Geology Report

Kaipara District

Northland

Submitted to:

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Appendices

Appendix 1: Geology Map of the Kaipara District

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1 Introduction

The Kaipara District is characterised by rolling hills of some of the most diverse and complex geology in all of New Zealand. The hills are generally underlain by the deeply weathered and tectonically sheared sedimentary rocks of the Northland Allochthon, bisected by broad valleys and incised gullies, which are filled with young alluvial sediment, intruded by volcanic and plutonic rocks, and mantled by coastal dunes. The Kaipara District's geology is unique to the country in that it tells a story of part of New Zealand's creation. Rock records tell us that the land subsided deep into the ocean, then uplifted again, was subject to sea-level rise and fall, explosive volcanism, and the emplacement of rocks from the seafloor.

There are no known active faults in the Kaipara District, and the Northland Volcanic Field is generally considered to be dormant. However, there are a number of geological hazards that affect the Kaipara District. Soft soils can consolidate under the load of new buildings, saturated sands and silts may liquefy and cause settlement, and the pervasively sheared rocks and high groundwater can cause slope instability on relatively gentle slopes. These geohazards and more are presented in a series of geotechnical hazard reports and maps prepared by ENGEO for various indicative growth areas of the Kaipara District.

2 Regional Geological Setting

The geological setting of Kaipara District has been established through a comprehensive review of published geological information for the area, principally the GNS 1:250000 map "Geology of the Whangarei Area" (Edbrooke and Brook, 2009), which is part of the prevailing map resource for New Zealand.

The Kaipara District's geological history can be generally described as six structurally significant evolutions, beginning with the Permian to Early Cretateous-aged (between about 298 million years and 100 million years ago) Greywacke basement rock emplacement (Edbrooke and Brook, 2009). This was followed by significant land subsidence approximately 26 million years ago (mya), creating a deep oceanic basin across the Kaipara District. As the Australian tectonic plate collided with the submerged land, great sheets of the sea floor were peeled off and thrusted over a submarine Kaipara District in a rare geological process called obduction. This process repeated several times, creating the chaotic and sheared rocks of the Northland Allochthon sequence. About this same time, ocean sediment accumulated in deep water turbidity flows and shallow water debris flows resulting in an alternating sequence of sandstone, siltstone and mudstone called flysch deposits.

As the Australian Plate continued to converge with the Pacific Plate, tectonic forces began to uplift the Kaipara District back out of the sea, exposing the accumulated deposits of Northland Allochthon, flysch, and sporadic outcrops of Greywacke basement rock. The thinner, denser Pacific Plate was forced under the Kaipara District, triggering an episode of volcanic activity, which began erupting onto the now terrestrial landscape.

More recently, alluvial and fluvial deposits of young pumiceous sands, weathered silts and clays, and organic material filled the low-lying valleys and gullies of the district, while wind-blown dune deposits developed along the east and west coasts.

3 Stratigraphy

This section is intended to provide an overview of the main formations of the Kaipara District. In an effort to consolidate the many different geological formations, we have grouped rock types together based on their age, mechanism of emplacement, and importance to the overall geology of the Kaipara District and associated geological hazards they may present. This grouping of geological units also forms the basis for our Geological Map appended at the back of this report. The intent of this is to describe the main geological units that make up the Kaipara District and not to name each individual unit.

3.1 Basement Terrane

The Basement Terrane of the Kaipara District is made up of four basement units (Maitai Terrane, Murihiku Terrane, Caples Terrane and Waipapa Terrane). The dominant rocks in the study area are Permian- to Early Cretateous-aged (between 298 Mya and 100 Mya) accretionary rocks of the Waipapa Terrane. These rocks are comprising predominantly of thin-bedded, alternating fine grained sandstone and argillite (claystone / mudstone) with massive beds of laminated argillite and highly fractured Greywacke sandstone.

Waipapa Terrane is typically strong to very strong, closely fractured and commonly contains veins of quarts, calcite, prehnite, chlorite and zeolite. The Basement Terrane are the oldest known rocks in the Kaipara District and most often are buried deep beneath younger rocks and soil, to form the basement of the region. Along the east coast, northeast of Mangawhai Heads, Waipapa Group rocks form sheer craggy cliffs in coastal exposures, and spiny mountainous terrain inland.

