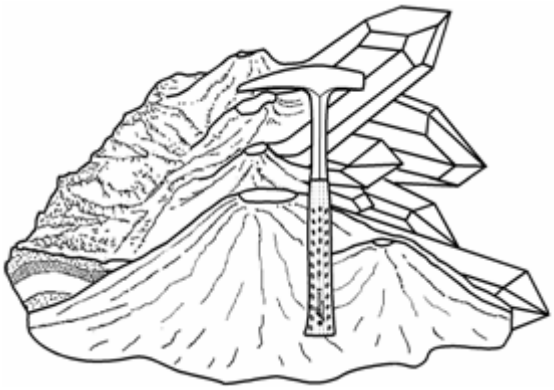


Geocene

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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.

Please contact Helen Holzer <heleneh_at_xtra.co.nz> (substitute @ for _at_)

NORTHWARD TILTING OF THE WAITEMATA GROUP EROSION SURFACE IN THE AUCKLAND REGION

Jill Kenny

All 3 figures are available as high resolution versions in Geocene_Kenny1.zip next to the Geocene 9 link.

The notion of potential northward tilting of the Auckland urban area first came from a discussion with Graham Mansergh concerning a poorly drained stream in central Howick – a conversation associated with research for an article on faulting in the Auckland region (Kenny 2008a). In a subsequent report (Kenny et al. 2011) the newly inferred ENE-trending Meadowlands Fault (Fig. 1) is postulated to have uplifted the suburb of Howick by about 60 m relative to the suburb of Botany to its south. The Howick block appears to be tilted slightly to the north, possibly as a result of this uplift. The south-flowing stream in central Howick became a poorly drained swamp as its southern outlet was elevated by tilting.

The Meadowlands Fault is thought to be an eastern extension of the Manukau Fault – a major ENE-trending fault that has uplifted Auckland Isthmus with respect to the Manukau Lowlands (Kenny et al. 2011, 2012) (Fig. 1). Is there evidence that the Manukau Fault also has northward tilting associated with it? Could northward tilting be a feature of the whole Auckland urban area?

Kenny (2008a) and Kenny et al. (2011, 2012) used borehole data, geophysical data, current topography and exposed geology to map the erosion surface of the Early Miocene Waitemata Group across the Auckland region (Fig. 1). The erosion surface is not at a constant elevation, but rather it is broken into blocks at subtly different heights. There is a concordance of ridges within each block, but a discordance between adjacent blocks. Where geologically plausible, a fault has been inferred, separating each block.

With continued observations of Auckland's topographic surface since these reports were published, it is possible to make additional assumptions.

Assumption 1:
Erosion, since the formation and uplift of the Waitemata Group erosion surface, has reduced the height unevenly across the whole region. Relatively erosion-resistant strata in the Waitemata Group have retained the form of the Waitemata Group erosion surface along ridge lines. Away from ridge lines, the less resistant strata have eroded in a regular and predictable pattern of streams and rivers, flowing either into the Waitemata Harbour or the Manukau Harbour. Across part of Auckland Isthmus, flow patterns have been interrupted by Holocene ash deposits and lava flows from the Auckland Volcanic Field. However, for the perimeter of Auckland Isthmus, and for western Auckland and southern North Shore, the predominant flow direction of main streams upon Waitemata Group substrate is approximately northwards. Whau River catchment is a prime example, flowing parallel to Portage Road northwards to the Waitemata Harbour from its upper catchment only 500 m from Green Bay on the Manukau Harbour.

The overall gradient of many suburbs around the upper Waitemata Harbour tends to slope northwards.

- Massey Heights slopes gradually northwards to Whenuapai.
- Titirangi slopes northwards through Te Atatu South to Te Atatu Peninsula.
- New Lynn slopes subtly northwards through Avondale to Rosebank Peninsula.
- Hillsborough and Lynfield have a NNW gradient through New Windsor to Pt Chevalier.

In eastern Auckland, the suburb of Pakuranga slopes northwards, from the highest area in the vicinity of Udys Road, through Farm Cove to Half Moon Bay. However, some streams draining the Howick-Pakuranga block are anomalous, with the central Howick valley, already mentioned in the introductory paragraph, having perhaps a hint of antecedency. Aviemore Stream and Stannilands Stream, skirting either side of Lloyd Elsmore Park, also have to force their way through increasingly higher ground southward before they reach Pakuranga Creek (which flows westwards along the disjointed western trace of the Meadowlands Fault). Note that in Fig. 1, the Waitemata Group erosion surface is shown, rather than the present topographic surface. The deep valley between Pakuranga and Howick is now filled with Holocene sediments, with Aviemore and Stannilands streams flowing southwards at either side, along the western and eastern Holocene borders with Waitemata Group sediments.

Across the northern perimeter of Auckland Isthmus, out of the influence of volcanic deposits, it is not unexpected that streams will flow northwards to the nearby Waitemata Harbour. Many of the roads built along resistant ridges of the Waitemata Group erosion surface in this area also tilt slightly north (for example, Ponsonby Road, Hobson Street, Symonds Street, St Stephens Avenue, Victoria Avenue, Bastion Point and Long Drive). This might be because they are all on the northern slopes of the Isthmus and naturally slope to the sea. However, there are no corresponding gently south-sloping roads or ridges on the southern side of the Isthmus. Slopes on this southern side tend to be very steep, developed on the highest ridges on the Isthmus and drain rapidly to the Manukau Harbour. Does this mean that the whole Isthmus is tilted slightly to the north-NNW?

North-facing slopes on the North Shore are also at a low angle, while south-facing slopes are steep. They are truncated by numerous WSW-flowing streams,

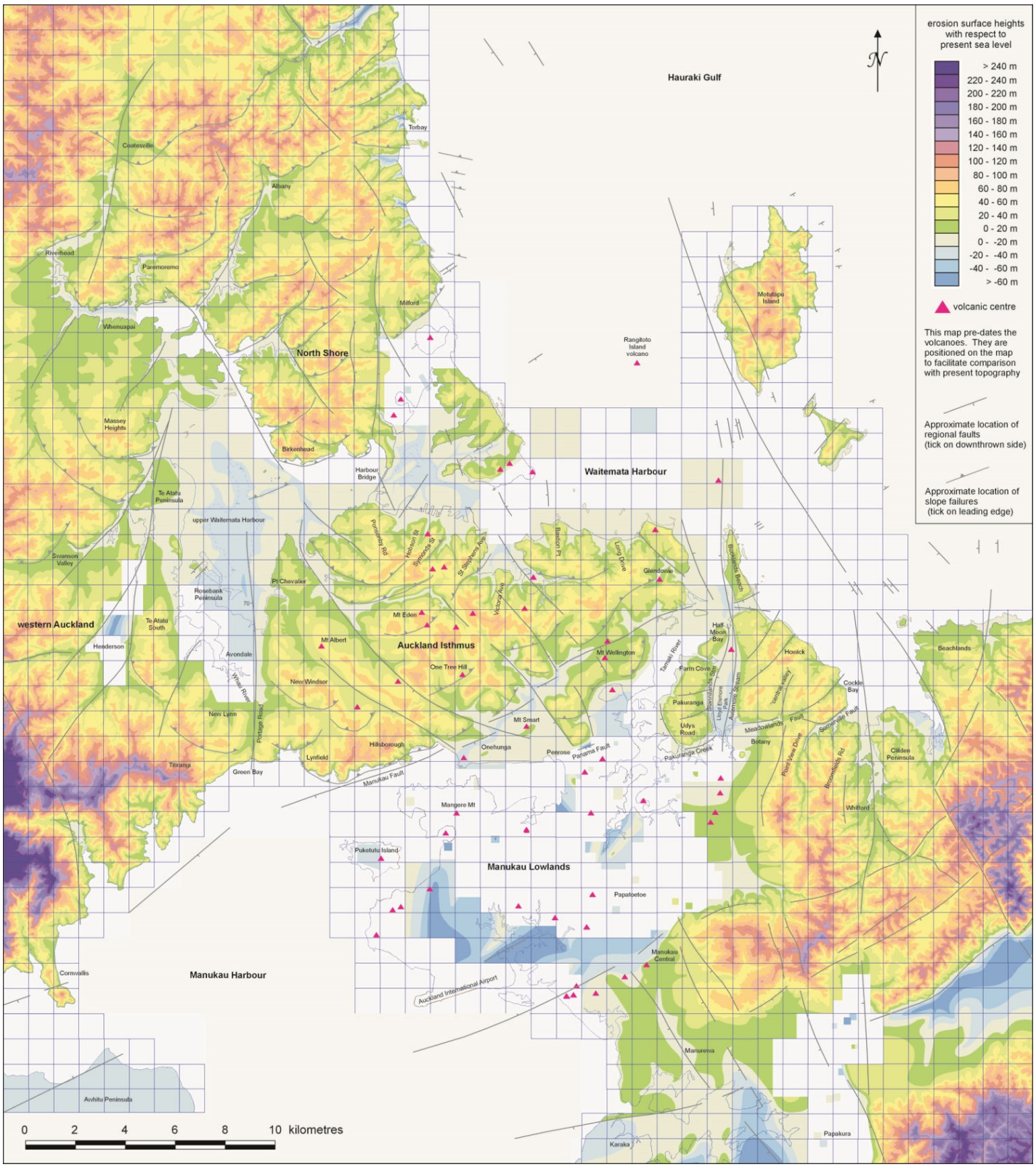


Fig. 1: Topography of the eroded surface of the Waitemata Group as it is today, including portions now concealed under younger sediments or volcanic material (modified from Kenny et al. 2011, 2012). The green-grey interface corresponds to present sea level; purple colours are highest elevations; blues below present sea level darken in colour with increasing depth. Areas of white represent areas of unknown elevation. Terrain in the highest eastern areas, where Waitemata Group sediments have eroded away, is greywacke. Large-scale faults, both published and inferred, are shown. Arcuate faults, inferred to be related to early Miocene sub-seafloor slope failures (Kenny 2008b; Kenny et al. 2011), are also shown. Although volcanoes (tiny red triangles) post-date the erosion surface, they are shown here as familiar landmarks in an otherwise unfamiliar erosion surface landscape. This figure is designed to be viewed a computer screen at greater than 150% zoom.

rivers and tidal estuaries that trace the leading edges of inferred gravity slides (Kenny 2008b, Kenny et al. 2011). The relatively erosion resistant strata involved in the leading edge of each recognised gravity slide forms a mappable arcuate pattern first recognised on the North Shore by Kenny (2008b) and extrapolated for up to 15 km southwards and westwards.

