Annexure 1c
The geology and landforms of the islands

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1.0 Introduction

The islands are composed of rocks that were formed during four different time periods. The islands' shapes and most of their landforms were produced in the last few hundred thousand years.

2.0 Basement greywacke rocks, the Waipapa Terrane Group

The greywackes (Waipapa Terrane Group) are the oldest rocks in the Auckland region. In Auckland City their occurrence at the surface is limited to the islands. The largest area of greywacke in the region forms the high-standing Hunua Ranges, but there the visible exposures of these rocks are small (in streambeds), or weathered in coastal cliffs. The largest and freshest exposures of these greywacke rocks and their features are on the more exposed coasts of the islands.

These hard grey rocks accumulated on the sea floor as sand and mud off the coast of Gondwanaland during the dinosaur age (Triassic and Jurassic periods, 250-145 million years ago). At this time, the coast of Gondwanaland lay along a boundary between crustal plates. Here the leading edge of the ancient oceanic Pacific Plate was sliding under (subducting) the edge of the Gondwanaland Plate. As the oceanic plate descended it dragged down the sea floor, creating a deep, elongate ocean trench parallel to the coast.

Pacific Plate oceanic crust - chert and pillow lava

The crust of the ancient Pacific Plate consisted of basalt pillow lava flows that had been extruded onto the ocean floor at the spreading ridge far out to the east. As the plate moved slowly westwards towards Gondwanaland, these flows became mantled by thin deposits of silica-rich mud (called ooze). The ooze was made up of the shells of dead microplankton that continually fell on the Pacific Ocean floor. The ooze eventually hardened into splintery red and green chert beds.

Trench sediment

As the ancient Pacific Plate moved down into the deep trench, the pillow lavas and chert became buried by sand and mud derived by erosion of the adjacent Gondwanaland. As the sediment layers built up in the trench, they were deformed by continual movement of the subducting Pacific Plate. Layers became stacked and progressively tilted towards Gondwanaland. Younger sediment, and sometimes much older layers of chert and pillow lava, were scraped off the top of the Pacific Plate (as if by a giant bulldozer blade) and incorporated into the growing pile of sedimentary rocks. In this way a wedge of rocks formed and continued to thicken and extend seawards for as long as subduction and the supply of sediment lasted.

As the sedimentary pile thickened, the older layers were compressed and hardened into greywacke. The deeper the rocks were buried, the more they were subjected to high temperatures and pressures, which started to metamorphose them. Mineral-rich waters passing through the rocks at depth deposited quartz and zeolite minerals in fractures to form the characteristic white veinlets of our greywacke rocks. The greywackes are Auckland's oldest rocks - we cannot trace the region and the city's origins back any further in time.

Deposition in the trench finished at the end of the Jurassic about 145 million years ago, as the large thickness of sediment that had accumulated was crunched up by collision forces between the two plates. These forces intensely folded, fractured and faulted the rocks and started to push them up out of the seas to form a coastal chain of mountains.

Two slightly different associations of Waipapa Terrane greywacke occur in the region - a western association (Hunua facies) of volcanic-derived sandstone with thrust slices of chert and less common basalt pillow lava; and an eastern association (Morrinsville facies) of well-bedded, coarser-grained, massive sandstone and occasional granite-bearing conglomerate. The eastern association, which occurs on Great Barrier, is usually more coherent, less disrupted, better bedded and less metamorphosed than the western association, which forms many of the inner islands of the gulf.

Examples

Localities identified for their significant exposures of different aspects of these greywacke rocks on the islands are:

- Cherts and their deformation - Island Bay, Waiheke; Pohutukawa Point, Waiheke; Horuhoru (Gannet Rock); Administration Bay, Motutapu
- Pillow lavas - Island Bay, Waiheke; Blackpool, Waiheke
- Trench sediments and their deformation (western association) - Island Bay, Waiheke
- Trench sediments and conglomerate (eastern association) - Harataonga, Great Barrier.

3.0 Regional subsidence - basal Waitemata Group

Following deposition, induration and deformation of the greywacke rocks, a long period (100-30 million years ago) followed of which we have no record in the Auckland region as no rocks of this age are preserved. During this time (80-55 million years ago) the Tasman Sea opened up and New Zealand split off from Gondwanaland. It would appear that for most of this long period the Auckland-Northland region was land which gradually eroded down to a subdued flat-lying landscape by the Oligocene (30 million years ago).