3.2 Northland Allochthon

Much of the Northland region is underlain by Cretaceous to Miocene rocks of the Northland Allochthon. The Northland Allochthon is a series of thrust sheets and mélange containing a range of sedimentary and igneous rocks emplaced across Northland as a result of thrusting and gravity sliding into the deepening Waitemata Basin.

Due to the nature of their emplacement, the thrust sheets (or nappes) are faulted, folded and sheared resulting in a complex structure that makes identification of the original stratigraphic units difficult. Stronger rocks of the Allochthon, such as the Mahurangi Limestone and Punakitere Sandstone can be seen in road cuts throughout much of district, particularly in the mountainous terrain between Topuni and Brynderwyn along State Highway 1, and between Brynderwyn and Matakohe along State Highway 12. Exposures of sheared Mélange and crushed Mangakahia Complex mudstones are less prevalent.

3.3 Waitemata Group

Interbedded sedimentary rocks of the Miocene-age Waitemata Group overlie Mesozoic basement terrain rocks. These rocks were deposited as submarine debris flows and turbidite flows, called flysch deposits, when the Kaipara District was deep underwater. Between basement Greywacke rocks, Northland Allochthon and the Waitemata Group, there is an unconformity in many parts of Northland due to erosion (Rickets et al., 1989).

Examples of Waitemata Group rocks in the Kaipara District are the sandstone and mudstone of the Pakiri Formation that form the rolling hills and paddocks between Mangawhai and Hakaru.

3.4 Volcanics

The Northland Volcanic Arc comprised two belts of volcanoes that erupted along both sides of Northland and Auckland between 23 and 15 million years ago (Hayward, Bruce, 2017). The western belt (Waitakere Group) consists primarily of the Hukatere and Waipoua Subgroups and include numerous offshore volcanoes. Hukatere Subgroup rocks outcrop between Waihue and the Kaipara Harbour and consist of remnants of several small satellite volcanoes. Waipoua Subgroup is located within the Hokianga-Kaihu area and primarily includes basalt flows, notably those capping the Tutamoe Range north of Dargaville, and volcanic derived sediments, such as the Omapere Conglomerate within the Hokianga-Kaihu area. Tutamoe is the onshore remnant of a large submarine shield volcano mapped offshore by geophysical methods (Edbrooke and Brook, 2009).

Between Tokatoka and Dargaville about 140 small basaltic, andesitic and dacitic intrusions extend through Northland Allochthon strata. Maungaraho is a prominent eroded andesite intrusion located around 4 km north of Tokatoka (southeast of Dargaville). Other intrusions are also present near Waihue, Hukatere and elsewhere.

The eastern belt (Coromandel Group) includes the remnants of volcanoes between North Cape and northern Coromandel Peninsula and includes rocks of the Taurikura and Whangaroa Subgroups. Rocks of the Whangaroa Subgroup do not notably outcrop within the Kaipara District.

The Taikura Subgroup comprises predominantly andesitic flows and volcanic derived sediments, with dacite domes, and andesite, diorite and granodiorite intrusions. Subaerial dacite domes and associated altered tuff forms the Pukekaroro Hills between Maungaturoto and Mangawhai. Near Mangawhai, dacite outcrops are mapped in the northwest adjacent to the Waipu Boundary Fault, and on the coast in the northeast forming steep, craggy cliffs and ridges.

The Kerikeri Volcanic Group is a Late Miocene- to Quaternary-aged volcanic group that includes a number of monogenetic (single eruption) basaltic volcanoes across Northland, with an isolated flow remnant outcropping in Mangawhai. This is the far southern extent of the field.

A large basalt flow outcrop is mapped to the northwest of Mangawhai town, with a smaller peak-like outcrop immediately west of the town adjacent to Kaiwaka-Mangawhai Road. In the northwest, basalt has historically been quarried in association with development of the land and the basalt rock has been used to construct low stone walls across the area.

