

Geocene

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Geocene is a periodic publication of GeoClub, a section of the Geoscience Society of New Zealand's Auckland branch.

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

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AN EXERCISE IN UNTANGLING THE COMPLEX GEOLOGY OF NORTHERN AUCKLAND USING SIMPLE LiDAR IMAGERY

Jill Kenny

All figures are available as high resolution versions in Geocene_Kenny2.zip next to the Geocene 10 link.

An exercise in untangling the complex geology of northern Auckland using simple LiDAR imagery

A quote from the former Gisborne office of the old NZ Geological Survey, 1985 (GSNZ Newsletter 68) - "Thought for the day: The most significant geological quandaries strike towards, and culminate at, the area of poorest outcrop, and then re-emerge on the other side with a different solution". Having a background of stratigraphic and tectonic research north of Gisborne, dealing with remnants of the East Coast Allochthon, I certainly agree with this statement.

The same seems to apply to the northern Auckland region, at the southern limits of the Northland Allochthon, where outcrop is poor, lithologies are not consistent from one outcrop to the next, and lithology boundaries are invariably concealed. The Northland Allochthon is well mapped from Warkworth northwards (Edbrooke & Brook 2009), but from Warkworth to a line roughly from Helensville to Albany (Fig. 1), the geology has not yet been conquered – at least not tectonically – and many ambiguities and conundrums still remain.

I am now attempting to tackle this problem, using an unusual technique – LiDAR imagery. Here is my contribution.

Background

The terrain of northern Auckland is steep, deeply incised hill country, often forested. The few reliable outcrops reveal that most of the region is composed of autochthonous or piggy-backed Waitemata Group turbidites (Spörli 1989) with small inliers of exotic allochthonous lithologies (Edbrooke 2001).

North of this region, the numerous lithologies are more easily mapped and the Northland Allochthon nappe-like thrusts are well constrained (Spörli & Hayward 2002). In the Silverdale area in the southern part of the region, allochthonous lithologies also outcrop and were attributed to being a lobe of "Onerahi Allochthon" (Hayward 1982), later reinterpreted and named the "Silverdale Dome" by Schofield (1989).

Emplacement of the Northland Allochthon was diachronous as it advanced southwards. It was initiated by plate boundary changes at the end of the Oligocene (c. 22 Ma ago), but it only reached as far as the northern Auckland region by about the middle to late Otaian (c. 20 Ma ago) (Hayward et al. 1989). Hayward (1982) postulated a phase of movement in the middle to late Otaian involving catastrophic sub-seafloor slope failures from the Wellsford area southwards as far as Albany, on the slopes of the subsiding Waitemata sedimentary basin.