Towards the end of this period, a new plate boundary began forming through New Zealand and the new collision forces resulted in a phase of rapid subsidence in the Auckland region, between 22 and 20 million years ago (early Miocene). A detailed record of this period of subsidence has been captured and preserved in the fossil-bearing sedimentary rocks of the basal Waitemata Group, which is best exposed in the cliffs of the islands.

As the low-lying Auckland region subsided, the sea flooded the land forming islands out of the low greywacke hills and ridges. Gravels and shelly sands were deposited on the beaches and in shallow water around the rocky shore of these islands. These deposits contain the fossilised remains of numerous shellfish, lampshells, sea eggs and corals. Intertidal and shallow subtidal rocky shore fossils are not often preserved and several sections at the west end of Waiheke contain examples of several hundred different species - a number of which are known only from this area. As the region subsided the sediments that were deposited (and the fossils they contain) record a progressive deepening. First the islands were submerged and eventually depths of 1000-2000m were reached and the Waitemata sedimentary basin was fully formed.

Examples

Localities identified for their significant exposures of different aspects of these greywacke rocks on the islands are:

- Most complete sequences: Fossil Bay, Waiheke; Ocean Beach, Motuihe
- Unique and rich fossils: Double U Bay, Waiheke; Oneroa, Waiheke
- Limestone and coastal karst: Limestone Point, Motuihe
- Deeper water barnacles and sea stacks: West coast of Motutapu.

4.0 Marine basin sediments - Waitemata flysch basin Group

The Waitemata sedimentary basin (which is unrelated to the modern Waitemata Harbour) was fully formed by 20 million years ago (early Miocene). It shallowed up to the north with the land beyond occupying most of the present-day Northland region. Erosion of this northern land produced sediment that was carried down rivers and streams to the coast, which lay in the vicinity of where Wellsford is today.

Large quantities of sand and mud that accumulated along the coastal shelf periodically became unstable and flowed in a slurry into the basin. This sediment was funneled down submarine canyons and on reaching the gentler slopes of the basin floor, spread out to form undersea fans of sediment, rather like a delta at the mouth of a river. As the sediment flowed down into the basin, the larger clasts dropped out first, followed by progressively finer and finer grains. These turbulent slurries, called turbidity currents, deposited the 10cm-3m thick layers of sandstone called the Waitemata Sandstones. These layers grade upwards from coarse or medium sand at their base to fine sand or mud at the top. Between the sandstone layers there are usually 5-20cm thick layers of softer, grey mudstone. These mudstone layers accumulated very slowly on the sea floor as mud settled out of suspension from the seawater overhead. Each sandstone bed was deposited in only a matter of hours, whereas the thinner mudstone layers accumulated during the periods of hundreds of years between each successive sediment flow.

The western boundary of the Waitemata Basin was formed by the large and actively growing submarine Waitakere volcano. Occasional volcanic quakes loosened the sea floor high on the volcano's slopes, causing volcanic gravel and sand to slide eastwards down into the Waitemata Basin as undersea lahars. These deposited thick beds of darker-coloured volcanic sediment (called Parnell Grit) within the sequence of more normal Waitemata Sandstones. Thick Parnell Grit beds can be seen in the cliffs and shore platforms of Motutapu and Motuihe.

In many places the layering we see in the Waitemata Sandstone cliffs is flat lying or only gently tilted, but elsewhere the layers are broken, folded or crumpled. Much of the tight folding of layers seen within otherwise unfolded sequences was probably produced by sliding or slumping of the near-surface layers within a few thousand years of their deposition.

During the 3-5 million years of the Waitemata Basin's existence, up to 1km thickness of sand and mud accumulated on its floor. As the layers built up, they were compressed and hardened into the sandstone and mudstone we see today. The best examples of Waitemata Sandstone sequences are exposed in the sea cliffs along the east coast of the Auckland region, with several examples on the islands.