The conspicuous NNW tilt of each slice from Birkenhead to Paremoremo was observed but not emphasised at the time of that 2008 report, although their discovery initiated a working hypothesis that these particular inferred faults were low-angle "thrusts" rather than steep, large-scale block faults. Other arcuate faults in the region were then also assessed to be low angle and were linked in a model of intra-Waitemata Group gravity slides, extending southwards and southwestwards to Auckland Isthmus and western Auckland respectively, nudged from the north by the southward migrating toe of the Northland Allochthon (Kenny et al. 2010). This hypothesis supports Hayward's (1982, 1993) proposal of allochthon-related gravity slides in the Silverdale area 5–10 km to the north. Therefore the erosion resistant leading edges of gravity slides have retained the form of the Waitemata Group erosion surface, while erosion either side of the resistant ridges has highlighted the gentle northerly tilt and steep south-facing leading edge of each slide. Of course this implies that any gravity slide that does not have a resistant leading edge will not show up in a topographic analysis. Judging by the number of gravity slides inferred, there are probably many others in and around them that are invisible.

Gentle north-facing slopes also exist in Pakuranga, Point View Drive ridge, the Broomfields Road area NW of Whitford, the Clifton Peninsula NE of Whitford, and the region south of Beachlands. The anomalous swampy central valley in Howick could be included in this group. Gravity slides are not mapped by Kenny (2008b) and Kenny et al. (2011) this far south, but the Manukau, Panama, Meadowlands and Somerville Faults are each delineated by steep south-facing slopes and gentle north-facing gradients. It is tempting to consider these to be the leading edges of gravity slides as well.

Assumption 2:
Re-evaluation of the Waitemata Group erosion surface map (Fig. 1) leads to speculation that, as well as southwards-directed gravity slides with arcuate leading edges, there are also four regional southwards step-down blocks, some also tilted subtly northwards (Figs 2&3). The northern, uppermost step (dark red in Fig. 2) includes relatively high, deeply incised hill country, eroded mostly into Waitemata Group terrain, north of an irregular line of gravity slide fronts from Riverhead and Paremoremo eastwards to approximately Torbay.

The second step-down involves the typical smaller-scale gravity slides common across the whole region (described in Assumption 1), as well as the larger scale northward-tilted surface of Massey Heights to Whenuapai (also mentioned in Assumption 1). The step down is roughly from Swanson Valley in the west to the southern Birkenhead coastline, then eastwards to Milford (Figs. 1 & 2), marked by the leading edges of a series of gravity slides and possibly offset by a N–S-trending fault (Kenny et al. 2012).

The third step-down (between the orange- and bright yellow-coloured areas in Fig. 2) crosses southern Auckland Isthmus diagonally, either along a series of gravity slide fronts or along the Manukau Fault. It contains small-scale arcuate gravity slides, many of which are concealed beneath products of the Auckland Volcanic Field (but revealed by borehole studies, Kenny et al. 2011, 2012). Along the southern edge, the Manukau-Panama-Meadowlands fault system has been reconfigured, so that it is now different to the maps presented in Kenny et al. (2011, 2012). It has been split up so that the eastern portion of the Manukau Fault is now positioned along a valley in the erosion surface, extending from offshore Hillsborough beyond Mt Wellington to perhaps Bucklands Beach peninsula. This new angle now parallels the major ENE-trending regional faults crossing the Manukau Lowlands further south (High 1975, Berry 1986), and is subparallel to leading edges of several gravity slides from Hillsborough to Glendowie. This step covers most of the Auckland Isthmus westwards to the Titirangi-Henderson area, and involves the north-tilted surfaces of Hillsborough/Lynfield to Pt Chevalier, Titirangi to Te Atatu Peninsula and New Lynn to Rosebank Peninsula.

The old alignment of the Manukau-Panama-Meadowlands fault system now becomes a disjointed splinter fault from Penrose through to Cockle Bay. This is the fourth major step-down (bright yellow on Fig. 2) and involves northward tilting of the Pakuranga block, subtle northward tilting in the Panmure area, and the small anomalous valley in Howick.

South of western Manukau Fault and Panama-Meadowlands fault splinter, the Waitemata Group erosion surface is poorly constrained, but much of what is known is below present sea level and lower than the series of steps. It is thought to be beyond the influence of Northland Allochthon-related gravity sliding and nudging (Kenny et al. 2011), and instead should be considered to be the northernmost down-dropped segment in a series of ENE-trending horsts and grabens, traversing the Manukau Lowlands and concealed by more recent sediments (Fig 2) (Berry 1986, High 1975, Kenny et al. 2012).

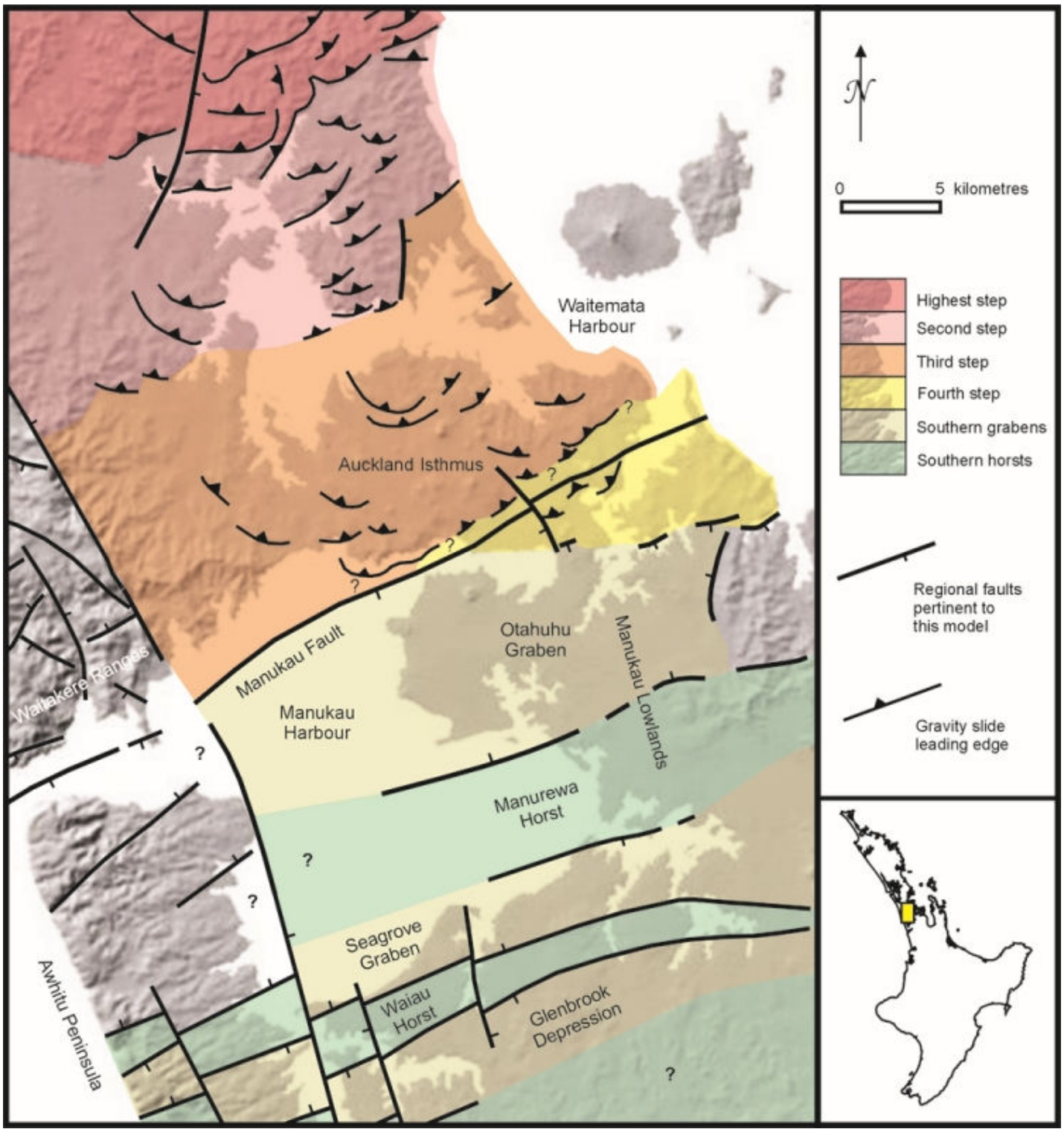


Fig. 2: Simplified map of the proposed series of steps in the Waitemata Group erosion surface. Most of the inferred regional faults in this area (Fig. 1) unnecessarily complicate the diagram and have been removed, leaving a clear picture of the cascading outward nature of the gravity slides from a point to the north of the map.

Points to consider:

Are these four steps actually large gravity slides with smaller-scale slides within them (Fig 3A), or are they related to the later ENE-trending horsts and grabens beneath the Manukau Lowlands Fig 3B)?

Northland and Auckland regions are thought to have been tilted gently westward (Hayward 2009, Hayward & Grenfell 2010). How much has a westward tilt influenced the subtle northward tilt of the numerous gravity slides and four main steps suggested here?

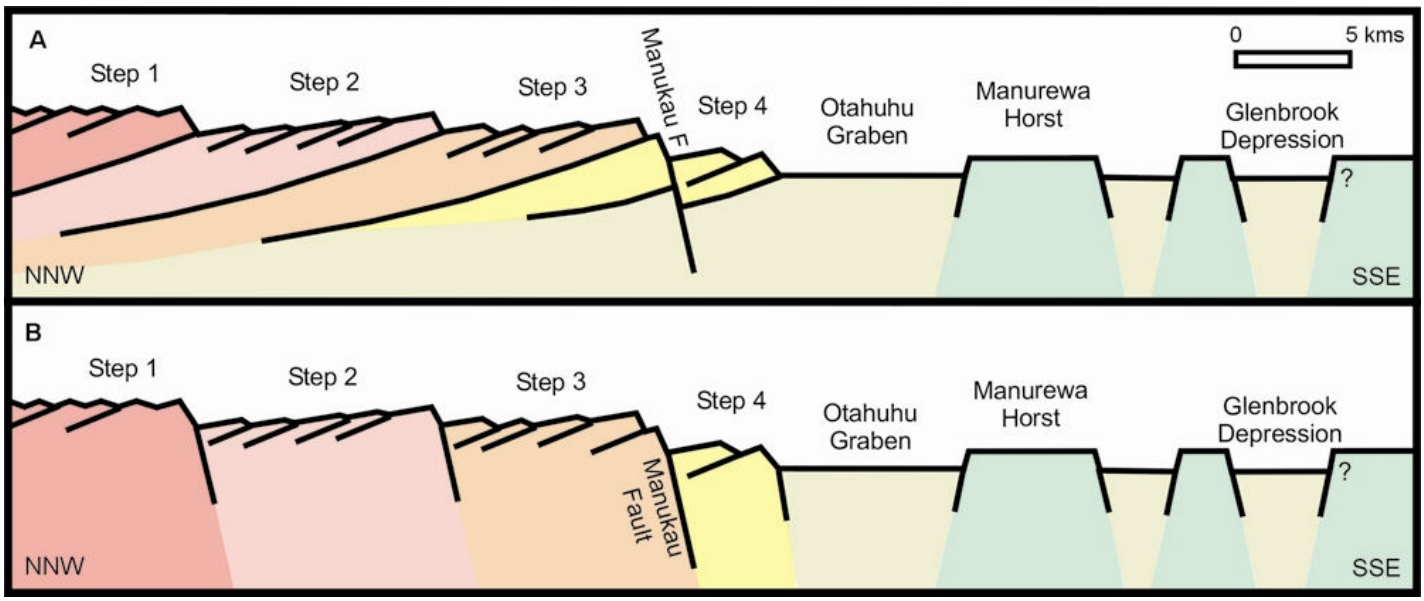


Fig. 3: Stylised cross-sections from roughly the top left to bottom right corners of Fig 2. Fig. 3A assumes that the steps coloured in Fig 2 form parts of a gravity slide sequence, nudged from the north by the toe of the Northland Allochthon. Fig 3B assumes that the steps are a northern continuation of the ENE-trending horsts and grabens that cross the Manukau Lowlands.