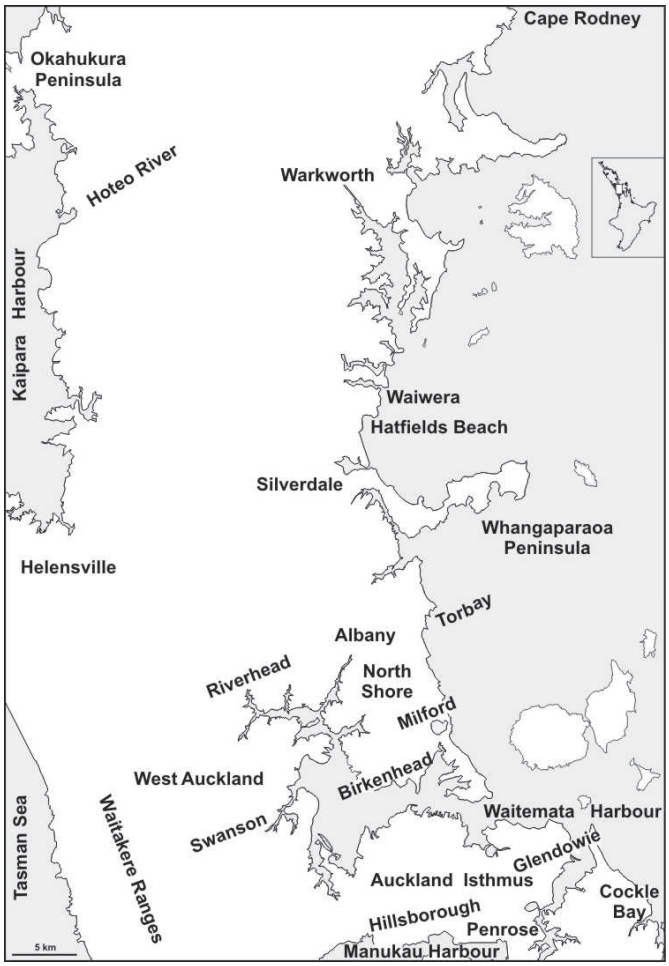


Figure 1. Localities mentioned in the text.

Kenny (2008b) mapped a series of arcuate-shaped asymmetrical ridges fanning out from an area just north of Albany southwards and southwestwards for more than 15 km. They were speculated to represent the current topographic expression of a series of imbricate gravity slides of dislocated, disrupted Waitemata Group sediments – a southwards continuation of the catastrophic slope failures caused as the early Miocene lower Waitemata Group sedimentary pile was "nudged" by the toe of the southward-migrating Northland Allochthon.

After the regional disruption, deposition of Waitemata Group sediments continued through the early Miocene and was followed by a period of uplift and erosion that formed the "late Miocene" (Kermode 1992) or Pliocene (Ballance 1968) Waitemata Group erosion surface. Kenny (2008a) and Kenny et al. (2011, 2012) developed the erosion surface concept using borehole and geophysical data, and Kenny (2013) has recently described the relationship between the erosion surface and the arcuate ridges. In essence, the relatively erosion-resistant strata involved in the leading edges of recognised gravity slides form

mappable arcuate patterns first documented on the North Shore of Auckland (Kenny 2008b). The form of the Waitemata Group erosion surface is retained along ridge lines, but away from ridge lines, the less-resistant strata have eroded in a regular and predictable pattern of streams and rivers, with the asymmetry highlighting the gentle north to northwesterly tilt and steep south-facing leading edge of each slide.

The presence of resistant strata forming arcuate ridges of course implies that there might also be a number of gravity slides that do not have resistant strata along their leading edges, and are therefore not prominent in the topography. Judging by the number of gravity slides inferred, there are probably many others in and around them that are invisible. Kenny (2008b) only researched as far north as Albany, however, the gentle northerly tilt of gravity slides supports Hayward's (1982, 1993) sketches for the Wellsford area.

Are there perhaps more gravity slides hidden within the anomalously thick pile of Waitemata Group strata north of Albany that could link the geology of the Auckland metropolitan area with that north of Warkworth? Could paucity of outcrop be overcome remotely perhaps, by using LiDAR imagery?

Use of LiDAR

LiDAR stands for "Light Detection and Ranging" – optical remote sensing technology that measures distance to laser-illuminated targets by analysing back-scattered light from those targets. LiDAR imagery is available for public viewing on the Auckland Council's GIS website. Unfortunately for those who live out of Auckland, it has been developed only to the boundaries of the new Super City. It gives opportunities to view superb mosaic aerial photograph images of the Auckland area, and it is even possible to investigate the positioning of waste water pipes across the whole region, or to scrutinise your neighbours' rates!

The research for this project has been achieved remotely by studying subtle texture changes and lineaments in various grey colours on the LiDAR map and by using other workers' maps that show bedding plane symbols or little crosses where they actually observed outcrop. I have given very little attention to juxtaposition of lithologies on published geology maps – how one lithology actually abuts against another is rarely observed in the field and is drawn on their maps according ideas in vogue at the time.

It quickly became apparent that a variety of geomorphological features, such as lineaments, bedding planes and terraces are visible on the LiDAR imagery. An initial plan to merely search for asymmetrical ridges and valleys evolved into a small but complex project. A map was prepared, using an arbitrary northern limit from Okahukura Peninsula in the west to Cape Rodney in the east (Fig 2). North of this limit the complex geology of Northland Allochthon is better understood and well documented (eg. Ballance & Spörli 1979; Isaac et al. 1994; Spörli & Hayward 2002; and northern New Zealand QMAPS – Kaitaia: Isaac 1996, Whangarei: Edbrooke & Brook 2009, Auckland: Edbrooke 2001). The map extends to a southern limit just south of Auckland Isthmus, to incorporate all the gravity slides proposed by Kenny since 2008.

