

An aerial photograph of a rugged coastline. The foreground shows steep, green hills with patches of brown rock. The middle ground features a deep blue bay with white waves crashing against the shore. The background shows a vast blue ocean under a clear blue sky with scattered white clouds.

# OUT OF THE OCEAN, INTO THE FIRE

History in the rocks, fossils and landforms  
of Auckland, Northland and Coromandel

Bruce W. Hayward

Aerial photography by **Alastair Jamieson**  
Drawings by **Margaret S. Morley**

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*These fingers of rock, called pillow lava, were extruded out onto the seafloor, 17 million years ago, on the slopes of the Waitakere Volcano - the largest stratovolcano ever erupted in New Zealand. Most of its 50 km-diameter cone has been eroded away by the Tasman Sea in the 15 million years since it stopped erupting. The volcano's remains form the Waitakere Ranges, west Auckland.*

Aerial photography by **Alastair Jamieson**  
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## **BOOK SUMMARY**

### ***Out of the ocean***

*Northland, Auckland and Coromandel Peninsula have the most diverse, and complex, geology in New Zealand. This is the first time the story of their 300-million-year (Myr) history has been prepared for a general readership. Almost all of the older rocks (older than 23 Myr) were deposited as sediment or erupted as lava on the floor of the ancient Pacific Ocean. The older basement greywacke rocks (chapter 2) were rafted along on the moving oceanic Pacific Plate and plastered onto the coastal edge of the supercontinent of Gondwana, prior to 110 Myr ago. Between 85 and 50 Myr ago these basement rocks split away from Gondwana as part of the New Zealand continent of Zealandia. Thin packets of coal measures and limestone were deposited on top of the eroded greywacke, 40-23 Myr ago (chapter 3).*

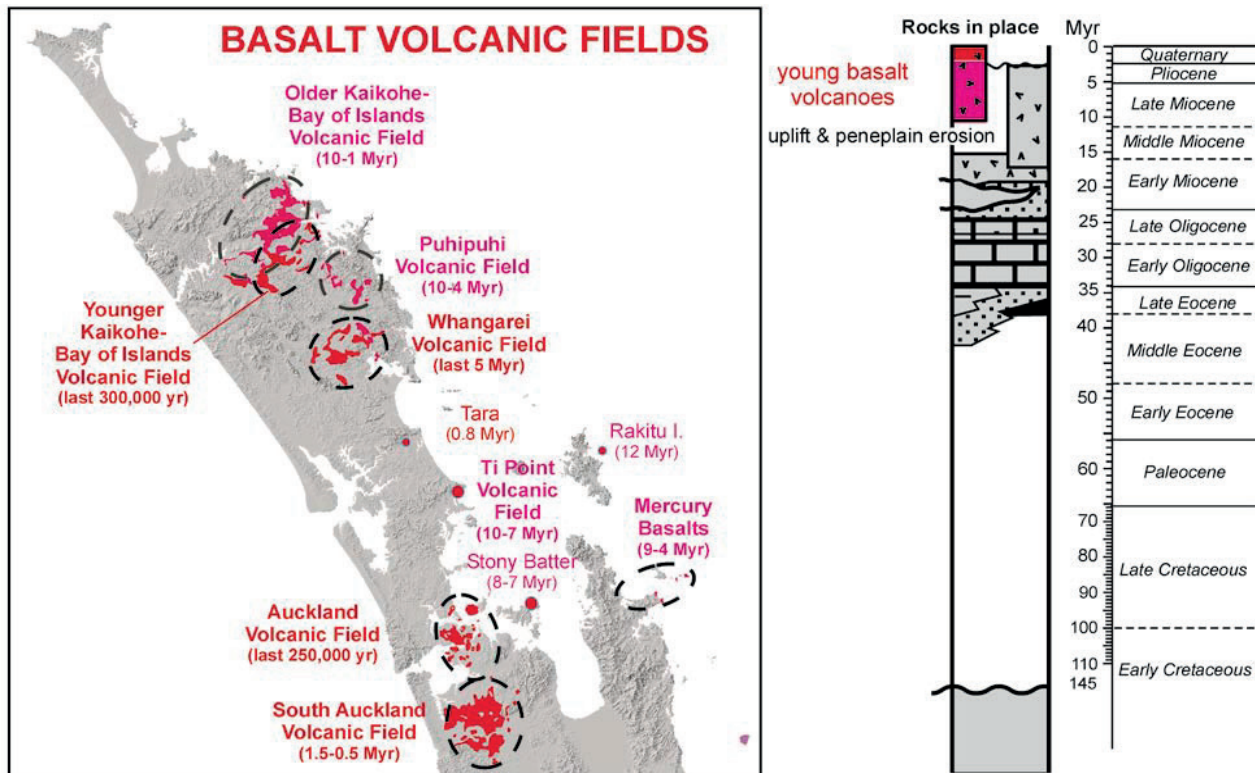
*Between 24 and 19 Myr ago, at least 100,000 km<sup>3</sup> of rocks that were erupted and deposited on the floor of the Pacific Ocean (110-23 Myr old) were pushed up out of the abyss by plate tectonic forces and slid into Northland and northern Auckland (chapter 4). They slid into the northern end of a 1-3 km deep marine basin created by regional subsidence. The southern end of the basin accumulated 1 km thickness of Waitemata Sandstone that was later uplifted to form Auckland (chapter 5).*

### ***Into the fire***

*Most of the subsequent history of northern New Zealand was dominated by fiery volcanic activity of greater diversity than any area of similar size elsewhere in the world. There were subduction-related volcanic arcs of andesite stratovolcanoes, giant caldera volcanoes, searing ignimbrite flows and rhyolite domes, including the largest cone volcano (Waitakere) and largest shield volcano (Waipoua) ever erupted in New Zealand (chapters 6, 7). These were followed by at least 200 small basalt volcanoes (explosion craters, scoria cones, shield volcanoes, plateau basalt flows) that erupted in seven “hot-spot-like” volcanic fields (chapter 9).*

*The region has been uplifted three times, pulled down once, tilted westwards, eroded down to an undulating coastal plain twice (chapter 8), and been torn apart by the recent foundering of the elongate Hauraki Gulf and plains. The present-day shape and landforms of northern New Zealand reflect its history over the last 5 Myr (chapters 10-12) with local uplift, erosion, volcanic activity, construction of New Zealand’s largest sand-dune barriers and harbours, and moulding of the coast by the oscillating sea levels of the Ice Ages (last 2.5 Myr).*

*A wide range of fossils document the evolutionary history of life in the sea and on land and include fossil ammonites, giant mussels, subtropical seashells, reef corals, soft-bodied fan worms, palms, ferns, miniature coconuts, seeds, leaves and the bones of extinct ichthyosaurs, turtles, lantern fish and moa. The rocks of northern New Zealand have played a pivotal role in building the region’s infrastructure, buildings and economy – greywacke and basalt for aggregate, limestone for cement and fertiliser, and clay for brick making. Silica sand provides raw material for glass-making, iron sand for the production of steel, halloysite clay for the whitest ceramics in the world. Mining for coal and kauri gum were major industries in early Northland. Gold mining still plays a significant role in the economy of the Coromandel region.*