Acknowledgements
Thanks to Bruce Hayward for suggesting improvements to the manuscript.

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GIANT FOSSIL BARNACLES PROVIDE PALAEOWATER DEPTH ESTIMATES FOR THE SUBSIDENCE OF THE WAITEMATA BASIN

Bruce Hayward

Over the past 20 years GeoClub has visited almost all of the known exposures of early Miocene basal Waitemata Group rocks (Hayward and Brook, 1984), searched for fossils and tried to interpret the sedimentary sequence in terms of rapid subsidence at the time of initiation of the Waitemata Basin (Hayward, 2004). At four of these localities we have marvelled at the large fossil plates (up to 18 cm long) of an extinct giant barnacle *Bathylasma aucklandica* (Buckeridge, 1983) (Fig. 1). This fossil barnacle is closely similar to the modern giant barnacle *Bathylasma alearum* (Fig. 2) which lives in deep water (400-1600 m) around New Zealand today (Foster, 1978).



Fig. 1. A block containing numerous fossil plates of the giant barnacle *Bathylasma aucklandica* from Mathesons Bay north side.



Fig. 2. Plates of the modern giant barnacle *Bathylasma alearum* dredged from 1120 m water depth on the Macquarie Ridge.

Giant barnacles fossil localities

Fossil *Bathylasma aucklandica* have been found at five basal Waitemata localities (Fig. 3):

Motutapu Island – a lens of barnacle plates occurs in mudstone around the side of a greywacke Miocene sea stack exposed on the west side of Motutapu Island (Buckeridge, 1975; Ballance and Smith, 1982). This was the first found and best known occurrence of this giant barnacle (Fig. 4) and also the type locality. Visited by GeoClub in 1994 and 2010.

Motuihe Island – small pockets of giant barnacle plates and one complete barnacle occur in irregular depressions on the surface of a Miocene greywacke stack to the south of Limestone Pt, west Motuihe Island (Ballance and Smith, 1982). Visited in 1993 and 2000.

Mathesons Bay – small lenses of giant barnacle plates occur at the interface between underlying shallow-water-fossil-bearing conglomerate and breccia and overlying mudstone at both the north and south ends of Mathesons Bay (Eagle et al., 1999). Visited in 1994 and 1998.

Motuketekete Island – rare single giant barnacle plates occur within Motuketekete Limestone on the northeastern side of the island (Campbell et al., 2004). This site has not been visited by GeoClub although we did sail past and examine the section from 50 m distance in 1993.

Omana – during a trip in 1997, a lens of *Bathylasma* plates was found in mudstone filling a depression on the surface of a greywacke palaeostack that projects through the intertidal platform composed of Waitemata sequence about 100 m off from the beach (Fig. 5).

Palaeowater depth estimates:

Bathylasma aucklandica's close descendant species *B. alearum* lives today around New Zealand at water depths of 400-1600 m (Foster, 1978). Unless there is good evidence to the contrary, it seems quite reasonable to infer that the fossil giant barnacles also lived at a similar depth range in the early Miocene.

There is no associated macrofauna in the mudstones in which the barnacle plates occur at Motutapu and Omana. The associated fossil foraminiferal assemblage at Motutapu (R10/f28) has 75% planktics and a benthic fauna inferred to have accumulated at 200-1000 m depth (Hayward, 2004).

At Mathesons Bay, several lenses of giant barnacle plates, with no associated macrofauna, occur at the boundary between underlying Cape Rodney Formation conglomerate with shelf macrofaunas (Eagle et al., 1999), and overlying massive mudstone with a foraminiferal fauna (R09/f44) having 70% planktics and a benthic fauna inferred to have accumulated at depths >1000 m (Hayward, 2004). Thus the 400-1600 m depth range of *Bathylasma* is

perfectly consistent with the evidence from Motutapu and Mathesons Bay.

At Motuketekete rare barnacle plates occur in Papakura Limestone which also contains several species of shelf-dwelling macrofossils (Campbell et al., 2004). The foraminiferal microfaunas from this unit (R09/f74, f83) have 15-25% planktics and benthics indicative of outer shelf depths (Hayward, 2004). This limestone could be displaced and therefore contain a mixed fauna. The precise stratigraphic location of the rare barnacle plates within this unit is not recorded and could perhaps be at the top of the unit as at Mathesons Bay. Thus a shallow extension of the depth range of fossil *Bathylasma* based on the Motuketekete occurrence still contains some doubt.

At Motuihe, the *Bathylasma* occur within small pockets of coarse sediment preserved in depressions on the surface of the greywacke stack. These are overlain by mudstone with 65-80% planktics (R11/f61) consistent with bathyal accumulation (Hayward, 2004). Here the giant barnacles sometimes co-occur with the octocoral Keratoisis (Ricketts et al., 1989) which lives down to 4000 m in modern seas (Grant, 1976). A bathyal depth range for *Bathylasma* is not inconsistent with the evidence from Motuihe.

Implications for the subsidence history of the Waitemata Basin:
Many basal Waitemata Group sections contain coarse sediment and/or inner-mid shelf macro- and microfossil assemblages (Hayward and Brook, 1984; Ricketts et al., 1989) overlain by massive mudstone and/or turbidite-deposited sandstone beds with microfossil evidence for accumulation at bathyal depths (>200 m, often >1000 m; Hayward, 2004). In most instances the large barnacle *Bathylasma* occurs fossil close to the boundary between the shallow-water basal Waitematas (Kawau Subgroup) and bathyal-abyssal flysch sequence (Warkworth Subgroup). Sometimes the boundary is sharp and marks a hiatus during which no sediment accumulated as the site subsided from ~50-100 m water depth down to >1000 m. In other places the boundary is overlain by massive hemipelagic mudstone marking slow sedimentation by deposition of mud out of suspension in the water column.

It is unlikely that turbidites could have flowed all the way south from the Kaipara shelf (50 km +) to the central part of the Waitemata Basin until the basin had foundered to depths of ~1000 m to create sufficient palaeoslope for the turbidity current to flow down. Where present, the fossil giant barnacles provide the only reliable record we have of this period of subsidence.

Initially as the Waitemata Basin began to subside, there were greywacke islands, coasts and land areas (up to about 100 m elevation) that were eroding and providing the coarse sediment that accumulated as the basal Waitematas. As subsidence continued these greywacke islands were all submerged and there was no nearby land to provide any terrigeneous sand. Clearly there must have been bottom currents sweeping the floor of the subsiding basin, otherwise microfossil ooze would have started to accumulate. In some places (e.g. Motutapu, Motuihe, Mathesons Bay, Omana) massive terrigeneous mud did accumulate during this period before the incoming of the first sand turbidites. In places like Motutapu and Omana the tops of former greywacke stacks were still sticking up out of the seafloor as submarine pinnacles providing hard surfaces onto which the *Bathylasma* could attach themselves.

Speed of subsidence of the Waitemata Basin:
One question that is hard to answer with any certainty is how fast was the subsidence of the Waitemata Basin? We can provide some constraints on this from the fossil ages and their calibration. The entire basal Waitemata Group (Kawau Subgroup) and turbidite sequence (Warkworth Subgroup) was deposited during the Otaian Stage (21.7-18.7 myrs ago; Hollis et al., 2010). The top of the Otaian Stage occurs within the lower part of the overlying Waitakere Group (Hayward and Buzas, 1979), which is approximately 1 km of sedimentary rock thickness above the basal Waitematas. This 1 km contains about 10% (100 m) pelagic mudstone that represents the time interval during which the 1000 m sediment thickness accumulated. The 90% turbiditic sandstones were deposited almost instantaneously on a geological scale. By comparison with hemipelagic mud accumulation at 1000-2000 m water depth around New Zealand today (e.g. DSDP 594, side of Bounty Trough; Nelson et al., 1986) a sedimentation rate of ~10 +/- 5 cm/1000 yrs is likely. Thus 100 m of mudstone would have taken an estimated 0.75-2 myrs to accumulate. Thus the turbidites in the central Waitemata Basin began accumulating ~20.7-19.5 myrs ago.

The marker fossil for the base of the Otaian stage is the upper bathyal-outer shelf benthic foraminifer *Ehrenbergina marwicki* (Hollis et al., 2010). It occurs in the barnacle-bearing mudstone at Motutapu (R10/f28) and Papakura Limestone on Motuketekete (R09/f74) and thus the upper part of the basal Waitematas are no older than 21.7 myrs. Therefore the 1000 + m of subsidence that created the Waitemata Basin took no longer than 1-2 myrs and possibly less than this. At an estimated 1 myrs this is a subsidence rate of 1 m/1000 yrs, which is similar to the present rate of subsidence of the Marlborough Sounds area (Hayward et al., 2010).

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HIGH-TIDAL WEATHERING RATES ON WAITEMATA SANDSTONE, HOBSON BAY, AUCKLAND

Bruce Hayward and Jill Kenny

Introduction

All around the coast of Auckland there are wide intertidal reefs and in many places high-tidal rock platforms are present. These features are developed in all the major rock types – Waitemata Group sandstone, Piha Formation conglomerate and Waipapa Group greywacke. Although the structure and variable strength of the rocks and strata play a significant role in the local development and shape of these high-tidal platforms, they are not dependant on the overall hardness of the rock, except that they may be wider in the softer Waitemata sandstone than in the harder Piha conglomerate or Waipapa greywacke. An extreme example of high-tidal platform development is a high tide notch where an overhang has developed above the platform, as at Paratutae Island, Whatipu.

The development of these platforms at high-tidal level is perhaps counter-intuitive as one would expect that waves would be the main erosive agent in this environment and that intertidal areas would be subjected to more wave attack than would areas at or above mean high tide. This has led to considerable conjecture and debate on some GeoClub trips as to the mechanism responsible for these high-tidal platforms. Such debate is not new and appears to have originated in New Zealand when Dana (1849) first described old hat islands based on his observations in the Bay of Islands. From the earliest studies it was recognised that high-tidal platforms are erosional remnants of cliff retreat. Surveys by Kennedy et al. (2011) on the Bay of Islands greywacke platforms showed that they were formed at all levels between mean high water neap to mean high water spring. They concluded that platform elevation was a function of the level at which waves erode or remove cliff rock and was higher on exposed shores than on protected ones.

