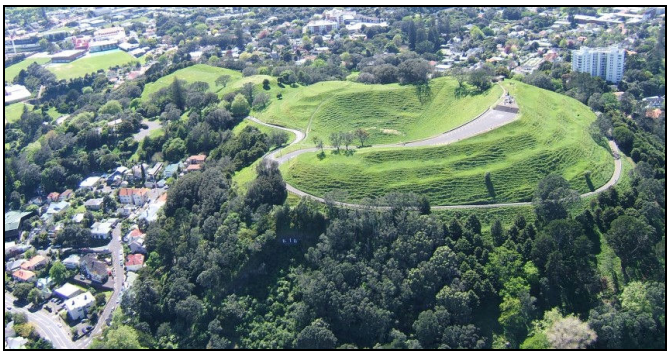


Fig. 7. Aerial view from the southwest over Maungawhau/Mt Eden showing the south cone with its deep central crater and low saddle (left) inferred to be formed by partial collapse of the scoria in this vicinity into the lava conduit flowing out beneath it. Hillside Cres lava flow bulge is covered by houses in the lower left of the photo.

Did Mount Eden erupt in numerous phases?

Searle (1962, 1964) inferred that the eruption of Mt Eden was intermittent with periods of eruption interspersed with quiet periods when swamp developed on the flow sequence. He based this scenario on the stratigraphic record in a well that had been dug in the lava flow field just northeast of the cone (Castle Drive, Fig. 2) in 1873 (Firth, 1874). This scenario of numerous pulses of eruption of Mt Eden was also repeated by Cox (1989).

Firth, who built the castle, after which Castle Drive on the north east side of Mt Eden is named, had a well sunk by hand on his property “with a view of obtaining a constant supply of water”. He wrote “I do not know that a record of my explorations will present any features of much interest to the general public. To myself, though unsuccessful in my search for water, they were full of interest, for, as I penetrated each successive lava stream, it seemed like the turning over of the leaves of some ancient and unknown book. … The point of commencement was 329 feet above sea level, and 313 feet below the summit of the mountain. The depth to which I penetrated was 212 feet, or within 117 feet of sea level at high water mark.” (Firth, 1874).

The log of the hand dug well indicates that it penetrated seven lava flows of varying thickness (a-g in Table 1) and was stopped while still in the oldest (g). The upper five flows were separated by scoria and/or volcanic ash and appear to have erupted in close succession without time for any soil or vegetation development and were close to the eruptive vent. These are inferred by us to be the full succession of Mt Eden lava flows at this location and that all erupted within a short period of time ~28,000 years ago.

Below the base of the Mt Eden flows (below flow e) there was 30 cm of baked clay with fern roots overlying 15 cm of fine scoria, which we infer to be the distinctive fine scoria ash erupted from Three Kings ~28,500 years ago that mantled all of Epsom, Royal Oak and spread across parts of Remuera (Kermode and Searle, 1966).

There may have been time between the Three Kings and Mt Eden eruptions for tree and fern colonisation with some soil formation. Below this is a 1m thick flow (f), much of which is described as being hard and scoriaceous. The source of this is unknown but it overlies 1.5 m of bedded freshwater sediment with the moulds of fallen branches preserved in it. This overlies the weathered surface of the lowest basalt flow (g). Firth (1874) noted that the bedded sediment was tilted at 45 degrees, which suggests that it may have been rucked up and pushed along by the incoming of the overlying flow (e). Perhaps the thin flow (f) is also part of this disturbed and rucked up zone and may be derived from the flow beneath (g).

Prior to the eruption of Auckland's volcanoes, there was a valley that flowed from the vicinity of Mt St John, beneath what is now the north end of Mt Eden and down to the Waitemata River valley between Birkenhead and Westmere (Affleck *et al*. 2001; Kenny *et al*., 2012). In boreholes west of Mt Eden, Eade (2009) used geochemistry and identified a deeper flow sourced from Mt St John and an upper flow or flows sourced from Mt Eden. Between the flows from the two sources he found vegetation and sediment that indicated a time gap of thousands of years between the eruptions of Mt St John and Mt Eden. He traced the Mt St John flow down the palaeovalley and found that it formed Meola Reef that projects out into the Waitemata Harbour.

