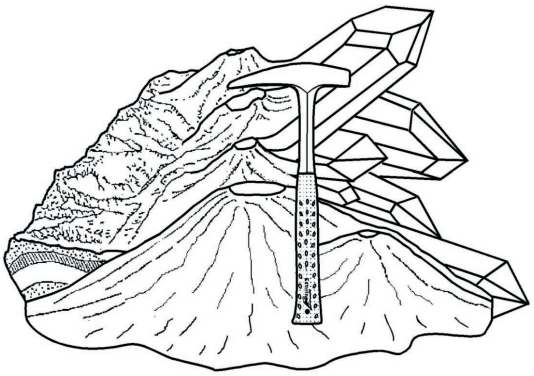


Geocene

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

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

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SELWYN ST LAVA CAVE, ONEHUNGA – BEST CAVE FOR YEARS

Peter Crossley

A lava cave was discovered by a Selwyn Street property owner in 2015 (Fig. 1). He reported it to the Auckland Council and its representative contacted me. The cave was broken into by a 1 m by 1 m trench dug for a water pipe down the length of the property (Fig. 2).



Fig. 1. Google Earth image of the properties in the vicinity of the lava cave west of Selwyn St, Onehunga, with the lava cave extent superimposed.



Fig. 2. Entrance to the cave in a trench dug for a water pipe.

During a quick visit, I soon established that it was much longer than the 50 m that the development surveyor had measured. In subsequent trips with a caving colleague, Ian Mander, the cave was surveyed (Fig. 3) and photographed (Figs 4–6).



Fig. 4. Some of the cave is only accessible by crawling.



Fig. 5. In some sections of the cave it is possible to sit or stoop.

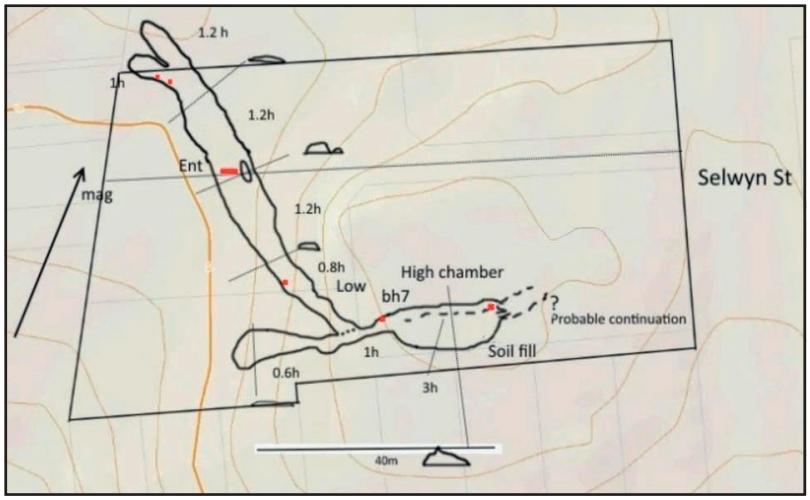


Fig. 3. Survey of the lava cave, superimposed on the property boundaries and contours.



Fig. 6. The high chamber has a gothic arch profile at the eastern end of the cave. The person is looking at the cone of soil that has fallen through the ceiling.

The total length is 122 m, with average width 5 m and a maximum of 8 m. Height varies from crawling, to mainly stooping, to 3 m, where the magnificent gothic arch resembles a similar feature in Wiri lava cave (Hayward *et al*. 2011). It also contains stalactites (Fig. 7) and curious lava dags (Fig. 8). The dags occur in a narrow part of the cave, just beyond a large chamber and are angled down-current. Their angle might be due to hot gases rushing through the small gap, or by movement of the top of the flow itself, dragging the semi-solid dags along. This is the only known occurrence of this feature so far in New Zealand. [Lava "dags" known as "blades" – see Editor's note]

The cave had never been open to the outside and so there is no rubbish in it and the wall and ceiling features are in excellent condition. Some of them are the best in Auckland. The floor is mainly clean with only a little mud in one section.

The cave roof in general is made of solid basalt with only occasional cracks. Very little has collapsed to the floor. Even though the span is quite wide (5–8 m), it appears stable, but there should not be heavy point loading on the centre of the arches. Any buildings should be built on reinforced concrete pads. The George Terrace buildings nearby have very similar caves underneath them without collapse so it would be worth studying them.

A quick dig at the end of the far eastern chamber (Fig. 6) showed that the passage probably continues past the soil fill. It is up flow so the cave may increase in size. The complexity of the George Terrace caves, about 250 m to the southwest, and the size of Scotlands Cave, 400–500 m to the northeast (Fig. 9), encourages me to think this.

In the future, it is recommended that there should be a permanent manhole entrance installed so that the general state of the cave can be checked. In order to prevent accumulation of rubbish and silt, storm water should not be piped directly into the cave.

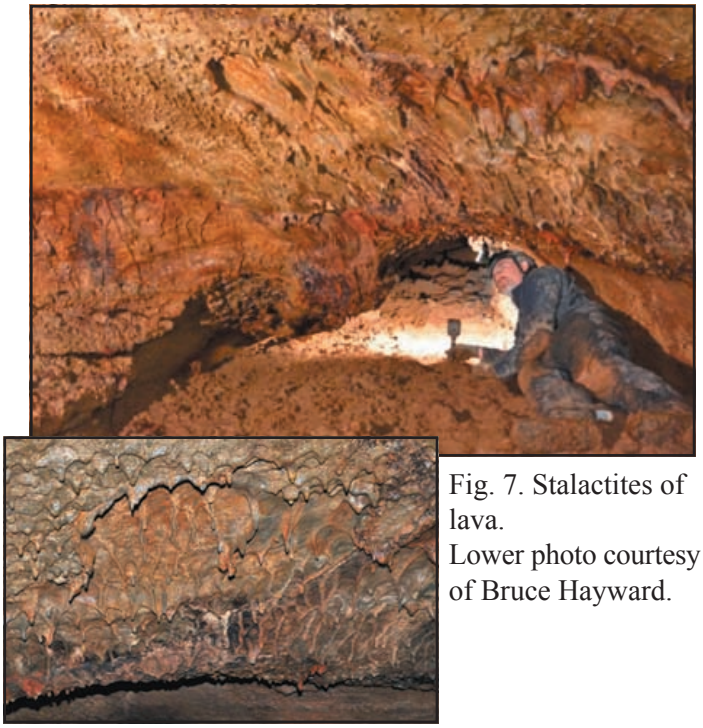


Fig. 7. Stalactites of lava.
Lower photo courtesy of Bruce Hayward.

Editor: *Additional information on "lava dags", actually termed "lava blades", has been adapted from website:*
http://www.goodearthgraphics.com/virtual_tube/blades.html

Lava blades are projections from the wall that tend to be parallel and regularly spaced. They grade from thin to thick; the thicker blades may have begun as thin blades that were then coated by upwelling lava. The edges may be smooth or stringy. They often occur near constrictions and the edges of lava falls – places where the velocity of the flowing lava may have been increased (by wind in the former and gradient in the latter). Lava blades are best known in Hawaiian lava tubes.

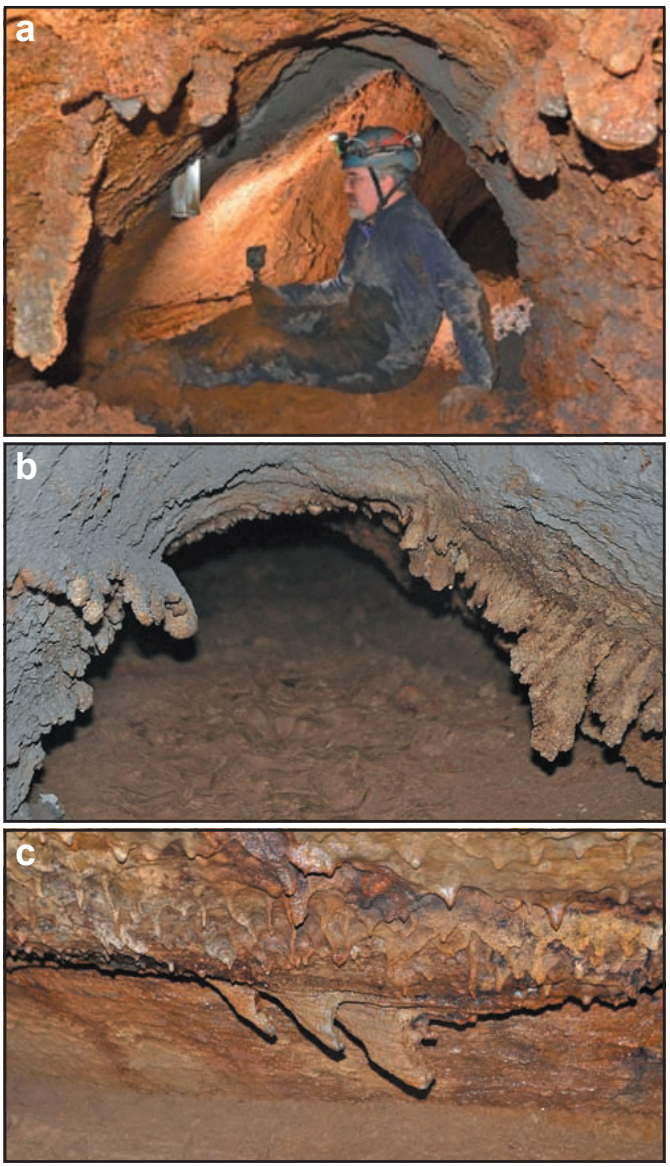


Fig. 8 a–c. Lava dags, blown by the wind. Notice also in photo (a) the end of a drill pipe, which is useful for talking with people on the surface.
Photos (b) and (c) courtesy of Bruce Hayward.

This is a significant, untouched cave in the Auckland Volcanic Field. It should be preserved, and access should be made possible to interested parties. Work is already under way to add this newly discovered cave to the schedule of protected outstanding natural features in the Auckland Council's Unitary Plan.

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Fig. 9. Google Earth image of part of Onehunga with lava caves superimposed. Selwyn St cave is the red slanting L shape just left of centre. Scotlands cave is oriented north–south at the top of the image, partly beneath the large orange-roofed building complex. Galway St cave is to its right. The George Terrace caves (Helena Rubenstein and Ratcliffe caves) are drawn as dark pink splotches near the bottom left corner. The lava flowed from One Tree Hill volcano 2.5 km to the north.

SMALL SATELLITE EXPLOSION CRATERS IN THE AUCKLAND VOLCANIC FIELD

Bruce W. Hayward

Summary

Four of Auckland's volcanoes had small explosion craters (100–250 m in diameter) that erupted through their tuff rings or lava flow fields within 200–700 m from their main vents. These are inferred to be satellite vents that erupted during the sequence of eruptions from their parent volcanoes. Fingers of magma are inferred to have branched off from the main conduit and encountered ground water as they approached the surface, producing small explosive blasts that threw out pulverised pyroclastic material, creating small craters surrounded by low tuff rings. It has not been possible to examine the composition of the tuff rings and thus either phreatomagmatic or purely phreatic (steam) eruption origins cannot be determined. All of these satellite craters have suffered from the growth of Auckland City: the satellite craters at Crater Hill and Wiri Mt have been completely destroyed; that at Pukewairiki has been reshaped into a stormwater settlement pond; and the Pigeon Mt satellite crater has been partly filled, reshaped and its site is in a private reserve with no public access.

The Pukewairiki and Wiri Mt satellite craters have not previously been recognised by geologists. Of several other small explosion craters in the Auckland field, Ash Hill and Cemetery Crater seem unlikely to have been satellite eruptions of their neighbouring volcanoes, whereas the three small Puhinui Craters may or may not have been satellite vents from McLaughlins Mt.

Introduction

There are around 50 volcanoes/volcanic centres in the Auckland Volcanic Field (Hayward *et al*. 2011a, b). Many consist of a large maar crater (200–1000 m in diameter) and surrounding tuff ring (e.g. Orakei, Panmure and Onepoto basins) or have remnants of an initial maar crater/tuff ring partly (e.g. Motukorea, Puketutu) or wholly (e.g. Mangere and Wiri mountains) buried by subsequent scoria cones and lava flows. The smallest maar craters recognised as separate volcanoes, because of the distance from their nearest neighbours, are 500 m or less in diameter at the crest of the tuff ring (Table 1) – St Heliers, Te Hopua, Boggust Park, Styaks Swamp, Cemetery Crater, Ash Hill and Puhinui Craters (Fig. 1).