3.5 Tauranga Group

Pliocene to Holocene-aged alluvium of the Tauranga Group comprise river, lake and estuarine sediments that have been deposited in river valleys. Subsequent sea-level fluctuations have resulted in sequences of alluvial terraces and flood plains. The Tauranga Group is mapped in the low lying areas in the Kaipara District adjacent large river systems (the Northern Wairoa River, Otamatea River, Arapaoa River, Oruawharo River), creeks, valleys, gullies, and mantling harbours and estuaries.

Expansive deposits of Holocene-aged alluvium of the Tauranga Group can be viewed along either side of the Northern Wairoa River near Dargaville. Elevated Pleistocene alluvial deposits can be observed near the Wairau River, south of Maungaturoto Bowling Club, between the river and Bickerstaffe Road.

3.6 Dunes

Pleistocene to Holocene-aged coastal sand deposits including shallow marine, beach and dune sands are located predominantly within coastal areas of the Kaipara District. Holocene-aged fixed dunes comprise loose and poorly consolidated sands with interdune lake and swamp deposits of minor sand, mud and peat. These deposits are generally stabilised by vegetation growth. Mobile (or active) dune deposits comprise bare sand dunes with sparse vegetation, and change to the distribution and formation of these deposits is ongoing as a result of coastal weathering and deposition processes. Holocene fixed and mobile dunes are mapped along and just inland from much of the west coast, including at Baylys Beach, Glinks Gully and Omamari; and on the east coast, south of Mangawhai Heads.

Pleistocene dune deposits are mapped along the west coast of the Kaipara District and extend some distance inland. In the east, they form most of the peninsula that Mangawhai Heads is built on, extend inside the Mangawhai Harbour and form vegetated rolling hills above the estuary into the southeast of Mangawhai. The deposits typically comprise weakly cemented and uncemented sands with preserved interdune deposits, where buried organic material has formed lignite. These lignite layers are notably observed at Baylys Beach as a capping layer, but may also be exposed along the shore following storm events.

Pliocene- to Early Pleistocene-aged fixed dune and interdune deposits of the Awhitu Group are present within Te Kopuru. These older dune deposits generally consist of moderately to weakly consolidated, dune-bedded sandstone and include paleosols (buried topsoils), lignite and carbonaceous mudstone and sandstone.

3.7 Residual Soils, Colluvium and Landslides

Residual soils form where soil and rock is subject to in-place weathering without being transported. Many ‘rock’ materials in the Kaipara District have a well-developed cap of residually weathered soils which behave differently to the intact or unweathered parent material. Residual soils are not individually mapped and are assumed to be present over almost all underlying ‘rock’ material.

Colluvium is present on most slopes in the district and differs from residual soil, in that it is mobilised soil deposited by gravity. Colluvium is commonly found in gullies and at the base of natural slopes where soil slowly creeps downslope due to the shrink / swell nature of the clayey soils. In more granular soil and rocky outcrops, colluvium presents as loose sediments at the base of the slopes deposited by slope wash and mass-wasting.

Landslide deposits are present on many slopes, typically as a result of instability within the residual soils, although deep seated landslides moving within the underlying sheared rock mass do occur in this terrain. These deposits are typically observed as mobilised soil and rock that can be encountered as largely intact, or as chaotic deposits of clay- to boulder-sized soils, and are described further in Sections 4.2 and 4.3.

4 Geological Hazards

This section is intended to help define what specific geological and geotechnical hazards are associated with this area, describe the mechanics of triggering these conditions, and note how relevant they are to the Kaipara District.

4.1 Active Faults

Although Kaipara District is one of the least seismically active regions in New Zealand, it has a rich history of active faulting that contributes to the complex geology present today. Based on the GNS New Zealand Active Faults Database, there are no known active faults within the District. The nearest active fault is the Waikopua Fault located approximately 92 km southeast of the District.

There are numerous unnamed, inactive faults mapped within the district that are generally located at the contact between the different geological units. These inactive faults are typically thrust faults associated with the emplacement of the Northland Allochthon rocks.

4.2 Seismic Hazards

The GNS New Zealand Active Faults Database indicates that there are no known active faults within the Kaipara District although there are a number of mapped inactive faults. The nearest mapped active fault is located southeast of Auckland, however ground shaking from unmapped faults or faults outside of the Kaipara District can still have an effect on infrastructure, buildings and the landscape.

