THE QUATERNARY HISTORY OF CHATHAM ISLAND, NEW ZEALAND

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The North Red Bluff Quaternary sequence, Petre Bay, Chatham Island.

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ABSTRACT

The Quaternary geology of Chatham Island has been investigated using several different techniques, including: tephrochronology, mineralogy, palynology and stratigraphy; in an attempt to draw together a Quaternary history for the Island.

The Quaternary record of Chatham Island comprises mainly deposits from terrestrial environments, predominantly thick blanket peats and aeolian sand, all of which range from latest Castlecliffian to Haweran/Recent in age. Quaternary deposits that demonstratably predate this age range (i.e. > Oxygen Isotope Stage 12) have not been recognised anywhere on the Island. Their absence is, at this stage, attributed to a major marine transgression across much of the northern and central portions of the Island during Oxygen Isotope Stage 11.

Two rhyolitic tephra produced during two of the largest eruptions from the Taupo Volcanic Zone are present on Chatham Island. The 27.1 ka Kawakawa Tephra is well preserved across most of the Island, occurring within most pre-Holocene sequences. The 345 ka Rangitawa Tephra, not previously recognised on Chatham Island, is found in a few scattered coastal locations where older, late Castlecliffian sediments are preserved. In the absence of any other forms of radiometric age control these two tephras have provided the principal means for time control within and between stratigraphic sequences on the Island.

Palynology has been used predominantly to determine climatic conditions at the time of sediment accumulation. Palynological investigations of seven sections of peat deposits have also demonstrated that cyclic changes in vegetation patterns have

occurred throughout the Quaternary on Chatham Island. However these changes have not been as significant as those that occurred on mainland New Zealand over the Quaternary. It is concluded that this indicates climatic deterioration during glacials may not have been as pronounced on Chatham Island as on the mainland.

Marine terraces created during former high sea level stands are preserved in several areas on Chatham Island. Quaternary terrace surfaces ranging in age from Last Interglacial (OIS 5e) to OIS 11 occur at heights of 3-5 m, 9 – 10 m, 16 m, 20 m and 30 - 40 m above sea level. An exhumed surface of Late Pliocene age occurs at 7 – 14 m a.s.l.. Terrace ages have been determined using cover-bed stratigraphy, and in particular the presence or absence of tephra marker beds.

Height-age relationships of marine terraces have been used to develop preliminary rates of tectonic uplift on Chatham Island. The resulting values range between 0.01 – 0.13 mm/yr and are very low compared with more tectonically active areas of mainland New Zealand. However, there is considerable variation in these rates across Chatham Island, indicating that the tectonic history of the Island over the Quaternary may be complex.

This thesis has also demonstrated that considerably more work is required to fully understand the Quaternary history of Chatham Island. In particular, better numerical age control on key deposits; more detailed, high-resolution pollen records from key locations; and obtaining stratigraphic records from a greater range of locations. This is particularly so for the southern uplands where older records are virtually inaccessible due to a thick blanketing of post-glacial peat deposits.

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CHAPTER ONE
INTRODUCTION

1.1 General Introduction

Chatham Island, largest in the island group collectively referred to as the Chathams, is host to some of the easternmo st Quaternary deposits of the New Zealand microcontinent - 'Zealandia' (Luyendyk 1995). In contrast to the Quaternary deposits of the New Zealand mainland, the Chatham Quaternary record has received relatively little attention in terms of geological research when considering the rich record of Cretaceous and Cenozoic sedimentation and volcanology in a setting far removed from the Pacific-Australasian plate boundary. For example, this work is currently only the third Ph.D. thesis to be produced on any aspect of the island's geology, the other two being those of Dieseldorff (1901), and Morris (1982). Most research dealing with the Quaternary has been in association with reconnaissance surveys covering the entire span of Chatham Islands' geological history or has been the by-product of surveys on the economic potential of the extensive blanket peat which covers a large portion of the Chatham Island land surface. Very little of this work has been published (refer to Chapter 2 for a more detailed coverage of previous work relating to this thesis).

This study has been undertaken with the aim of establishing the extent of the Quaternary record of Chatham Island and the sequence of events preserved within it, and to interpret these events in relation to the cyclic changes in global climate that occurred through the Quaternary. To accomplish this, the island's Quaternary geology was investigated by the author during field expeditions in the summers of 2004, 2005 and 2006. During field work, particular effort was put into identifying exposures which preserved the longest and most complete records of Quaternary sedimentation on Chatham Island. Discriminating marine terraces within the island's landscape, determining their height relative to modern sea level, and describing and sampling their cover-bed sequences also formed an important part of field work on Chatham Island. Many different techniques common to Quaternary science have been applied during both the field and in the lab. Volcanic ash layers derived from the Taupo Volcanic Zone (TVZ) in mainland New Zealand were identified using mineralogy and electron microprobe analysis (EMPA). Once identified, these tephras provided crucial chronohorizons for correlating stratigraphic sequences. Palynological analysis of peat and organic-rich deposits was performed to provide insight on vegetation patterns and changes in climatic conditions over time on Chatham Island. Clastic sediments were analysed in terms of grain size and mineralogy to investigate changes in depositional environments and sediment provenance, respectively. These changes were envisaged as being driven largely by changes in sea level increasing or decreasing coastal erosion, resulting in changes in sediment supply. Constraining the time interval preserved in marine terrace cover sequences using data generated from the analyses described above allowed minimum or maximum ages to be assigned to the cutting of the wave-cut surface underlying each terrace tread. Preliminary uplift rates for Chatham Island were then able to be generated using the height and age relationships of the marine terraces.

This thesis is structured to reflect the progression of techniques applied during the course of the research. To set the scene, the nature of the study area is first described, followed by a review of relevant publications relating to the Quaternary geology. Then the tephrochronological investigations are documented first, followed by chapters on palynology, stratigraphy, and marine terraces. The chapters are arranged this way because (with the exception of Chapter 3) each draws on information and data presented in the previous chapter(s).

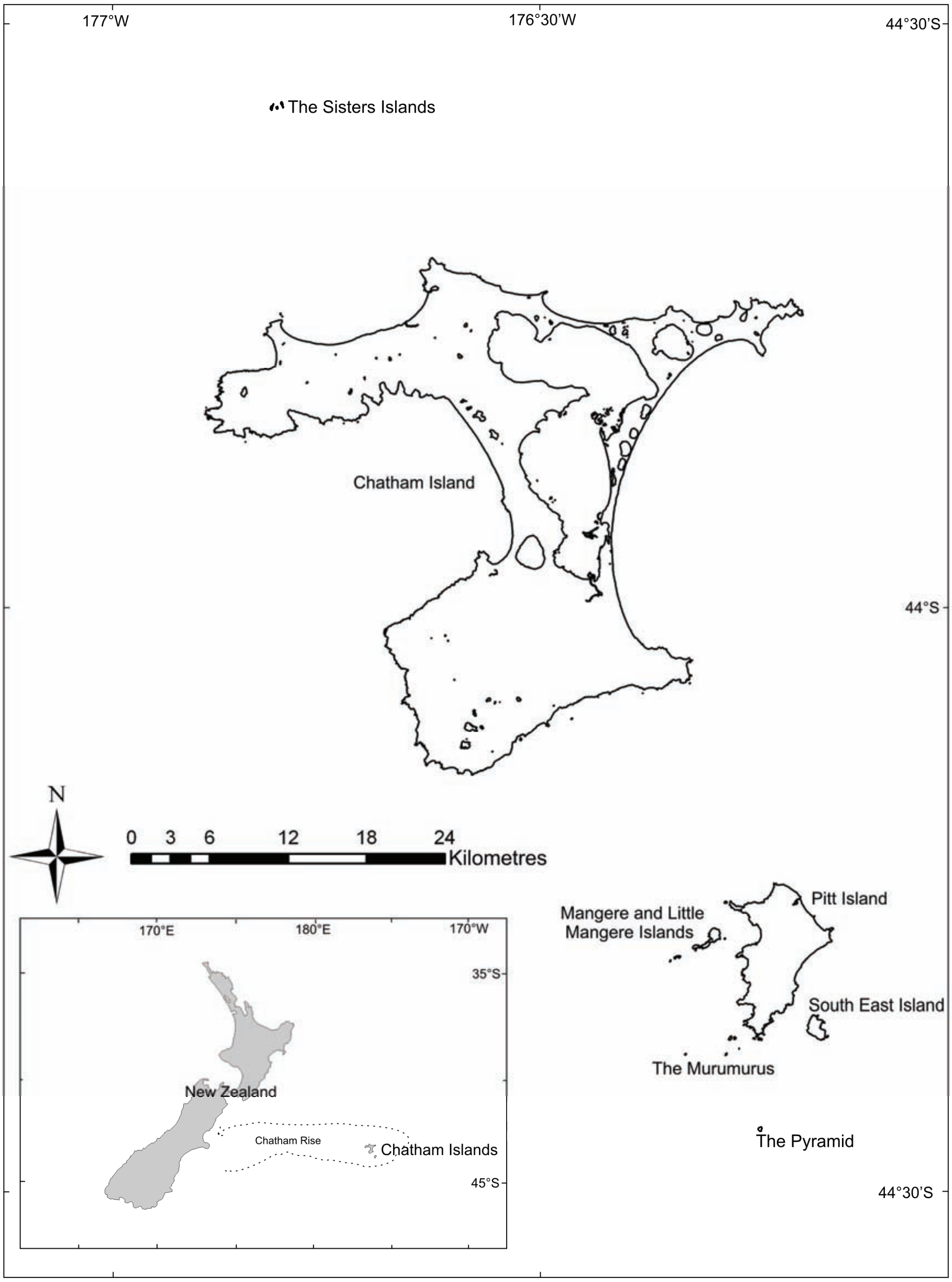
It is relevant to note that the period referred to herein as the Quaternary encompasses the interval between 2.59 Ma and the Present, as defined jointly by the International Commission on Stratigraphy and the International Union for Quaternary Research (Gibbard *et al.* 2007).

1.2 Introduction to Chatham Island

1.2.1 Location

The Chatham Islands are located approximately 900 km east of Banks Peninsula, at latitude 44ºS and longitude 176ºW (Figure 1.1). The group is composed of one large island – Chatham, which is the focus of this thesis, the smaller island of Pitt, and numerous smaller islands, rocky islets and reefs. Chatham and Pitt Islands are the only islands that are permanently inhabited. Completely surrounded by the vast Pacific

Figure 1.1: The Chatham Islands (not shown – Forty Fours Islands at 43º57'S, 175º50'W approx. and Star Keys Islands, at 44º13'S, 176º02'W approx.). Inset – Location of Chatham Islands relative to the New Zealand mainland.



Ocean, they sit on the large submarine plateau of continental crust known as the Chatham Rise, towards its eastern terminus.

1.2.2 Physiography

Physiographically the Chatham landmass is very low-lying, with no part exceeding 300 m in elevation. It has a very curious shape, constantly remarked upon by visitors, and has been described in a variety of ways including a horse shoe (Dieffenbach 1841), a Maori anchor stone (Wright 1959), a dumb-bell (Hay *et al.* 1970), hour-glass shaped (Mildenhall 1994a), T-shaped (Thomson 1983) etc, but this author prefers to think of it as resembling more of a cordless power drill shape. Figure 1.2 illustrates the physiographic features of Chatham Island and locations of places mentioned in this thesis. All grid references given in this thesis can be found on NZTM 260 Chatham Islands Sheets 1&2, 1981.

Chatham Island is about 90,000 ha in area. However almost a quarter of this area is taken up by water masses (lakes and lagoons), the largest of these being Te Whanga Lagoon, an 18,600 ha area of brackish water that is one of the dominating features of the island. There are only two rivers on the island - the Te Awainunga & Nairn Rivers, both of which are of small volume. There are numerous small streams and creeks. The island’s distinctive shape has resulted in an extensive coastline, large tracts of which are dominated by sandy beaches and sand dunes, which extend in an almost continuous belt from Waitangi West in the north, round past Kaingaroa to the east then southwards along the Hanson Bay coastline to Owenga, and between Waitangi and Ohira Bay along the coastline of Petre Bay. The remainder of the coastline is cliffed or composed of rocky headlands and boulder beaches.

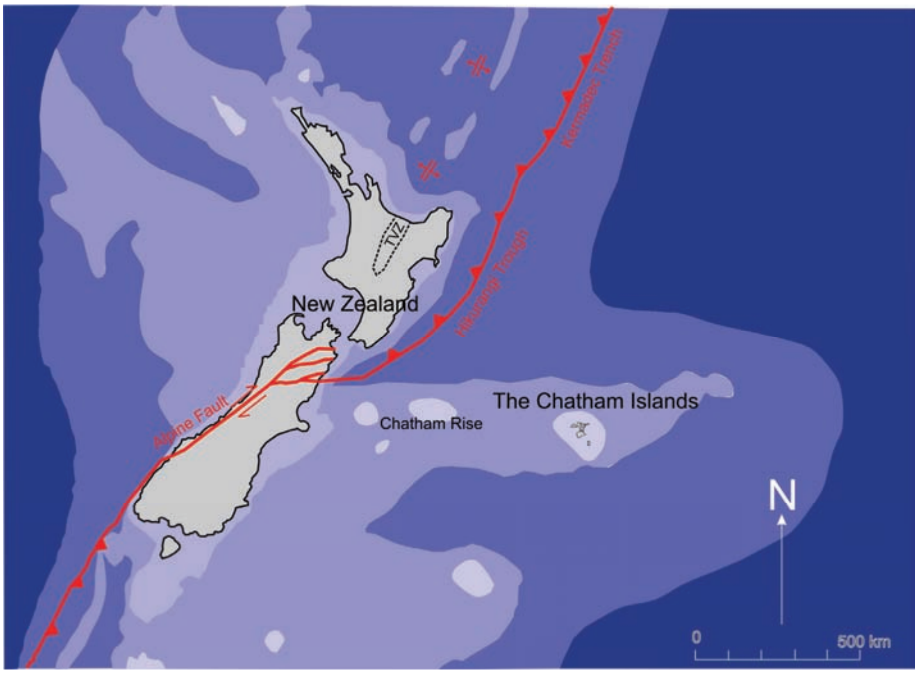
Chatham can be divided into two broad topographic regions: the northern and central parts of the island, which are in general very low lying (<70 - 80 metres a.s.l.) with the exception of several distinctive conical hills, and rocky headlands composed of Tertiary volcanics; and the southern portion of the island, often referred to as the southern ‘uplands’ or ‘tablelands’. Derived from the remains of a large Cretaceous shield volcano, the uplands form a broad sloping plateau rising from sea level at Waitangi, Te Matarae and Owenga to altitudes approaching 300 m a.s.l. along the southern coast, where they are steeply cliffed. They are in some places heavily dissected by stream flow within deeply incised gullies. The altitude of the uplands has been attributed in part to block faulting and rotation which has uplifted the large block of Southern Volcanics that forms the uplands (Wood *et al.* 1989).

1.2.3 Geology and tectonic setting

1.2.3.1 The Chatham Rise

The Chatham Rise (Figure 1.3) is essentially a block of continental crust composed of schist and meta-greywackes with a strong affinity to the Paleozoic-Mesozoic Torlesse Terrane (Wood *et al.* 1989, Herzer and Wood 1992). Prior to break-up, the northern margin of the Chatham Rise formed a (convergent) continental margin of Gondwana. At this time (~130 Ma) the Chatham Rise and Campbell Plateau portions of the New Zealand microcontinent were located adjacent to the Marie Byrd Land region of Antarctica, with the eastern end of the Rise (i.e. the Chatham Islands region) fitting into Pine Island Bay (Stilwell 1997).

Figure 1.3: The Chatham Islands in relation to the Australia-Pacific plate boundary (red line) running through New Zealand (TVZ = Taupo Volcanic Zone).



The northern margin of the Rise formed a south-west-dipping subduction zone, referred to as the Chatham Subduction Zone (Schellart *et al.* 2006). Late Cretaceous (100-120 Ma), back-arc extension driven by (slab) rollback along this subduction zone lead to extension in the Chatham Rise-Campbell Plateau regions. This period of extension culminated with spreading in the Bounty Trough, separating the southern margin of the Chatham Rise from the northern margin of the Campbell Plateau. At around the same time, the Hikurangi Plateau began to impinge on the Chatham Subduction zone (Schellart *et al.* 2006). The Plateau apparently extends for some 150 km below the Rise (Wood *et al.* 2003), however it was too buoyant to be fully subducted, which eventually resulted in cessation of subduction and locking of the Chatham Subduction Zone. The Chatham-Campbell-Hikurangi block then became amalgamated with the Pacific Plate (Schellart *et al.* 2006). Following the break-up of Gondwana, the New Zealand microcontinent, including the Chatham Rise underwent thermal relaxation and sank (Herzer and Wood 1992). The Rise and the locked Chatham Fossil Subduction Zone (Figure 1.3) remained relatively passive from then onwards. In nearly all paleo-reconstructions of the South Pacific region, the Chatham Rise (and Fossil Subduction Zone) is regarded as a passive structure which is simply carried along on the Pacific Plate.

1.2.3.2 Geology

To generalise, the Chatham Islands can be regarded as the eroded remnants of Late Cretaceous oceanic islands (Stilwell 1997). The pre-Quaternary geology and geologic history of Chatham Island have been described by Hay *et al*. (1970) and Campbell *et al.* (1993). Pre-Quaternary lithologies are dominated by mafic volcanics from three volcanic episodes during the Cretaceous and Tertiary, and by bioclastic Tertiary limestones.

The oldest lithologic unit present on the island is the Chatham Schist, which is believed to form the basement rock of the Chatham Rise, and on the basis of petrology and radiometric ages, is regarded as belonging to the Paleozoic-Mesozoic Torlesse Terrane (Campbell *et al.* 1988). It is juxtaposed against the younger Chatham rocks along a NE-SW trending fault running between northern Petre Bay and the Wharo area. The schist was almost certainly sub-aerially exposed during the Cretaceous, when the Chatham Islands area was located near the New Zealand-Antarctic boundary prior to the break-up of Gondwanaland. This is evidenced by the occurrence of schist detritus within the Cretaceous-aged Tupuangi Formation, exposed on Pitt and Mangere Islands, but not on Chatham (Campbell *et al*. 1993, Davies 2006). Following the schist in age on Chatham Island, are the Southern Volcanics which form the southern uplands. They are composed predominantly of mafic alkaline extrusive volcanics and were generated by a large shield volcano during the Late Cretaceous/Paleocene, forming part of a volcanic arc that became active following the split of the microcontinent of Zealandia from Gondwanaland (Campbell *et al.* 1993).

After the cessation of Cretaceous/Paleocene volcanism, crustal subsidence associated with rifting from Gondwanaland led to the Chathams becoming entirely submarine (Campbell *et al.* 1993). As a result, the bulk of the Late-Cretaceous and Tertiary record is dominated by limestones, of both biogenic and authigenic origin. There are at least nine different limestone units present on the island, the most extensive of which is the Te Whanga Limestone forming the main lithology in the central portion of the island, being superbly exposed around the western shores of Te Whanga Lagoon. Volcanism recommenced in the Islands during the Oligocene with the eruption of the Northern Volcanics, which form the twin lineaments of conical hills that dominate the landscape of the northern part of the island. This was followed in the Miocene with the eruption of the Rangitihi Volcanics which form the headlands of Maunganui Bluff and Cape Young on the island's northern coast. Both the Northern Volcanics and Rangitihi Volcanics are of mafic alkaline composition (Campbell *et al.* 1993). Other volcanics erupted during this time include the Whenuataru Tuff, and Pyramid Phonolite which are significant lithologies on some of the smaller islands to the south of Chatham (i.e. Mangere, South East and Pyramid Islands) but do not occur on Chatham itself. The driving forces behind the Oligocene – Miocene volcanism are not yet fully known.

The Chatham Islands remained predominantly submarine until at least the Late Pliocene. Recent investigations at the volcanic edifices of Mairangi volcano and Matakitaki volcano have shown that some of the eruptions associated with the late Eocene-aged Northern Volcanics may have been sub-aerial (Panter, *et al.* 2006). However it is most likely that only the cones themselves were emergent at this time, forming small volcanic islands, while the bulk of Chatham Island remained submarine. Full emergence of the Islands from the sea is, at this stage believed to have occurred no earlier than 2-3 million years ago (H. Campbell, pers. comm.) when the region began to rise. The driving forces behind this uplift are not yet fully understood.All Quaternary deposits on Chatham Island are collectively grouped into the Karewa Group of Campbell *et al.* (1993). In contrast to the Tertiary and older Chatham lithologies, the Quaternary deposits are predominantly of terrestrial origin (with the exception of one or two minor units), and presumably accumulated following re-emergence. They are dominated in volume and areal extent by peat, and to a lesser degree aeolian sand.

At least half of the island's surface is covered in peat, ranging in thickness from approximately half a metre to greater than ten metres (MacPherson and Hughson 1943, Hay *et al.* 1970 Richards 1987, Campbell *et al.* 1993). These are mostly oligotrophic blanket peats, with varying amounts of wood, and a very high wax content. This high wax content results from the input of litter from *Dracophyllum arboreum,* the main forest tree on the island, and an abundant litter producer with high levels of wax in its leaves (Wright 1959). The bulk of the peat is thought to be younger than 125 ka, having begun accumulating at the end of the Last Interglacial (Richards 1987, Mildenhall 1994a), but there are some much older peat units that occur as beds within older clastic sequences. There are also silts and loess, usually of local extent, and rhyolitic tephra beds derived from the Taupo Volcanic Zone. There are limited amounts of marine deposits, including marine sands, shell beds and gravel, but these are volumetrically minimal compared to the volume of terrestrial deposits, and are restricted to one or two high sea level events.

1.2.3.3 Tectonic Setting

At present the Chatham Islands are far removed from the active Pacific – Australasian plate boundary running through mainland New Zealand (Figure 1.3). This fact has led many researchers to suggest that they are tectonically stable which is supported by the lack of any significant seismic activity in the islands. Seismic reflection and refraction studies of the eastern end of the Chatham Rise have shown that the structure of the basement immediately underlying Chatham Island is quite complex. In general, it is dominated by a number of E-W striking half grabens, formed from block faulting associated with the rifting of Zealandia from Gondwanaland, and the formation of the Bounty Trough during the Late Cretaceous (Wood *et al.* 1989). Gravity modelling by Wood and Anderson (1989) indicated the presence of a basin structure underlying central Chatham Island. This basin is bounded to the north-west by a steeply-dipping north-east striking fault, and by a less steep north-west striking fault to the north-east. Faults recognised in their survey do not offset the Tertiary sequences, so are considered older than the Tertiary. This basin is essentially a half graben between the up-thrown horst of Chatham schist to the north, and a gently northward-dipping fault block composed of Southern Volcanics to the south. Uplifted marine terraces have been identified on the island (this work and others) and based on inferred ages from cover-bed stratigraphy; these indicate minimal uplift of the island. However, this uplift is not homogenous across the island, with rates being considerably higher in the south-west and some northern parts of the island than in the central and eastern parts (see Chapters 7 and 8).

1.2.4 Vegetation

A more detailed description of the present vegetation cover of Chatham Island and that which existed in pre-historic times can be found in Chapter 4 (Palynology). In short, the vegetation patterns of Chatham Island can be divided into three or four broad types:

1. Low shrubland-heath or fernland vegetation dominates poorly drained areas, which are typically underlain by peat. Large tracts of this vegetation type are found in the northern part of the island, and also on the open ‘clear’ areas of the southern uplands.
2. Pasture occurs on the better drained peat-free areas, in particular covering the central portion of the island, and the hills behind Waitangi, Te Matarae and Owenga.
3. Forest dominated by *Dracophyllum arboreum* is present over substantial areas of the southern uplands, and scattered remnants of broad-leaved bush occur in restricted areas in the northern and central portions (e.g. the Henga Scenic Reserve and the J.M. Barker Reserve at Hapupu).

1.2.5 Climate

The climate of Chatham Island is influenced by two main factors, (1) the surrounding ocean, and (2) a predominantly westerly weather pattern. The island’s position on the Chatham Rise means that it lies within a zone of strong convergence where two major ocean current systems meet - a warm current flowing southward from the tropics (the

East Cape Current) meets cold northward-flowing sub-Antarctic waters (the Southland Current) along the Chatham Rise. This, combined with the near continuous passage of atmospheric troughs and highs over the Chatham Islands results in a relatively temperate, but also highly changeable climate in the Islands.

Wind is a major factor of the island's climate, with calm/wind-free days rare. The dominant winds are, like New Zealand, from the westerly quarter. The influence of wind on the island is most obviously demonstrated by the state of coastal vegetation, with trees often knarled and twisted to the leeward side.

Weather records from the island show it experiences on average 225 'rainy days' (days where the rainfall exceeds 0.1 mm) per year (Thomson 1983). But this is deceiving because the average annual rainfall for the island is moderate, around 900 – 1500 mm per year, with much of this falling as frequent, transient light showers or drizzle. Soil moisture deficits are often recorded in the months of November and December, while excesses occur during the winter months, usually during May.

Temperatures are relatively mild all year round (mean annual temperature of 10.8º C) with little daily or seasonal variability, mostly due to the moderating effect of the surrounding ocean. Average summer temperatures are 17 - 18º C, and average winter temperatures 5 – 6º C. Frosts are extremely rare (maximum of 1 per year) as is snowfall.

The island skies are seldom cloud free, with an average of 200 overcast days every year. Consequently they receive limited sunshine – 1350 - 1550hrs or 30 - 40% of possible sunshine. Degree of cloud cover varies over the island, with the southern uplands being under cloud cover more often than the lowlands, as would be expected due to their higher altitude. The marine climate results in relatively high and consistent levels of humidity (Thomson 1983).

CHAPTER 2
REVIEW OF PRIOR RESEARCH INTO THE QUATERNARY GEOLOGY OF CHATHAM ISLAND

This review of the existing literature pertinent to this thesis is restricted to those works relating to aspects of the Quaternary geology of Chatham Island. Those more concerned with palynology and other botanical aspects are covered in the chapter on palynology (Chapter 4). Works covering the physical aspects, formation, age etc. of peat deposits are included in the geology portion, while works on pollen extracted from the peat are discussed within the palynology section. A summary list of all the previously described (formal and informal) Quaternary units on Chatham Island is presented in Table 2.1.

Many early and well renowned geologists visited Chatham Island in geological and botanical capacities, including Ernst Dieffenbach, Leonard Cockyane, Charles Fleming and Harold Wellman (although Wellman never actually published any of his observations on the Islands). Most of the earliest expeditions to the island (1840-1920) focussed efforts on the older rocks and fossils, as was the style of the time, e.g. Dieffenbach (1841), Haast (1868), Travers (1868), Hector (1869, 1895), Hutton (1873) and Dieseldorff (1901). Of these only four touch on any aspect of the island's Quaternary geology. Dieffenbach (1841) commented on features of Chatham Island peat, specifically that he believed he had observed the transition from peat to coal. Much of the older, well humified peat of the island often has a very lustrous appearance and conchoidal fracture, giving it the appearance of coal (MacPherson & Hughson 1943). Travers (1868) made observations on the nature of the Chatham Island landscape and noted the thickness of the peat 'soil' which was "…often 50 feet deep". He also observed that "In several parts of the island this peat has been on fire for years, burning at a considerable depth below the surface, which, when sufficiently undermined, caves in and is consumed". These peat fires were a phenomenon also observed by other visitors to the island, including Dieffenbach (1841), Cockyane (1901), and Macpherson & Hughson (1943). Dieffenbach (1841) included on his map the location of a peat burn he observed while on the island. Hector (1869) reported on specimens of flint fragments sent to him as part of a suite of rocks and fossils by H.H.

Table 2.1 Summary table of previous publications describing or discussing Quaternary strata on Chatham Island and the formal and informal units presented in these publications.

Marwick (1928)
Titirangi Series

MacPherson & Hughson (1943)
Lowmoor Peat
Moorland Peat

Dell (1960)
Owenga Shelly Sand

Hay *et al.* (1970)
Titirangi Sand
Wharekauri Sand
Moorland Peat
Rekohu Ash Shower Member
Cape Pattisson Formation
Okawa Point Formation
Owenga Formation
Waihi Peat
Younger Peats

Richards (1987)
Lowmoor peat
Sedge peat
Highmoor peat
Southern highlands red peat
Sandy peat

Campbell *et al.* (1993)
Moorland Peat
Wharekauri Sand
Hawaiki Formation
Unnamed partially marine unit
Titirangi Sand

McFadgen (1994) (*sand incursions*)
Te Onean
Okawan
Kekerionian
Waitangian

Travers and C. Traill. These flints are now known to form a sediment component of Castlecliffian to Recent deposits on the island (Campbell *et al.* 1993). In 1888 Hector produced a hand painted geological map of the Chathams which he submitted to the Department of Mines. It is essentially unpublished. He portrayed nine units on his map, the youngest of which is 'Sand Hills' which are of late Quaternary – Holocene age.

During 1924/25, the Otago Institute sent expeditions to the Chathams. Like the earlier expeditions, the focus was on the older geology and fossils. Publications produced included a preliminary account of the geology - Allan (1925), and a detailed account of the physiography and geological structure - Allan (1928), as well as numerous paleontological papers e.g. Marwick (1928), Brighton (1929, 1930), Fleming (1945) and Finlay (1929). Allan also produced a manuscript describing the geology in detail, but this was never published (Campbell *et al*. 1993). Marwick (1928) was the first to describe and collect from the Plio-Pleistocene Titirangi Sand, exposed at Titirangi Point.

In 1943 MacPherson & Hughson (1943) visited the Islands as part of a study into the economic potential of extracting montan wax from Chatham Island peat. A preliminary study associated with this work showed that among other things, the Chatham Island peats were of different ages and origins at different locations. MacPherson & Hughson (1943) discussed two different peat units present on Chatham Island. Lowmoor Peats - those bordering water, and filling hollows, and 'Moorland' or 'Upland' Peats. Most of their investigations focussed on the latter as they contained higher levels of montan wax. They described the (Moorland) peat as generally devoid of woody or fibrous structure, and appearing as a "well humified, cheesy mass". Based on this they suggested that it was derived mainly from mosses. They also noted the similarity in the sequence of peat present from site to site, in that… 'a section in Kaingaroa in the north, differs only in minor details from a section at Owenga in the south.'

MacPherson & Hughson (1943) also noted that the Moorland peats are older and that they probably accumulated under climatic conditions different to those of today. They also state that the peats were laid down on a flattish surface and that considerable planation of the land probably took place before the peat beds formed. MacPherson & Hughson (1943) also commented on the effect peat fires have had on the island's landscape/topography, in that fire often 'carves' terrace-like scarps and cliffs. They suggested that many of the island's lakes are formed in 'burnt out depressions from which the peat ashes were blown by the wind', a suggestion which probably holds true for lakes located on the southern uplands. During an attempt to extract cores from Lake Tuku-a-Taupo in 2005 it was discovered that there is less than 0.5 m of very unconsolidated deposits on the lake floor before pre-Quaternary bed rock is reached. MacPherson and Hughson (1943) also mentioned that at the time the authors were on the island, peat fires were still smouldering at some locations. They recognised the Rekohu ash shower (aka Kawakawa Tephra), describing it as 'the corky layer', occurring near the top of the peat section. A petrographic analysis by C.O. Hutton (in MacPherson & Hughson 1943) showed that this corky layer is largely made up of shards of rhyolitic glass, with minor amounts of quartz, feldspar, hypersthene, hornblende and rare zircon and rutile. They also noted the presence of several other pale coloured, mineral-rich horizons within the peat, but provided no further interpretation or analysis of these layers. They could not constrain an age for the Moorland Peat, but proposed that it must predate Moriori arrival (which occurred sometime during 400 – 1000 years ago, Sutton 1980, 1985, McFadgen 1994, McGlone *et al.* 1994, Matisoo-Smith *et al.* 1999) , based on the absence of any Moriori middens or artifacts within the peat. They also recognised that the Kawakawa Tephra could be used as a possible age marker.

In 1954, the Department of Scientific and Industrial Research (D.S.I.R.) sponsored an expedition to the Islands with the objective of exploring the area of the Chatham Rise and the Chatham Islands in an oceanographic context. This work involved performing numerous bottom soundings, dredging and bottom sampling to investigate the depth, geology and fauna of the sea floor around the islands. The expedition also collected specimens of molluscan faunas from the intertidal areas and beaches of Chatham and Pitt Islands. Several publications resulted from this expedition. Knox (1957) is the main bulletin describing the expedition, and includes two bathymetric charts: one of the Rise as a whole, and another of the Chatham Islands and surrounding waters. Dell (1960), also associated with the 1954 expedition, described and informally named the 'Owenga Shell Bed', exposed just north of Owenga at the southern end of Hanson

Bay, which he described as ‘ a large deposit of bleached mollusc shells’ and a favoured locality for collectors. Dell (1960) suggested that this bed is at least in part, Pleistocene in age, based on the fact that certain species previously collected from this location (and described as extant) have not been collected from anywhere else on the island.

In 1958/59 A.S.C. Wright visited the island to map the main soil types and to then compare the soils with those on the mainland in an effort to try and maximise the use of the island’s soil resources. Wright (1959) contains maps of the soil types (1:100,000) on Chatham Island, a land slope map, peat cover map, generalised geological map and a prehistoric vegetation pattern map for Chatham Island. In addition there is a discussion on the main soil types and their relationship to New Zealand mainland soils, the role of environmental factors in the soil pattern, and a history of land use on the island.

Wright (1959) made some interesting observations relating to Quaternary soil-forming deposits, including the presence of consolidated dune sands with shallow-water bedding features underlying peat at Kaingaroa and Owenga. These crop out again between Kaingaroa, Wharekauri and Te One, and form a ‘peneplain’ (*sic*) at ~55 metres above present sea level (a.s.l.), with another surface at ~20 m a.s.l. He also noted that beds of ‘pumiceous’ sands were common in the Awainunga (i.e. ‘Moorland’) Peat, and form ‘corky’ layers. He stated that although some of these layers may have been blown from the mainland (as suggested by MacPherson and Hughson, 1943), the older, deeper layers “may prove to be from a more local source” and went on to suggest that they were derived from activity in the Chathams - “the twin arcs of Petre and Hanson Bays suggest a line of collapsed craters”. From observations of eight Awainunga (Moorland) Peat profiles (2.4 – 6 metres in depth) he concluded that there is ‘no clear sequence from rush to forest peat, or regular cycles of peat development’ within the Moorland Peat. However Wright (1959) did make the point that salinity may be an important factor in explaining why Chatham has such great thicknesses of peat, because salt may retard decomposition of organic matter.

In 1957, the New Zealand Geological Survey sent an expedition to the Chathams to investigate the island's phosphate deposits. This trip lasted longer than planned due to bad weather, but resulted in the publication of the first detailed stratigraphic account of Chatham Island geology, 1:100,000 maps, and included the first coverage in any detail of Chatham Island's Quaternary deposits (Hay *et al.* 1970).

Hay *et al.* (1970) described and mapped nine Quaternary-aged units or formations. Two of these are early Pleistocene in age, whereas the others are all late Pleistocene or Holocene. Most are described as being related to transgression events, whereas the others are peat accumulations. Hay *et al.* (1970) also identified and mapped several raised beaches at 235 m, 76 m, 34 m, 14 m, 3 m and ~1 m a.s.l.

The oldest Quaternary formation recognised is the Titirangi Sand, which Hay *et al.* (1970) describe as a near-shore deposit which accumulated when sea level was 9 metres higher than present, during the upper Nukumaruan. The Titirangi Sand is unconformably overlain by the Wharekauri Sand, described as "..consolidated dune bedded quartz sand with at least 4 beds of peaty lignite.." as well as several fossil soil horizons, blanketing much of the older rocks that form the central and northern portions of the island. Hay *et al.* (1970) suggest that the time break between the Titirangi and Wharekauri Sands is not large, and that the Wharekauri Sand represents a transgressive deposit laid down in Lower Castlecliffian times.

The Owenga, Cape Pattisson, and Okawa Point Formations are all described as 'cover head' deposits of 14 m, 3 m and ~1 m raised beaches, respectively. The Owenga and Cape Pattisson Formations are both described as 'quartzose sand with rounded schist pebbles' at the type sections. The latter Formation also occurs as rounded basalt storm beach boulders and cobbles. The Okawa Point Formation is described as 'boulder cobble storm beach deposits' (*sic*), which are separated from the modern storm beach by a thin strip of swamp. The Owenga Formation was given a Last Interglacial age, based on the fact that it underlies Moorland Peat (in several locations). The Cape Pattisson Formation is given a Post-glacial age as it post-dates the Moorland Peat but Hay *et al.* (1970) give no supporting evidence for this statement). The Okawa Point Formation is correlated to the Holocene Climatic Optimum.

Hay *et al.* (1970) define three separate peat formations - Moorland Peat, Waihi Peat and Younger Peats. The Moorland Peat is described as blanketing all older formations. They suggest that the peat accumulated during a period of ameliorating climate during the Last Glaciation. The Waihi Peat is described as blanketing the Cape Pattisson Formation in the type area, occurring as bog or hollow fills in the surface of the Moorland Peat, and is indistinguishable from the Moorland Peat where the Kawakawa Tephra is absent. They inferred that the Waihi Peat accumulated towards the end of the Holocene Climatic Optimum. The Younger Peat is found accumulating in valley floors or raised bogs. The valley floor peat often contains abundant mineral matter. The Younger Peat is suggested to have accumulated after the ~1 m rise in sea level during the Holocene. No criteria for differentiation from the Waihi Peat are given.