In addition to the maar craters that are currently recognised as separate volcanoes, there are/were at least four other small, circular explosion craters that are so closely associated in location to larger volcanoes that they are best referred to as satellite vents. Two of these, at Pigeon Mt and Crater Hill, have been well documented, whereas two others, at Pukewairiki and Wiri Mt, have not previously been recognised as volcanic craters in the geological literature.

These small satellite explosion craters are assumed to have erupted in association with the eruptions of their host larger volcano, as a result of a branch of the same rising magma contacting cold water near the surface, resulting in a small phreatomagmatic eruption (mix of water and magma) away from the main fire-fountaining vent(s). Without detailed examination of the composition of the low ring of ejected tuff that surrounds each of these satellite craters, it is not possible to rule out the possibility that one or more of them originated by purely hydrothermal eruption of heated water, steam and pulverised country rock (and no magma).

Satellite explosion craters

Pigeon Mt / Ohuiarangi (Figs. 2, 3)

Heaphy (1860) was the first European to map and record the presence of a small crater near Pigeon Mt (numbered as volcano 7 on his map, Fig.4). Hochstetter (1864) figured this crater even more prominently on his beautiful map of Auckland's volcanoes and labelled it "Tuffcrater" (Fig. 5) and numbered it as volcano 41 in his text (Fleming, 1959, p.200). Thus both these early workers considered it to be a separate volcano. One

Table 1. Comparative sizes of small maar craters in the Auckland Volcanic Field and the distance from the centre of the nearest named volcano (modified from Hayward *et al*. 2012).

Crater	Diameter (crest to crest)	Tuff ring elevation	Distance to nearest volcano
St Heliers	500 x 400 m	40 m	2.2 km to Taylor Hill
Te Hopua	500 x 500 m	9 m	2.8 km to Mangere Mt
Boggust Park	450 x 300 m	8.5 m	2.7 km to Mt Robertson
Styaks Swamp	400 x 400 m	? 12 m	0.6 km to Green Mt
Cemetery Crater	250 x 250 m	10 m	1.3 km to Kohuora
Puhinui eroded	250 x 250 m	7 m	0.8 km to McLaughlin Mt
Puhinui arena	250 x 150 m	8 m	1.1 km to McLaughlin Mt
Puhinui pond	200 x 150 m	8 m	0.75 km to McLaughlin Mt
Ash Hill	200 x 200 m	6 m	0.9 km to Wiri Mt
Pukewairiki satellite	200 x 250 m	? 5 m	0.7 km to centre of Pukewairiki
Pigeon Mt satellite	150 x 140 m	5 m	0.6 km to Pigeon Mt
Crater Hill satellite	130 x 130 m	? m	0.2 km to centre of Crater Hill
Wiri Mt satellite	100 x 80 m	? m	0.4 km to Wiri Mt

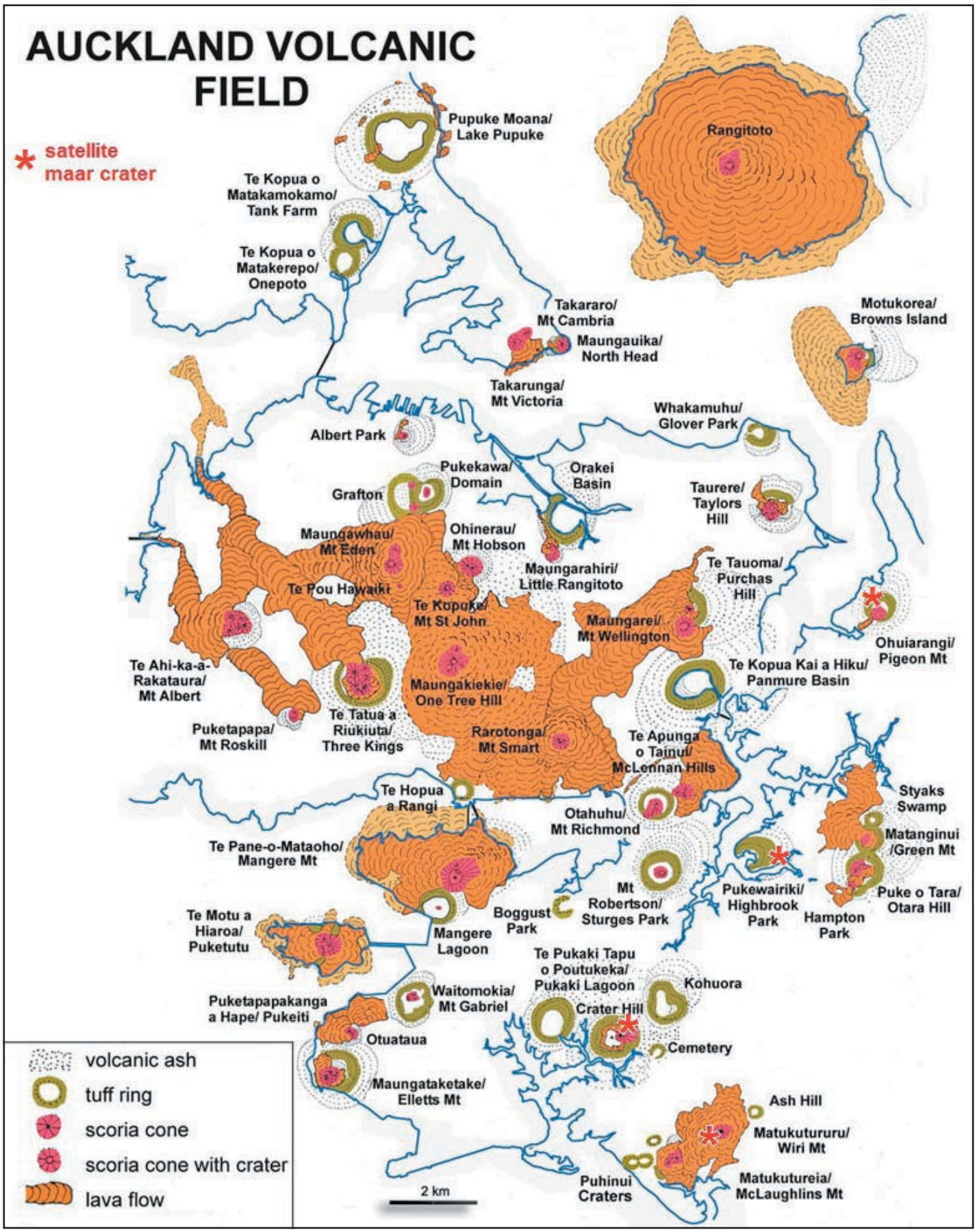


Fig. 1. Map of the Auckland Volcanic Field with named volcanoes/volcanic centres as currently recognised (Hayward *et al*. 2011a, b) and location of the four inferred satellite explosion craters discussed here (red asterisks).

hundred years later, Searle (1964) was the next to make a pronouncement on the origin of this small crater. He inferred (p. 94) that breaching of the main tuff ring "may well have occurred quite late in the volcanic history of the centre, as a result of minor explosive outbursts, for there is a very small explosion pit in the ground outside the rim and close to the breach." Les Kermode (1975) showed the small crater on his 1:25,000 industrial series geological map and in Kermode *et al*. (1992, p.49) wrote of: "A small explosion crater formed on the NW rim of the tuff ring."

Geoff Fairfield's (1992) map (p. 13) showed two small craters on the northwest tuff ring rim. The most obvious of these was the pond-filled crater mentioned by earlier workers (Figs 2, 3) and shown in a 1950's photograph (p. 16; and Hayward *et al*. 2011a, p.175). Fairfield followed



Fig. 2. 1939 vertical air photo of Pigeon Mt's main explosion crater and unquarried scoria cone with the NW satellite crater and pond in the top left.



Fig. 3. Satellite crater on the northwest crest of Pigeon Mt's tuff ring. Note the sharpness of the ring crest, a feature not apparent in other photos. Tamaki Estuary is in the background, with Rangitoto on the horizon. Musick Point is behind trees at right of centre, Motukorea (Browns Island) beyond it.
Photo: Horne family photo album, ?1910s–1920s.

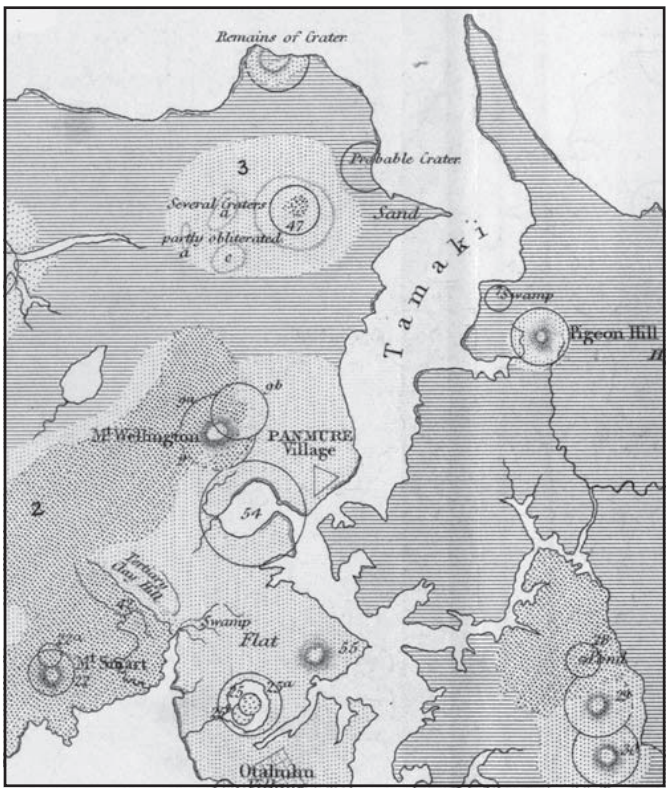


Fig. 4. Part of Heaphy's (1860) map of Auckland volcanoes showing the satellite crater to the northwest of "Pigeon Hill" labelled "Swamp" and numbered 7.



Fig. 5. Part of Hochstetter's (1864) map of Auckland volcanoes showing the satellite crater to the northwest of "Pigeon Hill" labelled "Tuffcrater".