Potential seismic hazards resulting from nearby moderate to major earthquakes can generally be classified as primary and secondary. The primary effect is ground rupture, also called surface faulting, where the ground immediately above and adjacent to the fault line will rupture. The common secondary seismic hazards include ground shaking, ground subsidence or uplift, soil liquefaction, lateral spread, landslides, tsunamis or seiches and flooding. Ground rupture is not expected within the Kaipara District, however secondary hazards can be expected to occur, as described below.

Ground shaking and subsequent effects on structures, infrastructure and engineering systems can be extensive and affect large areas. In geotechnical assessments, amplitude, frequency and duration of shaking are the main factors considered. As the Kaipara is not very seismically active, ground shaking values in engineering design are normally lower than the rest of the country.

Ground subsidence induced by widespread fault movement may occur during strong earthquakes. This process is often accompanied by an inundation or an increase in flood risk and may cause significant damage to roads, services and engineered structures.

Soil liquefaction results from loss of strength during cyclic loading, such as imposed by earthquakes. Soils most susceptible to liquefaction are clean, loose, saturated, uniformly graded fine sands below the groundwater table. The shaking causes pore water pressure to build and when this exceeds confining pressure the soils may deform and, in extreme cases, behave as a fluid. If that occurs, they are said to have 'liquefied'. If the liquefied soil vents to the surface or consolidates, then ground surface deformation may occur. Low-lying alluvial soils (sand and some silts) and dune sands are the most at risk of liquefaction, particularly when near a body of water such as a lake, river or the ocean.

Lateral spread involves lateral ground movement caused by gravity and seismic shaking. Lateral spread is most common in sloping ground or where a "free face" is exposed in close proximity to the site. A free face can include any near-vertical cut, but is commonly associated with riverbanks or creek terraces. Lateral spread requires the soil to liquefy and is a separate process from that which causes lateral displacement of soils on slopes.

Landslides and land instability can be triggered by earthquakes, expressing as lateral earth displacement along a slope, at the crest of a slope or as rockfall and rock avalanche, depending on the geological material making and slope geometry. Landslides are discussed in more detail in Section 4.3 below.

Flooding may be associated with earthquakes when ground shaking or ground rupture damages dams or levees / stopbanks along rivers, or when regional subsidence occurs.

4.3 Landslides

As noted above, landslides may be triggered by ground shaking during an earthquake, however other triggering factors are more common in the Kaipara District. Typically, landslides in this area are as a result of instability within the residual soils of the Northland Allochthon. These deposits present as mobilised soil and rock that can be encountered as largely intact, or as chaotic deposits of clay- to boulder-sized soils.

Areas at risk of landslides commonly show geomorphological signs of previous land movement. There may be rocky debris at the toe of a slope, hummocky or irregular soil mounds, well defined linear (or arcuate) slope breaks, exposed soils, tension cracks, a bulge at the toe of a slope, etc.

Human activities can also trigger landslides, particularly when diverting water over a slope, placing fill soils near the crest of a slope, or cutting soil away from the toe of a slope.

Areas of soft rock beneath hard, permeable covering units (basalt, limestone, etc.) can result in an unstable landscape. On the flanks of the Tutamoe Range (near Kaihu) this has resulted in extensive translational landslides where soft, sheared rocks of the Northland Allochthon underlie basalt lava flows.

4.4 Volcanic Activity

As described in Section 3.4, the Northland Volcanic Arc comprised two belts of volcanoes that erupted along both sides of Northland and Auckland between 23 and 15 million years ago (Hayward, Bruce, 2017). As such, further low-magnitude eruptions are unlikely, as it is generally considered that the volcanic fields within the Kaipara have a relatively low recurrence interval.

4.5 Consolidation Settlement

Consolidation settlement occurs when compressible soils are subject to increased stress, such as from new structure or fill loads. Weak clay and organic soils are most prone to consolidation settlement. Consolidation settlement is normally considered where fills or heavy structures are proposed in areas known to contain young alluvium, peat, or other soft soils.

4.6 Other Hazards

Karst – Limestone and other carbonate rocks are highly soluble in rainwater due to their dissolved carbon dioxide content, and piping failures can occur resulting in subsurface drainage channels along defects within the limestone rock mass. These can form near the ground surface, may be up to several metres wide, and may collapse to form sinkholes (karst topography).