Hay *et al.* (1970) formally named the Rekohu Ash Shower, which is now known to be the Kawakawa Tephra, as a member of the Moorland Peat Formation, and give a radiocarbon age determination of 39,600 ± 2,000 yrs B.P. (NZ-373). Further, they state that where present, the ash forms a marker in distinguishing Moorland Peat from younger peat deposits.

Hay *et al.* (1970) also gave a brief description of sand-dune deposits on the island. They discriminate between ‘Old’ and ‘Modern’ dune sands, with the Old ‘having developed since upper Flandrian/Holocene times, and the Modern dunes having developed since European times, the latter rapidly overwhelming the older dunes. Hay *et al.* (1970) mentioned abundant bird bones present in the sands.

Hay *et al*. (1970) also provide a discussion on the relationship between physiography and Quaternary history, making the following significant points:

- the current landscape of the island is the result of changing sea levels during the Pleistocene, rather than late Tertiary-early Pleistocene tectonism/diastrophism
- all emerged shore platforms appear to lack ‘full marine coverhead deposits’, possibly due to subaerial erosion during subsequent regressions

- there is good evidence for marine bench cutting episodes at the following elevations - 235, 76, 34, 14, 3, and ~1 m a.s.l.
- the Moorland Peat blankets all surfaces older and higher than the postglacial 3 metre bench
- a suggestion that the presence of fossil islands, stacks and reefs formed around various volcanic necks during high sea level stands

Through the 1970s, Chatham Island peat became the subject of many industrial-based investigations, most focussing on the economic potential of the wax contained within it. Examples of resulting publications include Culliford *et al.* (1972), Hemmingson (1972, 1974), Tate (1972), Palmer (1974, 1975), Passel and Mason (1974), Riske (1974), and Briggs (1979).

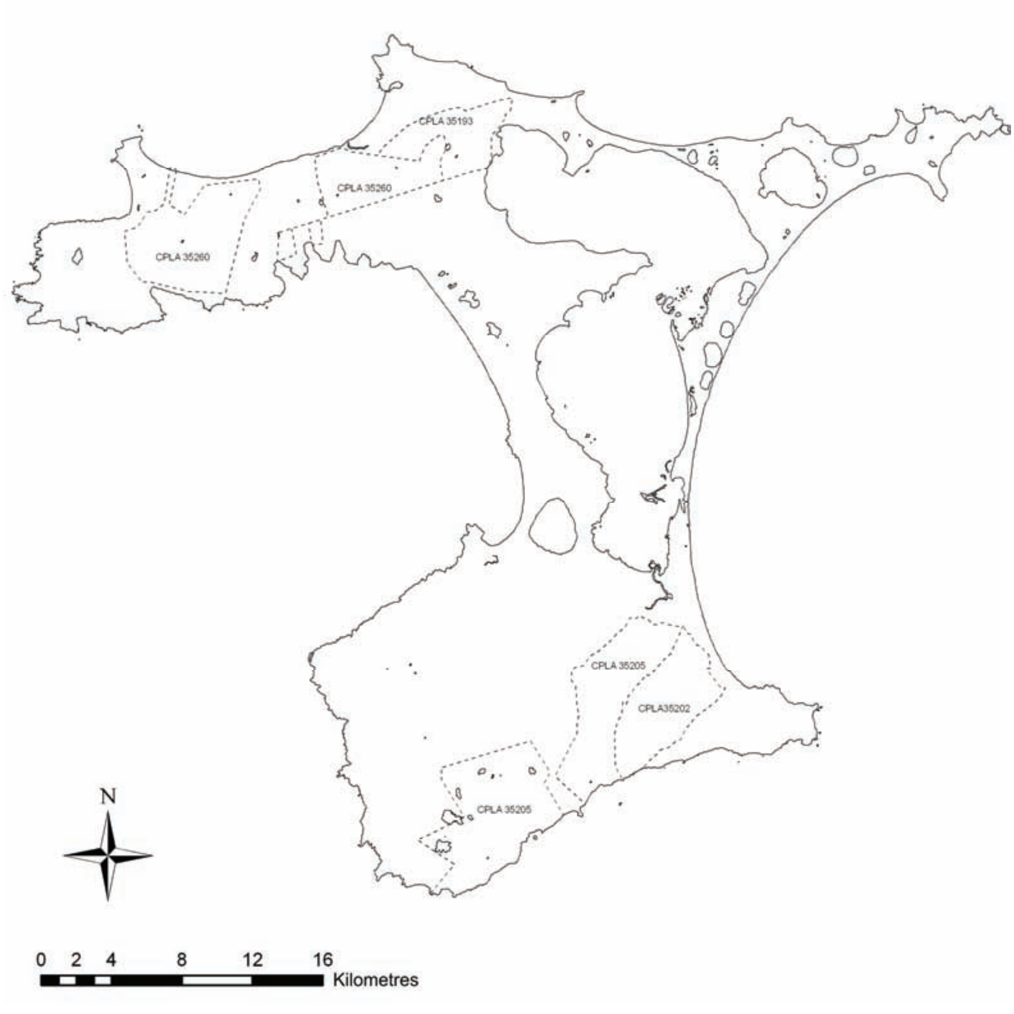
During the early 1970s the D.S.I.R. sent two research expeditions to Chatham Island. The results of both these expeditions have remained largely unpublished. The first took place during April of 1972, with the aim of trialling resistivity, penetrometer probes and other equipment for mapping the peat deposits, to briefly examine peat stratigraphy, and to collect samples for extraction of peat waxes, and for radiocarbon dating. Peat sections at several sites including Te Pukaha, north-west of Owenga, and the Nairn River valley were logged and sampled, and cores were extracted at sites in the Kaingaroa area. Resistivity and penetrometer data were collected from Kaingaroa, Te Pukaha, Kairakau, and near Lake Rotoparoa.

Milne (1972) commented on the clear stratification of the peat sections they (the members of the D.S.I.R. expedition) had observed, in particular woody versus non-woody horizons, and the presence of the Kawakawa Tephra as well as other thin (1 mm – 5 mm) mineralized horizons. He suggested that 'woody' peat layers within the peat profiles they had examined were derived from swamp environments, whereas the non-woody layers were derived from vegetation dominated by sedges, which had a considerably higher wax content (Milne 1972).

The second D.S.I.R. expedition to the Islands took place in Febuary of 1973 during a New Zealand Soil Bureau drilling programme. Of the 23 drill holes taken during this expedition, only two have subsequently been included in any publications (Mildenhall 1994a).

In 1985, Enmin Developments Ltd. (a subsidiary of Fletcher Challenge Ltd.) embarked on a prospecting operation to determine the potential of converting Chatham Island peat into liquid fuel. This expedition involved shallow drilling of a multitude of holes on a 1 km grid basis within four different crown licensed areas on the island (Figure 2.1). The results of this expedition are documented by Richards (1987). This report reviewed earlier divisions of Chatham Island peat stratigraphy and types including MacPherson & Hughson (1943), Wright (1959) and Hay *et al.* (1970), and discriminated five peat types based on the drill hole stratigraphy.

Figure 2.1: Location of the Fletcher Challenge Coal Prospecting Licence Areas (CPLA) on Chatham Island (after Richards 1987).



1. Highmoor peat which is equivalent to the Moorland peat of MacPherson & Hughson (1943) and Hay *et al.* (1970). Richards (1987) discriminates between Highmoor peat in the north of the island from that in the south. That in the south is harder, drier and more crumbly than that in the north. Unlike Hay *et al.* (1970) he makes no distinction between peat above and below the Kawakawa Tephra (unless there was a change in visual/textural characteristics).
2. Sedge peat (bog fill type) is a name applied to all peats containing *Carex*, with mosses (especially *Sphagnum*) as an important constituent. This type is described as extending over large parts of the island, but with variable thickness. It is always the highest and youngest member, covered only by the current root mat, and is still accumulating in some areas. The degree of fibre decomposition is variable.

3. Lowmoor peat - forms in a similar environment to the sedge peat, but lacks high levels of sedge fibres and has a darker colour. It is considered by the author to be a transition zone between the younger accumulating sedge peat and the older, underlying and compacting highmoor peat. Its distribution is limited to the northern part of the island.

4.Sandy peat – occupies three main positions in the peat sequence

- Throughout any of the other peat types there may be variable amounts of disseminated wind blown sand,
- There may be interfingering of dune sands and peat deposits with alternating layers of well rounded sands and peats,
- A sandy peat commonly occurs towards the bottom of the peat sequence and is ‘an excellent indicator of basement proximity’.

5. Southern highlands red peat – as its name suggests it is exclusively present in the southern highlands of Chatham Island. It is described as having a very distinctive red colour and often contains a large proportion of soft wood. The red colour is suggested to have resulted from staining from *Dracophyllum* vegetation. However other factors must be involved as red peat is absent from the northern and central portions of the island, and according to Wright (1959) these areas did have *Dracophyllum* vegetation cover prior to human arrival. It is possible that red peat was once present but has since been removed by fire.

> It is extensive on the southern plateau, underlying the young sedge peat, and overlying the older high moorland peat. Richards (1987) suggests that it is possibly younger than the northern lowmoor peat.

Richards (1987) comments on the presence of the Kawakawa Tephra, and also mentions the presence of two or three older ash horizons in the peat sequence that he had observed. Unfortunately the positions of these ash horizons were not included in his published drill hole stratigraphy.

Campbell *et al.* (1988) began an ongoing thorough investigation into the Cretaceous-Cenozoic Geology of the Chatham Islands. This work grouped all the previously recognised Quaternary lithostratigraphic units into a formal group, the Karewa Group after Karewa Point, located in the central part of the island. They commented that, apart from the Titirangi Sand, all Karewa Group units appear to be non-marine and of Late Pleistocene age. They also provide a slight redefinition of the Titirangi Sand. This work (Campbell *et al.* 1988) eventually led to the publication of Campbell *et al.* (1993) – a comprehensive description of and discussion on the Cretaceous and Cenozoic geology and biostratigraphy of Chatham Island. Although the focus of this work is on pre-Quaternary strata, it revised the Quaternary units and formations introduced by Hay *et al.* (1970). None of the Karewa Group sediments (apart from the marine Titirangi Sand and Owenga Shelly Sand) were specifically studied during the course of their work on the island.

For the first time Campbell *et al.* (1993) attempted a correlation of exposed Pleistocene (and older) lithostratigraphic units with the seismic units recognised by Wood *et al.* (1989). The Plio-Pleistocene Karewa Group sediments are correlated to part of Unit IV of Wood *et al.* (1989) and to the Kaikoura Synthem of Carter (1988) for the eastern South Island of the New Zealand mainland. Campbell *et al.* (1993) recognised a new informal unit “unnamed partially marine unit” which occurs in a small bay in the Petre Bay coastline, just north of Red Bluff. They provide a very broad age range of Nukumaruan-Castlecliffian-Haweran for this unit. The Pleistocene-aged Owenga Formation of Hay *et al.* (1970) is renamed the ‘Hawaiki Formation’, to avoid confusion with the Holocene-aged Owenga Shell Bed of Dell (1960), which itself was emended to ‘Owenga Shelly Sand’. Campbell *et al.* (1993)

also provided a radiocarbon age determination (NZ5381B-new ½ life) from shells within the Owenga Shelly Sand, of 480 ± 40 ^{14}C yrs B.P. They suggest that this formation may be present along much of the southern Hanson Bay coastline.

Campbell *et al.* (1993) define the Moorland Peat as the 'formal name given to all peat and peaty sand deposits overlying Wharekauri Sand and older rocks on Chatham Island', and regard it as a correlative of the Awainunga Peat of Wright (1959), Cape Pattisson Formation, Waihi Peat, Owenga (now Hawaiki) Formation, Okawa Point Formation and Younger Peat Formation of Hay *et al.* (1970). They also suggest that the c. 10m thickness of Moorland Peat present on much of the southern uplands is primarily post-glacial in age.

Campbell *et al.* (1993) also comment, as many others have done before them, that the Kawakawa Tephra may not be the only mainland volcanic event present on the island. Like Hay *et al.* (1970) they also propose that the geomorphological development and modern physiography of the island is the result of eustatic sea level fluctuations. However, they do state that due to improved age control and understanding of Plio-Pleistocene sea level changes and calibration of the Plio-Pleistocene timescale, the age interpretations of the various surfaces identified by Hay *et al.* (1970) are now invalid.

McFadgen (1994) investigated Holocene sand-dune stratigraphy on Chatham Island at the following locations: Waitangi West beach, Maunganui beach, Wharekauri, Tuapeka, Okawa Point, Lake Taia and Te Awapatiki to Owenga. He proposed four depositional episodes based on the sand deposits and associated soils:

1. Te Onean c. 5,000 – 2,200 yr BP
2. Okawan c. 4,500 – 450 yr BP
3. Kekerionean c. 450 – 150 yr BP
4. Waitangian c. 150 – present

McFadgen (1994) suggested that the sand forming these dunes was derived principally from marine erosion of existing sand deposits, and noted that the composition of the sand is similar to that of the pre-Holocene Wharekauri Sand. He was also able to use sea rafted Taupo (1850 ^{14}C yr BP) and Loisels (590 ^{14}C yr BP) pumice preserved within the sand deposits to correlate and date the episodes, and to correlate them with chronostratigraphic units in coastal sand dunes on the NZ mainland. The Te Onean Episode correlates to the Foxton dune building phase of Cowie (1963), and the Okawan, Kekerionian and Waitangian episodes to the Tamatean, Ohuan and Hoatan Chronozones, respectively (McFadgen 1985, 1994). He concluded that these depositional episodes may be related to coastal erosion triggered by storms, and are probably unrelated to sea level change, tectonic activity or cultural influence.

CHAPTER 3

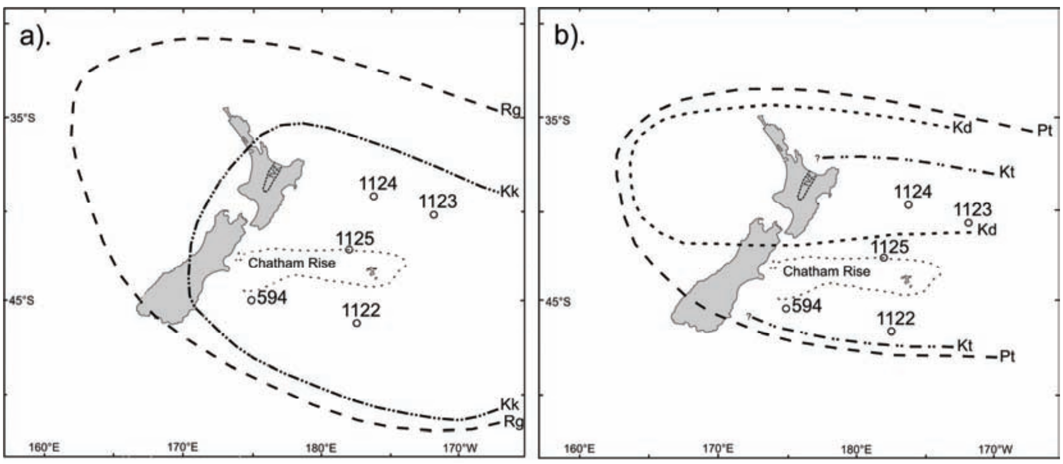
TEPHRA BEDS

3.1 Introduction

Rhyolitic tephra beds are now widely regarded as valuable chronostratigraphic markers within sedimentary sequences. In New Zealand we are 'fortunate' enough to have the Taupo Volcanic Zone (TVZ), which is without doubt the most active Quaternary rhyolitic system in the world (Alloway *et al.* 2005). It has produced numerous eruptions over its lifetime, with the total volume of magma discharged in excess of 10,000 km3 (Wilson *et al.* 1995). The resultant tephra beds are now used widely in New Zealand Quaternary stratigraphy, providing age control for geomorphological, palynological and stratigraphic studies.

Data from ODP leg 181 cores 1125, 1124, 1123 & 1122, extracted from the ocean to the east of New Zealand indicate that ash from some of the largest TVZ eruptions would have been dispersed over Chatham Island (Carter *et al.* 2004), which is located approximately 1000 km southeast of the TVZ (Figure 3.1). Currently two macroscopic TVZ-derived tephra beds have been recognised within Chatham Island Quaternary strata – the Kawakawa Tephra and the Rangitawa Tephra. These two tephras provide crucial age control for this current work in the total absence of any other forms of radiometric age determination.

Figure 3.1: Dispersal of major eruptive events from the Taupo Volcanic Zone (TVZ), after Carter *et al.* (2004) and locations of ODP and DSDP cores (open circles). Lines represent maximum known extent of volcanic ash from these eruptions **(a).** 27.1 kyr Kawakawa Tephra (Kk) and ~ 345 kyr Rangitawa Tephra (Rg). **(b).** 0.88 Ma Kaukatea Tephra (Kt), and the ~1Ma Kidnappers (Kd) and Potaka (Pt) Tephras.



3.2 Methods

The tephras in this study were identified by a combination of field characteristics and stratigraphic position in the field, and by mineralogical analysis (ferromagnesian mineralogy) and electron microprobe analysis (EMPA) of glass shards. Figure 3.2 shows a flow chart of sample treatment procedures involved in the preparation for glass shard and mineralogical analyses. As a result of transport over a considerable distance, both tephras are very fine grained and contain very low levels of crystal material (1-2 grams per kilogram) due to atmospheric sorting. So, large quantities of sample were processed to obtain enough crystal material to be representative.

Electron microprobe analyses were carried out on individual glass shards on an energy dispersive (EDS) Jeol JXA-840A electron microprobe at the University of Auckland's Geology Department. The analyses were collected using a Princeton GammaTech Prism 2000 Si (Li) EDS X-ray detector, a 20 µm defocused beam, accelerating voltage of 12.5 kV, beam current of 600 pA and 100 seconds live count time. At least 10 analyses were performed per sample with analyses recalculated to 100% on a water-free basis. Data from all analyses performed is contained within Appendix 1.

3.3 Kawakawa Tephra

The Kawakawa Tephra (Plates 4.1a & b) resulted from the large Oruanui eruption from the Lake Taupo region, 27,957 ± 957 cal. Yr BP (Lowe *et al.* 2008) years ago. The eruption released at least 530 cubic kilometres of magma as air fall tephra and ignimbrite deposits (Wilson *et al.* 1988). The air fall ash is regarded as being of co-ignimbrite origin, and is widely preserved all over New Zealand and also in ocean-floor sediments (Wilson *et al.* 1988, Carter *et al.* 2004). It is widely distributed over Chatham Island, occurring in nearly all pre-Holocene sequences, forming a very conspicuous pale layer within peat along many stretches of road cuttings. Consequently it has been remarked upon by many previous visitors to the island. It was first recognised as a tephra by MacPherson and Hughson (1943) and was later formally named as the Rekohu Ash Shower, a member of the Moorland Peat Formation by Hay *et al.* (1970). It is referred to in this work as the Kawakawa Tephra, after Froggatt & Lowe (1990). Appendix 2 provides a list of all sites where it has been

Figure 3.2: Sample treatment procedures for tephra samples

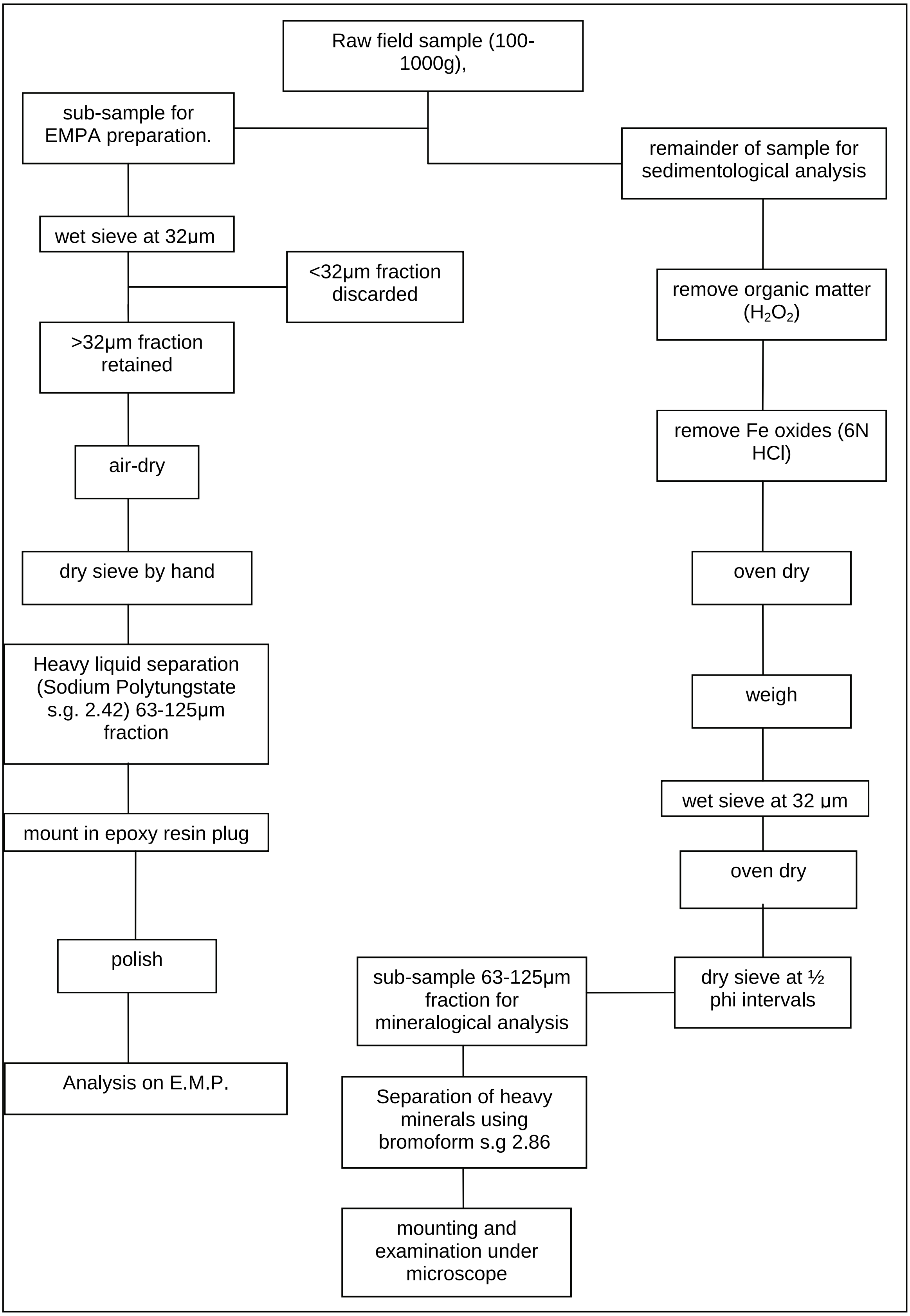
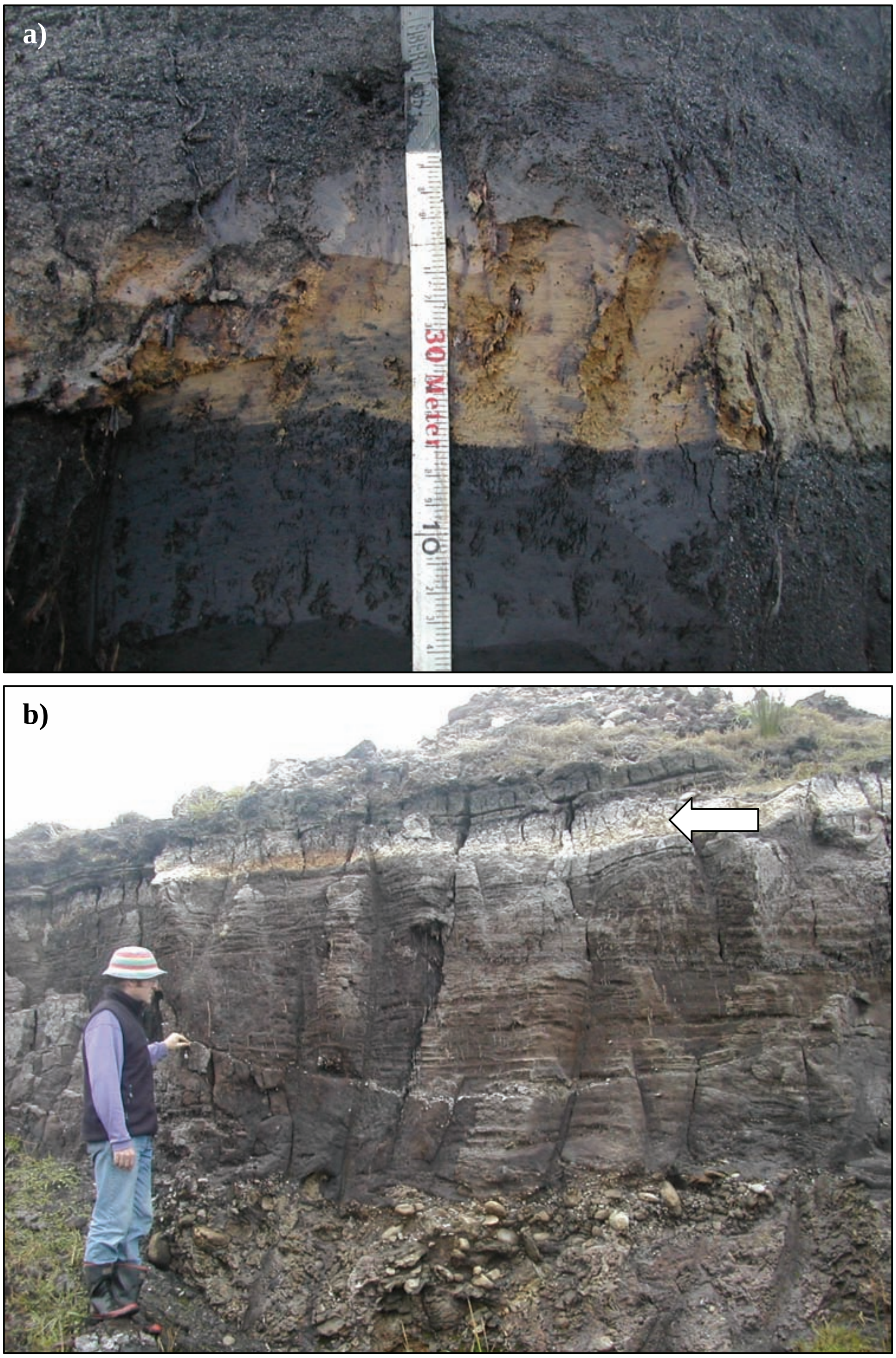


Plate 3.1: (a) the Kawakawa Tephra in peat at the Wharekauri-Kaingaroa turn-off quarry and (b) Stony Crossing (white arrow).



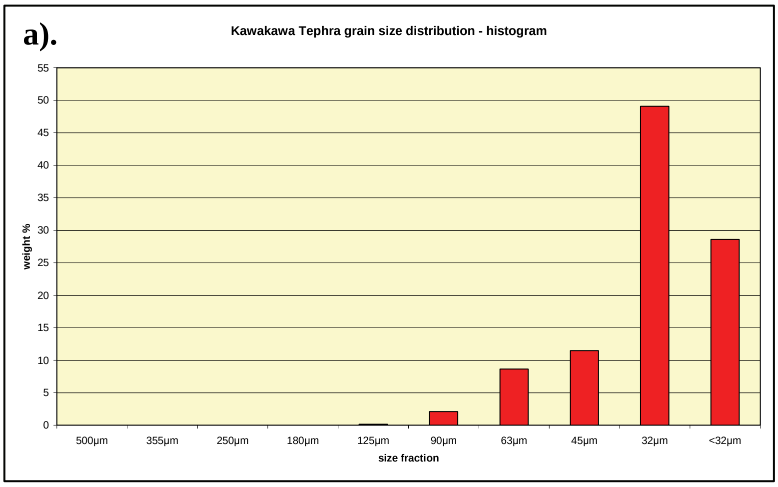
sampled and/or recorded in a stratigraphic sequence.

The tephra is preserved in a range of depositional settings. Most commonly it occurs within peat, particularly in low-lying regions (<60m a.s.l.). In contrast in regions of higher altitude and some coastal localities it occurs within aeolian sand or loessial material, often directly overlain by a peaty horizon or paleosol. There is also one recorded occurrence of it in lake sediments in a small lake just north of the village of Port Hutt (Holt 2003).

Detailed stratigraphic studies by Wilson (2001) demonstrated that the Kawakawa Tephra deposits of Chatham Island are composed of 3 separate fall units relating to individual eruptive phases of the Oruanui eruption (phases 5, 9 and 10. For the purposes of this work, the Kawakawa Tephra was treated as a single unit. The thickness of the Tephra bed varies with depositional setting. True air fall thickness is between 8-10 cm and it is best preserved where it fell in blanket peat and in lake deposits. Over-thickening to 10 - 18 cm has occurred where the Tephra fell in swamps and peat bogs where some degree of reworking by water movement may have occurred. Thinning occurred in loessial and aeolian sand environments as evidenced by pocketing of the deposit within the enclosing strata. Colour also varies with depositional setting. The Tephra is usually a pale yellow colour (Munsell colour 2.5YR 8/4 to 8/6) particularly where it occurs in loess or clay, but can be a very distinctive yellow-orange colour where it occurs in peat (Plate 3.1a), probably as a result of staining from tannins, (Munsell colour 10YR 6/8).

Texturally, it is very fine sand to coarse silt (Wentworth size class), with no grains (glass or crystalline) exceeding 250 μm in diameter (Figure 3.3). In terms of glass shard morphology, all appear to be ‘bubble wall’ shards (after Heiken 1972). No accretionary lapilli have been observed within Kawakawa deposits on Chatham Island. A mineralogical analysis of the Kawakawa Tephra on Chatham Island performed by C.O. Hutton found that the tephra was composed largely of shards of rhyolitic glass, with minor amounts of quartz, feldspars, hypersthene, hornblende, and rare zircon & rutile (MacPherson and Hughson 1943). Heavy mineral counts from selected Kawakawa samples collected during this study are presented in Figure 3.4.

Figure 3.3: Grain size analysis of Kawakawa Tephra from the Mairangi area (sample MR12), by weight percent displayed as a histogram (a) and cumulative percent (b). Raw data in Appendix 3A.



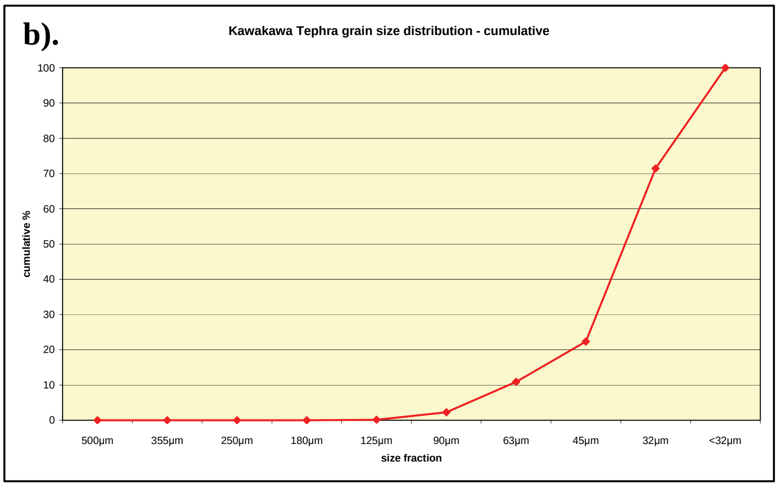
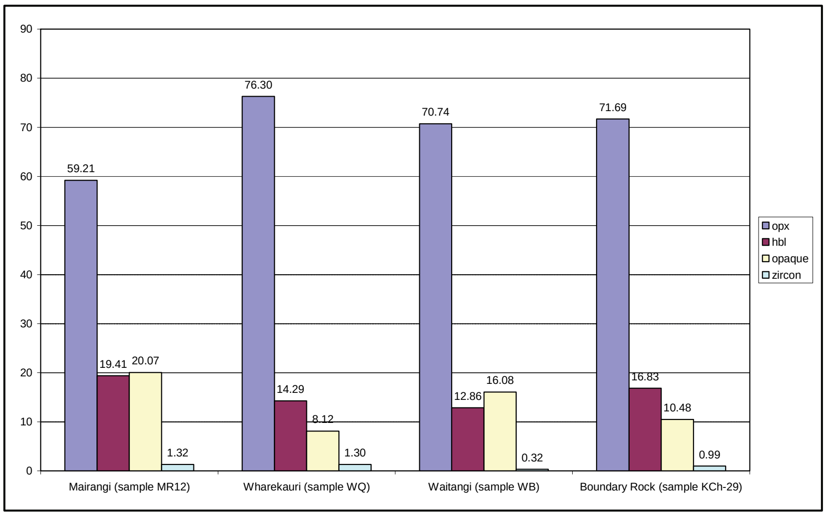


Figure 3.4: Heavy mineral counts (percentage of 63-125µm fraction) of selected Kawakawa Tephra samples (opx = hypersthene, hbl = hornblende, opaque = ilmenite, magnetite, Fe-TiO oxides etc. Raw data in Appendix 4A.

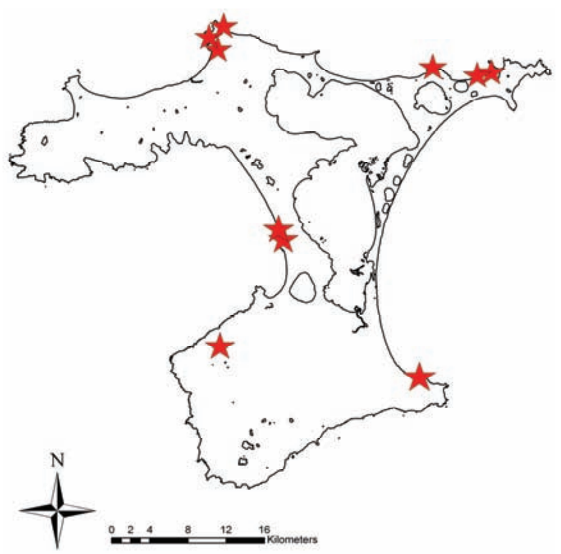


Summary electron microprobe results for selected Kawakawa Tephra samples from Chatham Island are presented in Figure 3.5, along with an example of analyses of Kawakawa Tephra from the type section (of Aokautere ash at Aokautere, Manawatu) on the New Zealand mainland. The Chatham samples fit well with analyses of the Tephra from the type section.

3.4 Rangitawa Tephra

The Rangitawa Tephra is associated with an exceptionally large eruption from the Whakamaru caldera, within the Taupo Volcanic Zone (Wilson *et al.* 1986), which occurred at around 345 ka (Pillans *et al.* 1996) towards the end of Oxygen Isotope Stage 10 (Kohn *et al.* 1992). This eruption was possibly the largest volcanic eruption of the Quaternary, involving at least 1000 km3 of magma erupted through a series of ignimbrite eruptions (Whakamaru Group ignimbrites) occurring over a considerable period of time (Wilson *et al.* 1986). The Tephra has been found as far away as 4000 km from source (Froggatt *et al.* 1986), and now forms a widespread mid-Pleistocene marker bed in New Zealand Quaternary sequences. It has not been previously recognised or formally identified on Chatham Island before.

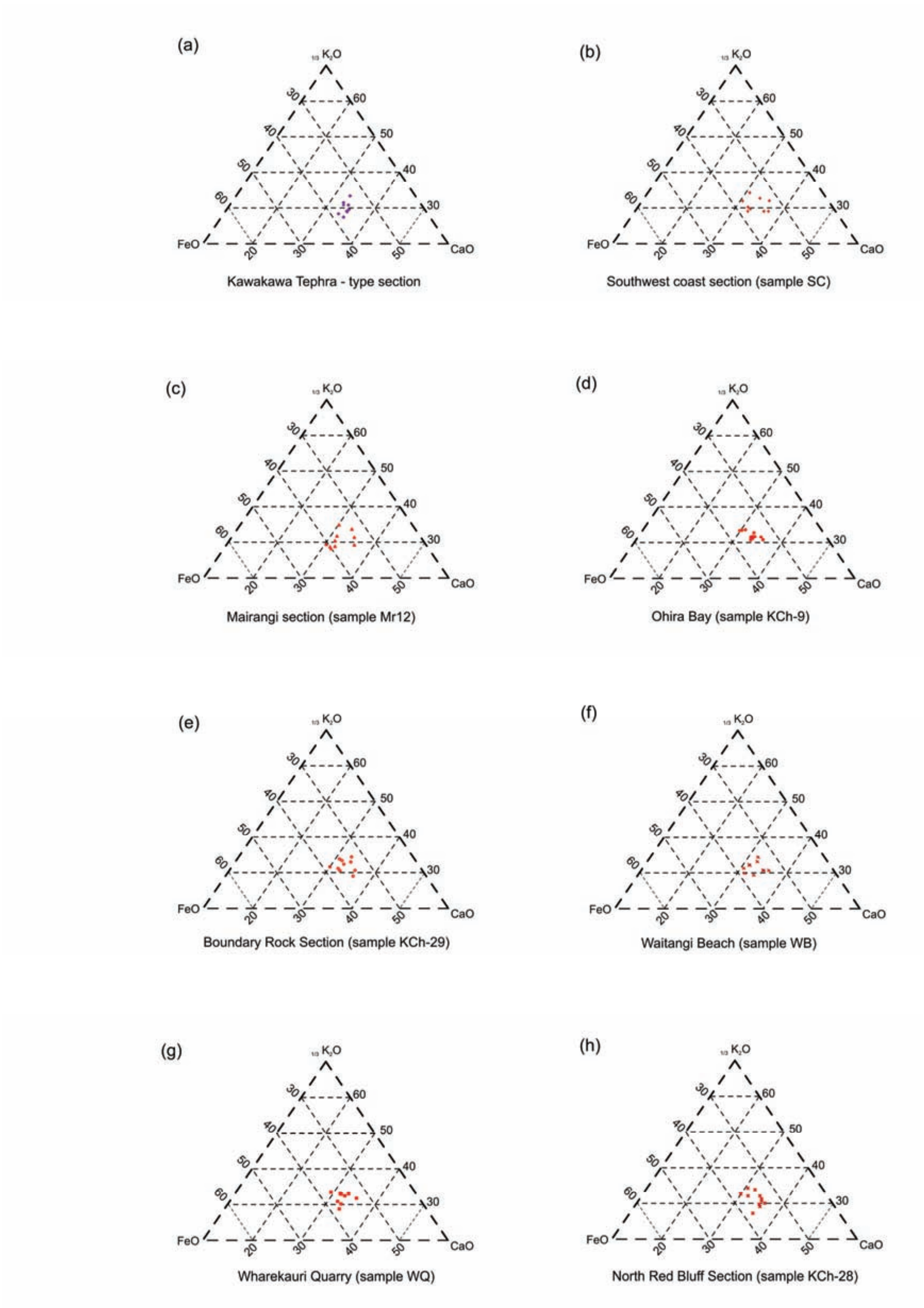
Figure 3.6: Locations of exposures containing the Rangitawa Tephra, shown in red stars.



