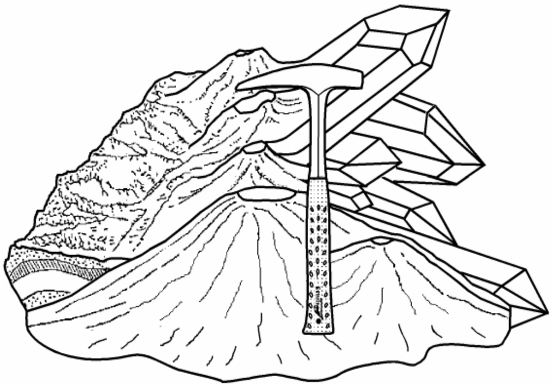

Geocene

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CONTENTS

CORNWALLIS SEA CAVE PROVIDES CLUES TO PAST COASTAL GEOGRAPHY

Bruce W. Hayward

Introduction

In February 2001, 30 members of Auckland GeoClub examined the geology around the southern end of Cornwallis Peninsula (Fig. 1).

Fig.1

As part of that field trip we took the steep clay track from the end of the road down to the boulder beach on the west side of the peninsula. We traversed the rocky shore for 100 m around the base of cliffs composed of volcanic conglomerate of the early Miocene Piha Formation. Just around the first point we came across a small pocket beach of andesite cobbles. At the back of the small beach is a 5 m-wide, 10 m-high cave extending 15 m back into the cliff (Fig. 2).

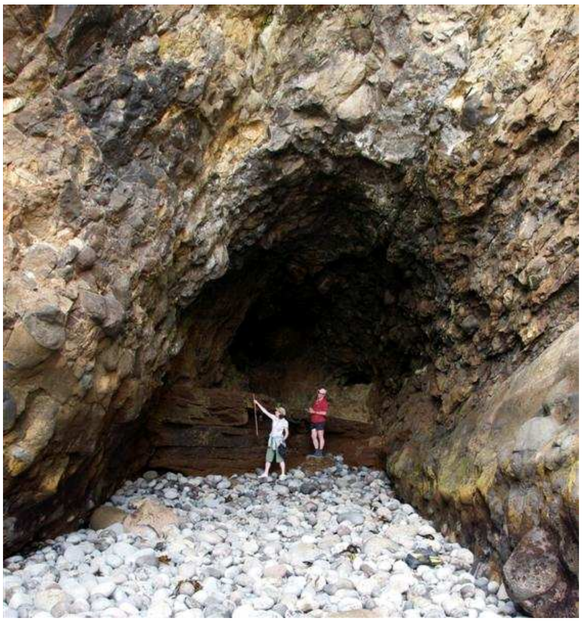

Fig.2

Limonite-cemented black sandstone in sea cave

In the back of the cave we discovered a 2 m + thick deposit of limonite-cemented sandstone, with slightly wavy, near-horizontal bedding. The base of the sandstone is hidden beneath the cobble beach, but the sandstone is overlain by 1-2.5 m of rubbly breccia with a soft clay matrix (Fig. 3).

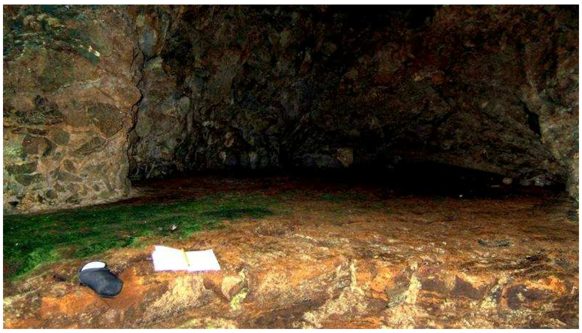

Fig.3

This breccia is clearly roof collapse debris that has accumulated in the back of the cave on its sandy floor. Wave erosion is removing the softer breccia faster than the underlying cemented sandstone and has exhumed some of the former sand floor of the cave (Fig. 4).

Fig.4

The base of the exposed limonite-cemented sandstone deposit is approximately mean high water level. Only storm waves on a high spring tide are likely to sweep to the elevation of the roof-collapse breccia.

The limonite-cemented sandstone was, prior to its cementation, titanomagnetite-rich sand, similar to the black sand on the nearby west coast beaches today. The well-sorted sand with thin near-horizontal bedding is suggestive of accumulation as beach sand in the back of the cave. A later trip further around the west side of the peninsula showed that there were further smaller deposits of limonite-cemented sandstone preserved at a similar level inside several other small caves all the way out to the southern tip of the peninsula. Today there is no sand out along this section of Cornwallis Peninsula coast. The preserved black sandstone in these caves indicates that this was not always the case.

Other exposures of limonite-cemented black sandstone at Cornwallis

Limonite-cemented black sandstone deposits exposed at sea level around Cornwallis wharf have been known since the time of Hochstetter's visit in January 1859 (Fleming, 1959). In the mid 20th century a 5 m+ thick deposit of cross-bedded limonite-cemented dune sandstone was exposed in a road cutting between the wharf and the end of the Cornwallis Peninsula Rd (Jones and Martin, 1965; Hayward, 1975; Kermode, 1992).

Discussion

The black sand preserved inside the caves along the south western side of Cornwallis Peninsula appears to have been deposited by the sea rather than wind. This implies that it was deposited during a period when sea-level was close to the present level, i.e. during a warm interglacial period. At this time there was more sand along this section of coast than there is today and thus the main Manukau Harbour channel was probably further to the south. It is likely that all the black sand deposits on the end of Cornwallis Peninsula (in the caves on the west side, 20 m above sea level in the saddle and on the beach on the east side) were deposited at the same time, when there was a build up of sand swept in from the Tasman Sea and deposited along the west coast of the peninsula. The sand dune deposits near the crest of the peninsula indicate that sand was blown up there and probably advanced as a dune tongue down to the Cornwallis wharf area. For this to happen a source of dry sand above high tide level needs to have been available on the west side of the peninsula. I speculate that a strip of black sand dunes built up along the western side of the peninsula (Fig. 5) and may also have cut our cave deposits off from the sea – as has happened today with the caves at Whatipu. This probably aided in the preservation of cave sand deposits.

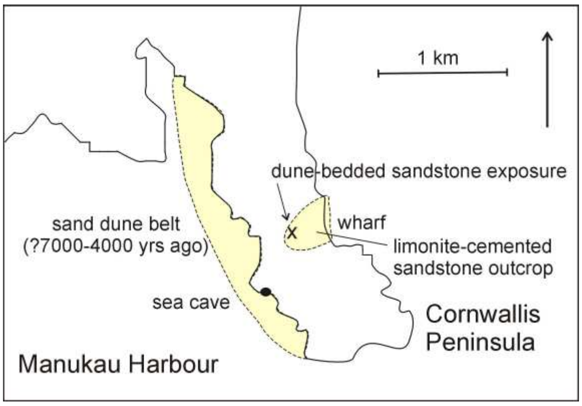

Fig.5

The big unknown is the age of these limonite-cemented black sand deposits. The source of black sand to the west coast has been available from the central North Island and Taranaki volcanoes for about the last 2 million years and most of Awhitu Peninsula sand dune barrier is younger than 1.2 million years. It is hard to believe that the Cornwallis Peninsula and sea caves have retained their present shape without considerable weathering during glacial low sea levels and erosion during interglacial high sea levels for anywhere near this length of time. Indeed it seems unlikely that these cave deposits would have survived through the Last Interglacial about 130,000 years ago, when sea level was 5-6 m higher than present. At that time, either sand would have completely filled the caves subtidally or it would have eroded out completely. I therefore speculate that the most likely age for the sea cave deposits is either towards the end of the Last Interglacial (c. 125,000 yrs ago) as sea-level was starting to fall or early Holocene, (c. 4000-7000 years ago) when sea level may have been 1-1.5 m higher than present. This is younger than I would initially have thought, based on the amount of limonite cementation of the sand.

Conclusion

Deposits of old black sand preserved in the back of sea caves along the southwest coast of Cornwallis Peninsula, together with similar wind-blown deposits on the nearby crest and eastern shore of the peninsula, suggest that during a recent interglacial period (possibly last Interglacial or the early Holocene) a strip of black sand dunes accumulated along the western side of the peninsula. The sand dunes have subsequently eroded away and this western shoreline is now a rocky coast.

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OAMARU’S ICONIC LIMESTONE

Margaret S. Morley

Every town and city seeks to promote itself as a desirable destination, Auckland is the “City of Sails”, while Wellington is “Positively Wellington”. The publicity machine of Oamaru did not need to look far to find its focus, the attractive heritage buildings with their intricate carvings are prominent on the street, while the limestone that gave them birth is beneath their feet.