Waitemata Group terrain scrutiny using LiDAR

Waitemata Group terrain typically erodes into a characteristic pattern of small, steep sided gullies, symmetrical in profile. This can be seen in the LiDAR image of the Auckland City GIS map (Figs. 3A & 4). Fortunately for the simplicity of this project, LiDAR imagery disregards vegetation and only shows the shape of the land's surface – with surprising detail at high magnifications. Forested areas are literally laid bare. Therefore, with no vegetation to conceal the ground surface, it is even possible to differentiate conglomerate facies from areas of other Waitemata Group lithologies (Fig. 3B).

Some valleys are asymmetrical, with one side steeper in profile than the other side (Fig. 3C). Almost invariably, this asymmetry is exhibited as steeper gradients facing south, southeast or southwest, and the larger examples form curious arcuate and sinuous shapes across the countryside when mapped (Fig. 3D). Small-scale lineaments (hillside scale) are ubiquitous on the LiDAR map (Fig. 3E). They could represent erosion along faults, joints, bedding planes or nothing at all. Larger scale lineaments might also correspond to faults (Fig. 3F).

If the steeper slopes are treated as potential leading edges of gravity slides, and slide plains are drawn on the map at the base of the steeper slopes, many of these features can be connected to form a series of large east–west gravity slide fronts. Some of these slides link with slides involving lithologies associated with the Northland Allochthon (Edbrooke 2001) or postulated from arcuate faults (Kenny 2008b). Potential gravity slides and inferred regional faults are shown in Fig.2 using the LiDAR map as a base map.

Discussion

The existence of a sub-horizontal "late Miocene" Waitemata Group erosion surface has made it possible to infer regional block faulting in the Auckland Isthmus, North Shore, west Auckland and south Auckland areas (Kenny et al. 2011, 2012). In these areas, the regional faults cut the postulated nudged "gravity slides". In each fault-bounded block, the gravity slide leading edges and the erosion surface are one and the same thing, with a subtle northward tilt visible in places (Kenny 2013).

In northern Auckland, which has been uplifted to a higher average elevation than Auckland, erosion is more dramatic and the two concepts of a) erosion



Figure 2. Hypothetical geology map of northern Auckland using LiDAR imagery.
This figure is designed to be viewed online (see above) at high magnification.