Expansive Soils – Certain cohesive soils have a tendency to shrink and swell, particularly with seasonal fluctuations of soil water content. This behaviour has implications for foundation design and the performance of surface structures.

Sulphate Attack on Concrete – Water-soluble sulphates are capable of chemically reacting with the components of concrete, causing accelerated corrosion and resulting in a shortened design life. High sulphate soils and groundwater are common where excessive amounts of gypsum or other sulphate containing minerals are present.

Other sources of acid sulphates can come from seawater, peat deposits and industrial wastewaters. In the Kaipara District, low-lying alluvial deposits are most susceptible to sulphate attack on concrete.

5 Summary

Because of the rich tectonic history, extreme subsidence and explosive volcanic past, the geology and geomorphology of the Kaipara District is quite unique. Each geological unit tells us a story about how and when it was created. The geology is important to understand, because it speaks to the geotechnical properties, strength characteristics, and engineering properties of the rocks and soils. From this understanding, we consider the main geohazards to consider within the Kaipara District to be consolidation settlement in soft ground, land instability near steep land or Northland Allochthon rock units and liquefaction in young alluvial sand deposits. All of these geohazards can be adequately managed during the development cycle, however early recognition is key to understanding and developing an effective and efficient solution.

6 References

Hayward, B 2017. Out of the Fire into the Ocean (2017), Auckland, New Zealand: Geoscience Society of New Zealand

Ricketts, B.D., Ballance, P.F., Hayward, B.W. and Mayer, W., 1989. Basal Waitemata Group lithofacies; rapid subsidence in an early Miocene interarc basin, New Zealand. Sedimentology 36 (4), pp. 559–580.

Institute of Geological & Nuclear Sciences (2009). 1:250000 Geological Map 2, S. W. Edbrooke, F. J. Brook Geology of the Whangarei Area.

7 Limitations

i. We have prepared this report in accordance with the brief as provided. This report has been prepared for the use of our client, the Kaipara District Council, to be included as part of the Kaipara District Plan, in relation to the specified project brief described in this report. No liability is accepted for the use of any part of the report for any other purpose or by any other person or entity.

ii. Only a limited amount of information has been collected to meet the specific financial and technical requirements of the client's brief and this report does not purport to completely describe all the site characteristics and properties. The nature and location of geologic units and faults are from published maps and reports referenced below, and it should be appreciated that actual conditions could vary from the assumed model.

iii. This Limitation should be read in conjunction with the Engineering NZ / ACENZ Standard Terms of Engagement.

We trust that this information meets your current requirements. Please do not hesitate to contact the undersigned on (09) 972 2205 if you require any further information.