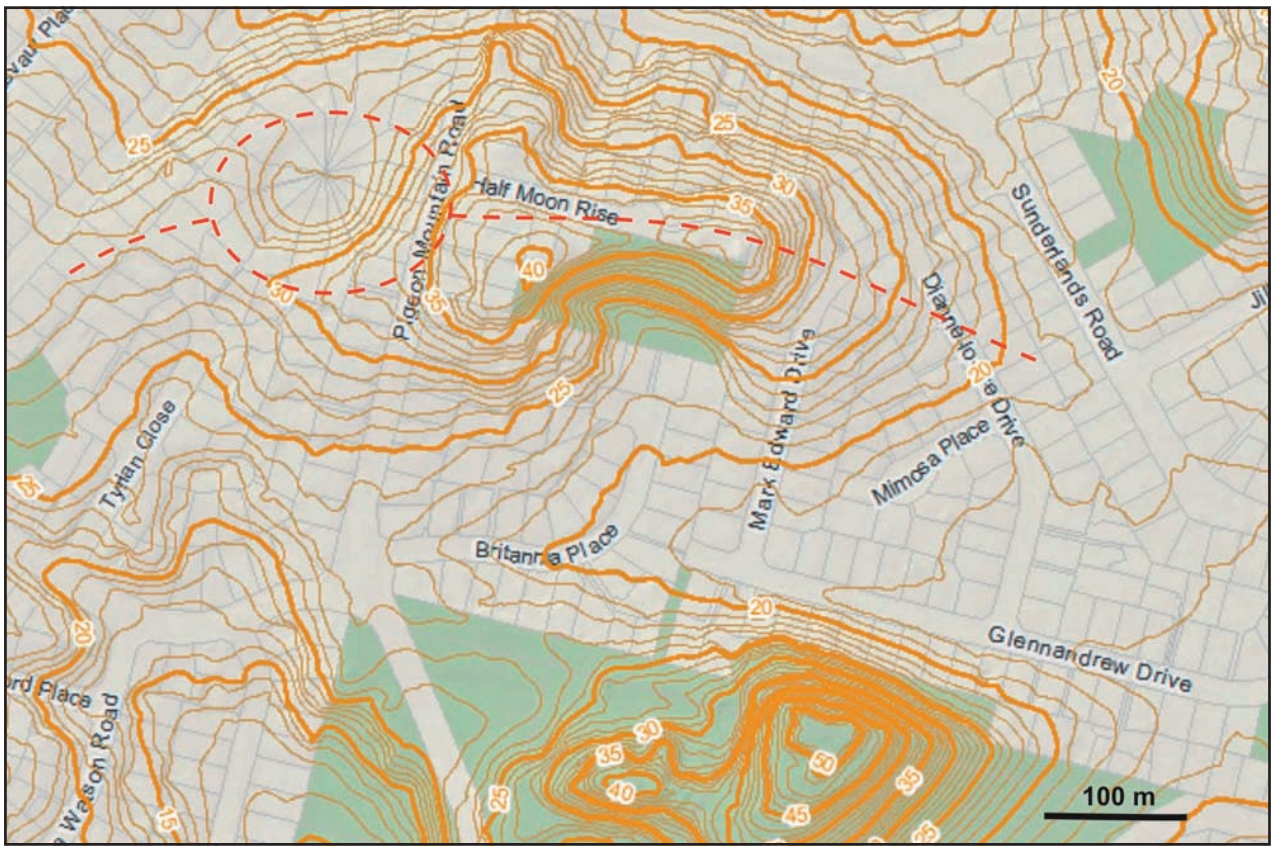


Fig. 6. Lidar map (1 m contours from Auckland Council web site) of northern half of Pigeon Mt volcano. Dashed red circle outlines the contours of the satellite explosion crater that still remain in spite of considerable ground reshaping for development.

Searle's interpretation and described this satellite crater (p. 16) as "a small steam explosion crater forming a circular pond". He notes that "until the 1970s this fine miniature explosion crater once supported a pond that dried up completely during the summer months. Today this crater is scarcely recognisable, in spite of the developer's assurances that it would be preserved for posterity. It is covered with pink concrete and surrounded by houses." The site today is a private grassed and concreted reserve owned jointly by all 15 properties that back on to it (Fig. 6). The pond has been filled but the shape of the crater is still discernible in the contours (Fig. 6). Unfortunately there is no public access.

Fairburn's (1992) crater 2 was apparently located beneath Pigeon Mt Rd adjacent to the pond crater. It is not mentioned, nor acknowledged, by Searle or Kermode and so Fairburn's interpretation of its former existence must remain questionable. I assume the former existence of a buried crater must be based on road cuttings and excavation near where the road passes over the crest of the tuff ring. The local dip of the bedded tuff presumably outlined a small depression but probably could be interpreted as air-fall tuff draped over two local crests on the tuff ring. No exposures are now present. The map in Fairburn (1992, p. 13) that shows this second crater is attributed to "G. Fairfield after L.O. Kermode, 1991", which suggests that Kermode may have discussed a possible interpretation of the tuff bedding with Fairfield, but none of Kermode's publications mention a possible second small crater in this vicinity.

Pukewairiki / Highbrook Park

I can find no previous recognition of a possible small satellite maar crater through the outer eastern slopes of this tuff cone. Pukewairiki itself is believed to be one of the older volcanoes in the field with the tuff ring eroded on the south side (Fig. 7) and inferred to have been breached by the sea during the higher sea level of the



Fig. 7. 1960 vertical aerial photo of Pukewairiki tuff cone and crater with an oval depression on the eastern (far right) outer slopes that is inferred to be an eroded satellite explosion crater.

Last Interglacial (ca. 130,000 yrs ago) (Searle, 1964; Kermode *et al*. 1992; Hayward *et al*., 2011a). Pukewairiki volcano was not recognised by Heaphy (1860) nor Hochstetter (1864) and was first identified as a volcano by Firth (1930).

When studying the new Lidar map (Fig. 8), I noticed an unusual eroded depression on the eastern slopes of Pukewairiki tuff cone that is hard to explain away as natural stream erosion. Unfortunately this natural depression was utilised and remoulded into a storm water settlement pond during industrial subdivision within the last decade. This has resulted, however, in the site of this natural bowl-shaped depression being included within public reserve (Fig. 9). I infer that this depression was a partly eroded satellite explosion crater.

Crater Hill

Heaphy (1860), Hochstetter (1864) and Firth (1930) mapped Crater Hill volcano and noted the presence of a scoria cone, basalt lava and lava caves inside the main crater, but did not mention the existence of a small crater (130 x 130 m) inside the northeast corner of the crater. This was first reported by Searle (1961, 1964), who also mentions a second small crater on the eastern rim of the tuff ring. Examination of the aerial photograph (Fig. 10) published by Searle (1961) shows that the depression in the east is still present today and is better interpreted as a slump scallop (Hayward *et al*., 2011a). Houghton *et al*. (1999, fig. 5) recognised this northeast crater (Fig. 11) as the northernmost of four vents aligned north-northeast through Crater Hill and described it as "a small pit crater … which is probably the source of locally dispersed beds". Unfortunately the Southwestern Motorway was built right through the eastern side of Crater Hill and destroyed all trace of this small satellite crater.

Wiri Mt / Matukutururu

I can find no evidence that a small (100 x 80 m) explosion crater has previously been recognised by geologists, 0.4 km to the southeast of Wiri Mt on the west side of Roscommon Rd and 100 m north of Hautu Drive. A circular depression with a swampy bottom can be seen quite clearly on aerial photographs (Figs 12, 13). The



Fig. 8. Lidar map (2 m contours from Auckland Council web site) of Pukewairiki tuff cone volcano. Dashed red circle outlines the contours of the inferred eroded satellite explosion crater that still remain, in spite of considerable ground reshaping for a stormwater pond.



Fig. 9. The inferred small satellite explosion crater on the east side of Pukewairiki has been remoulded into a stormwater settlement pond in a public reserve.

underlying and surrounding lava flows from Wiri Mt were removed by quarrying in the latter two decades of the twentieth century and the crater site is now beneath an industrial subdivision and quite unrecognisable (Fig. 14). I infer the small satellite crater exploded through the lava flow field late in the history of Wiri Mt's eruption sequence. Its location is on the line joining Wiri and McLaughlins mountains, suggesting that the location of all three vents may have been determined by an NE-striking fault line.

Other possible satellite maar craters

In the discussion above, I have recognised four small satellite explosion craters closely associated with, and inferred to have been formed at the time of, eruption of four of Auckland's volcanoes. Could any of the other small explosion craters (Table 1), which have been recognised and named as separate volcanoes in the Auckland field, have been satellite explosion craters from their larger neighbours?

Ash Hill

This 200 m diameter maar crater and low surrounding tuff mound is 0.9 km northeast of Wiri Mt on the same NE-striking alignment with McLaughlins Mt and the newly recognised satellite crater (Fig. 15). A tree buried by the Ash Hill eruption has been dated at 31800 ±250 cal yrs BP (Hayward, 2008). This is within error of radiocarbon and Ar–Ar ages of Wiri Mt (Lindsay *et al*. 2011). Wiri Mt has a residual negative magnetic anomaly that places eruption within the time of the Mono Lake excursion at 32500–33500 cal yrs BP (Cassidy and Locke, 2010). Ash Hill has a weak positive magnetic anomaly (Cassidy and Locke, 2010) and therefore seems to have erupted slightly earlier than Wiri Mt and probably therefore should still be recognised as a separate volcano.



Fig. 10. Oblique aerial photograph from the south over Crater Hill before the Southwestern motorway was carved through the eastern side but quarrying of the scoria cone was already well advanced. Note the small oval crater on the tuff ring crest on the northeast corner (top, right of access road).
Photograph by Whites Aviation, 1958.



Fig. 11. Vertical aerial photograph of the small satellite explosion crater on the northeast crest of Crater Hill tuff ring, 1959.



Fig. 12. 1959 vertical aerial photograph showing Wiri Mt being quarried (top right) and a 100 m diameter circular depression on the west side of Roscommon Rd (bottom left).



Fig. 13. Oblique aerial photograph from the west over partly quarried Wiri Mt with the inferred small satellite explosion crater in bottom right foreground south of the house. Photograph by Whites Aviation, 1961.

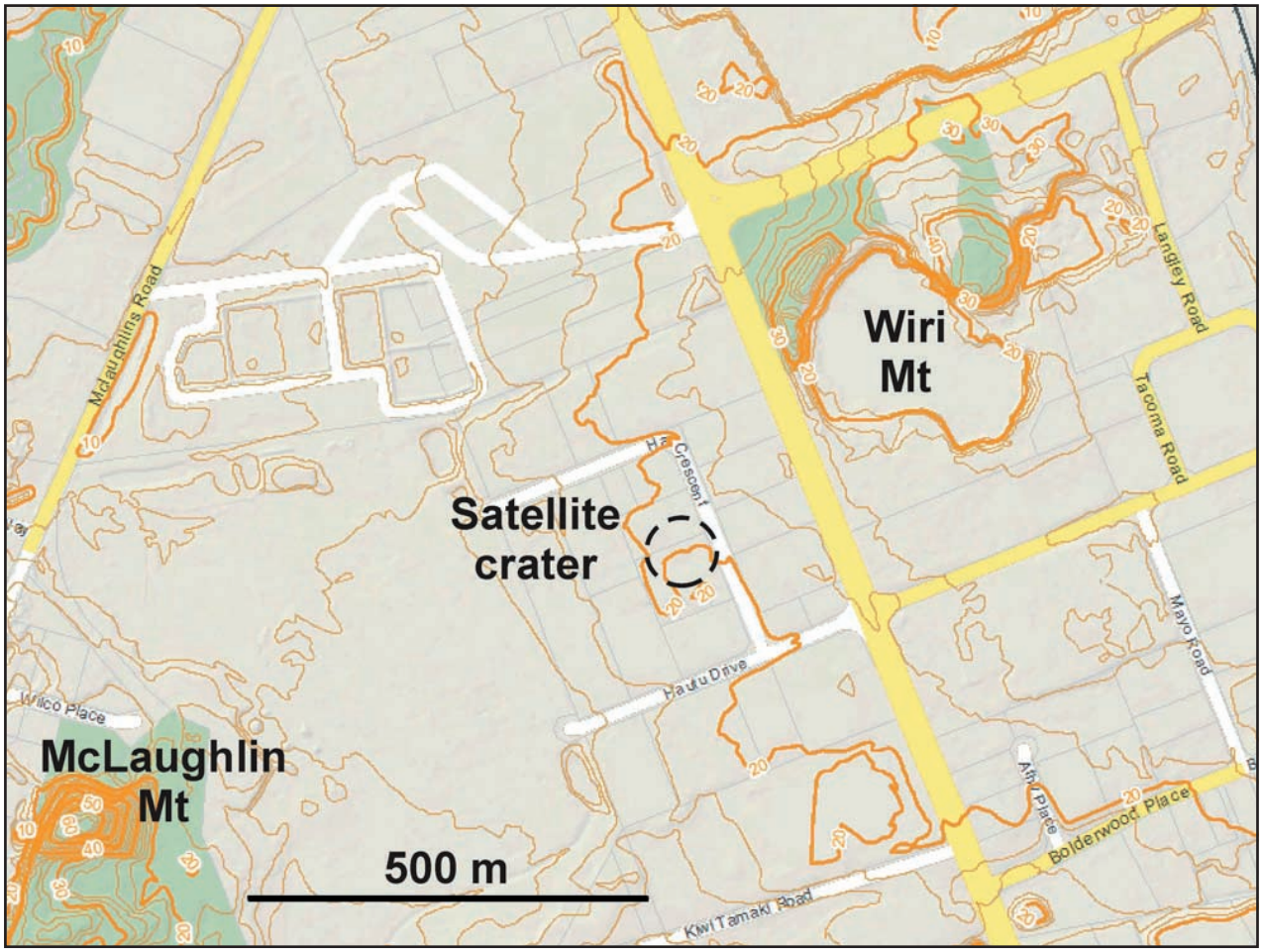


Fig. 14. Lidar map (2 m contours from Auckland Council web site) of the remains of Wiri Mt volcano today. Dashed red circle outlines the location of the destroyed satellite explosion crater now hidden beneath factories on Ha Crescent.