The Rangitawa Tephra has been preserved as a macroscopic horizon within terrestrial deposits at several sites across Chatham Island (Figure 3.6 and Plate 3.2). Presumably it would have originally blanketed the entire island, but it has since been eroded from low lying regions.

Thickness is variable, being approximately 15 cm at Matarakau and Kaingaroa to almost 30 or 40 cm in the Red Bluff area. It is usually a pinkish colour (Munsell colour 5YR 7/4), and like the Kawakawa Tephra, is usually bracketed or overlain by a paleosol or peaty horizon. The Tephra is in varying stages of devitrification, with little to no glass devitrification changes along section. For example, at the North Red Bluff site (GR

Figure 3.5: $1/3K_2O$:FeO:CaO plots of Kawakawa Tephra from the type section (of the Aokautere Ash) at Aokautere (a) and Kawakawa correlatives from Chatham Island (b – h).



465620) where the Tephra is 15 cm thick it is completely devitrified, while at an exposure 1 km to the south (GR 466608) where thickness is greater than 30 cm it is still highly vitric. In the Mairangi area, at one site (GR 391826), the Tephra is quite fresh and is approximately 15 cm thick, while at a similar site approximately 1 km to the south (GR 392811), where it is almost completely devitrified, thickness is greater than 25 cm, suggesting a combination of environmental factors are involved in the degree of devitrification.

Plate 3.2: The Rangitawa Tephra exposed along the coast at Red Bluff.

Texturally the Tephra is very fine sand to coarse silt when fresh (Figure 3.7). Morphology of the glass shards are, like the Kawakawa Tephra, bubble wall type.

The initial identification of samples as the Rangitawa Tephra was accomplished by mineralogy. Most samples (vitric or not) contain varying levels of a hydrated mica mineral interpreted to be biotite or phlogopite, and bi-pyramidal quartz, as well as orthopyroxene, hornblende, opaque minerals (e.g. ilmenite, magnetite etc.) and zircon (Figure 3.8). However, this is not necessarily diagnostic, as other tephras from large eruptions could produce similar assemblages in a distal setting, for example the Potaka Tephra. EMPA aided in further confirmation of the samples as Rangitawa Tephra (Figures 3.9 and 3.10). Initially the EMPA results from Rangitawa Tephra samples were regarded with caution. The combination of the age of the Tephra, the

Figure 3.7: Grain size analysis of the Rangitawa Tephra from the Kaingaroa area (sample KRS) by weight percent, displayed as histogram (a) and cumulative percent (b). Raw data in Appendix 3.

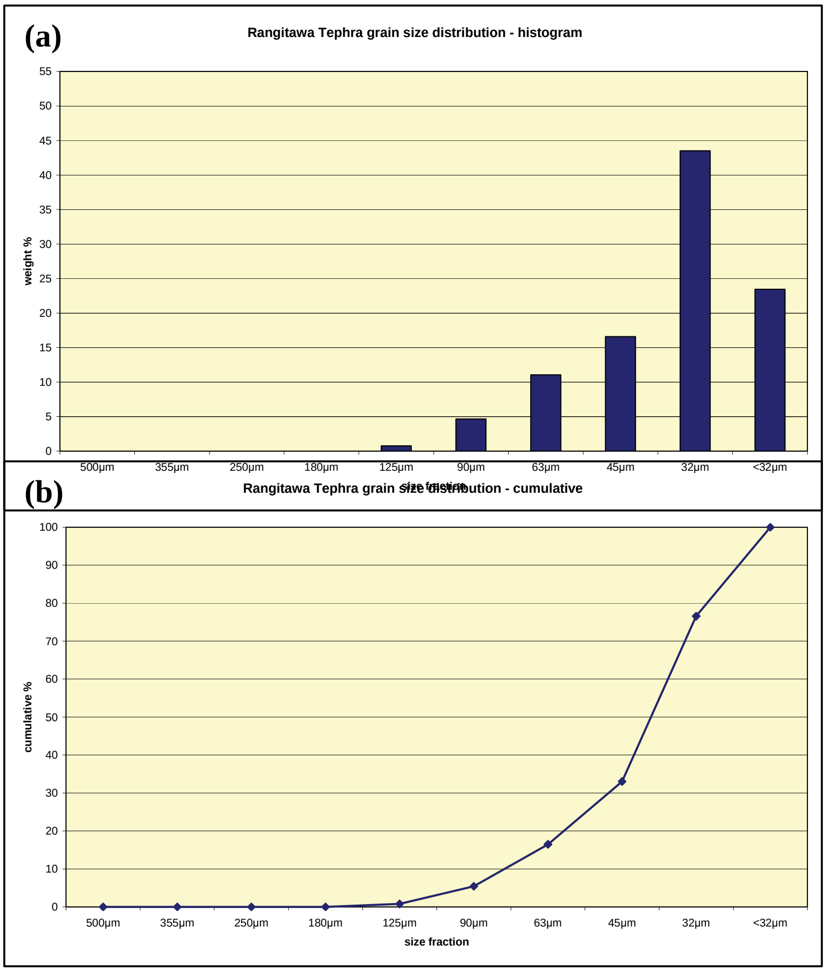
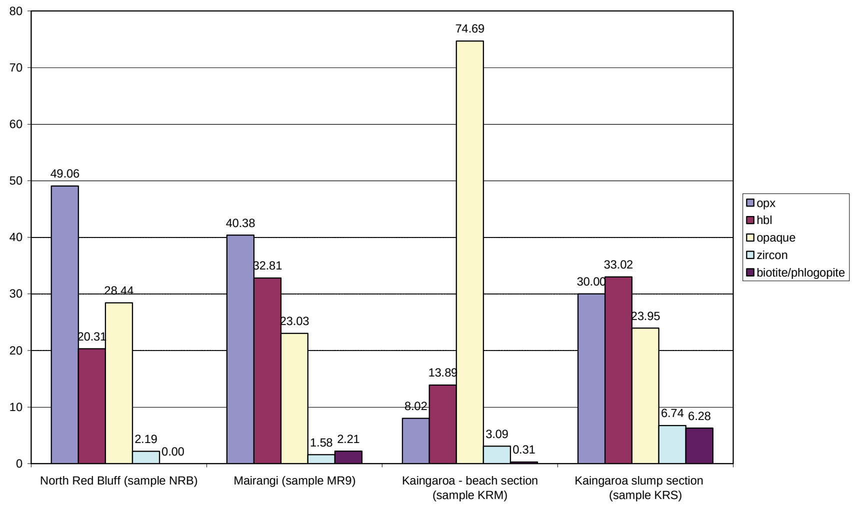


Figure 3.8: Heavy mineral counts (percentage of the 63 – 125 µm fraction) of selected Rangitawa Tephra samples (opx = hypersthene, hbl = hornblende, opaque = ilmenite, magnetite and Fe-TiO oxides etc). Raw data in Appendix 4B.



degrees of devitrification of samples and the very fine texture of the deposits would suggest that it is possible that the glass has undergone secondary hydration and possibly alkali exchange. However, sodium values from most samples are within a reasonable range (3.47 – 3.98 weight %, see Appendix 1A, section II), and results from most of the Rangitawa samples from Chatham Island are in good agreement with those published from other sites e.g. Froggatt *et al*. (1986). Also the analyses obtained on Rangitawa Tephra glass from the type section in the Rangitikei River Valley (Figure 3.10) are consistent with the Chatham Island data.

A reliable identification of the Rangitawa Tephra is crucial to understanding the chronology of Chatham Island Quaternary strata and underlying marine terraces, so a sample of zircons from the Rangitawa Tephra bed within the North Red Bluff Quaternary sequence was submitted for fission rack dating to the Fission Track Thermochronometry Laboratory at the University of Melbourne Earth Science Department. The analysis returned an age of 350 ± 50 ka for the sample (Appendix 5). This is in good agreement with the accepted age of 345 ± 12 ka (Pillans *et al*. 1996). The high uncertainty of ± 50 ka results from the youth of the sample (B. P. Kohn, pers. comm.). Uncertainties from other fission track dates on Rangitawa Tephra zircons range from ±30 to ±90 ka (Pillans *et al*. 1996).

3.5 Discussion

Dispersal of these tephras to Chatham Island is the result of exceptionally large eruptions from the TVZ and New Zealand's prevailing westerly wind system. The effect of the winds is particularly highlighted in the case of the Kawakawa Tephra. Its isopach pattern shows that greatest thicknesses occur to the southeast of source (Carter *et al*. 1995), while minimal thicknesses occur in other directions. It has been suggested that the westerly wind flow is enhanced during glacial periods (e.g. Stewart and Neall, 1984, Fenner *et al*. 1992) favouring distribution of the tephra in this direction, possibly farther than it would have been dispersed under westerlies of similar strength to that of today.

The importance of wind in tephra dispersal would explain the absence of the Rotoehu Ash on Chatham Island. The Rotoehu Tephra was also derived from a relatively large eruption from the T.V.Z., the Rotoiti eruption from the Haroharo Volcanic Centre

Figure 3.9: 1/3K_2O:FeO:CaO plots of Rangitawa Tephra from the type section in the Rangitikei River Valley (a) and Rangitawa correlatives from Chatham Island (b)-(g).

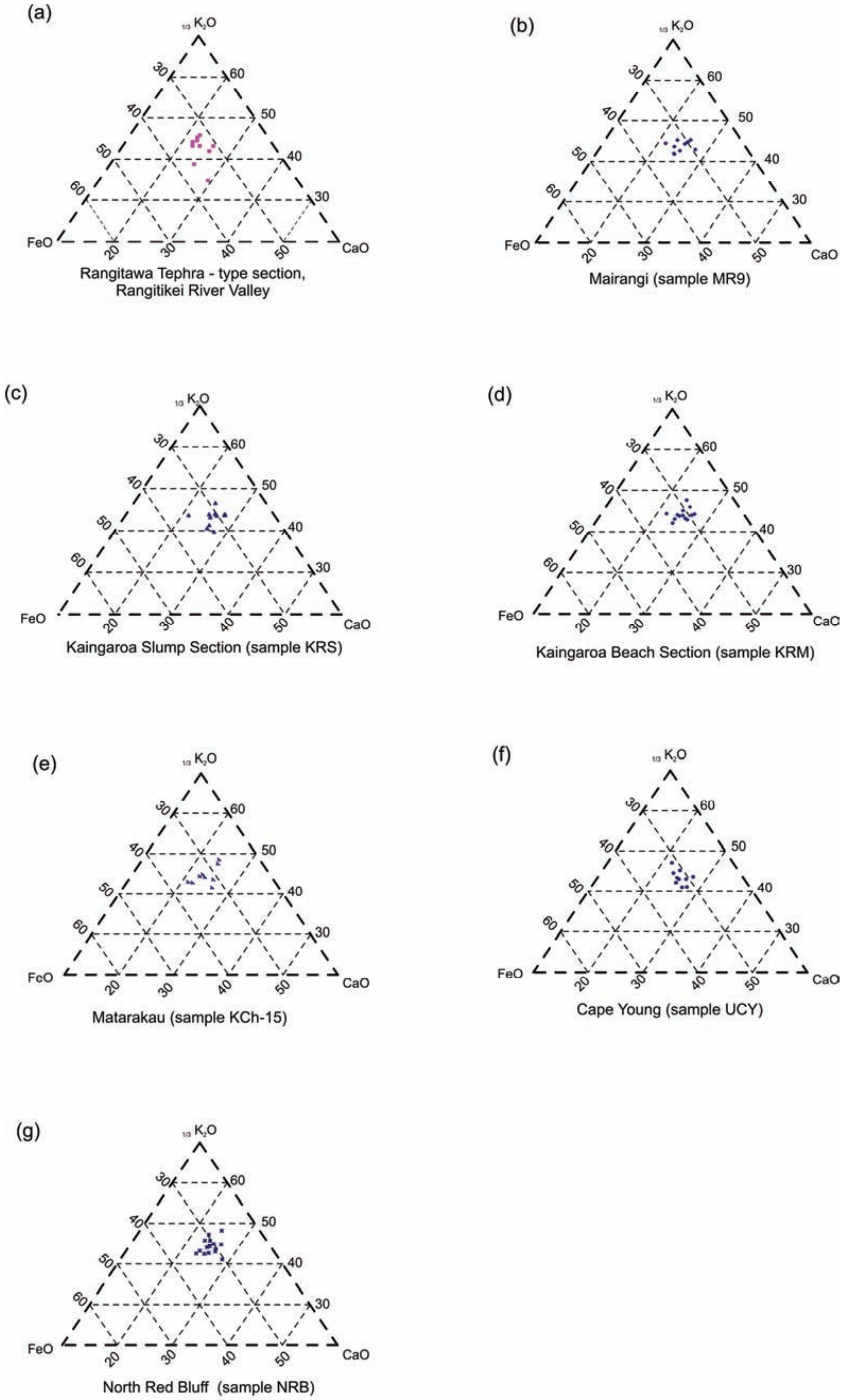
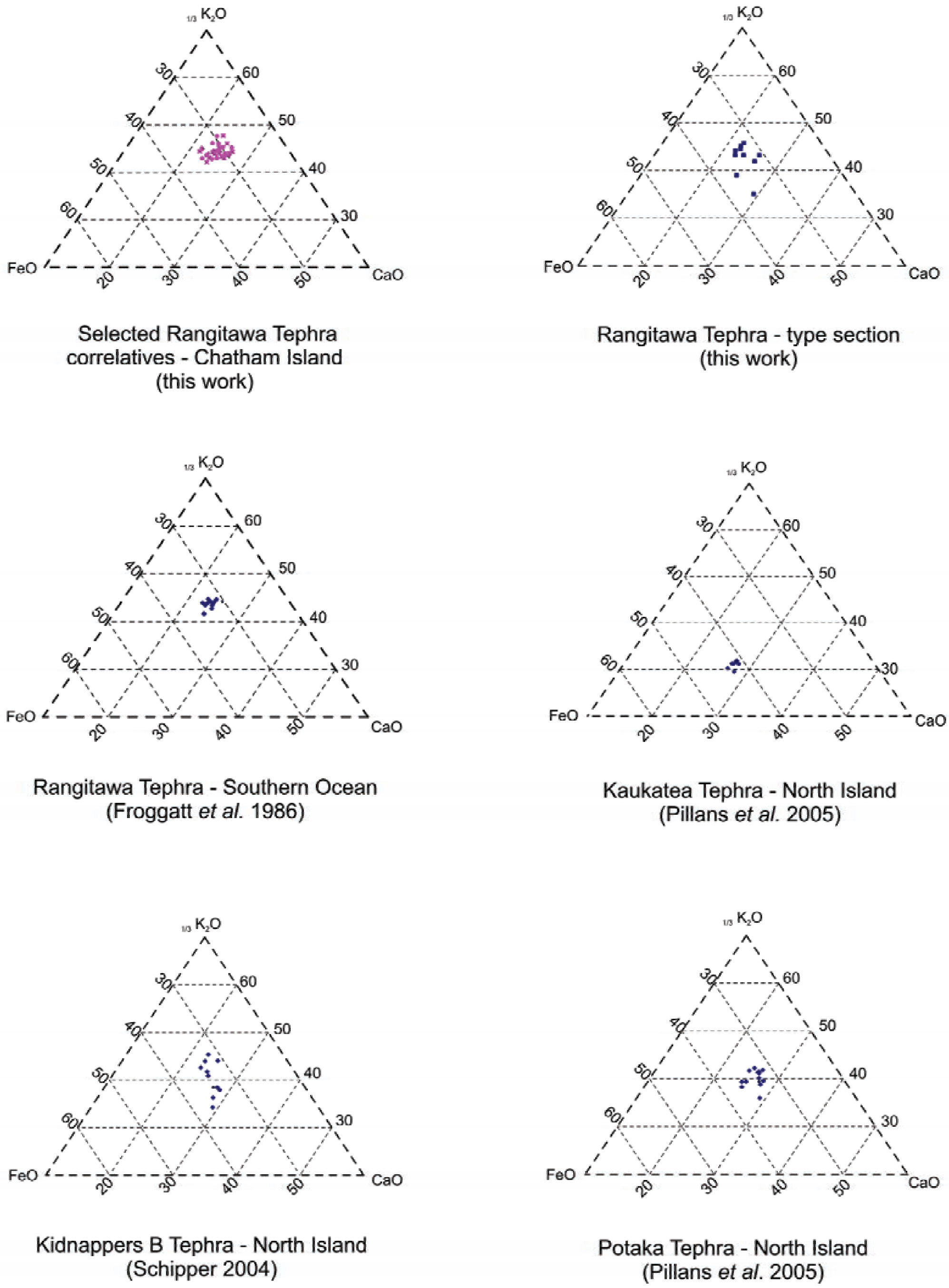


Figure 3.10: $1/3K_2O$:FeO:CaO plots of Rangitawa correlatives from Chatham Island, Rangitawa Tephra from the type section and from cores from the Southern Ocean, and plots of other widespread Pleistocene tephra marker horizons.



(Vucetich and Puller 1969). However, the Rotoehu Tephra is most commonly found to the north-east of source, and in marine cores from the Bay of Plenty region, while it is absent from all cores to the east of the North Island (ODP 1122-25), suggesting southerly winds were prevalent at the time of eruption, which were not conducive to dispersal of the tephra to Chatham Island. Currently no other rhyolitic tephras have been recorded on Chatham Island, presumably because their eruptions were not of a large enough magnitude, or in the case of the Rotoehu, the wind systems were not favourable. Few other tephra have been recorded in DSDP cores 1122 and 1125 (Carter *et al*. 2004, Alloway *et al*. 2005), the cores most proximal to Chatham Island (at 230 km and 150 km distance, respectively, Figure 3.1). It is possible that some have been preserved as crypto-tephras within peat. A preliminary attempt was made in this study to determine if this was the case. A core through the Moorland Peat from near Ohira Bay (GR 394719) was X-rayed in the hope that any micro-horizons of tephra would be visible. Unfortunately the section contained too much silty and sandy material, obscuring any crypto-tephras that may have been present. Subsequent processing of samples from this core showed no appreciable amounts of volcanic glass, except from within the region of the Kawakawa Tephra.

Carter *et al.* (2004) and Alloway *et al.* (2005) indicate that at least three other named Quaternary tephras would have been dispersed over Chatham Island – the Kaukatea (0.88 Ma), Kidnappers-B (c.1.0 Ma) and Potaka (c.1.0 Ma) Tephras. All occur in the four ODP Leg 181 cores proximal to Chatham Island but have not yet been recognised on the island. Glass shard compositions (as determined by EMPA) of Potaka, Kidnappers-B and Rangitawa Tephras are quite similar, however the compositions of the Potaka and Kidnappers-B Tephras are generally spread over a broader area of the plot than those of the Rangitawa Tephra (Figure 3.10). Deposits from the 0.5 Ma - ~2.4 Ma age range are either not present on Chatham Island, or are not currently exposed (refer to Chapter 5 - Stratigraphy). Those that may once have existed on Chatham Island have presumably been removed by erosion. Thus if the Kaukatea, Potaka and/or Kidnappers-B Tephras were deposited on the island they too have since been eroded away.

3.6 Analysis of tephra-like layers

Although the Kawakawa and Rangitawa Tephras are the only two primary tephra deposits known to occur on Chatham Island, several other pale coloured, silt-rich horizons occur within the Quaternary cover-deposits of Chatham Island. In the field these units strongly resemble tephras, leading many previous workers to attribute their origin to volcanic eruptions, without further examination of their mineralogy or physical characteristics (e.g. Richards 1987). These units are composed predominantly of quartzose silt- and clay-sized material, with low levels of sand-sized material. Mineralogy of the sand-sized fraction of these units is typically dominated by quartz, with some opaque minerals, i.e. ilmenite, magnetite and Fe-TiO oxides, and, in some cases, minor amounts (<5%) of rhyolitic glass (heavy-mineral counts of the sand-sized fraction of these layers can be found in Appendix 4B and C). In most cases the units are not primary tephra deposits. EMPA of the ilmenite fraction of some of these layers has been used to aid in differentiation of these pale layers from devitrified tephra beds. EMPA have been also performed on rhyolitic glass from some of these layers in an attempt to identify which tephra it was originally derived from, therefore providing a maximum age for the layers. Raw and normalised EMPA of rhyolitic glass from samples mentioned in this section can be found in Appendix 1A, section III, while the raw analyses of ilmenites can found in Appendix 1B. Grid references and depth position of the samples are included in these appendices. A description and EMPA of a horizon of sea-rafted pumice encountered along the southern Hanson Bay coastline are also included at the end of section.

3.6.1 Descriptions of tephra-like layers

KCh05-1

This sample is from a silt-rich pale layer which occurs below the Kawakawa Tephra, within Maipito Formation sediments exposed in a road cutting along the Waitangi-Owenga Road. Mineralogically it is dominated by quartz, with minor amounts of opaque minerals. It contains no glass.

KCh05-2

KCh-05 is from a distinctive silt-rich pale layer exposed within the type section of the Maipito Formation (see Plate 3.3a). Mineralogically it too is dominated by quartz, with minor amounts of opaque minerals and does not contain glass.

Plate 3.3: Examples of pale, tephra-like layers on Chatham Island. a) KCh05-2, b) KCh05-44, c) KCh-30 and d) MKTU and MKTL.

KCh05-7

This is from a pale pink silty layer within peat exposed within the Kaingaroa Beach section (Chapter 4, section 4.6.4 and Chapter 6, section 6.5). The mineralogy of the sand fraction is dominated by fresh-looking quartz (some bi-pyramidal), euhedral ilmenite and magnetite, and minor amounts of euhedral amphibole, hornblende and zircon (see Figure 3.8 and Appendix 4B for the heavy mineral count from this sample). This sample was found to contain very minor amounts of rhyolitic glass. This glass was analysed some time after the ilmenites, as the initial KCh05-7 sample was too small to yield enough glass to analyse, and it was re-sampled at a later date. The glass correlated with that of the Rangitawa Tephra (Figure 3.9d) and the deposit is now regarded as a primary airfall deposit of Rangitawa Tephra.

KCh05-44

Sample KCh05-44 is from a distinctive pale silty clay layer within Maipito Formation sediments, exposed in a road cutting along the Waitangi-Tuku Road (Plate 3.3b). The mineralogy of the sand fraction is dominated by fresh-looking quartz, euhedral ilmenite and magnetite, and minor amounts of euhedral amphibole, hornblende and zircon. In the field, this unit strongly resembled devitrified Rangitawa Tephra exposed at North Red Bluff (section 3.4).

KCh-30

This sample is again a distinctive pale, silt-rich horizon (Plate 3.3c). It occurs within the Boundary Rock cliff section, the full age range of which is unknown (section 4.6.6). Mineralogy of the sand fraction of this sample is dominated by quartz, with minor amounts of magnetite, ilmenite and rhyolitic glass.

KRS-UPL

This sample comprises a very thin, discontinuous silt-rich horizon within peat in the Kaingaroa Slump sequence (Chapter 4, section 4.6.3). The sand-sized fraction contains quartz and rhyolitic glass.

LCY –Lower Cape Young

This unit is from a pale layer opportunistically sampled from an exposure at Cape Young. It is from the lower of two pale layers initially thought to be tephras, the other being UCY (Upper Cape Young), which is now correlated with the Rangitawa Tephra (Figure 3.9). The sample is composed predominantly of silt and clay-sized material. The sand fraction is dominated by quartz, with a minor ferromagnesian component composed predominantly of opaque minerals, zircon and orthopyroxene. It contains no glass.

Matakatau – lower (MKTL)

This sample is the lower of two silt-rich pale layers exposed along the Waitangi-Tuku road, near Matakatau Stream (Plate 3.3d). Again, the mineralogy is dominated by quartz, with opaque minerals, zircon and very rare pyroxene.

Matakatau-upper (MKTU)

MKTU is the upper of two distinctive pale silt-rich horizons exposed in a road cutting along the Waitangi-Tuku Road (Plate 3.3.d), near Matakatau Stream. The mineralogy of the sand fraction is dominated by quartz, with opaque minerals, zircon and very rare pyroxene.

Owenga Wharf (OwWh)

This unit is a thick (c.1 m) unit of orange silty material within the cover-bed sequence of the 9 m marine surface, exposed in a cliff face adjacent to the Owenga Wharf. The mineralogy of the sand-sized fraction is again dominated by quartz, with opaque minerals, zircon and very rare pyroxene.

3.6.2 Ilmenite analysis

Electron microprobe analyses of ilmenites* extracted from some of these pale layers described above have been compared with analyses of ilmenites from the Rangitawa Tephra, (from both the type section and from Chatham Island and from detrital Chatham Island ilmenites, derived from the dominantly basaltic local volcanic rocks.

The following graph (Figure 3.11) plots the MnO vs. MgO contents of the ilmenites from the samples described above. There is a clear separation between ilmenites derived from the (rhyolitic) Rangitawa Tephra and ilmenites derived from the local (basaltic) Chatham Island volcanics. It is quite clear to see that the ilmenites from KCh05-7 and KCh05-44 have come from a rhyolitic source. The ilmenites from KCh05-1, KCh05-2, KCh-30, MKTLU, MKTL and LCY are more similar in composition to those derived from the local basaltic volcanics. This suggests that

* Note: All ilmenite analyses were carried on the same apparatus as described on page xx, however a 10µm focussed beam was used instead of a 20µm focussed beam.

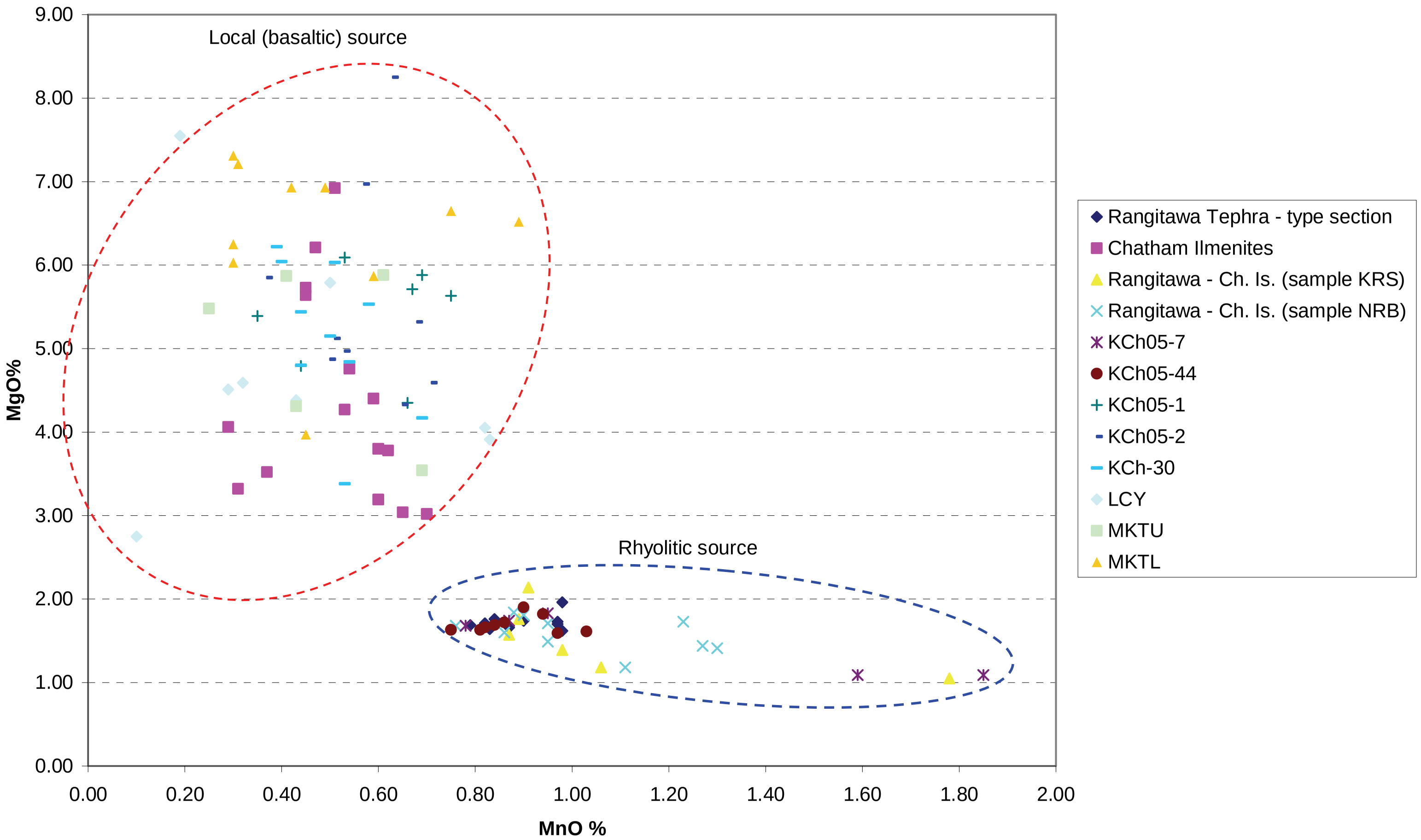


Figure 3.11: MnO vs. MgO composition of ilmenites from some of the tephra-like pale units on Chatham Island.

these units are not primary tephra deposits, but most likely aeolian (loessial) deposits formed from wind blown sediments which, in some cases, include reworked rhyolitic glass.

Further detailed study into the potential and significance of variations in ilmenite is desirable. Analysis of ilmenites from the Kawakawa Tephra and other TVZ eruptives should be performed to determine whether there are any significant variations in ilmenite composition between rhyolitic tephras. This was not done here due to the preliminary nature of the study. Also, the detrital ilmenites used here were extracted from one sample of beach sands from one location on Chatham Island, and cannot be considered representative of detrital ilmenites across Chatham Island. Analyses need to be collected from detrital ilmenites from beach sands and aeolian deposits from across Chatham Island, and also from ilmenites collected directly from the different volcanic formations on Chatham Island (and the surrounding islands). This would produce a representative data set of ‘local’ ilmenites. Such a dataset may also prove valuable to other sediment provenance studies on Chatham Island, for example variations in source areas/rocks of aeolian deposits over time.

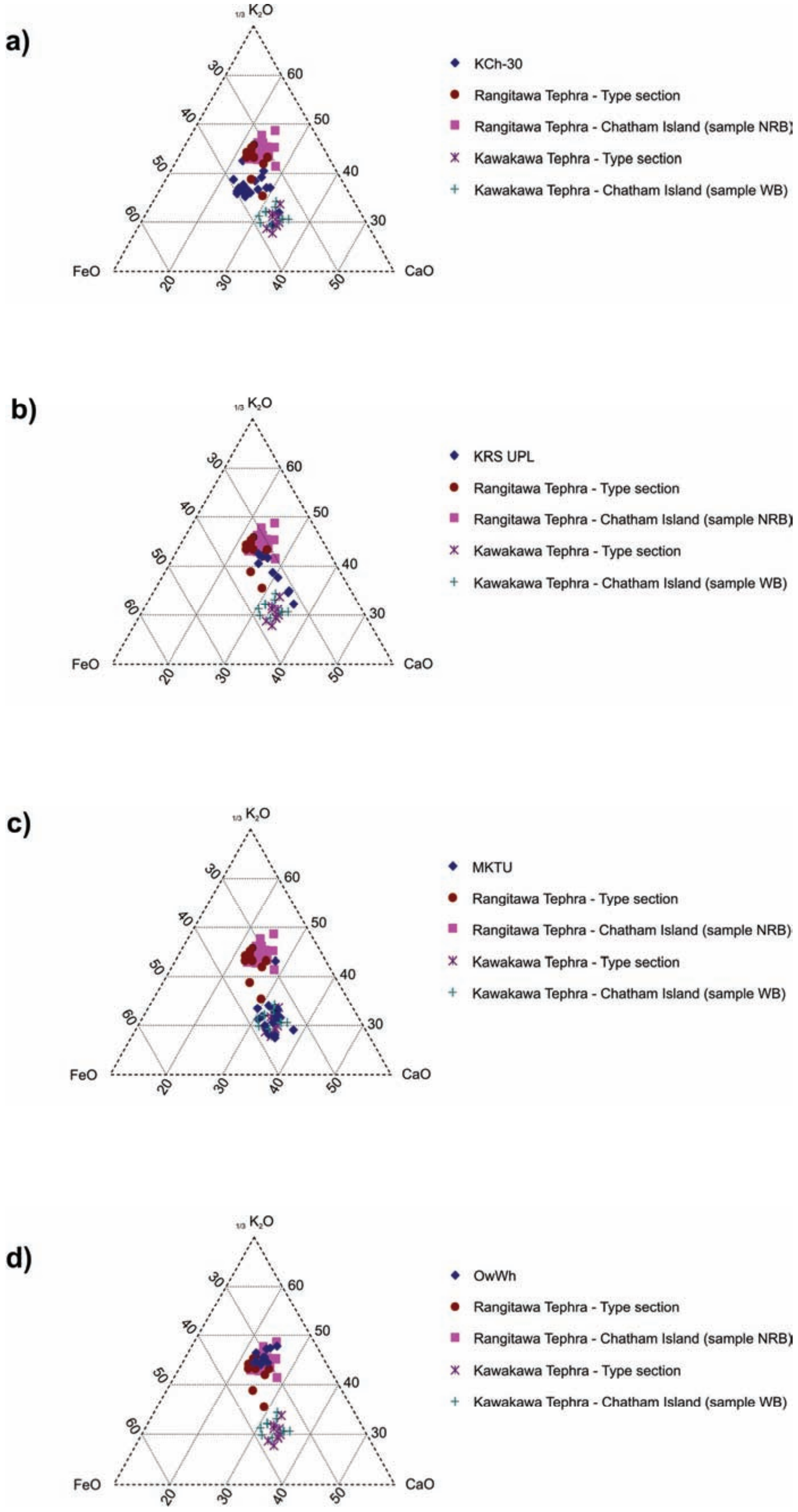
3.6.3 Volcanic glass analysis

The following graphs (Figure 3.12) plot the analyses obtained from glass shards from within some of the units described above. MKTU, shows a strong affinity to the Kawakawa Tephra, while OwWh matches well with the Rangitawa Tephra. The population of analyses obtained from KCh-30 do not match either the Kawakawa or Rangitawa Tephras (Figure 3.12), nor do they match with any other (known) TVZ rhyolitic tephra. Levels of CaO are similar to those of the Rangitawa Tephra, while levels of FeO are similar to those of the Kawakawa Tephra, and levels of K2O are intermediate between the two tephras. Analyses of the glass within KRS-UPL are spread across both the Rangitawa and Kawakawa Tephra compositional fields, suggesting it has been reworked out of both tephras, both of which occur in the vicinity of the site.

3.6.4 Sea rafted pumice

This sample (KCh05-16) comprises sea-rafted pumice clasts preserved within young (Holocene) dune sands along the southern Hanson Bay coast (Plate 3.4). The pumice

Figure 3.12: 1/3K_2O:FeO:CaO plot of analyses of glass shards from tephra-like pale layers compared with Rangitawa Tephra and Kawakawa Tephra, a) KCh-30, b) KRS-UPL, c) MKTU, d) OwWh.



horizon occurs at approximately 2 m above modern sea level. Two units of sea-rafted pumice are known to occur on Chatham Island – Loisels Pumice and Taupo Pumice (McFadgen 1994). The analyses of this sample suggest that it is the latter, Taupo Pumice (Figure 3.13).

Plate 3.4: Sea-rafted Taupo pumice (black arrow) within sand along the southern Hanson Bay coast.