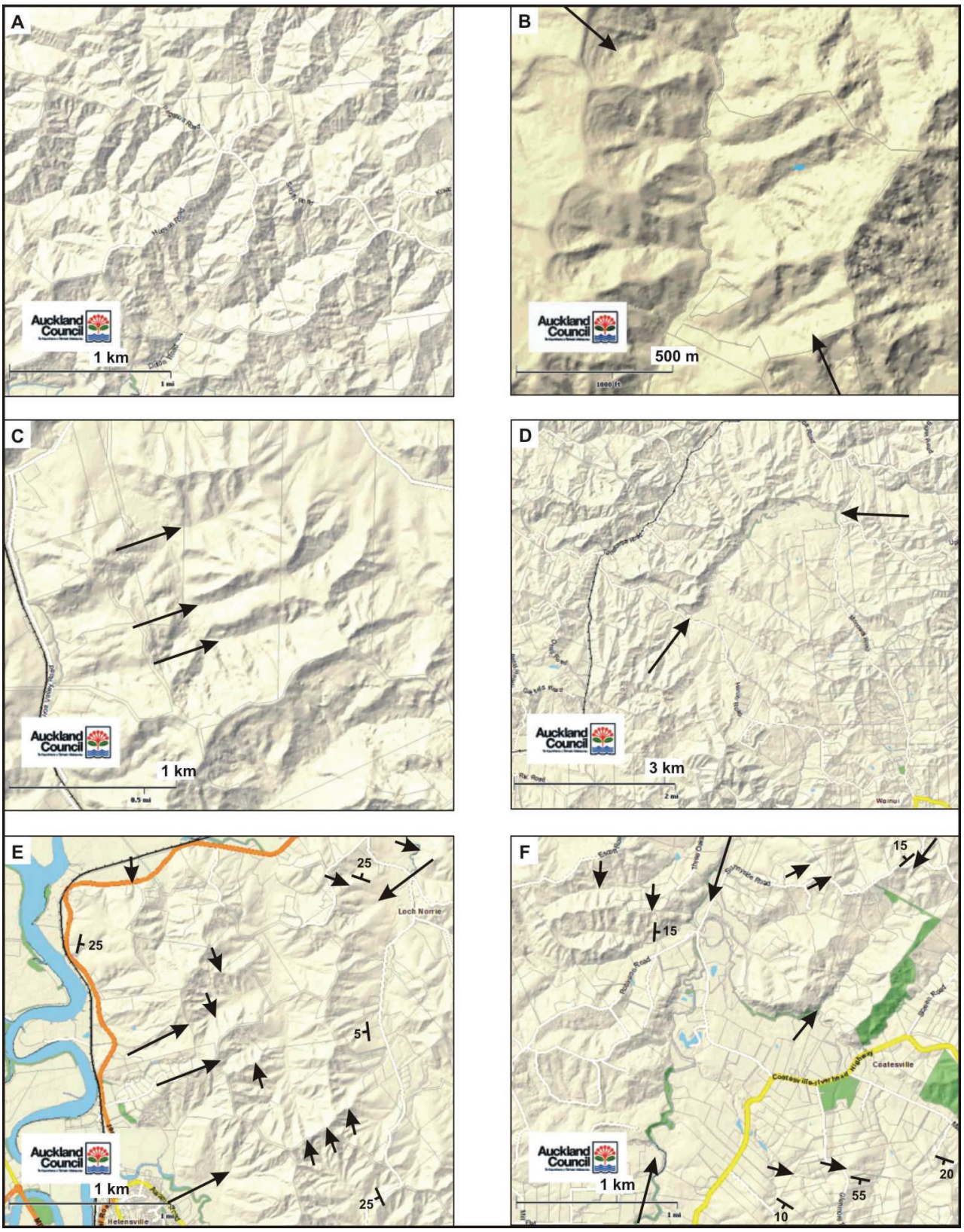


Figure 3. Use of textures on an Auckland City Council GIS map to postulate geological fabric in a complex setting (refer to Figure 4 for locations).
A: Symmetrical valleys eroded in Waitemata Group lithologies. **B**: Contrasting LiDAR textures in Waitemata Group topography. To the left of a rough line between the two arrows is the normal smooth texture of the Waitemata Group. To the right is the rough texture of the Albany Conglomerate facies in the Group. **C**: Asymmetrical valleys eroded in Waitemata Group lithologies (arrowed). **D**: Steep slopes (arrowed) that might follow the leading edge of a gravity slide from the northern sector. **E**: Lineaments that might represent faults (long arrows) or bedding planes (short arrows). Nearest known bedding is shown. **F**: An example of a lineament that represents a known fault (Rangitopuni Fault, long arrows). Also shown is a strong lineament that might represent a fault (medium arrows) and local bedding (short arrows). Nearest known bedding is shown. Green patches are reserves on the GIS base map.



Figure 4.Locality map for Figs. 3A–F.

surface and b) gravity sliding diverge to show their true colours.

a) The Waitemata Group erosion surface is less obvious in northern Auckland because intense erosion has lowered much of the Waitemata Group terrain, removing most of the uppermost strata. The original erosion surface now only exists as isolated high plateau remnants on highest inland catchment boundaries.

As an example to illustrate the effects of erosion in this area, it is clear from the meandering nature of the Hoteo River, that it formed on an uplifted flat plane, tilted slightly to the west (Hayward & Grenfell 2010). It has since become deeply incised in that same meandering pattern (Fig. 5). This antecedent river and some high plateau remnants at 250–300 m above sea level (Fig 5), clearly visible on the LiDAR image, are the only clues that the Waitemata Group erosion surface once existed as far north as here. In such steeply dissected terrain, it is surprising that these remote high plateaux have retained their form.