Limestone geology

In the early Oligocene 35-32 million years ago, the New Zealand area was largely under water and consisted of just a few islands (e.g. Fleming, 1962). Ototara Limestone is composed of bryozoa which accumulated on the sides of Eocene-Oligocene volcanic cones. These cones had erupted in shallow seas in the vicinity of what is now the Oamaru coast. Since there was no land to provide sediment, the bryozoan shell deposit remained pure with very little added mud or sand (Ototara Limestone is more than 95% calcium carbonate). The friable bryozoa were later buried by further sediment and compacted and lightly cemented into limestone. Ototara Limestone is not fractured by joints nor strongly cemented or recrystallised. This makes it is easy to cut. Because of its purity, it does not weather fast and if it is sealed with silicone it has great durability as a popular building stone.

GeoClub visit, November 2009

On one trip during our Otago visit we were fortunate to be escorted around Parkside quarry (Fig. 1) near Weston, Oamaru, by co-owner Linda Mitchell.

Fig.1: Parkside Quarry, 2009.

She gave us a fascinating glimpse into the history and quarrying operation. It is the largest building stone quarry in New Zealand. There are now two quarries at Parkside, one producing building stones and one on the opposite side of the hill for fertiliser. Their own verdant sheep farm is testament to the value of adding lime to the soil. The owners estimate that at the present rate of extraction there is at least another 1000 years of quarrying on the site. The available depth is limited because the rock is saturated with ground water 30 m down.

From 1862 there were various small limestone quarries, now disused, in the Oamaru District. Parkside is the only one still operational. In 1908 when Parkside Quarry was opened, stone masons used heavy picks and shovels. Blocks were taken away by steam trains. Linda pointed out that the large cracks in one face of the quarry are not faults but resulted from the early use of explosives. The pure white limestone is worked today using circular metal saws, 3 m in diameter. Rails are pre-set to guide the double chainsaws across the quarry floor. The limestone blocks are broken out with a large forklift-loader, transferred to trucks and stockpiled near the factory. Dust is kept to a minimum by cutting blocks wet. Each weighs four tonnes, but after drying this reduces to two tonnes. These impressive piles were dazzling in the sunlight.

There are 3 breakdown saws, each 1.8 m in diameter and strengthened with tungsten tips. One of these is semi-computerised and the original saw has been modified to feed stone through automatically. Using plans, the blocks are cut to the specific requirements of each building. Today Oamaru Limestone is usually used as a veneer with a thickness of 100 mm and not as structural components of a building as in the earlier days. Oamaru stone is cheaper than wood for cladding houses, so long as it does not have to be transported far. Completed orders are strapped and stacked onto pallets for transportation. Parkside supplies blocks for about three houses a week. It is important that the blocks are laid by builders in the same orientation as they were in the ground. If placed “out of its bed” (i.e. bedding plane vertical) the stone flakes and deteriorates necessitating early replacement of that block.

Some 2% of the limestone is second grade because of small iron impurities. This is sort-after by carvers who gain inspiration for their sculptures from the coloured banding. Finished sculptures are sealed with water and silicon. The cost of transporting sculptures is critical so pieces are weighed before dispatch. Sometimes a piece is further refined or an additional section pared down.

Some layers in the quarry are too hard and cemented and are not suitable for building. An alternative use has been developed for these, in which they are crushed for use by farmers to surface farm races for dairy cows, thus minimising mud and being therapeutic for their hooves.

Fossils bivalves, whale and penguin bone have been found in the limestone.

The Opera House in downtown Oamaru was the first major building to be built of Parkside limestone. It has recently been restored, upgraded inside with modern equipment and was the venue for the 2009 Geological Conference. The GeoClub members who attended the conference appreciated its atmosphere and décor. The heritage Harbour Street was a great attraction highlighting buildings as they were in the 18th century (Fig. 2).

Fig. 2. 19th century banks in Oamaru’s main street, made of Oamaru Stone.

We visited various factories, shops, watched a Clydesdale horse, a penny farthing being ridden and attended a light-hearted historical play. The Geological Society annual dinner was held in another Oamaru stone building - the New Zealand Malt Whisky Company in the historic precinct. The majority of guests dressed in period costume adding to the atmosphere created by vast rooms stacked high with barrels.

Thanks:
To Bruce Hayward for reading the MS and suggesting improvements.

RATE OF CLIFF RETREAT, MURIWAI

Bruce W. Hayward

When I was doing field work for my PhD in the Waitakere Ranges in the 1970s I took photographs of many different features. One feature that intrigued me was the water expulsion “flames” within the volcaniclastic sedimentary rocks that form the cliffs behind Fishermans Rock, Otakamiro Pt, at the south end of Muriwai Beach (Fig. 1).

Fig. 1. Oblique aerial photograph of Otakamiro Pt, south end of Muriwai Beach, showing the high-tidal shore platform (Fishermans Rock) along the northern side with people fishing from it.

I published a picture of these structures in the field guide to Muriwai (Hayward, 1979, Fig. 24). When revisiting the site in 2005 with Geoclub, I took out the picture in the field guide (Fig. 2) and relocated the feature. To my initial surprise the detail of the structure had changed (Fig. 3) and then I realised that this would have been due to cliff retreat over the intervening 30 years. This part of the cliff is seldom if ever pounded by breaking storm waves, so the main method of erosion is presumably from wetting and drying from salt spray and the consequent growth of salt crystals in the spaces between the sand grains.

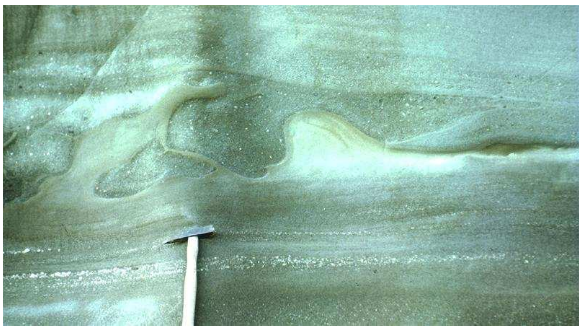

Fig. 2. Water expulsion features in volcaniclastic sandstone, Fishermans Rock, Muriwai, 1975.

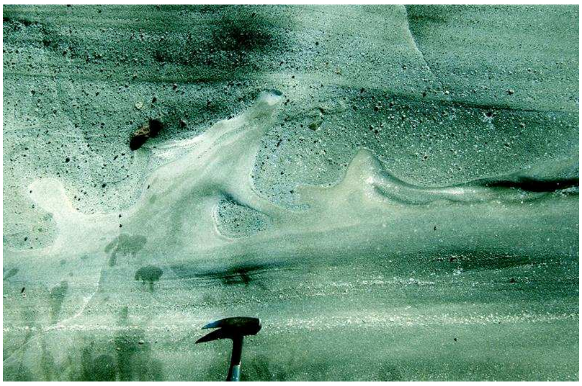

Fig. 3. The same water expulsion features in volcaniclastic sandstone, Fishermans Rock as in Fig. 1, Muriwai, 2005.

Comparison of the two pictures enables me to estimate the amount of cliff retreat that has occurred in 30 years at about 5 cm or 15 cm/100 yrs. This translates to a rate of 1.5 m per 1000 yrs or approximately 11 m in the last 7000 yrs since sea level reached its present level after the end of the Last Ice Age. The width of the adjacent high tidal platform on Fishermans Rock is approximately this width (Fig. 4) and supports my hypothesis that the width of intertidal rock platforms today usually equates to the amount of cliff retreat that has occurred during the Holocene period of present sea level.

Fig. 4. The high-tide platform of Fishermans Rock at Muriwai has been formed by cliff retreat behind over the time since sea level reached its present level in the early Holocene about 7000 yrs ago. Photo taken on Geology II field trip 1969.

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AN OVERVIEW OF SEQUENCE STRATIGRAPHY

Rhiannon Daymond-King

Sequence stratigraphy is a geological tool which links groups or packages of sedimentary deposits, bounded by unconformities or sequence boundaries, to stratigraphic units controlled by changes in relative sea level and sediment supply. It emphasises facies relationships and stratal architecture within a chronological framework (Catuneanu *et al*., 2009).

Sequence stratigraphy is an important tool of the exploration geologist because it allows prediction of subsurface strata, especially in conjunction with seismic surveys. It can be used to predict reservoir presence and quality, as well as source rock presence and quality (Bohacs and Suter 1997), and the presence and quality of suitable seal rock.

The type of deposits in the different packages depend primarily on a) relative sea level, b) sediment supply, and c) their accumulated effect on the accommodation space available and rate of sedimentation within that space.

Sea level – tectonism/eustasy/bounceback

Relative sea level is measured between the sea surface (usually mean sea level, MSL) and a local datum. The three main mechanisms of sea level change are tectono-eustasy; sediment-eustasy; and glacio-eustasy (Neal *et al.,* 1993).

Tectono-eustasy is controlled by deformation of the ocean basin, isostatic changes in crustal/lithospheric thickness caused by stretching and/or cooling (Allen and Allen 2005). Viscous flow of the mantle may also cause nonpermanent subsidence or uplift known as dynamic topography (Allen and Allen 2005).

Sediment-eustasy is controlled by addition of sediments to basins causing sea level rise, and also loading or unloading of the lithosphere through deposition and/or erosion.