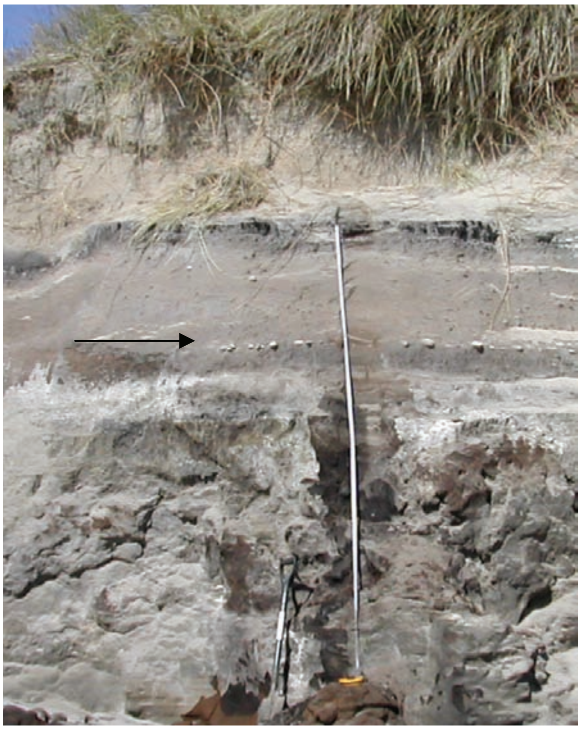
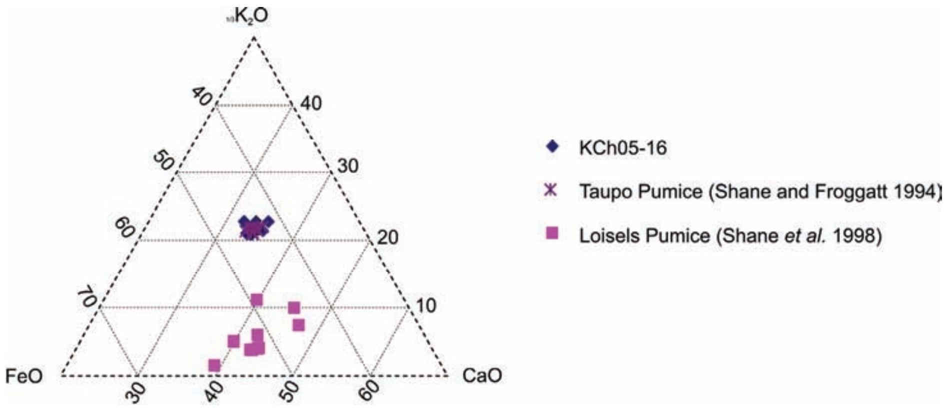


Figure 3.13: 1/3K_2O:FeO:CaO plot of analyses of KCh05-16 pumice compared with Taupo Pumice (Taupo Tephra) and Loisels Pumice.



CHAPTER 4
PALYNOLOGY

4.1 Introduction

Fossil pollen analyses and paleovegetation studies are a widely used and often powerful tool in Quaternary stratigraphic studies and paleoenvironmental reconstructions. However, relatively few palynological analyses, either modern or fossil, have been undertaken on Quaternary sediments from Chatham Island. This is surprising given both the spatial and temporal extent of peat deposits on the island, as peat is one of the most ideal media for preserving pollen. The palynology of the Moorland Peat has been studied to some extent by Mildenhall (1976 & 1994a), but these analyses were mostly restricted to Last Glacial and post-glacial-aged peat sequences at three locations on Chatham Island.

A significant feature of pollen rain on Chatham Island is that it contains pollen derived from mainland New Zealand, the bulk of which is from species that do not occur on the island. These are predominantly members of the genus *Nothofagus* and the family Podocarpaceae. It has been suggested that this exotic or long-distance fraction provides a direct means of correlation between mainland New Zealand and Chatham Island pollen records (McGlone 2002). The long-distance transport of pollen has been recorded both from Australia to New Zealand (Moar 1969a), and from Australia and New Zealand to other offshore Islands (Moar 1959, 1969b, Salas 1983, Pocknall 1982, McGlone and Moar 1997, McGlone *et al.* 1997).

The palynological analyses presented within this chapter have largely been undertaken to determine what climatic conditions existed at the time of peat accumulation, i.e. glacial vs. interglacial, and where relevant, to relate those conditions to the nature of the adjacent deposits.

4.2 Flora of Chatham Island

Chatham Island has a flora that is distinct from, yet closely related to, that of mainland New Zealand. One of the most remarkable features is the large endemic component. There are at least 40 species of plants endemic to the island group, which translates to 10% of the Islands' total flora, and includes 2 monotypic genera (Wardle 1991). Another significant feature is the absence of prominent mainland taxa, most notably large emergent forest trees. The Podocarpaceae and the southern beeches (*Nothofagus*), which are major taxa on the New Zealand mainland, do not occur on the island and have evidently been extinct in the region since the Tertiary (Mildenhall 1994a). The forest canopy is instead made up of smaller tree and shrub species, many of which are endemic e.g. *Dracophyllum arboreum*, *Melicytus chathamicus* and *Olearia traversii.* Other notable absences include *Leptospermum* (manuka), *Pittosporum* and tussock grasses. Why these taxa could not or did not colonise the Islands when others, such as *Melicytus*, *Phormium*, *Myrsine*, *Pseudopanax*, *Coprosma*, *Senecio* and *Olearia* etc could and did is somewhat of a mystery to botanists. It is not yet known when or how the island received its present complement of species, however it must have been relatively recently because the geological evidence implies that the Chathams have only existed as an emergent landmass during the last ~4 million years, or probably less (Campbell *et al*. 1993, 2006).

The original vegetation cover of Chatham Island has been extensively modified by human activities. The first human inhabitants of the Chatham Islands were the Moriori, a Polynesian people genetically indistinguishable but culturally distinct from the New Zealand Maori. Archaeological evidence has suggested that the Moriori arrived in the Chathams either relatively early, between 800 to 1000 A.D. (Sutton 1980, 1985) or somewhat later at around 1450 A.D. (McFadgen 1994, McGlone *et al.* 1994). Radiocarbon dating of kiore or Polynesian rat bones (*Rattus exulans*) implies that they may have arrived somewhat later, during the 14th Century (Matisoo-Smith 2002, Matisoo-Smith *et al.* 1999). The Moriori did not practise horticulture (Sutton 1982) as terrestrial plant foods were not a significant food source (Sutton 1980). Therefore it is unlikely that they performed significant forest clearance to make way for cultivation (as did the Maori on mainland New Zealand) and did not alter the natural vegetation to any significant degree.

Chatham Island was first sighted by Europeans during November of 1791. The first European sealers and whalers subsequently arrived during the early 1800's. Between initial arrival and 1840 the number of European settlers/whalers/sealers remained small (<100). They too apparently undertook little clearing of the land. However, it should be noted that during 1807 a crew member of the sealing vessel *Cornwallis* recorded that in many places on Chatham Island, large underground peat fires were burning (King, M. 2000). These fires may have been ignited by fires intended for clearance of forest. In 1835, two groups of Taranaki Maori totalling 900 arrived in the Chathams. King, M. (2000) provides a comprehensive account of what subsequently transpired between the indigenous Moriori inhabitants and the newly arrived Maori.

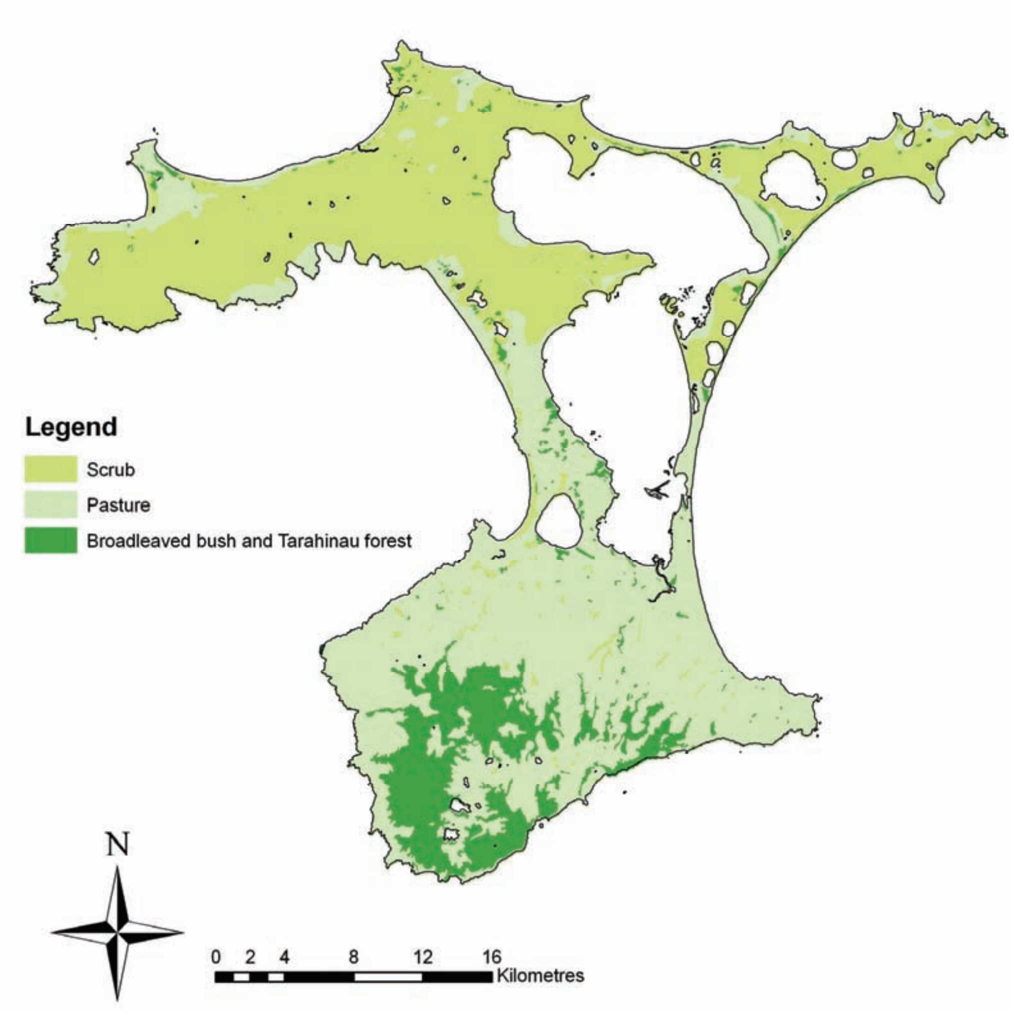
During the 1840's the first shore-whaling stations were established in the Chathams, and with them came more European settlers. Agriculture was initially established on Pitt Island in 1840, and began on Chatham Island soon after. Most clearance of the island's original vegetation to make way for farming apparently took place during the 1860's.

Originally, much of the island would have been forested. Broadleaved bush composed of *Melicytus chathamicus*, *Hebe*, *Olearia* and *Corynocarpus laevigatus*, would have occupied the better drained areas, particularly in the lower northern and central portions of the island. Tarahinau or tree heath forest composed predominantly of *Dracophyllum arboreum*, with *Pseudopanax* and tree ferns dominated the peatier, wetter areas and large areas of the southern uplands. Low shrubland and fernland persisted in areas unfavourable to forest, particularly on active peat domes, forming 'clears' or, clear areas, scattered through the forest (Wardle 1991).

Today, broadleaved bush exists only as a few remnants in the northern and central regions. Tarahinau forest is restricted to the southern uplands, where it still covers large areas. Pasture now dominates most of the well drained regions, particularly where the soils are developed on limestone, volcanic material or aeolian sand. On the wetter, peatier areas the vegetation is often a mosaic of shrubland, and open area 'clears', dominated by fernland and poor quality pasture. This vegetation dominates large tracts of northern Chatham Island. Figure 4.1 presents a map of the present day vegetation distribution of Chatham Island.

Coastal areas are dominated by marram grass, particularly on young and accumulating sand dunes. More stabilised sands bear a cover of small coastal shrubs, including *Pimelea*, *Myrsine*, and *Coprosma*. Originally the endemics *Myosotidium hortensia* and *Embergeria grandifolia* would have dominated these communities, but they have suffered greatly from introduced animals, and are now restricted to a few isolated localities (Crisp *et al.* 2000). A comprehensive description of the vegetation communities of Chatham Island can be found in Wardle (1991).

Figure 4.1: Map of present day vegetation cover of Chatham Island (data source: NZTM 260 Chatham Islands Sheets 1&2, 1981).



The nature of the Chatham Island floral structure means that interpreting pollen spectra obtained from a sequence of peat, and relating observed changes in vegetation assemblages to changes in climate will be different from and more difficult than on the mainland. On Chatham Island changes in vegetation may be controlled more by moisture availability and exposure rather than actual changes in temperature. Species richness of Chatham Island, and the other southern oceanic islands of New Zealand, is the result of a combination of area and temperature and the climatic fluctuations of the Quaternary have had little effect on vegetation development (McGlone 2002, Chown *et al.* 1998).

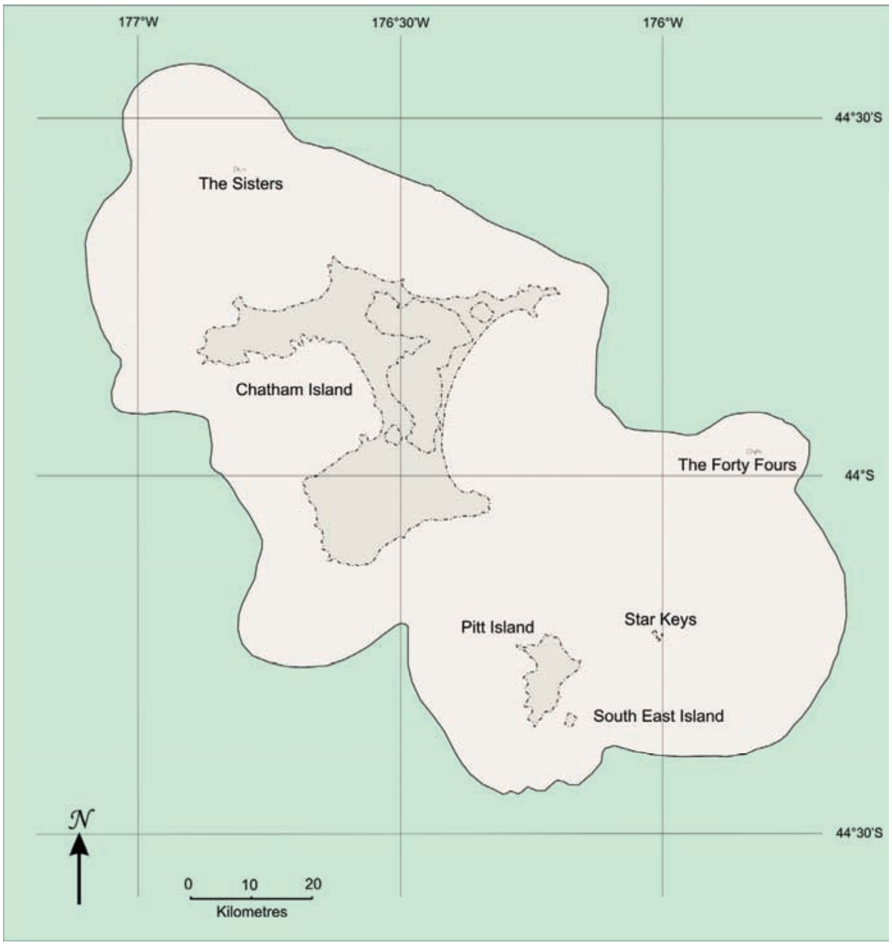
Mainland vegetation changes through the Quaternary are largely attributed to a combination of temperature depression, changes in precipitation regime, increased windiness and decreased insolation due to climate changes associated with Milankovich forcing. Sea surface temperatures to the south of Chatham Island may have fallen to between 4 and 8 º C lower than present during glacial periods (Fenner *et al.* 1992, Weaver *et al.* 1998, Wilson *et al.* 2005), allowing the Antarctic convergence to move northwards by 5 degrees of latitude (Nelson *et al.* 1993). How this change affected Chatham Island is unknown. Apparently there was minimal change in ocean temperatures and currents to the north of the Chatham Rise, and the colder sub-Antarctic water may have been compressed against the Rise's southern flank (Nelson *et al.* 1993). Also, the maritime nature of the island may have moderated the effects of any temperature drop associated with sea surface temperature changes. The most significant factor in driving changes in vegetation patterns may have been eustatic sea level fall, which would have increased the area of dry land in the Chatham region by at least two fold (Figure 4.2), which may have subsequently led to a change in the position of the water table and increased exposure in the higher reaches of the island, resulting in less available moisture.

4.3 Previous palynological investigations

The earliest record of palynological analysis on sediments from Chatham Island is that of Erdtman (1924) who commented on the high levels of exotic or long-distance pollen within Chatham Island peats. Moar, in Hay *et al.* (1970) described the pollen flora from an exposure of the Moorland Peat, near the now closed Kairakau School (Figure 4.3). From his observations of the preserved flora he suggested that the Moorland Peat had accumulated under mild climatic conditions, similar to that of the present day.

Mildenhall (1976) investigated the long-distance fraction of pollen spectra from sequences of peat at 3 different sites (Figure 4.3). He made a significant suggestion in this work: - that fluctuations in the levels of exotic pollen, and also fluctuations in the ratio of the dominant species can be used to divide the Chatham Island pollen record into zones and can also be used to relate the records to the climate of mainland New Zealand at the time of accumulation/deposition.

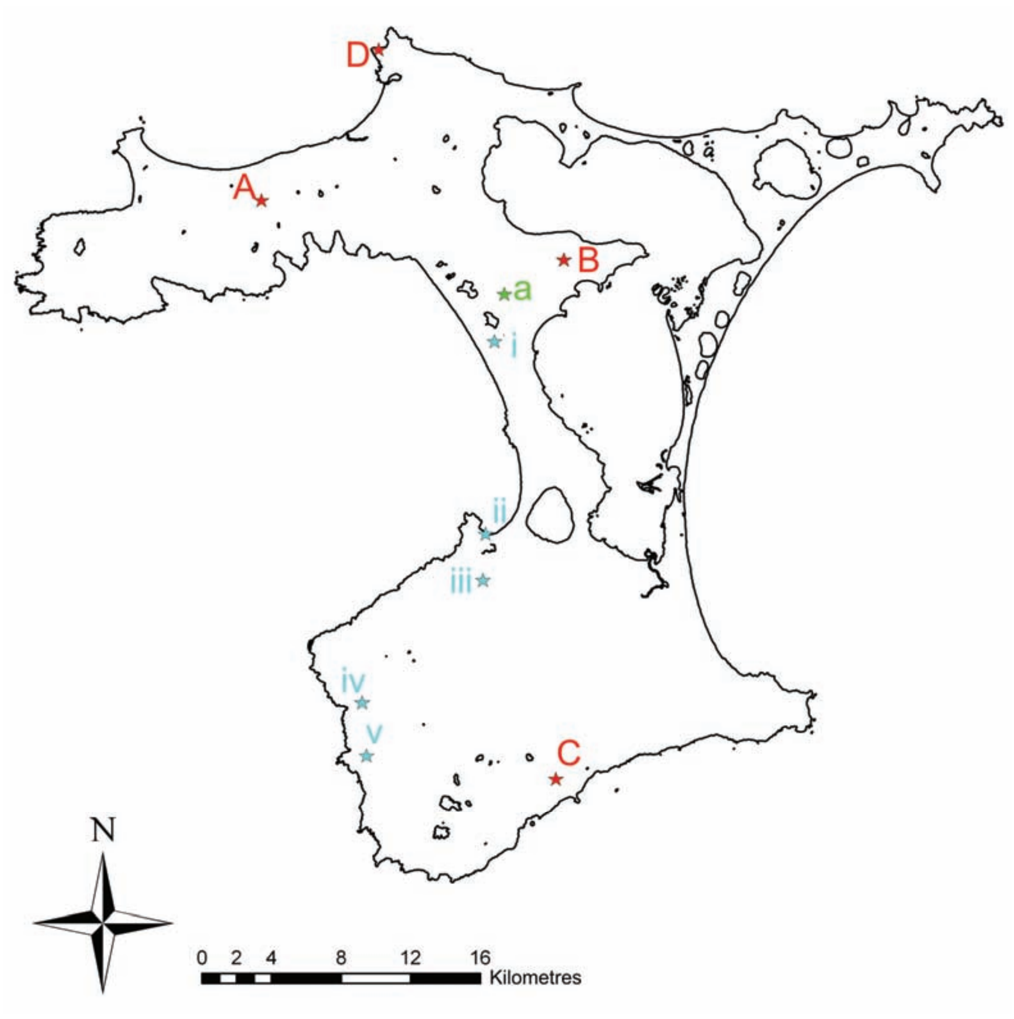
Figure 4.2: Map showing possible maximum extent of dry land in the Chatham Islands region the during the global Last Glacial Maximum at 21 ± 3 ka (Mix *et al.* 2001, Barrows *et al.* 2002), assuming a 120 m drop in sea level, relative to present, and minimal/no tectonic uplift.



pollen derived from mainland New Zealand forests within the modern pollen rain and noted that local pollen production on the island must be relatively low as it does not mask this exotic fraction.

Mildenhall (1994a) subsequently published the full pollen records from his three sites as part of a larger bulletin on the Cretaceous to Recent palynology of Chatham Island

Figure 4.3: Locations of sampling sites of previous palynological works mentioned in the text.



sediments. He also examined the pollen flora from a number of spot samples from other Quaternary sediments from various locations around the island. From the palynological analyses of the 3 Pleistocene-Holocene sequences at Mt Dieffenbach, Te Pukaha and Oropuke (Figure 4.3) he proposed biostratigraphic zones for Chatham Island pollen records which correlate with glacial and interglacial periods over the last 150,000 years (Table 4.1).

Mildenhall (1994a) investigated the sequences in an attempt to develop a zonation with which isolated samples could be correlated. It was anticipated that through these zones and additional information from McGlone (2002), the peat sequences and individual beds investigated in this present work could be assigned to a glacial or interglacial period. If the changes represented by these zones occurred in response to climatic fluctuations during the late Quaternary then similar changes should have occurred during previous climatic cycles. Thus the older peats encountered in this work should be able to be assigned to a glacial or interglacial period or climate based on their floral assemblages. Interglacial conditions are represented by increased levels of *Dracophyllum*, *Coprosma*, *Myrsine*, tree ferns, and low levels of Asteraceae. Levels of long-distance pollen increase and are dominated by Podocarps. Glacial conditions are represented by increased levels of Asteraceae pollen, as well as Restionaceae and *Gleichenia*, and low levels of trees and shrubs – *Dracophyllum*, *Coprosma*, *Myrsine* and tree ferns. Levels of long-distance pollen are low and are dominated by *Nothofagus* (Mildenhall 1994a, McGlone 2002).

Table 4.1: Description/definition of the four pollen zones for the Moorland Peat, proposed by Mildenhall (1994a).

ZONE	DEFINITIVE FLORAL FEATURES OF ZONE		Dominant long distance element	Age/MIS
	Significant Taxa within zone	Absent/Reduced Taxa		
RESTIONACEAE	**Restionaceae**,	Shrubby taxa	*Nothofagus*	Penultimate glacial (MIS 6)??
DRACOPHYLLUM-MYRSINE	***Dracophyllum*** and ***Myrsine*****,** *Astelia*	*Plagianthus*	Podocarps and *Nothofagus* approx. equal	Last Interglacial (MIS5)?
COMPOSITAE (ASTERACEAE)	**Asteraceae** and **Restionaceae**, *Dracophyllum* and Cyperaceae, *Gentiana*	*Myrsine*	*Nothofagus*	Last Glacial/LGM (MIS 2/3/4?)
RESTIONACEAE-DRACOPHYLLUM	***Dracophyllum*** and **Restionaceae**,	Poaceae, Cyperaceae and Asteraceae	Podocarps, *Ascarina lucida*	Post-glacial (MIS1)

Mildenhall 1994a and McGlone 2002 have stated that peat accumulation slowed considerably or ceased altogether during the Last Glacial Cold Period[*] (LGCP). This implies that records of vegetation from the LGCP may not be preserved within peat sequences. Another option is of course lake sediments. Chatham Island has numerous freshwater lakes and a large brackish lagoon (Te Whanga Lagoon). Unfortunately most of the lakes probably formed behind post-glacial sand dunes, and thus would not contain sediments that are old enough for the purposes of this investigation. A reconnaissance coring expedition by members of the Massey University Geography programme in 2003 found that many of the lakes were sand–bottomed and thus hand operated corers could not be used to extract sediment cores. However, a 4.5 m core containing the 27.1 ka Kawakawa Tephra near the base was obtained from a small unnamed lake near the fishing village of Port Hutt. This core, and others collected during that expedition are currently awaiting processing for palynological analysis as part of the Ph.D. project of a member of the expedition. The Port Hutt core was sampled for phytolith analysis (Holt 2003) and the phytolith assemblages present within the core were dominated by both grass-type and fern-type phytoliths before and after the fall of the Tephra.

All records presented in this work contain at least one of the two rhyolitic tephra horizons known to occur on the island. These tephras provide the best chronohorizons for correlation between Chatham Island and mainland New Zealand, in the absence of additional age control.

There are many pollen records from terrestrial locations on mainland New Zealand that contain the Kawakawa Tephra, and so cover similar age ranges to sites studied in this work (e.g. Sandiford *et al.* 2003, Mildenhall 1994b, McGlone & Topping 1983, Newnham *et al.* 2007), as well as offshore marine records (e.g. Wright *et al.* 1995). Pollen evidence from deposits adjacent to the Kawakawa Tephra on mainland New Zealand indicate that the vegetation at the time of the eruption was dominated by mixed shrubland and grassland in the central North Island, mosaic shrubland and forest in the upper North Island and dominantly open grassland in the South Island (McGlone 1988, Newnham 1999).

[*] after Lowe *et al.* (2008), defined as spanning the period 30,000 – 18,000 cal. yr B.P. and encompassing the Last Glacial Maximum at 21,000 ± 3,000 cal. yr B.P.

However, mainland pollen records from the time of the considerably older Rangitawa Tephra (i.e. OIS 10 and older) are somewhat rarer, and are limited to Mildenhall (1994b, 2003), Mildenhall *et al.* (1977), Bussell (1986) and Kohn *et al.* (1992). These limited pollen records from deposits adjacent to the Rangitawa Tephra indicate that during OIS 10, the southern North Island hosted a low, sub-alpine scrubland that was similar to the vegetation present during the Last Glacial Cold Period (Mildenhall 1994b, Mildenhall *et al.* 1977). The Wanganui region had a cover of coastal beech and podocarp forest during the preceding interglacial (OIS 11) which then became dominated by typical glacial flora of scrubland and grassland during OIS 10 (Bussell 1986). The offshore record from ODP 1123 (located approximately 350 km north-east of Chatham Island) contains pollen dominated by *Halocarpus* and *Phyllocladus* in the glacial period of OIS 10 suggestive of sub-alpine shrubland vegetation on the mainland at that time (Mildenhall 2003).

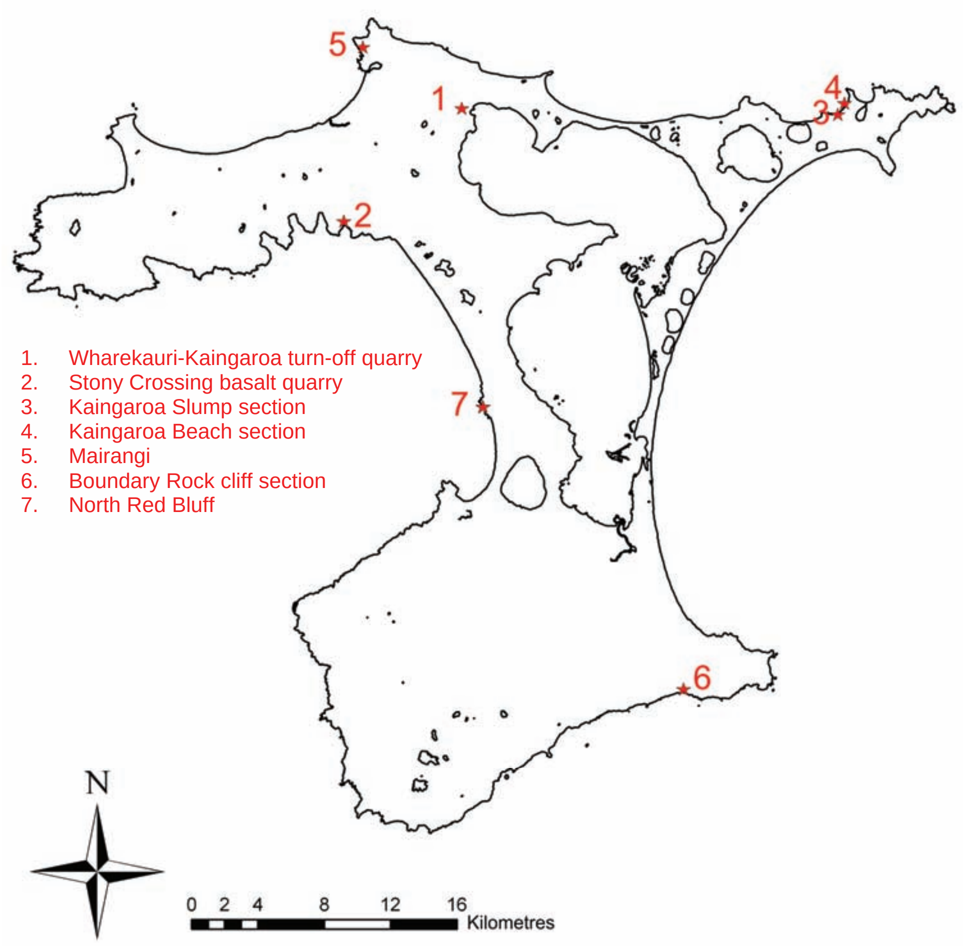
As mentioned earlier, the palynological analyses in this work have been undertaken to provide information about paleoclimate at the time of deposition. I have attempted to reconcile the spectra encountered with those described by Mildenhall (1994a) and McGlone (2002) as glacial or interglacial. The sections sampled and described in the following text were chosen not necessarily for their suitability for paleovegetation studies, but because they occurred in association with a significant chronohorizon e.g. a tephra layer.

4.4 Methods

4.4.1 Sampling

All deposits sampled for palynological analysis were naturally exposed in open faces, i.e. cliffs, road cuttings etc, or holes. The locations of all sites sampled in this study are presented in Figure 4.4. Hand-operated corers would have been preferable at certain sites but use of these was often restricted by the occurrence of zones of aeolian sand within the peat sequence. Most hand-operated corers, for example, the Russian D-section and the Hiller corer, cannot be driven through sandy deposits. Faces or exposures to be sampled were cleared back with a spade until fresh deposits were exposed. Most peat encountered was of a very waxy texture, a feature very common to the older Chatham Island peats, believed to be the result of humification and compaction and possibly from accumulation under warmer temperatures than other, more fibrous peat deposits (Leamy and Blakemore 1960). Once suitably exposed, the deposits were sampled using 5 or 10 cc medical syringes with the nozzle removed. The syringes were then sealed in plastic bags. Samples were taken at intervals ranging from 2 cm to 10 cm depending on the site and the thickness of the deposit. In some instances bulk samples were collected, usually from thin peat beds within dominantly clastic sequences. Not all samples collected from a site were processed. For most sites, one sample per 10 cm was processed for pollen, which has resulted in a low resolution record. This approach was taken mostly because of the amount of time required to process, analyse and count each sample. A high resolution record is not as necessary for gaining broad climatic information as it might be for a detailed vegetation dynamics study. It also allowed for samples from a greater range of sites to be processed and analysed over the course of the research.

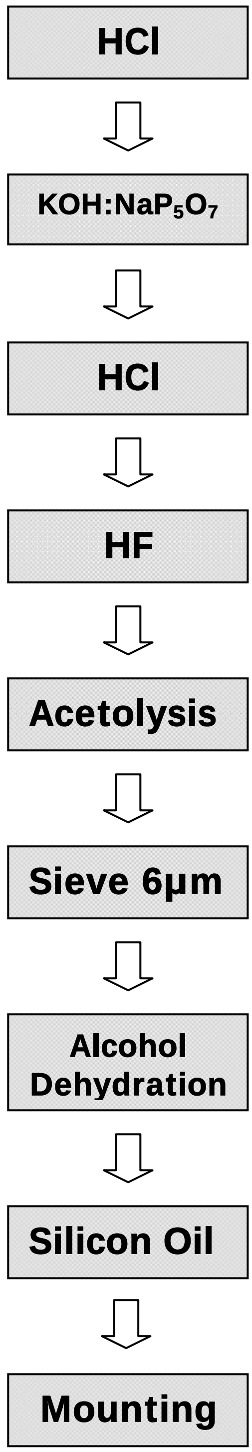
Figure 4.4: Locations of pollen sampling sites for this work.



4.4.2 Sample Processing

Samples were processed for pollen in the standard fashion (Figure 4.5). One cubic centimetre of sample was treated following the methods of Faegri & Iversen (1989), and Moore *et al*. (1991). The pollen concentrate was suspended in silicon oil (2000 centistokes/m per sec.) and mounted on a glass slide under a coverslip and sealed with paraffin wax. Two slides per sample were produced for counting. The excess pollen-silicon samples were retained in vials in case further slides were required.

Figure 4.5: Summary diagram of pollen sample preparation treatment procedure.



4.4.3 Counting and Identification

Pollen on each slide was counted until at least 200 grains of dryland pollen had been counted per slide. Dryland pollen (i.e. pollen of trees, shrubs, and herbs) comprises the *pollen sum*, which is also referred to as the *count total*. Pteridophyte spores (excluding tree ferns) and pollen of aquatic taxa, of only local significance, were excluded from the pollen sum/count total, as was the long-distance pollen, as it does not directly relate to island vegetation. Raw pollen counts for all sites can be found in Appendix 6.

The identification of pollen and spores was facilitated by standard palynology references for New Zealand pollen and spores including Moar (1993), Large and Braggins (1991), as well as photographic and slide reference collections within the Massey University Geography programme pollen laboratory.

4.4.4 Presentation of data

Both Dodson (1976) and Mildenhall (1976) have commented on some of the issues surrounding identifying certain Chatham Island palynomorphs to the genera or species level. Two species of *Dracophyllum* (*D. arboreum* & *D. palludosum*) are not reliably distinguishable. This is significant as *D. arboreum* is a major component of Chatham Island tree heath forest, while *D. palludosum* is a component of 'clear' vegetation. Based on the inability to reliably distinguish the two, Mildenhall (1994a) grouped all Epacridaceae together, including *Cyathodes*, which is also common in 'clears'. He proposed that the bulk of the Epacridaceae pollen would probably be from *Dracophyllum arboreum*. This approach has been followed here, with all Epacridaceae grouped together in the small trees and shrubs category. Mildenhall (1994a) also chose to group all members of the Asteraceae family together, again based on difficulties in reliably distinguishing species. This has been done here also, with all Asteraceae pollen grouped together within the small trees and shrubs category. However, a note was made as to whether there was a dominant Asteraceae morphology within a sample (section 4.6.7).

The pollen count data are presented as histograms on percentage pollen diagrams produced in the Tilia and TiliaGraph programs, with levels of each taxon presented as a percentage of the pollen count total/pollen sum. Species and groups of species not included in the total pollen count, i.e. Pteridophytes, wetland/aquatics and long – distance pollen are also expressed as a percentage of total dryland pollen.

Taxa have been grouped into the following vegetation categories, after McGlone (2002):

1. Poaceae (grasses)
2. Small trees and shrubs, including all Epacridaceae, all Asteraceae, *Coprosma, Myrsine, Melicytus, Pseudopanax, Plagianthus* and also palms;
3. Herbs including *Astelia chathamica*, *Gentiana chathamica* and all Chenopodiaceae;
4. Pteridophytes, including tree ferns (*Dicksonia* and *Cyathea*) and other, undifferentiated trilete fern spores, *Microsorum pustulatum* (formerly *Phymatosorus diversifolius*), monolete fern spores (psilate and textured) and Lycopodiales;

5. Wetland including, Haloragaceae, Restionaceae and *Gleichenia*;
6. Long-distance pollen.

These five assemblages (excluding long-distance pollen) represent prominent components of glacial – interglacial vegetation spectra on Chatham Island (Mildenhall 1994a, McGlone 2002).

4.4.5 Long Distance Pollen

Long-distance pollen was initially counted as part of the pollen counts, but is excluded from the pollen sum. For two sites an additional count of long-distance pollen was undertaken in an attempt to further investigate the significance of this fraction in terms of representing climate change on the New Zealand mainland. Many samples contained very low levels of exotic pollen (<1%) making it statistically unsound to conclude that the 1 or 2 grains encountered during the pollen count accurately represented the dominant long-distance taxon at that time. For this 'specific' long-distance count, 100 grains of long-distance pollen were counted per sample. The two sites chosen were the Stony Crossing basalt quarry site and the Boundary Rock cliff site. Results from these specific long-distance counts are presented as pollen diagrams in Appendix 7, and also as a summary graph within the main pollen diagram of the source site. The summary diagram within the main pollen diagram shows the data as a proxy of warm versus cold. The 'warm' component includes Podocarp/hardwood forest taxa (*Podocarpus*/*Prumnopitys* type, *Dacrydium cupressinum*, and *Dacrycarpus dacrydiodes*) which are the main element of forest of mainland New Zealand during interglacials (McGlone 1998), while the 'cold' component includes *Nothofagus*, *Phyllocladus* and *Halocarpus* which are significant components of forest and low alpine shrubland during glacials (McGlone 1988). This pattern has also been observed in the orbitally tuned pollen record of ODP DSDP 1123 which spans the entire Quaternary period (Mildenhall 2003).