Examples

Localities identified for their significant exposures of different aspects of these Waitemata Group sedimentary rocks on the islands are:

- West coast of Motutapu
- Ocean Beach section, Motuihe.

5.0 Miocene to pleistocene volcanism - includes Coromandel Volcanic Arc Group

The Auckland region was subjected to further tectonic compression and the Waitemata Basin and sediments that were deposited in it were pushed up out of the sea to form land from about 18 million years ago. As the rock was pushed up above the sea to form land, water erosion and chemical weathering began eating away at and slowly eroding it. Over the last 18 million years the eastern part of the region has been uplifted further than the west, allowing deeper erosion in the east in the vicinity of the islands which has exposed the older greywacke rocks that further west underlie the Auckland isthmus at depth.

From about 18-4 million years ago, dry land extended right across from the Auckland isthmus to the Coromandel Peninsula and Great Barrier. During most of this time a volcanic arc of large andesitic stratovolcanoes and rhyolitic caldera volcanoes erupted periodically along the line of present day Great Barrier and the Coromandel Peninsula. Andesitic stratovolcanoes have a central steep-sided cone composed of lava flows and breccias which is surrounded by a gently sloping ring plain composed of laharic volcanic breccia deposits, like Mount Taranaki or Mount Ruapehu today. The ring plain of some of these stratovolcanoes that form Coromandel Peninsula extended a long way west, with small eroded remnants of a 16-14 million year old volcano still preserved in two small outcrops on the eastern end of Waiheke.

On northern Great Barrier the deeply eroded plumbing of one of the oldest (18-16 million years old) Coromandel Volcanic Arc stratovolcanoes can be seen as dikes of andesite and dacite intruding greywacke. Most of the southern two-thirds of Great Barrier are also underlain by the eroded flows, breccias, lahar deposits and shallow plumbing of further, slightly younger (14-10 million years old) andesite stratovolcanoes. Rare freshwater lake sediment occurs within the stratovolcano sequence in the south.

Later in the Miocene, 10-8 million years ago, rhyolitic volcanism broke out in a number of places at the northern end of the Coromandel Volcanic Arc. Caldera-forming (collapse crater) volcanoes erupted ignimbrite and rhyolitic domes in the Hirakimata (Mount Hobson) area of central Great Barrier and at Rakitu. Te Ahumata plateau on southern Great Barrier is formed of a thick ignimbrite deposit, probably the remnant of a formerly much more extensive sheet erupted from Hirakimata caldera. Large rhyolitic eruptions also occurred to the north of Great Barrier during this same period. Eroded rhyolite domes and ignimbrite form the Mokohinau islands and seafloor outcrops over a wide area. A small quantity of basalt occurs with the rhyolites at Rakitu and the Mokohinau islands, and its ascent from the mantle may have been the catalyst that generated the rhyolitic eruptions.

Slightly later in the Miocene, 8-7 million years ago, a basaltic andesite volcano with extensive lava flows erupted near the east end of Waiheke. Boulder fields of this rock at Stony Batter are the eroded remnants that provide the only evidence for this volcano's former existence. Other volcanoes of similar age also erupted near Cape Rodney to the north.

Around 5-3 million years ago, the Hauraki Gulf and Firth of Thames areas were forced upwards, tilting the Coromandel Peninsula to the east and much of the Auckland Region to the west. Following this up-doming, the elongate central strip subsided dramatically about 3-2 million years ago to form the gulf, the firth and the Hauraki Plains to the south. About this time (3-1.5 million years ago), another stratovolcano was produced by eruptions of dacite in the centre of the gulf, forming Little Barrier volcano. Despite erosion, the volcano still retains some of its original shape with a steep-sided central cone surrounded by gently sloping ring plain remnants.

Examples

Localities identified for their significant exposures of different aspects of these Miocene to Pleistocene volcanoes on the islands are:

- Fort Hill, Waiheke
- Stony Batter, Waiheke.

6.0 The ice ages and the shape of the islands

The world has experienced alternating periods of cold and warm climate during the ice ages of the last few million years. There have been at least 30 of these cold-warm cycles in the last 2 million years. Each cycle lasted 40,000-100,000 years and included a warm period similar to today and a cold or glacial period when large ice caps formed on southern and northern hemisphere continents. These ice caps froze large amounts of the earth's water on land and resulted in major worldwide drops in sea level of 130-50m during each ice age period. Sea level has only been up around its present level during the peaks of the warmer periods, for about 10 per cent of the time in the last 2 million years. It has probably never risen more than about 6-10m higher than what it is today.