9.1 Distribution and age of the basalt volcanic fields in northern New Zealand.

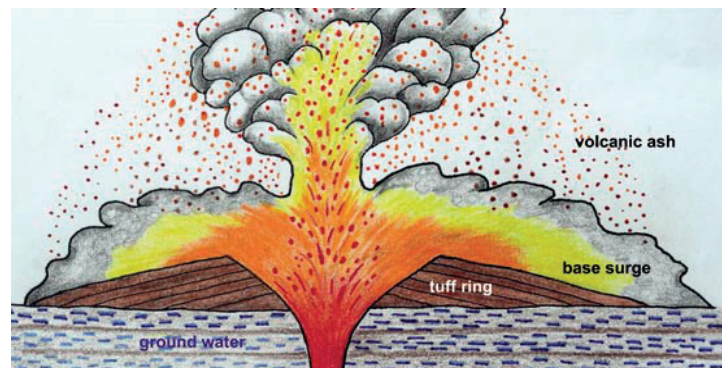
## STYLES OF BASALT ERUPTION, ROCK TYPE AND LANDFORM

Eruption style	Scientific term	Rock produced	Landform
Wet explosive	Phreatomagmatic, Surtseyan	Tuff (hardened volcanic ash)	Explosion crater (maar), tuff cone or tuff ring
Fire-fountaining & fiery explosive	Hawaiian & Strombolian	Scoria (lapilli, cinders), spatter, volcanic bombs	Scoria cone (cinder cone)
Lava outpouring	Strombolian & Hawaiian	Basalt lava	Lava flow, lava field, or lava shield

The shape of a Northland or Auckland basalt volcano depends on the styles of eruption that formed it. Its size depends on the volume of magma expelled and duration of the eruptions. These volcanoes erupted in three basic styles resulting in the production of three different types of volcanic rock and three different kinds of landform.

### Wet explosive eruptions

When many of Auckland and South Auckland's basalt volcanoes first erupted, the rising magma came in contact with near-surface water in aquifers or swampy ground. As this hot magma (about 1200°C) encountered cold water, its surface chilled instantly, solidified, and explosively fragmented. The water flashed to steam, resulting in a violent explosion. A rapidly expanding cloud of steam, magmatic gas, fragmented lava and other pieces of rock from the



9.2 Cartoon of a wet explosive eruption from a small basalt volcano. These typically form an explosion crater surrounded by a tuff ring or cone composed of hardened layers of volcanic ash. Drawing by Margaret Morley.



9.3 View from the west across Pukaki explosion crater and surrounding tuff ring/ tuff cone, Auckland. The flat floor of the crater is filled up with lake and marine sediment.

The solid particles that were blasted into the air and fell back to the ground are called tephra. Tephra is divided on the basis of particle size into ash (fragments smaller than 2 mm), lapilli (2-64 mm across), and blocks and bombs (greater than 64 mm). Wet explosive eruption columns rise to heights of several kilometres and the volcanic ash and lapilli within them might be blown some distance away by the wind. Fallout tephra accumulates on the ground downwind of the volcano. Blocks of solid rock ripped from the walls of the volcano's throat might be thrown out of the vent on ballistic trajectories, to land nearby (9.4).

Around the denser base of the eruption column, base surges of superheated steam, gas, ash and lapilli can be blasted out sideways (9.2) at speeds up to hundreds of kilometres per hour. These turbulent ground-hugging surges (9.14) might devastate and partly bury areas within 3-5 km of the vent and are the most dangerous style of eruption produced by these small basalt volcanoes. As these surges pass, they commonly leave behind wavy beds of fine ash, sometimes with cross-bedded dune forms.

Wet explosive eruptions usually come in a series of pulsating episodes interspersed by short periods of inactivity. Typically these eruptions produced a relatively shallow (50-100 m deep), wide (200-1000 m), circular explosion crater surrounded by a low ring of bedded volcanic ash and lapilli. The ash and lapilli were erupted wet, and as the layers dried out they hardened into a creamy-brown rock called tuff. Thus the raised ring of rock around the explosion crater is called a tuff ring. A



9.4 A sea cliff exposure of bedded tuff on Motukorea/ Browns Island, Auckland. This tuff accumulated as wet ash around the explosion crater. Each layer represents an explosive eruption pulse. Rock fragments include smaller grey basalt from the chilled surface of the rising magma and a large, rounded, brown block from the underlying country rock (Parnell Grit). Wavy and cross-bedded layers of ash in the middle of the section were left behind by fast-moving base surges of searing gas, steam and ash.

tuff ring usually has its circular crest forming the rim of the crater, with relatively steep slopes back into the crater and gentler slopes (c. 5-10°) on the outside (9.3). The steeper inner slopes are often formed by a series of slump scarps as a result of sections of the tuff ring slipping back into the crater after being deposited. A larger tuff ring may be called a tuff cone.

If magma supply ceased before all the groundwater

## Box 32. MINIATURE FOSSIL COCONUTS

The most famous fossil coconuts in New Zealand are periodically found washed up on Coopers Beach, Northland. They are not the full-size coconuts that grow on coconut palms on tropical islands that we try to knock down in coconut shies at fairs. These are miniature coconuts, 3-5 cm long, with the characteristic three eyes at one end. We now know that they are the nuts of a relative of the South American “mountain coconut” (*Parajubaea cocoides*), known as cococumbe in Ecuador where the nuts are a popular food. Today this palm grows close to the equator in South America, but at high altitudes, where the temperatures are not too dissimilar to present-day Northland. The mountain coconut palm tree is of similar size and appearance to the classic coconut palm.

The miniature fossil coconuts at Coopers Beach are generally flattened as a result of burial beneath a thick sequence of sediment. They erode out of freshwater sedimentary rocks at the back of the beach or from shallow subtidal reefs just offshore. Occasionally small fossil coconuts are also washed up at Taipa Beach a few kilometres to the west.

Much older, but similar small coconuts have been found at Waikiekie Quarry in southern Northland. These fossils occur in 28 million year old (Late Oligocene period) muddy limestone that accumulated on the floor of the ocean well offshore from land. The coconuts must have floated out to sea and become waterlogged before sinking to the seafloor. They are not usually as flattened as those from Coopers Beach.



8.12 Mature mountain coconut palm growing in Ecuador, similar to the one that produced the small coconuts found in Northland.

8.13 Miniature fossil coconuts (3-5 cm long) from Coopers Beach, Doubtless Bay, ~10 Myr old. Photographer Heather Smith.



8.14 Small fossil coconut from Waikiekie Quarry, north Kaipara, ~28 Myr old.

### Box 34 continued



9.27 The northern end of Lake Manuwai, Kerikeri's irrigation water storage lake, is bordered by the best-developed fluted basalt karst in New Zealand. Unfortunately the only access is by kayak.



9.28 Left: Three spectacularly fluted basalt boulders, Stony Batter, Waiheke Island.



9.29 Right: Wairere Boulders is a privately-run tourist attraction in the upper Hokianga. Boardwalks lead through a huge heap of giant basalt boulders that have slid down into the valley from the bluffs above. Humic acid-rich water running over the boulders has dissolved their surface into large flutes. This large flower-shaped boulder has rolled over (top to the left) and the originally vertical fluting has been tilted to near-horizontal. Photographer Egon Eberle.

