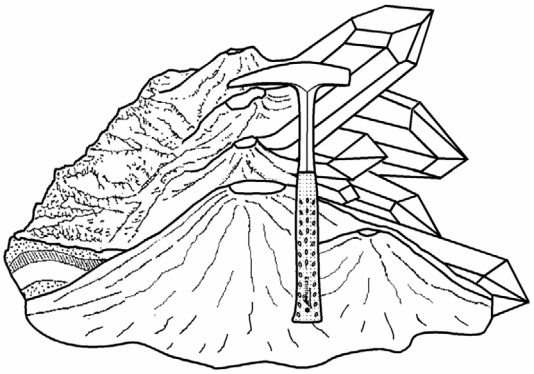


Geocene

Auckland GeoClub Magazine
Number 22, May 2020

Editor: Jill Kenny

Editor – This issue of Geocene has been updated. Some images on pages 4 and 5 have been removed to minimise possible copyright issues. An explanation and reference to each deleted image has been added to its vacant space.

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

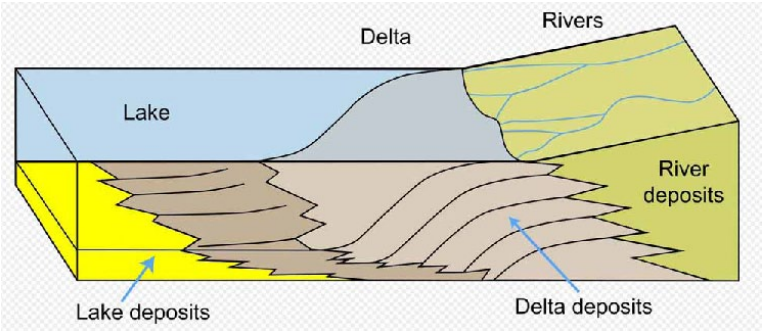
Contributions about the geology of New Zealand (particularly northern New Zealand) from members are welcome. Articles are lightly edited but not refereed.

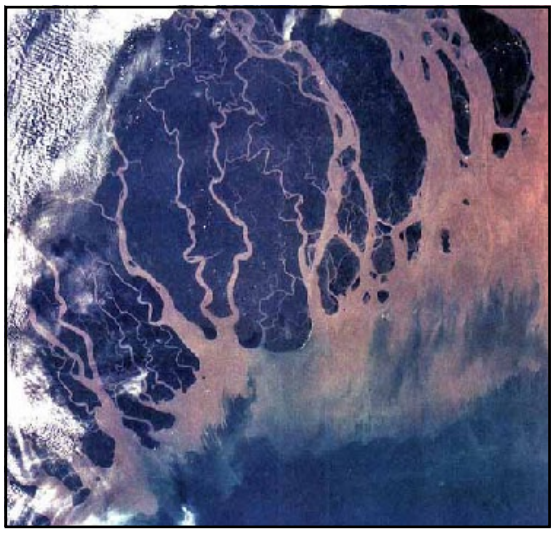
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RIVER DELTAS, BIRD'S FOOT DELTAS, DIGITATE DELTAS, SILT JETTIES – WHAT IS A SILT JETTY?

Wendy Goad

River deltas are places where sediments, transported by a river, are deposited into shallow, nearshore bays. As the sediment accumulates, underwater plant communities establish, trapping more sediment and eventually leading to the building of land.
(Diagram courtesy of Wikipedia, Author AntanO, Creative Commons Attribution 4.0 International License)



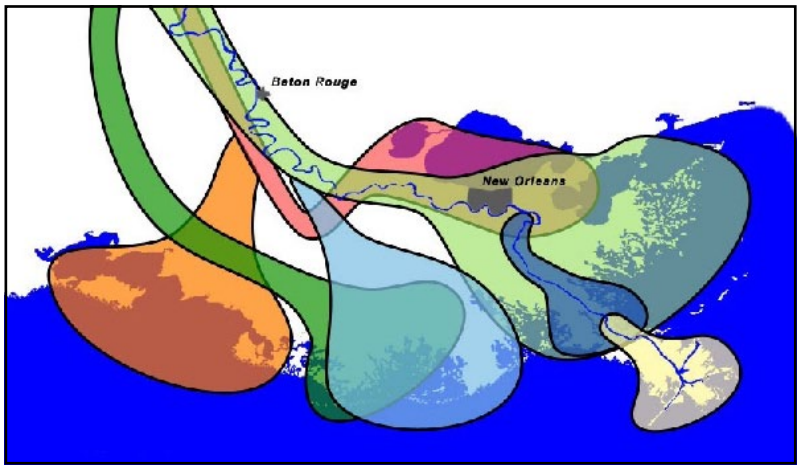


The size and shape of a delta is controlled by the balance between watershed processes that supply sediment, and receiving basin processes that redistribute, sequester, and export that sediment. The size, geometry, and location of the receiving basin also plays an important role in delta evolution.
(Photo is of the Ganges River Delta, courtesy of Wikipedia)

The Ganges Delta in India and Bangladesh is the largest delta in the world.

Bird's Foot Deltas

The quintessential example of a bird's foot delta is the delta of the Mississippi River. As each section of land, called a delta lobe, continues to build, the river's path to the Gulf becomes longer and more difficult. In response, the river eventually changes course, cutting a shorter route to the Gulf and the whole process begins again The abandoned lobe gradually sinks and erodes, leaving behind barrier islands.