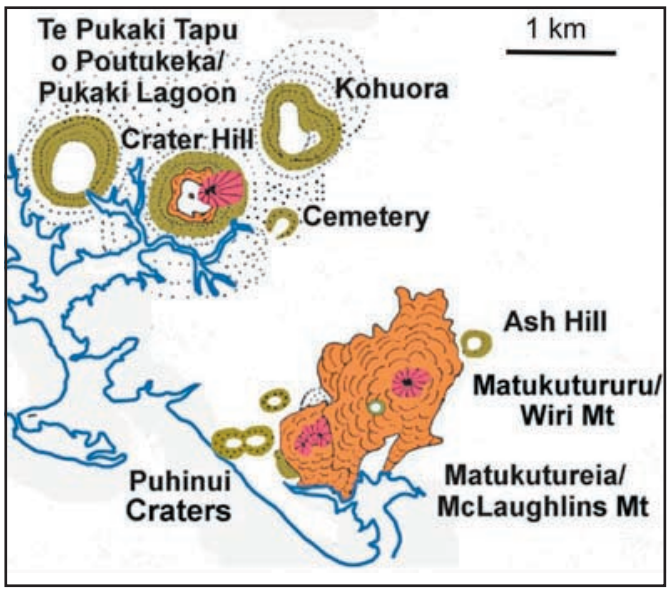


Fig. 15. Map of the southern group of volcanoes in the Auckland Volcanic Field and the numerous small craters close to Wiri and McLaughlin Mts.

Puhinui Craters

This group of three small maar craters has not been dated (Hayward *et al*. 2011b, 2012) and could be considered to be satellite vents from nearby (0.75–1.1 km distant) McLaughlins Mt volcano. The degree of erosion of Eroded Crater, and to a lesser extent of Arena Crater, may suggest that they are older than McLaughlins Mt and its partly buried maar crater (Fig. 15).

Styaks Swamp

This 400 m diameter maar crater is just 0.6 km from Green Mt's large maar crater and scoria cone. Green Mt is poorly dated at 19800±9000 cal yrs BP and Styaks Swamp is undated (Lindsay *et al*., 2011) although ash from Styaks Swamp eruptions overlies Green Mt lava flows (Hayward *et al*., 2011a). Thus Styaks Swamp crater could possibly be considered to be a late stage satellite crater of its larger neighbour Green Mt, but this is highly conjectural.

Cemetery Crater

This 300 m diameter maar crater with surrounding tuff ring is about the same distance (1.3 km) from the centres of two much larger maar craters – Kohuora and Crater Hill (Fig. 15). Cemetery Crater is undated (Hayward *et al*. 2001b), but both Kohuora and Crater Hill have radiocarbon ages within the range 34000–32000 cal yrs BP (Lindsay *et al*. 2011). Crater Hill, however, has a negative residual magnetic anomaly and Kohuora does not (Cassidy and Locke, 2010) and therefore Crater Hill is considered to have erupted during the Mono Lake Excursion (33500–32500 cal yrs BP) and Kohuora probably slightly earlier (Lindsay *et al*., 2011). There is no evidence that would indicate that Cemetery Hill was or was not a satellite eruption of either of these two volcanoes.

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QUIZZES

Know your volcanoes. Match photos 1 – 5 with volcano names A – E.
(Answers on last page)

1.



2.



3.



4.



5.



Possibilities to choose from:-

A Auckland Domain
B Crater Hill
C Mt St John
D Tank Farm
E Te Hopua (Gloucester Park)

Where is this Waitemata Group cliff?
(Answer on last page)



Possibilities to choose from:-

a Emu Point, Motutapu Island
b Mission Bay / Bastion Point
c Long Bay, southern end
d Cape Horn, north coast Manukau Harbour
e Whangaparaoa Head

REPORT ON THE CRETACEOUS UNCONFORMITY AT WAITAPU BAY, WHANGAROA HARBOUR, NORTHLAND

Seabourne Rust (seabourne.rust@gmail.com)

Abstract

The lithology and extent of a Cretaceous unconformity between strata of the Tupou Complex (Mid Cretaceous / ?Motuan Stage) and Punakitere Sandstone / Mangakahia Complex (Late Cretaceous / ?Haumurian Stage) is described from the western side of Waitapu Bay, in the Whangaroa district, Northland, New Zealand and some aspects of regional geology are discussed.

Introduction: A Geological Background

The foundations of the New Zealand region or micro-continent are a series of rocks or 'terranes' that once formed the margin of the supercontinent called Gondwana. Some of these basement rocks can be seen today in the mountain ranges of the South and central North Island and along the eastern fringe of Northland (Edbrooke & Brook, 2009).

At the Pacific coast to the east of Whangaroa, Permian – Late Jurassic age, weakly to moderately metamorphosed clastic sedimentary rock of the composite **Waipapa terrane** is dominated by massive or bedded, extensively jointed, fine-grained sandstone and mudstone with common areas of mélange and broken formation. Minor rock types include chert and intercalated basaltic volcanic rocks.

North of Whangaroa, including offshore islands and Karikari Peninsula, the base of the sequence is the distinctive **Mount Camel Terrane** including the Houhora Complex. Mount Camel terrane is a mix of clastic rocks, basalt, basaltic andesite, silicic pyroclastic rocks and granophyre intrusive rocks (GNS Science, 2012).

The eroded upper surface of these basement rocks is a **mid-Cretaceous unconformity** representing exposure and erosion of the New Zealand region prior to break up of Gondwana approximately 120–80 million years ago. It dips west from the outcrop area in eastern Northland, with the thickness of covering Cretaceous and Cenozoic strata increasing to more than 3000 m near the west coast at Hokianga (Isaac *et al*., 1994; GNS Science, 2012).

Although some of the covering rocks are in-situ (ie. autochthonous), the majority across much of Northland are exotic, brought in by later tectonic movement, known as the 'Northland Allochthon'.

The **Northland Allochthon** was derived from the former passive margin clastic sedimentary wedge that had been deposited northeast of what is now the Northland peninsula. A basal mélange unit of the allochthon is succeeded by a nappe of Eocene to earliest Miocene calcareous mudstone and micritic limestone (**Motatau Complex**), in turn overlain by a nappe of mid-Cretaceous **Tupou Complex** near Whangaroa, unconformably overlain by mainly Late Cretaceous conglomerate, sandstone and mudstone (**Mangakahia Complex**), outlined in Brook *et al*. (1988) and Isaac *et al*. (1994). These are the strata discussed in this report. The highest nappe is Cretaceous and Paleogene spilitic basalt, lesser gabbro, and minor pelagic mudstone (**Tangihua Complex**).

Internal structure of the thrust-bound units of the Northland Allochthon is often complex and can include imbricate stacking of beds and zones of broken formation and mélange; in many areas the structure is not resolved (Brook *et al*., 1988; Isaac *et al*. 1994; Edbrooke & Brook, 2009).

Following emplacement around 23 million years ago, the Northland Allochthon thrust sheets and underlying autochthon of the Whangaroa area were tilted to the northwest (Brook & Hayward, 1989; Isaac *et al*. 1994). Large portions of the resulting uplifted allochthonous rocks in the south were quickly removed and the truncated tilted sequence was intruded then unconformably overlain by early Miocene (c. 20 million year old) Wairakau Volcanics, which include the remains of a laharic ring plain (Hayward, 1991). The more resistant Whangaroa volcanic rocks form some of the key landmarks in the area, such as St Pauls Rock (Ohakiri) high above Waitapu Bay.

Significance and extent of exposure at Waitapu Bay

Within the Northland Allochthon strata, the early–mid-Cretaceous (120–80 million year old) **Tupou Complex** (Brook & Hayward, 1989) at Whangaroa is unconformably overlain by Late Cretaceous (80–65 million year old) Mangakahia Complex sediments known as the **Punakitere Sandstone**. The boundary or contact between these two rock formations is known as the **'Cretaceous Unconformity'** and represents a period of time where the older Tupou rocks were eroded and later covered by the somewhat younger marine sediments of the Punakitere Sandstone.

According to Brook & Hayward (1989) and Hayward & Kenny (1996), the exposure at Waitapu Bay is the "*best exposure of several around Whangaroa, where Late Cretaceous conglomerates and micaceous sandstone unconformably overlies with sedimentary contact an irregular surface of Early Cretaceous Tupou Formation*". The site is in the vicinity of NZMS 260 grid reference P04/799837, located on the "point 200 m north of Ota Point", and although surrounded by steep privately-owned land, is accessible by boat/kayak. The locality is also recorded in the New Zealand Fossil Record Electronic database as: P04/f0040. I visited the site in October 2014.

The Cretaceous Unconformity is indeed best exposed in outcrop on the shore platform near the northeast tip of the point described above. The somewhat irregular surface of the Unconformity can be traced along the tidemark for about 50 m, before disappearing into the bay and being obscured by harbour sediment (Fig. 1). It reappears across the bay to the north, below land administered by the Department of Conservation.

Description of the key rock units at Waitapu Bay

Tupou Complex (Mt Camel Terrane derivative)
Lithology and structural features: Strongly indurated, massive, yellow-brown, fine- to coarse-grained sandstone can be seen below the Unconformity at Waitapu Bay (Figs 2, 3), while thin-bedded sandstone and mudstone are also present in coastal exposures and inland, around Whangaroa Harbour, at Taupo Bay and further north. Tupou Complex rocks are structurally complex with widespread bedding-parallel shear and boudinage development, and local mélange zones up to several metres thick. High- and low-angle faults are common and the rocks are extensively jointed (Brook & Hayward, 1989; Isaac *et al*., 1994). Locally, beds of granule to pebble conglomerate and pebbly coarse-grained sandstone are interbedded with the thin-bedded sandstone and mudstone. Beside the road to Tauranga Bay is an outcrop of Early Cretaceous Tupou Complex with granitic pebbles (Hayward & Smith, 2002). Laminated siliceous mudstone and chert are also minor components.

Age and timing of emplacement: The age of the Tupou Complex is inferred to be no older than Early Cretaceous (?Motuan Stage) based on a bivalve in a concretion collected from a conglomerate bed, but the concretion is likely to have been reworked (Hay, 1975). The Tupou rocks have similarities in lithology, provenance, deformation style and metamorphism to the Mt Camel terrane basement rocks of probable Early Cretaceous age that are present to the northwest. For example, rocks of the **Tupou Complex** show consistently high potassium and thorium counts. High potassium counts may be explained by the length of time exposed to weathering of the feldspar and mica-rich granitic rock (GNS Science, 2012). It is possible that the Tupou rocks are part of a single thrust sheet of displaced Mt Camel terrane (Isaac, 1996). They are believed to have been entrained during allochthon emplacement.

Mangakahia Complex (Punakitere Sandstone)
Lithology and Structural features: Although widespread across the region, the **Punakitere Sandstone** (Isaac *et al*., 1994, after Hay, 1960) is often only poorly exposed. Along the shore at Waitapu Bay it comprises weakly to moderately indurated, alternating thin to thick-bedded quartzofeldspathic, commonly micaceous, sandstone and mudstone with minor mudstone-dominated flysch (Figs 4, 5). Pebbly sandstone, grit and conglomerate beds are other minor components (Figs 6, 7). The unweathered rocks are grey, but weathered sandstones are yellow-brown, and are commonly friable, with the mudstones typically a reddish brown (Fig. 8). Evans (1992) recorded massive to laminated, olive-grey, micaceous sandstone locally, with conglomerate near the base at Waitapu Bay as part of his Punakitere 'subfacies 2'.

Locally, there is evidence of significant deformation with considerable variation in dip and bedding orientation (Fig. 4). The internal structure of Punakitere thrust sheets is complex and the stratigraphic thickness difficult to estimate, but original stratigraphic thickness is thought to have been 1–3 km (Isaac *et al*., 1994). A Late Cretaceous age (ie. Piripauan–Haumurian Stages) is indicated by fossil molluscs occurring in concretions, including rare ammonites (Bell & Clarke, 1909) and the large bivalve *Inoceramus* (Fig. 9) and dinoflagellate assemblages (Brook & Hayward, 1989).