Early on Bell and Clarke (1909) inferred that subaerial weathering causes the retreat of the cliffs and that marine erosion removes the waste from their base, leading to the high-tidal shore platform development. Around Auckland, Bartrum (1916, 1924, 1926, 1935) was fascinated by this topic. He suggested that the platforms formed at the level of permanent water saturation of the rocks, with the lower intertidal saturated rocks more resistant to wave erosion than those above that periodically dried out.

A recently constructed walkway on the Parnell edge of Hobson Bay (Fig. 1) provided a serendipitous opportunity to study aspects of this interesting topic. The walkway was constructed by Auckland City Council contractors in 2006 around the base of the weathering and vegetated cliffs of Waitemata sandstone. These cliffs are now far more protected from wave erosion than they would have been before the Waterfront Drive embankment was constructed across the mouth of Hobson Bay in the 1930s and certainly before Rangitoto erupted further away in the entrance to the Waitemata Harbour about 600 yrs ago.

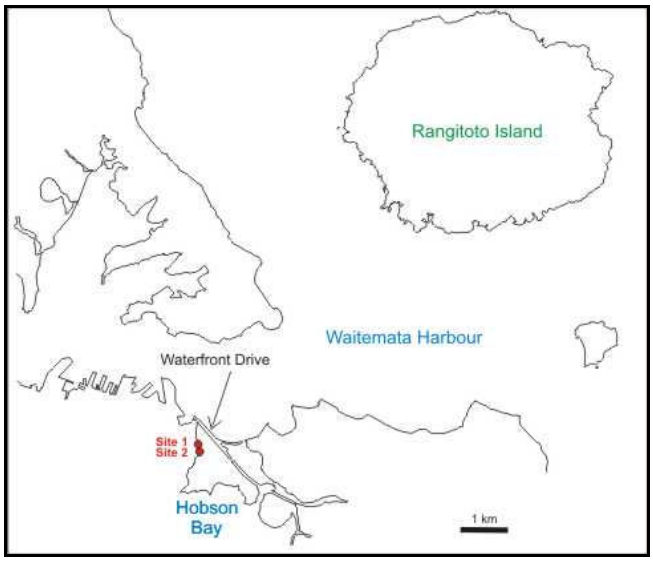


Fig. 1. Location of study sites on the Parnell side of Hobson Bay.

For several hundred metres the new walkway has been built up 0.5–1 m above the level of the mid-tide beach so that its top is at about mean high water springs level (Fig. 2). In most places the landward side of the 1 m-wide walkway abuts the foot of the cliffs, and the seaward side is a rock retaining wall constructed using boulders and cobbles of Waitemata sandstone collected locally from around the base of the cliff. The boulders and cobbles had been cemented together with a concrete mortar, usually with the larger boulders forming the lower part of the wall and progressively smaller cobbles higher up.



Fig. 2. A section of the Hobson Bay walkway and retaining wall with the upper cobbles already deeply eroded after just 6 years.



Fig. 3. Study site 1 was where part of the Hobson Bay walkway had been built across a small embayment with retaining walls on both the seaward (right) and landward side (left). Note the uneroded cobbles on the landward side, compared with those on the seaward side.



Fig. 5. Part of study site 2 where the higher cobbles were considerably more eroded than those lower down.

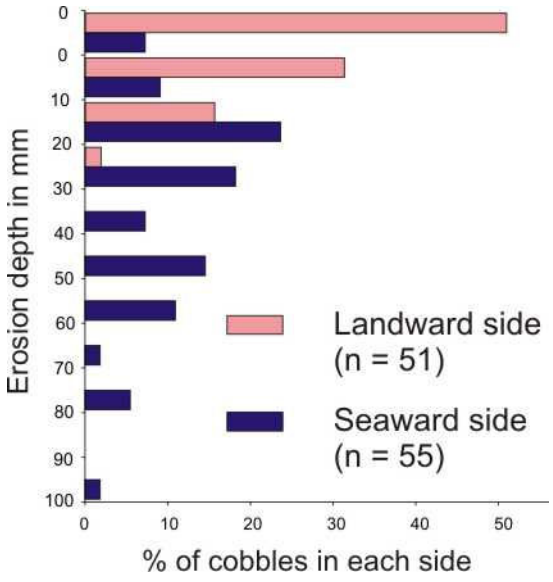


Fig. 4. Histograms showing the percentage of cobbles in the seaward-facing and landward-facing retaining walls of the Hobson Bay walkway (site 1) to have eroded to different depths below the 2006 mortar (in 10 cm groups). N = number of cobbles measured.

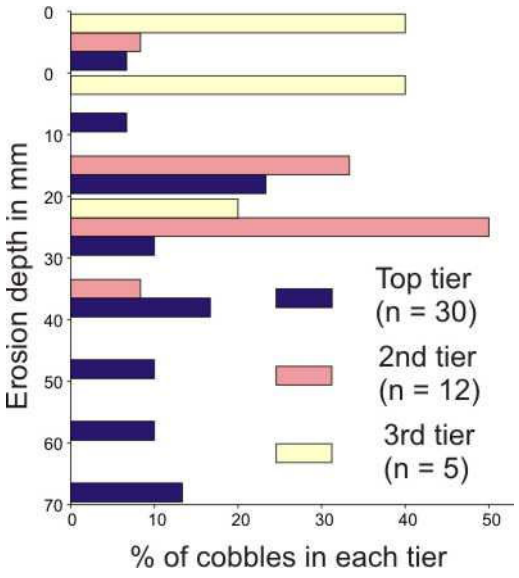


Fig. 6. Histograms showing the percentage of light-coloured sandstone cobbles in the upper, 2nd and 3rd tiers of the Hobson Bay retaining wall at site 2 to have eroded to different depths below the 2006 mortar (in 10 cm groups). N = number of cobbles measured.

Our observations and measurements were made in October 2012, ~6 years after the walkway and retaining wall was constructed.

Qualitative observations

In many places the sandstone cobbles in the upper part of the wall have already eroded badly (Fig. 2), and in some places they have completely disappeared. Lower in the wall most of the boulders and cobbles showed little or no sign of erosion. Rare cobbles of basalt and greywacke have been included in the retaining wall and show no sign of any weathering. The sandstone boulders and cobbles clearly come from a number of different layers in the cliffs above and each has different resistance to erosion. The darkest sandstone appeared to be the most resistant and formed most of the larger, boulder-size rocks and showed minimal or no erosion/weathering since the wall was built. Occasionally, layered sandstone or even some mudstone layers were in the cobbles and there was clear spalling of layers off along the bedding planes in these. In a few places it appeared as if the entire sandstone cobble had popped out of the mortar leaving only a mould of its former shape.

If we ignored all the darker, more resistant sandstone rocks and the places where whole cobbles had washed out and just concentrated on the lighter-coloured massive sandstone cobbles, we could still see an obvious pattern to their weathering/erosion. The cobbles of lighter-coloured sandstone in the upper layer of the retaining wall at about mean high water level had weathered and eroded dramatically since the wall was built, whereas those lower in the wall appeared to be wetter and had eroded back far less. The weathering surface of some of the dry cobbles in the top of the wall was powdery and would readily wash away with the next tide to reach this height, thus exposing the next layer of sandstone to weathering.

In some places the wall was clearly in the shade of pohutukawas for most of the day, whereas in other places the wall would be exposed to drying sunshine for at least half the day. There appeared to be slightly greater weathering and erosion of the cobbles that get more drying out than those in the shade. In a similar pattern, there seemed to be greater erosion/weathering of cobbles that were more likely to get more wave splash than those sheltered by a reef in front.

Quantitative results

Study site 1 was where the walkway had been constructed across a small embayment with a retaining wall on each side (Fig. 3). We measured the greatest amount of erosion that had occurred below the mortar level on every cobble forming the top tier of the retaining wall (along a 12 m section) on the seaward and landward sides of the walkway (Fig. 4). These measurements showed dramatically more erosion of the seaward cobbles (mean 31 mm) than the landward ones (mean 5 mm). The deepest erosion was 92 mm on a seaward cobble and just 21 mm was the maximum on a landward cobble. 31% of the landward cobbles showed no perceivable erosion compared with 9% of the seaward cobbles (Fig. 4).

Study site 2 was 100 m south of site 1, where a 5 m section of seaward-facing retaining wall was exposed to the sun for at least half the day and the upper part contained cobbles of light-coloured sandstone in the upper three tiers, although few in the third tier down (Fig. 5). We measured the greatest amount of erosion that had occurred below the mortar level on every light-coloured sandstone cobble in the top, 2nd and 3 rd tier of the retaining wall (Fig. 6). Although there were fewer qualifying cobbles in the 2nd and 3rd tiers, there was still a clear trend with mean depths of erosion of 42 mm on the top tier, 30 cm in the 2nd tier and 14 mm in the 3 rd tier. All cobbles in this study showed some erosion at this site.

Discussion

At site 1, the cobbles measured were all at the same elevation and contained the same range of sandstone lithologies. The only differences were that the seaward cobbles would have experienced more sunlight and more wetting from high tide wavelets and spray than those on the landward side. It seemed clear that weathering of the cobbles on the seaward side due to wetting and drying, and maybe some salt crystal growth, was on average six times faster on the seaward cobbles than on those just 1 m away on the other side of the walkway.

At site 2, the measured cobbles were all of the same lithology and had the same seaward-facing aspect in a sunny site. The only difference was that the cobbles in the lower tier were likely wet by almost every high tide whereas those in the top tier were probably not wet for periods of a week or so during fortnightly neap tides. These longer periods of drying out, and possibly more alternations between wet and dry condition, appear to have resulted in considerably faster rates of weathering and erosion.

This study seems to confirm that weathering and erosion is most rapid around high tide level where the rocks suffer frequent alternations between wet and dry condition, which seems to promote surface weathering with the high tides periodically removing the powdery surface material.

The mean rate of 30 mm of erosion of seaward-facing high-tidal sandstone cobbles in 6 years at site 1, gives a rate of 5 mm per year which would total 0.5 m in a century. This is quite believable for erosion at the base of Waitemata sandstone cliffs in particularly sheltered sites inside the harbour. We know that the lower Waitemata sandstone cliffs at Takapuna have eroded back ~2 m around a WW2 concrete structure in 50 years, giving a rate of 4 m per century of retreat in a much sunnier and more exposed setting than Hobson Bay.

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GROOVY ROCKS
Peter Scott

Having spent hours in and around rivers as a white water canoe instructor I am aware of river flow patterns and erosion features. I was intrigued by the vertical grooves or flutes that can be observed near the Turoa skifields, on the Mangawhero River (above the Mangawhero Falls), in the Tongariro National Park (39 19.171S, 175 30.149E). Intuitively I would have expected the maximum flow on the outside of the bend to have eroded and smoothed the homogeneous andesite rock. Instead, a series of fairly regular flutes have been formed with parallel edges progressively reducing upwards (Fig. 1). I have also seen larger and more defined flutes on another bend on the Whangaehu River, eroded into mud stone. I have not seen these flutes any where else then why only in this area?