## YOUNGER KAIKOHE-BAY OF ISLANDS VOLCANIC FIELD

The younger part of the Kaikohe-Bay of Islands Volcanic Field erupted in the last 300,000 years and retains most of its volcanic landforms. The majority of these volcanic centres are clustered around the central Northland town of Kaikohe, but there are also two centres further east towards Waitangi in the Bay of Islands. Most eruptions were dry and produced scoria cones, often with associated lava flows that spilled down adjacent stream valleys. Around Kaikohe there are eleven, mostly prominent, conical scoria cones (9.30) and an explosion crater with surrounding tuff ring. A lava flow from Te Ahuahu dammed a small valley forming the shallow Lake Omapere between Kaikohe and Okaihau about 80,000 years ago. The longest lava flow in the young Kaikohe-Bay of Islands Volcanic Field flowed 19 km down the Taheke Valley towards Hokianga



9.30 Te Ahuahu is one of the highest scoria cones in the Kaikohe-Bay of Islands Volcanic Field.



# Chapter 11. CRAFTING THE COAST

## CHAPTER SUMMARY

*The coastal diversity of northern New Zealand has been crafted by an interplay between coastal land building, drowning and eroding processes over the past 1-2 Myr, especially during the last 10,000 yr (Holocene period). During the Ice Ages of the last 2.6 Myr, the climate and sea level have alternated back and forth in cycles of 40,000 and 100,000 yr length. For 90% of this time, sea level has been lower than present. During the coldest glacial peaks, sea level was 60-130 m below present, with its lowest recorded level during the peak of the Last Glacial Period, just 18,000 yr ago. During the short (5000-10,000 yr long), warm, interglacial periods, sea level was within 10 m of present level, with its highest peaks around 10 m, 6 m and 1-2 m above present at 400,000, 120,000 and 7000-3000 yr ago.*

*Since the start of the Ice Ages, two large bays on the west coast have been transformed into New Zealand's largest harbours – the Kaipara and Manukau – by the building of sand-dune barrier/strand plains across their mouths. The growth of these barriers was a result of greatly increased sand supply to the west coast from large volcanic eruptions in the central North Island, particularly around 1 Myr, 300,000 yr, and since the Waikato River switched its course 22,000 yr ago, to flow out on the west coast instead of through the Hauraki Rift. In the Far North, large sand-dune tombolos were constructed during the same period, linking islands at North Cape, Mt Camel and Cape Karikari to the main part of Northland.*

*Valleys that had been eroded across the forested coastal plain during lower sea level, were drowned by the rising sea after the end of the Last Glacial Period, about 10,000-7500 yr ago. Where sediment supply was limited, these drowned valleys became the indented harbours and estuaries of the east coast and the branching inner reaches of Hokianga, Kaipara and Manukau harbours. With sea level rise, ridge and hill crests have become peninsulas and islands. Where sand supply was more plentiful, sand spits were thrown up across the mouths of estuaries, and beaches accumulated in bays. In the last 3000 yr, as sea level has dropped from 1-2 m higher than present, a series of sand dune belts have been deposited behind sandy shorelines on both coasts. At the same time, the 2-km-wide Miranda chenier plain, consisting of a sequence of shell banks, has accreted onto the west coast of the Firth of Thames.*

*Where sand supply has been low, degraded coastal cliffs from previous high sea-level stands, have been exhumed and eroded back at rates of 0.1-0.3 m per 100 yr for hard greywacke and volcanic rocks, and 0.6-3 m per 100 yr for softer Waitemata Sandstone. Marine erosion has been fastest where the rocks alternate between wet and dry during the tidal cycles, creating mid-tidal platforms in more porous sandstone and high tidal platforms and notches on harder rocks or on more exposed coasts. Intertidal guts, caves, tunnels and sea stacks mostly result from erosion along fault and joint planes that cut through the rocks.*

*North-moving longshore drift, abrasion and weathering have sorted out the components of the volcanic sediment supply to the west coast. Dense black titanomagnetite grains have been left behind and concentrated in the south, where old deposits are mined and used in making steel. White sand, composed of almost pure quartz, has been concentrated further north and is used for glass manufacture.*

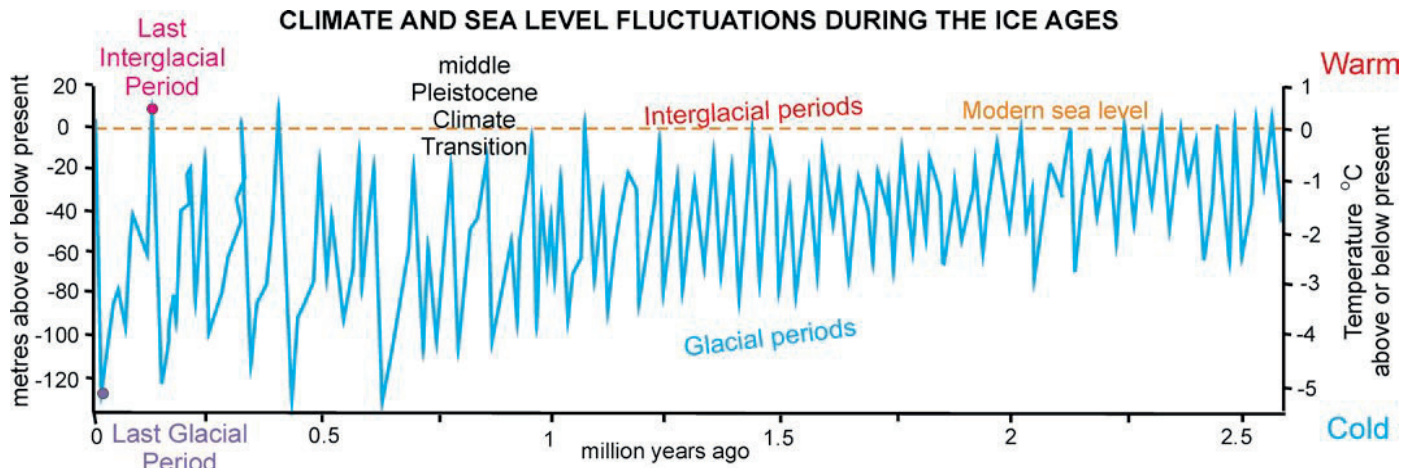
*Fossil bird and reptile bones occur in young sand dune, cave, swamp and midden deposits and provide evidence of the vertebrates that have been lost since the arrival of humans. Most noteworthy are the bones of a number of large,*

## ICE AGE CLIMATE AND SEA-LEVEL CYCLES (last 2.6 Myr)

*extinct flightless birds including four species of moa, and New Zealand's largest skink (also extinct).*

The Earth has experienced periods of extensive polar glaciation on a number of occasions back through deep time, with the most recent period in the last 2.6 Myr often referred to as the Ice Ages. Astronomically-driven cycles of warm and cold climate can be recognised throughout

most of Earth's history, but in the last 2.6 Myr their amplitude increased markedly and resulted in the cold glacial periods developing polar ice. Initially, up until about 1 Myr ago, the peaks and troughs (interglacial and glacial periods) of the climate cycles were 40,000 yr apart but this changed during the Middle Pleistocene Climate Transition (1.2-0.7 Myr ago) when the cycles lengthened to 100,000 yr. Thus, since 2.6 Myr ago, there have been