4.5 Results

4.5.1 Pollen

The majority of samples processed contained well preserved palynomorphs in suitable abundances for reliable counts to be obtained. In some cases samples were particularly pollen rich, which may have resulted from a combination of peat compaction and thorough humification. Samples containing poorly preserved pollen or no pollen at all usually had been collected from deposits that, based on stratigraphic and/or geomorphic evidence, would have been, at some stage, prone to oxidation and repeated wetting and drying. However, in one instance a sample from the middle of a continuous peat sequence (306 cm, Kaingaroa Slump, Figure 4.8) yielded no pollen at all, for no obvious reason. There were no occurrences of pollen of species or palynomorphs not previously recorded from Chatham Island, either in existing botanical surveys or palynological reports, including extinct palynomorphs.

One notable feature of the pollen obtained during this work is a distinct absence of Cyperaceae pollen. This is suspicious, as all previous pollen studies on the island (Hay *et al*. 1970, Mildenhall 1976, 1994a, and Dodson 1976) recorded some level of Cyperaceae pollen within their samples, with Mildenhall (1994a) identifying increases in the levels of Cyperaceae in association with glacial conditions. The probable explanation for the absence of Cyperaceae pollen is that the treatment processes applied here were too rigorous and the thin walled, somewhat delicate Cyperaceae pollen grains did not survive treatment.

As in most New Zealand and Chatham Island pollen records, pollen of *Corynocarpus laevigatus* (Karaka, or Kopi as it is known on Chatham Island), a significant component of broadleaved forest on both landmasses, was not recorded in any samples from this study. Dodson (1976) found it to be under-represented in the modern pollen rain on Chatham Island. Apparently pollen of this species does not preserve well (Mildenhall 1994a). Also it does not produce opal phytoliths (Kondo *et al.* 1994). This is unfortunate as it has also been suggested that the Kopi was introduced to the island by the Moriori (Mildenhall 1994a), however its poor pollen preservation and lack of phytoliths precludes pinpointing the timing of its arrival on the island in the pollen or phytolith records. One possible avenue for investigating the timing of arrival of Kopi to the island is starch grains. Fossil starch grains are being used increasingly in archaeological research (e.g. Haslam 2001, Babot 2001). The starchy nut within Kopi berries should be a source of starch grains. If the first appearance of Kopi starch grains within a profile occurred within the last thousand years it would indicate that Kopi were introduced, as Polynesians arrived on Chatham Island less than a thousand years ago (Sutton 1980, 1985).

4.5.2 Long Distance Pollen

Pollen derived from mainland New Zealand was encountered in variable amounts in most samples, although it was not always represented in the pollen count. Levels of long-distance pollen ranged from equivalent to 0 to 60% of total dryland pollen, but levels were most commonly around 5%.

The taxa encountered, in order of frequency were:

- *Podocarpus totara*/*Prumnopitys* type
- *Nothofagus* (Fuscospora)
- *Dacrydium cupressinum*
- *Phyllocladus* sp.
- *Dacrycarpus dacrydiodes*
- *Halocarpus* sp.
- *Dodonaea viscosa*
- *Casuarina*[*]
- *Ascarina lucida*

There were isolated occurrences (sighted only once or twice during the project) of *Metrosideros*, *Lycopodium ?australinium* and *Acacia*[*].

Fluctuations in the levels of exotic pollen usually coincided with variations in the species composition of the fraction i.e. when the long-distance fraction was very minor ~2% it was dominated by *Nothofagus* pollen, or contained approximately equal amounts of *Nothofagus* and podocarp pollen; while when levels were higher (~5%) the fraction is dominated by podocarp pollen. This relationship is highlighted particularly in the specific long-distance pollen counts. This relationship between levels of long-distance pollen and species composition was recognised and used by Mildenhall (1994a) in defining his pollen zonation. The variations observed often occurred concurrently with changes in local pollen levels, interpreted to be a response to climate change over the Quaternary.

It is relevant here to note that from this point on, when referring to the long-distance fraction of a sample and the climatic conditions indicated by the fraction, the use of the term ‘Podocarp’ includes *Podocarpus totara*/*Prumnopitys* type, *Dacrydium*

[*] Derived from Australia

cupressinum and *Dacrycarpus dacrydiodes,* but excludes pollen of *Phyllocladus* and *Halocarpus* as these species are associated with cooler climate flora on the mainland (Mildenhall 2003).

4.5.3 Microscopic charcoal

In paleovegetation analyses, microscopic charcoal particles, where encountered, are often counted along with pollen and spores. The presence of charcoal particles in significant amounts within the pollen record is taken to represent fire in the region of the site, and in the case of recent records, is often interpreted as the result of human activities in the area or, in the case of pre-human arrival as indicating increased droughtiness or increased frequency of natural fires. Microscopic charcoal particles have been counted along with pollen and spores and the resultant counts included in the pollen diagrams. Fragments were recorded according to their size, because particle size has been shown to relate to the proximity of a source fire to a site (Clark 1988, Blackford 2000). Thus, observed particles were placed into one of three size categories: large – particles >50 μm in diameter; medium – particles ranging from 20 to 50 μm in diameter; and small – particles <20 μm in diameter. As most samples are interpreted to pre-date human arrival at the island, <1000 years ago (Sutton1980, 1985), the fires responsible for any charcoal present must be of natural origin.

4.6 Sites studied

The sites sampled for palynological analysis are of varying age and span varying amounts of time. Most are Last Glacial or older. Age control is limited, with one or both rhyolitic tephra beds described in the previous chapter providing the only reliable age control.

4.6.1 Wharekauri-Kaingaroa turn-off quarry

4.6.1.1 Site description

This site comprises an open face of peat exposed in a basalt quarry adjacent to the Wharekauri/Kaingaroa roads intersection (Figure 4.4). The sampled section consists of 1.3 m of peat of the Moorland Peat, with *in situ* wood and tree roots becoming common towards the base. The peat sequence is underlain by 1.4m of quartzose beach and dune sand which becomes laminated and increasingly coarse towards the base. The sand rests on a surface cut into Cretaceous/Paleocene basalt lavas (Southern

Volcanics). Based on the height of this surface (16 m) in relationship to modern sea level and its position within the landscape, the surface is believed to have been cut during OIS 5e and thus would correlate with the Rapanui marine bench of Pillans (1983). The Kawakawa Tephra (27.1 ka) occurs at the top of the peat sequence. The landscape surrounding the site is gently rolling and blanketed with peat, with the exception of the lagoon margins.

The sequence was sampled from the base of the Kawakawa Tephra down to the top of the sand, at 5 cm intervals, although only one sample per 10 cm was subsequently processed for pollen. The peat deposits overlying the Kawakawa Tephra were not sampled as quarrying activities had greatly disturbed this portion of the section.

4.6.1.2 Present vegetation

The present vegetation occurring in the immediate vicinity of the site is best described as a mosaic of low shrubby heath composed of clumps of small shrubs, interspersed with areas of pasture grass, and very wet hollows with rushes, ferns and sphagnum moss.

4.6.1.3 Description and interpretation of the pollen record

The pollen record (Figure 4.6) has been divided up into three zones. The lower zone (Wq3) extends from the base of the section at 129 cm to 85 cm. It is characterised by a dominance of Epacridaceae pollen, with low but persistent levels of *Coprosma*, fern spores and *Myrsine*. Levels of cool-wet elements (*Gleichenia* & Restionaceae) are relatively low. Levels of Asteraceae pollen fluctuate between 15 and 45% of total dryland pollen.

The middle zone (Wq2) extends from 85 cm to 45 cm and comprises 4 samples. It is characterised again by a dominance of Epacridaceae pollen, but shows a rise in levels of the cool-wet elements, *Gleichenia* and Restionaceae, with levels of Restionaceae pollen approaching equivalent to 70% of the total count. Levels of long-distance pollen also increase, equivalent to 20% of the total count, and is dominated by *Nothofagus* pollen.

The upper zone (Wq1), from 45 cm to the base of the Kawakawa Tephra (0 cm) is marked by a significant decline in the levels of Epacridaceae pollen. Levels of wet-cool elements (*Gleichenia* and Restionaceae) remain reasonably high, with levels of *Gleichenia* increasing. There is also a decline in the levels of *Coprosma* and *Myrsine* pollen, and an increase in the level of grass pollen. Long distance pollen in both zones is a mix of *Nothofagus* and podocarps. Two peaks of microscopic charcoal occur within this zone – WqA at 19 cm and WqB at 39 cm. No significant changes in vegetation composition occur in association with these charcoal peaks and thus they do not represent local fires.

The overall trend displayed in the diagram is of increasing moisture levels, with zone Wq3 containing high levels of ‘dryland’ pollen i.e. Asteraceae, *Dracophyllum* and *Coprosma*, and low levels of ferns and aquatics. Zones Wq2 and Wq1 represent an increase in levels of moisture and possibly cooling, as indicated by the rise in *Gleichenia* and Restionaceae, and a decline in shrubs and trees. These three subzones can be correlated with the Asteraceae zone of Mildenhall (1994a), which represents cooling during the early stages of the Last Glacial period. The rise in Asteraceae and grass pollen in Zone Wq1 is what would be expected to accompany the onset of the Last Glacial Cold Period (LGCP). Also, the ratio of Podocarps to *Nothofagus* over the three zones is very low, and supports accumulation during the Last Glacial period.

4.6.2 Stony Crossing basalt quarry

4.6.2.1 Site description

This site comprises an open face of peat exposed in another basalt quarry, at a ford known locally as ‘Stony Crossing’, adjacent to Ohira Bay, on the road to Port Hutt (Figure 4.4). The section comprises approximately 3.5 m of peat with varying sand content, also of the Moorland Peat. The peat overlies medium to coarse quartzose sands over a coarse gravel which sits on a surface cut into Cretaceous/Paleocene basaltic lava flows (Southern Volcanics). This surface was measured at 16 m a.s.l. and is also interpreted to be the Last Interglacial marine bench (OIS 5e) and thus also equivalent to the Rapanui marine bench of Pillans (1983). The 27.1 ka Kawakawa Tephra is present as a 10 cm thick layer at 0.5 m depth.

4.6.2.2 Present vegetation

The vegetation assemblages present in the immediate vicinity of the site is described as low heath scrub dominated by bracken fern (*Pteridium esculentum*), *Gleichenia*, sedges, small shrubs (*Cyathodes robusta, Dracophyllum palludosum*) and European pasture grasses. Small remnant stands of *Olearia traversii* occur on sand dunes within 0.5 – 1 km of the site.

4.6.2.3 Description and interpretation of pollen record

A specific long-distance count was performed on samples from Stony Crossing following the initial pollen count (Appendix 7A). The long-distance values mentioned in the following descriptions and interpretations are those from the specific count. Any major discrepancies between long-distance values from the pollen count and the specific long-distance count are mentioned.

The pollen record, presented in Figure 4.7, has been divided into 3 zones. Zone Sc3, from the base to ~240 cm, is dominated by Epacridaceae pollen with low to medium levels of *Myrsine*, *Coprosma*, tree ferns, other ferns and low levels of grass and Asteraceae, and relatively low levels of *Gleichenia* and Restionaceae. The long-distance fraction is dominated by *Nothofagus*.

Zone Sc2 extends from 240 cm to 60 cm, just below the Kawakawa Tephra. It is also dominated by Epacridaceae pollen but there is a marked increase in levels of *Gleichenia* spores, and a fall in the levels of *Coprosma* and *Myrsine* pollen and tree fern spores. There is also a rise in the level of Asteraceae pollen. Levels of grass pollen remain low throughout the zone. The long-distance pollen is dominated by podocarps rather than *Nothofagus*, with the specific count showing a ratio of almost 90:1 pc:nf.

Zone Sc1, from the Kawakawa Tephra upwards is, like the previous zones, dominated by Epacridaceae pollen, *Gleichenia* spores and Asteraceae. There are also increased levels of Restionaceae pollen. *Coprosma*, *Myrsine* and tree ferns are present in very minor amounts. Long distance pollen remains dominated by podocarps, however levels of *Nothofagus* are higher relative to the previous zone. *Pteridium* spores appear in this zone at a depth of 25 cm.

Microscopic charcoal particles were observed in varying amounts in nearly all samples. The abundance of particles in the two uppermost samples is attributed to anthropogenic fire at or very near the site, and is also accompanied by a significant rise in bracken fern (*Pteridium*) spores.

The low but persistent levels of charcoal in the lower samples are somewhat puzzling and seem to suggest continued fire activity at or near the site over the history of peat accumulation. This is not reflected in the pollen spectra, although levels of charcoal do increase slightly, coincident with a rise in the levels of wetland elements *Gleichenia* and Restionaceae, which tend to colonise peat bogs following fires (Clarkson *et al*. 2004). Other possible explanations for the origin of this charcoal are explored later in the text.

The vegetation pattern displayed in the Stony Crossing diagram is more ambiguous than that of the Wharekauri-Kaingaroa turn-off quarry site. The summary diagram shows no significant or major changes in vegetation composition through the entire sequence. However, the local pollen appears to show a trend towards cooling, as would be expected if the sequence, like that at Wharekauri spanned the Last Glacial period.

The relatively high levels of *Coprosma* and *Myrsine* pollen and tree fern spores combined with the low levels of wet/cool elements and grasses in Sc3 suggest accumulation during warmer conditions than the rest of the sequence and the zone as a whole loosely resembles the *Dracophyllum*/*Myrsine* zone of Mildenhall (1994a) regarded as a possible interglacial vegetation by McGlone (2002). However, the long-distance fraction is dominated by *Nothofagus*, which implies that the climate of mainland New Zealand, at least, was relatively cool (Mildenhall 1976, 1994a and McGlone 2002). This discrepancy between the local and long-distance pollen may imply that the *Dracophyllum*/*Myrsine* zone accumulated during the earlier stages of the Last Glacial period, rather than during the Last Interglacial, as proposed by McGlone (2002). Alternatively it could indicate that Chatham Island vegetation did not respond to cooling during the onset of the Last Glacial at the same pace as the vegetation of New Zealand, i.e. Chatham maintained its interglacial flora, dominated by *Dracophyllum*, *Myrsine*, ferns etc, while on mainland New Zealand, podocarp forests were in decline or retreat.

The rise in *Gleichenia* and concurrent decline in *Coprosma* and *Myrsine* pollen in Zone Sc2 represents increased wetness, acidity and possibly cooling. However, this is again not reflected in the long-distance pollen. The long-distance count showed very high ratios of podocarp:*Nothofagus* of ~90:1 which is indicative of warm conditions on the New Zealand mainland (Mildenhall 1976, 1994a and McGlone 2002). This may represent interstadial warming on mainland New Zealand during OIS 3, or alternatively full interglacial conditions.

The decline in *Myrsine* and *Coprosma* to minimal levels and slight rise in grass and Asteraceae and grass in Zone Sc1 must represent increased cooling towards and around the Last Glacial Cold Period. This is also reflected in a peak in long-distance *Nothofagus* pollen. The upper 50 – 25 cm of the sequence appears to represent at least 25 ka of history at the site, based on the position of the Kawakawa Tephra. It has been suggested that peat accumulation slowed or ceased completely during the LGM, thus there may be no record from shortly after the Kawakawa Tephra to *c*.12 ka B.P. when post-glacial warming began. It is also probable that some thickness of peat has been removed by fire. The appearance of charcoal particles accompanied by the appearance of *Pteridium* spores at 25 cm probably represents the arrival of humans to the area, either the Moriori sometime around 1000 years ago, or Maori and/or Europeans in the 1800s. There is, however limited evidence to indicate that the Moriori used fire for stimulating bracken fern growth as the Maori did. Regardless, there is almost without doubt some amount of time missing in the region above the Kawakawa Tephra.

In terms of correlations with the sites of Mildenhall (1994a), the pollen spectra preserved in the Stony Crossing quarry are more similar to the Asteraceae zone than any of the other proposed zones, yet all three Stony Crossing zones lack the high levels of Asteraceae pollen recorded by Mildenhall (1994a) and all retain/maintain relatively high levels of *Dracophyllum* pollen throughout.

4.6.2.4 Comparison with Wharekauri-Kaingaroa turnoff record

As both the Stony Crossing site and the Wharekauri-Kaingaroa turn-off site are interpreted to overly the last interglacial marine bench, the pollen spectra should be correlatable. Overall, both sequences display a similar trend of increasing moisture and/or decreasing temperatures, however, there are some obvious significant differences. Wq3 and Sc3 show similarities in the dominance of *Dracophyllum* pollen, with low but persistent levels of *Coprosma* and *Myrsine*, and low levels of cool – wet elements. However Sc3 has significantly higher levels of tree fern spores and significantly lower levels of Asteraceae pollen. Both Wq2 and Sc2 are defined by an increase in wet cool elements and a decline in *Coprosma* and *Myrsine*. However Wq2 also shows a considerable decline in levels of *Dracophyllum* pollen, while *Dracophyllum* levels in Sc2 remain relatively constant. Levels of long-distance pollen do not vary significantly between the four zones.

These discrepancies between zones at the two sites could possibly be explained by local variations in hydrology and exposure, but another possible explanation is that Stony Crossing spans a longer period of time. The long-distance pollen count from Stony Crossing suggests that during Sc2, conditions on mainland New Zealand were relatively warm based on the very high ratio of podocarp to *Nothofagus* pollen. This may be indicative of interstadial warming during OIS 3, which is not reflected within the long distance fraction at Wharekauri-Kaingaroa turn-off quarry. Alternatively, the Stony Crossing record may span a longer period of time than the Wharekauri record, and the high levels of podocarp pollen in Sc2 represent interglacial warming, rather than interstadial warming. If this were the case then Sc2 would be a record of OIS 5 and Sc3 OIS 6. A specific long-distance count was not performed on Wharekauri-Kaingaroa turn-off quarry samples due to time restrictions, but if available would possibly provide a means for further comparison and correlation between the two sites, and may reveal that the long-distance fraction of Wq2 is also dominated by podocarp pollen which, at present, is not obvious in the standard pollen count due to masking by local pollen.

4.6.3 Kaingaroa Slump sequence

4.6.3.1 Site description

This site is located at the coast, 3.4 km south-west of the fishing village of Kaingaroa, within ten metres of the present beach (Figure 4.4). The section has been exposed by a slump that occurred in 2004, and is only a few metres above modern sea level. The sequence comprises inter-bedded peat and sand units, and includes the 345 ka Rangitawa Tephra. Initial investigations of the sequence imply that there is a considerable amount of time missing at this site as it is unlikely that the 2-3 metres of sand and peat above the tephra represent a complete record of deposition at the site over the last *c*. 350,000 years. There appears to be a disconformity located at the contact between the base of the sand unit at ~2 m and the underlying peat which contains the tephra bed. This disconformity surface is interpreted to have formed as the result of erosion and/or non-deposition at the site, and may have in fact resulted from marine planation of the older peat during transgression associated with an interglacial sea level rise, with the sand unit deposited during or after the peak of transgression. The Kawakawa Tephra is not present as a primary tephra fall deposit in the sequence, however a thin silty layer occurring at a depth of approximately 100 cm contains small amounts of rhyolitic glass shards whose glass chemistry has a strong affinity to that of the Kawakawa Tephra from other locations on the island (Chapter 3, section 3.6.3). This suggests that only minor deposition occurred at the site during the Last Glacial period. It is possible that a portion of the upper sequence has been removed through burning associated with land clearance. However, if this was the case then the uppermost sample or samples could be expected to contain abundant charcoal as was encountered in the Stony Crossing record.

4.6.3.2 Present vegetation

The vegetation present on the land surface that overlies the sequence is pasture, dominated by European grass species. The area seaward of the slump comprises coastal vegetation on sand dunes. Species present include marram grass, various coastal shrubs, *Geum* and the endemic sow thistle *Embergeria grandifolia.* A group of endemic Chatham Island forget-me-nots – *Myosotidium hortensia* - occupies an adjacent bay. A small stand of *Olearia traversii* trees once occupied the former surface that subsequently slumped down. At the time of sampling, these trees were slowly dying within the slump deposits.

4.6.3.3 Description and interpretation of pollen record

The Kaingaroa pollen record (Figure 4.8) has been divided into 5 zones. Zone Ks5 extends from the base of the sequence at 515 cm up to 450 cm. It is characterised by a dominance of Epacridaceae pollen and medium to high levels of *Myrsine* pollen and *Gleichenia* spores. Levels of Asteraceae increase from <5% at the base of the zone to 20% at the top. Grass and Restionaceae are also present. The long-distance fraction is very small (0-2%) and is made up of podocarps (dominantly *Podocarpus*/*Prumnopitys*-type) in the lower half of the zone and by *Nothofagus* pollen in the upper half.

Zone Ks4 is characterised by a major increase in *Coprosma* pollen and elevated levels of *Myrsine* pollen, and by a significant fall in the level of *Dracophyllum* pollen. Cool and wet elements *Gleichenia*, Restionaceae and grasses are largely absent. There are also low levels of broadleaf forest species. The zone also contains abundant small monolete fern spores of a smooth, psilate morphology. Levels of long-distance pollen present in this zone are the highest encountered during this work, exceeding 60% of the total pollen count and are dominated by podocarps. A major peak of microscopic charcoal (KsB) extends across the boundary between Ks5 and Ks4, the significance of which will be discussed in subsequent text.

Zone Ks3 extends from 260 cm, above a zone of interfingering peat and sand, to the base of the Rangitawa Tephra at 240 cm. The zone is characterised by a dominance of wet-cool elements – *Gleichenia*, Restionaceae, and grass. The long-distance fraction comprises 5% of total pollen and like Ks4, is also dominated by podocarps. This zone also contains a peak of microscopic charcoal (KsA), with all 3 samples that make up the zone containing significant levels of charcoal.

Zone Ks2 comprises the peat immediately overlying the 345 ka Rangitawa Tephra. Pollen and spores obtained from this zone showed evidence of oxidation and poor and uneven preservation of pollen and spores. Thus limited information can be drawn from them.

The entire upper peat unit, from 100 cm to 0 cm has been put into one zone, Ks1. The assemblage present in this zone is dominated by Epacridaceae and *Coprosma* pollen and tree fern spores. Cool and wet elements are absent. The long-distance fraction, though small is dominated by podocarps.

The vegetation record preserved within this sequence shows more pronounced changes in vegetation composition than the previous two sequences at Wharekauri and Stony Crossing. The assemblage preserved in Ks5 shows accumulation took place under a relatively moist climate, as indicated by the levels of Restionaceae, *Gleichenia*, *Dracophyllum* and *Myrsine*. Yet the low to medium levels of grass and Asteraceae pollen within the zone suggest certain areas within the region of the site may have been slightly drier than others. The dominance of *Nothofagus* in the long-distance fraction implies that conditions on the mainland were relatively cooler. Then, during the accumulation of Ks4 conditions became drier and possibly warmer, probably during an interglacial. This is indicated by the increased levels of *Coprosma*, *Myrsine* and *Pseudopanax* pollen and a decline of wet cool elements, with the continued increase of Epacridaceae and *Myrsine* pollen towards the top of the zone suggestive of increased warming. Thus the previous zone, Ks5 may represent climatic amelioration towards the end of a glacial period, when moisture levels were increasing allowing a resurgence of *Dracophyllum* and *Myrsine*. Yet cool and dry elements such as grass and Asteraceae still remained prominent. The dominance of *Nothofagus* within the long-distance fraction, as in the case of zone Sc3 at Stony Crossing, suggests that New Zealand and Chatham floras may respond to different climatic parameters, and/or that the timing of their responses to climate change are not synchronised with each other. This zone is followed by an influx of aeolian sand, which may represent a transgression of sand dunes in association with an interglacial rise in sea level. The very high levels of podocarp pollen in the long-distance fraction suggest that conditions on the mainland at this time were also interglacial. They also suggest that pollen production in the local area must have been very low at the time, for such extreme over-representation of exotic pollen.

A major peak of microscopic charcoal extends across the boundary between zones Ks5 and Ks4. This peak extends over a metre of the section, which suggests that fires were occurring over a considerable period of time at or near the site. Yet there are again no significant changes in vegetation composition associated with this charcoal, with the exception of a rise in *Gleichenia* and a fall of *Dracophyllum* which have been interpreted as the result of changes in climatic conditions rather than local events. The possible origins of this charcoal are further discussed in section 4.7.2, but are here regarded as having been produced by oxidation of organic matter occurring within the peat profile, which has been shown to result in charcoal like particles, rather than from a true fire (Kemp 1981).

There is then a return to wetter and or cooler conditions in Ks3, as represented by the increase in cool wet elements. However the continued dominance of podocarps in the long-distance fraction implies that conditions were still warm on mainland New Zealand. Stratigraphically, this peat should contain cool, glacial elements, as it underlies the Rangitawa Tephra, which fell towards the end of the OIS 10 glacial period.

The samples comprising zone Ks3 also contain significant amounts of microscopic charcoal (charcoal peak KsA on Figure 4.8). As was the case with peak KsB at the Ks4/5 boundary, these particles are again interpreted as the result of *in situ* peat oxidation processes. The main reason for this interpretation is that the combined amount of time spanned by both charcoal peaks is probably in excess of many thousands of years, and it is unlikely that fires could consistently burn for that long without exhausting all possible fuel sources or being extinguished by rainfall. Prolonged and repeated episodes of pre-human natural fires have been reported from New Zealand peat lands (McGlone *et al*. 1984) which are attributed to increased droughtiness. However, in the case of the Kaingaroa slump, levels of wetland pollen indicate, particularly in the region of KsA, that conditions were relatively moist.

Had preservation been optimal, the spectra preserved within Ks2 would be expected to show a change from cooler flora towards warmer flora, representing post-glacial warming following OIS 10.

The assemblages preserved within the upper portion of the sequence (Ks1) represent a distinctively interglacial flora, with high levels of Epacridaceae and *Coprosma* pollen and tree fern spores, with cool & wet indicators that are often dominant in glacial-aged peat absent, such as *Gleichenia*, Restionaceae & Poaceae absent. This is supported by the long-distance fraction which is dominated by both *Dacrydium cupressinum* (rimu) and *Podocarpus totara*/*Prumnopitys*-type pollen.

4.6.4 Kaingaroa Beach Sequence

4.6.4.1 Site description

This site is located several hundred metres north of the Kaingaroa slump section within the present day beach cliff (Figure 4.4). The section is composed of several metres of sands, clays and peat beds, and contains two tephra beds – the 26.5 ka Kawakawa and the 345 ka Rangitawa Tephras. Like the Kaingaroa slump site, this section is also interpreted to contain a major disconformity at the transition between the peat containing the Rangitawa Tephra and the overlying dune sands. As was the case with the Kaingaroa slump section, this disconformity is also interpreted to be the result of erosion in association with marine transgression over the peat, probably during the Last Interglacial, as unlike the slump section, the Kawakawa Tephra is present in this sequence, within a peat bed above the dune sands. The three peat beds at 250 - 278 cm, 380 - 410 cm and 674 - 704 cm have been sampled for pollen and the records are presented in Figure 4.9.

4.6.4.2 Present vegetation

The beach front cliff containing the sequence supports a coastal vegetation community, with ice plants (*Disphyma*), geranium (*Geum*), coastal grasses, sedges, *Coprosma* and Marram grass.

4.6.4.3 Description and interpretation of pollen record

Zone Km3 encompasses samples from the basal peat bed (674 - 704 cm) which contains the 345 ka Rangitawa Tephra. All samples from this zone were taxon poor. Pollen obtained from the samples underlying the tephra were reasonably well preserved and usable. However the samples from above were dominated by very poorly preserved pollen grains, some of which were mere ‘ghosts’. The samples from below the Tephra are dominated by grass pollen, and thus probably accumulated under dry glacial conditions, which is supported by the absence of ferns and wetland elements. Although preservation of the samples from above the Tephra is poor, the identifiable pollen indicate a slightly warmer and wetter climate.

Zone Km2 comprises the samples from the middle peat bed at 380 - 410 cm. This bed contains three silty horizons composed of very fine quartz. The bed and silt layers are interpreted to be of a glacial climate. Pollen flora from all but the top sample is dominated by Asteraceae, with minor amounts of Epacridaceae, *Coprosma* and other taxa. Levels of long-distance pollen are low, and where present, are dominated by *Nothofagus*. This peat probably accumulated under vegetation dominated by Asterad shrubs and trees e.g. *Olearia chathamica* and *O. Traversii,* during a glacial period, as indicated by a dominance of *Nothofagus* pollen in the long-distance fraction.

Zone Km1 comprises the peat bed at 250 - 278 cm, which contains the 27.1 ka Kawakawa Tephra. Samples obtained from this bed also showed signs of possible oxidation and variable preservation. Pollen from samples above and below the Tephra is dominated by Asteraceae and grass, with low levels of Epacridaceae and *Coprosma.* Ferns and other wet elements are virtually absent. The long-distance fraction is low ~1%, and is dominated by *Nothofagus*. The dominance of grass and Asteraceae pollen combined with low levels of *Dracophyllum*, *Coprosma* and fern spores, as well as the low levels of long-distance pollen, dominated by *Nothofagus* pollen, typifies the Asterad zone (Table 4.1) of Mildenhall (1994a) which contains the Kawakawa Tephra.

4.6.5 Mairangi Section

4.6.5.1 Site description

This section is located in a west-facing exposure near the Mairangi blowhole, around two kilometres south of Cape Young, the northernmost part of the island (Figure 4.4) and ~600 m to the south-west of a site sampled and described by Mildenhall (1994a). The section comprises a sequence of silts, sandy silts, sands and peat beds overlying Late Miocene/Early Pliocene tuffaceous marine sediments (Momoe-a-toa Tuff). The sequence contains both the 27.1 ka Kawakawa and the 345 ka Rangitawa Tephras. The peat beds within this sequence have been analysed for pollen, with the results presented in Figure 4.10.

4.6.5.2 Present vegetation

To the landward side of the site, the vegetation cover is pasture. The seaward side has a thin covering of ice plants (*Disphyma*), stunted pasture grass and prostrate shrubs.

Small remnants of broadleaved bush dominated by *Corynocarpus laevigatus* occur within one kilometre of the site.

4.6.5.3 Description and interpretation of pollen record

The lowermost and thickest peat bed (Mr4) is a hollow-fill peat bog, with a distinctive dish-shaped profile in the exposure. The pollen contained within it is dominated by Poaceae, also with high levels of *Gleichenia* spores and Restionaceae pollen, with low to medium levels of Epacridaceae pollen and low levels of *Coprosma*, *Myrsine* and Asteraceae. Levels of long-distance pollen are low (0 – 2 %) and are dominated by podocarps.

The next peat bed (Mr3) at 425 - 433 cm, contains elevated levels of *Coprosma* and *Myrsine* pollen relative to the previous peat bed. Levels of Epacridaceae pollen and tree ferns have slightly increased, while levels of grass, Restionaceae and *Gleichenia* have fallen significantly. Levels of long-distance pollen are high approaching 20 % of the total count and are dominated by podocarps.

The next two peat beds (378 - 388 cm and 398 - 411 cm) combined, form zone Mr2, bracketing the 345 ka Rangitawa Tephra. The flora of both beds is dominated by *Gleichenia* spores. Dryland vegetation is dominated by grass and Asteraceae. Levels of *Dracophyllum*, *Myrsine* and other ferns are reduced. Levels of long-distance pollen are very low (0 – 2 %) and are dominated by *Nothofagus* (in the upper bed). Both beds contain microscopic charcoal particles, possibly indicating fire in the region at the time of accumulation.

The uppermost peat bed, (Mr1) is considerably younger than those described above. It sits 8 cm below the 27.1 ka Kawakawa Tephra, in loessial clay material. It is dominated by *Dracophyllum* and Asteraceae pollen with low levels of *Coprosma*, *Myrsine*, *Gleichenia* and grass. The long distance fraction is small (4%) and contains equal levels of *Nothofagus* and podocarps (*Podocarpus* and *Dacrydium*).

The high levels of grass pollen in the basal peat bed (Mr4) would typically imply accumulation under cool, dry glacial conditions. However the levels of *Gleichenia* and Restionaceae present in this zone are indicative of moisture, so it is probable that one of these is of local significance rather than regional. The fact that this bed is overlain by aeolian sand suggests that it precedes a sand incursion possibly associated with an interstadial or interglacial sea level rise. The nature of the deposit itself i.e. a hollow fill rather than a blanket peat also suggests that the wet elements were of local significance, while the grass is more representative of regional vegetation at that time.

The flora of Mr3 is distinctively interglacial or interstadial, with elevated levels of *Coprosma*, *Dracophyllum*, *Myrsine* and tree ferns, while grass and Asteraceae pollen are greatly reduced. This peat probably began accumulation following the peak in sea level rise that was responsible for depositing the underlying sandy unit.

As Mr2 brackets the 345 ka Rangitawa Tephra it would be expected to contain glacial floral elements. This is reflected in the dryland pollen, which is dominated by Asteraceae and grass pollen, consistent with deposition during a cold, glacial period. The high levels of *Gleichenia* spores in both beds are again probably only significant locally. Both samples within Mr2 contain microscopic charcoal particles indicating occurrence of fire near to the site. This may explain the observed increase in levels of *Gleichenia* spores within the zone, but it is equally possible that this increase occurred in response to a shift in climatic conditions or hydrology.

Positioned between Mr2 and Mr1 is a thick unit of tuffaceous sandy silt, which is composed of reworked volcanic deposits. This deposit is unstructured and contains no stratigraphy, yet represents some 200 ka at the site. Mr1 appears to have accumulated under dry and possibly warm conditions, based on the high levels of *Dracophyllum*, combined with low levels of cool – wet elements. The bed's sub-Kawakawa Tephra position would suggest deposition during either the Interstadial OIS 3 or the Last Interglacial, OIS 5.

As mentioned earlier (section 4.6.5.1) Mildenhall (1994a) examined the pollen flora from a sequence exposed at a site several hundred metres north of this Mairangi site (Figure 4.3). Based on its position and the type of deposits it contains, it is probably at least partially correlatable with the section described here. The 10 - 15 cm tephra in Mildenhall's (1994a) Momoe-a-toa Quaternary sequence is almost certainly the 345 ka Rangitawa Tephra, which provides a point of correlation between the two sites. In general, conditions at the Mairangi site were wetter than those at the Momoe-a-toa site as evidenced by the higher levels of *Gleichenia* and Restionaceae encountered at the former. Both sites appear to represent dry coastal environments.

The occurrence of the 345 ka Rangitawa Tephra within the sequences at the Kaingaroa Slump, Kaingaroa Beach and Mairangi sequences provides a time plane for correlation between the three sites. Mr2 and Ks3 are both dominated by *Gleichenia*; however there are significant differences in the levels of dryland pollen taxa between the two, with Mr2 containing higher levels of grass and Asteraceae than Ks3. Also, the long-distance fraction of Ks3 is 5 % of the total pollen, and is dominated by podocarps, while in Mr2 it is only 0 – 2 % and contains *Nothofagus*. Ks1 correlates well with Mr2 below the Tephra. Correlations with peat above the Rangitawa Tephra are not possible due to the poor state of the pollen obtained from the peat in this stratigraphic position at the Kaingaroa slump and Kaingaroa beach sites. The lower larger peat layer, Mr4 is loosely correlatable with the lower part of the Kaingaroa beach section (450 – 515 cm), however, at Kaingaroa slump, levels of *Dracophyllum* pollen are overall much higher than at Mairangi, while at Mairangi grass levels are much higher than at Kaingaroa. Mr4 and Kr4 are both tentatively regarded as having accumulated under interstadial or interglacial conditions.

4.6.6 Boundary Rock cliff section

4.6.6.1 Site description

This site is located in an exposed face at the end of a farm track, just above the cliffs that truncate the southern uplands at the south-east end of the island (Figure 4.4). The name ‘Boundary Rock’ comes from the small rocky island named Boundary Rock that is visible from the site. The section comprises interbedded peat and silt layers, some with varying levels of sand. The 27.1 ka Kawakawa Tephra is present at a depth of one metre. The vegetation in the area of the site is pasture; however swampy areas and small forest remnants occur within a few kilometres.

The peat beds were initially interpreted as representing warmer/wetter periods, as the Kawakawa Tephra, which fell during a glacial period, is contained within a thick aeolian silt layer, implying that sedimentation at this site during glacials is dominated by clastic material. All peat beds are of a very fine texture with little macroscopic material. The thick basal peat has been divided up into 2 zones, and the 3 smaller peat beds in the middle-upper part of the sequence form individual zones.

4.6.6.2 Description and interpretation of pollen record

A separate count of long-distance pollen was also performed on the Boundary Rock site samples following the initial pollen count (Appendix 7B). This was done with the aim of establishing how many climate cycles might be preserved within the basal peat, and also to confirm whether the upper thinner peat beds accumulated during relatively warm periods i.e. interstadials or interglacials. As was the case with the Stony Crossing record, the long-distance values mentioned in the following descriptions and interpretation are those from the separate count and any major discrepancies between long-distance values from the pollen count and separate long-distance count are mentioned.

The pollen record is presented in Figure 4.11. The lowest, oldest zone Br6 extends from the base to 306 cm. Overall, the pollen flora is dominated by *Dracophyllum* and *Gleichenia*, with levels of grass, *Coprosma*, tree ferns and Asteraceae pollen all in the range of ~10-20%. The long-distance fraction is minimal, with no long-distance pollen encountered during counts in some samples. The separate long-distance count indicates that levels of *Nothofagus* and podocarp pollen are almost equal, with ratios in general, less than 1 (Appendix 7B).