Heights above sea level in the Hoteo hinterland are only surpassed by the Waitakere block in western Auckland, where the erosion surface can be seen at 350 m elevation (Hayward 1983, 2009). It is higher than most of central Auckland, where the erosion surface, although block faulted, has maintained an intermediate elevation of no more than 100 m above sea level (Kenny 2008a, Kenny et al. 2011, 2012). Further south, the same erosion surface has been subjected to more extreme block faulting, dropping it to more than 60 m below sea level in the Manukau Lowlands (beyond the southern border of Fig. 2) and raising it to about 120 m above sea level in the hills east of the Manukau Lowlands.

b) Gravity slides are postulated to have reached as far south as the southern coast of the Auckland Isthmus, with their leading edges corresponding to the Waitemata Group erosion surface (Kenny 2008b, 2013). In the northern Auckland area, with its higher elevations and vigorous erosion, the relatively erosion-resistant leading edges of the gravity slides packets have still been reduced in height to some extent and no longer coincide with the old erosion surface that now only survives as isolated remnant plateaux.

Using the asymmetry of some valley profiles within the Waitemata Group terrain, and with the assistance of the LiDAR imagery, it has been possible to map additional potential Northland Allochthon-related gravity slide fronts - part of an imbricated series of catastrophic slope failures that slid into this area from the north, infiltrating and disrupting the accumulating Waitemata Group sediments (Kenny 2008b). The asymmetrical erosion disparity is possibly forming where the leading edge of each slide contains more erosion-resistant lithologies than elsewhere in the slide package. This differential erosion seems to be revealing gravity slides that would otherwise remain unnoticeable in the hilly terrain. Of course using the same logic, leading edges of gravity slides that do not contain resistant lithologies, and therefore do not form asymmetric valleys, will not be detected using this strategy.

Asymmetry of valley profiles, with opposing sides at significantly different angles, are common worldwide, and are often attributed either to geological changes across the valley, or to subtle differences in climate and weathering on similar lithologies on shaded versus sunny, and/or wetter versus drier sides of the valley (eg. Leopold et al. 1995; Wohl 2000). If the Waitemata Group lithologies were susceptible to subtle weathering changes on shaded and therefore wetter slopes, then most of the east–west-directed valleys would have steeper south-facing slopes. This is not the case. It is clear from the overall LiDAR texture of valleys eroded in Waitemata Group terrain (Fig. 3A) that most valleys are symmetrical. Occasionally valleys are asymmetrical, with steeper south-facing slopes. It is these that have been mapped as potential gravity slide fronts.

Textures and lineaments on the LiDAR imagery for northern Auckland support the structural sequence of events for this region: with increasing proximity northwards to the Northland Allochthon itself, allochthon lithologies and “piggy-backed” Waitemata Group sediments (Spörli 1989) are involved in the postulated gravity slides (Hayward 1982, 1993) and are offset by subsequent regional faulting (Fig. 2) (Kenny 2008a, 2008b; Kenny et al. 2011, 2012).

This study using LiDAR imagery answers some questions about the geology of northern Auckland.

- North of the “Silverdale Dome”, Waitemata Group sediments attain an apparent thickness of many kilometres. This is inconsistent with findings in a study of apatite fission track and vitrinite reflectance data by Raza et al. (1999), which concluded that the Waitemata Basin sequence was subjected to low temperatures of less than 60ºC due to shallow burial of only up to 1 km. Earlier, Hayward (1993) had suggested that the anomalous thickness was probably produced by a series of imbricate thrust sheets. The succession of gravity slides mapped using LiDAR supports this hypothesis.

- There is a sudden lateral transition between turbiditic East Coast Bays Formation and thick sandstone-dominated Pakiri Formation between Hatfields Beach and Waiwera (Schofield 1989). This seems to be the southern limit of the more erosion-resistant Pakiri Formation, and with assistance from LiDAR, it can be traced right across to the west coast as a juxtaposition of more elevated, robust topography of the Pakiri Formation to the north (depicted on Fig 2 as a faint dotted zone from Hatfields Beach westwards), against the smaller scale eroded valleys typical of the East Coast Bays Formation to the south. The lateral juxtaposition is logical if they are separated by one or more gravity slide planes.