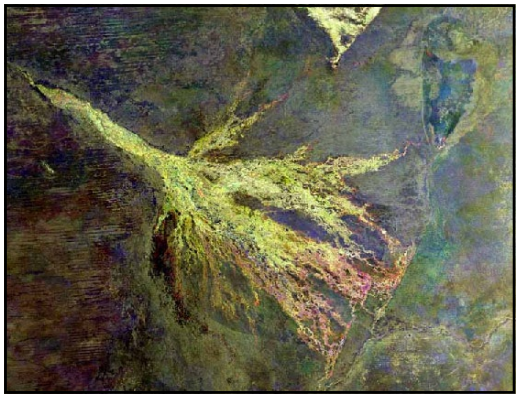
(Diagram courtesy of Wikipedia)

	Salé Cypremort	4,600 years BP
	Cocodrie	4,600–3,500 years BP
	Teche	3,500–2,800 years BP
	St Bernard	2,800–1,000 years BP
	Lafourche	1,000–300 years BP
	Plaquemine	750–500 years BP
	Balize	550 years

Inland Deltas

Sometimes a river divides into multiple branches in an inland area, only to rejoin and continue to the sea. Such an area is called an *inland delta*, and often occurs on former lake beds. The Inner Niger Delta is a notable example (not shown here; see Wikipedia.com).

In some cases, a river flowing into a flat arid area splits into channels that evaporate as it progresses into the desert. The Okavango Delta (illustrated here) in Botswana is a well-known example of this (photo courtesy of Berkeley Lab Computing Sciences - Geldenhuys & Vu, 2014).



Cuspate Deltas
Where the river borne sediment meets incoming waves head on, that sediment can be distributed evenly on both sides of the river mouth, forming an arrow shape as shown here on the Tiber River mouth.
(Google image from website “Geography and You”, with photo courtesy of NASA)



Tide-Dominated Deltas
Erosion is an important control in tide-dominated deltas, which may be mainly submarine, with prominent sandbars and ridges forming a dendritic structure.

The Ganges/Brahmaputra Delta illustrated here is tide-dominated, dendritic in nature, and at more than 105,000 km^2 in extent, is the largest delta in the world.
(photo courtesy of Google images)



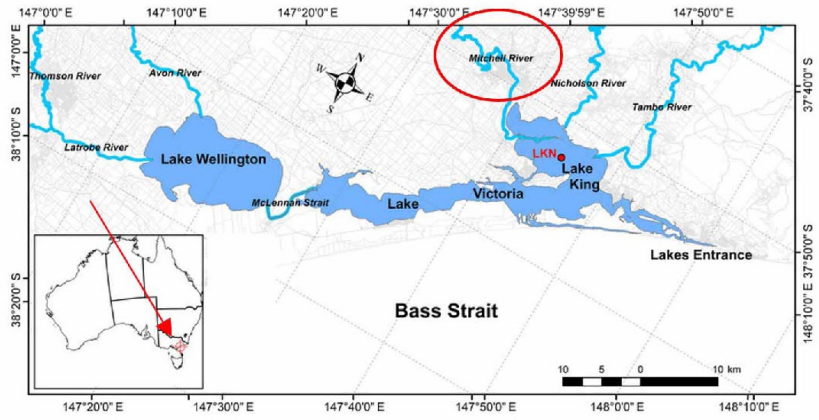
So what about THE SILT JETTY?

“Silt Jetty” is an Australian term referring more specifically to the Mitchell River delta located in southeastern Victoria, Australia.

The delta is a classic form of digitate delta (from the Latin for finger), extending along the western shoreline of Lake King to Eagle Point Bluff and then eastwards as long winding silt jetties.

The jetties extend almost 8 km into the lake as low narrow tongues of sediment that were formally bordered by a wide zone of reed swamp. The silt was deposited over the past 8,000 or so years, since the rise in sea level resulted in sand barriers forming across the Gippsland coast, leading to creation of the Gippsland lakes (Wikipedia.com).

The major factor in the growth of the jetties is the virtual absence of tidal currents on Lake King and the presence of a shoreline reed swamp that trapped a large proportion of the river sediment and afforded protection from wave attack.



Editor – Image removed for copyright reasons.
The image was of Mitchell River silt jetties.

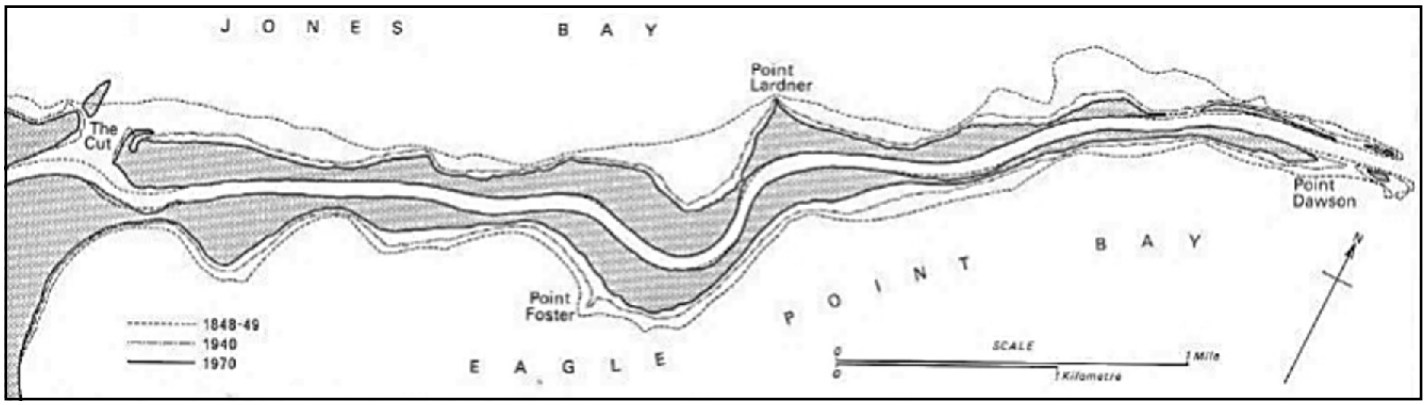
Editor – Image removed for copyright reasons.
The image was of Mitchell River silt jetties.