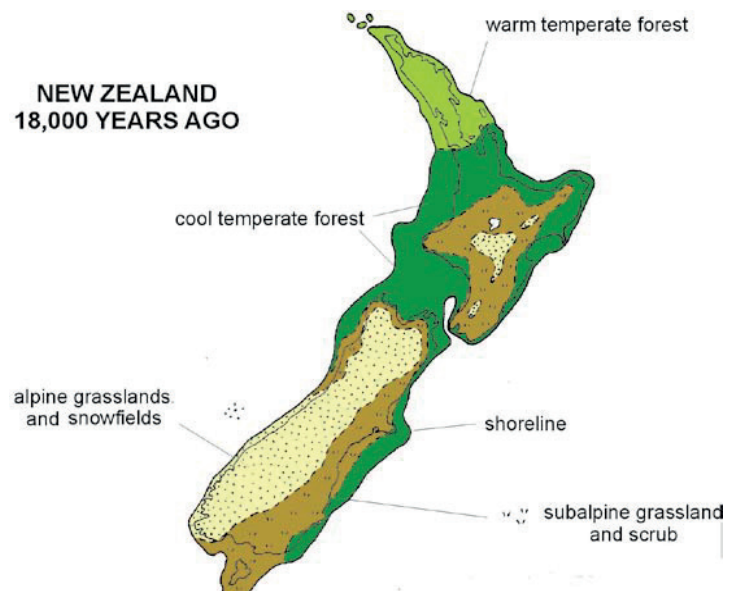
11.1 Global climate and sea-level curve for the past 2.6 Myr (Ice Ages).

Although the cycles had become 100,000 yr long, the peaks of cold glacials and warm interglacials each lasted only a few thousand years. In the more recent cycles, the Earth's climate slowly declined in a saw-tooth-like series of oscillations over a period of 80,000 yr after the peak warmth. After each glacial low, the Earth's climate warmed up much faster, often in less than 10,000 yr (11.1).

During the intense cold of all the glacial intervals since the Middle Pleistocene, almost all the forest of New Zealand's South Island and southern North Island disappeared and was replaced by subalpine grassland and scrub, with snow fields and glaciers developing in the more mountainous areas (11.2). In the northern North Island, forest persisted over all but the highest peaks through the glacial periods. Studies of the pollen record captured in lake and swamp sediments indicate that the composition of our northern forests changed through the climate cycles. During the warmer interglacial times, the forests were dominantly mixed podocarp-broadleaf in composition, much like they are today. During colder times, the forest, particularly in higher and more inland locations, became dominated by southern beech and shrublands of temperate climates, rather like the South Island vegetation today.

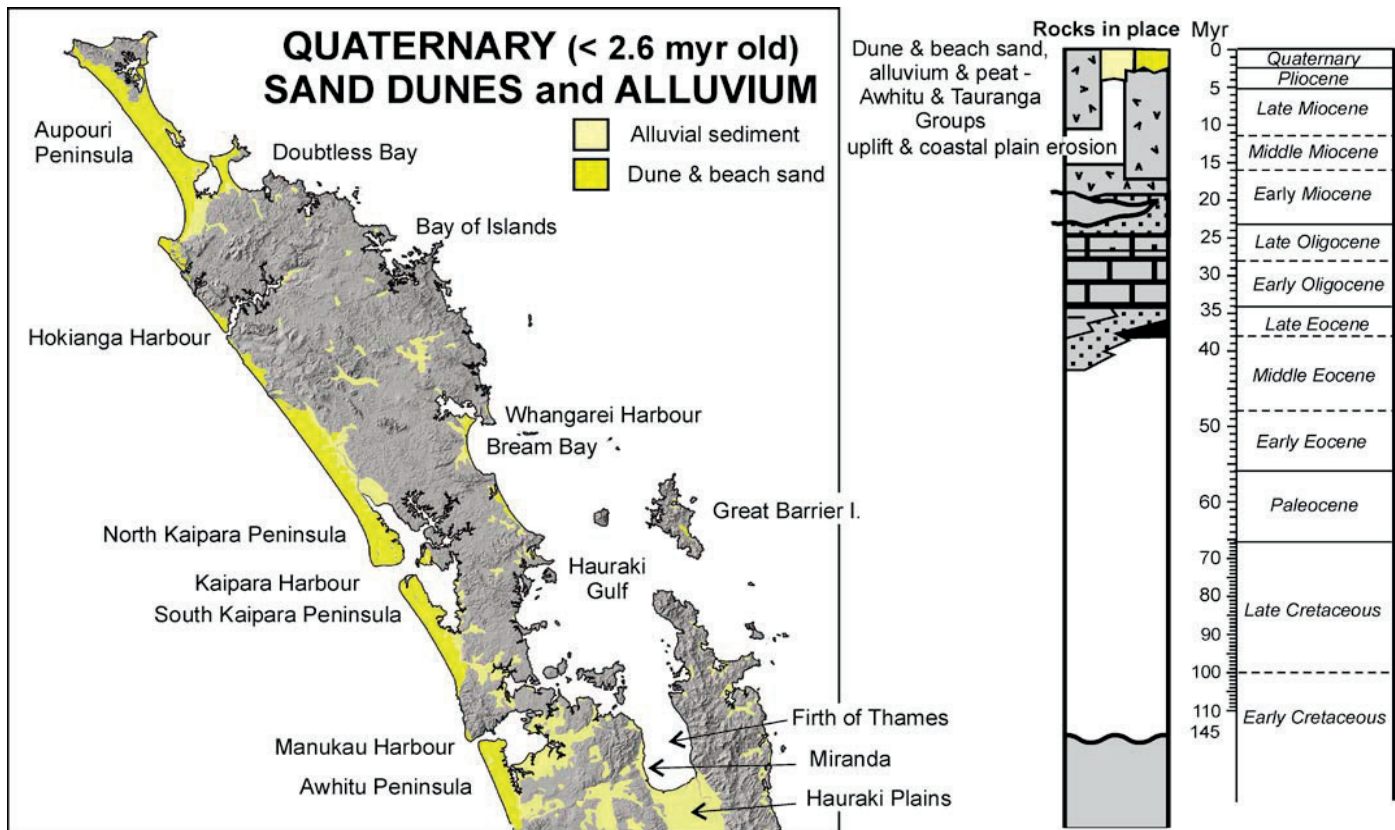
A direct result of the climate cycles, and mimicking them in periodicity and amplitude, were sea-level cycles (11.1). During the more recent, severe glacial peaks, a large amount of the Earth's water was captured on land in polar ice caps, especially in Eurasia and North America. This ice was sourced, via evaporation and snow fall, from the oceans and as a consequence sea level fell. During the most severe glacials, such as the Last Glacial

peak just 18,000 yr ago, sea level fell to as low as ~130 m below present, but for most of the Ice Ages sea level was fluctuating between 100 and 30 m lower than present. Sea level has only been high and close to the present for about 10% of the time in the last 1 Myr. These sea-level cycles have had a greater impact on the shape of northern New Zealand than the fluctuating climate cycles, as will become clear later in this chapter.



11.2 Map of New Zealand during the peak of the Last Glacial Period just 18,000 yr ago, when sea level was ~130 m below present. Because of the cold, the latitudinal vegetation zones were much further north than today. New Zealand would have looked very similar to this during each of the last seven major glacial periods in the last 700,000 yrs, since the Middle Pleistocene Climate Transition.

## WEST COAST SAND-DUNE BARRIERS (last 2 Myr)



11.3 Distribution of Quaternary (last 2.6 Myr) sedimentary rocks and sediments in northern New Zealand and stratigraphic column showing their relationship with the underlying rocks.