During the coldest part of the last ice age, just 20,000 years ago, sea level fell to 130m lower than present. Although other parts of New Zealand were glacier and ice cap covered, the Auckland Region was still covered in forest. Today's harbours and the Hauraki Gulf were forested valleys, with streams flowing seawards across broad coastal plains. In Auckland a small river flowed down the forested Waitemata valley and straight out past Motutapu hills beneath what is now Rangitoto. From there it still had 120km to flow to reach the coast out beyond Great Barrier and the Mokohinau islands. All of the islands were hills and ridges joined together by lower lying valleys and plains. Waiheke and Ponui were separated from the Coromandel Ranges by an extension of the flat land of the Hauraki Plains. Great Barrier and the Mokohinau islands were joined together and linked to mainland North Island.

Following the peak of the last ice age, the world's climate began to warm, the ice caps slowly melted, and the world's sea level rose correspondingly. Sea level reached its present level about 7000 years ago, although a slightly warmer period 6000-3000 years ago, resulted in a temporary rise of 1-2m above what it is now. Some low-lying coastal terraces were formed intertidally at this time (for example, the flats of Motukorea, carpark flats at Matiatia, Waiheke).

The cycles of wildly fluctuating sea levels had a major impact on the shape of the islands and their coasts. During each ice age, erosion on land increased because of colder weather and lowered base level for the streams. Sediment poured down the rivers (especially the ancestral Waikato River flowing down through the Hauraki Plains) and was spread along the coasts by longshore drift. The valleys on and between the islands' hills were progressively eroded down to levels well below present sea level. At the end of the last ice age the rising sea encroached on the land and the sand that had built up along the coast was swept shoreward. For several thousand years after the sea reached its present level, vast quantities of sand were thrown up against the land to form beaches, terraces and dune barriers.

Inside the Hauraki Gulf, where sand supply was not so great, the river and stream valleys were drowned to become the modern embayed coastlines and islands. Outside the Hauraki Gulf, on the east side of Great Barrier, there was a greater supply of white quartz sand which was thrown up on the beaches and formed sand dune barriers across the mouth of several valleys forming Whangapoua Harbour and Kaitoke Swamp. Cobbles eroding from the laharic breccias forming the cliffs of Little Barrier have been transported by storm waves down both sides of the island and formed the extensive cuspate boulder flat of Te Titoki Point on the leeward southwest corner of the island.

Most of the cliffs around the islands are very young and have eroded out of the sloping hillsides in just the last 7000 years. The intertidal reefs in front of the cliffs are an indication of the amount of cliff retreat since sea level rose. Some of the higher cliffs in harder greywacke or andesite rocks, such as those on the northern coasts of Waiheke and Little Barrier and eastern coast of Great Barrier, would have been carved back during each successive period of higher sea level. These would have become weathering inland bluffs and forested scree slopes during the intervening intervals between the ice ages.

Today the youthful coasts of the islands are still changing. They erode in some places and grow in others as nature continues to respond to the post-ice age rise in sea level, the present pulse of sea level rise, and to the variable patterns of winds, waves and currents.

Examples

Localities identified for their significant examples of young coastal and terrestrial landforms on the islands are:

- Motukaha tombolo, Waiheke; Te Matuku Spit, Waiheke; Stony Batter, Waiheke
- Te Titoki Point cuspate foreland, and Pohutukawa Flat rock fall, both Little Barrier
- Man o' War Passage, Kaitoke Swamp, and Whangapoua Harbour, all Great Barrier.

7.0 Young volcanoes - Auckland Volcanic Field Group and Auckland lava caves Group

Much of Auckland city is built over the products and landforms of the young Auckland Volcanic Field in which basalt was erupted from about 50 volcanoes over the last 300,000 years. Three styles of eruption produced the small basalt volcanoes of the Auckland Volcanic Field. While some volcanoes were formed by only one style of eruption, many were formed by a combination of all three. The style of eruption at any particular time depended upon how much gas was dissolved in the magma, the rate of magma upwelling, and whether it came in contact with water.