Mitchell River silt jetties
(This and upper right photo courtesy of Google images)



Tamba River cuspate delta
(Photo courtesy of N. Rosengren)

The elongated digitate form of the Mitchell River silt jetties, compared with the neighbouring smaller cuspate delta of the Tambo River, indicates that this part of the lake is well sheltered from both westerly and easterly winds. The Tambo River Delta has an elongated shape and protrudes 2.5 km south-westward into Lake King. The delta has infilled a funnel-shaped embayment and continued sedimentation has extended the delta into Lake King.



Map of the Mitchell River slit jetties protruding into Lake King (Bird, 1978).

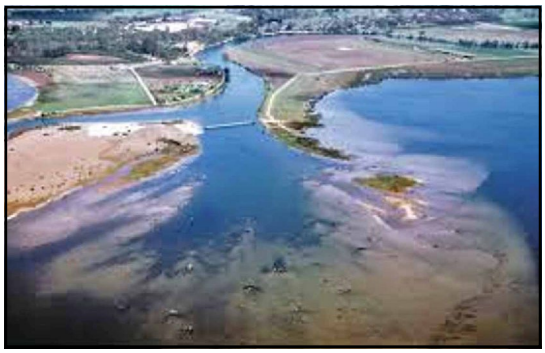
Since the early 1900s, the reed swamp on the Mitchell River has largely disappeared, with the result (as illustrated above) that the shorelines of the delta are now eroding banks of silty deltaic materials. Much of the swamp scrub cover on the delta was cleared and replaced by pastureland. Other factors, such as trampling by cattle grazing on riverbanks, access by anglers, and scouring by boat wash, are of increasing importance as the reed fringe disappears.

By 1959, the delta was clearly in course of decay, and in places the shoreline had receded more than 20 m. Comparison with outlines shown on modern air photographs shows that the delta area has been reduced from 2.68 million square miles in 1848–49 to 1.48 million square miles in 1970, little over half its original extent (Bird, 1978).

As with the Tambo River Delta, this is clearly related to the increased effectiveness of wave erosion following die-back of the fringing reeds, mainly due to increasing salinity of Lake King since the artificial opening of Lakes Entrance in the early 1900s. The delta has been breached in several places to produce small islands. The southern arm has receded by approximately 500 m since 1849, and detailed field mapping since 1970 has shown that some sectors are retreating at rates of up to 10 m per year (Bird, 1978).

Large quantities of sediment (mainly silt and sand) are still brought down by the Mitchell, particularly during floods, but since the opening of the 'Cut' opposite Eagle Point Bluff, much of it has been carried out to settle on the floor of Jones Bay and a small delta is forming.

Attempts have been made to protect the shoreline with artificial structures and introducing salt-tolerant plants such as Spartina have had limited success.



The delta of the Mitchell River showing the 'Cut' and the sediments being deposited by it. (photo from Bird, 1978)

Aerial image looking from the delta out along the silt jetties and clearly showing the 'Cut' bottom left. Notice how close the jetties got to the opposite side of the lake (within 400 m). (photo courtesy of Google images)

Editor – Image removed for copyright reasons.
The image was of Mitchell River silt jetties.

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ORBICULAR GRANITE LOCALITIES IN SEPARATION POINT GRANITE, KAITERITERI COAST, NELSON

Bruce W. Hayward

On the 2007 and 2019 Geoclub trips to Northwest Nelson we made a special detour to visit an in-situ exposure of orbicular granite near Kaiteriteri. This locality and a number of others nearby (Fig. 1) were recorded by the late Huko Kobe (1988), a former member of Geoclub. Kobe (1988) did not provide detailed descriptions of where each locality was. Instead he gave a general locality name for each and a sketched small-scale map of a number of the localities (Kobe 1988 fig. 3). Both trips chose to visit Breaker Bay, the closest locality to Kaiteriteri Beach, and after a short search it was relatively easy to locate Huko's exposure in this small bay.

Subsequently I spent part of another day trying to locate three more of Kobe's coastal localities, north of Kaiteriteri. These were much harder to locate than his locality 2 in Breaker Bay (Table 1). Kobe (1988) describes the detailed features of each locality and of the orbicules that usually have plagioclase- and biotite-dominated cores and alkali feldspar, quartz, biotite or magnetite combinations in the outer shells.



Fig. 1. Map showing orbicular granite localities recorded by Kobe (1988) from the coast north of Kaiteriteri, Nelson.