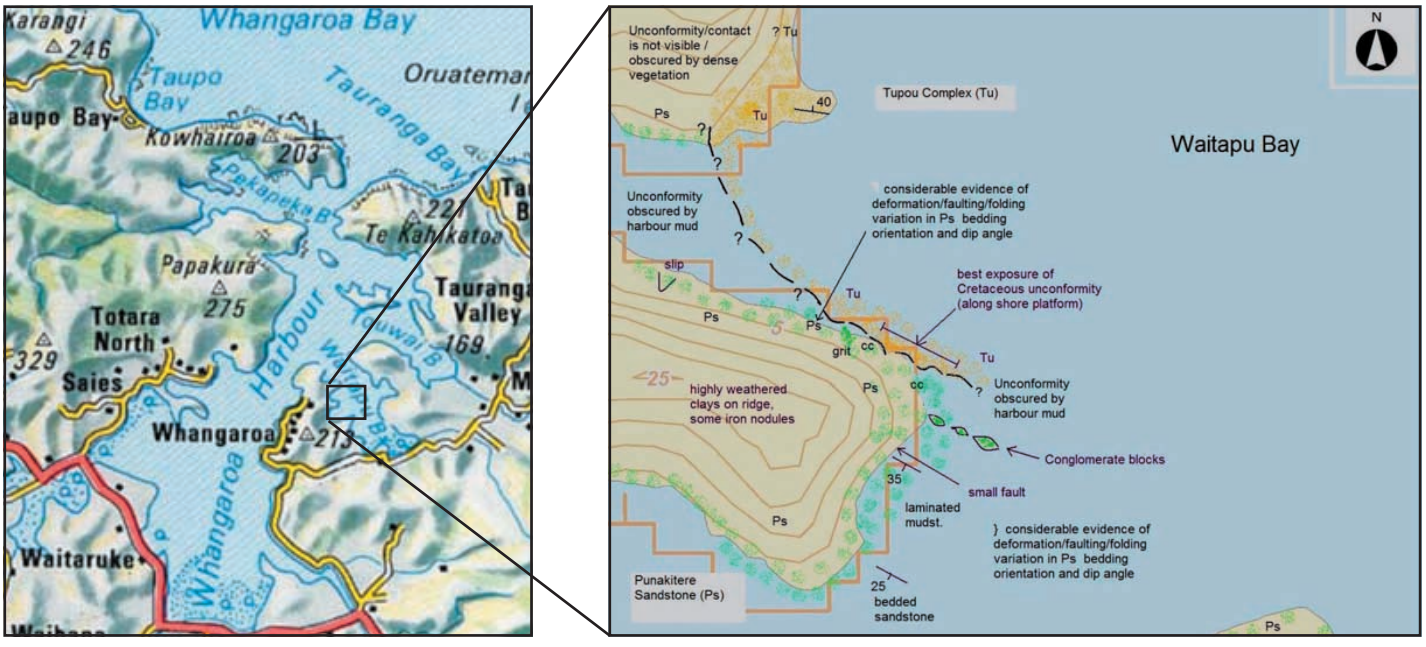


Fig. 1. Maps of Whangaroa harbour and the western Waitapu Bay locality with some geological notes.

Once again, geochemical signature (e.g. high potassium and thorium) suggests derivation from eroded Tupou Complex/Mount Camel terrane rocks.

To conclude, the **'Cretaceous Unconformity'**, perhaps best exposed on the western shore of Waitapu Bay, Whangaroa Harbour, reveals that Tupou Complex rocks were eroded during the mid to Late Cretaceous, the time period when the greater New Zealand region or 'Zealandia' broke away from Gondwana. This erosion surface was in turn covered by slightly younger marine sediments of the Mangakahia Complex (Punakitere Sandstone).



Fig. 2. The author standing at the Cretaceous Unconformity, with yellow, massive sandstone of the Tupou Complex to the left and grey Punakitere Sandstone and mudstone to the right.



Fig. 3. Exposed on the shore platform at low tide, Waitapu Bay, Whangaroa Harbour: Late Cretaceous Punakitere Sandstone (left) unconformably overlies strongly indurated, jointed, massive sandstones of the Tupou Complex covered by oysters (right) at grid reference P04/799837.



Fig. 4. Steeply-dipping, well-bedded exposure of grey Punakitere Sandstone and mudstones on the shore of Waitapu Bay north of Ota Point, Whangaroa Harbour.



Fig. 5. Fine-bedded Punakitere Sandstone and mudstone, with some deformation, alongside a small fault.



Fig. 6. An exposure of pebbly grit within the Punakitere Sandstone to the northwest of the Cretaceous Unconformity site.

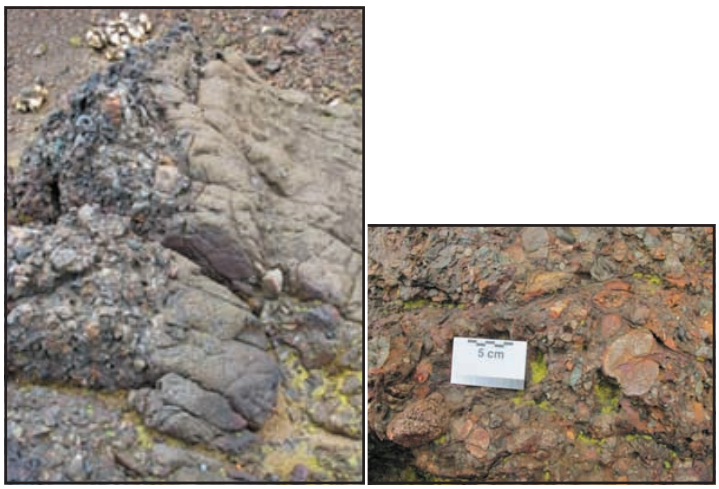


Fig. 7. Left: Conglomerate blocks within Punakitere Sandstone form a small reef exposed on the shore platform at low tide, south of the Cretaceous Unconformity site, Waitapu Bay, Whangaroa Harbour.
Right: Close up of conglomerate showing rounded clasts of variable size and lithology including Tupou-like sandstone, granitic rocks and chert.



Fig. 8. Typical exposure of bedded Punakitere Sandstone and mudstone, showing characteristic weathering to friable yellowish clays with brownish iron banding.



Fig. 9. Late Cretaceous fossil shells including the large bivalve *Inoceramus* cf. *australis*? within a piece of hard cemented concretion from the Punakitere Sandstone, found on the shore at Waitapu Bay, Whangaroa. FR:P04/f0040

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Terry Peterson instigated the study and provided land access, Diane Yanakopulos accompanied the fieldwork and took photos; advice and assistance was also gratefully received from Bruce Hayward & Jack Grant-Mackie. Bruce & Jill Kenny helped improve the article. To all, I offer my sincere thanks.

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TI POINT BASALT – INTRUSIVE OR EXTRUSIVE?

Bruce W. Hayward

Auckland Geology Club has had two field trips to Ti Pt (in 2004 and 2012) to look at the Miocene basalt exposures and seek to determine whether they are the eroded remnants of flows (extrusive) or subvolcanic plumbing (intrusive). On both occasions we came away rather unsure what the meagre field evidence was telling us. If the Ti Pt basalt is extrusive lava flows then it could provide additional clues to the late Cenozoic history of the region. The basalt at Ti Pt is the largest outcrop of late Miocene Ti Pt Basalt that mostly outcrops in the Leigh area with smaller outcrops forming the Sugar Loaf and Barrow Hill and occurring in several other places (Fig. 1).

Previous work

Cox (1881) and Bartrum (1920) both interpreted the Sugar Loaf and Ti Point as erosional remnants of an intrusional basalt neck and a dike, respectively (Fig. 1). In contrast, Ferrar (1934) called the basalt at Ti Pt a large flow. He noted that "H.G. Cousins (in MS) records tuffs on the east side of Ti Point" and Ferrar (1934) wrote "tuffs" on the southeast corner of Ti Pt peninsula on his geological map. Bartrum (1920) also referred to Cousins' unpublished work thus: "Mr H.G. Cousins, Director of the Teachers Training College, Auckland, closely studied this rock some years ago, and very kindly has allowed me to read his unpublished thesis thereon. He shows

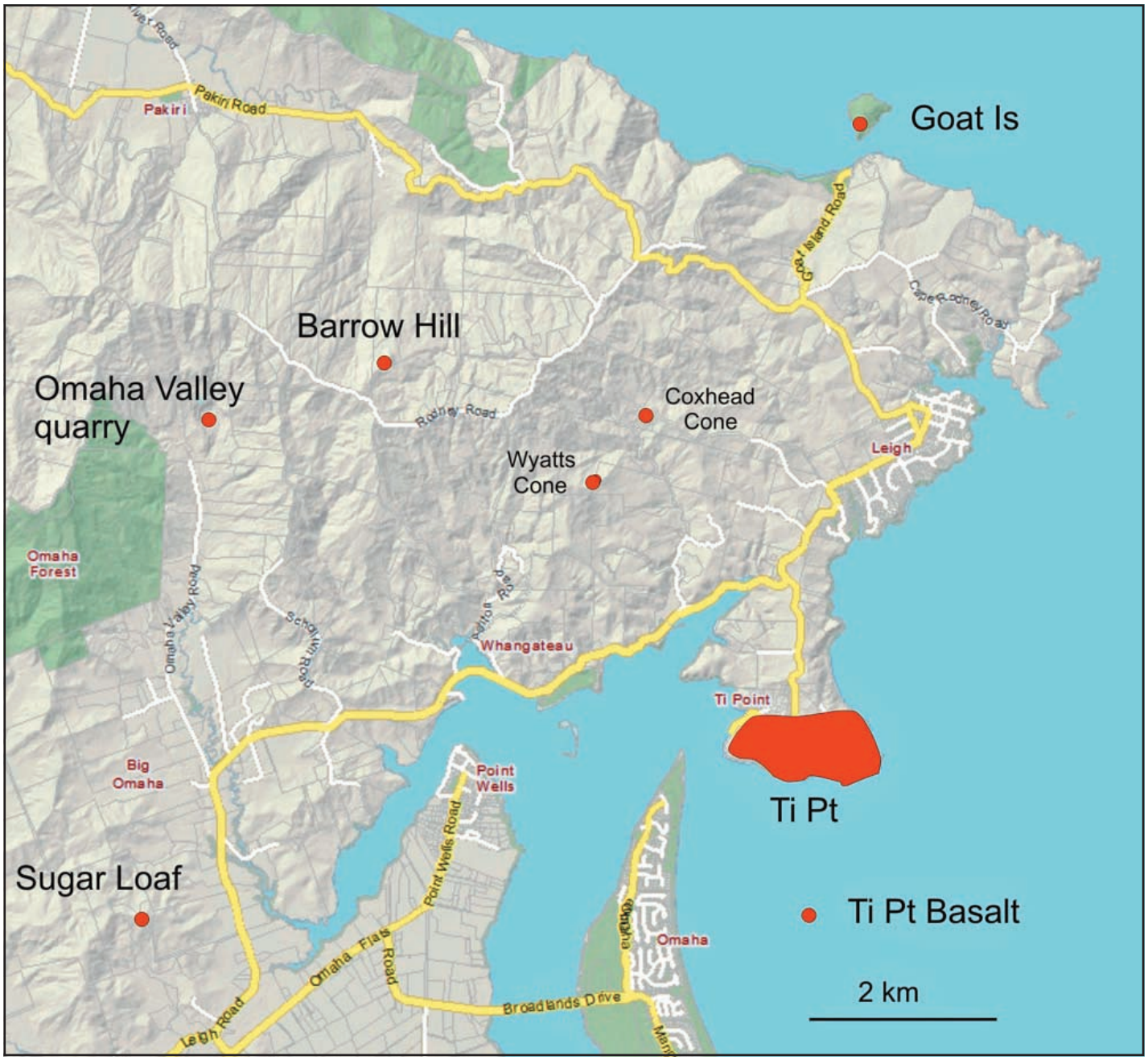


Fig. 1. Outcrops of late Miocene Ti Pt Basalt around the Leigh area, north Auckland.

that the eruption has burst through the Waitemata beds, and concludes, mainly from consideration of denudation, that the period of extrusion was probably Upper Miocene." [I can find no thesis by Cousins in the University of Auckland library catalogue, although he attended geology courses in the 1890s].