With this new information, we reinterpret the observed sequence in Firth's well. It does not necessarily suggest that Mt Eden erupted in several phases separated by long quiet intervals. Instead we think that the well probably passed right through the flows that poured out on the northeastern side of Mt Eden, then went through thin scoria from Three Kings, then through disturbed swamp/lake deposits before bottoming in the Mt St John lava flow. Ironically Firth must have been within metres of reaching freshwater in the fractures of the lowest lava flow (g) within the bottom of the palaeovalley.

TABLE 1—Log of Firth's Well

Flows	Altitude (base of flow)	Intercalated Material
	Surface 329 ft	Soil and scoria cover 12 ft
(a) 6 ft	311 ft	Scoria and ash, 12 ft Loose red scoria, 8 ft
(b) 12 ft	279 ft	Loose blocks, ash and scoria, 42 ft
(c) 9 ft	228 ft	Red and yellow ash, 4 ft
(d) 27 ft	197 ft	Red scoria, spatter, and ash, 36 ft
(e) 8 ft	153 ft	Baked clay with root moulds and fine ash, 2 ft
(f) 3 ft	148 ft	Mud, with timber and leaf (raupo) impressions and bedded sediments, 5 ft
(g) 26 ft	117 ft	
	(end of shaft)	

Table 1. Abbreviated log of Firth's well, Mt Eden (from Searle, 1962).

Conclusions

The elongate shape of Maungawhau/Mt Eden was likely produced by eruption from just two main lava fountaining craters, not three or four as previously inferred. Two adjacent scoria cones can be recognised in the footprint and shape of the volcanic mountain, with the northern, less distinct scoria cone apparently having a breached crater opening to the north. We recognise six protuberances around the lower slopes of the cones that we infer were the places where viscous lava was expelled late in the life of the eruption. Much of this viscous lava did not flow far before congealing and forming steep basalt slopes, the largest of which formed the southeastern hill on which The Pines apartments now stand. All these late vents were at similar elevations (~120 m ASL) part way up the slopes of both scoria cones.

Previous workers have suggested that the south cone was younger than vents to the north, but we are tempted to suggest that they erupted together, at least in their later phases, because of the similar elevation which magma rose up inside both conduits before pushing out through the scoria cones and also because both have two high points on their crater rims – one on the south side and one on the north side that may have been produced by the same winds which directed the fountaining.

The sequence encountered in a well dug in 1873 through the lava flow field close to the northeast base of the northern cone encountered freshwater sediment and tree moulds between the lowest flow and five higher flows which has previously been interpreted to indicate that Mt Eden erupted in several pulses separated by a long quiet interval. Recent recognition that lava flowed from Mt St John down a palaeovalley that now lies beneath Mt Eden (Eade, 2009) is now a more plausible explanation for the lower flow in the well, with the indicated time gap corresponding to that between the eruptions of undated Mt St John and the younger Mt Eden.

Acknowledgements

We thank Jill Kenny and participants on the field trip for their perceptive comments and suggestions and Jill for suggesting improvements to the draft.

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MAUNGAWHAU'S DISTINCTIVE LAVA FLOW LOBES

Jill Kenny

The detailed contour lines and LiDAR imagery available for public viewing on the Auckland Council's GIS website clearly delineate steep gradients in the topography surrounding Maungawhau (Mt Eden) volcano. From my knowledge of the suburbs of Mt Eden, Epsom, Eden Terrace and Newmarket, I am aware that these steep gradients are the terminal and lateral faces of lava flows issuing from Maungawhau. Although older lava flows have reached more than 3 km from Maungawhau (i.e. beyond Eden Park to Western Springs - Kermode 1992), younger flows were clearly more viscous and each lobe tended to form a high buttress as it cooled and ceased to flow.

Just for fun, I traced around these lava lobe buttresses (Fig. 1). I added known crater positions (purple crosses on the map). Two are located on Maungawhau itself (A and B) and one has been added at the Auckland University Epsom Campus (former Teachers' Training College) carpark in Epsom Ave (C). It is the quarried out Te Pouhawaiki volcano (Hayward *et al*. 2011). Likely flow directions have been drawn purely from the shapes of the lobes on the map.