Most Auckland volcanoes started life with a series of explosive eruptions. These occurred when rising magma encountered ground or surface water, which produced superheated steam. Gas dissolved in the magma was released explosively with the steam and a mushroom-shaped cloud of ash and shattered rock from the volcano's throat was thrown hundreds of metres into the air. A shallow explosion crater up to 2km across and 100m deep was formed and debris from the collapsing cloud built up a low, circular rim of bedded ash and debris, known as a tuff ring.

Lava-fountaining eruptions occurred when gas-rich magma reached the surface without coming into contact with water. The gas was released quickly, creating frothy lava that was sprayed from the vent as a near-continuous stream of brightly glowing fragments. As they flew through the air, the fragments cooled to form red-brown or black scoria, which accumulated around the vent and built up a steep-sided scoria cone, often with a deep central crater.

Lava flows developed when degassed magma rose in the vent and burst out from the base of the cone or breached the explosion crater rim. Rivers of lava initially flowed off down existing valleys, but if the outpouring continued a sequence of overlapping flows was sometimes erupted. This built up a cone called a shield volcano that gently sloped away in all directions. When the lava flows cooled they solidified into a hard, dark, fine-grained rock, called basalt. This has been used extensively in Auckland for kerbstones and many older buildings, including a number made of basalt from Rangitoto (for example, the Melanesian Mission House, Mission Bay; and Kinder House, Parnell).

Two of the youngest volcanoes in the Auckland field formed Rangitoto and Motukorea (Browns Island) in the Hauraki Gulf. Motukorea is thought to have erupted between 15,000 and 10,000 years ago, when sea level was considerably lower than now and the Waitemata Harbour was still a forested valley system. Motukorea initially erupted explosively forming a shallow explosion crater and surrounding tuff ring. Parts of the tuff ring form the ridge, cliffs and reefs on the north-east side of the island. Lava-fountaining built a scoria cone in the middle of the explosion crater. Portions of some of the early-formed scoria cone were rafted off by lava flow and form small hills around the main cone. Degassed lava poured out from around the base of the western and southern sides of the scoria cone, breached and overtopped the tuff ring and flowed up to 2km west and south to form an extensive lava flow field. Most of this field is now drowned beneath the harbour, but the flat southern and western parts of Motukorea and the surrounding reefs are the upper parts of the lava flow field.

Rangitoto is the youngest and by far the largest volcano in the Auckland volcanic field. It erupted just 600 years ago and the finding of footprints in wet ash on nearby Motutapu indicates that its eruption was witnessed by local Maori. Rangitoto erupted in the middle of the main channel into the Waitemata Harbour and its initial eruptions appear to have been highly explosive with large volumes of ash being deposited over the northern half of Motutapu. Once sufficient of the volcano had built up above sea level the dominant styles of eruption switched to fire-fountaining over the central vent area and the outpouring of enormous volumes of relatively hot, fluid basalt lava flows. The fire-fountaining built up a series of scoria cones in the centre of the growing island with remnants of two earlier cones forming distinctive bumps on either side of the last formed steep-sided cone with its deep crater. The lava flows poured out in all directions from around the flanks of the scoria cones and built up a gently sloping, circular shield volcano of many overlapping flows. Soon after the last flows had been erupted some of the still fluid magma withdrew down the vent causing the scoria cones to subside and creating a shallow moat around them. Some of the thicker feeder flows high on Rangitoto formed thick crusts around them while the lava flowing inside was still molten. Later the fluid lava flowed out of the internal tubes leaving behind lava caves, which are mostly accessed through sections of collapsed roof.

Examples

Localities identified for their significant examples of the volcanic landforms and structures of the Auckland Volcanic Field on the islands are:

- Motukorea
- Rangitoto; lava caves, hornito, lava flow crust, flow levees and flow lobes, all on Rangitoto.

8.0 Geology of individual islands

8.1 Pakatoa, Ponui and Rotoroa

These three islands are composed entirely of Mesozoic Waipapa Terrane greywacke rocks. Because their east coasts are exposed to rough seas from the Hauraki Gulf, they are more eroded on this side and have some of the freshest exposures of these rocks in the gulf. Several of the eastern sections on these islands provide excellent exposures of the complex deformed structure and sedimentary features of the western association.