Hopgood (1961) recognised an intrusive dike (Goat Island) and sill (Omaha Valley quarry) and four other high points around Leigh composed of Ti Point Basalt. The only extrusive he recognised was lava flows forming Ti Point. He states that "since the basalts baked sediments of the Waitemata Group, and have evidently flowed over a topography eroded in them at Ti Point, they are probably Pliocene in age." [There are no exposures to be seen today of baked Waitemata Group rocks].

Heming (1980) states that a "major outcrop of Ti Point lavas are at Ti Point, which appears to be composed of lava flows." Heming (1980) took issue with Hopgood's (1961) interpretation that basalt at Barrow Hill and other conical hills in the region was intrusive. Heming noted the absence of fragmental material and intrusive textures and argued that the presence of vertical columnar-jointing at both the Sugar Loaf and Barrow Hill indicated that they were more likely to be eroded parts of lava flows.



Fig. 2. View west across the southern edge of Ti Pt showing cobbles and boulders of basalt forming the shoreline. They are inferred to have been derived from higher elevations.



Fig. 3. View southeast from the southern edge of Ti Pt showing basalt boulders forming the shoreline. Note the flat top ("late Miocene peneplain") of Tawharanaui Peninsula in the distance.

Smith *et al*. (1993) state that: "The major occurrence of volcanics in the Ti Point area is a lava-flow remnant at Ti Point. Two other substantial outcrops (Barrow Hill and Sugar Loaf) and several smaller outcrops in the Leigh–Mangawhai area are the eroded remnants of volcanic plugs or dikes." They attributed this last statement to Heming (1980), although it is the opposite of what Heming inferred. Edbrooke (2001) also cited Heming (1980) as stating that west-dipping flows in the vicinity of Ti Point suggest a vent offshore to the east, now eroded away.

In summary, most recent workers have accepted that the massive basalt and associated volcaniclastics that form the end of Ti Point are an eroded lava flow or flows, an interpretation first proposed by Ferrar (1934) presumably on the basis of the presence of red (?baked) lapillituff and the relatively fine-grained crystallinity of the basalt.

Age of Ti Point Basalt

Stipp (1968) and Stipp and Thompson (1971) provided an early K-Ar date for Ti Point basalt at 8.44 Ma. In the 1990s, Smith *et al*. (1993) dated a representative suite of five samples of Ti Point Basalt which gave a late Miocene age in the range of 10.46–8.37 Ma. Their one sample from Ti Point itself gave an age of 8.73±0.54 Ma.

Geological observations

Cobbles and boulders up to 2–4 m diameter occur right around the mid–high tide shoreline of Ti Point (Figs 2–4), from 100 m north of the wharf on the west side almost to the sand at the southern end of Torkington Bay (Fig. 5). None of these are exactly in-situ, but most are derived from basalt that outcrops on the nearby (10–100 m) hillsides or cliffs above. Actual in-situ basalt is mostly confined to the east side of the southern end of Ti Pt forming cliffs, points and the intertidal platform from the south end of Torkington Bay to the southeast point of Ti Pt (Figs. 4, 6). In-situ basalt also occurs in the foreshore in one small section on the south coast. In many places the hills at the southern end of Ti Pt are covered with large rounded boulders and cobbles of basalt (Fig. 7)



Fig. 4. View north up the east side of Ti Pt from near the south end, showing the basalt boulder foreshore. In-situ basalt occurs in the cliffs on left (beneath pohutukawa trees) and in the foreshore point 200 m away.

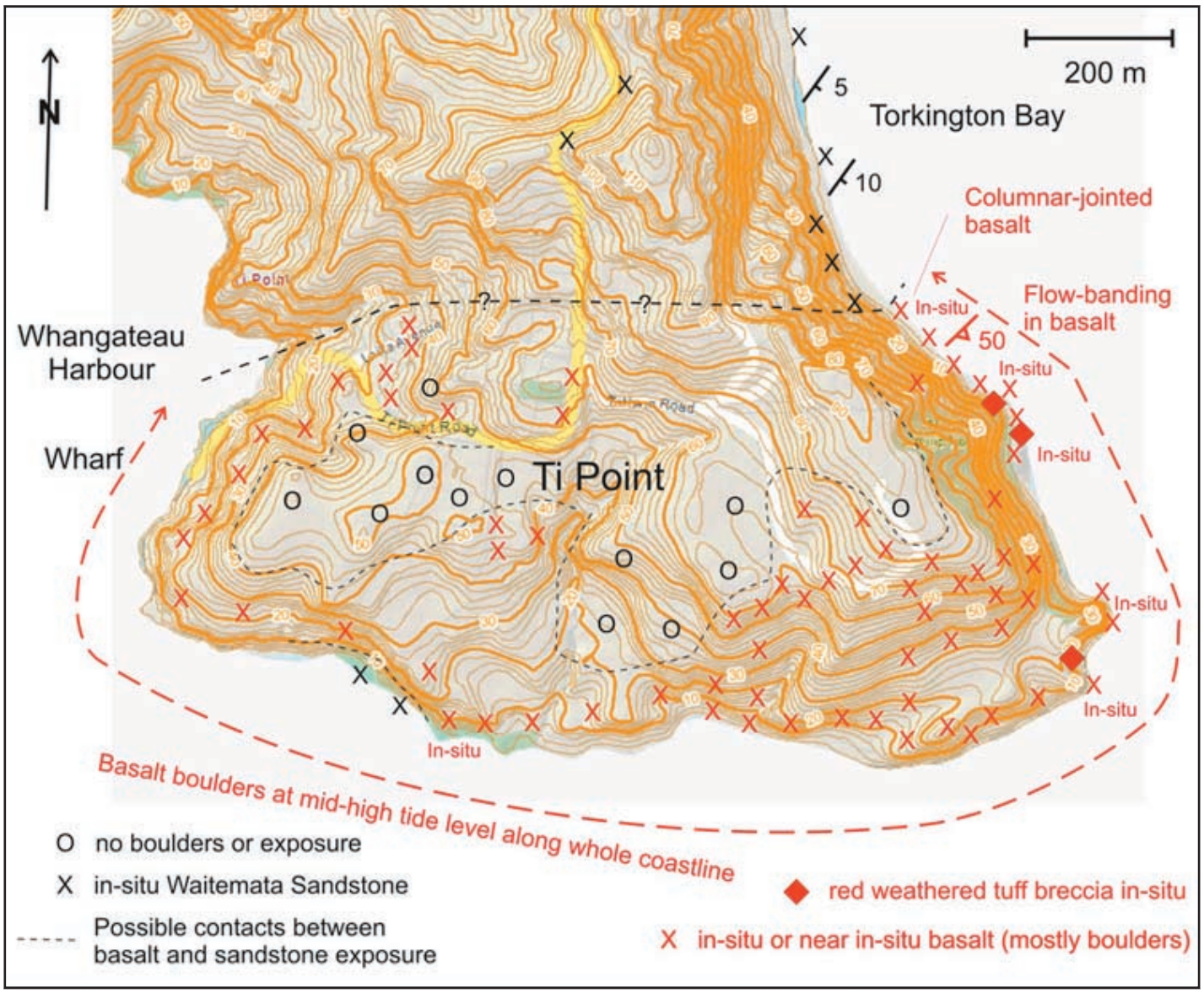


Fig. 5. Map of the south end of Ti Pt peninsula with geological observations.



Fig. 6. View south to vertically- and horizontally-jointed basalt point at southeast corner of Ti Pt.



Fig. 7. View east along ridge covered in lichen-coated basalt boulders at southeast corner of Ti Pt.

and these are inferred to be erosional remnant core stones from large weathered masses of basalt that once existed at higher elevations.

In-situ bluffs and cliffs of basalt near the southeast point consist of massive basalt cut by wide-spaced, irregular, near-vertical and horizontal joints (Fig. 6). Exposures of in-situ basalt in the foreshore may be massive or have vertical, horizontal or sloping planar jointing. Columnar joints were only observed in one place - close to the Waitemata Sandstone at the southern end of Torkington Bay, where the columnar joints are ~1 m in diameter and tilted to dip 60–70 degrees to the north (Figs. 8, 9). Columns of this diameter usually indicate a thick mass of cooling lava (flow or intrusion) (e.g. Mt Eden flows in Auckland).

Fluting has been developed by slow solution on some boulders, almost entirely restricted to higher elevations on ridge crests (Hayward, 2012). I suggest that this is because the high ridge-crest boulders are almost in-situ and have been sitting exposed up there for hundreds of thousands of years. Boulders lower down the hillslopes seldom have much fluting, which suggests they are gradually on the move and periodically roll or change angle, not allowing enough time for solution to become advanced.

All the basalt seen has a relatively fine-grained matrix which suggests fairly rapid cooling and crystallisation, either in a flow or a shallow or thin intrusive body.

In-situ, red (?baked) fragmental lapillituff occurs with the basalt lava on the southeast point and on the point at the southernmost end of Torkington Bay (Fig. 10). The lapillituff has angular-subangular clasts of scoria and denser weathered basalt. In all localities the lapillituff is massive (Fig. 10) with no obvious stratification and no bedding as often develops in airfall tuff deposits. In one place (south end Torkington Bay) basalt lava appears to overlie lapillituff with a sharp subhorizontal contact and nearby lapillituff appears to overlie lava with a more gradational contact.

No contacts between basalt (or lapillituff) and Waitemata Sandstone are exposed. Along a short section of the southern coast, Waitemata Sandstone is exposed in-situ (Fig. 11) at mid–low tide level and appears to pass beneath in-situ basalt 50 m to the east. At Torkington Bay, ~20 m of Waitemata Sandstone overlies greywacke at the north end and dips southeast at 5–10 degrees to extend beneath the basalt at the southern end of the bay. Two weathered road cuts of Waitemata Sandstone occur on the crest of the main ridge of Ti Pt at 90 m elevation above the middle of Torkington Bay. All around the hills of southern Ti Pt there are extensive areas (o in Fig. 5) with no basalt boulders on the surface distributed in amongst areas with lots of boulders. These suggest that the parent rock in these areas is not basalt lava and may be weathered lapillituff or Waitemata Sandstone, but there are no fresh exposures to determine which.

Interpretation

The observations above are not definitive as to whether the basalt at Ti Pt is a thick lava flow(s) or irregular intrusive body(ies). In favour of extruded lava flow is the fine-grained matrix of the basalt rock and the presence of erupted lapillituff and these two aspects appear to have convinced many of the recent geologists in their interpretation. But finer-grained matrix can be produced in quickly cooled shallow intrusions and massive lapillituff (baked or unbaked) can fall back into volcanic vents and be preserved up to several hundred metres subsurface. The massive character of the exposed



Fig. 8. North-tilted columnar basalt in the foreshore at the southern end of Torkington Bay.

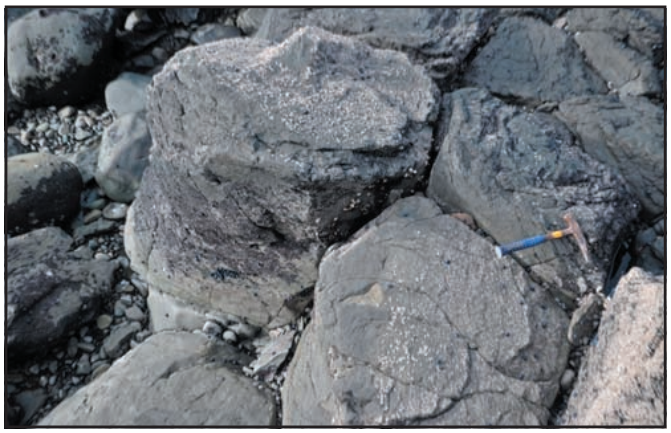


Fig. 9. 1-m-diameter basalt columns at south end of Torkington Bay.



Fig. 10. Massive, red (?baked) lapillituff at southernmost end of Torkington Bay. Height of photo 1 m.

lapillituff is possibly more consistent with a subsurface vent fill than an unbedded, subaerial deposit.

The basalt at Ti Pt clearly overlies Waitemata Sandstone, on the southern shore and in Torkington Bay, consistent with a lava flow origin, but Waitemata Sandstone at 90 m elevation just to the north of the basalt outcrop requires the presence of a major fault downthrowing the basalt to the south or an extremely steep northern slope on a late Miocene valley in which the basalt would have accumulated if it was a flow. If the areas with no boulders in the Ti Pt hills do delineate weathered Waitemata Sandstone outcrops, then the basalt must be intrusive.