I also added lava caves (marked on the map as purple shapes) – Tarata St-Ashton Rd caves (labelled 1 and 2) to the southwest of Maungawhau (Hayward & Crossley, submitted), near Epsom-Remuera Croquet Club at the southeastern corner of Melville Park (3), a rumoured cave in Disraeli St, near Melville Park (B. Spörli, pers. comm. 2012) (4), and a possible cave at the western end of Ranfurly Road West, beneath an entrance to the Epsom Campus (5). I have included the cave at Mortimer Pass, Newmarket (6), even though it did not form in the same way as other lava caves – it is a pull-apart rift feature, perpendicular to the direction of flow, and only a few metres inboard from the terminal face of a viscous lava lobe. It is a 35 m-long remnant (Kermode 1994), with its northern continuation having been destroyed in the construction of Mortimer Pass.

Notice that lava flow arrows seem to emanate from 3 vague points – the northern and southern vents on Maungawhau and also from Te Pouhawaiki and its neighbour south of Maungawhau.

Notice also that the lava caves (apart from the Mortimer Pass pull-apart rift) are all on the southern side of the Maungawhau pedestal. The ESE-trending caves crossing Tarata St and Ashton Rd are thought to be parts of the same cave. The up-flow direction is towards Te Pouhawaiki. The up-flow direction of the lava lobe containing the possible cave in Ranfurly Rd West is also towards Te Pouhawaiki. Orientations of lava caves in the vicinity of Melville Park are not known, and flow directions of their encasing lava lobes are ambiguous as to likely source vent – in this vicinity the SSE-directed flows could be from Maungawhau or Te Pouhawaiki.



Fig. 1. Significant lava flow lobes around Maungawhau (centre), with probable flow directions, craters and lava cave positions superimposed.

A sketch map by the late Les Kermode (Fig. 2) shows the imposing pedestal of viscous lava flows radiating from Maungawhau, similar to those I have drawn in Fig. 1. He has also mapped older, less viscous flows that reached Eden Park in the northwest of his map and Potters Park in the southwest where they encounter lava from Three Kings volcano (lowest third of his map). Interestingly, he has drawn these older flows originating from somewhere south of Maungawhau, while only the younger, viscous flows appear to originate from Maungawhau vents.



Fig. 2. Sketch map of Maungawhau lava flows drawn by Auckland geologist Les Kermode (date unknown) as he recognised and measured them on location. Place names have been added by Kenny for this publication.

In both Fig. 1 and Fig. 2, flow sources from Maungawhau are logical, but what about the southern flow source(s)? Up-flow directions point straight to Te Pouhawaiki. In Fig. 2 it is even illustrated that older flows reaching Eden Park from the south could also have originated south of Maungawhai, i.e. Te Pouhawaiki.

Using lava flow directions from both Fig. 1 and Fig. 2, it is tempting to speculate that most, if not all, the southern flows originated from Te Pouhawaiki. They are less viscous and have therefore had the ability to flow further from source. They are topographically lower and are overlain by more viscous flows that clearly emanated from Maungawhau vents.

The age of Te Pouhawaiki volcano is not known. It may be younger than Maungawhau (which has been dated at 28,000 years old, Lindsay *et al*. 2011), as it appears to be the site of a small eruption that has just managed to force its way through Maungawhau lavas. However, using the direction and elevation of lava lobes, the topographically lower, less viscous lava, especially south of Maungawhau, appears to have originated from Te Pouhawaiki volcano. This implies that the vent is *older* or contemporaneous with early Maungawhau and has been almost obliterated by it. If older, it can only be a few hundred years older, because neither Maungawhau nor Te Pouhawaiki is overlain by ash from Three Kings volcano, dated as 28,500 years old (Lindsay *et al*. 2011).

Apart from the Mortimer Pass pull-apart rift cave, there are no known caves in the viscous lava pedestal of Maungawhau. All known or suspected caves are inferred to have formed in the less viscous, *underlying* lava possibly from Te Pouhawaiki. Viscosity clearly plays a part in lava cave formation in Auckland.

And another conundrum: how far did lava, possibly issuing from Te Pouhawaiki, flow? Is the lava that reached Potters Park actually from Te Pouhawaiki, rather than from Maungawhau? More controversially, is the lava that reached Eden Park also from Te Pouhawaiki?