Flutes may be observed worldwide in limestone and sometimes in igneous rocks such as basalt. One explanation for the fluting down the sides of basalt boulders is that they were formed over very long time periods by acidic water associated with soil around the roots of epigean plants top of the boulders (Hayward and Kenny, 2011, Hayward 2012). This is not the case here.

In the North Huxley River, Otago I noted large flat topped boulders standing approximately 1m above average water height, which exhibited regular wavelets eroded on the top of the rock, at right angles to the flow direction. These ripples could have been formed by the flow over the top lip initiating a series of eddies which eroded the rock top. There was some erosion at water level due to water and rock abrasion but no regular features.

I suggest the river bank fluting is caused by the rapid current flowing on the outside of the bend forming eddies against a vertical homogeneous rock bank. An irregularity, a bump say, causes an eddy which initiates a series of counter rotating eddies around the bend, which in turn erode into the rock amplifying the eddies and the erosion. The flutes are deepest at high water flow levels (strongest currents) and cease at levels above maximum flood height but continue below normal river height and reduce at riverbed level due to abrasion. If this is the case, this process is not unique and why is it not found in other areas of moderate rainfall and homogeneous rocks e.g. limestone areas of Britain? Is it something in the Ruapehu water?

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Figure 1: Fluting in andesite in the Mangawhero River, Tongariro National Park.

THE ROYAL OAK CRATERS

Bruce Hayward and Jill Kenny

Summary

In mapping the volcanoes of Auckland, Heaphy (1860) and Hochstetter (1864) recognised several "tuff craters" in the Royal Oak area between One Tree Hill and Three Kings. A century later, Searle (1962) re-examined the area, by then largely covered in houses, and recognised 12 tuff volcanoes, some "clearly defined" and others "not precisely indicated". Soon afterwards, Kermode and Searle (1966) reinterpreted them as hollows on the volcanic ash-mantled surface of lava flows from One Tree Hill. Using high resolution LiDAR topographic maps (0.5 m contours) we have been able to locate all the "craters" recognised by Heaphy, Hochstetter and Searle, but are inclined to agree with Kermode and Searle (1966) that they are all more likely hollows on the irregular surface of lava flows that have been sealed by ash erupted later from Three Kings Volcano. This interpretation is supported by a number of man-made exposures and drill holes in the subsurface geology.

Introduction

Hochstetter (1864, translated by Fleming, 1959, p. 199) wrote: "The farms and villas lying between One Tree Hill, the Three Kings, and the town of Onehunga owe their fertility and luxuriance of their meadows, fields and gardens to the excellent soils produced by weathering volcanic tuff. An eye little practised in geology could however recognise in the characteristic terrain little more than an undulating very fertile land, with odd swamps and shallow ponds in the hollows between the low hills. Only after more scrupulous observation, can the circular arrangement of the hills be recognised and the conclusion drawn that this terrain is made up of numbers of tuff cones." He mapped five distinct "tuff craters" in the Royal Oak area (Fig. 1).



Fig. 1. Royal Oak portion of Hochstetter's (1864) map of the volcanoes of Auckland. Craters with numbers are discussed in the text.

Charles Heaphy had produced a map of the Auckland volcanoes before Hochstetter's visit (Mason, 2002) but it seems to be lost. A tracing of a map, held in the Turnbull Library, was thought by Mason (2003) to be of this early Heaphy map. But when examined in detail it is too different from his final 1860 map for this to possibly be true. It could just as easily be a tracing of a draft map by Hochstetter (H. Grenfell, pers. comm.). Heaphy's published map (1860) produced after Hochstetter's visit shows "several indistinct tufa craters" in the southern part of the Royal Oak area but it is not possible to determine the exact location of any of his small circles. It is possible that Heaphy may have simply tried to copy Hochstetter, whom he showed around and drafted maps for in 1859. Heaphy wrote on his 1860 map: "Geological sketch map of the Auckland District by C. Heaphy, 1857. (corrected to Feby. 1859)".

It was another century before the volcanoes shown on Heaphy's and Hochstetter's maps in the Royal Oak area were reconsidered, by Ernie Searle (1962) who was making the first comprehensive study of the whole Auckland Volcanic field. Searle called them "The Epsom Tuff Volcanoes" and recognised all that Hochstetter had identified but also inferred that a number of additional small hollows and hills were also less distinct craters and parts of tuff rings (Fig. 2).

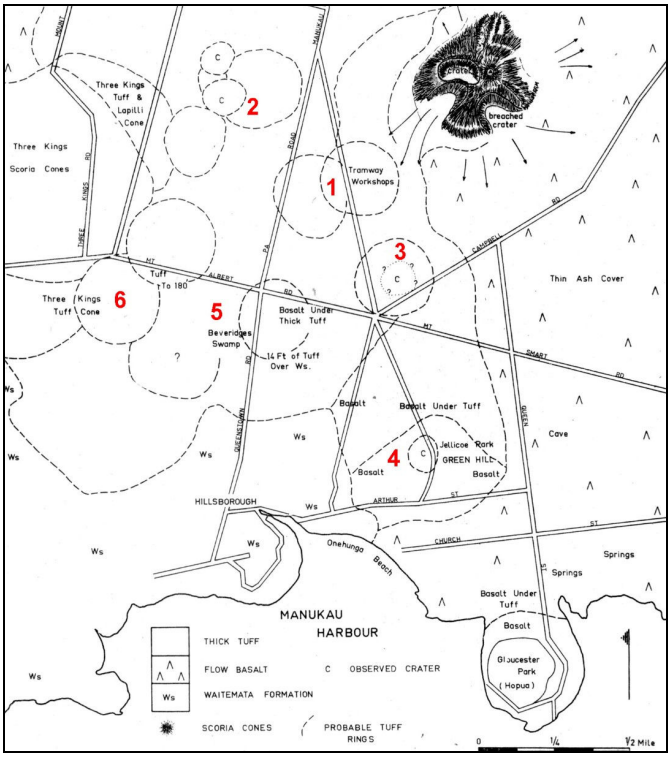


Fig. 2. Royal Oak portion of Searle's (1962, fig. 6) map of the volcanoes of central Auckland. Craters with numbers are discussed in the text.

Kermode and Searle (1966) and Kermode (1992) discounted all of Hochstetter's (1864) and Searle's (1962) craters. They reinterpreted them as depressions on the surface of One Tree Hill lava flows or low areas dammed between the sandstone hills and the lava flows, all of which had been mantled by several metres

of volcanic ash that had been erupted later from nearby Three Kings volcano. The ash had hidden virtually all of the rocky lava flow surface and sealed the natural depressions which became ponds and swamps that may have resembled small maar crater lakes when visited by Hochstetter in 1859. This reinterpretation of the Royal Oak craters as swampy depressions has remained in vogue for the past 40 years (e.g. Kermode, 1992; Hayward et al., 2011).

We suspect that Kermode may have been influenced in reaching this different interpretation by his familiarity with lava caves and the uneven surface of lava flow fields such as Rangitoto, with which he would have been familiar. Examination of the latest LiDAR 0.5 m contour map of Rangitoto shows numerous places where there are subcircular depressions up to 250 m across and up to 5 m deep (e.g. Fig. 3) that could be mistaken for craters if they were thickly draped with ash and filled with water creating ponds and swamps.

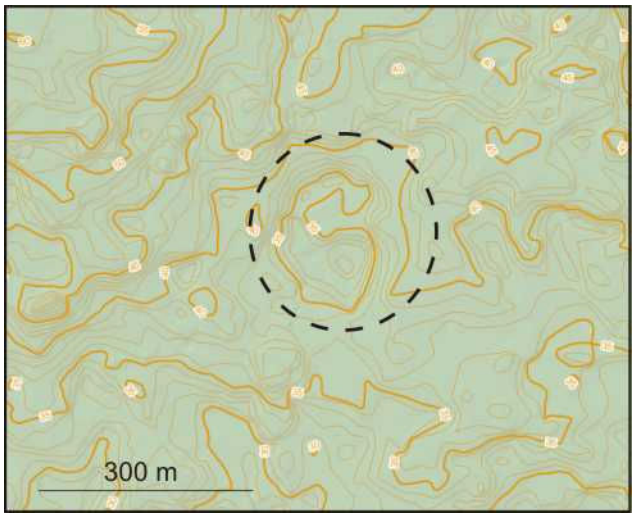


Fig. 3. Present-day contour map of part of the eastern lava flow field of Rangitoto volcano highlighting a circular depression similar in size and depth to those in the Royal Oak area. Base map from Auckland Council GIS Viewer with 1 m contours.

In June 2012 a group of 19 GeoClubbers toured the sites identified by Hochstetter (1864) and Searle (1962) as volcanic craters and tuff rings to see where they were, what they looked like now that they are covered in suburban houses and roads, and to try to assess for themselves what the was the likelihood that Hochstetter was correct. While Hochstetter had the advantage of not having the landforms obstructed or modified by later city development, in 2012 we had the advantage of road cuttings and the records of a number of subsequent excavations and boreholes that gave us an insight into the underlying sequence of rocks. We also had the advantage of having on hand LiDAR topographic maps at 0.5 m contour intervals.

Hochstetter and Searle's Royal Oak Craters

On Hochstetter's (1864) map (Fig. 1) and Searle's (1962) map (Fig. 2) we have numbered their Epsom craters and refer to them in numbered order below.

1. Tramway Workshops

Hochstetter described a single crater at this location – "When the traveller on the road from Auckland to Onehunga [Manukau Rd] has just passed One Tree Hill, the road leads over two low elevations which belong to a tuff cone, and, in the depression between the two elevations, it cuts across the middle of the accompanying crater."

Searle (1962) showed two circular depressions in this location, which up until 1956 had been modified by the flattening of the central area on the west side of Manukau Rd for tramway workshops. He states "Bartrum (1924) recorded the occurrence of moa bones in the bedded deposits of a remnant of a tuff ring near the old tramways workshop. The presence of the … bones in … the swamp deposits beneath the superficial 10ft of tuff above the basalt shows that a period of quiescence existed between effusion from One Tree Hill and deposition of the tuff."

Today's Hochstetter's depression is recognisable at the intersection of Lewis and Manukau Rds. Recognition of a tuff ring was not at all clear, however, and just as plausible is a tuff-draped small valley with Manukau Rd built up to create the present 0.5-1 m-deep depression (Fig. 4). Across the road, the flat floor and high cuttings of the workshops is evident within the Goodland St subdivision and is unlikely to be the second "crater" recognised by Searle (1962) who states "a larger centre, between Manukau and Pa Rds, north of Royal Oak School, is indicated by a central depression and a low enclosing ridge, but it, too, has been greatly modified.". We recognise this second crater as the 300 m-diameter circular depression with a flat floor centred on the intersection of Epworth and Beckenham Avenues (Fig. 4).