8.2 Waiheke

Waiheke is mainly composed of greywacke rocks of the western association of the Waipapa Terrane. Hard beds of red chert occur in a number of places and because of their resistance to erosion they often form the more prominent coastal points and high-standing ridges on the island. Basal Waitemata Group sedimentary sequences outcrop along the coast in several places at the west end of the island and provide an excellent record of the initiation of the region's subsidence about 22 million years ago. High on the ridges of the east end of Waiheke are the greatly eroded remnants of two periods of Miocene volcanism - 16-14 million year old andesitic breccia transported here as lahars from the Coromandel volcanoes, and 8-7 million year old andesitic basalt lava flows from a small shield volcano that now form the distinctive boulders of Stony Batter.

8.3 Motutapu, Rakino and the Noises

These islands are predominantly made of greywacke rocks of the Waipapa Terrane's western association, with a mix of hardened sandstone, chert and pillow lava basalt. Small sections of basal Waitemata Group conglomerate and siltstone outcrop in the cliffs on the west side of Motutapu and east side of Rakino. On Motutapu the basal sequence passes up into the deeper water Waitemata Sandstones that accumulated in the early Miocene Waitemata sedimentary basin. Several beds of submarine lahar deposits (Parnell Grit) are present within the Waitemata Sandstone sequence. Volcanic ash from Rangitoto thickly drapes the surface of Motutapu, especially over its northern half.

8.4 Motuihe

The tops of several ancient early Miocene sea stacks and a somewhat larger island made of Waipapa Terrane greywacke occur in the southern half of Motuihe. These are overlain by thin sequences of basal Waitemata Group conglomerate and sandy limestone that accumulated in shallow water as the region was subsiding around 22 million years ago, but most of the island is composed of sediment that accumulated in the Waitemata sedimentary basin following subsidence. This is interbedded sandstone and mudstone (Waitemata Sandstones) and one 20m thick submarine volcanic lahar deposit (Parnell Grit) which outcrops in the cliffs around much of the island.

8.5 Motukorea

Motukorea is one of the youngest and least modified of Auckland's young basalt volcanoes. The northwest cliffs are eroded into the remnant northwest arc of its tuff ring, which had been produced by early explosive eruptions of ash. The high central hill is a scoria cone with a deep crater. Surrounding low knolls of scoria are portions of cone that had been rafted away by lava flows. The southern and western sides of the island are underlain by lava flows, which extend well out beneath the waves. The extensive 1-2m high flat that forms the southern and western sides of the island is a high tidal terrace that was built up in the lee of the island during the Holocene high sea-level stand, 6000-4000 years ago.

8.6 Rangitoto

Rangitoto is the youngest (600 years old) and by far the largest of the volcanoes in the young Auckland basalt volcanic field. It erupted in the middle of the Waitemata Harbour's main channel, initially with voluminous ash eruptions, some of which mantled nearby Motutapu. These explosive ash eruptions were followed by fire fountaining which built up a series of scoria cones around the main central vents and form the steeper knobs of the island's summit. Around the base of these growing scoria cones, enormous quantities of basalt lava flowed out in all directions forming a gently dipping, circular shield volcano, which now forms the bulk of the island. Many of these flows were slow moving aa types with cooled carapaces of angular blocks, but when they reached the sea they often developed branching, finger-like tubes when the hot lava came in contact with cold water. Many of the flows, especially those higher on the island, developed a thick crust of cooled solid basalt with molten lava still flowing inside. Sometimes the lava flowed out from inside the flows, leaving empty elongate lava tubes or caves.

8.7 Little Barrier (Hauturu)

Little Barrier is the eroded remains of two dacite volcanoes. Remnants of the older 3 million year old dacite dome only occur near sea level in the northeast corner, with less eroded remnants of a younger 1.5 million year old dacite stratovolcano forming the bulk of the island. The distant profile of Little Barrier preserves the original shape of this stratovolcano with a steep-sided central cone and surrounding gently dipping laharic ring plain.