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REVISED MAP OF MT EDEN VOLCANO

Bruce Hayward, Jill Kenny, Garry Carr
and Les Kermode

We have combined our respective maps from the preceding articles and added the distal extent of the flows from the 1:50,000 geological map by the late Les Kermode (Kermode, 1992) to get this new revised map of Maungawhau, Mt Eden volcano.

Reference:
Kermode, L.O., 1992. Geology of the Auckland urban area.1:50,000. Institute of Geological and Nuclear Sciences geological map 2.



ASHTON-TARATA LAVA CAVE, SOUTHWEST MOUNT EDEN

Bruce Hayward and Peter Crossley

Very few lava caves have been recorded from within the flows from Mt Eden, Auckland. Mortimer Pass lava cave is the only one that has been named and described, partly because it is the only lava cave of rift origin in Auckland (Kermode, 1994). This note is written to record the occurrence of a small lava tube on the southwest slopes of Mt Eden.

On two occasions in October and November 2007, we were asked by Auckland City Council heritage staff to go out, look at and report on the heritage values of holes that had appeared when footpaths were being relaid on the side of two adjacent roads on the west side of Mt Eden Rd. The visits were undertaken independently by us.

Ashton Road lava cave occurrence

The first hole inspected was in the footpath outside 16 Ashton Rd. It opened out into a small cave oriented east-west with a north-south width of c. 4 m and an E-W length of 6 m+ (the western extent was not explored beneath the road, because of the narrow 0.5 m high passage. The cave has an inverted V cross-section with the apex only 0.1 m below the footpath level and 1 m above the floor. The ceiling was festooned with pristine lava stalactites, some 5-8 cm long and 1 cm diameter. Lower, steeper parts of the wall had larger lava dribbles down them. At the foot of the wall on the southern side was a small lava bench at the former level of the top of a flow surge. Where visible the floor is still pristine frothy solidified lava indicating that the last lava surge was highly gaseous. There was evidence of a previous breakthrough under the grass verge that had been filled with lava blocks and rubble adjacent to the present breakthrough block debris.

Tarata Street lava cave occurrence

Two weeks later we were called out again to look at an elongate channel beneath the footpath in the next road to the west. It lay across the entrance driveway to 11 Tarata St. It was ~12 m long tube, ~1-1.5 m across. The height inside the tube varied from nothing to 1.3 m with a narrow arched cross-section (Fig. *). On the ceiling at the east end were a number of 5-10 cm stalactites. Walls of the western sector had vesicular dribbles. At the west end under the ground the cave widened to about 3m with tree roots and some rubbish from a previous entry. Another small cave was seen under the tar seal about 20 m away outside no 7 Tarata Street. It was too small to get into.

All the caves were sealed over again.

The elongate orientation of both of these tubes is similar and it seems highly probable that they are separate sections of the same lava tube that fed the lava lobe that lies within. The sections are 80 m apart and separated by two properties. The Ashton Rd section (83.5 m above MSL) is 2.5 m higher than the Tarata St section (81 m) indicating the cave was the conduit of lava flowing from east to west.

References:

Kermode, L.O., 1994. New Zealand lava caves worth preserving for their geologic and geomorphic features. Geoscience Reports of Shizuoka University 20, 15-24.

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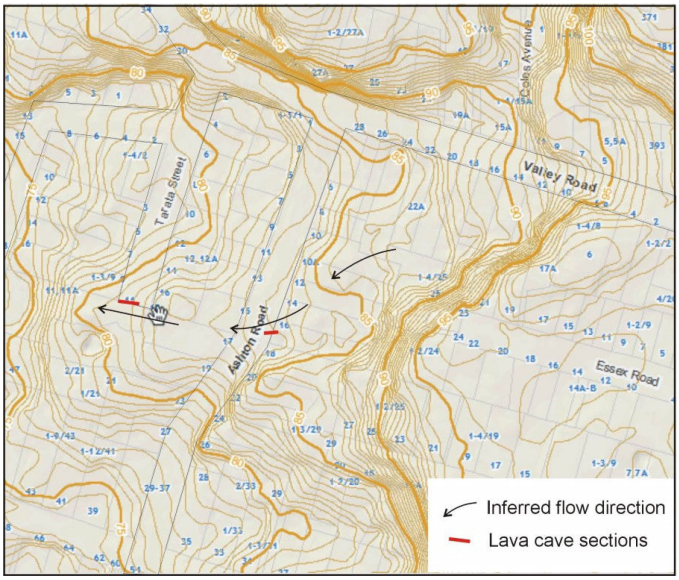


Fig. 1. Location of the two sections of Ashton-Tarata lava cave, Mt Eden.