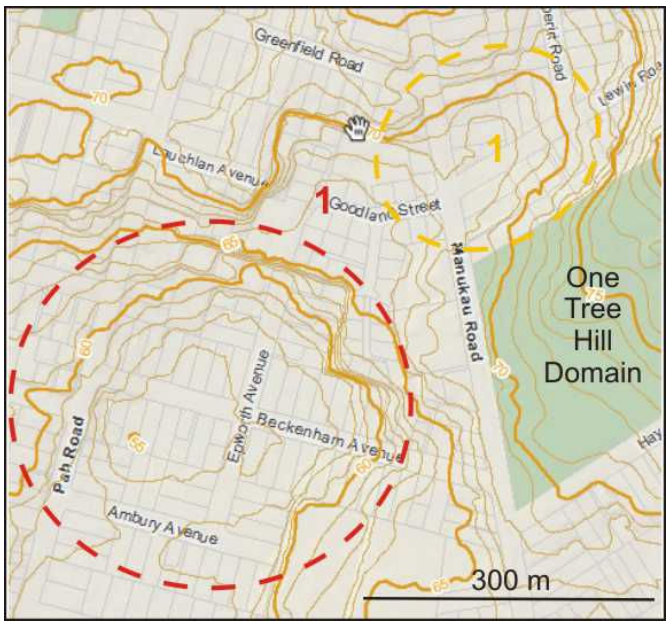


Fig. 4. Present-day contour and street map of area east of One Tree Hill Domain around Manukau Rd. Location of Hochstetter's tuff crater 1 (in gold from Fig. 1) and Searle's two craters 1 (in red from Fig. 2). Base map from Auckland Council GIS Viewer with 1 m contours.

In shape this is one of the more convincingly circular potential craters in the area, but a tuff-draped circular depression on the surface of lava flows is an equally compelling explanation.

2. Liverpool St

Hochstetter states that "one can count two or three other small tuff cones at the foot of Three Kings on the south-east side" and Searle wrote "a fine section cut through a tuff ring … is exposed in a cutting in Liverpool St. The tuff is bedded and slumped down the flank of the ring, but here the confused topography suggests that a cluster of vents were active in the vicinity. Their constructional forms coalesce and interfere with one another to such an extent that precise interpretation is not possible."

The cutting is now a protected and much visited feature of Auckland's geology and exhibits a small anticline that we infer to be produced by tuff draping an underlying narrow spur of Waitemata Sandstone that runs down from the intersection of Buckland and Selwyn Rds (Fig. 5). In the LiDAR contours we can recognise three or so irregular depressions in this vicinity, but we think the Kermode explanation for their origin is more likely than volcanic craters. The elongate depression centred on the intersection of Buckland Rd and Torrance St (Fig. 5) coincides with a crater mapped by both Hochstetter and Searle.

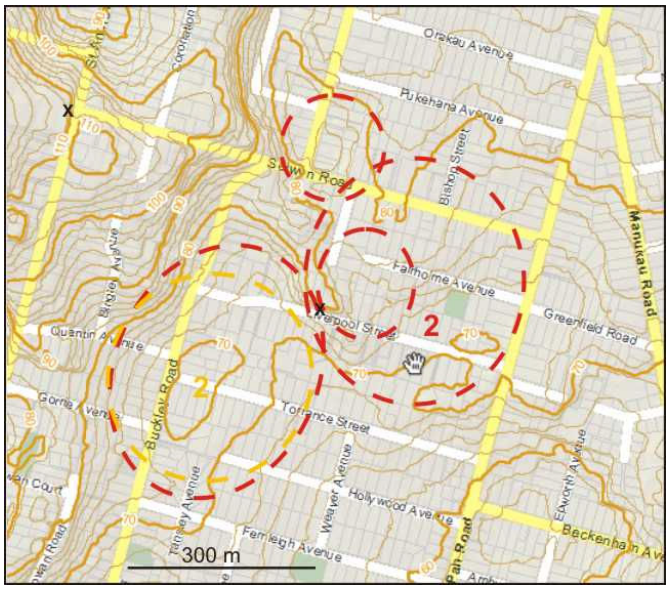


Fig. 5. Present-day contour and street map of area between Pah and St Andrews Rd in vicinity of Liverpool St. Location of Hochstetter's tuff crater 2 (in gold from Fig. 1) and Searle's complex of craters 2 (in red from Fig. 2). Base map from Auckland Council GIS Viewer with 2 m contours.

3. Royal Oak shopping centre

Hochstetter wrote "before the Royal Oak Hotel is reached, there is close by on the left hand side of [Manukau Rd] a small circular freshwater lake, scarcely 30 ft in diameter, filling the crater floor of a very small, very depressed tuff cone, the western margin of which has been cut through by the road." Searle (1962) commented "Although it is not now possible to recognise this feature on the ground or on air photographs, it may be accepted as the site of a former vent." This small depression is easily identified on the new LiDAR map in the sealed yard of 2 Turama Rd and neighbouring properties (Fig. 6). The pond has clearly been drained and partly filled, but was it a volcanic crater? A raised tuff ring rim seems to be lacking and was not obvious even in Hochstetter's time, so a tuff-mantled depression on a One Tree Hill lava flow seems more likely.

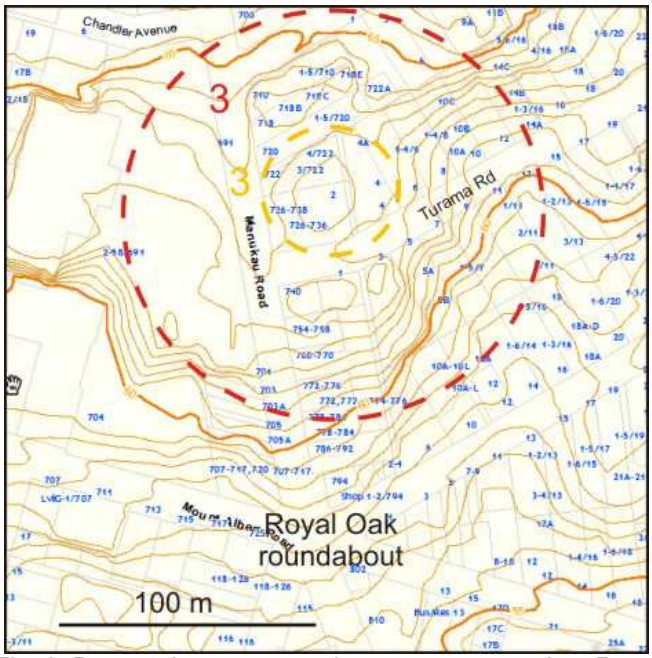


Fig. 6. Present-day contour and street map centred on Royal Oak roundabout on Manukau Rd. Location of Hochstetter's tuff crater 3 (in gold from Fig. 1) and Searle's tuff cone and craters 3 (in red from Fig. 2). Base map from Auckland Council GIS Viewer with 0.5 m contours.

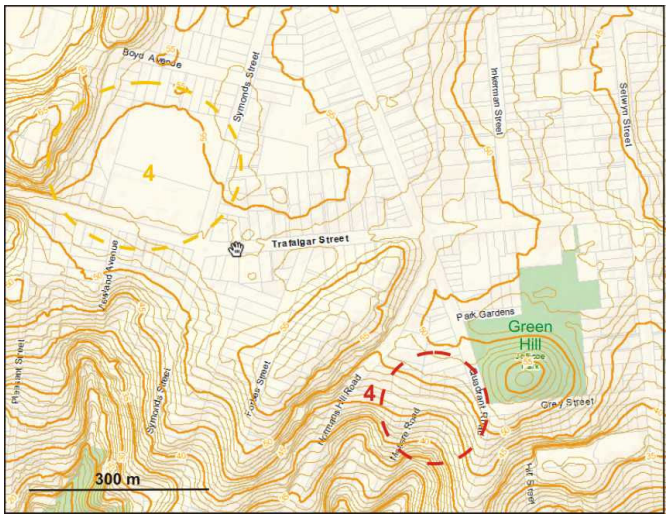


Fig. 7. Present-day contour and street map south of Royal Oak roundabout centred on Trafalgar St and Jellicoe Park (Green Hill). Location of Hochstetter's tuff crater 4 (in gold from Fig. 1) and Searle's crater 4 (in red from Fig. 2). Base map from Auckland Council GIS Viewer with 1 m contours.

4. Jellicoe Park (Green Hill)

Jellicoe Park in Onehunga covers the top of the rounded conical hill once known as Green Hill (Fig. 7). Hochstetter briefly wrote "At the crossroads … the traveller is in the centre of a shallow crater-depression belonging to the tuff cone of Green Hill."His published map, however, (Fig. 1) only shows a crater (4) some distance to the northwest of Green Hill and not at the crossroads. Searle (1962) says "Green Hill is also a body of tuff built in part over the lava flows. Its original form is poorly preserved … and the location of the crater is not now as obvious as it would appear to have been at the time of Hochstetter's visit, for his map shows a well defined craterial depression."

The south side of Green Hill slopes steeply down to the Onehunga foreshore 55 m below. This slope runs west for several km along the south side of Trafalgar St Waitemata Sandstone ridge (Kermode, 1992). It seems far more logical that Green Hill is an erosional hill made of sandstone and draped by Three Kings tuff at the east end of this ridge. One Tree Hill lava flows encountered this sandstone ridge as they flowed down the pre-volcanic valley and turned east to flow down beneath what is now the heart of Onehunga (Kenny at al., 2012). We recognise Hochstetter's "crater" as the flat-floored, very shallow, semi-circular depression that forms the grounds of Royal Oak Intermediate School on the corner of Trafalgar and Symonds St, 500 m northwest of Green Hill. It is not convincing as having had a volcanic origin.

5. Beveridge Swamp

Today the flat, drained floor of Beveridge Swamp is occupied by Marcellin College, Seymour Park and some industrial and residential properties. Queenstown Rd runs through the middle and Mt Albert Rd across the northern side. The former swamp is bordered by a semicircular ridge on the east, south and west side. Hochstetter (1864) wrote "Beveridge Swamp is enclosed by a tuff cone which is in an excellent state of preservation" and showed it as completely encircling the crater (Fig. 1).

Searle (1962) inferred the presence of two craters (Fig. 2) in the depression. "It is confined in the south by a ridge of Waitemata rocks, trending east from the Hillsborough Tertiary high, that is only slightly overlain by tuff. The basin itself is floored with basalt at the eastern end, and … near the middle of the basin drilling revealed basalt 40-50 ft thick beneath a cover of 20 ft of ash. The area is in fact, essentially a valley that has been invaded by basalt flows from One Tree Hill and modified at the head by volcanic activity of the Mt Cecilia volcanoes." "Mt Cecilia is a considerable mound of tuff coalescing with the Three Kings tuff ring. That it is not the product of a single phreatic vent is shown by remnants of small rings disposed about different centres."

A building excavation at Selwyn Village in 2010 showed the presence of just 2 m of tuff overlying weathered Waitemata Sandstone on the ridge on the south side of Hochstetter's well-preserved tuff cone and it seems most likely that the entire semicircle of hills has an inner skeleton of Waitematas buried beneath tuff that thickens in the northeast (closer to Three Kings volcano). We agree that the flat-floored Beveridge Swamp is reminiscent of a crater, but this is not well supported by the subsurface geology (described by Searle above) and it probably owes its origin to thick ash and other sediment filling a swamp that was formed by One Tree Hill's flows damming the head of a small side valley, as inferred by Kermode and Searle (1966) and Kermode (1992). This flat-floored circular feature has limited subsurface data and future excavations, drillholes or geophysical surveys are needed to be certain that it is not a crater.