Zone Br5 comprises the two samples between 306 -280 cm. It is marked by very low levels of Restionaceae, and decline in Poaceae and Asteraceae, and a rise in *Cyathea*. Long distance pollen is dominated by podocarps with a very high ratio of podocarp to *Nothofagus.*

Zone Br4 extends from 280 cm to the top of the major basal peat unit at 268 cm. It is marked by a major decline in *Gleichenia* and a rise in Restionaceae. Levels of tree ferns also increase. The long-distance pollen is very low, with the upper sample in the zone containing none and the lower samples containing low levels of *Nothofagus* and *Phyllocladus*. The separate long-distance count showed that podocarps were dominant (58 - 79%) with the ratio between 1.3 and 4.3.A major peak of microscopic charcoal is recorded in this zone, possibly representing a fire at or near the site.

Zone Br3 comprises the peat bed from 240 cm to 215 cm, and is, like the basal peat, dominated by *Gleichenia* spores. The dryland pollen is dominated by Epacridaceae and *Coprosma*, with varying levels of Asteraceae, tree ferns and grass. The long-distance fraction is almost completely dominated by podocarps, although like much of the basal peat, this is not reflected in the total pollen count, only the separate long-distance count.

Zone Br2 comprises the next peat bed from 207 cm to 194 cm. The flora of this bed is quite different from the previous 4 zones in that it is dominated by dryland pollen - Epacridaceae, *Coprosma* and Asteraceae, with virtually no wet elements – i.e. *Gleichenia* and Restionaceae. The long-distance fraction is 1 – 5 % of total dryland pollen, with podocarps dominant at the base of the layer, and *Nothofagus* dominant at the top.

The uppermost peat layer, zone Br1, is again dominated by Epacridaceae, with significant levels of Asteraceae. *Coprosma* levels fall, and there is still a notable absence of wet elements. The long-distance fraction is small to invisible in the pollen count, but the separate long-distance count shows that podocarps are dominant throughout. There is again a trend of increasing *Nothofagus* levels from the base to the top of the layer, as was seen in Br2.

The lack of age control within the basal peat bed makes it very difficult to determine exactly how much time it represents. When looking at it as a whole, zones Br6, 5 and 4 could all be interpreted as glacial, based on the dominance of *Gleichenia* (Mildenhall 1994a). The specific long-distance count of these zones shows almost equal amounts of *Nothofagus* to podocarp pollen and a very low *Nothofagus*: podocarp ratio, which is indicative of glacial conditions on mainland New Zealand (Mildenhall 1976, 1994a). There are no obvious changes from relatively cool to relatively warm conditions reflected in either the pollen diagram or the specific long-distance count. An exception is a peak in levels of long-distance pollen within zone Br5, dominated by podocarps near the top of the sequence, that would on its own represent interglacial, or interstadial conditions, which is also reflected in local pollen.

The peat bed of Br3 appears to have accumulated under interglacial conditions, based on the high levels of podocarp pollen. Local conditions were very wet and acidic, however the regional flora may have been much drier, based on high levels of Asteraceae and *Dracophyllum* and a lack of other fern species. The local dryland pollen of the basal sample (240 cm) is dominated by grass and Asteraceae, implying that the peat may have begun accumulating towards the end of a glacial period, although this is not reflected in the long-distance pollen.

Between Br3 and Br2 there is a major change in moisture availability at least on a local scale, with the complete disappearance of wetland elements, notably *Gleichenia* and an increase in *Coprosma* and *Dracophyllum*. The trend in the long-distance fraction from podocarp-dominance at the base to *Nothofagus* dominance at the top suggests that climatic conditions shifted from interglacial to glacial during the accumulation of the peat bed. This is also reflected in local pollen with a decline in *Coprosma* and *Dracophyllum* and a rise in Asteraceae in the uppermost sample (194 cm), but there is no rise in levels of grass pollen.

Br1 continues the trend of lower moisture levels than the basal zones, with *Dracophyllum* and Asteraceae the dominant taxa. The long-distance pollen shows the same trend as that of Br2, with an increase in the levels of *Nothofagus* from the base up. However podocarps remain dominant throughout.

The overall trend of decreasing moisture at the site may be related to local changes in hydrology. Marine cliffing events, possibly associated with regional tectonic uplift may have modified drainage extensively over the history of deposition at the site. The exposure of the sequence is currently not more than 20 metres from a 150 metre high cliff cut into the southern uplands.

Without any age control additional to the Kawakawa Tephra at 1 m it is difficult to assign ages to the peats with any certainty. It is possible to 'count back' from the 27.1 ka Kawakawa Tephra, assuming the silt layers are loessial in origin and accumulated during glacials. Using this rationale, Br1 accumulated during a moist and warm episode prior to the Last Glacial Cold Period (after Lowe *et al.* 2008), so the most obvious candidates are the relatively warm interstadial OIS 3, or the Last Interglacial

(OIS 5). Br2 would then represent either OIS 5 or possibly OIS 7, and then Br3 would be either OIS 7 or OIS 9.

The possible age range of the basal peat unit is less obvious. Br4 closely resembles glacial flora, with a peak in grass and low levels of long-distance pollen. However, the high levels of Epacridaceae and Restionaceae more closely resemble warm conditions like those of the postglacial at Oropuke (Mildenhall 1976, 1994a). The long-distance pollen is dominated by podocarps, although the ratio of podocarps to *Nothofagus* has decreased somewhat from Br5. Br5 may be interglacial, as indicated by high levels of Podocarpaceae pollen, *Dracophyllum* and tree ferns. Br4 may then represent the tail end or transition between interglacial conditions of Br5 and the subsequent glacial. Therefore, Br4 and Br5 may represent either OIS 8 or 10 and OIS 9 or 11, respectively.

The local flora of Br6 also resembles interglacial conditions, with the dryland fraction dominated by *Dracophyllum* and ferns, tree ferns and others. However long-distance pollen has almost equal proportions of *Nothofagus* and podocarps, which is characteristic of the glacial Asteraceae zone. It is possible that more discrete vegetation changes within this basal peat have been overlooked due to the low sampling resolution.

If these correlations are correct and the sequence does extend as far back as OIS 12, it begs the obvious question: where is the Rangitawa Tephra? Possible answers are that: it was not preserved at the site, or, that the whole sequence is younger than 345,000 years. The latter is believable when considering the rates of accumulation of both the peat and clay layers. Twenty centimetres of peat over 100,000 years is very minimal by any standard.

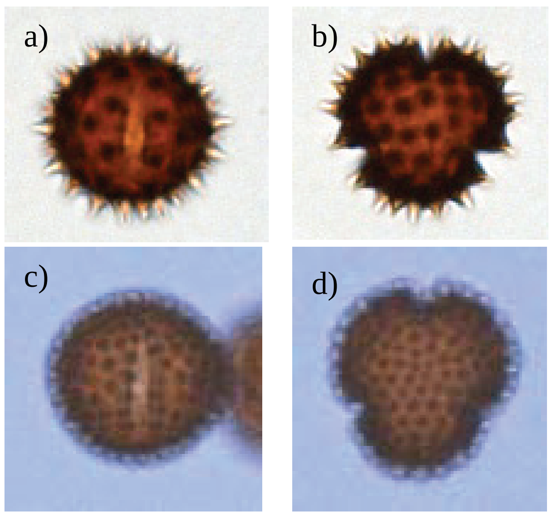
Apart from the 27.1 ka Kawakawa Tephra, no other primary tephra beds occur within the sequence. However a silty layer at 210 cm was found to contain minor amounts of rhyolitic glass shards. Electron microprobe analyses of these were inconclusive (Chapter 3, section 3.6.3). Most shards plotted well with respect to each other, yet the population does not correlate with any known New Zealand rhyolitic tephra. Potassium values are in general lower than the other Rangitawa correlatives identified on the island. Analysis of ilmenite grains from this layer (Chapter 3, section 3.6.2) indicates that it is not a primary tephra deposit. It is possible that these shards are reworked Rangitawa Tephra and if so they would provide a minimum age estimate for the middle of the sequence. From this, the maximum possible age of the interglacial/glacial represented by Br2 is OIS 9.

The peak of microscopic charcoal that is recorded in zone Br4, possibly represents a fire at or near the site at that time. Changes in pollen spectra associated with this peak include a major rise in Restionaceae, a decline in *Gleichenia*, and small rises in Poaceae and Asteraceae. These changes could also have easily arisen due to changes in climatic conditions rather than fire. Restionaceae typically is an initial coloniser of peat burns on Chatham Island yet so is *Gleichenia dicarpa* (Clarkson *et al.* 2004) which shows a major decline in this zone.

4.6.7 Red Bluff

Three samples were collected from within a peat bed immediately underlying the Rangitawa Tephra, from an exposure of Quaternary deposits that overly Paleocene-Eocene Red Bluff Tuff at Red Bluff in central Petre Bay (GR 466608, several hundred metres south of the North Red Bluff Quaternary sequence discussed elsewhere in the thesis). The pollen record from this site is presented in Figure 4.12.

Figure 4.13: Pollen grains of *Olearia semidentata* (a) equatorial view, (b) polar view; and *Olearia traversii* (c) equatorial view, (d) polar view.



The pollen flora of all three samples, from the top, middle and bottom of the layer are dominated by Asteraceae, with 15 - 20 % *Coprosma* and *Dracophyllum*. The Asteraceae pollen dominating these samples closely resembles that of the endemic *Olearia traversii* (Chatham Island Akeake), rather than that of other Chatham Island *Olearia* species (e.g. *O. semidentata*, *O. chathamica*) (Figure 4.13). Akeake is a common lowland forest tree especially on stabilising dune systems. The basal sample contains abundant fern spores which are probably associated with wetter conditions during the early formation of the peat bog. However the overall pollen flora is indicative of accumulation under dry coastal conditions. The long-distance pollen fraction is again low, and is dominated by *Nothofagus* pollen. A separate long-distance pollen count revealed only 1 - 2 podocarp grains per 100 *Nothofagus* grains. The position of this peat bed immediately below the Rangitawa Tephra indicates that it most probably accumulated during the glacial period of OIS 10. This is reflected in the local and long distance pollen.

4.7 Further discussion

The above interpretation and discussion of the pollen records examined in this thesis point to certain issues that require further discussion.

4.7.1 Long distance pollen

There are significant issues surrounding the significance of the long-distance fraction, particularly the question - what are the fluctuations really representing? An increase in the levels of long-distance pollen within the total pollen of a sample could conceivably represent:

- increased strength and/or persistence of westerly winds in the New Zealand region

  and/or

- a decrease in levels of local pollen production, reducing their ability to 'mask' the long-distance component.

In the case of zone Ks4 of the Kaingaroa slump section, extremely high levels of long-distance pollen were reported, approaching the equivalent of 70% of total pollen, which must result to some extent from reduced local pollen production. Yet increased windiness may have had some influence too. Increased wind circulation has been proposed to have occurred during the Last Glacial period (Stewart and Neall 1984, Nelson *et al.* 2000) and may be common to previous glacials. However, the dominance of podocarps in the exotic fraction indicates that Ks4 is interglacial or interstadial.

Changes in the proportions of taxa within the long-distance fraction may represent:

- A change in the vegetation composition at the source area, presumably in response to changes in climatic conditions;

  and/or

- A shift in strength and pattern of winds, i.e. the dominant source region of the pollen shifts due to changes in wind patterns.

Based on wind circulation patterns, the bulk of the long-distance pollen is most probably derived from North Island forests. Northland forests may have contributed a significant portion of the long-distance pollen, as pollen records from the region show that much of Northland remained under podocarp/*Nothofagus* forest during the Last Glacial period (Newnham 1999), while much of the remainder of the North Island and all of the South Island was under shrub or grassland (McGlone 1988). The fact that during glacial periods the long-distance fraction is dominated by *Nothofagus* pollen suggests that Northland may have been a source region.

The presence of the two rhyolitic tephra horizons provides an excellent opportunity to test the general theory that *Nothofagus* represents a cool glacial climate while podocarps represent warm or interstadial/interglacial climates. Both tephras are regarded as having been erupted during glacial periods OIS 2/3 and 10 respectively, and long-distance (and local) flora of bracketing peat is usually consistent with accumulation during a glacial period. The long-distance fraction is low (<5%) and dominated by *Nothofagus* or containing equal amounts of *Nothofagus* and podocarp pollen. This seems to confirm that the long-distance pollen is a reasonably reliable indicator of climatic conditions in the southern Pacific region.

Another significant question revolves around what other species are carried to the island. It is easy to recognise that long-distance transport of pollen occurs when it is dominated by species that are not native to the island. However, what about species that are native to both the mainland and Chatham Island? For example, *Coprosma*, Poaceae, and tree ferns are significant floral components of both Chatham Island and mainland pollen records. They could conceivably be transported to and incorporated into Chatham Island pollen records, where they would essentially be indistinguishable from local pollen of the same species. This could have the effect of falsely raising levels of these species in the pollen diagram. This is significant in the case of *Coprosma* which appears to be more common in interglacial floras on Chatham Island (Mildenhall 1994a, McGlone 2002), but can be a major component of glacial shrubland floras on New Zealand.

Pollen records spanning the Plio-Pleistocene from ODP site 1123, located 350 km north-east of Chatham Island (Figure 3.1), contain significant levels of New Zealand pollen and spores delivered to the site by both fluvial and aeolian means. These include *Coprosma*, and also *Dicksonia*, *Gleichenia*, *Microsorum*[*] and monolete fern spores (Mildenhall 2003), all of which occur in Chatham Island pollen records, proving that pollen of these species is also transported long-distances from source. However it is most probable that these mainland-derived palynomorphs would only be present in Chatham Island records in minor levels. *Nothofagus* and Podocarpaceae are renowned for their long-distance travel (McKellar 1973, Meyers 1973). They are anemophilous and produce pollen in massive amounts. Other long-distance elements that occur within Chatham pollen records are not so well renowned. Pollen levels of taxa other than *Nothofagus* and Podocarpaceae recognised in both this work and that of Mildenhall (1976), are invariably low and only occur in a few samples e.g. *Dodonaea viscosa* and *Metrosideros*, and this is probably the case also for *Coprosma*, fern spores and other species as well. Those that do reach Chatham would do so in such minimal numbers as to not influence pollen diagrams at all.

Generally, fluctuations in levels and composition of the long-distance fraction seem to match well with changes in local floral assemblages. However there are certain notable discrepancies, including zone Sc3 at Stony Crossing, and Ks5 at Kaingaroa, where the local flora indicates accumulation under interglacial vegetation, while the long-distance fraction implies that the mainland was under glacial vegetation. These discrepancies suggest that mainland New Zealand and Chatham Island flora may respond to global climate change differently. The observed variations imply that the flora of Chatham takes longer to respond to a cooling in climate, and possibly responds sooner to warming. Perhaps deterioration of climate during a glacial is more pronounced in mainland New Zealand than on the maritime Chathams. As is the case

[*] formerly *Phymatosorus*

today, the surrounding ocean must have played a role in moderating the island climate during the glacial periods.

Considerably more work is required to fully understand the significance and potential of long-distance pollen in Chatham Island pollen records, which is beyond the scale of this project. An intensive modern pollen rain study carried out over a period of years is required to understand how seasonal variations in wind patterns and strength relate to the levels and composition of the long-distance pollen rain reaching Chatham Island. This would also show whether long-distance pollen rain is homogenous across the island, or whether certain areas, e.g. the southern uplands receive more. However, as New Zealand's forest cover is now heavily modified, results from this study may not be directly applicable to fossil pollen assemblages.

4.7.2 Microscopic charcoal particles

Charcoal particles were encountered in varying amounts at most sites sampled. However there were no obvious correlations in charcoal peaks between sites, even though the tephrostratigraphic evidence shows that sites almost certainly span similar periods of time or overlap to some degree. This suggests that if fires on the island were responsible for the charcoal particles, then they must have been extremely small and localised, as charcoal particles are easily distributed over wide areas.

The most predominant causes of natural fires are lightning strikes or volcanic activity. Peat-covered areas can also be subject to fires caused by spontaneous combustion of methane. Lightning strikes are unlikely to ignite the moist, peat-forming vegetation of Chatham Island, which has been present on at least parts of the island for more than 350,000 years. Drier coastal forest may have been more susceptible. It has recently been suggested that certain natural catastrophes can result in forest die off (McFadgen *in* Butler *in press*), which would provide adequate fuel for a lightning strike fire. The most likely event to cause this on Chatham Island would be a tsunami, a phenomenon which has inundated parts of the island on at least two occasions during historic times (1868 and 1960), and thus most probably during earlier pre-historic times. There are no data available on the frequency of lightning strikes on Chatham Island, however meteorological records indicate that thunderstorms, (required to produce lightning) occur on average on 4 days per year (Thomson 1983). Thus the frequency of lightning strike on Chatham Island can be assumed to be low.

Geological evidence shows that volcanic activity in the Chathams region ceased at ~2.7 Ma following the eruption of the Pyramid Phonolite (Campbell *et al.* 1993), thus volcanism could not have ignited fires within the time span of these records.

There is also no record of the occurrence of fires in Chatham peats caused by spontaneous combustion of methane, although there are numerous accounts (e.g. Dieffenbach 1841) of underground peat fires burning for considerable periods of time (months to years) from burning associated with land clearance. Thus it seems that fires, localised or otherwise, were an infrequent event on pre-human Chatham Island.
The possible presence of allochthonous charcoal particles cannot be discounted. Fires have been a regular occurrence in the New Zealand region since <2000 years, following the arrival of man (McGlone & Wilmshurst 1999), and pollen evidence shows that they have occurred sporadically throughout New Zealand Quaternary history. Australia has a more vigorous history of bushfires, both natural and anthropogenic spanning back to at least 350,000 years (Singh & Geissler 1985). The existence of long-distance pollen within Chatham Island deposits proves that small particulate matter like charcoal and pollen can reach the island from not only New Zealand, but also Australia. Convection during bushfires pumps soot particles high into the atmosphere making them available for long-distance transport (Clark 1988). It is already well known that transport of dust from Australia to New Zealand occurs following major dust storms (Mokma *et al.* 1972, Marx *et al.* 2005, Marx & McGowan 2005) and it has been suggested that charcoal particles may be included in this dust fraction too (Butler *in press*). The latter author has also suggested that dust including small charcoal fragments may be distributed globally from many continental sources.

If present, allochthonous charcoal peaks would be composed entirely of fine particles, uniform in size due to atmospheric sorting and particle fallout during transport (Faegri & Iversen 1989). Most peaks present within these records contain a range of particle sizes. However peaks WqA & WqB in the Wharekauri Quarry record are composed dominantly of fine particles and thus may represent long-distance fires.

Although some charcoal peaks reflect actual fires, the possibility exists that some of the counted particles may not be true charcoal. Charcoal-like particles can be produced *in situ* in surface and sub-surface positions within peat without any fire at all (Kemp 1981, Boyd 1982). This would explain the particle-size distribution of the charcoal fraction in the Stony Crossing record, and also why some charcoal peaks are spread over what equates to a long period of time in the record e.g. Kaingaroa Slump section peaks (KsA & KsB). It would also explain why some samples contain low, levels of charcoal fragments of all sizes. In charcoal counts from natural fires small particles <20 μm are the most abundant, and levels tend to decrease exponentially with increase in size. However, in several of the samples in this work, abundances of size classes do not follow this pattern with some samples containing more large and medium particles than small. It could be argued that a fire occurred in close proximity to the site; however, in most of these cases, the total number of charcoal fragments encountered was quite small (<10% of total pollen), whereas if a fire had occurred on site, then charcoal would be expected to dominate the sample. Also, in these cases there is no major change in vegetation composition that would be expected to follow a fire at the source, which on Chatham Island would be a disappearance of woody taxa/shrubs replaced by rushes and *Gleichenia*. The environmental significance of this '*in situ* charcoal' is not well understood. It probably forms by dehydration and oxidation processes at the peat surface (Kemp 1981).

Thus, when considering the low probability that natural fires occurred on Chatham Island, combined with the charcoal particle-size data, it seems unlikely that all the peaks of charcoal-like particles represent actual fires on the island.

4.7.3 Response of vegetation to ash fall

Ash fall from volcanic eruptions is known to damage vegetation through smothering, loading of foliage and slowing of photosynthesis. Both eruptions recorded in the above pollen records resulted in significant thicknesses of ash being deposited on the vegetation of the sites. However, none of the records indicate significant changes in vegetation composition following ash fall. The Stony Crossing record shows no major changes pre- and post- Kawakawa Tephra; the Mairangi record also shows no major changes following the fall of the Rangitawa Tephra. Wharekauri has insufficient data following the Kawakawa; and Kaingaroa slump also has insufficient data following the Rangitawa due to poor preservation in the samples above the Tephra. The Kaingaroa beach sequence shows a strong rise in fern spores in the peat above the Rangitawa Tephra. However, the quality of pollen preservation in these samples is also quite poor so these data cannot be considered reliable. An increase in fern spores may reflect low pollen production at the site rather than increased ferns (McGlone & Meurk 2000), both of which may have occurred in response to tephra fall. Mildenhall (1994a) also recorded no significant changes in vegetation composition following the fall of the Kawakawa Tephra at Mt Dieffenbach, Te Pukaha and Oropuke. This suggests that the island's vegetation was not greatly affected by the fall of these tephras. It is probable that the ash fell over a period of days with rainfall and wind possibly removing it from foliage before severe damage occurred. An alternative explanation for the lack of evidence of vegetation response could be that if it occurred it did so within a relatively short period of time, and is preserved at a finer resolution than the sampling interval. Or, alternatively, disconformities exist between the upper and lower limits of the tephra and the pollen samples, as is the case in drill holes from the Wellington region (Mildenhall 1994b).

4.8 Concluding remarks

One must be cautious in drawing conclusions from the above palynological data, because pollen dynamics on Chatham Island probably need considerably more research than they have received to date. Interpretation of the data presented here is complicated by several factors, predominantly low sampling resolution combined with a lack of age control apart from the two rhyolitic tephra beds and other relative geomorphic and stratigraphic evidence. In the case of the continuous peat sequences, vegetation changes of small duration and small scale shifts in vegetation composition would likely have been missed, especially where peat accumulation rates appear to be minimal and a single one centimetre of peat thickness may in fact contain 100 – 1000 years worth of pollen. Regardless, much useful information has still been obtained. Comparison of the record at Wharekauri-Kaingaroa turn-off quarry with Mildenhall (1994a)'s pollen zones indicates that it spans the Last Glacial period. Thus the underlying wave-cut surface is tentatively confirmed as the Last Interglacial marine bench. Pollen zonation and long-distance pollen information suggests that the Stony Crossing section may possibly be older than first thought, and could extend back to OIS 6.

Palynology of the peats at Kaingaroa Slump section, Kaingaroa Beach section and Mairangi provide a record of vegetation of ancient peats from a time span not previously studied on Chatham Island, with the possible exception of a limited study at Momoe-a-toa (Mildenhall 1994a). It is likely that the Boundary Rock record also covers a comparable if not older record of vegetation in the area, but this cannot be proven until further suitable age control is found.

Overall, most pollen samples can be related to the zones proposed by Mildenhall (1994a), and McGlone (2002) allowing further interpretation of the other deposits at the sites and the sites themselves. This palynological evidence will be utilised in discussions of Quaternary stratigraphy in the following chapters.

Investigation of samples adjacent to the two tephra beds lends further support to the theory of Mildenhall (1976, 1994a) that long-distance pollen provides a direct means of correlating Chatham Island (and also other offshore island's) pollen records with those of mainland New Zealand.

Based on the relationships between local pollen spectra, tephra beds and long-distance pollen, it appears that cyclical changes in vegetation composition have occurred on Chatham Island throughout the Quaternary, and that wind patterns have been such that the island has received a more or less constant 'supply' of forest pollen from mainland New Zealand forests.

CHAPTER 5
STRATIGRAPHY

5.1 Introduction

To date, the Quaternary stratigraphy of Chatham Island has been the subject of limited research. Most works dealing with Quaternary deposits have involved only the youngest strata, primarily Last Interglacial and younger (i.e. OIS 5e – 1). This is largely because deposits of this age range are the most abundant and widely exposed across the island, and also because the focus of many previous expeditions was on investigating the economic potential of Chatham Island peats (e.g. MacPherson and Hughson 1943, and Richards 1987), the bulk of which are of Last Interglacial age or younger. The most detailed study of Quaternary strata and sediments published is that contained within Hay *et al*. (1970). They describe four recognisable Quaternary stratigraphic units and interpret them in relation to eustatic sea-level fluctuations (Chapter 2). Campbell *et al.* (1993) subsequently reviewed and revised the stratigraphy of Hay *et al.* (1970), but did not undertake any further investigation of Chatham Quaternary stratigraphy, with the exception of two fossiliferous shallow-marine units – the Titirangi Sand (Nukumaruan, Early Quaternary) and the Owenga Shelly Sand (Recent).

A revised stratigraphic nomenclature for Chatham Island Quaternary deposits is presented in Table 5.1. All Quaternary strata belong to the Karewa Group (after Campbell *et al.* 1993). Karewa Group sediments disconformably overly all older rocks on Chatham Island. The group has accumulated following the uplift of Chatham island from a marine environment to a terrestrial one sometime during the Late Pliocene (Campbell *et al.* 1993, 2006). Thus the bulk of the Karewa Group sediments are terrestrial in origin. Marine deposits are limited to near-shore shell beds, beach sands, and gravel lags of minor extent.

This chapter deals with the stratigraphic investigations undertaken as part of this thesis. The existing stratigraphic units are described, and new formations are introduced and defined. Descriptions of all stratigraphic sections examined during fieldwork are presented in Appendix 8, while the more important sections are described within the text and their significance highlighted and discussed. These sections have been correlated with New Zealand chronostratigraphic stages, and where possible individual units have been correlated with the Oxygen Isotope Stage (OIS) chronology of Shackelton *et al.* (1990). Most of these correlations are based on stratigraphic relationships with rhyolitic tephra marker beds, but further independent age control is desirable to confirm these correlations.

Table 5.1: Revised Stratigraphic Nomenclature for Chatham Island Quaternary Deposits.

TE AWAPATIKI SHELLY SAND

New Formation

Inferred age:	Last Interglacial (OIS 5), late Pleistocene.
Type section:	GR 569536 Southern Hanson Bay Coastline.

OHIRA BAY BOULDER GRAVEL

New informal unit

Inferred age:	Last Interglacial (OIS 5) or Penultimate interglacial (OIS 7), late Pleistocene.

HAWAIKI FORMATION

First described by:	Mutch in Hay *et al.* (1970) (as Owenga Formation).
Further defined/described by:	Campbell *et al.* (1993).
Inferred age:	late Pleistocene (possibly Penultimate interglacial, OIS7).
Type section:	Not designated, but implied by Hay *et al.* (1970) as in the north bank of Hawaiki Creek, Owenga township.

OWENGA SHELLY SAND

First described by:	Dell (1960) (as Owenga Shell bed).
Further defined/described by:	Campbell *et al.* (1993).
Inferred age:	Late Holocene (RC date of 480 ± 40 yr).
Type section:	Not designated.

WHAREKAURI SAND

First described by:	Hay *et al.* (1970).
Further defined/described by:	Campbell *et al.* (1993).
Inferred age:	Late Castlecliffian – Recent.

Table 5.1 continued

Type section:	Not designated, but implied by Hay *et al*. (1970) as same location as Titirangi Sand.

MOORLAND PEAT

First described by:	MacPherson & Hughson (1943).
Further defined/described by:	Hay *et al.* (1970), Campbell *et al.* (1993), Mildenhall (1994a).
Inferred age:	Late Castlecliffian – Recent.
Type section:	Not formally defined, but Mildenhall (1994a) proposed that an exposure of Moorland Peat at Te Pukaha be designated as the type section.
Members:	Highmoor peat Lowmoor peat Southern highlands red peat

MAIPITO FORMATION

New Formation

Inferred age:	Late Castlecliffian – Recent.
Type section:	GR 439544, cliff exposure behind Chatham Island radio station.

TITIRANGI SAND

First described by:	Marwick (1928) (as Titirangi Series).
Further defined/described by:	Hay *et al.* (1970).
Inferred age:	Early Nukumaruan; Early Quaternary.
Type section:	GR 497724, shore of Te Whanga Lagoon.

5.2 Stratigraphic nomenclature

5.2.1 Formal Units/Formations

TITIRANGI SAND

This formation comprises richly fossiliferous shelly sands present beneath younger terrestrial Quaternary sediments in the central part of Chatham Island. The fossil fauna of the formation is dominated by the bivalves *Gari* and *Tawera* (Campbell *et al.* 1993), indicative of deposition in a shallow, sheltered marginal marine environment. Campbell *et al.* (1993) highlights the significance of this formation in that it is the oldest post-Cretaceous formation to contain terrigenous sediment, namely quartzose sand and pebbles derived from Chatham Schist. Also its position disconformably overlying a deep water limestone unit (Motorata Limestone, Opoitian/Pliocene) indicates that the formation was deposited following uplift and emergence of Chatham Island. The formation is regarded as Early Nukumaruan in age based on biostratigraphic evidence.

WHAREKAURI SAND

This formation is described as comprising consolidated dune-bedded quartzose sand with beds of peaty lignite, and overlies all pre-Quaternary deposits on Chatham Island (Campbell *et al*. 1993). Hay *et al.* (1970) initially assigned a Nukumaruan age to the formation, as they interpreted it to have accumulated shortly after the Titirangi Sand. However there is no firm evidence for this, and Campbell *et al.* (1993) subsequently broadened the age range to Nukumaruan – Recent.

A type section for the Wharekauri Sand has not been formally designated, although Hay *et al.* (1970) imply that it is the same exposure as that of the type section of the Titirangi Sand. In their original description of the formation, Hay *et al.* (1970) suggest that it represented sand advance associated with an interglacial sea level rise in early Castlecliffian times. However, the formation actually comprises numerous sand units of varying ages that were deposited during separate transgression events during different climatic cycles, rather than simply just one cycle as implied by Hay *et al.* (1970). This is particularly apparent in the few sections of pre-OIS 5 deposits on the island, where units of Wharekauri Sand are separated by paleosols, disconformities, or units of other formations. These represent significant periods of time when depositional conditions changed, presumably in response to repeated cycles of climate change throughout the Quaternary.

Subdivision of the formation into separate formal units assigned to Oxygen Isotope Stages is not justified or practical, because separate units can only be recognised at a few limited exposures, and these units are not, at this stage, mappable with even the smallest degree of certainty.

Across the island, and within exposures of Quaternary sequences, the appearance and nature of the formation is essentially the same. However there are variations in the degree of dune bedding, the level of consolidation, mineralogical composition, sedimentology, and the presence and number of ‘peaty lignite’ horizons.

The beds of 'peaty lignite' described by Hay *et al.* (1970) are probably thin peat stringers that have dried and hardened, resembling lignite. Such stringers have been observed at many outcrops of Wharekauri Sand across the island. The presence or absence and number of peaty horizons should not be regarded as a defining feature of the Wharekauri Sand.

The grain size of the Wharekauri Sand ranges from fine sand to coarse pebbly sand. Units within the formation also often contain thin horizons of scattered, rounded to angular pebbles. The pebble lithologies normally reflect the dominant pre-Quaternary lithology in the immediate vicinity of the exposure, yet usually contain clasts of black or orange chert. The orange chert is now known to be derived from the Miocene Taoroa Limestone, preserved under Maunganui Bluff. However, the origin of the black chert is unknown (H. Campbell, pers. comm.), and it is probably derived from another limestone unit, no longer represented in the Chatham Islands. Mineralogical composition of the formation varies from site to site, reflecting inputs from different source rocks in the site vicinity. The Mesozoic Chatham Schist is the principle sediment source. Variations in levels of ferromagnesian minerals result from varying inputs from volcanic sources; while abundance of calcareous material increases in units at sites proximal to limestone outcrops (section 5.3.1).

As alluded to previously, deposition of the units within the Wharekauri Sand is attributed to sand dune advances, which have accompanied eustatic sea level rise during interglacial periods. Many units show evidence of vegetation and soil development towards their upper contacts, which would have occurred following dune stabilisation, once landward transgression of the dunes ceased.

MOORLAND PEAT

The term Moorland Peat is the formal name applied to all peat and peaty sand deposits overlying the Wharekauri Sand and older rocks on Chatham Island (Campbell *et al.* 1993), and incorporates all previously described peat units (Table 5.2). Various aspects of the Moorland Peat have been covered in previous publications. Most of these regard the formation as late Haweran in age (Last Interglacial to Recent). This age range is based on the presence and stratigraphic position of the now well dated 27.1ka Kawakawa Tephra, several radiocarbon dates obtained from various depths within peat profiles at Mt Dieffenbach, Te Pukaha and Oropuke (Mildenhall 1994a) and near Kairakau (Moar, in Hay *et al.* 1970), as well as palynological evidence (McGlone 2002). However, investigations undertaken during the course of this work have discovered occurrences of Moorland Peat in close proximity to or containing the ~345ka Rangitawa Tephra. This extends the age range of the Moorland Peat to late Castlecliffian-Haweran-Recent in age.

There is currently no type section for the Moorland Peat, although Mildenhall (1994a) suggested that the profile of a peat burn at Te Pukaha be designated as the type section; however this has yet to be formalised.

The formation is composed of several different types of peat. By far the most significant of these in terms of thickness and extent are the 'Moorland' or 'Highmoor' peats, as described by MacPherson and Hughson (1943), Hay *et al.* (1970) and Richards (1987). The Highmoor peat is here regarded as an informal member of the Moorland Peat.

Table 5.2: Moorland Peat correlatives presented in previous publications

Campbell *et al.* (1993)	This Work	MacPherson & Hughson (1943)	Hay *et al.* (1970)	Richards (1987)	Related soil groups of Wright (1959)
MOORLAND PEAT FORMATION All peat and peaty sand deposits overlying Wharekauri Sand and older formations on Chatham Island.	**Lowmoor peat member**	**Lowmoor peat** (no age given)	**Younger Peat** (Holocene - Recent)	**Sedge peat** (no age given)	**Mautere loamy peat, Matarae peaty loam, Pateriki peaty sandy loam and loamy peat, Hapupu sandy peat, Mautere loamy peat, and Tapuika peat**
				Lowmoor peat (no age given)	
	Southern highlands red peat member			**Southern highlands red peat** (no age given)	**Awainunga peat and Awainunga-Rekohu complex**
	Highmoor peat member		**Waihi peat** (<26,500 yr)		
		Moorland/upland peat (None given, although peat interpreted to be from previous climatic period)	**Moorland peat** (Last Glaciation)	**Highmoor peat** (>20,000)	

Highmoor peat member:

The Highmoor peats are stratified blanket peat deposits, with many wood-, sand-, and silt-rich horizons. They are best described as resembling black shoe polish in texture and colour, characteristics which have resulted from a combination of thorough humification and compaction, and high wax content. The Awainunga peat and

Awainunga-Rekohu soil complex of Wright (1959) are developed in the Highmoor peat member.

The bulk of the Highmoor peat appears to have accumulated between the Last Interglacial (125 ka – 75 ka) and the Last Glacial Cold Period (30 ka – 80 ka), and is, for the most part, no longer accumulating, with the exception of restricted areas still under *Dracophyllum* forest on the southern uplands. As mentioned above, there are limited occurrences of much older, late Castlecliffian peat deposits on the island. The stratification within the Highmoor peat member has been described as similar across the island, with silty and woody layers occurring at similar positions within peat profiles at many different locations (Hay *et al*.1970, MacPherson and Hughson 1943). There are not enough exposures of the older Castlecliffian Highmoor peat to be able to establish whether similar patterns occur within these older peat deposits. Other peat types which have been described in previous publications (Table 5.2 and also refer to Chapter 2), within the formation are generally much younger, and lack the wax content and degree of humification of the Highmoor deposits. Based on these differences two additional members of the Moorland Peat have been defined to describe these younger deposits.

Southern highlands red peat member (after Richards 1987).

This member comprises peat with a distinctive red colouration, interpreted to be from inputs of *Dracophyllum* litter. Like the Highmoor peat member, the red peat also contains significant amounts of plant wax (Richards 1987). It also typically contains abundant woody material, much of which is interpreted as the remains of *Dracophyllum arboreum* (Richards 1987). It was initially regarded as occurring exclusively in the southern highlands, but has subsequently been encountered at lower altitudes along the coast north of Owenga. It overlies Highmoor peat and sand, and is overlain by sand or Lowmoor peat, and is of Holocene age. Along the coast to the north of Owenga, one to two metres of southern highlands red peat overlies Highmoor peat containing the Kawakawa Tephra, and post-glacial dune sand.

Lowmoor peat member:

This unit comprises fibrous peat which is usually very wet and lacks the high wax content of the older Highmoor peat member. The Lowmoor member typically occurs around the margins of lakes, lagoons and waterways, in hollows and also forms small raised bogs. The Lowmoor peats are Holocene in age and are still accumulating today. They are thus the youngest member within the Moorland Peat formation, typically overlying Highmoor peat, Southern highlands red peat or Holocene sand or alluvium. This member is equivalent to the Lowmoor deposits of MacPherson and Hughson (1943), the Younger Peats of Hay *et al*. (1970), and the Lowmoor and Sedge peats of Richards (1987). The Mautere loamy peat, Matarae peaty loam, Pateriki peaty sandy loam and loamy peat, Hapupu sandy peat, Mautere loamy peat and Tapuika peat soil series' of Wright (1959) are all developed in the Lowmoor peat member (Table 5.2).

MAIPITO FORMATION

The term Maipito Formation is proposed for the silt and sandy silt cover-bed deposits on Chatham Island. Thin peat beds associated with or developed in these deposits are included in the Formation. The Formation is predominantly composed of re-worked palagonitic tuff derived from pre-Quaternary volcanic rocks, namely Red Bluff Tuff (Paleocene/Eocene), Northern Volcanics (Late Paleocene – Late Miocene) and the Mairangi Group volcanics (Late Miocene – Late Pliocene). Varying amounts of sand- and silt-sized quartz derived from the Chatham Schist are admixed within the reworked tuff. Conspicuous pale-coloured silt-rich horizons, strongly resembling rhyolitic tephra beds, are also a common feature of the Formation (Plate 5.1, and also Chapter 3, section 3.6).