Fig. 2. Location of lava cave break-in outside 16 Ashton Rd, Mt Eden.



Fig. 3. Looking down through the footpath break-in to part of the Ashton Rd lava cave section.

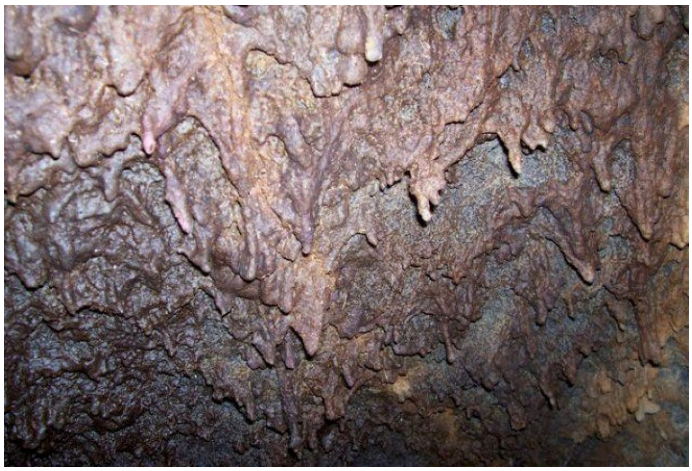


Fig. 4. Lava stalactites on the ceiling of the Ashton Rd lava cave.



Fig. 5. Location of lava cave break-in across the driveway of 11 Tarata St, Mt Eden.



Fig. 6. View eastward along the Tarata St lava cave section.



Fig. 7. View westward along the Tarata St lava cave section.

ONE TREE HILL LAVA CAVES
Murray Baker

In early September 2103 whilst having a chat with Bruce Hayward about geological field trips that the GeoClub had been doing, we found we had had a common childhood experience of exploring One Tree Hill lava caves. Bruce told me that recently the GeoClub had investigated the high lava "benches" on Mt Eden and One Tree Hill. In particular they had discussed the high lava flows on One Tree Hill as evidence of high volumes and levels of lava in once complete craters.

In the case of One Tree Hill, the question is - was the "Archery Club Crater" a complete crater but breached in the last part of the volcanic activity? It is possible that lava flowed from this crater in a southwest direction prior to the breach. If so this would account for the large amounts of very solid lava flows at such high levels. Discussing this aspect lead us to consider the lava caves.

Harking back to our childhood experiences Bruce said that he had gone into some of the "lava caves" on One Tree hill in his early years on the western and southern sides. As a former resident in Campbell Road I knew the park very well and had been into these lava caves too (Fig.1).

OTH lava cave 1 (Figs 2-3)
The lava cave in the western horse-shoe shaped crater (that is on the western side of the road by about 30 metres and opposite the car park – Fig. 3). I certainly crawled some distance into this cave as a kid. So recently I asked my brother, Neil if he had been in the lava caves on One tree Hill too. I didn't remember that we had been in the caves together. I was surprised to learn that he had been in the lava caves about two or three years before me. We compared memories and agreed that the lava cave is about 10 m –15 m in length and not regular. It has a blocky floor and roof and is a narrow crawl.

OTH lava cave 2 (Fig. 4)
The other cave is a smaller feature high on the slopes of One Tree Hill near the Archery Club
It is a cave where a kid could only squeeze into in a vertical manner but it did not go any distance – in fact one could barely hide out of sight of someone at the entrance. The position with reference to the midway car park of the summit road is 20-30 degrees west of a line in the direction of the archery club and situated on the upper part of the steep slope (Fig. 4).

I also had memories of my eldest brother, Lee talking of yet another lava cave. In his early working years he was at a construction site for the National Women's Hospital. The work of excavation was under the lava to the north west of One Tree Hill. I spoke to Lee very recently. Our conversation showed my earlier memory to be wrong. Nevertheless our chat revealed another geological detail that is interesting.