Glacio-eustasy is controlled by climate, lowering sea level during glaciation and raising it during deglaciation (Neal et al 1993).

An equation relating sediment supply, accommodation space and relative sea level change is: Δ water depth = Δ eustasy + Δ subsidence + Δ compaction – sediment deposited (Myers and Milton, 1996).

Surfaces and Boundaries

SB: Sequence Boundary. Sequence boundaries are identifiable surfaces able to represent a single timeline continuous from the coast to the deep basin. Some features commonly associated with sequence boundaries are paleosols and incised valleys on land, erosional truncations, unconformities and condensed sections in offshore marine settings.sequence boundaries may be identified on seismic by bold, high amplitude reflectors that are relatively continuous from shelf to basin floor. Identifying slumps or basin-floor fans can help with sequence boundary placement (Hansen and Kamp 2006). A SB is formed at the end of a highstand in sea level, at the time when relative sea level begins to fall, and the coastline and shelf edge begin to move basinward. Sediments from the following sequence onlap the aerial part of a previous sequence boundary, and downlap onto the basinward part of the sequence boundary. A SB may lack a basinward shift in facies if formed when the rate of eustatic sea level fall is less than the rate of basin subsidence, so that no relative fall in sea level occurs at the shoreline position (Kendall 2003).

MFS: Maximum Flooding Surface. Marks the time of maximum flooding or transgression of the shelf, separating the HST from the TST (Vail and Mitchum 1977). In the offshore basin it is often a condensed section; radioactive, glauconitic, pyritic or organic shales may be present. Condensed sections often contain increased microfossil abundance, permitting accurate age determination (Carter *et al.,* 1998). Condensed sections often contain marine hardgrounds, omission surfaces, radioactive matter, glauconite or high organic matter, and as such are easily recognised in outcrop and well logs – used by Galloway (1989) as alternative location for the sequence boundary.

TS: Transgressive Surface. Formed by the first significant flooding event in a sequence. This marks the onset of the period when the rate of increase in accommodation space is greater than the sediment supply. It separates the TST from the LST (Kendall 2003).

Parasequences

Parasequences may be pro-gradational, retrogradational or aggradational with respect to each other (Figure 1).

At any one locality in New Zealand, a mid-Pleistocene sequence contains up to four stratal discontinuities: the sequence boundary, ravinement surface, local flooding surface, and downlap surface. These physical surfaces are regionally diachronous in outcrop, and should be differentiated from theoretical isochronous horizons such as the maximum flooding surface or peak eustatic/local sea level (Carter *et al.*, 1998).

Running laps – onlap, downlap, toplap

Onlap is generally a sign of either increased accommodation space, or increased sediment supply, or a combination of both. The coastline may retreat landward through rising sea level.

Downlap occurs against a fairly flat surface, often as a result of progradation over a sequence boundary or condensed section. The downlap surface itself is not a single regional surface and does not usually coincide with maximum flooding horizon (Carter *et al.*, 1998).

Toplap may occur during a forced regression as sea level drops, or in a situation of oblique progradation (Figure 2) due to increased sediment supply but without an increase in accommodation space.

Truncation of beds is usually a sign that there is an unconformity against the truncated beds, often a transgressive ravinement surface or a forced regressive aerial erosion surface.

Package deal – Systems tracts

The following are described within the scheme put forward by Hunt & Tucker 1992, 1995; Plint & Nummedal 2000; Kendall 2003.

Falling Stage Systems Tract (FSST): Also known as Early Lowstand Systems Tract (ELST), or as Regressive Systems Tract (RST) together with LST. Caused by falling sea level, with high enough sedimentation rate that the sequence progrades obliquely (Figure 2) or downsteps. An erosional ravinement surface is often developed at the coastline as it steps basinward. Downlap occurs basinward onto the previous sequence boundary.

Lowstand Systems Tract (LST): Formed at lowest part of the sea level curve (Figure 3), with the development of limited accommodation space during a lowstand (Kendall 2003). The depositional setting is below the shelf margin break and includes basin floor fans often filling incised valleys. This tract is not preserved in all sequences.

Transgressive Systems Tract (TST): Deposits formed from the onset of coastal transgression to the time of maximum transgression of the coast, just prior to renewed regression. Parasequences downlap onto the transgressive surface (TS) in a basinward direction, and onlap and retrograde across the transgressive surface in a landward direction. Erosion is caused at the coastline as it moves landwards with rising sea level. Sedimentation is commonly low basinward and condensed sections may form (Kendall 2003).

Highstand Systems Tract (HST): Formed when sediment accumulation rates exceed the rate of sea level rise, or when sea level is at a high stillstand. Parasequences prograde basinward. Depending on the sedimentation rate and the slope, they may downlap onto the maximum flooding surface. Basin floor fans may spill into the deeper basin, or with low sedimentation rates there may be a condensed section basinward.

Schools of sequence stratigraphy

In 1669, Nicholaus Steno recognised that strata are formed as heavy particles settle out of a fluid, and that some strata contain remnants of other strata must be younger (Neal *et al.*, 1993)

What may be considered the earliest form of sea-level based stratigraphy was the Telliamed by de Maillet, published in 1748. De Maillet proposed that the Earth's water envelope diminished in volume through time, a single one-way sea-level fall known as Neptunism (Emery 1996). This caused erosion on the exposed tops of primitive mountains, with deposits prograding outwards at new lower sea levels, much like a forced regression.

Independent vs. dependent aspects

Model independent aspects of sequence stratigraphy are the basic concepts: stratal stacking patterns, terminations, accommodation space, base-level changes, systems tracts linked to types of shoreline trajectories, the idea of bounding sequence stratigraphic surfaces, and finally a workflow to subdivide the section into a succession of units bounded by stratigraphic surfaces (Catuneanu *et al.,* 2009).

Aspects of sequence stratigraphy that are model-dependent include the precise nomenclature of systems tracts (e.g. Figure 4), different types of genetic deposits, the nomenclature of sequence stratigraphic surfaces, and the selection of sequence boundaries (Catuneanu *et al.,* 2009).

Depending on situation, any one of the models may provide the optimum approach to the sequence stratigraphic analysis. For example, the selection of sequence boundaries may depend on depositional setting or the type of data available for analysis (Catuneanu *et al.*, 2009).

Vail's 1987 model (Figure 5) recognises a mid-cycle condensed section and maximum flooding surface, with the SB situated above the HST and below the basin-floor fans and forced regression package within Vail's TST. Hunt and Tucker's 1992 & 1995 model (Figure 5) introduces the FSST for the forced regression part of the sequence, and moves the SB to between the FSST and the LST at the lowest sea level. Van Wagoner's 1990 model, following Vail 1987, contains LST, TST and HST tracts, but places the SB between the HST and LST and a MFS between the TST and HST.

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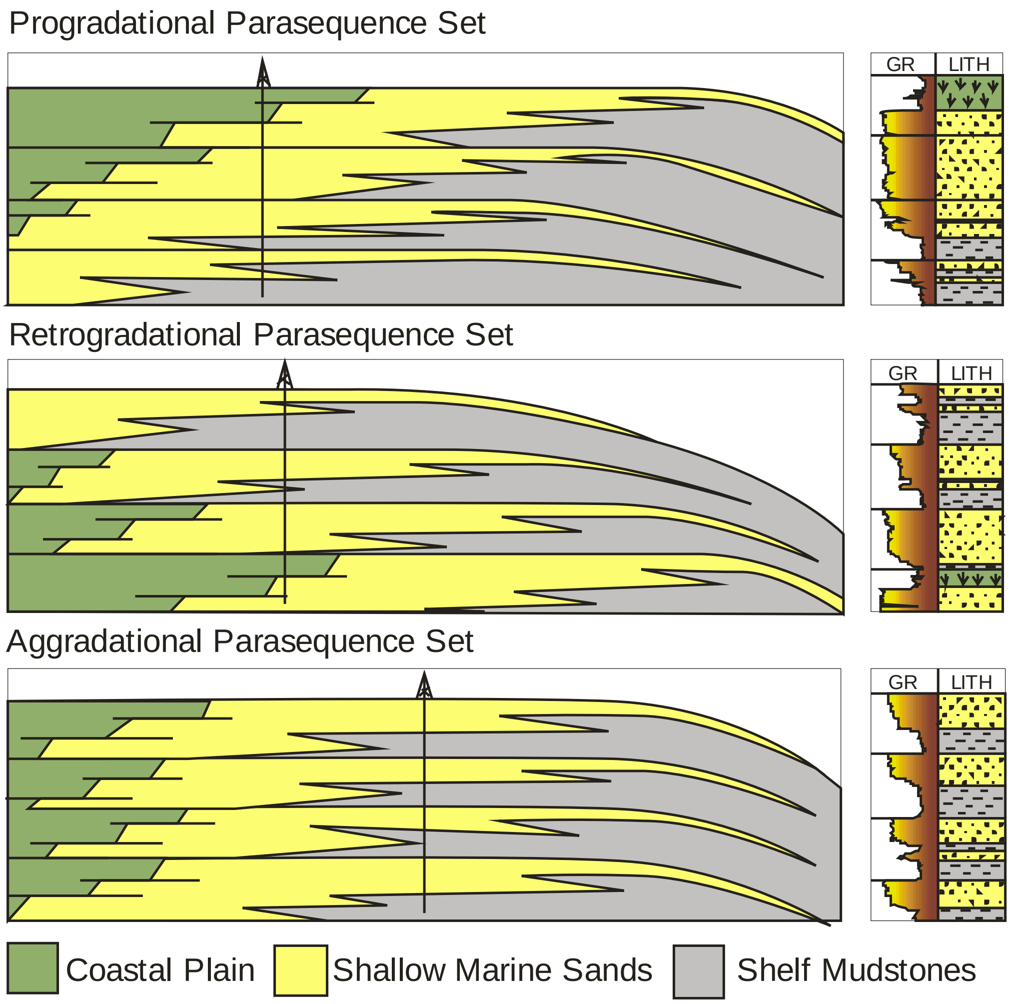


Figure 1: Parasequence sets and log responses. After Van Wagoner, 1990.