The Maipito Formation is very similar in appearance to tuffaceous beds of older volcanics from which it is derived. Where it directly overlies these older deposits it can be distinguished by a number of criteria, most predominantly changes in colour, texture and structure (Plates 5.2 a. and b.). The older tuff beds are often finely bedded or laminated (millimetre-centimetre) at low to moderate angles reflecting accumulation on the flanks of a submarine volcanic mound. In contrast Maipito Formation sediments lack this lamination, having instead a blocky soil structure with evidence of soil formation and biological activity such as root channels and worm burrowings. The Formation mineralogy also contains quartz, which is absent from the dominantly basic volcanics. These deposits cannot satisfactorily be assigned to or associated with any of the existing Quaternary formations described from Chatham

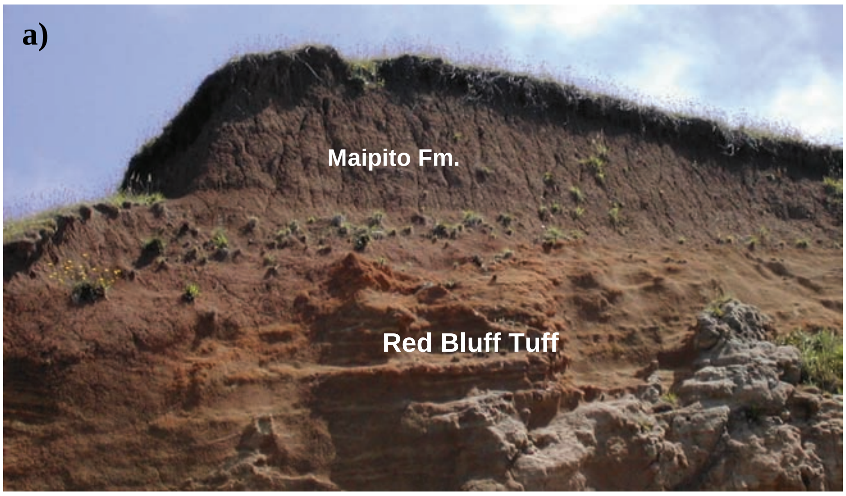
Island (i.e. Wharekauri Sand or Moorland Peat), so have been recognised as a new formation.

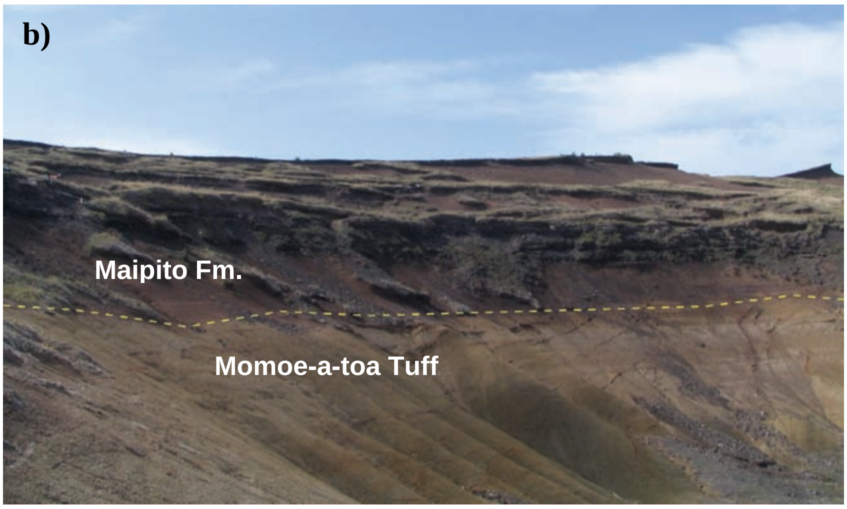
The type section for the Formation is the cliff exposure located to immediately to the west of the Chatham Island Radio Station, located off the Waitangi to Tuku Road (GR 439544). The section comprises several metres of Maipito Formation sediments, containing the 27.1 ka Kawakawa Tephra near the top. The name Maipito comes from Maipito Road near the town of Waitangi, an area where the deposits of the formation blanket the pre-Quaternary geology.

Plate 5.1: Sequence of Maipito Formation sediments exposed on the Waitangi-Owenga Road. The position of the Kawakawa Tephra is indicated by the upper arrow, while the position of a silt-rich pale coloured layer is indicated by the lower arrow.

The units within the Formation range from Castlecliffian to Haweran to Recent in age, and are present in varying thickness in most parts of Chatham Island, often interdigitating with both the Wharekauri Sand and Moorland Peat Formations, particularly in the Mairangi and Kaingaroa areas. Both the Kawakawa and Rangitawa Tephras can be found interbedded within the Formation. It is best exposed in road cuttings along the Waitangi to Tuku and Waitangi to Owenga Roads (Plate 5.1), and in the type section located in the cliff behind the radio station. It is also interpreted to be present beneath much of the Wharekauri Sand and Moorland Peat deposits that blanket the island, as is indicated by drill hole data presented in Richards (1987). The Mangahau, Tiki and Huro soil series of Wright (1959) are developed within sediments of the Maipito Formation.

Plate 5.2: Contact between sediments of the Maipito Formation and older underlying tuffaceous beds.
a) 1-2m of re-worked palagonitic ash of Maipito Formation overlying Red Bluff Tuff, exposed above Waitangi Wharf. Note sub-vertical cracks, and slightly darker colour of the Maipito Formation, while underlying volcanics have sub-horizontal bedding.
b) exposure of Maipito Formation (dark brown) overlying Momoe-a-toa tuff (olive brown) at Mairangi.



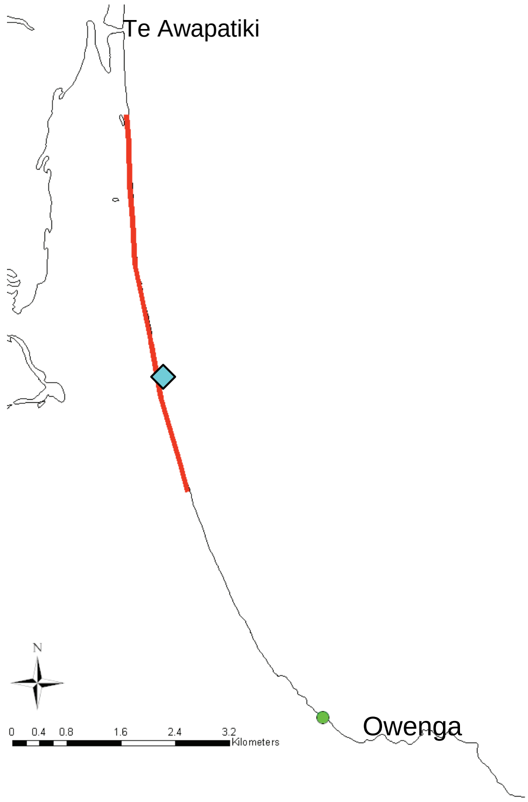


TE AWAPATIKI SHELLY SAND

This is a new formation comprising shell-rich sands that crop out along the coast to the north of Owenga township (Figure 5.1). The formation is composed of dark coloured, strongly horizontally laminated beach sands containing abundant disarticulated and reworked bivalve shells and shell fragments (Plate 5.3 a. and b.). The dark colour of the sands results in part from the fact that they are dominated by heavy minerals, and also from translocated peaty material and tannins derived from overlying peaty deposits.

The type section (GR 569536) for the Te Awapatiki Shelly Sand is in an exposure within the coastal cliff present along the Hanson Bay coastline, as depicted in Figure 5.1.

Figure 5.1: Region where Te Awapatiki Shelly Sand is exposed, as indicated by the red line. The blue diamond marks the location of the type section, while the green dot marks the location of the type section for the much younger Owenga Shelly Sand.



The abundance of heavy minerals is in stark contrast to most other sand units on the island, e.g. the Wharekauri Sand, which is quartzose. The mineralogy of the formation is dominated by pyroxene (mostly clinopyroxene, with minor orthopyroxene) with lesser amounts of quartz, feldspar, magnetite and euhedral garnet (Appendix 9). The most likely source of the majority of these minerals are the basaltic lavas (Southern Volcanics) exposed at the southern end of Hanson Bay. During the sea level rise accompanying the Last Interglacial (OIS 5e), increased erosion of these lavas from wave action would have resulted in greater inputs of basic minerals into what was (and is today) a dominantly quartzose beach sand. This unit is demostratably older than the Owenga Shelly Sand, as it is overlain by >2 m of sand, peaty sand and peat deposits. It is here interpreted to represent the Last Interglacial transgression in the Owenga region. The name is from the area where Te Whanga Lagoon opens to the sea, known as Te Awapatiki, meaning ‘path of the flounder’.

The formation is species poor. Almost all fossils are disarticulated valves of *Paphies ventricosa*, reworked by current action. This species is abundant in the modern beach environment, both in the vicinity of exposure of the formation, and on mainland New Zealand. The formation has not been recorded anywhere else on the island at this stage, although vibro-coring of the low plains in the region between Maipito Road and the Waitangi-Owenga Road intersection encountered shell-rich sandy deposits at around one metre below the surface. This is possibly Te Awapatiki Shelly Sand.

Plate 5.3: a) Te Awapatiki Shelly Sand (base) exposed beneath younger dune sand and Moorland Peat at the type locality, on the coast, ~8km north of Owenga Township. b) heavy mineral-rich, horizontally layered sands and shelly layers within the Te Awapatiki Shelly Sand.

HAWAIKI FORMATION

This formation was initially introduced by Hay *et al.* (1970), as the Owenga Formation and was subsequently renamed by Campbell *et al.* (1993) to avoid confusion with the Owenga Shelly Sand. It comprises a sandy gravel lag deposit that overlies a surface cut into older lithologies in the region of the Owenga township, and is regarded by Hay *et al.*. (1970) as the Last Interglacial (OIS 5e) marine bench, yet there is no firm age control for this correlation. The Formation is disconformably overlain by the Moorland Peat. Campbell *et al.* (1993) suggests that the Formation can probably be demonstrated as indistinguishable, lithologically, from the Wharekauri Sand.

OWENGA SHELLY SAND

This unit was initially recognised and defined by Dell (1960). It comprises shell-rich storm-beach deposits of Recent age. A radiocarbon date of 480±40 (NZ5381B; new half life) years B.P. has been obtained from shells within the sand (Campbell *et al.* 1993). It is inferred to be present along much of the Hanson Bay coastline, where it overlies older Holocene peat and dune sands and the Te Awapatiki Shelly Sand.

5.2.2. Informal units

OHIRA BOULDER GRAVEL

This is an informal name for the boulder gravel, interpreted as a lag deposit resting on a marine planation surface cut into Late Cretaceous/Paleocene lava flows (Southern Volcanics) exposed in a quarry at the ford of Stony Crossing near Ohira Bay (Plate 5.4). The gravel is composed of small to large highly weathered basalt boulders ranging from 10 cm to 60 cm in diameter, and smaller quartz, schist and chert pebbles, in a coarse sandy matrix. This lithology closely resembles the composition of the modern day beach deposits at Ohira Bay. The gravel is overlain by Wharekauri Sand and Moorland Peat.

Based on the proximity and height of the wave-cut surface to modern day sea level, the gravel was initially interpreted to have accumulated during the high sea level stand of the Last Interglacial (OIS 5e). However palynological analysis of the overlying Moorland Peat indicates that that it may in fact be older, possibly OIS 7 (section 4.6.2.3). However additional age control is required to confirm this. If the gravel is

Last Interglacial in age, then it can be correlated with (a number of) other described units on Chatham Island, e.g. the basal portion of the Hawaiki Formation.

Plate 5.4: Ohira Bay boulder gravel exposed in the basalt Quarry at Stony Crossing, near Ohira Bay (*Photo J. Begg*).

5.3 Interpretation of the significant stratigraphic sections

Thick sequences of Quaternary deposits are relatively common on mainland New Zealand, particularly in the Taranaki-Wanganui-Rangitikei region, where the interplay between tectonic uplift and eustatic sea level fluctuations have combined to deposit and preserve repeated cycles of marine and terrestrial deposits, resulting in hundreds of metres of Quaternary sediments (Naish and Kamp 1995). The Chatham region, on the other hand, is largely aseismic, experiencing minimal tectonic uplift. Terrestrial deposits have been subject to erosion, particularly those in lower areas where, in the absence of significant tectonic uplift, the cyclic fluctuations in eustatic sea level erode and remove the deposits of the previous glacial/interglacial cycle, i.e. the slate is essentially wiped clean. This, combined with the susceptibility of deposits in terrestrial environments to erosion, and periods of non-deposition have resulted in a scattered and fragmentary Quaternary record on Chatham Island. Exposures of sediments that pre-date OIS 5 are rare, and much of the older deposits that are preserved on the island are buried beneath a thick blanket of younger Moorland Peat. Thus it is important to understand the record of those long, pre-LIG sequences that do exist. Two such sequences are described in the following text.

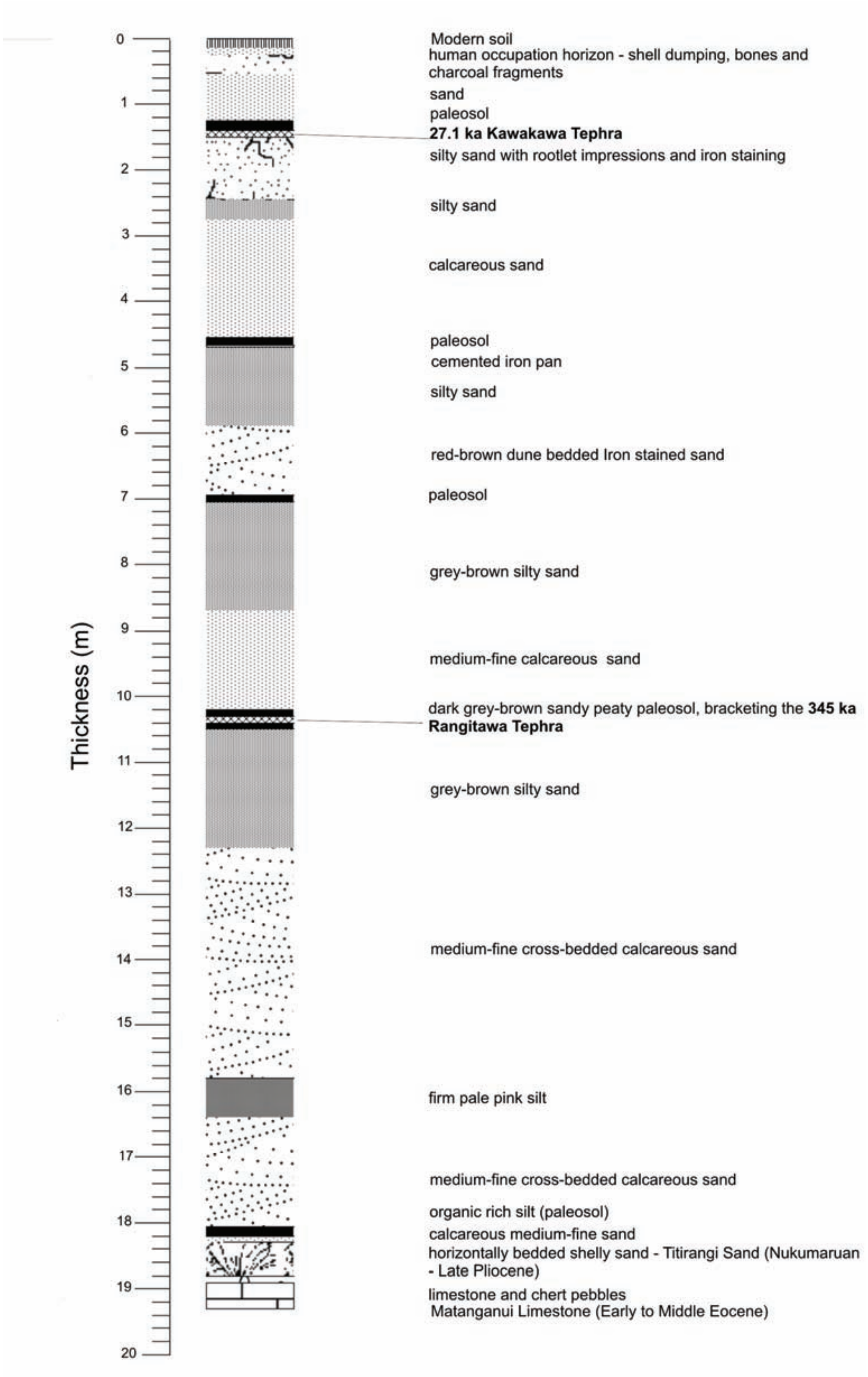
5.3.1 North Red Bluff section

This section is located in a cliff within a small bay to the north of Red Bluff, in central Petre Bay (Plate 5.5). The sequence of strata within the section is the informal "unnamed partially marine unit" (*stet.*) of Campbell *et al.* (1993), who briefly described the unit and speculated an age range of Nukumaruan to Haweran. The sequence comprises some eighteen metres of predominantly sand and sandy silt units, of the Wharekauri and Maipito Formations, with interbedded paleosols. With the exception of the lowermost units, the entire sequence is terrestrial in origin.

Plate 5.5: North Red Bluff Quaternary sequence looking south, with the crest of Red Bluff visible in the distance. The black dashed line marks the wave-cut surface at 7m a.s.l.and the yellow and pink dashed lines represent the Kawakawa and Rangitawa Tephras, respectively.

The sequence overlies a wave-cut surface cut into Early-Middle Eocene Matanganui Limestone (a stratigraphic column of the sequence is presented in Figure 5.2). Resting on the wave cut surface is a thin gravel lag deposit, composed predominantly of limestone cobbles, with occasional quartz and chert pebbles. This lag deposit is conformably overlain by around one 0.5 – 1m of Nukumaruan/Early Quaternary Titirangi Sand. Titirangi Sand crops out at three other locations in central Chatham Island and has been encountered in a borehole near Waitaha Creek (Campbell *et al.* 1993, Richards 1987). At these locations it is interpreted as having accumulated in a

Figure 5.2: Stratigraphic column of the North Red Bluff Quaternary Sequence (note: *paleosol* refers to a buried soil horizon).



quiet lagoonal environment. The Titirangi Sand exposed in the Red Bluff area differs from these other exposures. Its faunal content is impoverished when compared to the assemblages at the other exposures, and this is interpreted to have been due to it being deposited in an open sandy coastline environment (A. G. Beu, pers. comm.). A full list of fauna within the Sand at this site is presented in Table 5.3.

The Titirangi Sand is overlain by organic-rich silt, interpreted as a paleosol, which is in turn overlain by several metres of finely laminated current-bedded beach sands. Within this unit is a conspicuous firm layer, which varies in thickness from 20cm to 75cm. This unit is composed of calcareous silt, and is interpreted to represent the development of a small lagoon or estuary at the site, which was subsequently overwhelmed by more sand. The remainder of the units within the section are all aeolian sands, silty sands and buried soil horizons. Both Chatham Island rhyolitic tephra marker beds are present within the sequence.

The sequence preserves a record of repeated cycles of sand incursion, occurring as the result of landward transgression during interglacial sea level rise, followed by periods of landscape stability, soil and vegetation development. This is reflected in both the sedimentology and the mineralogy (Figure 5.3) of the sand units (the relevant raw data can be found in Appendices 10 and 11). The units have been deposited in a pattern, from clean, well sorted sands followed by less well sorted, silt-rich sands with increased evidence of soil formation. The well sorted sands are interpreted as representing high sea level stands during interglacial periods. They are dominated by calcareous fragments derived from erosion of limestone, with varying amounts of ferromagnesian minerals, dominantly pyroxenes, and limited amounts of quartz and feldspar. This mineralogy reflects increased erosion of limestone exposures by wave action during high sea level stands. Limestone is the dominant pre-Quaternary lithology in the central region of Chatham Island. These interglacial sand units are followed by finer, less well sorted aeolian sands, which, mineralogically, are dominated by quartz and to a lesser extent feldspar with minor amounts of magnetite. These units are interpreted to represent glacial periods where the bulk of the sediment was derived from areas of the continental shelf exposed during low sea level stands. Thus the sediment is quartzose, and the calcareous input is minimal (Figure 5.3).

The deposition of these units takes place during the early stages of sea level fall. When the continental shelf reverts to terrestrial conditions vegetation becomes established and soil development occurs. This is reflected in the silt deposits and paleosols adjacent to the Rangitawa Tephra, which was erupted during the latter stages of the glacial period of OIS 10. The Tephra deposit overlies a unit of silty sand and a paleosol. This soil redeveloped into the Tephra deposit after it fell. The soil is then overlain by a unit of calcareous interglacial sands. The 27.1 ka Kawakawa Tephra, deposited during the last glacial period, during OIS 2, also occurs in proximity to a buried soil horizon.

Table 5.3: List of macrofossils preserved within the exposure of Titirangi Sand in the North Red Bluff Quaternary sequence. Identifications by A.G. Beu.

Bivalvia:

Paphies porrecta (Marwick), abundant
Tawera marthae Marwick, common
Ruditapes largillierti (Philippi), common
Glycymeris (Glycymerula) modesta (Angas), 2 whole valves, abraded.

Gastropoda:

(All rare)
Axymene aucklandicus (Hutton)
Xymene drewi (Hutton),
Cominella sp., one juvenile,
Buccinulum sp.,
?*Paratrophon* or similar muricid,

The units present within the sequence have been tentatively assigned to the now well known chronology of Pleistocene climate cycles based on the marine oxygen isotope curve of Shackleton *et al.* (1990). My correlations in Figure 5.3 and 5.4, are largely underpinned by the position of the units relative to the two rhyolitic tephra marker beds. It becomes obvious that a considerable number of cycles are missing between the Titirangi Sand at the base of the sequence, and the overlying units. Other older units that once existed in this stratigraphic position must have been removed by erosion during a high sea level stand. Proxy sea-level curves based on isotope and other data suggest that OIS 11, the interglacial period that preceded the fall of the Rangitawa Tephra, was accompanied by the greatest sea level rise (13 – 20 m above

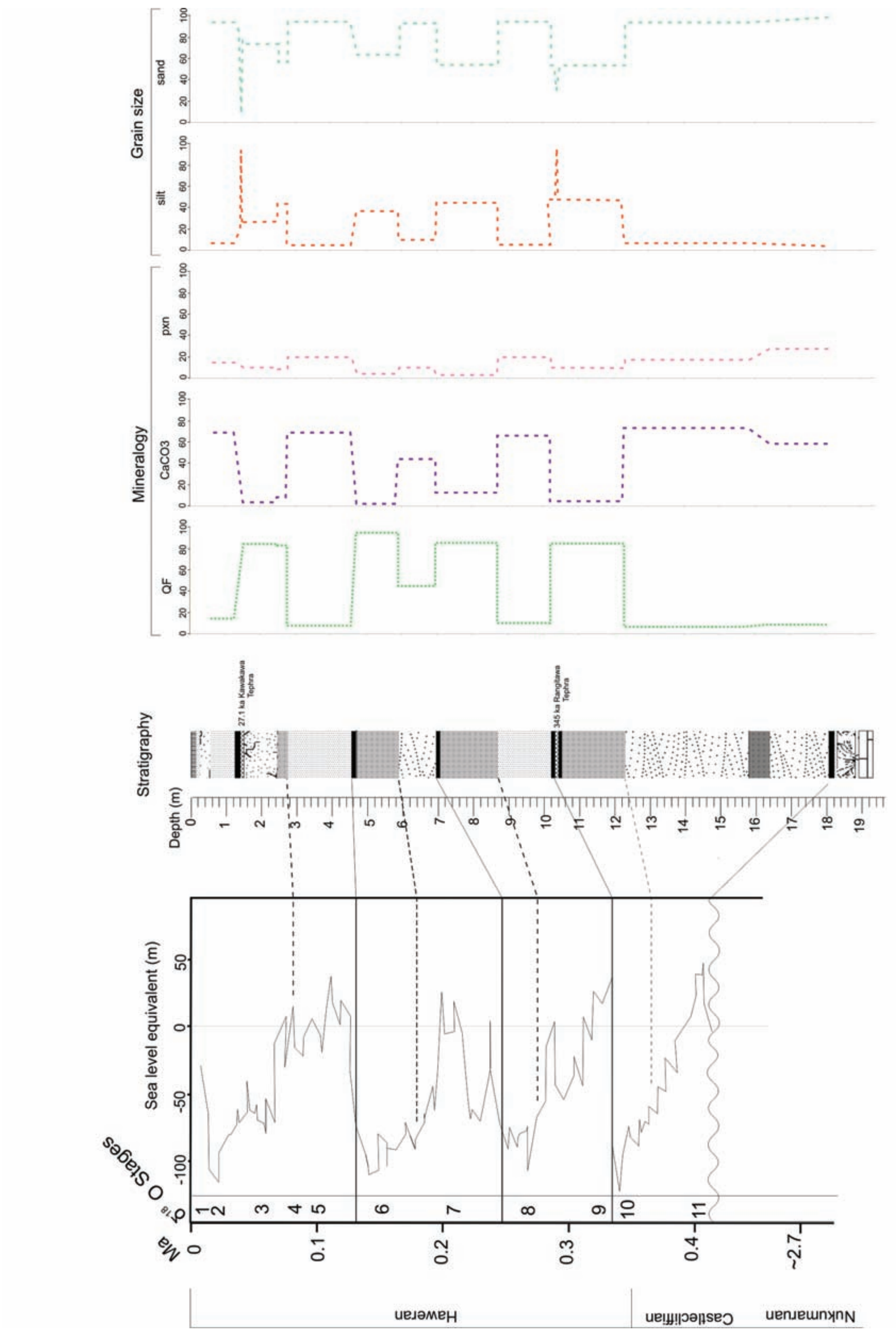


Figure 5.3: Graph illustrating the mineralogical and grain size components of the units within the North Red Bluff Quaternary sequence. (note: the data for each unit within the column was obtained from one channel sample collected as to be representative of that unit. Also, grain size data from the two tephra has been included, but not mineralogical data).Lithologies explained in Figure 5.2, QF = quartz and feldspar, pxn = pyroxene.

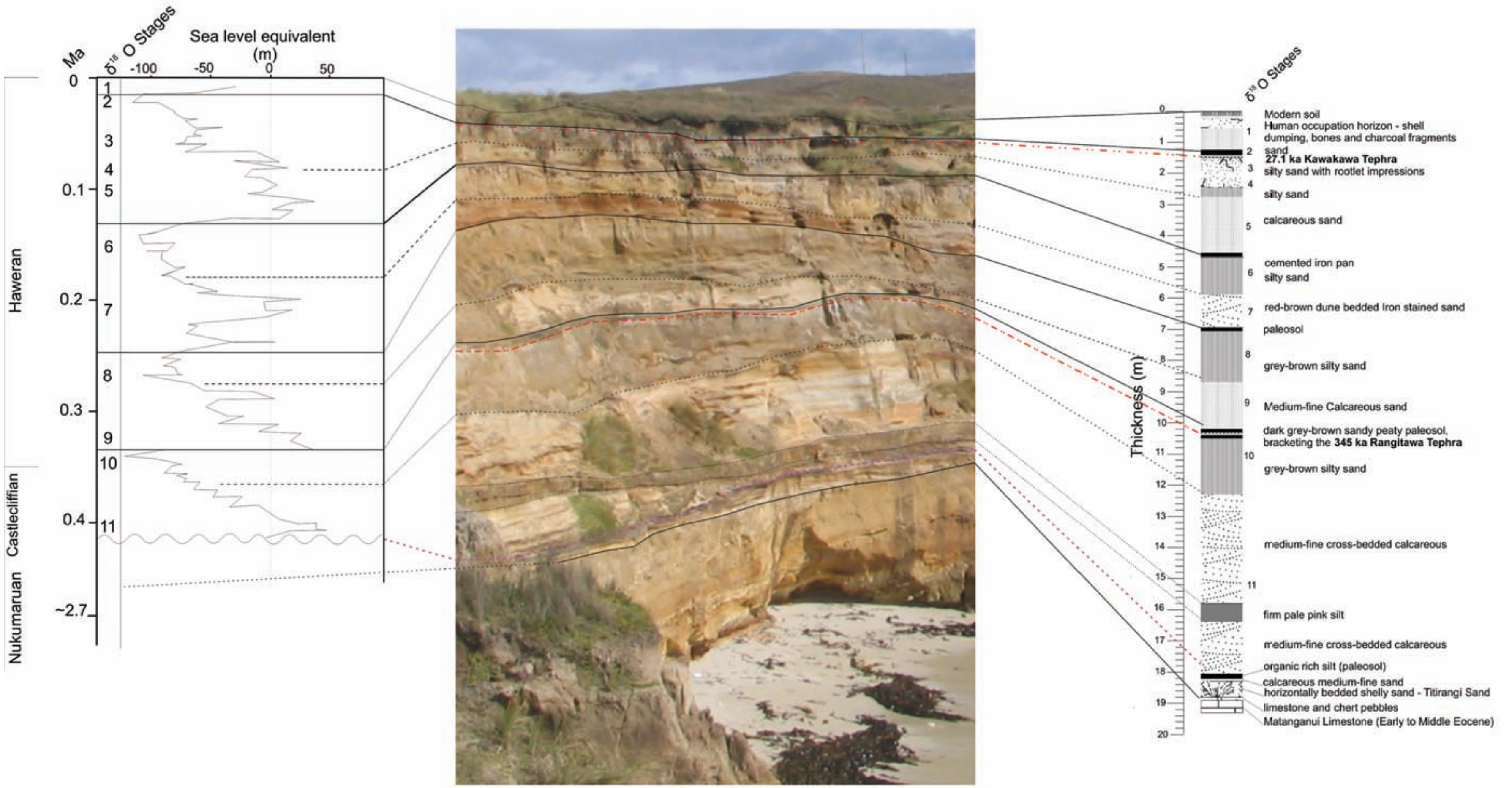


Figure 5.4: Correlation of units within the North Red Bluff Quaternary Sequence with OIS stages and equivalent changes in sea level.

present) out of the last ten glacial/interglacial cycles (Hearty *et al.* 1997, 2007). It was most probably responsible for the erosional removal of those units that may have previously existed above the Titirangi Sand. The paleosol overlying the Titirangi Sand (at 18.05 m – 18.20 m) must have formed following this erosional period. As mentioned above, tectonic uplift is not as prominent in the Chathams region as it is on the mainland, thus deposits, particularly in coastal areas, are not so well protected from erosion by marine incursion during subsequent high sea level stands.

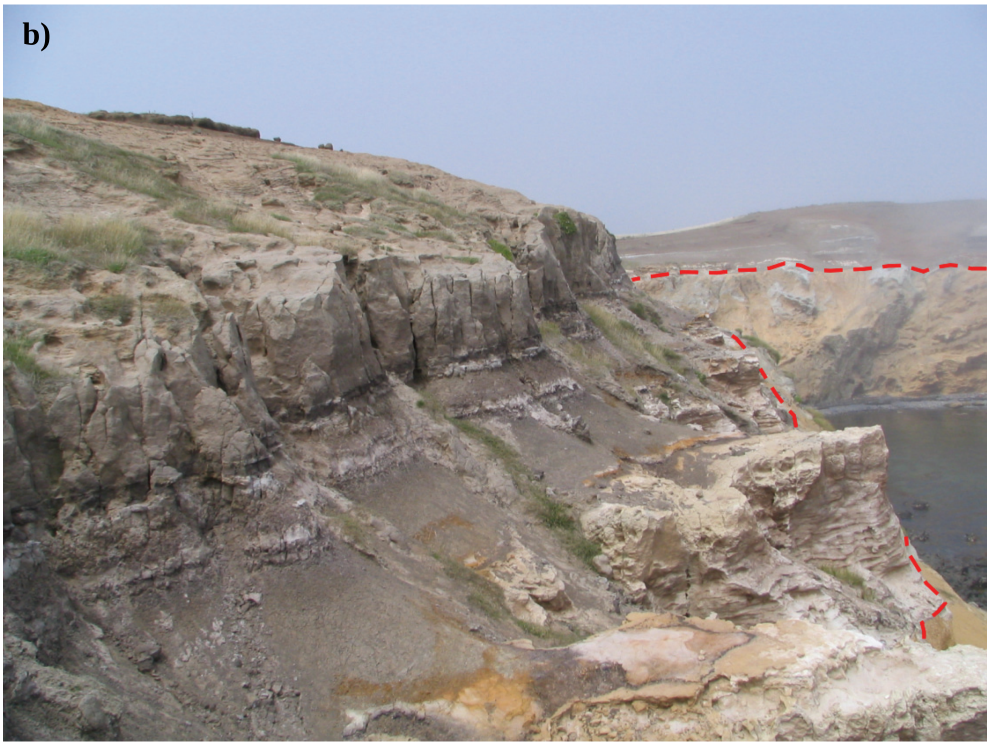
The late Castlecliffian and Haweran portion of the North Red Bluff sequence of strata is present in the wider Red Bluff region, draped over older Paleocene/Eocene volcanics. The wave-cut surface overlain by the basal lag and Titirangi Sand is only exposed in the North Red Bluff cove area. Elsewhere, to the south, the units contain increased amounts of silt-sized material, but a similar pattern of relatively sand-rich deposits followed by relatively silt-rich deposits persists. The Rangitawa Tephra is well preserved along this length of the coast.

5.3.2 Mairangi Sequence

A second significant exposure of pre-Last Interglacial (Castlecliffian – Haweran) deposits is exposed in the Cape Young/Mairangi area (Plate 5.6. and Figure 5.5). The sequence is also composed of terrestrial sediments and at its maximum is ten metres thick. It drapes over and around the older volcanics at Cape Young, Momoe-a-toa and Mairangi volcano and over the Late Cretaceous/Paleocene Tutuiri Formation in the Takapu - Tioriori area.

The sequence is dominated by silt, silty sand and sand units of the Maipito and Wharekauri Formations, with numerous inter-bedded peat beds and buried soils. The two rhyolitic tephra maker beds are also present within the sequence. Where the sequence overlies competent lithologies, (mostly basalt pillow lavas) a planar, wave cut surface is obvious (see Plate 5.6.b), marking the disconformity between the older submarine volcanics and the young Quaternary terrestrial sequence. However, where the underlying lithology is dominated by palagonitic ash and tuff beds, the disconformity is not so obvious.

Plate 5.6: a) View of the Mairangi - Cape Young area, where late Castlecliffian – Haweran – Recent terrestrial deposits blanket the Miocene Volcanics. b) Closer view of the sequence of deposits, overlying the wave cut surface at c. 35m a.s.l.(red dashed line).



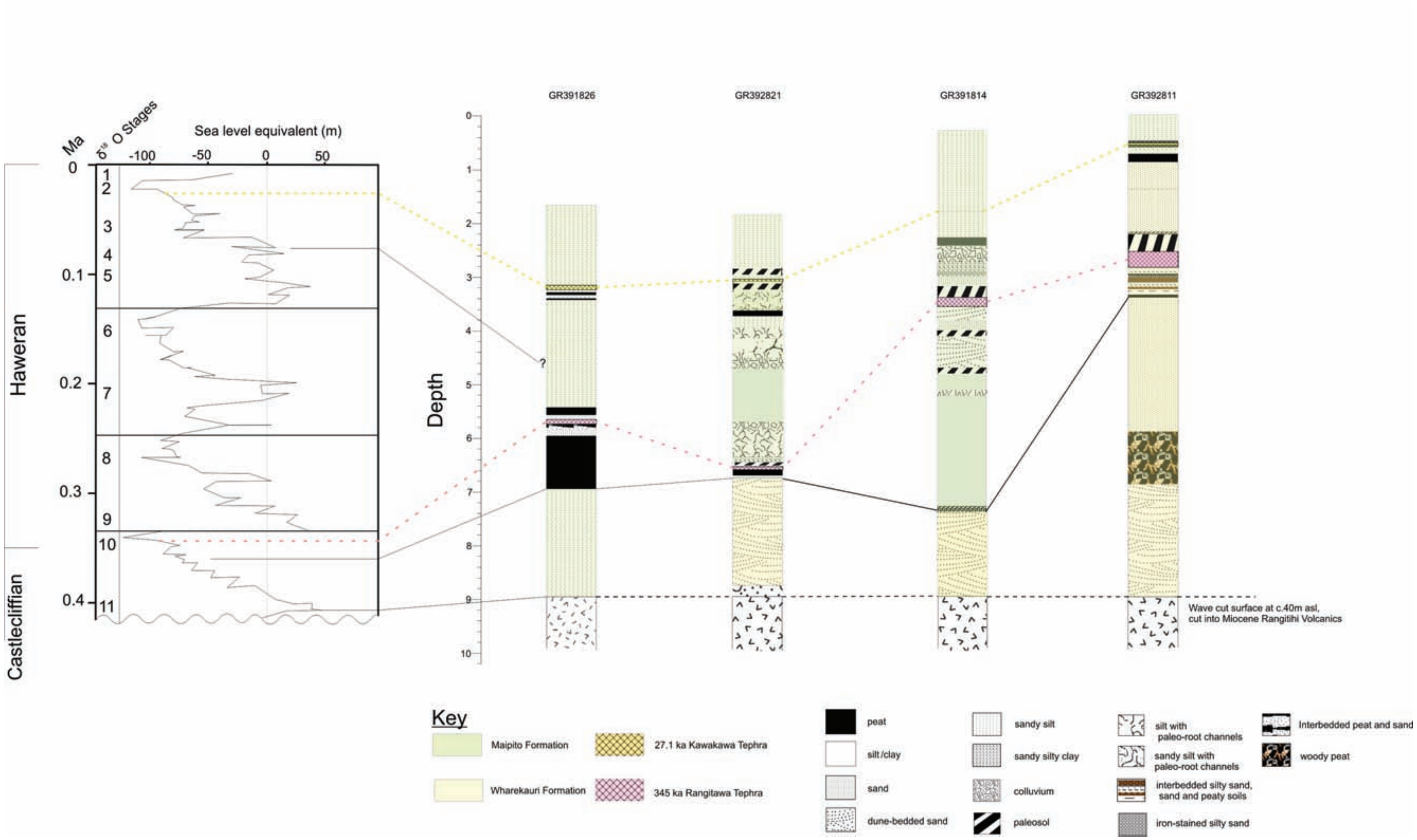


Figure 5.5: Stratigraphic columns through Quaternary cover-bed deposits from selected locations in the Mairangi area.