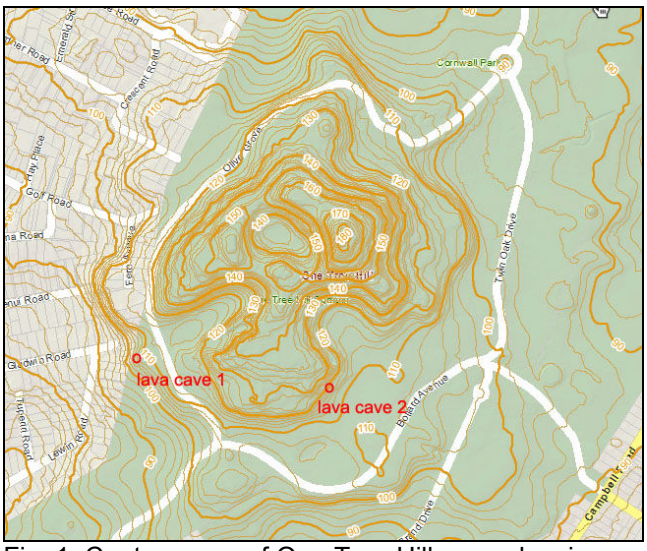


Fig. 1. Contour map of One Tree Hill cone showing locations of OTH lava caves 1 and 2.




Figs 2-3. Views of the present day blocked entrance to One Tree Hill lava cave 1, below the lip of the western breached crater, 2013.

What I had thought was a lava cave turned out to be a service tunnel big enough to drive a large vehicle through. This service tunnel runs under the hospital possibly between National Women's and the old Greenlane Hospital (Heart Unit). In the process of excavating or enlarging that tunnel Lee remembered the rock was in a soft crumbly mixed-up grey clay and volcanic material. I interpret this to be tuff possibly from early activity of the One Tree Hill eruptions rather than

Three Kings tuff which over lies the last eruptive scoria and lavas of One Tree Hill.

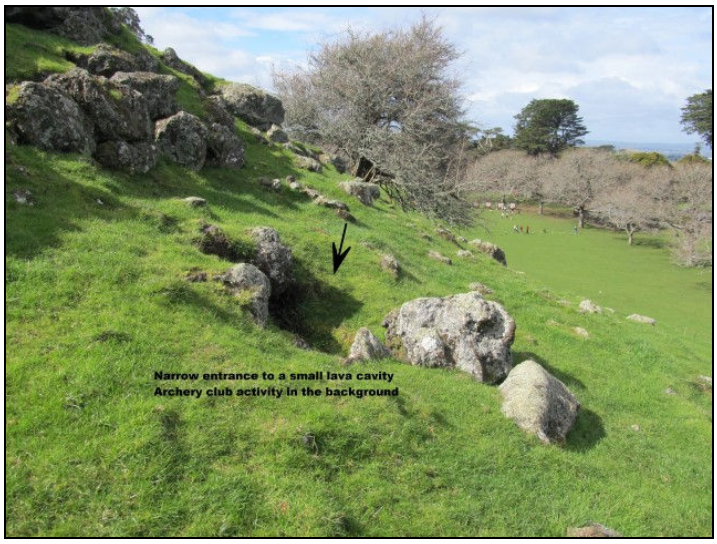


Fig. 4. Present day narrow entrance to a small lava cavity on the slopes above the southern side of Archery Crater (note activity in background), 2013.

IN-SITU TREE MOULD IN PURCHAS HILL TUFF RING

Bruce Hayward and Jill Kenny

During an GeoClub field trip to the lower western side of Mt Wellington in July 2013, we diverted to examine a road cutting at the Stonefields Ave - College Rd intersection. It was made a few years ago and is starting to weather and become overgrown but we could still clearly see many of the features of the Purchas Hill tuff ring (Hayward, 2006). Several of us had examined the exposure a few times in the past and so it was a surprise to find the top of a vertical cylindrical hole easily visible in the upper part of the exposure (Figs 1, 2).





Figs 1-2. Road cutting on the side of Stonefields Ave near the intersection with College Rd showing the cylindrical tree mould piercing the tuff ring exposure.