Breaker Bay (Kobe's locality 2)

This is in a 10 x 10 m area of mid-tidal rocks at the north end of the beach (Figs 2, 3). At the time of the visit, some of the rocks were hidden by sand. Dense barnacles or

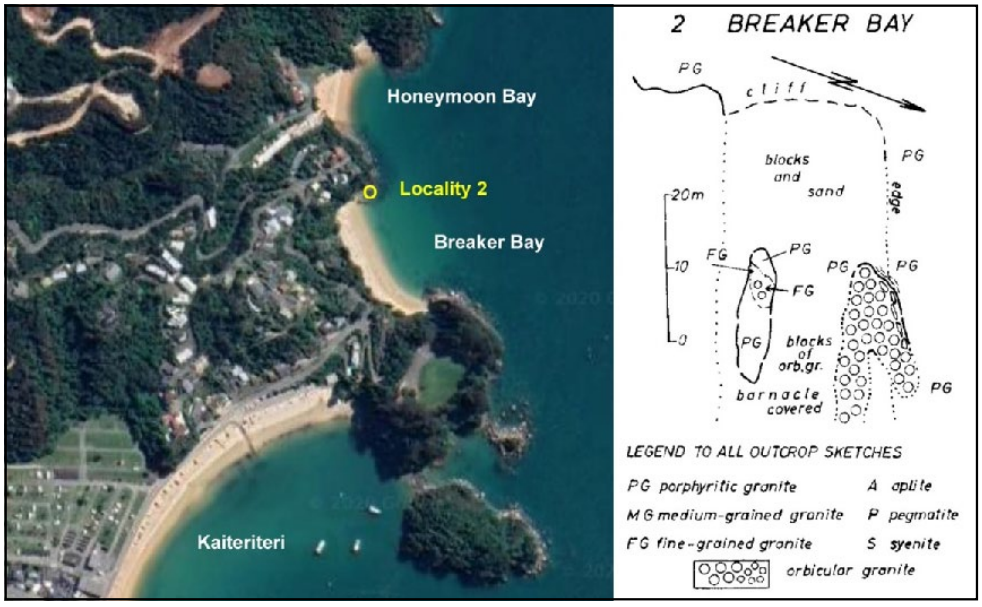


Fig. 2. More precise location of Kobe's (1988) locality 2, Breaker Bay, Kaiteriteri and Kobe's (1988, fig. 3) sketch plan of the locality in detail.

Table 1. Additional data on Kobe's (1988) orbicular granite localities on the coast north of Kaiteriteri.

Locality 2.	Breaker Bay, north end of beach;	41.032475°S, 173.021355°E.
Locality 3.	Coquille Bay, 250 m east of north end of beach;	40.989395°S, 173.034181°E.
Locality 4.	Guilbert Pt – North, not relocated by me, but said to be 60 m south of 4a.	
Locality 4a.	Apple Tree Bay – South, 70 m south of south end of beach,	40.998716°S, 173.036264°E.
Locality 7.	Honeymoon Bay NW, Not relocated by me.	

tube worms over most of the exposed rocks made it difficult to see the orbicules, although their spherical shape could be recognised in some places (Fig. 3). In several places where sand had recently moved away, clean 10 cm diameter orbicules could be seen, especially in boulders between the two in-situ low reefs. The orbicules are single-shelled.



Fig. 3. Spherical orbicules clearly obvious in 1 m-diameter boulder despite the dense barnacle cover, Breaker Bay (locality 2).



Fig. 4. More precise locations of Kobe's (1988) localities 3 and 4a on the coast adjacent to the Abel Tasman Track.

Coquille Bay (Kobe's locality 3)

This locality is 250 m north of the beach (Figs 4, 5) and can only be accessed at low tide by walking around the bottom of the low cliffs. It occurs in a small embayment (Fig. 6) where an exposure of in-situ orbicular granite can be seen (Fig. 7). I suspect Kobe's sketched area (Fig. 5) has been covered by a subsequent slip. There are also a number of boulders and cobbles of multi-shelled orbicular granite in the intertidal zone, some of which have eroded out the spherical orbicules (Fig. 8).



Fig. 6. Small bay 250 m east of the north end of Coquille Bay where in-situ and loose boulders of orbicular granite can be seen.



Fig. 7. In-situ face of multi-shelled orbicular granite at locality 3, Coquille Bay. Photo 60 cm across.

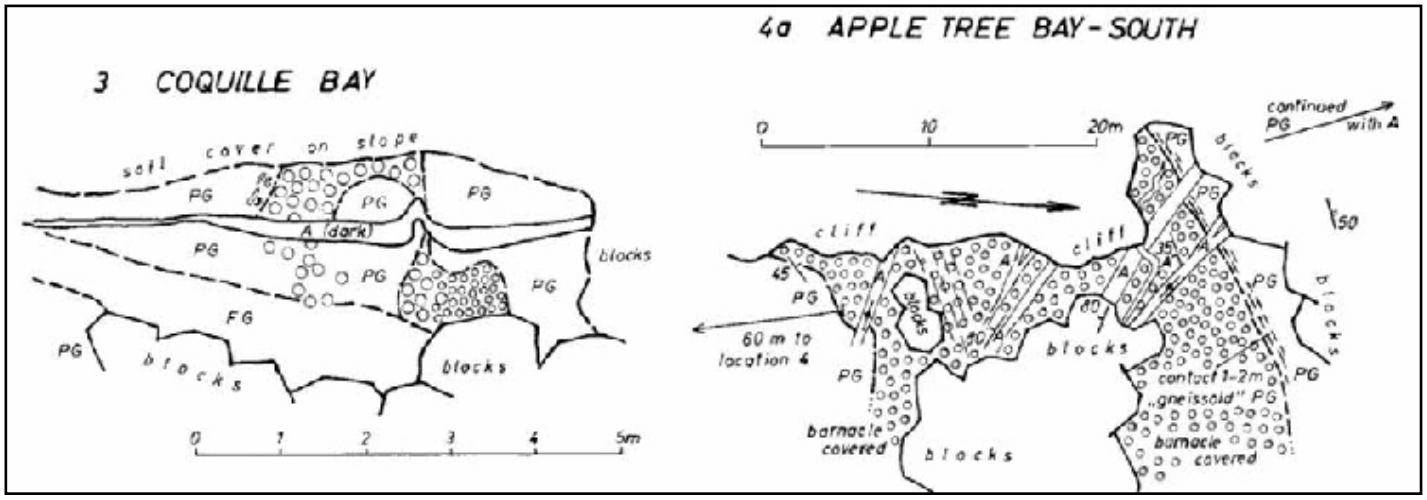


Fig. 5. Kobe's (1988) sketch plans of his locality 3, Coquille Bay, and locality 4a, Apple Tree Bay.