By the beginning of the Ice Ages (2.6 Myr ago), most of northern New Zealand had been uplifted above sea level with some areas, especially in the northwest, many hundreds of metres high. The Hauraki Rift had probably started to subside by this time as well. The west coast was not long and straight as it is today, but had two large embayments – the Manukau and Kaipara bays (11.4). In the Far North, erosion of the uplifted blocks had created a series of islands around the Three Kings, North Cape, Mt Camel and Cape Karikari, which were separated from most of Northland by shallow seas.

Since the start of the Ice Ages, major sand-dune barriers have grown across the mouths of the large west coast embayments creating the Awhitu and South and North Kaipara peninsulas and the 100 km-long Aupouri Peninsula in the Far North (11.3, 11.5-11.7). The explanation for the sudden growth of west coast sand-dune barriers was the vast increase in sand supply to the coastal system during that period.



11.4 Reconstructed paleogeographic map for northern New Zealand at the start of the Quaternary period (Pliocene-Pleistocene boundary), about 2.5 Myr ago.



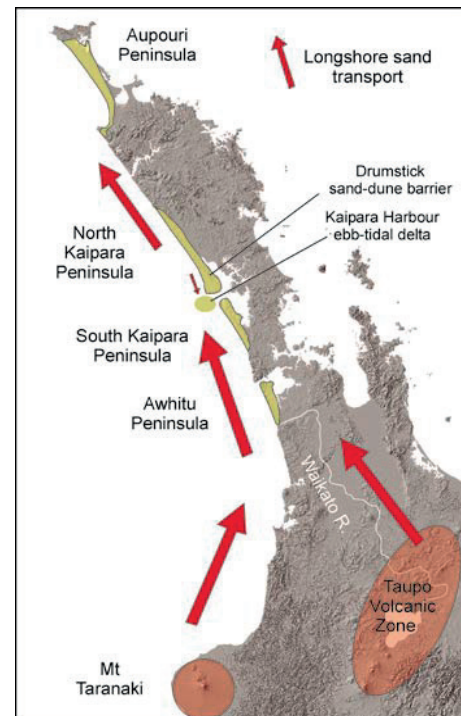
11.5 View south from the southern Waitakere Ranges to the eroding, 285 m-high north end of the Awhitu Peninsula sand-dune barrier that was built across the mouth of the Manukau bay in the last 2 Myr.

### **Sand supply**

A little after 2 Myr ago, an ancestor of Mt Taranaki started erupting in the vicinity of New Plymouth and volcanic activity broke out in the Taupo Volcanic Zone in the centre of the North Island. Both volcanic areas have been erupting large volumes of lava and ash, off and on, ever since. Coastal and terrestrial erosion of the andesitic ash and lahar deposits around Mt Taranaki and its ancestor volcanoes has provided a considerable quantity of sand to the west coast continental shelf sand budget. Similarly, terrestrial erosion of the voluminous rhyolitic ash layers and ignimbrites, erupted from the centre of the North Island, resulted in huge quantities of pumice and sand being carried down the Waipa River and delivered to the sea at or near Port Waikato. After 22,000 yr ago, the Waipa River was joined by the Waikato River, which brought with it increased quantities of ignimbrite-derived sediment.

### **Longshore sand transport**

Throughout most of the last 2 Myr there has been net longshore drift and sediment movement from south to north up the west coast from Cape Egmont to the Kaipara Harbour and beyond (11.6). The dominant southwest swells hit the coast obliquely with the surging waves sweeping sand diagonally up the beach. The returning wave surge flows straight back down the sloping beach. As a result much of the voluminous volcanic-derived sediment supply to the west coast has been carried progressively northwards. This northerly longshore transport of sand is a long-term process, driven by dominant southwest swells, imposed on top of much shorter seasonal and storm-induced transport of sand back and forth on and off the beaches. Where there was excess sand, often during falling sea level, it was thrown up at the back of beaches. Here the dry sand was blown



11.6 Large volcanic eruptions over the last 1.8 Myr, in Taranaki and the centre of the North Island, provided much of the extra sand to the west coast that resulted in the construction of the dune barriers that enclosed the Manukau and Kaipara harbours, and the Aupouri Peninsula tombolo in the Far North.

inland to create sand-dunes.

The orientation of the present-day North Kaipara sand-dune barrier appears to be anomalous and suggestive of south-directed growth. Indeed its southern end probably has grown southwards at times of high sea level, like today. A local reversal in sand transport direction on the coastline has probably been caused by the large ebb-tide delta of sand banks, which have built up off the mouth of the large Kaipara Harbour. The delta alters the direction

## Box 46. BEACH SAND

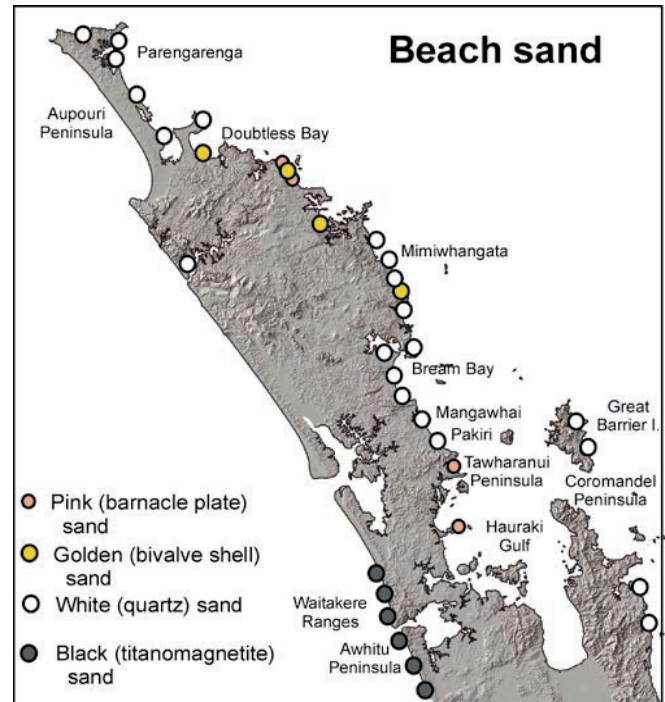
The colour of the sand on the beaches around northern New Zealand (11.9) is highly variable and depends on a number of factors, such as the proximity to the mouths of sediment-carrying rivers and streams; whether or not the local cliffs are made of soft, rapidly eroding material; and whether there are rich offshore shell beds. The main source of the beach sand has been from the Waikato River, which in the last 22,000 years has flowed out to the west coast as it does today. For hundreds of thousands of years prior to that it flowed out into the Hauraki Gulf on the east coast, carrying vast quantities of volcanic ash- and ignimbrite-derived sediment.

A small proportion of the Waikato River sediment (about 5%) was heavy black grains of titanomagnetite, which moves far more slowly northwards up the west coast by longshore drift than the much lighter quartz, feldspar and volcanic glass grains. Hence the beaches just north of the Waikato River mouth, along the Tasman coast of Awhitu Peninsula and the Waitakere Ranges, are rich in black sand (11.10). Small patches of black sand can be found around the inner Hauraki Gulf beaches – reminders of the time when the Waikato flowed out on the east coast.