Paleogeographic and tectonic considerations

If the basalt at Ti Pt is extruded lava flow(s) then the Waitemata Sandstone sequence in this area must have been completed uplifted out of the sea and almost its entire ~800–1000 m of sequence removed by erosion during the period 18–9 Ma. Since then there can have been no further uplift, and erosion has slowed to remove most of the rest of the erupted basalt but not much more Waitemata Sandstone (in the Ti Pt area). But 8.5 myrs ago in the late Miocene world, climate was considerably warmer than now and global sea level was 10–30 m higher than present (Fig. 12). No valley would have eroded below a base level determined by sea level and thus the deepest valley (near the coast) would be no lower than 10 m above sea level. Thus if the basalt at Ti Pt is a valley-filling flow, then there must have been subsequent downthrow to get some basalt below present sea level where it occurs today. This is a novel idea for the Leigh area to have had overall tectonic subsidence in the last 8 Ma. All existing tectonic models suggest that there has been further uplift throughout eastern Northland over this time (e.g. Kenny, 2013).

Current thinking is that the flat-topped ridge crests throughout Northland and Auckland regions are remnants of a near flat coastal plain that had developed across most of northern New Zealand by ~5 Ma. This



Fig. 11. Basalt boulder (mushroom rock) sitting on a neck of eroded in-situ Waitemata Group mudstone on the southern shore of Ti Pt. The top of the pedestal marks the former elevation of the high-tide shore platform eroded in Waitemata rocks.

requires a tectonic model of rapid mid Miocene uplift, a long quiet period with extensive erosion followed by limited renewed tectonic displacement (mostly uplift) since 5 Ma (e.g. Kenny, 2013). The high sandstone ridge crest to the north, between Pakiri Hill and Dome Valley, is 350–400 m above sea level and could be separated by a thrust fault from Ti Pt peninsula (Kenny, 2013). South of Kenny's thrust fault, there is another lower, ridge-crest "terrace" at 90–120 m ASL between Cape Rodney–Ti Pt and Tawharanui Peninsula (Fig. 3), which may be the much eroded remnant of a "late Miocene peneplain" or at least seems to strongly imply uplift of at least 50–80 m since the time of eruption of Ti Pt basalt (as sea-level has been no higher than 30 m ASL since then).

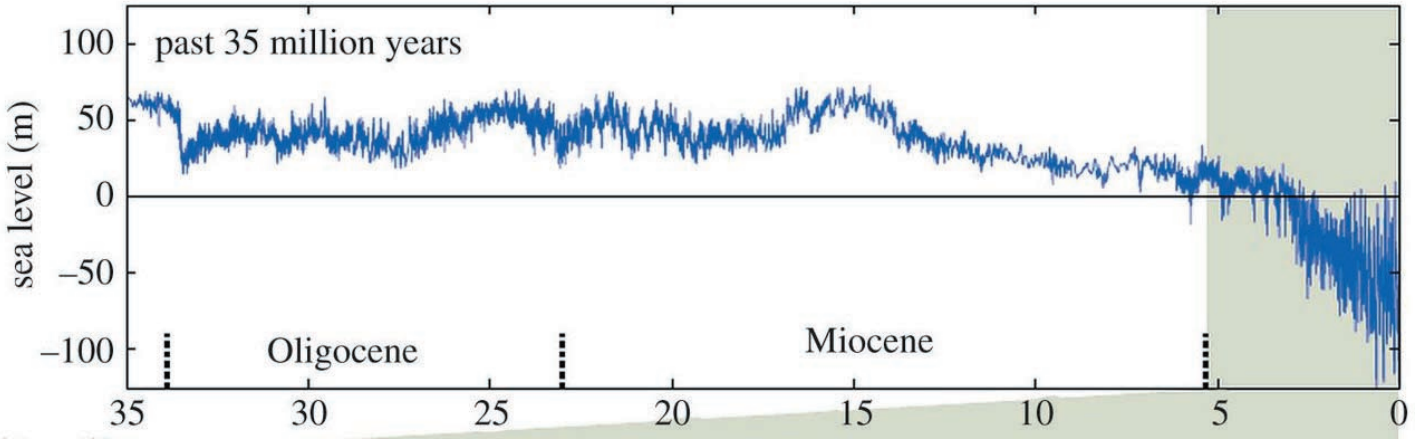


Fig. 12. Calculated global sea level for the last 35 million years (from Hansen *et al*., 2013).

Conclusion

Exposures of the basalt at Ti Pt and its contacts are inconclusive as to whether this basalt was intrusive or extrusive. Sea level in the late Miocene, at the time of basalt emplacement, was 10–30 m higher than present and thus if the basalt was a lava flow, subsequent subsidence is required. This is inconsistent with modern understanding of the tectonic history of the region and inconsistent with evidence of an uplifted coastal terrace at 90–120 m ASL forming the backbone of Ti Pt peninsula. I therefore conclude that at Ti Pt, as at most other Ti Pt Basalt outcrops, the basalt is shallow intrusive, possibly with a complex network of thick dikes, sills and volcanic neck with some erupted lapillituff fill.

Acknowledgements

I thank Jill Kenny and Mike Isaac for discussions on this topic. The mapping presented here was undertaken by the author on an additional field trip which included a coastal traverse to Torkington Bay.

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HOLOCENE FOSSIL FOREST AND UPLIFT AT SPONGE BAY, GISBORNE

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In May 2015, an Auckland Geology Club trip visited Sponge Bay, near Gisborne (Fig. 1), on a 0.7 m low tide to look at the well-known uplifted Holocene estuarine sequence (Brown, 1995). In addition to this sequence exposed in the 8 m high bank at the back of the beach (Fig. 2), we also found a number of upright tree stumps sticking out of the low tide sand (Fig. 3). The earliest report of buried trees exposed in the cliff at Sponge Bay is Pullar & Patel (1972). They visited Sponge Bay in October 1957 and noted matai (a log) and totara (wood) 9 m from the surface (presumably the carpark at the top of the cliff). In May 1995, one of us (LB) photographed a single intertidal stump. An earlier photo of Sponge Bay taken in May 1982 shows a shingly beach and no obvious intertidal stumps. An in-situ fossil forest has not been reported previously (Fig. 4) and thus we assume that the amount of sand on the beach must have been low during our visit and we were lucky enough to see the tree remains (Figs 5, 6) that may have been buried by sand when other geologists visited, or the tide was in when they were there. Brown (1995, p.29) does however record sampling shells in the beach cliff from 0.2 m above a tree in growth position – first observed in September 1985, and 1 m below the fallen trunk. The tree was within blue-grey estuarine silt and overlain by shell-bearing gravel at the base of the Holocene sequence. Ota *et al*. (1988) did not record any in-situ trees in their Sponge Bay stratigraphic column, but Ota *et al*. (1990) do. They made no mention of the protruding fallen trunk (matai) first recorded in October 1957 and again in May 1982 by LB, and still there in May 1995.



Fig. 1. Location of Sponge Bay, near Gisborne, Poverty Bay and of other East Coast locations with in-situ Holocene fossil forests within estuarine sequences.



Fig. 2. The bank at the back of Sponge Bay beach exposes (between the areas of sloping grass) an 8 m thick Holocene sequence of estuarine sediment.

How old are the trees?

Radiocarbon dates are given in radiocarbon years, but these need to be calibrated using a southern hemisphere and atmospheric or marine adjustment to get calendar years before present (BP = AD 1950). The conventional radiocarbon dates cited here come from Brown (1995, Table 1) and have been calibrated using the programme



Fig. 3. Looking west across Sponge Bay in 2015, showing some of the in-situ fossil forest tree stumps sticking out of the low tide sand.



Fig. 4. Looking west across Sponge Bay in 2009, showing a similar view to Fig. 3, but with no tree stumps visible above the sand.



Fig. 5. Upright tree stumps sticking up above the sand and low tide, Sponge Bay, 2015.



Fig. 6. The tallest tree stump sticking up out of the low tide sand at Sponge Bay, 2015.

OxCal (v. 4.2, Bronk Ramsey, 2009) using the SHCal13 atmospheric curve for wood (Hogg *et al*., 2013) and for marine shell samples the Marine13 curve (Reimer *et al*., 2013). All calibrated ages are quoted in calendar years before present (cal yrs BP = before AD 1950) with 2-sigma (95%) uncertainties.

The tree stump observed in-situ at Sponge Bay by Brown (1995) was not sampled and dated, but shell from the silt that buried it was dated at 8200±78 radiocarbon years (= 8950–8450 cal yr BP) (Fig. 7). If Brown's (1995) in-situ tree was part of the fossil forest exposed in the beach in 2015, as seems most probable, then the Sponge Bay fossil forest must be slightly older than the dated shell, ~9000–8700 cal years, as it was presumably killed by rising sea level. Other radiocarbon dated wood samples from within 5 km of Sponge Bay (Okitu Beach – 8408±103 radiocarbon years, Kaiti – 8391± 91 radiocarbon years [= 9530–9100 cal yrs BP]) are of similar age and could be from the same event. Remember that after the end of Last Glacial, 18,000 yrs ago, sea level rose progressively from ~120 m below now to the present level by ~7400 years ago at an overall rate of 1.2 m/100 yrs.

What was the Holocene rate of tectonic uplift at Sponge Bay?

We cannot calculate this from the estuarine sequence or fossil forest as we do not know precisely what sea level was at the time of their deposition and growth. A layer of airfall Waimihia Tephra (3400±100 cal yrs BP) occurs unconformably above the estuarine sequence at Sponge Bay at an elevation of ~7 m above MSL today (Fig. 7). If the tephra had been deposited below MHW level, the tides would have dispersed the pumice tephra and it would not have been preserved. So the Sponge Bay section must have been above MHW (0.7 m above MSL) when Waimihia Tephra was deposited. At that time sea level around New Zealand was 1–2 m above present (e.g. Clement *et al*. 2008) and thus the lowest elevation that the Waimihia Tephra was deposited was at 1.5–2.5 m above MSL. Thus since 3400 cal yrs BP there has been a maximum of 4.5–5.5 m of uplift, at a rate of <1.3–1.6 m/1000 yrs. If, however, we assume that there has been little or no erosion of the flat-lying upper surface of the estuarine sequence (now at 6.5 m above MSL), then its upper surface must have been preserved by uplift of the estuary once post-glacial sea-level rise had more or less ceased (~7400–6500 cal yrs BP). This gives a tectonic uplift rate of ~1 m/1000 yrs.

Other Holocene fossil forests along the North Island East Coast

Similar in-situ fossil forest tree stumps within estuarine sediment sequences (estuarine sediment below and above) have been recorded from six other East Coast North Island coastal localities at Waihau Bay, Pakarae, Wairoa, Waimoana, Kaiwhata, Opouawe (Fig. 1) and have been dated as 8400–8000 radiocarbon years (Ota *et al*., 1988, 1989)(= 9500–8600 cal yrs BP). The Sponge Bay in-situ forest is of similar age to these and so we assume that the trees at Sponge Bay also have estuarine sediment beneath. This is confirmed by the test bore log drilled at Awapuni on the Poverty Bay coast near Gisborne (Mildenhall & Brown, 1987).

The occurrence of these in-situ trees within estuarine sequences along the full length of the North Island east coast suggests that there was a slight regression and stillstand in rising post-glacial sea-level at that time (Ota *et al*., 1988), which has also been detected in the postglacial marine sediments underlying Christchurch (Brown & Weeber, 1992, 1995). Ota *et al*. (1984) also present data of fossil trees at the Conway Coast, North Canterbury dated at the same 8400–8000 radiocarbon years old.