Fig. 8. Loose intertidal cobble showing 3-dimensional orbicules at locality 3, Coquille Bay.



Fig. 9. Section of coast where in-situ and large boulders of orbicular granite can be seen at locality 4a, south end Apple Tree Bay.

Apple Tree Bay (Kobe's locality 4a)

This locality is 70 m south of the beach and occurs in an area of low cliffs bordered by a sloping bouldery intertidal zone (Fig. 9). It requires mid tide or lower to get along to it from the beach. Low tide is needed to get to Guilbert Pt (locality 4) and around to locality 3 and Coquilles Bay. Here at locality 4a you can see in-situ exposures of orbicules around high tide and large boulders with them at mid-high tide (Fig. 10). In these boulders, the cores (of plagioclase) of the single-shelled orbicules are often less resistant and have eroded down to a lower level than the more erosion-resistant outer shells of alkali-feldspar (Fig. 10). The orbicular granite is cut by younger aplitic and pegmatic dikes.

Reference

Kobe, H.W. 1988. Petrography of orbicular granitoids in the Separation Point batholith, northwest Nelson, New Zealand. *New Zealand Journal of Geology and Geophysics* 31: 493–504.



Fig. 10. 1–1.5 m diameter boulders of orbicular granite, locality 4a, Apple Tree Bay.

Postscript:

The sites described here are legally protected and should not be hit with a hammer or sampled.
Leave any loose rocks where they occur.
Sampling for research would require a permit.
Leave the rocks the way you see them so others can find and enjoy them.

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ROCKFALL AT TUIALAMU, UPOLU, WESTERN SAMOA

Garry Carr

On February 12 2018, in the tail end of Cyclone Gita, a major rockfall occurred at Lalomanu Beach, Upolu, Western Samoa (Samoa Observer 14 February 2018). It blocked the major road (Main South Coast Road) providing access to Lalomanu Beach but alternative routes were available. At the time of my visit (July 2018) the slip had not been cleared, however access round and across the toe of the slip had been constructed. The slip stretches to virtually the top of the slope and was still moving when clearing the rockfall was first attempted (a day after the rockfall occurred), according to locals.

The topography is spectacular here, with vegetated cliffs up to over 200 m tall rising from Lalomanu in the east to almost Aufaga in the west. The highest point is not far west of the location of the rockfall. The road occupies a narrow area of flat land between the cliffs and the lagoon enclosed by a coral reef, as shown in Fig. 1. This flat area is underlain by coralline sands as well as rocks derived from the basaltic cliffs.

The cliff top slopes down to the east and rises up to the cone of Lua-o-fafine, which is to the left of this photo. Note also some quarrying at the base of the cliffs in the foreground. There was also a small quarry at the base of the cliffs at the site of the landslip (Samoa Observer 14 February 2018). This small quarry is also visible in the Google maps image (Fig. 2a) by the letter d in Rd in the centre of the image. Note also a landform that extends out into the lagoon, which I suggest is an earlier and larger rockfall from the cliffs immediately to the south of the volcanic cone of Lua-o-fafine.



Fig. 1. Aerial view of the rockfall taken the day after it occurred and before any remediation work. To the right is the fringing reef with the lagoon reaching almost to the cliffs. The beach in the background is Lalomanu beach. Note how the rockfall extends out into the lagoon and the lobate forms on the slip surface itself suggesting a fluidised flow mechanism. Photo taken for the Land Transport Authority (of Samoa).

Geology

According to Stearn (1944) – "Upolu is a deeply eroded mass of Pliocene lavas surrounded by a drowned barrier reef and partly buried by late Pleistocene and Recent lavas. Upolu was submerged so rapidly in late Pleistocene time that only narrow and interrupted fringing reefs grew on



Fig. 2a. A Google maps (2018) image of the area of the rockfall showing the location of the Lua-o-fafine crater. North is up. (Google maps have redone their satellite images recently and now show the rockfall - Figs 2b & c).



Fig. 2b. Google map image downloaded March 2020 showing the modified rockfall (in colour too). (Same scale as Fig. 2a)



Fig. 2c. This close-up Google Earth image taken in 2018 shows the rockfall in more detail and the road label removed.



Fig. 3. The rockfall viewed in July, 2018. The foreground is the access round the slip for vehicles to negotiate and has been modified considerably from the original slip deposits.

the steep shores of Pliocene rocks while a wide barrier reef developed on the gentle slopes of the flat-lying Pleistocene lavas."

The February 2018 slip has occurred in Holocene-aged basaltic rocks of the Salani Formation (Kear 1967) and, based on proximity (less than 1 km distant) and topography, were most likely erupted from Lua-o-fafine cone (Figs 2a & 2b) although other sources (cones) are present further inland within a few kilometres. Age relationships between the different cones is unknown at this time.