- Matapoura Conglomerate is a submarine canyon- and channel-fill deposit within Timber Bay Formation of the Waitemata Group in the central Kaipara area. Another conglomerate, the Albany Conglomerate facies within the East Coast Bays Formation of the Waitemata Group, occurs in discontinuous lenses from north of Helensville to south of Albany. It contains clasts similar to Matapoura Conglomerate as well as rare clasts derived from the Northland Allochthon and it has been extensively deformed by thrusting and associated deformation. Hayward (pers. comm. 2013) speculates that Albany Conglomerate is the lateral equivalent of Matapoura Conglomerate, caught up in the Northland Allochthon as it migrated southwards past Kaipara. However, there is a gap of more than 20 kms between the two conglomerates that he hasn’t been able to explain. He suggests that detachment of part of the Matapoura Conglomerate by the advancing front of the Allochthon, then jumbling of that material as the front progressed southwards, could have formed the pockets of disrupted Albany Conglomerate. Using LiDAR imagery, the “gap” is now inferred to be filled with a series of subsequent gravity slides from sources presumably devoid of conglomeratic material.

- Geology maps of northern Auckland (eg. Edbrooke 2001, Edbrooke & Brook 2009) show two Waitemata Group conglomerates that contain

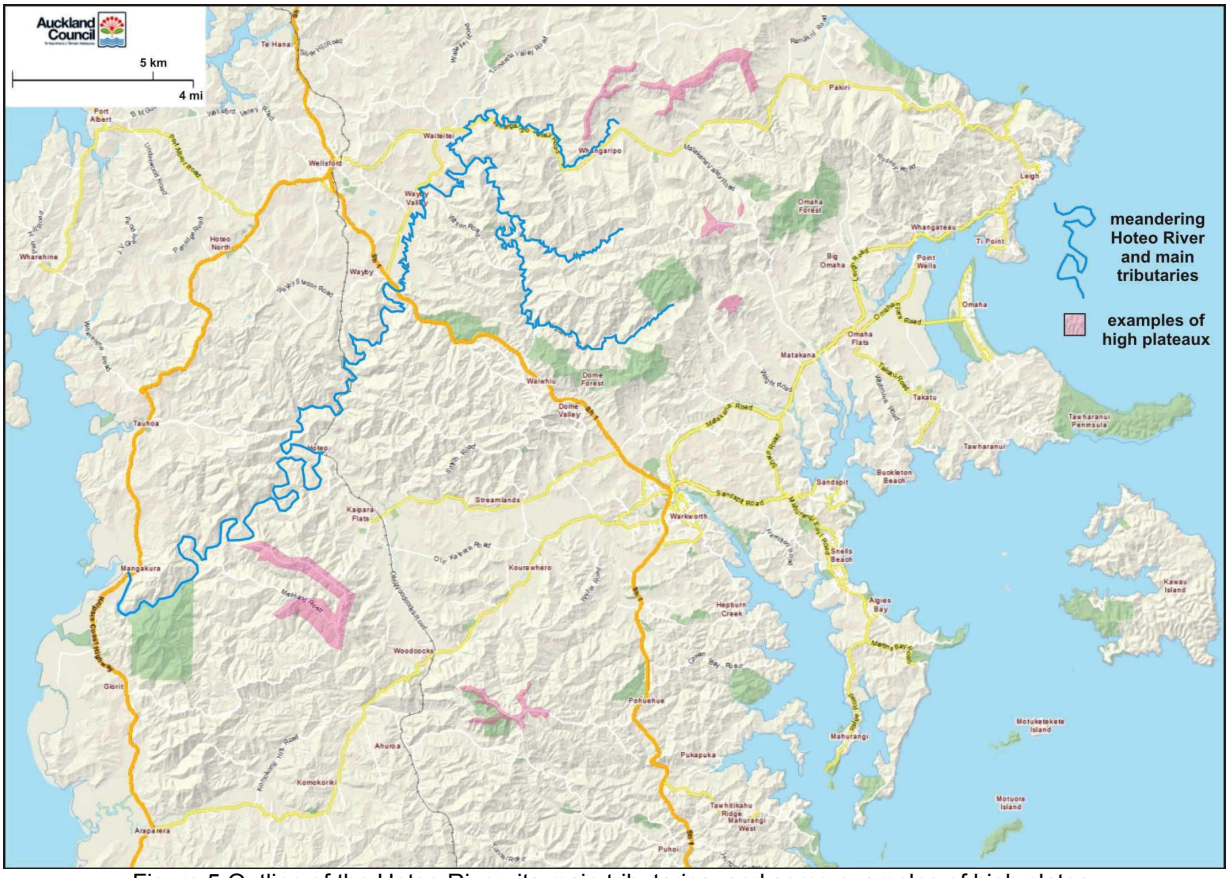


Figure 5.Outline of the Hoteo River, its main tributaries, and some examples of high plateaux representing the old Waitemata Group erosion surface. (Green patches are reserves on the GIS base map.)

suites of remarkably similar Allochthon-dominated clasts, but separated by a geographic gap of more than 20 kilometres Matapoura Conglomerate is a submarine canyon- and channel-fill deposit in the central Kaipara area. Albany Conglomerate is a submarine fan deposit and occurs in extensively deformed, discontinuous lenses from north of Helensville to south of Albany (Hayward 1993). It is possible the two facies were once from the same location, with Matapoura Conglomerate being the proximal submarine canyon portion and Albany Conglomerate being the downslope, distal submarine fan portion of the same system (Hayward, pers. comm. 2013). Gravity slides identified by LiDAR imagery could have displaced the Albany Conglomerate southwards. Using LiDAR imagery, the "gap" is now inferred to be filled with a series of subsequent gravity slides from sources further north, presumably devoid of conglomeratic material.