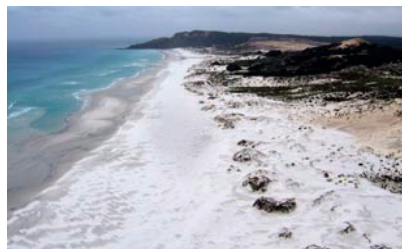
As the lighter grains have progressively moved northwards up the east and west coasts of Northland, the

volcanic glass and feldspar have been destroyed and mainly quartz (silica) has reached the Far North, creating the white sands of the Aupouri Peninsula tombolo (11.11) and especially Parengarenga Harbour. On the east coast the same mix of volcanic-derived sand has poured into the Bay of Plenty as well and over the last few climate cycles been moved northwards along the coast, providing the brilliant white silica sands of the eastern Coromandel Peninsula, Great Barrier Island, Pakiri, Mangawhai, Bream Bay and Mimiwhangata.

In some east coast bays north of Auckland, there is very little mineral sand being washed up on the shore, because there is no major river discharging sediment onto this coast. In these places, the locally-derived, broken-up shells of subtidal shellfish and other organisms with shelly hard parts, have accumulated. If the shells are dominantly bivalve, especially tuatua, the beach appears golden orange as at Cable Bay, Doubtless Bay (11.12). If the shells are dominantly broken barnacle plates, the beach appears pink, as on the north side of Tawharanui Peninsula (11.13). Inside the harbours and around the shores of the inner Hauraki Gulf, the sand is various hues of buff-brown (11.14) derived from the eroding and partly weathered greywacke basement and Early Miocene sedimentary rocks.



11.9 Map showing locations of examples of different coloured beach sand around northern New Zealand.



11.10 Top left. Black sand at Anawhata, Waitakere Ranges coast. 11.11 Top centre. White sand forms Ngakengo Bay, near North Cape. 11.12 Top right. Golden sand at Cable Bay, Doubtless Bay. 11.13 Lower left. Pink sand, east of Omaha, Tawharanui Peninsula. 11.14 Lower right. Buff-brown sand at Takapuna Beach.

## Box 47. WHITE SAND TO GLASS

White sand from dunes north of Auckland has been used for many decades, and still is in a small way, in the manufacture of glass for local use. The white sand is near pure quartz (silica,  $\text{SiO}_2$ ), derived originally from the huge rhyolite eruptions in the centre of the North Island, which have been erupting on and off for the last 1.8 Myr. Pumice, quartz, feldspar and other minor components in these giant ash eruptions washed down rivers into the sea and, over thousands of years, have been transported northwards by longshore drift, particularly up the west coast of Auckland and Northland. During this northwards transport, the pumice and feldspar have broken up or weathered away and dense grains of iron sand have been left behind. Thus the quartz-sand component has been naturally concentrated and purified.

Some of this quartz sand was carried by tidal currents into the Kaipara

Harbour and thrown up to form beaches on its eastern shore at Tapora, Glorit and other places south towards Helensville. Westerly winds blew the white beach sand inland forming sand dunes like those at Tapora today, and in places blew the sand up into the surrounding hills, where it accumulated in thick drifts at elevations of 50-75 m above present sea level. These deposits are currently being quarried at Tapora and Glorit, and have in the past been worked near Kaukapakapa. Impurities are removed from the ancient dune sand (11.20) and then it is transported to Auckland for glass manufacture.

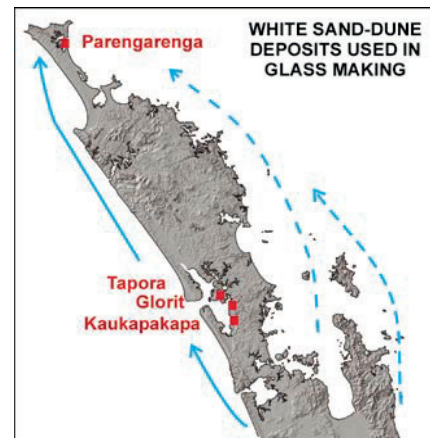
The largest silica sand deposit in New Zealand is the spectacular white dunes that form Kokota Spit that encloses Parengarenga Harbour near North Cape (11.21). For many decades this sand was sucked from here onto barges offshore that then took it south to Auckland. The original source of the Parengarenga sand is also believed to be the huge rhyolite eruptions around Taupo. This sand was probably transported north by longshore drift up the west coast, but some could have come up the east coast at times of lower sea level during the Ice Ages (11.22).



11.20 Heaps of white quartz sand at the Glorit purification plant.



11.21 Kokota Spit at Parengarenga, near North Cape, is made of exceptionally pure white quartz sand, which has been used in the manufacture of glass in Auckland.



11.22 Location of white quartz sand deposits that have been used for glass manufacture in northern New Zealand.



11.23 Other silica-rich white sand beach and dune deposits, which have not been mined for glass manufacture, occur up the east coast of northern New Zealand, especially on the east coast of Great Barrier Island and between Pakiri and Mangawhai Heads, as seen in this photo.

*11.31 Kai-iwi lakes, north of Dargaville, fill hollows within the North Kaipara sand-dune barrier on Northland's west coast. They occur in a depression between the older barrier and a belt of younger dunes that was added about 300,000 yrs ago. Photographer Alastair Jamieson.*



In many places there are elongate hollows between the different dune belts, which are now occupied by lines of linear dune lakes or swamps (11.26, 11.29). In some places excess sand accumulated at the bottom of a cliff or steep slope (e.g. Awhitu Peninsula) and strong winds blew

the sand up steep valleys or guts to build small dune fields on the cliff tops and beyond.

***Whatipu sand flats***

Sea level is currently rising (0.3 m since the 1880s) and now most of New Zealand's beaches and foredunes are eroding slowly as nature tries to restore the equilibrium between sand on the beach and the inshore seafloor. An exception to this occurs along the coast of the southern Waitakere Ranges, where the Whatipu sand flats and sand dunes have built out 1 km from the rocky cliffs since the 1920s (11.32, 11.33). This is one of the few areas of sand accretion on the coast of New Zealand at the present time

and it is a result of a unique situation. Maori traditional histories document that a similar large sand flat and dunes ("the lost land of Paoraē") existed offshore from the north end of the Awhitu sand-dune barrier in the 18<sup>th</sup> century and was eroded away by the sea over a number of decades around AD1800. In the first half of the 19<sup>th</sup> century large sand islands were present outside the entrance to the Manukau Harbour. It would appear that a large slug of excess sand has been moving northwards in this area. Observations in the last 50 years show that this northwards longshore drift of sand continues today and in the last decade it has all but filled up Karekare Bay and its front is advancing into Piha.