When I first observed the rockfall (Fig. 3), my initial impression was that there is pyroclastic material overlain by more massive lava flows. However, on examination of the slip debris, loose pyroclastic material does not seem to be common. In Fig. 3, the light grey areas in the rock fall are thick(er) massive basalt lava flows that are fractured by cooling joints. The large boulders in the slip, many over 2 m in size, appear to be derived from the lava flow at the top of the rockfall. There were still a number of what appeared to be boulders in the cliff face in this lava flow that seemed to be in a very precarious position, so lingering at the base of the rockfall or attempting to climb the rockfall was deemed hazardous and not attempted. Indeed, locals suggested that it was best not to tarry at the base of the rockfall. The redder areas of the cliff face are thin scoriaceous lava flows and/or welded pyroclastic material, as suggested by numerous boulders (shown in Figs 4–6). It seems that fractures in these thin flows are rare.

The new exposure here represents an opportunity to examine a thick, well exposed vertical sequence of a Samoan volcano.



Fig. 4. There were numerous boulders of what appears to be numerous thin flows of vesicular lava and welded pyroclastic material. The proximity to the vent of Lua-o-fafine volcanic cone supports this suggestion.



Fig. 5. Another view of the scoriaceous boulders.



Fig. 6. Basalt lava from the fractured lava flows also has a banded appearance.

Cyclone Gita caused extensive flooding with well above average rainfall recorded in the days prior to the slip occurring. Over 200 mm of rain was recorded in many measuring stations on the 9th of February (Samoa Meteorology Division 2018). Given that the landslide occurred during the heavy rainfall event of Cyclone Gita, it is likely that water pressure in the fractured lavas caused the slope to fail.

The origin of the cliffs from Lalomanu to Aufaga

Fepulai and Nemeth (2018) state that landslides and rockfalls on volcanic islands in tropical climates are characteristic landscape-shaping features and Samoa is no exception, according to their work. The cliffs between Lalomanu and Aufaga have the appearance of being very young. However, they must predate the formation of the current day reef, which would have formed in response to the sea level rise from last glacial period. The implication is that most recent erosion or rockfall has been confined to surface slips rather than being deep seated events such as this rockfall.

Based on the topography of the Lua-o-fafine volcano, its lava apron would have extended above sea level at least several kilometres to the south into what is now relatively deep sea. Kear and Wood (1959) illustrated this, sketching in suggested contours on a map of the area. Where has this material gone?

Kear and Wood (1959) suggested there is a fault running parallel to the coast downthrown to the south. They also suggested that it was probably due to a large scale slide rather than to tectonic forces.

Flank collapse of the volcanic edifice (island collapse) has been cited to form the highest of cliffs in Hawaii (Hazlett & Hyndman, 1996). Cronin *et al.* (2005) suggested that large-scale collapse is a possibility for Samoa. “Close examination of bathymetric records offshore from the cliffs may reveal whether this hypothesis is true or false. A common feature of large oceanic islands such as Savai’i and Upolu is that they rise steeply from surrounding deep ocean floors. In addition, their slopes are made up of lavas and volcanic debris that in part cover unstable, mud-rich ocean sediments. Because of this situation, the stage is set for large-scale collapses from the steep flanks of the volcanoes, often from the submarine flanks.” Williams *et al.* (2014) document a large scale collapse on Ta’u, American Samoa. Improved bathymetric records offshore from the cliffs may reveal whether this hypothesis is true or false.

Normal erosion, I believe, is an unlikely agent, due to the formation of a barrier reef that protects the base of the cliff from the ocean waves. Several researchers have commented on this subsidence of the Samoan Islands, for example Stearn (1944), and more recently due to the magnitude 8.1 Earthquake of 2009, Morner *et al.* (2018) and Sand *et al*.(2015). The coral reef, it seems, can develop at the rate of subsidence, thus protecting the cliffs from normal sea erosion.

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OLIGOCENE SHRIMP BURROW NETWORK AT PUPONGA POINT (ABEL HEAD), NORTHWEST NELSON

Bruce W. Hayward

One of the many geosites visited by the Auckland Geology Club during its November 2019 field trip to Northwest Nelson was to Puponga Point/Abel Head on the northern side of the entrance to Puponga estuary near the foot of Farewell Spit. The main focus of the visit was to look at the disconformity between the Paleocene Farewell Formation fluviatile sequence and the overlying shallow marine Oligocene Matapo Sandstone of the Nile Group and its sequence of sandstone, glauconitic siltstone, limestone up into mudstone. The disconformity between parallel beds of Farewell Formation and Nile Group represents an erosional hiatus between at least 55 and 33 million years ago with no sedimentary rock of this age preserved locally.

The best place to see the disconformity is at the tip of the point where there is a small picturesque intertidal islet with a hole through it (Fig. 1). Here the disconformity (Fig. 2) is directly overlain by about 5 m of massive quartz sandstone beds with considerable limonite development and minor mudstone interbeds (given the informal name "Kaihoka Member" by Titheridge,1977). The "Kaihoka Member" is separated from the overlying glauconitic sandstone (informal "Rakopi Member"), containing fossil heart urchins, by another erosional unconformity.



Fig. 1. The disconformity between Paleocene and Oligocene strata runs through the Puponga Pt islet, seen here from the west.



Fig. 2. The Paleocene-Oligocene disconformity (hammer bridges it) at the tip of Puponga Pt, opposite the small islet (Fig. 1). Younger (Oligocene) sedimentary rocks are on right.