Another possible explanation is that on the North Island east coast there was tectonic uplift along 400 km of coastline in one or more earthquake events within this time interval. The uplift at each locality would have had to exceed 1 m to give the forest sufficient time to establish and grow to mature trees (>100 yrs) as sea level continued to rise. If the uplift occurred along this length in one event then it was likely to be a large rupture on the megathrust between the Pacific and Australian plates, but it is more likely that there were a number of separate

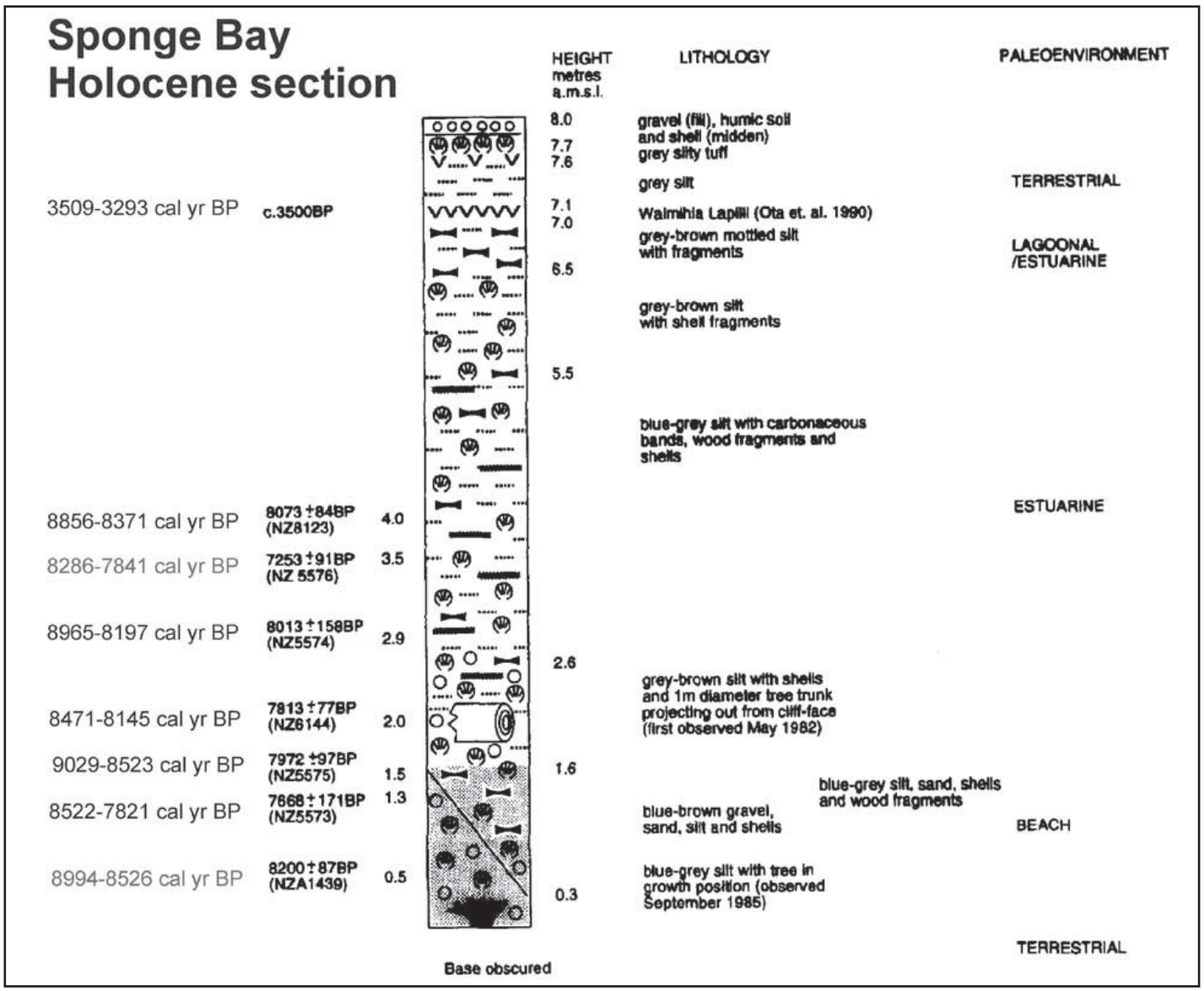


Fig. 7. Stratigraphic column for the bank at the back of Sponge Bay (after Ota *et al*., 1990; and Brown, 1995). The original radiocarbon ages are given immediately left of the column and the newly calibrated ages in calendar years BP are given on the far left. The calibrated age of the Waimihia Tephra is from Lowe *et al*. (2013).

local uplift events caused by ruptures on faults within the shallow overlying Australian Plate. Wilson *et al*. (2007a) identified two episodes of tectonic uplift (of ~3 m each at ~9000 and 8500 cal yrs BP) in similar estuarine-fluvial sequences at Pakarae, 20 km north of Sponge Bay. Thus it could have been the first of these earthquake events that had uplifted the estuarine sequence at Sponge Bay for sufficiently long for a forest to grow before it was drowned by continued post-glacial sea-level rise.

Older in-situ fossil tree stumps (9700–9380 radiocarbon years) also occur within estuarine sequences at Pakarae and White Rock and these have been inferred to have grown along the coast during a short-lived stillstand or reversal in sea-level rise at about this time (Berryman *et al*., 1992; Wilson *et al*. 2007b). This coincides with another stillstand recorded from Christchurch at 9700–9300 radiocarbon years (1170–1070 cal yrs BP), in addition to the 8700–8300 radiocarbon years (above) and a third at 7500–7300 radiocarbon years (8300–7600 cal yrs BP) (Brown & Weeber, 1992, 1995). This latter stillstand has also been noted in Singapore (Bird *et al*., 2010).

What does the Sponge Bay fossil forest tell us about the sea-level history?

The Sponge Bay fossil forest must have grown above extreme high tide, probably 0.5–2 m above MSL (spring tidal range 1.7 m). The overlying 6.5 m of cockle and mud-snail-bearing estuarine mud (Fig. 7) accumulated intertidally at MSL ± 0.5 m. The youngest dated estuarine sediment is 8050±200 cal yrs BP at 3.5 m above the oldest dated estuarine sediment at 8700±250 cal yrs BP (Fig. 7). This suggests that there was ~4 m of relative sea-level rise (includes ~0.5 m of tectonic rise) as this

sediment was deposited. The uncertainty limits of the dating, however, give a time interval of 200–1100 yrs for deposition of this sediment and therefore a very wide range of rates of sea-level rise of 0.25–2 m/100 yrs.

If we accept an uplift rate of 1-1.5 m/1000 yrs for Sponge Bay and extend this rate back to the time of forest growth ~9000–8700 yrs ago, then the forest (now at MSL) has been uplifted by 8.5–13.5 m since then and sea-level ~8700 yrs ago was 9–14 m below present level. This is precisely where sea-level is estimated to have been around New Zealand at that time in the latest reconstructions (Wilson *et al*., 2007a, Fig. 3).

Climate Change

Mangroves (Avicennia) grew in Poverty Bay – East Cape during the early to mid Holocene dated as between 12000 to 8000 cal yrs BP, and are recorded at two locations, Sponge Bay and the Awapuni test bore, Gisborne (Mildenhall & Brown, 1987; Mildenhall, 1994). They would have migrated around East Cape and other east coast promontories at a time when temperature was at least one degree warmer than present and climate was relatively frost free, and extensive estuarine mudflats occurred along the coast. The disappearance of mangroves from the East Coast has been the result of a sea level rise causing loss of suitable habitat, combined with increased frostiness, lower rainfall and lower humidity (Mildenhall, 1994).

Summary

The in-situ stumps in the beach at Sponge Bay are the remains of a fossil forest that was growing there ~9400–8700 years ago when sea level was ~9–14 m lower than present. Since that time there has been ~8.5–13.5 m of tectonic uplift at an average rate of 1–1.5 m/1000 yrs.

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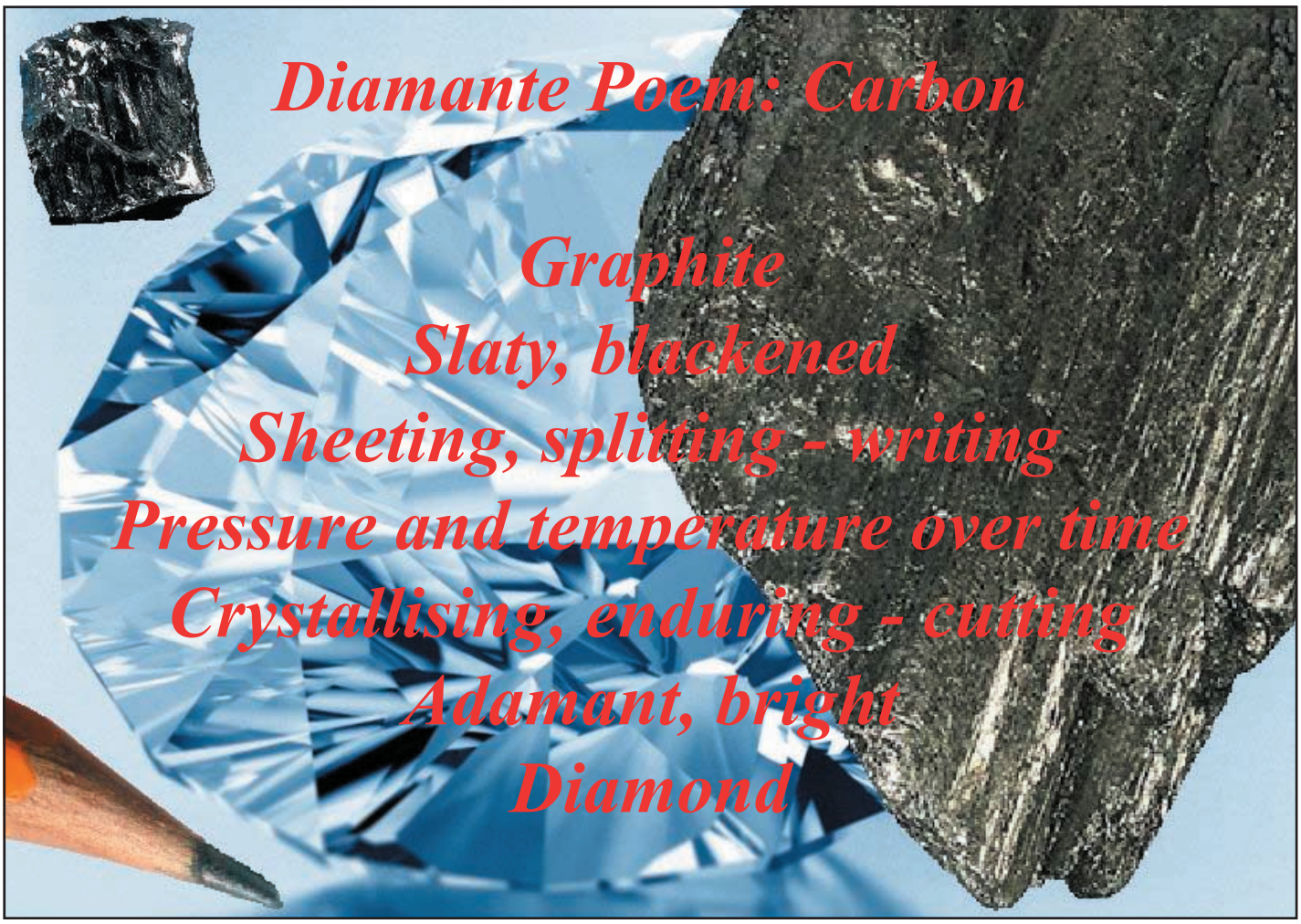
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The class I am a student teacher in (year 5-6) learned how to write Diamante Poems this week.
The rules for a diamante poem are as follows: 2 topics, either synonyms or antonyms; topic noun followed by two adjectives and three gerunds; the centre line must be either four nouns or a short phrase describing the change of topic; then three gerunds and two adjectives describing the second topic noun. As the diamante poem should be in the shape of a diamond, I chose that as a topic…

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QUIZ ANSWERS

Know your volcanoes.

1 = E, Te Hopua, photographed during reclamation for the port of Onehunga

2 = C, Mt St John

3 = A, Auckland Domain, Duck Ponds - North Head and Mt Victoria in background

4 = D, Tank Farm. Lake Pupuke explosion crater top right of photo, Onepoto Basin explosion crater bottom left.

5 = B, Crater Hill. Familiar view when landing at Auckland International Airport.

Where is this Waitemata Group cliff?

e Whangaparaoa Head (eastern end of Whangaparaoa Peninsula - superb 3-dimensional example of steeply dipping strata)