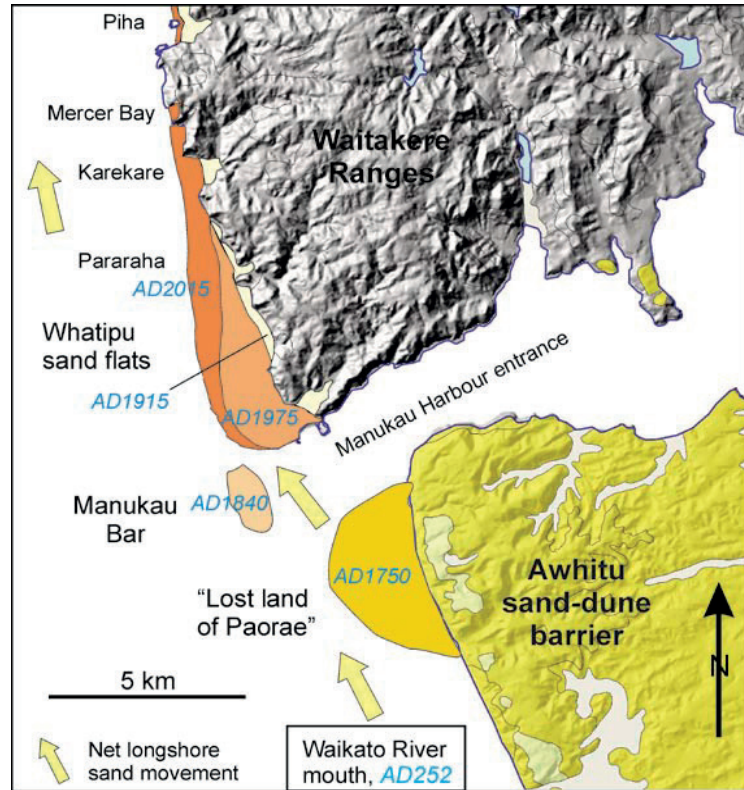


*11.32 This 1 km-wide sand flat with low dunes at Whatipu, southern Waitakere Ranges, built out from the cliffs in the early 20<sup>th</sup> century and currently is moving slowly northwards as a result of longshore drift, driven by dominant southwest swells. This photo was taken in the 1990s and the flat is now covered in more vegetation. The northern tip of the Awhitu Peninsula sand-dune barrier can be seen across the Manukau Harbour entrance. Photographer Alastair Jamieson.*

11.33 Right. In the last 250 yr, sand that once formed an extensive coastal flat, attached to Awhitu Peninsula, has moved northwards across the mouth of the Manukau Harbour and built the Whatipu sand flats. At present the sand is continuing its gradual journey northwards up the west coast of the Waitakere Ranges. This appears to be a pulse of excess sand that was discharged onto the west coast by the Waikato River, soon after the AD232 Taupo eruption. This excess sand has been slowly moving up the coast since then.

A likely cause of this pulse of excess sand is the AD232 Taupo eruption and break-out flood from Lake Taupo, which would have resulted in a large quantity of ignimbrite-derived sand being carried down the Waikato River into the west coast sand system over just a few decades after the eruption. Since then, the sand has moved northwards at a net rate of about 2.5 km per century – a rate compatible with the recent record of movement. Although the excess sand is progressing northwards there have been local pulses of sand build-up and sand erosion that have lasted a few months to a few decades.

Now that this pulse of extra sand has moved north past the coast of Awhitu Peninsula, this sand-dune barrier is starting to erode on its western side particularly at the northern end. Not helping this



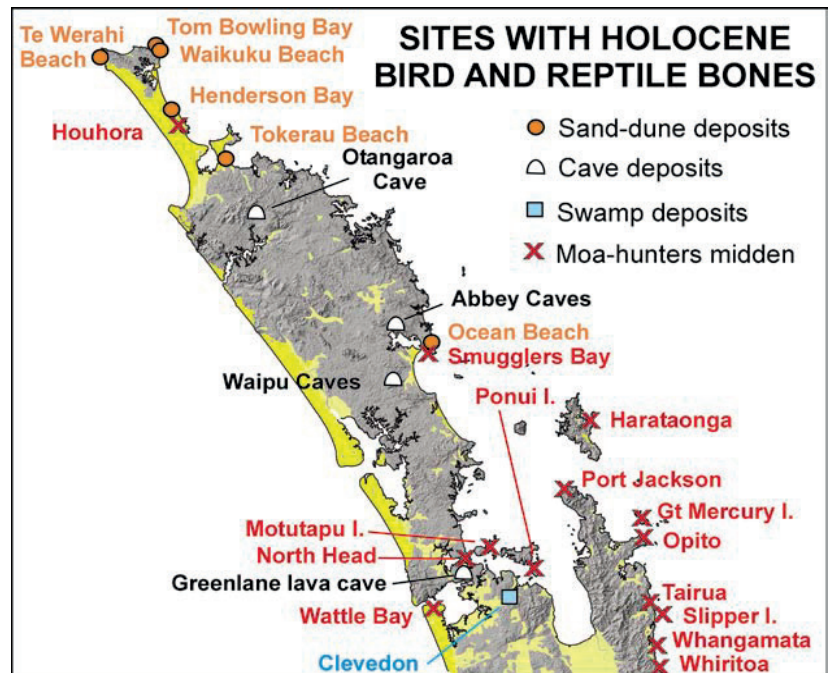
situation is the fact that the natural sediment supply coming down the Waikato River has been greatly reduced in the last century by the construction of hydroelectric dams upstream and sand dredging in its lower reaches.

### Box 49. FOSSIL EVIDENCE OF MOA AND OTHER VERTEBRATES

No fossilised bones of land vertebrates older than Holocene (last ~10,000 yr) have been found so far in northern New Zealand. Preserved bones of birds, and sometimes reptiles and amphibians, have been found in Holocene sand-dune, swamp and cave deposits (mostly younger than 6000 yr) and also in the midden (rubbish heaps) of early Maori (younger than 800 yr).

The only significant find of bones preserved in a peat swamp has been a large collection of bones from three species of moa, including two complete skeletons, which were excavated from a swamp near Clevedon in the early 19<sup>th</sup> century. Bones are often found preserved buried in sediment or even in the open on the

11.34 Locations where rich deposits of bones from moa and other birds and reptiles have been found in northern New Zealand. All are younger than 10,000 yr (Holocene).





### Box 49. Fossil moa and other vertebrates .. continued

floors of limestone caves and fissures. Since there are few good limestone karst areas in northern New Zealand, the number of bone finds in these situations have been small. The two richest deposits have been in the extensive Waipu Caves network and in a small, seldom-visited cave at Otangaroa, in northern Northland. Moa bones have also been found in a small fissure near Abbey Caves, Whangarei. The bones of a number of smaller birds have been recovered from the Waipu and Otangaroa caves, as have bones of four species of the native New Zealand frog, *Leiopelma*, including two of the three known extinct species. Also found in these cave deposits are bones of the only known extinct New Zealand skink (*Oligosoma northlandica*). There are probably a number of other extinct species, but they cannot easily be recognised from their skeletal remains. The bones of the extinct Northland skink are recognised because they are larger than any living New Zealand species, with the original animal probably being up to 25 cm long. Moa bones were found in a lava cave on a building site at Greenlane Hospital in Auckland in 1957.

The richest record of the pre-European bird fauna of northern New Zealand comes from bones that have been buried in sand dunes in the Far North – mostly behind Te Werahi Beach (Cape Reinga), Tom Bowling and Waikuku Beaches (North Cape) and Tokerau Beach (Doubtless Bay). In the latter half of the Holocene (last 4000 yr), all these sand-dune systems have gone through cycles of active sand-dune building and stable periods of forest establishment across them. As with the Kaipara sand-dune barriers, the episodes of sand-dune building probably occurred during times of minor sea-level fall, such as 1000-600 yr ago. The bones now found eroding out of the dune deposits are from birds that probably died on the dunes and were



11.35 Parts of the fossilised skeleton of a Mappin's moa (*Pachyornis geranoides*) and two flax snail shells (*Placostylus ambagiosus*) unearthed by moving wind-blown sand in the 2000-3000 yr old sand dunes behind Tom Bowling Bay, North Cape. Width of photo 50 cm. Photograph by Phil Millener.