At the islet everyone was focused on the disconformity (Fig. 3), which is the highlight of the Geotrip's description of this site (Calkin, 2019) and it was not until I looked up at the rocks near the top of the islet's low cliffs on the north side that I saw the beautifully displayed trace fossils (Fig. 4). A search of the web showed that these have been documented by Titheridge (1977, fig. 5.10) in his unpublished MSc thesis, but otherwise I failed to find mention, nor photographs of them. So here are some photographs (Figs 5 & 6).



Fig. 3. View from the east of geoclubbers examining an unconformity at the foot of the north side of the Puponga Pt islet. The trace fossils are best seen in the rocks above their heads in the islet's cliffs.



Fig. 4. Dark rusty brown burrow networks are well-exposed in the orange sandstone layers in the upper cliffs of the Puponga Pt islet.



Fig. 5. *Ophiomorpha* burrow networks in a 1.5 m thickness of Oligocene sandstone, north cliffs of Puponga Pt islet.



Fig. 6. Eroding *Ophiomorpha* branching burrow networks cemented with limonite in a 1 m thickness of Oligocene sandstone, north cliffs of Puponga Pt islet.

The trace fossil network of connected and branching burrows occurs in the lower 3 m of "Kaihoka" sandstones. Some of the burrows appear to have a knobbly outer lining and they are therefore most appropriately identified to the trace fossil genus *Ophiomorpha*. The trace fossils are beautifully displayed because they have been preferentially replaced by dark brown-black limonite, which contrasts with the orange (iron-stained) sandstone. In modern settings these open burrow networks are known to be made by callianassid snapping shrimps (Shinn, 1968) at a wide variety of depths from intertidal to at least 900 metres depth (Hayward, 1976).

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YOUNG AGE FOR DROWNED FOSSIL FOREST AT RANGIHAEATA (TAKAKA) SUGGESTS ONGOING REGIONAL SUBSIDENCE

Bruce W. Hayward

Summary
An in-situ drowned forest, inferred to be mostly of salt-marsh ribbonwood, occurs in the intertidal zone at Rangihaeata, Northwest Nelson, at an estimated elevation 0.6–1.1 m below the level it would have been growing 1500 years ago. This provides evidence for a relative rise in sea level in the past 1500 years attributed to a combination of actual sea level rise during the past 150 years (~0.3 m) and inferred slow regional subsidence (~0.5 m).

Introduction
In November 2019 an Auckland Geology Club group visited a drowned forest eroding out of the back of the beach at Rangihaeata, near Takaka, Northwest Nelson (Figs 1–4). The lower trunks and root systems of many trees are exposed about 50 m west of the end of Fosters Road, Rangihaeata, where they are being eroded out by the sea. The former level of the ground when they were growing is clearly discernible (Fig. 3).

Elevation of the drowned forest
During the visit, the group discussed their clear observations that the ground through which the trees were growing was well below present spring high tide level today. Our conclusion was that the age of the forest was likely to be about 8000 years, just prior to the post-glacial sea level rise that would have drowned and killed it (Squire, 2013), as shown for many other fossil forests around New Zealand at this elevation (e.g. Hayward, 1997; Hayward & Brown, 2015). It was conceded that



Fig. 1. Map of Northwest Nelson showing location of drowned forest and sea level study site of Figueira *et al*. (2012).







Fig. 2 (above left), Fig. 3 (above right) and Fig. 4 (left). Different views of drowned forest in upper intertidal zone, Rangihaeata.



Fig. 5. Natural vegetation zonation along the high tidal edge of Whanganui Inlet with the high tidal shrub zone of salt-marsh ribbonwood and flax between the salt marsh rushes and native forest.

there was a slight chance that the forest was a lot younger and may have been drowned as a result of fairly rapid more recent subsidence combined with known sea level rise of 0.3 m in the last 150 years (e.g. Hayward *et al.*, 2012).

As a result of these discussions, we took a sample of wood from an in-situ tree stump and surveyed in the elevation of the fossil ground surface with respect to the tide level at the time. We used the published tide charts to obtain an estimate with respect to mean sea level (mid tide). We also surveyed elevation of the drowned forest floor with respect to spring high tide level as estimated from the wash-up line at the back of the relatively sheltered beach. The two methods provided elevation estimates that were within 0.1 m of each other with the forest floor level 1.4±0.1 m above mean sea level (MSL) or 0.7±0.1 m below mean spring tide level (MHWS) and 1.1±0.1 m below highest astronomical tide (HAT).

Squires (2013) has speculated that these tree stumps were kahikatea. None are sufficiently large, however, to support this hypothesis. Woody trees like this must grow above the HAT unless they are mangroves (only in northern North Island) or salt marsh ribbonwood, *Plagianthus divaricatus* (which grows between MHWS and just above HAT, Fig. 5). This woody shrub grows up to 3 m high and older plants can have trunks of 10 cm or more in diameter. It seems likely that most of these are the trunks and roots of salt marsh ribbonwood which would have grown between MHWS and HAT. If this is true then the forest floor at which they grew is now 0.7-1.1±0.1 m lower with respect to MHWS. There are several larger diameter trunks that may be some other woody tree that lived just above HAT, fractionally higher than most salt-marsh ribbonwood (see Fig. 3).

Age of fossil forest

The piece of branch from one of the trees was sent to Waikato University Radiocarbon Dating Laboratory (Wk50688) and has returned a radiocarbon age of 1592±26 years BP* (Alan Hogg written communication). The calibrated age in calendar years (with 95% probability) is 1521–1371 cal yrs BP (before 1950 CE*). This tree was growing here therefore somewhere between 429 and 579 CE, approximately 1500 years ago. This is quite different from the expected age of about 8000 years old and requires an explanation.