On closer inspection it was clearly the mould of a vertical tree trunk that had presumably rotted away after being buried by the volcanic ash that was erupted about 10,000 years ago. The hollow mould extended down the same height as the tuff exposure, but could be partly filled with ash or soil, so we do not know the actual depth down to the base of the tuff to the ground surface that the tree was growing on.

Because the tuff is relatively soft it is likely that in a few years the exposure will have weathered to a clay soil and be overgrown by grass or other vegetation that will hide or destroy this feature. Thus we have penned this short note to record its existence together with photographic evidence.

Reference:

Hayward, B.W., 2006. The relationship between Purchas Hill and Mt Wellington. Geocene 1: 2-3.

IS COROMANDEL PENINSULA RISING?
Bruce Hayward and Margaret Morley

In the Geoscience Society book "Continent on the Move" summarising the state of knowledge of New Zealand Geology there is a map (Berryman et al., 2008, p.142) that shows the present-day tectonic instability of coastal New Zealand. It shows areas that are going up, areas that are going down and areas that are considered to be stable. On this map all of the coast of Coromandel Peninsula is shown as presently being pushed up at a rate of between 0 and 1mm per year.

The question of whether the east side of Coromandel Peninsula was subsiding, stable or going up, arose on the GeoClub's April 2013 field trip, led by Roger Briggs, to the coastal geology between Whiritoa and Whitianga. The structure and stratigraphy of the Coromandel Peninsula suggests that quite likely there is an eastward tilt in the rocks of the Coromandel with evidence of former rhyolitic and other volcanism now drowned beneath the continental shelf east of the peninsula. This apparent historic subsidence in the east contrasts with the Berryman et al. (2008) map that suggests that now Coromandel Peninsula is being pushed up.

We stayed overnight at Tairua during the GeoClub trip so Margaret Morley and I took the opportunity to look for evidence of the present tectonic state of this area that might be present in any nearby marine terraces. The best place to capture such a tectonic history is to look at terrace surfaces that may have formed on the sheltered marine edge of a harbour or lower estuary such as occurs at Tairua. Terraces and sand spits on the exposed coasts may have their elevations less certain because of the possibility of storm beaches and wind-blown sand dunes. Terraces in the upper reaches of estuaries may also be slightly elevated above tidal levels by accumulation of sediment deposited by large floods coming down the rivers.

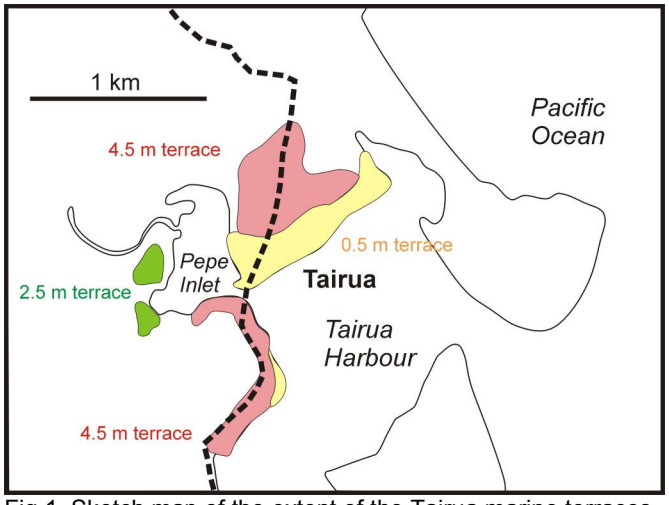


Fig.1. Sketch map of the extent of the Tairua marine terraces.

We soon recognised that much of the central part of Tairua township, on both sides of the entrance to Pepe Inlet, was built over two distinct terraces (Figs 1-2). Most of the shops and area closest to the edge of the Tairua Harbour is underlain by well sorted, fine to medium sand that is loose and uncemented and clearly of Holocene age. It appears to be identical in character to the clean sand of the adjacent intertidal harbour flats. This loose sand forms an amazingly flat terrace that we measured at being ~0.5m above highest astronomical tide level (HAT), as judged by the lowest extent of grass and highest obvious flotsam level.



Fig.2. The two terrace levels (0.5m & 4.5m) on the edge of Tairua Harbour, south of Pepe Inlet mouth.