The most robust bones in the sand dunes are those of the extinct, flightless moa. Four of the nine known species lived in the North Island and bones of all four have been found in the sand-dune deposits in the Far North. These were the Little Bush Moa (*Anomalopteryx didiformis*), Mappin's Moa (*Pachyornis geranoides*), the Stout-legged Moa (*Euryapteryx curtus*) and the North Island Giant Moa (*Dinornis novaeseelandiae*). The Giant Moa (weighing up to an estimated 240 kg) was the tallest bird in the world (up to 3 m tall with neck outstretched), but not the heaviest. The most common moa in northern New Zealand appear to have been the Stout-legged and Mappin's moa (11.36, 11.38), both of which are inferred to have lived in the mosaic of grassland, shrubland and forest habitats around the northern coasts and dunes. The other two moa are inferred to have preferred the high rainfall forest of inland northern New Zealand, though they periodically ventured out onto coastal dunes.

Bones of all four North Island moa species occur in middens from the early periods of Maori occupation (800-

buried by their advance. In the Far North, at Te Werahi, Tom Bowling and Waikuku beaches, the bones eroding out of the sand dunes occur together with multitudes of the large bleached shells of the flax snail (*Placostylus*; 11.35).

The bird bones present include a mix of land species from forest, open shrubby country and wetland, together with sea birds. Many of the larger, more robust bones came from species that are now extinct and include the New Zealand crow, pelican, adzebill, raven, laughing owl, and North Island takahe, as well as smaller extinct birds such as the huia, North Island snipe and stout-legged wren. The New Zealand pelican was our country's heaviest flying bird, with some individuals weighing up to 12 kg – very close to the world's heaviest flying bird. Also present in the dunes are bones of species that were once widespread around New Zealand, but no longer live on the mainland North Island, such as kakapo and the ancient reptilian tuatara.



11.36 Bones from the stout-legged moa, *Euryapteryx curtus*, that were buried by blowing sand behind Tokerau Beach in Northland about 1000 yr ago (Late Holocene) and recently exhumed by wind erosion. In collections of Auckland Museum. Photograph 60 cm across. Photo courtesy of Auckland Museum.

### Box 49. continued

400 yr ago). There is no convincing evidence that any moa survived beyond AD1600. The arrival of humans in New Zealand, around 800 yr ago, resulted in the extinction of the moa and other bird species mentioned above. The larger bird species were hunted for food, but other human-facilitated impacts came from predation by feral dogs and kiore (Polynesian rats), and forest clearance. Moa were clearly a much prized resource in those early days as a source of food, feathers and skins for clothing, and bones for fish hooks and pendants. In northern New Zealand, older middens containing butchered moa remains include those found at Houhora in Northland; North Head and Motutapu Island in Auckland; and Port Jackson, Opito, Tairua, Whangamata and Whiritoa on the Coromandel Peninsula.

Other evidence of the former presence of moa comes from fragments of moa egg shells and rare intact eggs found in the Far North sand dunes. The most widespread sign of the former presence of moa are their polished gizzard stones that occur in soil layers throughout northern New Zealand. Gizzard stones are also found in eroding sand dunes, including the older sand-dune barriers that may have been deposited as far back as 1.5 Myr or more. Moa fed on a range of fibrous twigs and leaves taken from low trees and shrubs and they needed stones in their gizzard to help masticate the plant material, as they lacked teeth to do this job.

Most gizzard stones (gastroliths) are 1-2 cm in size (11.37) but they can be smaller or larger, up to 6 cm across. The most common rock types for gizzard stones were various kinds of abrasion-resistant quartz, such as chert, jasper and even common opal. The moa may have preferentially picked up and swallowed the harder rock types, possibly attracted by their glinting appearance, but undoubtedly softer rocks they may have picked up soon ground down in their gizzard and the more resistant



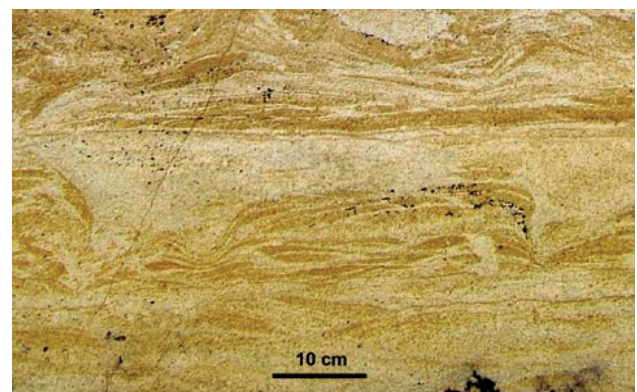
11.37 A selection of moa gizzard stones from sand-dune deposits at Mitimiti, west coast of Northland. Note that all are rounded and polished white or cream chert that would have been more resistant to abrasion in the moa gizzards than the local basalt rocks. Width of photo 12 cm. University of Auckland collection.



11.38 A stout-legged moa like this may have left the footprints in wet sand on the edge of a dune lake near Muriwai, about 1 Myr ago. Drawing by Margaret S. Morley.

quartz ones became dominant. Sometimes a concentration or heap of moa stones are found representing the contents of one moa gizzard left behind when all the rest of the moa remains broke down. The most distinctive moa gizzard stones are those that have a polished concave side that can only have been formed by another stone grinding against it inside a gizzard.

The rarest preserved evidence of the former presence of moa is their footprints. In New Zealand, there are ten recorded sites where moa footprints have been recognised in plan view by their distinctive three-toed impressions preserved in weakly consolidated mudstone or ash. One of these sites is in northern New Zealand, at Henderson Bay in the Far North. There is also one probable footprint site in west Auckland, where the impressions of moa footprints can be seen in vertical cross-section in 1 Myr-old sandstone layers deposited within the South Kaipara sand-dune barrier sequence near Muriwai (11.39).



11.39 Vertical cross-section through layers of sand that were deposited on the wet edge of a dune lake near Muriwai about 1 Myr ago. The two depressions pushed into the iron-stained sand layers and filled with lighter-coloured sand are inferred to be the fossil footprints of moa.

***Out of the Ocean into the Fire*** tells, for the first time, the fascinating geological history of the formation of northern New Zealand and the history of its past biota.

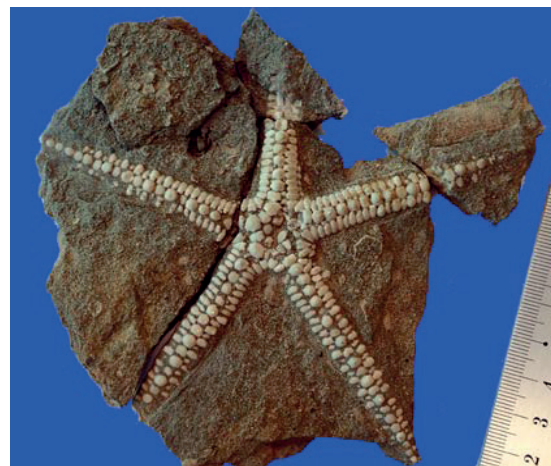
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- 200 small basalt volcanoes in 7 fields
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- NZ's best examples of a butte (Taratara), lava plug (Tokatoka), natural jetty (Whangarei Heads), pillow lavas (Muriwai), lava caves (Auckland), huge spherical concretions (Hokianga), mud volcano (Runaruna)
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