Hypothesis to explain the age of this drowned forest

If my assumption that most of these woody stumps and roots were in fact salt-marsh ribbonwood, then there has been a relative rise in sea level of 0.6–1.2 m in the last 1500 years. There are several possibilities to explain this:

1. sea level has risen;
2. local ground surface has subsided as a result of compaction;
3. the area/region has subsided as a result of one or more co-seismic (earthquake) events;
4. the area/region is slowly subsiding aseismically, possibly as a result of increased sea water loading on the adjacent crust (continental shelf) as a consequence of post-glacial sea level rise.

1. *Actual sea-level rise*
   It is now well-established that sea level has risen globally in the last 150 years and around New Zealand by ~0.3 m in that time (e.g. Gehrels *et al.*, 2008; Grenfell *et al.*, 2012). Evidence for any additional sea-level rise or fall between 1500 and 230 years ago is not well-established, with sea level more likely to have been slightly higher than present 1500 years ago than lower (e.g. Dougherty & Dickson, 2012). Thus it would seem that global sea level rise could account for no more than ~0.3±0.1 m of the relative sea level rise required.
2. *Compaction*
   Compaction of sediment is well known to occur in muddy or peaty sediment, especially when further sediment is loaded on top. In this instance there seems to have been very little sediment other than loose sand and shell that might have been deposited on top of the firm sandy peaty soil that the tree stumps were established in. While compaction cannot be ruled out as contributing to the relative sea level rise, it seems unlikely or minimal.
3. *Co-seismic events*
   Co-seismic subsidence of up to 1 m or more has been documented to have occurred during major earthquakes in the plate boundary deformation zone, east of Northwest Nelson (e.g. Hayward *et al.*, 2016). Golden Bay and Northwest Nelson, however, are regarded as being tectonically quiet and stable (e.g. Beavan & Litchfield, 2012) and unaffected by earthquake displacements.

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* The years 'Before Present' (BP) is the standard method of quoting a radiocarbon date where present is defined as 1950. Thus yrs BP equals years before 1950. The term Common Era (CE) is identical to AD but is becoming more commonly used internationally as it is non-religious (christian) and there is some debate as to exactly when Jesus was born.

4. *Aseismic subsidence*
   Fifteen years of satellite GPS measurements have shown that slow vertical movements of the Earth's surface are occurring in New Zealand and differ around the country (e.g. Houlie & Stern, 2017). There are inferred to be a number of potential drivers of these changes, including tectonics and loading of the crust (isostatic). Slow subsidence of the Northwest Nelson region could be a significant contributor to the inferred rise in relative sea level at Rangihaeata. In support of this inference are the observations by Figueira *et al*. (2012) based on studies of salt marsh foraminifera in a core 30 km away in Whanganui Inlet (Fig. 1). They found evidence for a rise of 0.55 m in relative sea level in the last 800 years. If the actual sea level rise of ~0.3 m is deducted from the 0.55 m there was ~0.25 m of subsidence in 800 years that could be attributed to slow regional vertical land movements (VLM).

Conclusion

If the inferred Whanganui Inlet rate of slow VLM (0.25 m per 800 yrs) is calculated for the 1500 years since the Rangihaeata forest was growing, then there may have been ~0.5 m of regional subsidence during that period. Adding 0.5 m to the actual sea level rise for the past 150 years (0.3 m) gives ~0.8 m of relative sea level rise at Rangihaeata in the last 1500 yrs. This is consistent with the estimated 0.6–1.2 m of relative sea-level rise based on the present elevation of the fossil forest.

The ribbonwood was probably growing around the edge of a brackish marsh inland of a low sand dune or beach ridge around the shore of this part of Golden Bay (Fig. 6). The ponded marsh water level would have been around MHWS. The estimated rise in relative sea level (~0.8 m) would have eroded the fringing dunes (Bruun's Rule) and killed and drowned the ribbonwood. Sand and gravel shorelines are very responsive to environmental changes driven by sea level rise or by variations in storminess, so it is common for swamp deposits to be exposed along sandy coasts because the shoreline has receded. Although Bruun's Rule can be no more than a guide to shoreline change along sandy shores, a rise in sea level of 0.8 m would be expected to be accompanied by a retreat of the shoreline of the order of 40 to 80 m.

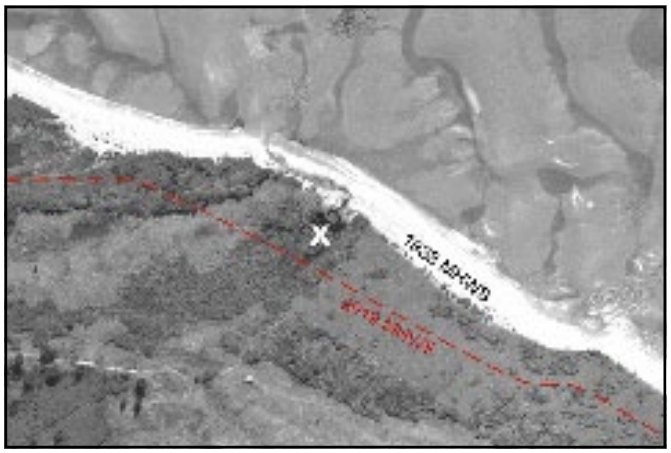


Fig. 6. 1938 air photo showing the amount of shoreline erosion that has occurred in the last 80 years, mostly in the last 40 years, X marks the location of the exhumed fossil forest that would have been buried and water-logged in the shallow freshwater lagoon behind the beach ridge in 1938.

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