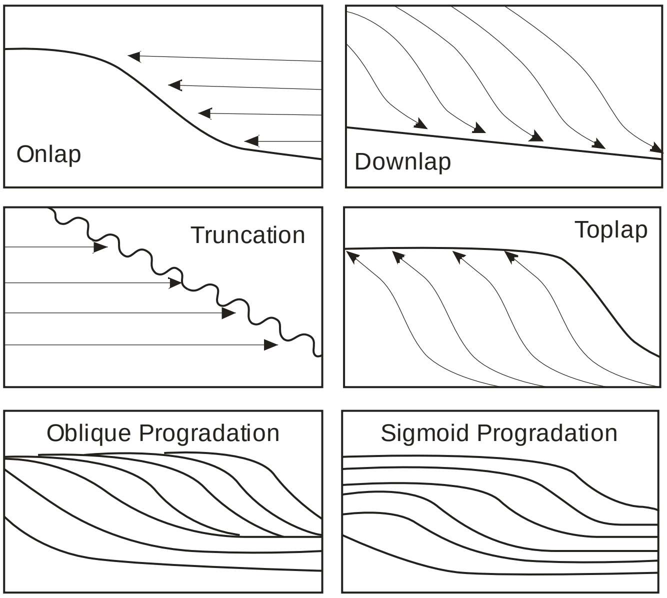


Figure 2: Types of surface terminations and progradation. After Vail and Mitchum 1977.

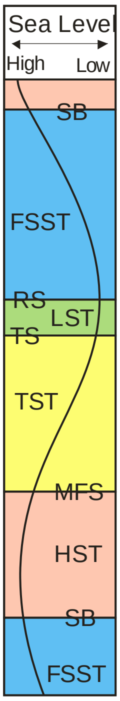
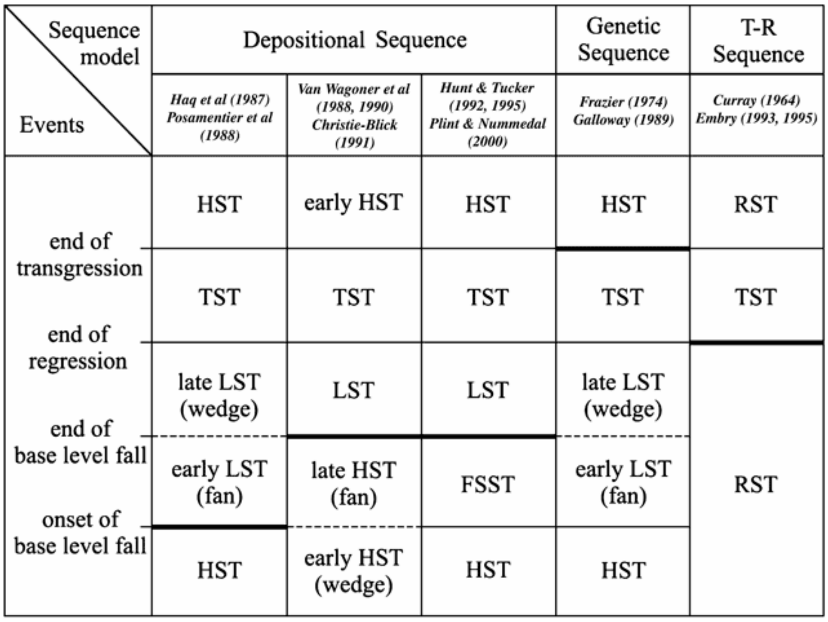


Figure 3: Systems tracts and sea level



Sequence model / Events	Depositional Sequence			Genetic Sequence	T-R Sequence
	Haq et al (1987) *Posamentier et al (1988)*	*Van Wagoner et al (1988, 1990)* *Christie-Blick (1991)*	*Hunt & Tucker (1992, 1995)* *Plint & Nummedal (2000)*	*Frazier (1974)* *Galloway (1989)*	*Curray (1964)* *Embry (1993, 1995)*
	HST	early HST	HST	HST	RST
end of transgression	TST	TST	TST	TST	TST
end of regression	late LST (wedge)	LST	LST	late LST (wedge)	RST
end of base level fall	early LST (fan)	late HST (fan)	FSST	early LST (fan)	
onset of base level fall	HST	early HST (wedge)	HST	HST	

Figure 3: Different sequence stratigraphic models, with sequence boundary in bold.
From Catuneanu 2002.

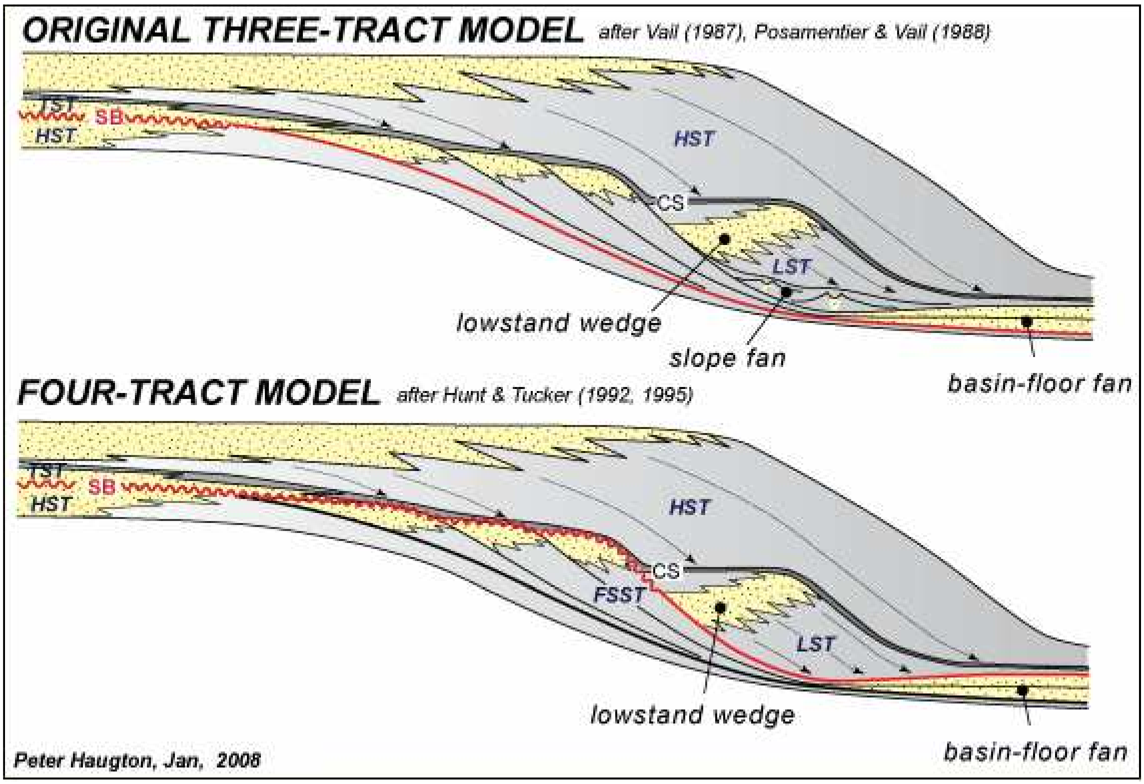


Figure 4: Comparison between Vail's and Hunt's models. From Holland, 2008

GRAFTON VOLCANO

Bruce Hayward, Jill Kenny, Roger High, Sian France

Summary

The results of recent borehole drilling and building excavations in the Grafton-Auckland Domain area are used to better constrain the geology in this area and to recognise a far more extensive volcano underlying the suburb of Grafton than previously thought. The central and western parts of this Grafton Volcano comprise a tuff ring arc (forming higher parts of Grafton Rd ridge and buried beneath Auckland Hospital) surrounding a 600 m diameter explosion crater (extending from Khyber Pass to Auckland Hospital) filled with a 50 m+ thick solidified lava lake (basalt), which underlies and surrounds scoria cones/mounds that erupted from two vents within the crater (Outhwaite Park, east end of Auckland Hospital). The Grafton Volcano has previously been only partly recognised because its products and landforms are buried beneath the 2-10 m of volcanic ash that forms the western sector of the Domain tuff ring.