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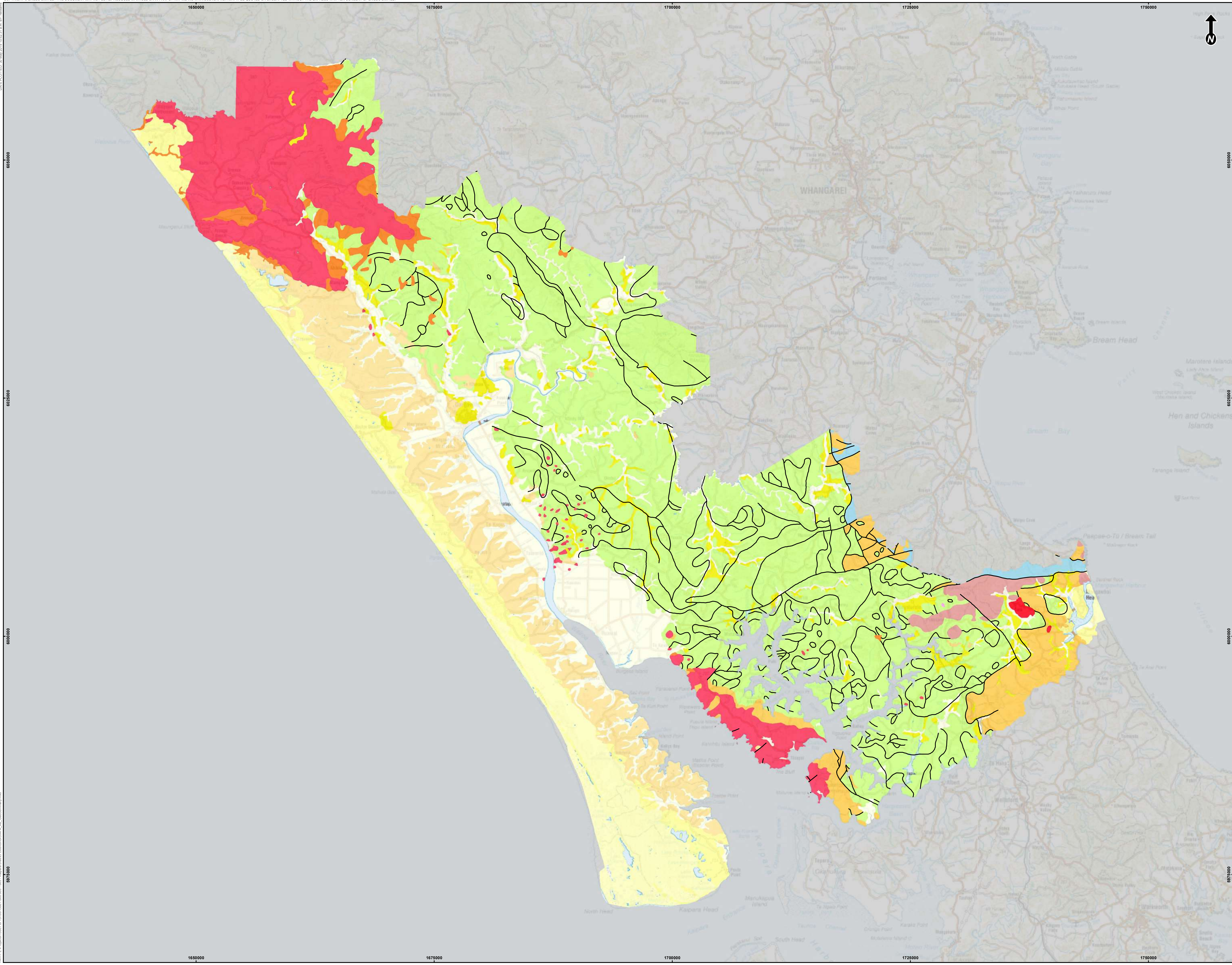
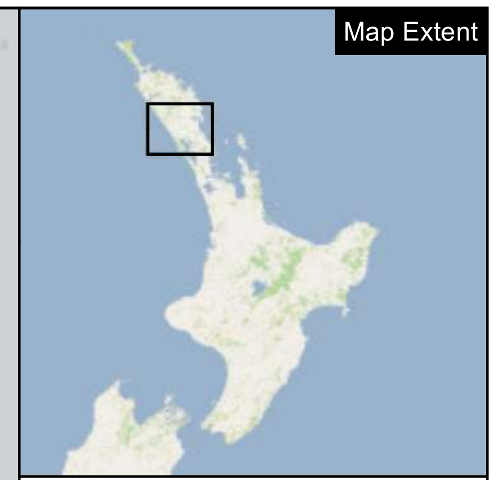
APPENDIX 1:

Geology Map of the Kaipara District





Legend

Inactive Faults

Geological unit key group

- Holocene Alluvium
- Holocene Dunes
- Landslide deposits
- Pleistocene dunes
- Early Pleistocene - Middle Pleistocene alluvium
- Late Pliocene - Early Pleistocene alluvium
- Kerikeri Volcanic Group
- Awhitu Group
- Ti Point Volcanic Group
- Coromandel Group
- Waitakere Group
- Waitemata Group
- Northland Allochthon
- Te Kuiti Group
- Waipapa composite terrane

0 — 13,000 Metres

PROJECTION: NZGD 2000 New Zealand Transverse Mercator

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Title: Kaipara District Summary Geology Plan		
Client: Kaipara District Council		Appendix: A
Project: Geotechnical survey and hazard mapping	Designed: CW Drawn: RW Checked: RJ Date: May 19	Size: A2
Proj No: 15601.000.000	Scale: 1:250,000	Revision: A

ORIGINAL FIGURE PRINTED IN COLOUR