8.8 The Mokohinau islands

The Mokohinau islands have an entirely volcanic origin, being the eroded remains of late Miocene rhyolitic volcanism at the northern end of the Coromandel volcanic arc. Also present is evidence of minor associated andesitic and basaltic volcanism. Burgess and the associated northern islands in the group are composed predominantly of ignimbrite and rhyolite lava, whereas the southern island Fanal is entirely formed by a rhyolite dome.

8.9 Great Barrier (Aotea)

Eastern association greywacke rocks underlie all of Great Barrier and appear above sea level to form the high northern part of the island, north of Katherine Bay and also along a small area of coast in the east around Harataonga. The largest part of the island, in the centre and south, is composed of the eroded remnants of mid Miocene andesitic stratovolcanoes and their laharic ring plain deposits. In the north, the subvolcanic plumbing from beneath a slightly older stratovolcano has been exposed by erosion to reveal numerous andesite and dacite dikes cutting through the underlying greywacke. The high central Hirakimata (Mount Hobson) part of Great Barrier is composed of the erupted products of a late Miocene rhyolitic caldera volcano. Ignimbrite is widespread. The high, flat-topped Te Ahumata plateau of southern Great Barrier is composed of the eroded remnants of a formerly far more extensive sheet of ignimbrite that may have been erupted from the Hirakimata caldera volcano. The eroded columns and flow-banded rhyolite of several steep-sided domes form high pinnacles and ridges around Hirakimata.

The shape of Great Barrier today is a result of a long period of erosion of the andesite and rhyolite volcanoes by streams and waves. When sea level rose after the end of the last ice age the lower reaches of the stream valleys were flooded by the sea and became bays and inlets. Those on the western side remain today as Port Fitzroy, Whangaparapara and Blind Bay. On the eastern side an abundant supply of quartz sand was thrown up as sand dune barriers across the entrance to the bays creating Whangapoua Harbour and Kaitoke Swamp.

8.10 Rakitu

Rakitu is the eroded remains of a small rhyolitic caldera volcano that erupted in the late Miocene. Welded and non-welded ignimbrite is the predominant rock type with older, rather altered rhyolite lava outcropping on the north coast and fresh intrusive rhyolite forming the high southwest corner. A small outcrop of dark basalt lava occurs within the rhyolite sequence of Black and White Rock, off the west side of the island.

9.0 Glossary of geological terms

Term	Meaning
aa flow	viscous lava flow with sharp rubbly outer surface
andesite	grey volcanic rock formed by cooling lava with an intermediate silica content (52-65 per cent)
argillite	hardened mudstone
basalt	dark volcanic rock formed by cooling lava with a low silica content (45-52 per cent)
bathyal	water depths of 200-2000m
beach rock	beach rocks, shells and sand cemented together
bomb impact sags	depression made by a volcanic bomb landing
boudin	layer of sandstone pulled apart to form 'a string of sausages'
boxwork weathering	rectangular pattern of hard rusty ribs (of limonite) produced by weathering of jointed greywacke
breccia	rock composed of angular gravel-sized fragments of rock
broken formation	beds broken-up by deformation
chenier	long, narrow beach ridge of shell or sand built out across intertidal flats
chert	extremely hard siliceous rock
clast	fragment of pre-existing rock
conglomerate	sedimentary rock composed of rounded pebbles, cobbles or boulders
dacite	light grey volcanic rock formed by cooling lava with a high silica content (>65 per cent)
dike	a sheet-like body of igneous rock that cooled and solidified after being intruded in molten state, and cross-cutting an existing rock
eastern association	the eastern association (or Morrinsville facies) of Waipapa Terrane greywacke
exposure	place where weathered rock and soil has been removed to expose rock beneath
flaggy	rock with a natural tendency to split into flat oblong slabs
fluting	grooves dissolved on surface of rock by water
foraminifera	microscopic shell-bearing marine amoeba-like organisms
geology	study of rocks
geomorphology	study of landforms
Gondwanaland	ancient southern supercontinent
greywacke	hard compacted sedimentary rocks forming the basement rock of the Auckland Region