From the new subsurface information we infer that the Domain Volcano probably erupted 5-100 years after the Grafton Volcano from a separate batch of magma that rose up the conduit. The Domain explosion crater erupted 500 m east of Grafton Volcano and blasted through and destroyed the eastern arc of Grafton Volcano's tuff ring and basalt-filled crater floor, creating its own 600 m diameter explosion crater and surrounding tuff ring. Later dry eruptions produced a small central scoria cone again with lava flows or a lava lake filling its explosion crater. Late phase lava withdrawal down the vent may be responsible for a 10 m difference in the height of the top of the basalt lava in the higher eastern part of the crater from that in the western and northern (duck ponds) parts. Subsequently a swampy lake formed in the western part of the Domain crater and accumulated 6-9 m thickness of peat and clay on top of the basalt. The fractures and rubble within the solidified lava flows/lakes of Grafton and Domain volcanoes now forms a significant groundwater reservoir utilised by Auckland Hospital and the Domain.

Whether the Grafton and Domain volcanoes are recognised as separate volcanoes or merely two halves of a more complex single volcano is a matter of personal opinion and semantic debate.

Introduction

In April 2010 a group of GeoClubbers met in Auckland Domain and spent several hours exploring on the ground, the evidence provided by recent drilling of a basalt volcano that has been largely hidden from site and little known until now – the Grafton Volcano. Most of the remains of this volcano lie buried beneath volcanic ash erupted from its immediate neighbour the Domain Volcano. It lies beneath the area now occupied by Auckland Hospital, the Auckland Medical School and the surrounding older suburb of Grafton (Fig. 1).

Fig.1: Aerial photograph, 2009, of the location of Grafton Volcano, west of Auckland Domain explosion crater and mostly buried beneath the western part of the Domain Volcano's tuff ring.

Previous studies

Charles Heaphy (1860) was the first to map Auckland's volcanoes (Fig. 2) and presented his map to the Auckland Mechanic's Institute in 1857 (Mason, 2003). At the time he was the Surveyor-General of Auckland Province and would have been skilled at map reading and preparation. His map shows volcanic ash covering the area we recognise as the Domain Volcano and Grafton. The nearest recognised volcano is shown as a large circle (15) drawn around the high point at the junction of Symonds St and Khyber Pass.

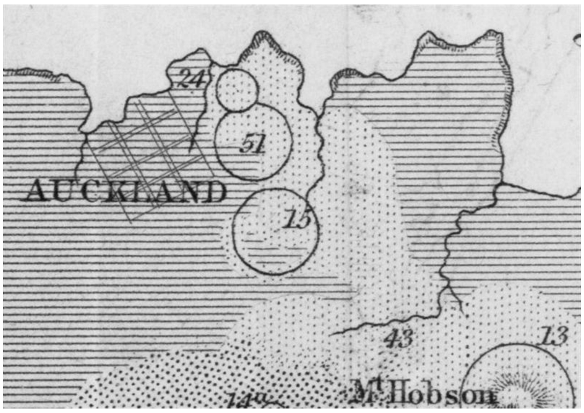


Fig.2: Part of Heaphy's (1860) map of Auckland's Volcanoes showing only tuff mapped where the Domain and Grafton Volcanoes are now recognised (east of 15, a volcano recognised at the top of Symonds St).

In early 1859, Ferdinand von Hochstetter (1864) mapped the volcanoes of Auckland in more detail than Heaphy. His original map was drafted by Heaphy and later transcribed by Petermann and published in Germany (Fig. 3). He shows four small tuff craters and/or mounds between the top of Symonds St and the Domain. If they are accurately located, then one is centred on the small scoria cone in the centre of Auckland Domain, another on Outhwaite Park's low scoria cone hill and two on the high ridge near the junction of Symonds St and Khyber Pass. In his account (translated by Fleming, 1959, p.191), Hochstetter wrote "South of the town of Auckland, along Khyber Pass, four small tuff cones lie together. The Domain and the gardens and farm establishments attached to it owe their exceptionally fertile soil to these tuff cones, which still to some extent show depressions representing their craters."

Fig.3: Part of Hochstetter's (1864) map of Auckland showing a small tuff crater/mound (in grey) on the site of the Domain volcano and another centred on Outhwaite Park, Grafton.

After a century, Ernie Searle (1962) was the next to undertake extensive studies of Auckland's volcanoes. Both he and later Les Kermode had the benefit of many years of excavation and drillhole records to better interpret the geology observed on the ground by Heaphy and Hochstetter. On his map (Fig. 4) he shows tuff covering all the area from the top of Symonds St to the Domain and within this identifies the Domain crater surrounded by a tuff ring and with a "scoria mound" in the middle. He also shows a second slightly larger "scoria mound" forming Outhwaite Park hill. He writes (Searle, 1962, p.61) "The group of volcanoes on the higher ground at the head of the Mechanics Bay. Time and man have obliterated many of their features but even in the middle of last century it was impossible to define them precisely, because eruptions had been predominantly explosive and the whole area was heavily blanketed with tuff. One large centre was probably at the top of Symonds Street. There is now no crater to fix its exact position but the thickness of the tuff mantle and the coarseness of the fragments suggest that the centre was there.

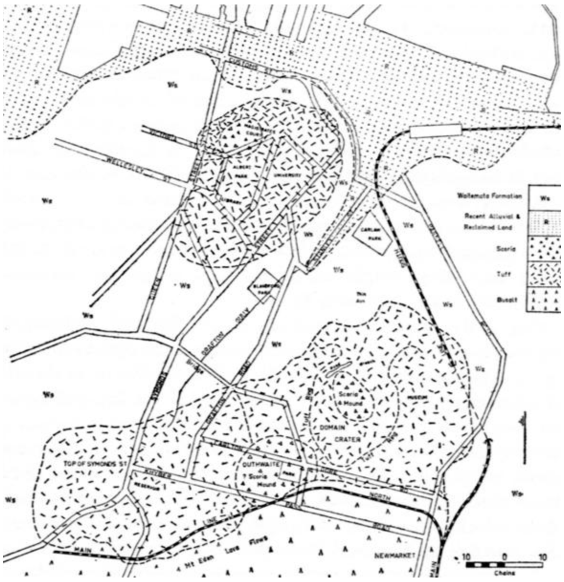


Fig.4: Searle's (1962, Fig. 10) map showing the location of volcanic rocks and centres in central Auckland, including scoria mounds in the Domain crater and another centred on Outhwaite Park.

The most distinctly defined is the cluster of volcanic structures near the Auckland Domain. The main feature is a wide explosion crater … surrounded by a horseshoe ring of tuff. The Domain was the only area in this group where activity extended beyond the explosive stage. A small lava flow buried in tuff beneath the Auckland Hospital building shows that lava was erupted from at least one vent. A scoria cone, built by lava spouting in the centre of the crater, is represented by the irregular hillock on which the glasshouses now stand, and another scoria cone may have been built on the rim of the crater near Outhwaite Park."

On Kermode's (1992) 1:50,000 geological map of Auckland City, the Domain Volcano is labelled with its explosion crater floored by alluvium (ta) and encircling a central scoria cone. A mantle of tuff is mapped forming the Domain tuff ring and extending as a tongue over Grafton and over the top of Symonds St to Eden Terrace in the south-west. An Outhwaite Park scoria mound is not mapped. In Kermode *et al*. (1992) Kermode described the Domain Volcano as a "Simple, large tuff ring about 700 m diameter and breached to the north by erosion. A plume of tuff extends WSW to the top of Symonds St. The small central scoria cone is surrounded with alluvium. Lava has been penetrated 30 m beneath the hospital, and at a similar depth outside the tuff ring to the west beneath the university medical school. The Outhwaite Park scoria mound (24 m above the Domain playing fields) could be associated with this lava." In this and other reports Kermode reported 48

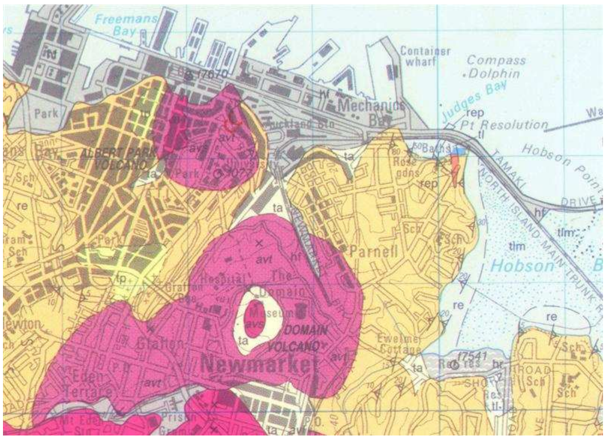


Fig.5: Part of Kermode's (1992) colour 1:50,000 map of the Geology of Auckland. The scoria cone (avs) is shown in the middle of the Domain explosion crater with volcanic tuff (avt) covering all of the Grafton area and up to the top of Symonds St.

volcanoes in the Auckland Volcanic Field with Outhwaite Park scoria mound counted as part of the Domain Volcano.