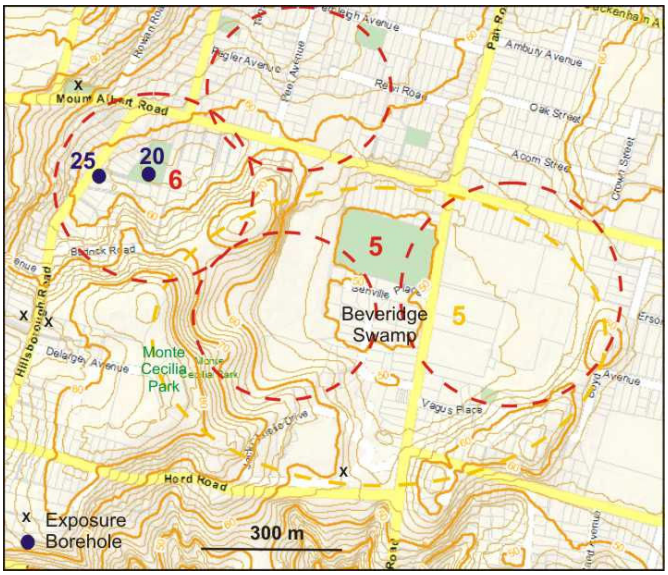


Fig. 8. Present-day contour and street map south of Mt Albert Rd centred on Monte Cecilia Park. Location of Hochstetter's tuff crater 5 in Beveridge Swamp (in gold from Fig. 1) and Searle's crater complex 5 and 6 (in red from Fig. 2). Base map from Auckland Council GIS Viewer with 1 m contours.

6. Hillsborough Bowling Club

One of the small craters inferred by Searle (1962) to have contributed to the thick tuff cap of Mt Cecilia is in the deep depression at the north end of Hillsborough Rd (Fig. 8). Part of the flat floor of this small valley is now occupied by the Hillsborough Bowling Club. Borehole 36 (Fig. 9) on the ridge to the southwest of this depression has 5 m of tuff overlying the Waitemata ridge. Borehole 20 in the floor of the depression (Figs 8, 9) contained 13 m of tuff overlying 2 m of clay sitting on Waitemata Sandstone. Boreholes 25 and 25a (Fig. 9) also in the floor of the depression, intersected 18-19 m of tuff overlying 8-9 m of clay, a basalt flow and clay sitting on Waitematas. In borehole 25, 5 m of clay separates the top of the flow (presumably from One Tree Hill) from the base of the tuff (presumably from Three Kings). The stratigraphy in these cores does not support an inferred crater origin for the depression, but is consistent with it being a pre-volcanic side valley that was invaded by a side branch of the One Tree Hill lava flows (Fig. 10). Many thousands of years later (as inferred from the thick clay) voluminous ash from the

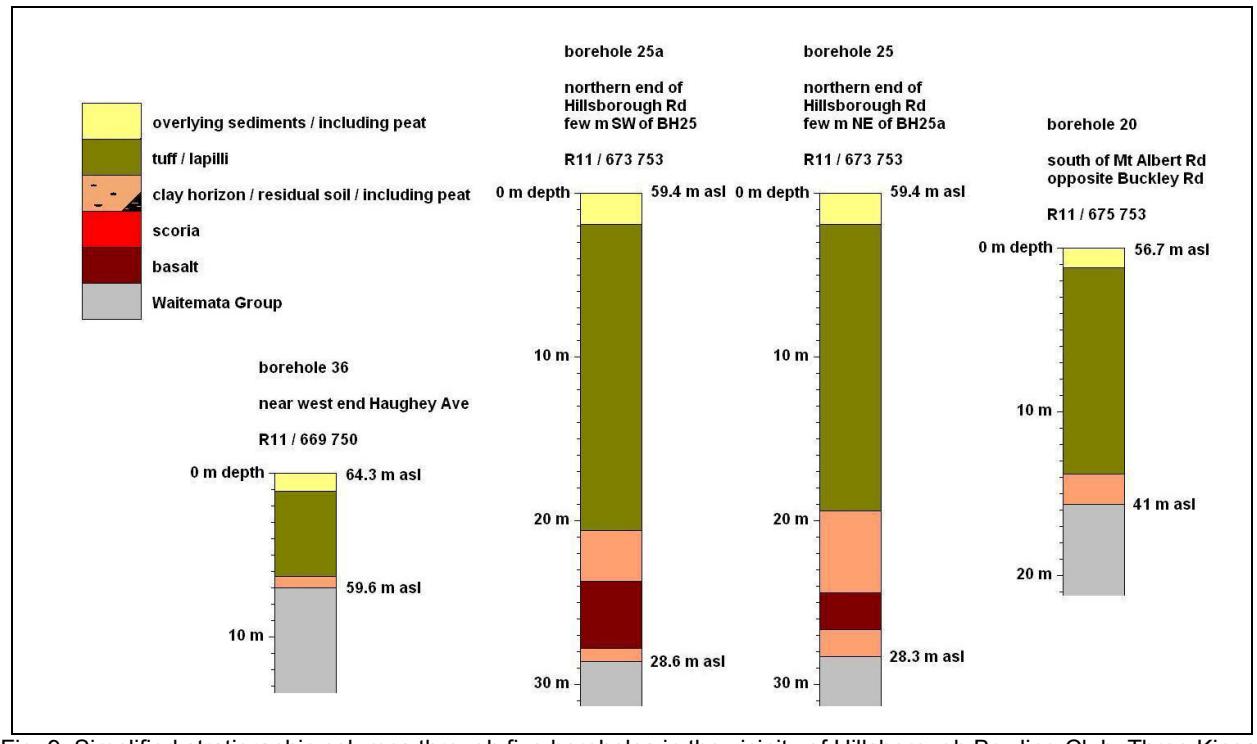


Fig. 9. Simplified stratigraphic columns through five boreholes in the vicinity of Hillsborough Bowling Club, Three Kings.

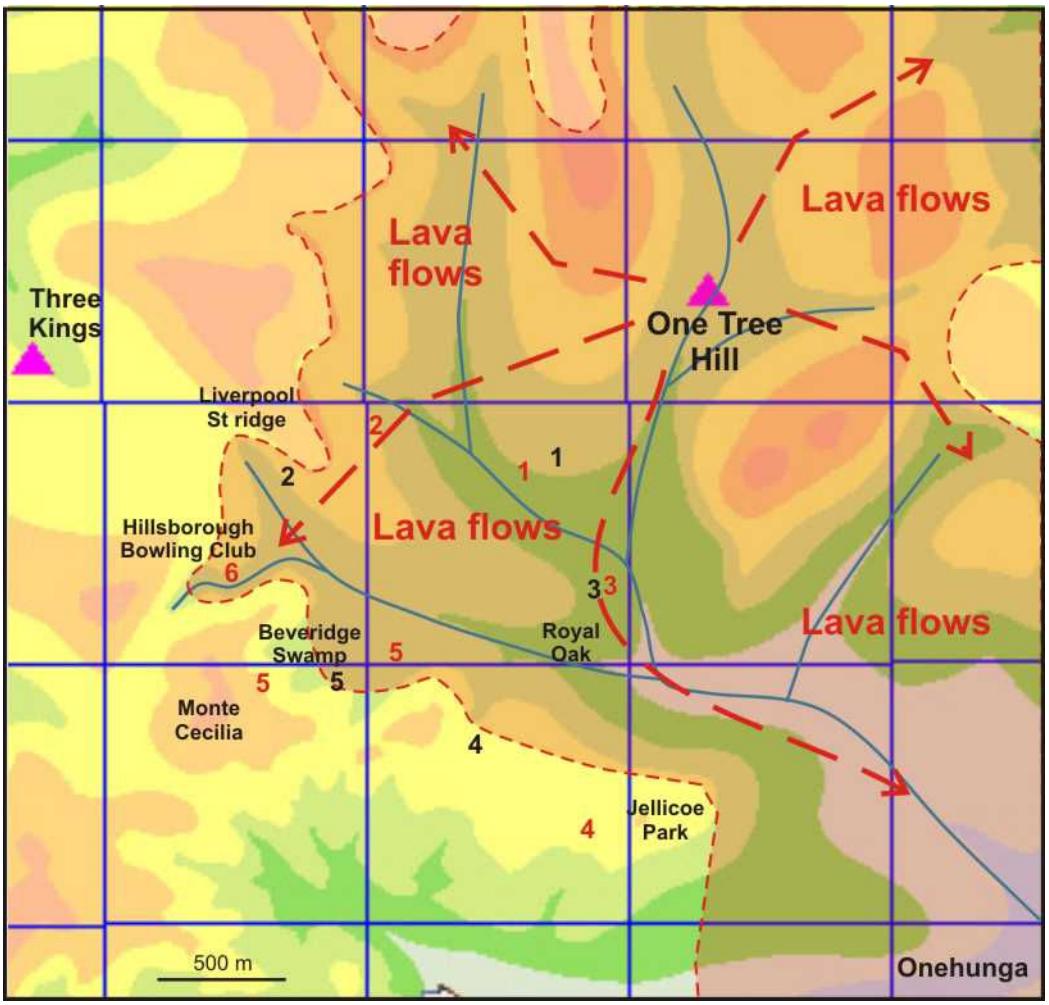


Fig.10. Colour-contoured (10 m vertical interval between colour bands) pre-volcanic topographic map of greater Royal Oak area. Blue shows inferred stream courses and pink shading and red arrows shows inferred lava flows that flooded down the main valley from One Tree Hill volcano. Based on surface exposures and borehole data (part of Fig. 4 of Kenny et al., 2012). Numbers are the approximate locations of Hochstetter´s and Searle´s craters (from Figs 1 and 2) superimposed on the pre-volcanic topographic map using the grid.

nearby Three Kings volcano (28,500 years ago) mantled the whole landscape.voluminous ash from the nearby Three Kings volcano (28,500 years ago).

Conclusions

We could find no conclusive evidence that supported the hypotheses of Heaphy (1860), Hochstetter (1864) and later Searle (1962) that any of the depressions in the Royal Oak area had a volcanic crater origin. We agree that some of the landforms, or reported ponds, swamps and landforms prior to urbanisation, were suggestive of small volcanic craters, but later exposures, excavations and boreholes favour the explanation of Kermode and Searle (1966) and Kermode (1992).