Term	Meaning
hornito	small spatter cone formed on top of lava flow
ignimbrite	volcanic rock formed by deposition and partial welding of a high temperature, high velocity flow of fragmented magma
intra-plate volcanism	volcanism erupting through a tectonic plate
joint	a fracture in rock
karst	distinctive landforms produced by solution of limestone rock by rainwater
keystone fault	x-shaped double fault
laharic breccia	deposit of angular boulders and cobbles left behind by a passing volcanic mudflow (called a lahar)
landform	form of the surface of the land
lava cave/tube	an elongate hollow left behind inside the solidified outer crust of a lava flow when the molten lava inside flowed out
levee	elongate ridge of rocks or sediment deposited on either side of a river or lava flow
limestone	a sedimentary rock comprising more than 50 per cent calcium carbonate (lime, shell)
limonite	rust-coloured iron oxide mineral formed during the weathering of iron-rich rocks
lozenge	rhomb-shaped pieces of rock
macrofossil	fossils that can be easily seen without magnification
Mesozoic	age of reptiles, between 235 and 65 million years ago
microfossil	fossils that cannot be seen without magnification
Miocene	period of time between 23 and 5 million years ago
mollusc	shellfish and snails
mudstone	sedimentary rock made of mud
normal fault	fault in which overhanging rocks moved downwards
octocoral	group of deepwater tree corals
ostracods	tiny crustaceans sometimes known as water fleas or seed shrimps
pahoehoe flow	fluid lava flow with wrinkled outer skin
paleontology	the study of fossils
Parnell Grit	thick beds of volcanic pebbles, grit and sand deposited on the floor of the Waitemata Basin by submarine lahars
pillow lava	elongate, pillow-like fingers of lava formed when lava flows under water, often seawater

Term	Meaning
rhyolite	light grey, pink or white volcanic rock formed by cooling lava with a high silica content (>65 per cent)
rock	any mass of mineral matter, whether consolidated or not, which forms part of the Earth's crust
sandstone	sedimentary rock made of sand grains
scoria	red or black vesicular material erupted from a volcano
scoria cone	steep-sided volcanic cone composed of scoria, produced by fire-fountaining eruptions
shell spit	narrow spit of shells built-up on or near the shoreline
shield volcano	gently-sloping volcanic cone composed of numerous overlapping, fluid lava flows
stack	small rocky islet
stratotype	a section of sedimentary rock deposited during a period of geological time and used to define that period of time
stratovolcano	steep-sided volcanic cone made of andesite lava flows and breccia
subtidal	shallow marine depths below low tide
surge deposit	volcanic ash bed left behind by a sideways explosive surge of hot, often wet, gas-rich ash
tension gash	gash-like split in rock caused by pull-apart tension
thrust	low angle fault
tombolo	a spit of sand, shell or rocks linking an island to the mainland
top hat island	a small island with the shape of a top hat when the tide is out, formed by a central remnant islet surrounded by a wide shore platform
tsunami	tidal wave generated during an earthquake
tuff	rock made of hardened ash
tuff ring	a raised circular ring of bedded ash built up around a volcanic explosion crater
type locality	the rock locality where the type specimen of a fossil species, mineral or rock was first found and named
type section	the section of rock exposure designated as the most typical when a formation is named and described
vein	a sheet-like body of minerals crystallized in a joint or fissure
volcanic bomb	a solid block thrown out by an erupting volcano
Waipapa Terrane	group name for greywacke rocks of east Auckland

Term	Meaning
Waitakere Volcano	giant volcano that erupted off the west coast of the Waitakere Ranges between 22 and 15 million years ago forming a volcanic island that has since been eroded away, except for its eastern slopes which now form the Waitakere Ranges
Waitemata Basin	deep submarine depression that lay off Auckland 20 million years ago, on the floor of which the Waitemata Sandstones accumulated
Waitemata Sandstone	interbedded sandstones and mudstones that accumulated on the floor of the deep Waitemata Basin
Waitemata Group	group name for sedimentary rocks that accumulated in the Waitemata Basin, as it was forming and after it became deeply submerged
water expulsion structure	swirly shape of bedding disrupted by the outflow of water from the sediment beneath
weathering	the processes that break down rocks to clay and sediment
western association	the western association (or Hunua facies) of Waipapa Terrane greywacke