Roger High in Opus International (1999) summarised the subsurface geology encountered in drillholes on the Auckland Hospital site and in the surrounding area as part of an assessment of the groundwater resources that might be available for the hospital to utilise. This report provides much new information upon which our note is largely based.
Cassidy *et al*. (2007) presented the results of gravity and aeromagnetic surveys over the area of the Domain and Grafton. These recognised a large positive anomaly centred beneath the western arc of the Domain tuff ring in the vicinity of the Auckland University medical school but extending southwards beneath Outhwaite Park, northwards beneath the hospital and eastwards beneath the Domain crater. These were interpreted to indicate the presence of a sizeable body of buried dense magnetic basalt. With the assistance of drillhole records this body was modelled in a cross-section (Fig. 5 in Cassidy *et al*., 2007) as two crater-filling masses – one beneath the Domain crater and a larger one under the suburb of Grafton. Both extend down to 100-150 m beneath the surface – their inferred depth of the explosion craters.

The drillhole record

The drillhole record available to us for this little study comprised the simple driller's logs from a combination of the bore holes put down in: 1. the Domain and nearby properties assessing the groundwater resource that feeds the Domain ponds and the brewery wells near Khyber Pass; 2. the Auckland Hospital grounds for two major new buildings; and 3. the University medical school grounds for a large new building.

Building on the work of Roger High (Opus Consultants, 1999), the thickness of the main lithologies going downcore were summarised for each drillhole and written beside the site of each on maps and used to infer the subsurface structure and sequence.

Interpretation

Present-day topography:

The present-day topography (Fig. 6) best reflects the youngest land-forming events. This was clearly the eruption sequence that produced the Domain explosion crater and its small central scoria cone built by late phase fire-fountaining. The crater is surrounded by a horse-shoe shaped tuff ring. The wide low area on the north side may reflect the ridge and valley topography of the underlying pre-volcanic Waitemata Sandstone surface. There is a second narrower low point in the south in the vicinity of the Carlton Gore Rd entrance to the Domain. The northwestern sector of the tuff ring is well formed and dips steeply down on the outside towards Grafton Gully. The steep inner wall of the western sector of the Domain tuff ring defines the tuff ring's location. Here in the west the tuff ring crest includes two high points – one 15 m high beneath Outhwaite Park and surrounding area, and a second 8 m high mound beneath the eastern end of the Hospital grounds. These mounds slope west down to a flat-floored arcuate valley extending from Khyber Pass (under the motorway) along Park Ave to Auckland Hospital. This could well be the western part of the explosion crater of a second, earlier volcano with two scoria mounds within it. To the west of the valley the land rises steeply to Grafton Rd and Symonds St – possibly the western part of the tuff ring thrown out from the earlier volcano (Fig. 6).

Near-surface geology:

Exposures around the Outhwaite Park mound had long ago convinced geologists that it was made of scoria probably build by fire-fountaining from a vent in this position. More recently, excavations for buildings on Park Rd opposite the Domain have on several occasions exposed weathered scoria overlain by 2-10 m of Domain tuff (containing small blocks of basalt) that imply that the Outhwaite Park scoria cone erupted before the Domain tuff ring was built. Tuff is near the surface of the Hospital mound, but its shape suggests that it too could be an earlier scoria cone that is thickly mantled by Domain tuff.

Sub-surface geology of the Domain Volcano:

Drillholes (Fig. 7) show that the higher eastern level of the Domain's explosion crater floor is underlain by up to 5 m of soft sedimentary fill overlying basalt lava which laps onto the tuff ring. The lower western level of the Domain's crater floor has 6-8 m of peat and clay overlying basalt lava. It would seem that the youngest part of Domain Volcano eruptions spilled basalt lava into the explosion crater from around the base of the actively fountaining central scoria cone. These lava flows or lava lake built up c. 10 m higher in the eastern arc of the crater than the western, or perhaps the level of the lava lake in the west subsided as molten lava within it flowed back into the vent. A drillhole at the Carlton Gore Rd entrance to the Domain, and low point in the tuff ring, encountered 6 m+ of basalt below 3 m of fill (Fig. 7). Downslope from this, and near the railway line, boreholes encountered two lava flow units separated by 2-4 m of tuff that also suggests that some of the lava from the Domain crater overflowed through the Carlton Gore Rd saddle and flowed a few hundred metres towards Newmarket. Following cessation of volcanic activity, the basalt fill in the crater became water logged and a swampy lake developed on top of it in the lower western part, gradually filling with swamp peat.

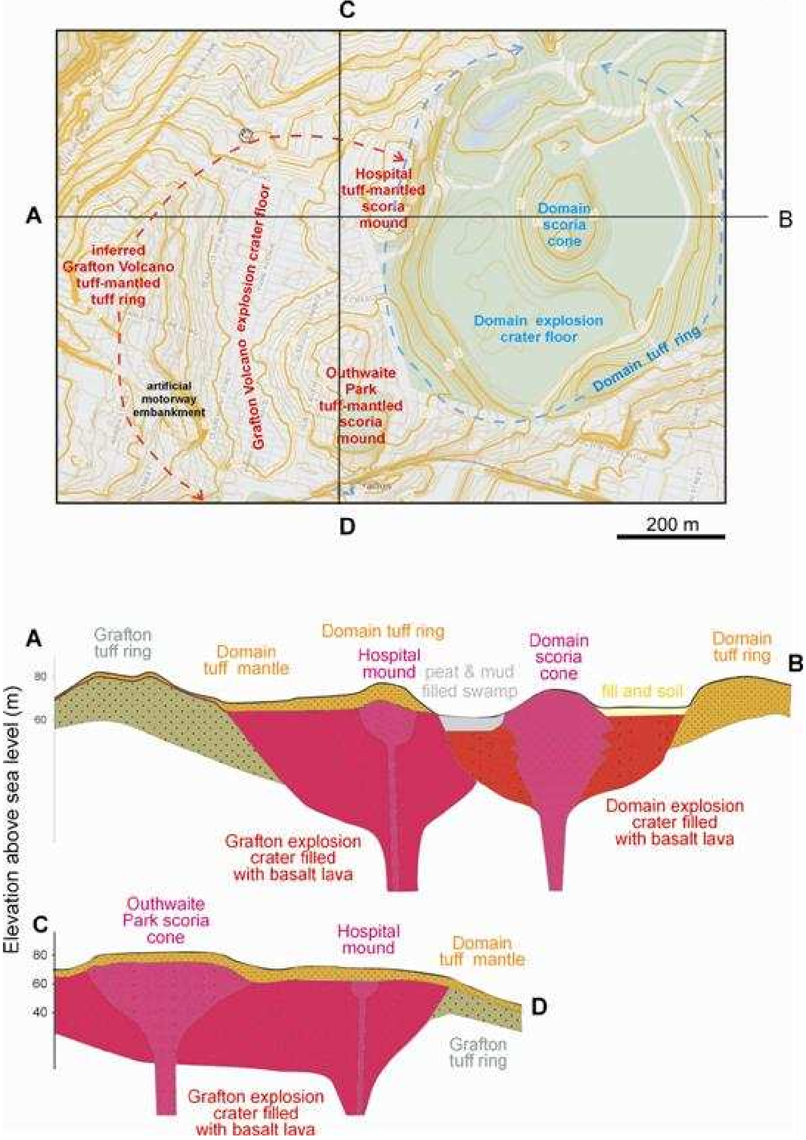


Fig.6. Present-day topography of the Domain and Grafton (from ARC) shows the well-developed Domain central scoria cone, surrounding explosion crater and tuff ring. Also shown are the inferred location of the tuff-mantled explosion crater, tuff ring and two scoria mounds (Outhwaite Park, Hospital) of an earlier Grafton Volcano. Two schematic cross-sections illustrate our interpretation of available surface and subsurface data.

Sub-surface geology of Grafton, west of the Domain:

Drillholes show that an extensive sheet of basalt lava is encountered at an elevation of c.63 m ASL beneath most of Grafton from Seafield View Rd to the Domain (Fig. 7). The western edge of this basalt appears to be the rising ground of our Grafton Rd tuff ring remnant. The northern boundary is well established by drillholes to run almost east-west through the Hospital ground (Fig. 8). One drillhole in the western part of the Hospital defines a southwards dipping slope of an earlier tuff ring with the basalt lava lapping up against it. Here the earlier tuff ring and the basalt filling its crater is buried beneath the later tuff erupted from the Domain, which is up to 15 m thick on the Domain tuff ring crest and progressively thins away from the Domain down to 2-4 m thick in the vicinity of Park Ave (Figs 7, 8). Towards the centre of this former crater (Auckland Medical School), the drilled basalt has thicknesses in excess of 35-50 m (Fig. 7). Drillholes located on the Hospital mound passed down through tuff and ?scoria and into thick basalt at the same level (c. 63 m) as elsewhere in the older crater. One Hospital water bore, near the boundary with the Domain, drilled 96 m of basalt and was still in basalt at its base. This is located on the side of the Hospital mound and may have drilled down through solidified basalt in a conduit that fed lava to the surface. Drillholes on the Outhwaite Park located solid basalt at a variety of levels (45-58 m ASL) beneath scoria mantled by tuff. Thus the Outhwaite Park mound seems to have been a larger scoria cone than the small mound sitting on top of the crater-filling basalt sheet in the Hospital grounds.