- In mapping the Helensville–Whangaparaoa area, Schofield (1989) recognised a large central area of steeply-dipping Waitemata Group (which he called Paremoremo Formation) containing Albany Conglomerate but lacking Parnell Grit, overlying Northland Allochthon, surrounded at least to the south, east and northwest by gently-dipping Waitemata Group (which he called East Coast Bays Formation), containing Parnell Grit but lacking Albany Conglomerate and, in the east, lying directly on Waipapa Terrane greywacke. My recognition, using LiDAR, of extensive gravity sliding right through this central area provides a possible explanation for this anomalous juxtaposition of two quite different associations of rocks (as proposed by Hayward, 1982).

- Sediments supposedly younger than gravity sliding, i.e. above Schofield's "mid-Otaian unconformity", are possibly also affected by gravity sliding. These are younger strata within the Waitemata Group and also the Waitakere Group, maybe as young as 17 Ma, and occur from Okahukura to Waitakere Ranges along the western side of northern Auckland (shaded subtle pink in Fig 2). Although the advance of the Allochthon is diachronous southwards, the notion of gravity slides affecting these strata must be treated cautiously. Possible explanations include:

- Topography in the vicinity of younger strata might occasionally have steeper southern slopes, but they are not associated with gravity slide fronts;

- Two different sliding events – it might be acceptable for young strata in the far southwest of the mapped area to be involved in gravity sliding, but lithologies in the Okahukura area in the northwest corner are also underlain by thrusts (Edbrooke 2001). So were there later, younger phases of gravity sliding?

This study is not aimed at remapping the northern Auckland region, but merely to investigate the use of a different form of remote sensing to aid others in their attempts to decipher the geology. I have explored this topic with little knowledge of the idiosyncrasies of Northland and northern Auckland geology, except that it certainly does remind me of my research years at East Cape, where you think you have a logical explanation, but over the next ridge it is again illogical. Perhaps lack of knowledge of northern Auckland is an advantage in this study, because the geological problems can be explored from a fresh perspective. Maybe it is possible to see the wood for the trees, or in this case remove the wood altogether, with the all-piercing LiDAR.

Acknowledgements:
I have had many deep and meaningful discussions with Bruce Hayward on the map results with unusual use of LiDAR imagery. The map has been on a table behind my work desk for a few months. He has pored over it many times and admits some of the geological mysteries of this area are possibly unravelled. However, this procedure is still way outside his comfort zone and he usually leaves the room with a bemused expression on his face. I appreciate his attempts to keep me from going entirely off the rails, or even out of the ball park. He has read the manuscript and says – "go for it"!

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