We infer that prior to the eruption of One Tree Hill, probably more than 50,000 years ago, Royal Oak was in the centre of a major southeast-flowing valley (Fig. 10) that drained most of the Epsom area and flowed down past Onehunga to the Manukau Valley (Kenny et al., 2012). Voluminous lava flows from One Tree Hill almost completely filled this valley, not quite overtopping the crest of a major west-east-oriented sandstone ridge between Monte Cecilia and Jellicoe Park. These flows dammed the heads of several small side valleys in the Monte Cecilia area creating swamps. The lava flow field was rocky and highly irregular with a number of large and small depressions, up to 200 m across and 5 m deep. The large explosive eruptions of ash and later fine scoria from nearby Three Kings Volcano, 28,500 years ago, completely buried the rocky surface of the lava flow field in the Royal Oak-Epsom area. This ash sealed the depressions on the lava flow surface such that they filled with water and became small ponds and swamps, many of which were still visible when Hochstetter passed by. This ash and fine scoria cover thins and gets finer away from Three Kings volcano which supports the inference that none of it was erupted locally from any of the Royal Oak “craters”.

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VOLCANOES RECOGNISED BY HOCHSTETTER ON THE MANGERE LOWLANDS

Bruce Hayward

Summary
Hochstetter's (1864) map of the geology and volcanoes of Auckland showed fifteen separate volcanoes on the Mangere Lowlands between Mangere Bridge and Papatoetoe. Firth (1930), Searle (1959, 1961) and Kermode (1966, 1992) only showed ten of these. In this note, I record the observations made during a GeoClub field trip to the locations of each of the five other volcanoes mapped by Hochstetter. These observations together with the advantage of modern LiDAR contour maps lead me to also discard them as unlikely volcanic centres.

Introduction
On January 17 1859 Hochstetter spent one day examining and mapping the volcanoes of the western side of the Mangere Lowlands from Mangere Mt south to Maungataketake and returned to Onehunga. Again late in February 1859 Hochstetter joined William Buckland and over the course of several days visited the eastern parts of the lowland on horseback and mapped the volcanoes (Johnston and Nolden, 2011). Hochstetter's resulting geological map of Auckland (1864) showed six named scoria cones - Mangere, Puketutu, Pukeiti, Otuataua, Maungataketake, Boulton's Hill - each surrounded by lava flows. He also showed nine "tuffcraters" - four with "sunken cones of eruption" (Fig. 1).



Fig. 1. Mangere Lowlands portion of Hochstetter's (1864) map of the volcanoes of Auckland. Volcanoes with crosses are those no longer recognised as volcanic centres.

In August 2011, a GeoClub field trip made a special trip to visit many of these mapped volcanoes, as some of them are no longer recognised by recent geologists (e.g. Firth, 1930; Searle, 1959, 1961, 1964; Kermode, 1966, 1992).

"Boulton's Hill"
All but one of the scoria cones are well-known and their form well documented (before being quarried away in some cases). The exception is Boulton's Hill mapped by both Heaphy (1860) and Hochstetter (1864) as an area of basalt and scoria occupying the flat peninsula of present-day Favona Rd. Hochstetter wrote (translation by Fleming, 1959) "The hill east of Mt. Elliot [Mangere Mt] that forms a peninsula projecting into Onehunga Bay seems to indicate an independent point of eruption, which I have named Boulton's Hill in memory of Mr Boulton, the surveyor who undertook measurements on my behalf in this district". This peninsula is a completely flat portion of the Mangere Lowlands and examination of the cliffs surrounding it show that it is underlain by Pleistocene pumiceous sedimentary rocks of the Tauranga Group (Kermode, 1966, 1992).

We discussed how Heaphy and Hochstetter could have gotten this wrong and decided that they might not have had time to venture over there and must have made their observations from the top of Mangere Mt. We suspect that they may have confused the location with a ridge 800 m east of Mangere Mt, in the direction of Favona Rd peninsula (now underlying modern Mahunga Drive), which is composed of Mangere Mt lava flows and may have had mounds of scoria on its crest that had been rafted away from the eastern breach of Mangere Mt scoria cone. This does not appear to be a separate volcanic centre however.

Two "Tuffcraters with swampy bottoms"
Hochstetter mapped four "tuffcraters" south of Mangere Mt. One is Mangere Lagoon with its small scoria cone, and a second is well-known Waitomokia, and labelled as such, with its scoria cones shown in the middle. Shown northeast and only a couple of hundred metres from Waitomokia is a crater labelled "tuffcrater with swampy bottom". The location where this crater is shown was examined and found to be almost flat (Fig. 2) and may have been swampy when visited by Hochstetter but could not have been surrounded by any sort of tuff ring. There is no evidence to support a crater in this location. Maybe Hochstetter saw swampy ground and inferred this to be a crater, or possibly during his rapid visit he mistook the large and elongate Waitomokia swamp to be two craters.

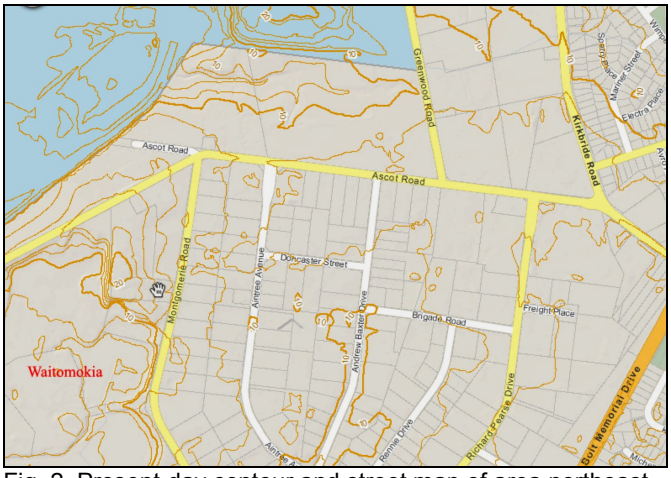


Fig. 2. Present-day contour and street map of area northeast of Waitomokia where Hochstetter (1864) showed one of his two "tuffcrater with swampy bottom". Base map from Auckland Council GIS Viewer.

Hochstetter also shows a triangular-shaped "tuffcrater with swampy bottom" approximately 1 km southeast of Mangere Mt. This location lies between present-day Bader Drive and Halls Ave (Fig. 3) which is a shallow elongate depression 1-2 m deep at most and now with a straight drain down the centre. This was clearly swampy ground when Hochstetter presumably saw it from the top of Mangere Mt but has no sign of any tuff ring around it. Excavation of the nearby southwest motorway a few years ago also showed this flat area to be underlain by a sequence of Pleistocene rhyolitic sediment and peat. There is no good evidence to support an inferred volcano at this location.

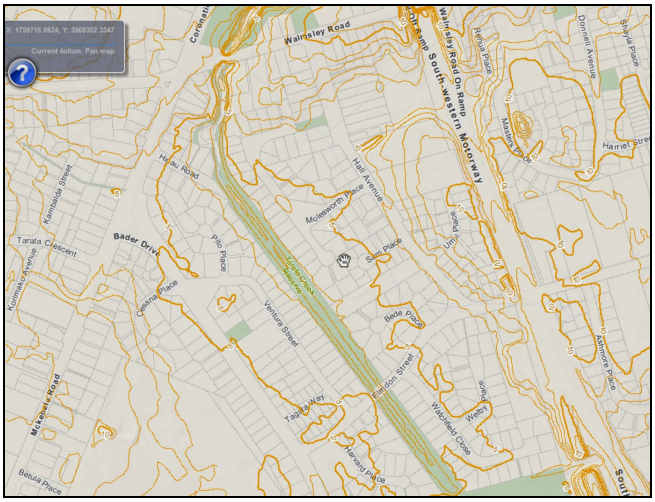


Fig. 3. Present-day contour and street map of area southeast of Mangere Mt where Hochstetter (1864) showed one of his two "tuffcrater with swampy bottom". Base map from Auckland Council GIS Viewer.

"The five Tuffcraters of Kohuora"
In the east central part of the Mangere Lowlands Hochstetter's map shows and labels five tuffcraters surrounded by pink-shaded volcanic ash labelled "fertile volcanic soil" (Fig. 1). Three of these are recognisable by their location and shape as the well-known, large maar craters surrounded by 25-30 m high tuff rings, and now known as Pukaki Lagoon, Crater Hill and Kohuora. Two other "tuffcraters" are also shown. One lies between Pukaki and Kohuora, immediately north of Crater Hill. Its location can be traced to the former swamp that is now drained to form the large playing fields of Aorere Park (Fig. 4). Contours show that this was a shallow depression at 14 m above sea level and is surrounded by flat land with extremely gentle slopes rising 1-2 m above the floor in the north. On the south side the slopes rise gently up the outer northern parts of the tuff rings of Kohuora and Crater Hill, which probably dammed a small creek at the time of eruption, resulting in the formation of this swamp-filled shallow depression. There is no good evidence to support a volcanic crater origin for this former swamp.

At the eastern end of his five "tuffcraters" Hochstetter shows an elongate N-S depression, with no name. Its approximate extent has been transcribed onto a modern contour and street map (Fig. 5) and shows that it would have covered an extensive area of western Papatoetoe, from the old shopping area beside the railway station northwards for 1 km. This area is almost completely flat today with no more than 1 m of elevational difference over most of it. A small stream drained it to the southwest into the Manukau Harbour. There is no topography or geology that supports a volcanic origin and I surmise it must have been covered in wetland vegetation in 1859 for Hochstetter to infer another "tuffcrater" in this vicinity.

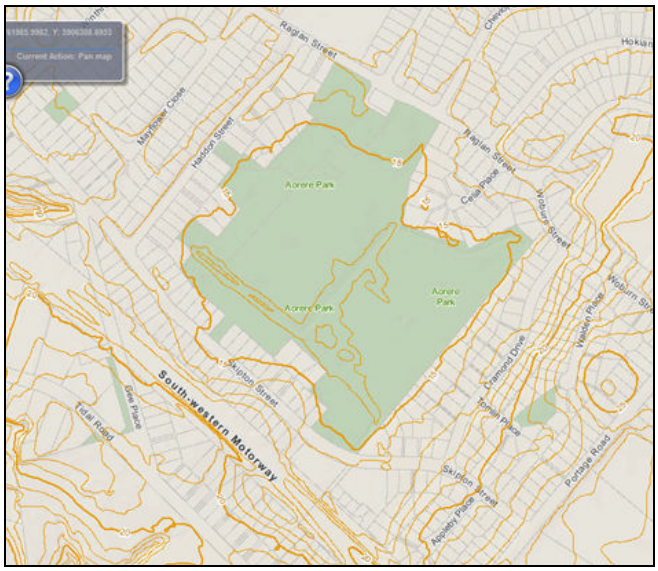


Fig. 4. Present-day contour and street map of Aorere Park area where Hochstetter (1864) showed one of his "five tuffcraters of Kohuora". Base map from Auckland Council GIS Viewer.



Fig. 5. Present-day contour and street map of area where Hochstetter (1864) showed the two easternmost of his "five tuffcraters of Kohuora". Base map from Auckland Council GIS Viewer.

Thus, like Firth, Searle and Kermode, our observations can only confirm three true volcanic craters out of Hochstetter's original "five tuffcraters of Kohuora".

Acknowledgments
I thank Jill Kenny for helpful discussions.

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