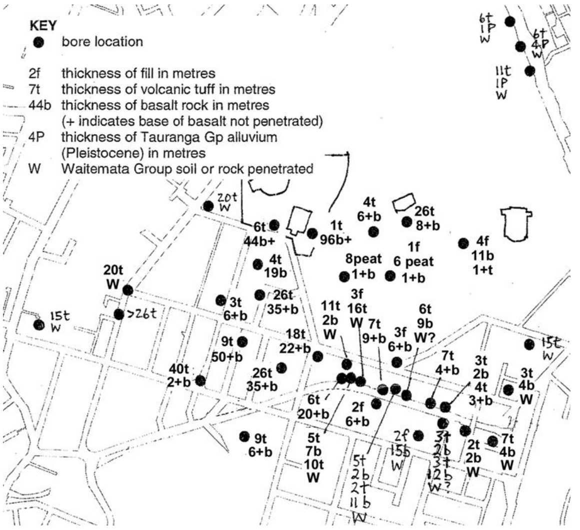


Fig. 7. Map of Grafton-Domain area showing location of major drillholes with a summary of their encountered startigraphy. Values are in metres. Original compiled by Opus Consultants (1999) with some additional data compiled by the authors.

Inferred Grafton Volcano

The subsurface geology provides confirmation of our initial interpretation of the topography. Wet explosive eruptions were centred on the Outhwaite Park-Medical School area. They threw up a tuff ring around a 500-600 m diameter explosion crater. In the west the tuff ring has a 20 m high mound (Grafton Rd-Symonds St) probably built up on top of an underlying ridge of Waitemata Sandstone.

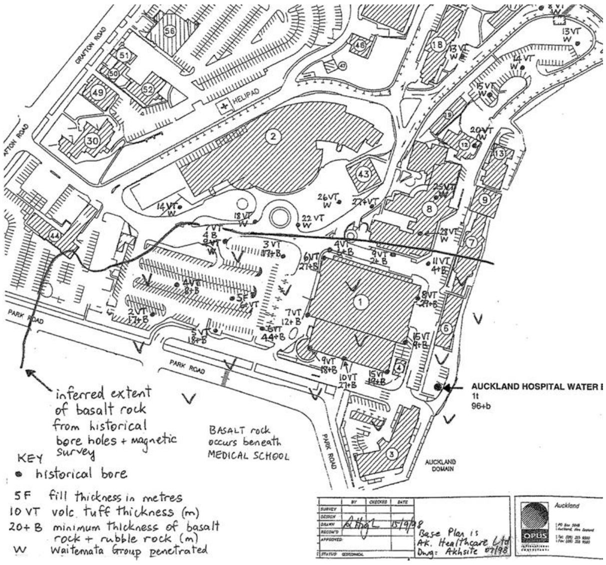


Fig. 8. Map of the Auckland Hospital area showing record of more closely spaced geotechnical drillholes with summaries of their encountered stratigraphy. From Opus Consultants (1999), but based on bore information from others.

The thick cap of tuff on the Khyber Pass ridge and around its junction with Symonds St (which Hochstetter and Searle interpreted as a volcanic centre) quite possibly is the deposits of ash blown 500-800 m west from the Grafton Volcano explosive phases by the wind.

After the groundwater that powered the explosive eruptions was used up, the Grafton Volcano switched to dry, fire-fountaining from an Outhwaite Park vent and later from a vent beneath the east end of the Hospital. While fire-fountaining was building up small scoria cones, a large volume of lava flowed out from around their bases and filled the explosion crater with a lava lake right up to the level of its lowest point near the junction of Park and Grafton Roads. The lava lake solidified into a 50 m+ thick sheet of lava flows.

Relative ages of the Grafton and Domain volcanoes

A precise age has not yet been determined for rocks from either of these two volcanoes. A radiocarbon date from a tree beneath the Domain tuff ring gave an age of >50,000 years (Grenfell and Kenny, 1995), but that is the limit of our knowledge at present. No drillholes nor excavations in the Grafton area have ever found evidence of a buried soil or preserved vegetation around the contact between the basalt lava, scoria or tuff of Grafton Volcano and the mantling tuff from the Domain. This implies that there was not much time between the two volcanic eruptions – maybe less than several hundred years. The latter phases of the Grafton Volcano were dry, whereas the initial phases of the Domain Volcano were wet and clearly involved considerable volumes of ground water.

The Domain explosion crater blasted through the eastern side of the Grafton Volcano and its crater. We suggest that much of the water that powered the Domain's explosive eruptions was probably derived from water that had accumulated in the Grafton crater and saturated the fractured basalt sheet. This would probably have taken a minimum of 5 to 10 years after eruptions at Grafton ceased. We also suggest that the second batch of magma that rose to the surface to erupt as the Domain Volcano probably came up the same conduit from the mantle and through the crust as used by the magma that fed the slightly earlier Grafton eruptions. When the Domain magma rose to close to the surface it must have reached the blocked plumbing beneath the Grafton Volcano (containing basalt that had solidified in the conduit since Grafton stopped erupting) and at this high level in the crust (maybe only a km or less beneath the surface) the rising magma made a slight deviation to erupt as a new vent in the Domain, only 500 m or less from those that produced the Grafton Volcano.

Thus we hypothesis that the Grafton and Domain Volcanoes are a pair that were fed by two separate batches of magma that came up essentially the same conduit and erupted within 10-50 yrs of each other. Two other examples of similar pairs of vents/volcanoes that were erupted in close proximity to each other and thought to be separated by a similar short duration are Purchas Hill-Mt Wellington, two vents on Rangitoto (Needham *et al*. in press), and maybe Otara Hill-Hampton Park (pers. comm., John Cassidy). In both of these latter two examples the geochemistry of the two component batches of magma in each is significantly different and this needs investigating in the case of the Grafton-Domain volcanoes pair. It should be noted that much of the tuff erupted from the Domain contains cobble-sized blocks of basalt that are probably derived from explosive disruption of the solidified lava lake that was in the eastern part of Grafton explosion crater and were therefore not a product of the second batch of magma. Whether the Grafton Volcano is recognised as a separate volcano from the Domain or whether they are regarded as two adjacent vents of the same volcano is a matter of personal preference and semantics.

Acknowledgments:

We thank Jan Lindsay and Ian Smith for reading these scribblings and suggesting improvements. We thank Tracy Howe for obtaining additional borehole logs from the Grafton-Domain area, which have proved useful in further sorting out the subsurface geology.

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MT HOBSON LAVA FLOW
Bruce Hayward

In the middle of 2009 I read with concern that the NZ Transport Agency was about to start work to create a fourth land in a south direction on the Southern Motorway between the Newmarket Viaduct and the Greenlane interchange. I was concerned because I knew that in the cuttings along this stretch of motorway (Figs 1, 2) were the only currently known exposures of the lava flows that came out of Mt Hobson's breached crater.

Fig.1: Exposure of columnar-jointed basalt lava flow from Mt Hobson at the foot of the cutting beneath trees below the Dilworth School playing fields, on the Southern Motorway in 2007.

Fig.2: Location of the exposure of Mt Hobson lava flow in cutting of the Southern Motorway between Market Rd bridge (photo taken from here) and Omahu Rd bridge (distance), 2007.

I felt a little better when I read that the fourth lane would all be built within the present width of the motorway using the pull-off strip.

In late November 2009 work began and I was dismayed to see diggers in alongside the small exposure of basalt lava flow. The following week I noticed that the exposure was covered by cloth and I feared the worst. After many calls and emails I got in touch with the public liason person for the job, who told me that yes indeed a concrete retaining barrier and sprayed concrete was to be the new clean finish for this cutting, beneath the playing fields of Dilworth School (formerly Hobson Park). The best they could do would be to arrange for me to visit the outcrop alongside the motorway to take photos and samples before the lava flow exposures were hidden behind concrete.

Early in December I made the visit, the cloth curtains were drawn and I whacked off a few pieces of rather weathered highly vesicular basalt. The access route to the outcrop was along the embankment above the motorway beneath the Market Rd overbridge. This embankment has been out of the weather (and hard to see) since the cutting was made in the early 1960s. To my delight, there under the bridge was a wonderful stratigraphic section that will not be covered by concrete as part of the present work. Several large blocks of in-situ basalt were much fresher and denser than down by the carriageway so I took some more for the University and GNS geochemists and for possible Ar-Ar dating.