A second terrace underlay a major section of Tairua north of Pepe Inlet mouth and the harbour and also forms a 100-200 m wide flat that the main highway and school to the south of Pepe Inlet mouth. We measured the height of the front of this almost horizontal terrace in several places and found it to be 4 m above the lower terrace and ~4.5 m above HAT. We chanced upon a road cutting through the edge of this higher terrace in front of 26 Hornsea Rd (Fig. 3). The terrace here is composed of moderately cemented, clean, fine-medium sand with some iron-staining and limonite veining. It appeared to be older than Holocene in origin. At the top of the cutting the sand was overlain by 0.4 m of orange-brown friable aphanitic sediment then 0.3 m of organic-rich soil.



Fig.3. The Hornsea Rd cutting showing the excavated riser between the lower and upper terraces. The aphanitic layer identified as Tuhua Tephra (7000 yrs old) is labelled near the top of the section sitting on top of the cemented sand.

The aphanitic layer appeared to be a weathered tephra which Roger Briggs was confident was Tuhua Tephra from nearby Mayor Island (40 km offshore to the SE). Tuhua Tephra is dated at ~7,000 years old (Shane et al., 2006). For Tuhua Tephra to be preserved overlying the surface of this terrace requires that it was above sea level at the time and provides strong evidence that

the higher terrace was not formed during the mid Holocene high stand (~6000-2000 yrs ago).

Around the world and New Zealand the two most recent periods when sea level was higher than present are the mid-Holocene and the Last Interglacial (~120,000 years ago). The actual elevation of these high stands varies globally and requires stable sections of coast to measure the terrace heights. There seems to be a consensus that the Last Interglacial sea level was ~5-7 m above present (Kopp et al., 2009; Beavan and Litchfield, 2012) and that around northern New Zealand the mid-Holocene sea-level was probably 1-2 m above present (e.g. Kennedy, 2008; Hayward, 2012; Lewis et al., 2013).

It seems highly probable that the two terraces recognised at Tairua are indeed from these two periods of higher sea level and that both were constructed of sand at intertidal elevations like the present tidal flats centred on an elevation of mid tide ± 0.5 m. The spring tidal range at Tairua today is 1.5 m. Thus the two terraces beneath Tairua township are ~1.3 m and 5 m above MSL and the approximate elevation at which they were deposited. These elevations are within the generally accepted range for the height of sea level during the mid Holocene and Last Interglacial respectively and indicate that there has been no significant (ie. >0.01 mm/yr) tectonic uplift or subsidence on this part of Coromandel Peninsula in the past 120,000 years. Continuous GPS monitoring of the vertical elevation of one site in the Coromandel Peninsula (Whitianga) extends back to 2003 and over this short period indicates no significant subsidence or uplift occurring (Beavan and Litchfield, 2012).

Around the SW edge of Pepe Inlet there is another terrace, partly covered in houses, at 2.5-3 m above HAT. Its extent (~400 m) is much less than the other two terraces (2 km +) – neither of which can be identified in this locale. The age and origin of this third coastal terrace is as yet unknown and needs more detailed study. It could have an aggradational alluvial component or may be it was formed during a lower sea level stand within the Last Interglacial peak. An inferred origin of this third terrace during the mid-Holocene highstand would imply uplift of 1-2.5 m at a rate of 2-5 mm/yr which is contradictory to the stable inference from the other two, more extensive terraces.

On return to Auckland and writing this note, we came across a similar study undertaken more than 50 yrs ago by David Kear and Barry Waterhouse (1961) at Waihi Beach, a few kilometres down the coast to the south of Tairua. They recognised and surveyed a number of aggradational marine terraces, the lowest two of which were 2-3 m and 5-6 m above MSL (converted from their measurements in feet) and correlatable to the mid-Holocene highstand and the Last Interglacial. They conclude that their study implies that the Waihi Beach area has been tectonically stable for hundreds of thousands of years. They do however recognise additional terraces at 20, 30, 100 and 150 m above MSL which, if they had a marine origin imply significant uplift earlier in the Quaternary. In passing Kear and Waterhouse note similar and slightly higher marine terraces along this section of Coromandel coast (but not Tairua) that imply that there may have been some localised uplift in places during the Holocene.

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