Under the bridge was rather dark for photography (Fig. 3) but the sequence from top down was:

2 m thinly bedded fine tuff
sharp contact
~1 m of red-brown clay (weathered volcanic material ?scoria, ?tuff, ?flow)
grading down into
1 m + of basalt flow becoming more weathered upwards.

Fig.3: Part of the exposure of Mt Hobson lava flow and weathered soil overlain by lighter coloured tuff (inferred to be from Three Kings Volcano) located beneath the Market Rd bridge over the Southern Motorway, 2009.

Previous workers (e.g. Kermode *et al.*, 1992) have inferred that lava flowed out from the breached Mt Hobson crater and flowed both north towards Newmarket and south towards Omahu Rd roughly along the line of the present Southern Motorway and railway line (Fig. 4)

Fig. 4. Looking south over Mt Hobson and down the Southern Motorway in 2009 showing the Market and Omahu Rd bridges. The lava flows are inferred to have oozed from the breached crater and flowed north and south approximately along the present route of the motorway and adjacent railway line.

I infer that the sequence under the bridge comprises the top of the south-directed flow, possibly overlain by fine scoria at the foot of the Mt Hobson scoria cone. There has then been a long period (tens of thousands of years) of weathering beneath forest cover to produce the deep clay soil. This is then overlain by 2 m of wind-blown volcanic ash erupted presumably from Three Kings, 29,000 yrs ago (Lindsay & Leonard, 2009).

To my knowledge this may be the first recording of the relationship between Mt Hobson and Three Kings eruptions and clearly indicates that Mt Hobson may be older than about 60,000 yrs. I note that previously some geologists have inferred that Mt Hobson was younger than Three Kings (e.g. Homer *et al.*, 2000).

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Book Review: Wegener's Jigsaw: a biography by Clare Dudman published by Hodder and Stoughton 2003.

The man, who first recognised that movement of the earth's plates explained many geological riddles, started his scientific career as a meteorologist. Albert Wegener was a German with a strong pioneering spirit, testing his endurance to the limit with adventurous treks across Greenland in the early 1900's. The vivid writing allows readers to visualise perils of the ice, the toll on humans, dogs and horses. We wince when a shot is heard; or cringe when frost-bitten toes are amputated with a penknife.

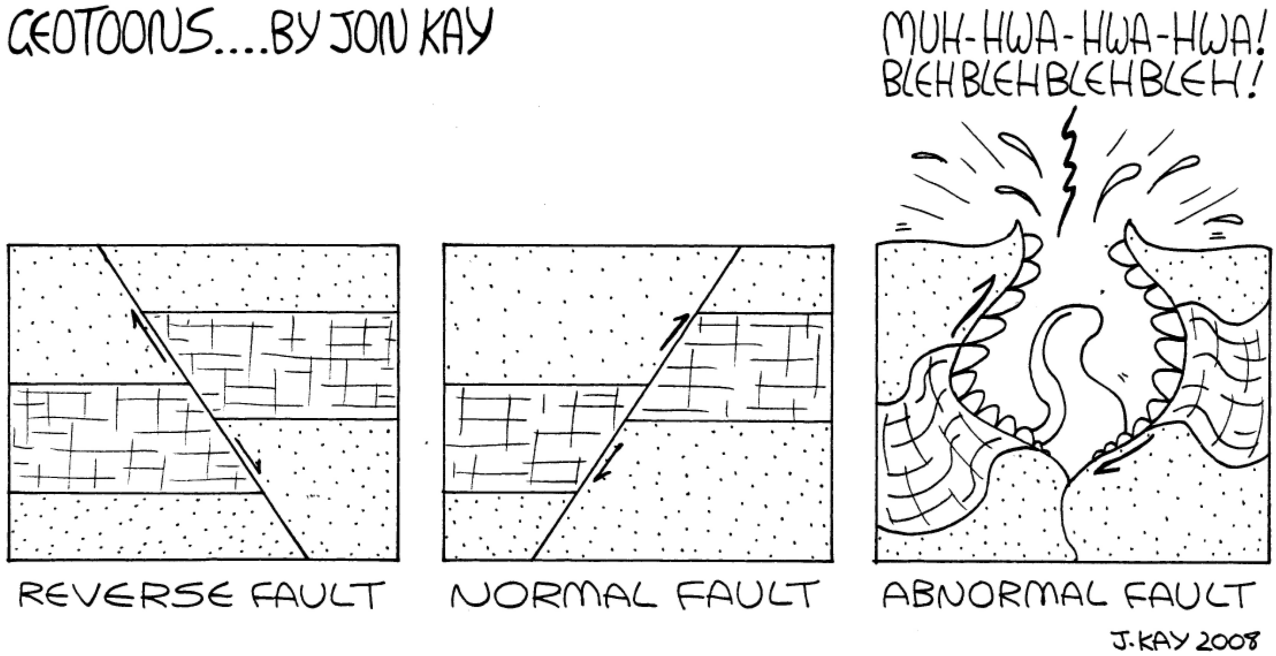
Wegener's lectures on his discovery were received with ridicule by the established geological community causing him to endure set-backs and much humiliation. His achievements are set against the background of his own family, his wife and daughters, giving fascinating insights into his complex character.

His passionate drive to discover remained strong throughout his life.

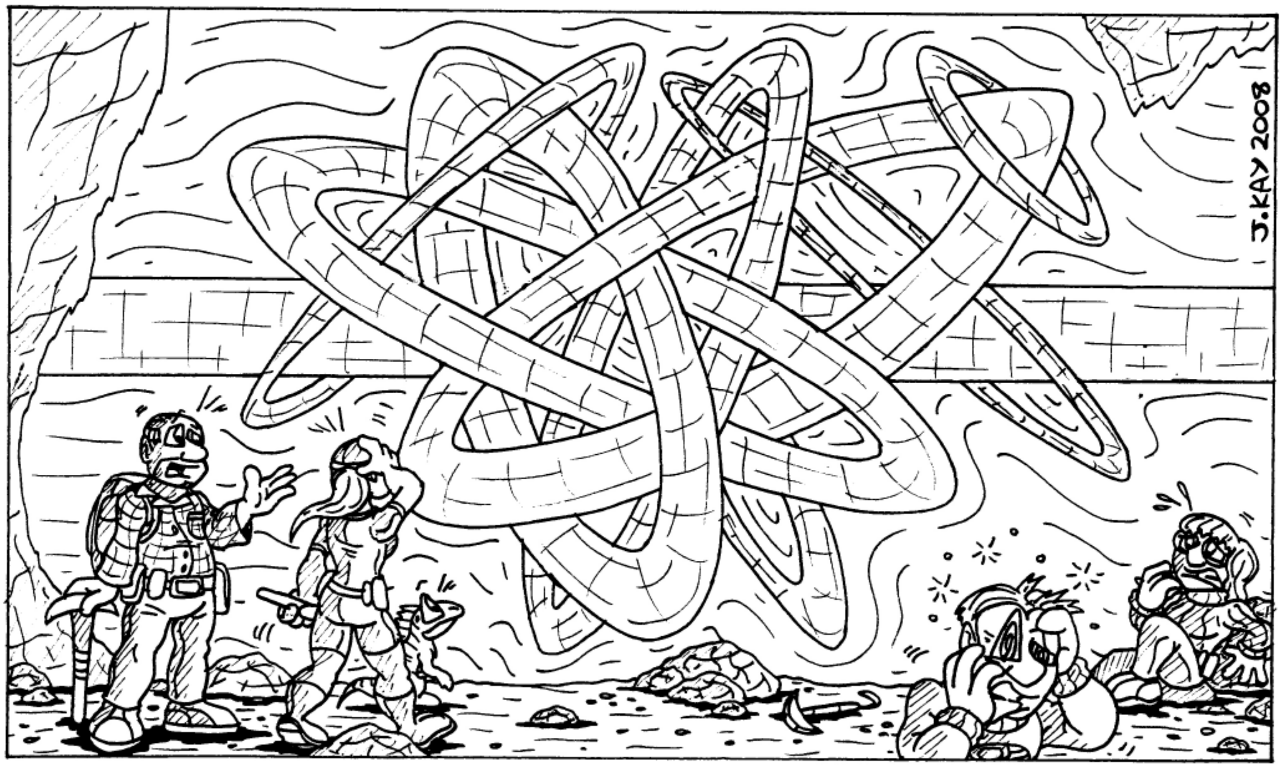
This book is highly recommended, I obtained a copy from Manukau libraries, but it will be coming your way soon, courtesy of Auckland Super City.

Margaret Morley

GEOTOONS....BY JON KAY



GEOTOONS....BY JON KAY



"WE CALL THIS FOLD 'THE BRAIN SCRAMBLER'. CAREFUL! FIFTEEN GEOLOGISTS HAVE GONE INSANE JUST LOOKING AT IT...."

GEOTOONS..... BY JON KAY