Unfortunately no basal shell lag is preserved on the surface itself, which precludes any biostratigraphic age control. It is overlain only by a thin gravel lag deposit, composed of rounded and now thoroughly weathered basalt cobbles. Chert pebbles also occur. This deposit is overlain by one to two metres of coarse unconsolidated dune sands of the Wharekauri Formation. The Rangitawa Tephra occurs within a sequence of clay and peat layers above this sand unit, which suggests that the underlying surface was probably cut during the high sea level stand of OIS 11 and the sands deposited following the peak in sea level.

The sequence itself is somewhat deceiving in its appearance, in that at first glance, the observer would assume to be seeing at least 2 or three prominent white tephra layers. However, on closer inspection these conspicuous pale layers (e.g. those visible in the foreground of Plate 5.6b), which often form small bluffs in the outcrop, are in fact layers of silt-rich sand, their conspicuous whiteness coming from the weathering out of the large white quartz grains. I make this point because previous visitors to the area have remarked on the existence of numerous (tephra) marker beds within the sequence, when the true markers – the Rangitawa and the Kawakawa are not nearly as obvious from a distance.

The sandier units within the sequence have been interpreted as having accumulated during high sea level stands, while silt-rich units and associated peat beds are thought to represent relatively cold, glacial conditions. There are considerable lateral variations in the number and thickness of units within the sequence, and correlating the stratigraphy is complicated by numerous erosional unconformities and slumping events. These variations are illustrated in Figure 5.5. Within sequences at certain localities in the area there are at least one or two units of what appears to be colluvium, composed of now highly weathered rounded and angular clasts of volcanic material (Plate 5.7). These colluvial horizons vary in thickness from twenty centimetres to two metres. The larger of these have been interpreted as debris aprons of colluvium produced from erosion of the Mairangi volcano or other volcanic remnants no longer in existence. These (larger) deposits do not appear to be of marine origin (i.e. gravel lags). They occur within other terrestrial units, the clasts within them displaying great variance in degree of roundness, and they often contain organic material within the matrix.

Plate 5.7: Examples of colluvium units in the Mairangi area: a) relatively large angular clasts (mm – cm scale) within a brown, organic-rich sandy-silt matrix; b) smaller (mm scale) angular to rounded clasts within an orange silty matrix; divisions on scale are 1cm.

5.4 Concluding remarks

To briefly summarise, the Quaternary stratigraphy of Chatham Island is dominated by formations of terrestrial origin – namely the Moorland Peat, Wharekauri Sand and Maipito Formations. Marine sediments are rare, comprising the Titirangi Sand, Te Awapatiki Shelly Sand, and Ohira Bay boulder gravel.

Following further stratigraphic investigations undertaken as part of this research it has been necessary to redefine some of the pre-existing Quaternary stratigraphic units present on Chatham Island, namely the Moorland Peat and Wharekauri Sand. Three new units have also been defined – the Te Awapatiki Shelly Sand, the Maipito Formation and the Ohira Bay boulder gravel.

Investigation of the more comprehensive stratigraphic sequences preserved on Chatham Island has indicated that there is a significant gap in the Islands' Quaternary record. Deposits pre-dating OIS 11 are rare, and it is postulated that large parts of the pre-OIS 11 record have been removed by erosion associated with sea level transgression.

CHAPTER 6
MARINE TERRACES

6.1 Introduction

Marine terraces are the geomorphic expression of a former sea level still-stand. They are typically formed during interglacial periods, when sea level rises and marine transgression occurs. Wave action cuts a new marine platform, upon which marine sediments are deposited. Following the maximum high-stand, sea level falls and exposes the interglacial marine platform, which then begins to accumulate terrestrial sediments. In tectonically active areas, uplift results in the new platform being raised and preserved, out of reach of subsequent interglacial high sea levels. The uplifted marine platform consists of a sub-horizontal surface with a fossil sea cliff at its inner margin, with the base of this fossil cliff marking the shoreline at the high-stand of the marine transgression that formed the surface (Pillans 1983).

The sequence of deposits on an uplifted wave-cut surface, referred to as the terrace cover-beds (Pillans 1990), follows a typical pattern representing the passage from initial formation under marine conditions, exposure to sub-aerial conditions following sea level fall, and to full terrestrial conditions with continued uplift. A typical cover-bed sequence contains marine sediments (gravels, beach/littoral sand, shell beds etc) at the base, overlain by aeolian sand deposits i.e. dune sand, followed by increasingly terrestrial deposits, including peat, volcanic ashes and loess-paleosol sequences.

Coastal areas of tectonically active regions typically have a step-like sequence of marine terraces parallel to the present coast. These have formed during separate interglacial and/or interstadial sea level rises, and subsequently uplifted. Accurate control on the age of formation of marine terraces allows uplift rates to be calculated (Wellman 1972, 1979, Pillans 1983). Determining the age of formation can be done by dating the cover bed deposits, using numerical, calibrated, relative or correlated age dating Pillans (1990).

Marine terraces and wave-cut platforms created during former high sea level stands have been identified at several locations on Chatham Island, in both this and previous studies. This chapter reviews previously recognised marine terraces and presents new terrace data generated during the course of this study. Ages are proposed for all terraces described, with ages based on the nature and thickness of cover-bed deposits, presence or absence of tephra marker beds, pollen evidence, and the relationship of terraces to other geomorphic features and to modern day sea level. The ages and heights of the terraces are used to estimate tentative uplift rates for Chatham Island.

6.2 Previous works on Chatham Island marine terraces

Hay *et al.* (1970) described emergent marine benches at 6 different heights on Chatham Island. The highest and oldest of these, at 235m (770ft) is the broad, gently sloping surface of the southern uplands. This surface is generally regarded as either a lithologic/relict feature – i.e. the original flank slope of the Cretaceous/Paleocene Southern Volcanics shield volcano (Allan 1928), or a sloping surface generated during rotation associated with block faulting in the Chatham's region (Wood *et al.* 1989). However Hay *et al.* (1970) considered it to be an emerged shore platform. They did not identify any lithological evidence for this i.e. marine cover beds resting on the surface. The second highest terrace surface at 76 m, is described as forming a high plateau in the northern part of the island. But again Hay *et al.* (1970) did not present any lithological evidence for a marine origin associated with this surface.

The four lower terraces Hay *et al.* (1970) described are more restricted in extent than the 235 m and 76 m surfaces. They describe a 34 - 40 m surface (110ft Te Awainanga raised beach) occurring in only one locality on Chatham Island, along the vehicular track next to the coast between Owenga Township and Te Awapatiki. Tonkin *et al.* (unpublished) later found that this surface is not of marine origin, and is, in fact formed by a raised peat dome developed on an underlying marine surface at 3-5 m a.s.l. Hay *et al.* (1970) also describe a surface at 14 - 21 m (47 - 70 ft) preserved in the Owenga, Point Durham and Waitangi regions. A 4 – 8 m terrace (15-25ft Manakau Point raised beach) is also described. At Cape Pattisson, Wharekauri and Hapupu it is cut into Wharekauri Sand, while at Point Durham, Cape Fournier and Manakau Point it is cut into basalt lavas (Southern Volcanics) and is described as forming a narrow wave-cut platform backed by a boulder beach deposit. They describe remnants of a marine bench at 1 metre that can be found at many locations around the island, including Okawa Point, Cape Pattisson and Ohira Bay. The ~1 m and 4 – 8 m surfaces were attributed to post-glacial rises in sea level and the 14 – 21 m and 34 – 40 m surfaces to the Last and penultimate Interglacials, respectively.

Tonkin *et al.* (unpublished) investigated marine terraces in the Owenga, Manakau Point and Point Durham regions and recognised two surfaces of marine origin at 3 and 9 m above modern sea level. They assigned the 3 m surface to the Last Interglacial, and the 9 m surface to the penultimate or older interglacial. Their 9 m surface is equivalent to the 14 - 21 m terrace of Hay *et al.* (1970). They regard Hay *et al.* (1970)'s Manakau Point bench at 4-8 m as having formed during a brief still stand period during uplift of the 9 m surface, rather than representing a separate high sea level stand.

Campbell *et al.* (1993) did not undertake any field investigations of terrace surfaces, but did present the distribution of four different surfaces (labelled h1 – h4) on which they mapped from aerial photographs. The heights of these four surfaces were estimated at:

h4	± 10 m
h3	± 20 m
h2	30 – 40 m
h1	50 – 60 m

6.3 Terraces investigated during this work

The terms 'marine terrace' and 'wave-cut platform' have been adapted from the usage of Pillans (1990). A **marine terrace** is a planar landform bounded along its inner edge by a fossil sea cliff, and on its outer edge by a sea cliff (fossil or modern); underlain by evidence for marine origin, such as marine sediments and/or a wave-cut platform or planation surface. A **wave-cut platform** is defined as a planar surface overlain by marine sediments and/or evidence for marine origin, e.g. boring by marine organisms. However, several of the surfaces discussed in the following text do not, strictly speaking, fit all these criteria. They commonly occur in association with or parallel to the current coast, and despite the lack of evidence for marine origin, such surfaces are considered wave-cut because there is no other reasonable explanation for their genesis. There are no river aggradational terraces present on Chatham Island, as there are no gravel bed rivers.

As mentioned previously (Chapter 1, section 1.2.3.3) the Chatham Rise area, including the Chatham Islands is quiescent, tectonically and seismically. On mainland New Zealand, tectonic uplift is largely responsible for preserving marine benches cut during high sea-level stands. However without this tectonism, marine terraces created on Chatham Island cannot be expected to have a similar degree of preservation as those on mainland New Zealand e.g. terraces in the Taranaki-Wanganui region. Recognition and age interpretation of marine surfaces and associated features, e.g. strandlines, on Chatham Island is complicated by blanketing by younger deposits, particularly Moorland Peat, by a lack of (marine) cover bed deposits, particularly in more exposed coastal regions, and also by as yet poor age control over the age of geomorphic surfaces.

Terraces and wave cut surfaces have been identified at the following heights above modern sea level. They are arranged in stratigraphic order

Late Quaternary age

c. 3 - 5 metres

c. 9 – 10 metres

c. 16 metres

c. 20 metres

c. 30 - 40 metres

Latest Pliocene – Early Quaternary age

c.7 – 14 metres

Representative cover bed sequences overlying the marine surfaces are presented in Figure 6.1.

3 - 5m terrace

This is the lowest terrace investigated during this study. It equates with the 3 - 5 m terrace investigated by Tonkin *et al.* (unpublished) and is also probably equivalent to the h4 surface mapped in the Owenga region by Campbell *et al.* (1993). It was apparently not recognised by Hay *et al.* (1970). The surface is best preserved in the southern Hanson Bay area, to the north of the township of Owenga. The terrace slopes very gently inland at <1 degree, and terminates against a fossil cliff cut into the c. 9 –

Figure 6.1: Simplified representative cover bed sequences overlying marine surfaces on Chatham Island. Red dashed line denotes position of the wave cut surface.

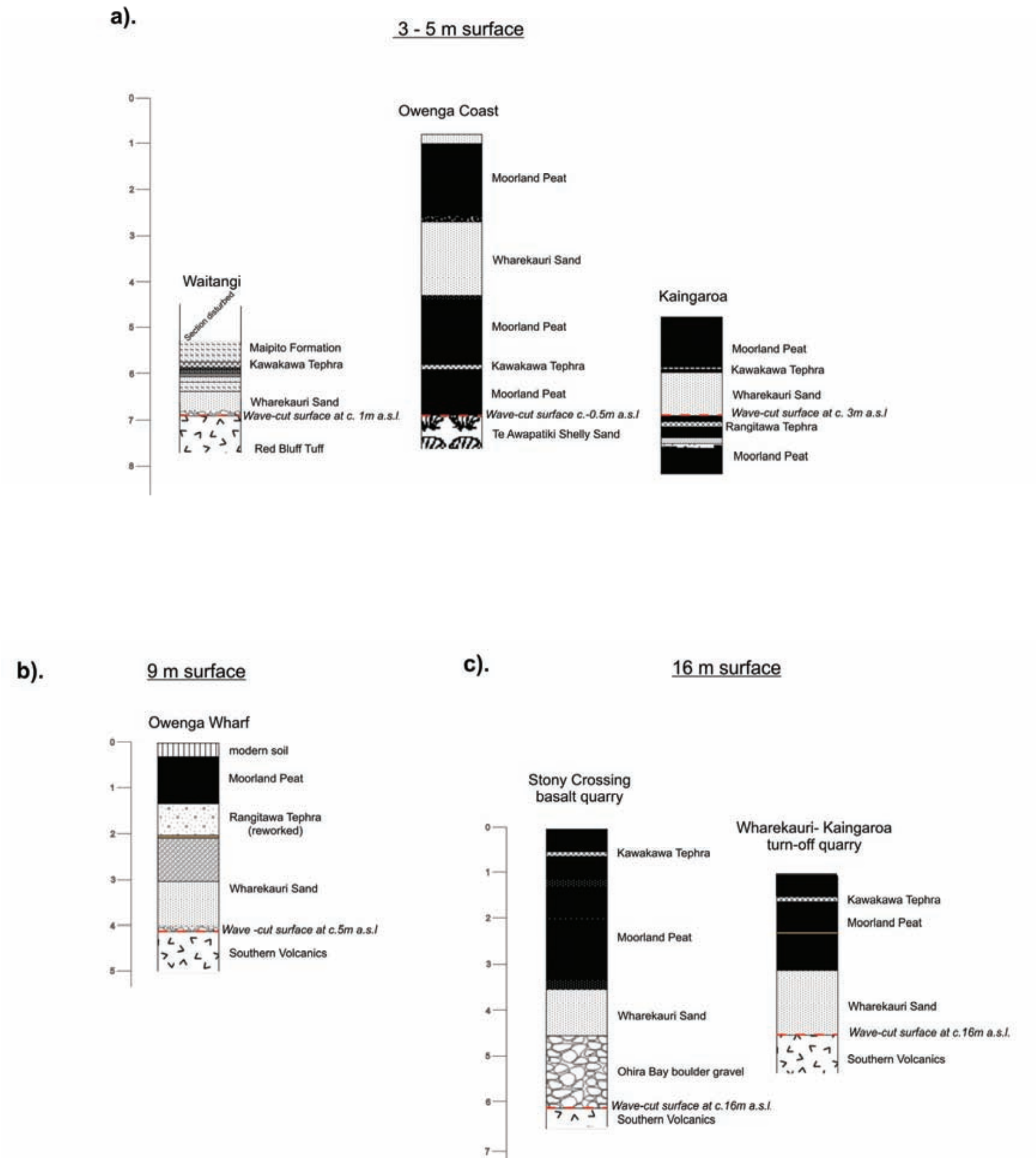
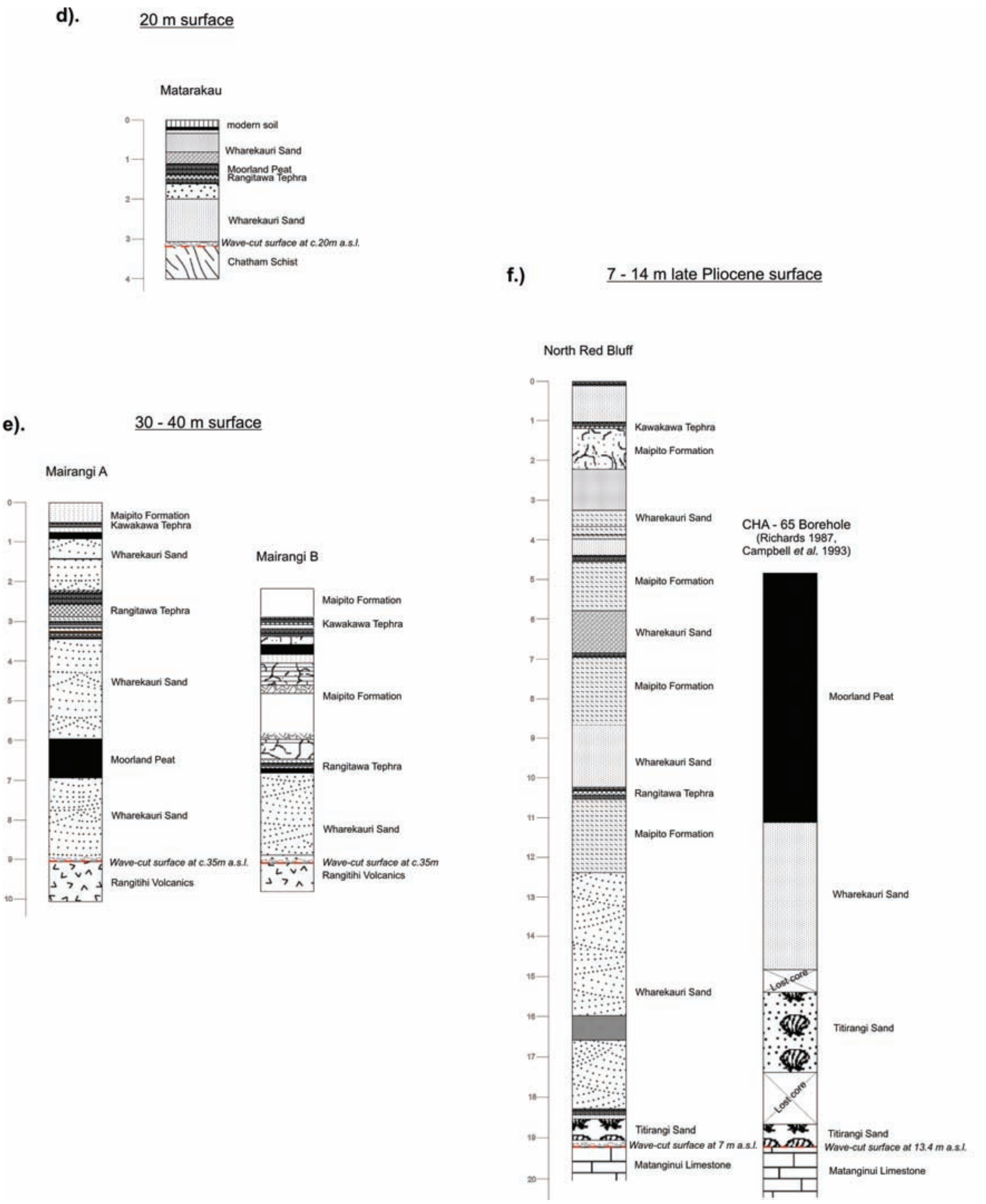


***Figure 6.1** continued on the following page.*

Figure 6.1: *continued.*



10 metre surface (Plate 6.1a). It is also present in the Kaingaroa region and near Waitangi township.

The marine deposits underlying the terrace in the Owenga region comprise shell-rich ferromagnesian sands (Te Awapatiki Shelly Sand, Plate 5.3) overlain by Moorland Peat containing the Kawakawa Tephra, dune sand (Wharekauri Formation), and southern highlands red peat. Hence this surface and its underlying strata are regarded as Last Interglacial in age, rather than Holocene.

At Kaingaroa the surface terminates against a fossil cliff adjacent to the ‘main road’. The cover-bed sequence (at this location) underlying the terrace surface has been exposed by slumping in the outer sea cliff of the surface. It comprises approximately 1 metre of Moorland Peat over 1 metre of weak horizontally laminated dune or beach sands. These sands rest on a sharp erosional surface that has apparently been cut into much older peat which contains the 345 ka Rangitawa Tephra (Plate 6.2).

At Waitangi a small remnant of the surface is preserved to the west of the mouth of the Nairn River (Plate 6.3). Here the wave-cut surface is overlain by a very weak gravel lag, followed by beach sands and thin peat beds. The Kawakawa Tephra is preserved at approximately half a metre above the wave cut surface, within reworked tuffaceous material of the Maipito Formation.

Based on the terrace’s position relative to modern day sea level and the presence of the Kawakawa Tephra within the cover bed sequence, the terrace was most probably formed during the Last Interglacial period. Tonkin *et al.* (unpublished) also assigned the terrace to the Last Interglacial. However, at Kaingaroa, pollen evidence suggests that all the peat accumulated during warm interglacial/post-glacial conditions (section 4.6.3.3). Also, the absence of the Kawakawa Tephra within the cover bed sequence at Kaingaroa implies a post-glacial age. However, as mentioned in section 4.6.3.3., a thin silty layer containing relatively small amounts of rhyolitic glass shards occurs towards the base of the upper peat. Though not a primary tephra deposit the glass chemistry of the many of the shards from this layer have a strong affinity to analyses of Kawakawa Tephra (refer Chapter 3, section 3.6.3). It appears only minor

Plate 6.1: a) 3-5 metre terrace (yellow dashed line) and 9 metre terrace (orange dashed line) in the southern Hanson Bay area, and b) the 9m terrace in the vicinity of Owenga township.

deposition/accumulation occurred at the site during the Last Glacial period and peat accumulation resumed with post-glacial warming.

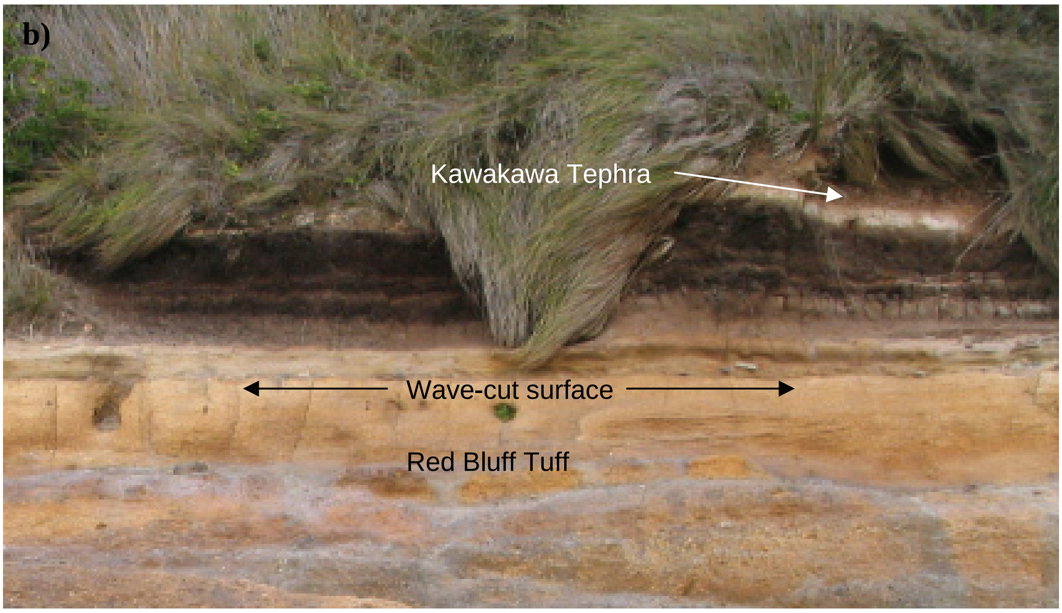
Plate 6.2: The Kaingaroa Slump section underlying the 3-5 metre surface in the Kaingaroa area.

9 – 10 metre surface

The 9 – 10 m surface is also best preserved in the southern Hanson Bay region. The surface slopes gently inland to the hills at the base of the southern uplands. Tonkin *et al.* (unpublished) also examined this surface. Most of the township of Owenga as well as the southern portion of the Waitangi-Owenga road, sits on this terrace (Plate 6.1a). The wave-cut surface and overlying cover-bed sequence are well exposed near the Owenga wharf (Plate 6.1b). Remnants of this surface also occur at Waitangi township, Maunganui Bluff, and Waitangi West. Little examination of cover-beds was undertaken in any of these other areas, due largely to a lack of exposure and lack of cover-beds. At some locations the cover-bed sequence consists of only dune sand (Wharekauri Sand) overlain by a weak peat bed or peaty soil containing the Kawakawa Tephra.

Tonkin *et al.* (unpublished) assigned this 9 metre terrace to the penultimate or older interglacial. They attribute the lack of deposits, particularly the absence of any considerable thickness of Moorland Peat, to erosion or to environmental conditions (in the Owenga region at least) not being conducive to peat development. It is possible that at other locations there are greater thicknesses of Moorland Peat overlying this surface, as would be expected when considering its age, but there are simply no insightful exposures at the right locations.

Plate 6.3: a) Last Interglacial marine bench exposed at Waitangi, b) closer view of the wave cut surface and overlying cover bed sequence.



There is some limited evidence for an older age for this 9 m surface. Within the cover-bed sequence of the surface exposed in the cliff immediately to the west of the Owenga wharf is a unit of unconsolidated, almost fluffy yellow-orange silty material, which resembles the Kawakawa Tephra in general appearance, but not texture. It is composed almost entirely of silt- and clay-sized particles, however the fine sand-sized fraction contains shards of rhyolitic glass, angular quartz and euhedral ferromagnesian mineral grains and strongly resembles the sand fraction extracted from devitrified Rangitawa Tephra from other locations on the island (for example Kaingaroa, North Red Bluff and Mairangi). Electron microprobe analyses of glass shards from this unit show a strong affinity to analyses of Rangitawa Tephra (Figure 3.12d). This suggests that the 9-10 m surface may have been created during the Interglacial that preceded the fall of the Tephra, in OIS 11. However, the deposit shows signs of over thickening so is probably not a primary tephra deposit and may have been reworked. Also, the glass shards analysed were of poor quality and showed signs of weathering and thus were not ideally suited for microprobing, rendering the analyses unreliable. Uplift rates calculated for this surface using the younger (OIS 7) age match well with those calculated for the 3-5 metre Last Interglacial surface in the Owenga region, while those calculated using the older (OIS 11) age are considerably lower (refer to later text and Appendix 12 for calculation and discussion of terrace uplift rates).

16 metre surface

Remnants of a terrace surface at 16 m are preserved in the Ohira Bay region, Wharekauri/Tuapeka and Waitangi West regions. The wave-cut surface and cover-bed sequence are exposed in two quarries, one at Stony Crossing near Ohira Bay and the other at the Wharekauri-Kaingaroa intersection. At both sites the platform is cut into basaltic lavas of the Cretaceous/Paleocene Southern Volcanics (Plate 6.4). The wave-

Plate 6.4: The c. 16 m surface exposed in a basalt quarry at Stony Crossing, near Ohira Bay.

cut surface was measured at 16 m above modern sea level. At Stony Crossing this surface is overlain by 1 - 2 m of boulder beach deposits (Ohira Bay boulder gravel) followed by approximately 1 m of quartzose dune/beach sand (Wharekauri Sand) and 2 - 3 m of Moorland Peat, with the Kawakawa Tephra within the top half-metre.

A similar sequence is present at the Wharekauri-Kaingaroa turn-off quarry, but the Ohira Bay boulder gravel is absent, with the surface instead being directly overlain by coarse pebbly Wharekauri Sand. This reflects the difference in beach environment between these two sites following terrace formation and mirrors the modern beach environments in the immediate vicinities of the sites. Ohira Bay is exposed to the open ocean, with active erosion of basalt lava flows producing a boulder beach. At the Wharekauri site today the beach near to the quarry is the low energy shore of Te Whanga Lagoon. During interglacials the lagoon may have been a fully open inlet of the sea but would have remained relatively sheltered from strong ocean currents, resulting in the formation of a sandy beach.

Based on the similarity in surface heights and cover-bed sequence it is reasonable to suggest that the surfaces exposed at the two sites is of the same age. During initial field investigations this surface was assigned to the Last Interglacial, based on the thickness of peat between the basal sands and the Kawakawa Tephra. However, pollen evidence suggests the Stony Crossing surface may be older than the Wharekauri-Kaingaroa turn-off quarry surface. Pollen analysis was performed on the peat sequence at both sites (refer Chapter 4, sections 4.6.1 & 4.6.2). Pollen spectra recovered from the Wharekauri peat sequence show a trend of decreasing temperature from the base towards the Kawakawa Tephra, which correlates well with the last Glacial 'Asteraceae' zone described by Mildenhall (1994a) and McGlone (2002). While the spectra obtained from the Stony Crossing peat show a trend of cool conditions at the base of the sequence, following by a seemingly long period of warmer conditions, and then a return to cooler conditions towards the time of the Kawakawa Tephra. This pattern is based mostly on the long distance pollen (i.e. derived from mainland New Zealand forests, refer Chapter 4), which at certain levels within the profile is in disagreement with the local pollen spectra (refer to Chapter 4, section 4.6.2 for a full discussion of the pollen record at the Stony Crossing site). The pollen evidence suggests that it is possible that the 16 m surface at Stony Crossing may have been cut earlier than that at the turn-off, i.e. during the penultimate interglacial, OIS 7, rather than the Last Interglacial, OIS 5. However, this seems unlikely when considering at both Stony Crossing and Wharekauri-Kaingaroa turn-off quarry, the wave cut surface is at the exact same height. Another possible explanation is that peat accumulation began earlier at Stony Crossing and the sequence there contains a record of OIS 4 (pollen zone Sc3), OIS 3 (pollen zone Sc2) and OIS 2 (pollen zone Sc1), while at the turn-off quarry, only OIS 2 is recorded. Further detailed examination of the long distance pollen at both sites is required to better understand the age relationship between the two sites.

c. 20 metre surface

A wave cut surface of limited distribution at c.15 – 20 m is present at Matarakau, and Tioriori. This surface is very similar in height to the 16 m surface described above. However, the surface and cover beds in these areas are considerably older than those exposed at Stony Crossing and Wharekauri-Kaingaroa turn-off. The 345 ka Rangitawa Tephra is present within the cover-bed sequence in these areas thus indicating the underlying surface was cut prior to OIS 10.

c. 30 – 40 metre surface

A remnant of a surface at c.30 – 40 m above modern sea level is well exposed in the coastal cliffs in the Mairangi area (Plate 5.6b). The surface is overlain by 5 -10 m of cover beds containing the Rangitawa Tephra (section 5.3.2). This surface is equivalent in height to and may correlate with either the h2 and/or h1 terraces/surfaces of Campbell *et al.* (1993) and with the 34 - 40 m Te Awainunga raised beach of Hay *et al.* (1970), although the latter was later found to be formed by a raised peat deposit (Tonkin *et al.* unpublished).

The cover-bed deposits imply that this surface also predates OIS 10. The deposits between the marine cut surface itself and the Rangitawa Tephra comprise dune-bedded quartzose sands with a weak gravel lag at the base, presumably deposited following retreat of the sea across the surface. This suggests the surface was cut during OIS 11. However, the c. 20 m terrace described above, which occurs at Tioriori within 2 - 3 km of Mairangi, is also regarded as OIS 11, thus the 30 - 40 m surface must be older, and any deposits spanning from the time of cutting to ~OIS 11 have been removed. There is no evidence of a fault within the area.

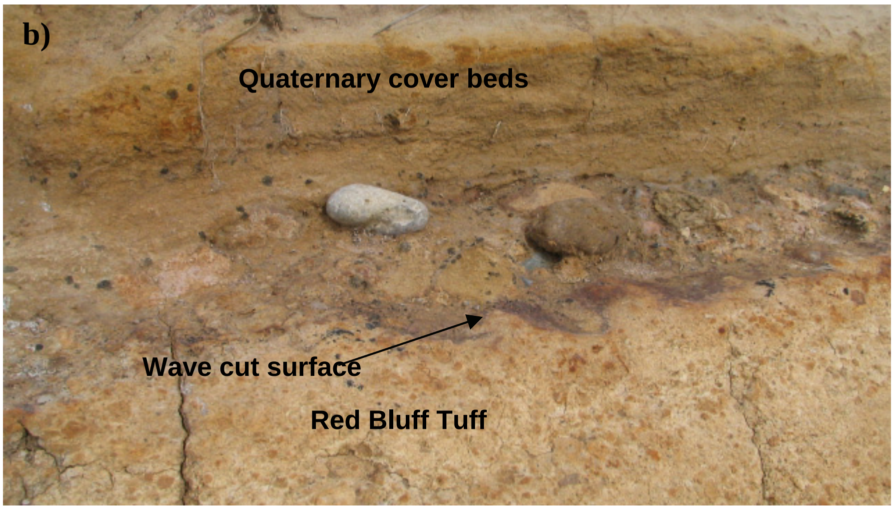
Latest Pliocene – Early Quaternary age c.7 – 14 metre surface

A wave cut surface at c. 6 - 7 metres a.s.l. is exposed at the base of a significant cliff sequence in a bay to the north of Red Bluff (Plate 5.5). The surface itself is cut into Eocene/Oligocene aged Matanganui Limestone and is overlain by around 18 metres of cover beds which are predominantly terrestrial deposits of the Wharekauri Sand and Maipito Formations. Directly resting on the surface is 0.5 - 1 m of Titirangi Sand which is of earliest Quaternary age, suggesting that this surface pre-dates all the other recognised surfaces by well over 1.5 Ma. It is believed that successive high sea level stands must have transgressed over this surface and the overlying Titirangi Sand, subsequent to its deposition and removed any deposits spanning the period ~2.4 Ma to OIS 11 (refer section 6.3.1). The same surface is apparently preserved below younger deposits in the Wharekauri area, near Waitaha Creek, where the contact between Matanganui Limestone and Titirangi Sand was encountered at 13.4 metres a.s.l. within a borehole during the Fletcher Challenge drilling programme. This borehole (CHA 65R) underlies an area mapped by Campbell *et al.* (1993) as surface h3. However it is most probable that like at North Red Bluff, successive high sea level stands have transgressed over this site sometime after the deposition of the Titirangi Sand, and that the h3 surface in this area was generated by one of these later high stands.

6.4 Discussion of terraces

The terrace information presented above combines to form a somewhat confusing picture of eustatic sea-level change and tectonic uplift/subsidence on Chatham Island. One curious feature of the marine terraces on Chatham Island is a lack of marine cover-bed deposits on the wave-cut surface. This was also recognised by Hay *et al.* (1970). The presence of marine deposits is regarded as a defining feature of marine terraces and wave-cut platforms (Pillans 1990). However, at certain localities, e.g. Wharekauri-Kaingaroa turn-off quarry and Mairangi, evidence for marine conditions at the position of the inferred wave-cut surface is very weak. With the exception of three localities (Stony Crossing basalt quarry – Ohira Bay boulder gravel, North Red Bluff Quaternary sequence – Titirangi Sand, and north Owenga coast – Te Awapatiki shelly sand), none of the marine surfaces examined in this work bear identifiable marine or near-shore deposits. Most surfaces are overlain by coarse to medium beach and/or dune sands, often with a very thin gravel lag deposit at the base. This lag deposit usually comprises only a few scattered clasts (Plate 6.5) within a coarse sandy matrix. During the Fletcher Challenge drilling project, no (Quaternary) marine deposits were encountered over the older Tertiary rocks, other than the Titirangi Sand (Richards 1987).

Plate 6.5: Thin gravel lags on former wave cut surfaces. a) gravel lag composed predominantly of chert and limestone pebbles overlying 7 – 14 m surface in Te Whanga Limestone at the North Red Bluff Quaternary sequence, b) thin scattered pebble horizon overlying 3-5 m surface on Red Bluff Tuff at Waitangi.



The strikingly planar surfaces and major differences in age and lithology of deposits either side of each surface, at locations such as Wharekauri-Kaingaroa turn-off quarry, Mairangi and other sites, are best explained by marine action (in the absence of other planation mechanisms e.g. glacial ice). The lack of fossiliferous marine deposits from all but two surfaces also precludes age control by biostratigraphy (and uranium/thorium dating of shell material). It is possible that any fossils within the cover-beds on the wave-cut surface have been destroyed by leaching from rain and ground water acidified through contact with the Moorland Peat.

Thicknesses of cover-bed sequences overlying these wave-cut surfaces are highly variable. This is the case for sites on the same age surface, and for sites on surfaces of different ages, i.e. a younger surface may bear a thicker sequence of cover deposits than an older surface. This results from a number of factors such as the variation in rates of peat accumulation, as well as variable rates of aeolian deflation and/or deposition.

The cover-bed sequences do indicate that there are major discrepancies between terrace heights and ages between locations around the island. For example: the 20 m surface at Matarakau, where the Rangitawa Tephra within the cover beds indicates pre-OIS 10 formation; the 16 m surface at Stony Crossing and Wharekauri-Kaingaroa turn-off which is most likely the Last Interglacial (or penultimate interglacial) marine bench; and the latest Pliocene – Early Quaternary 7 – 14 m surface at North Red Bluff and near Waitaha Creek, which is lower than considerably younger surfaces. Explanations for these anomalies must lie in the history of tectonic uplift and subsidence of Chatham Island.

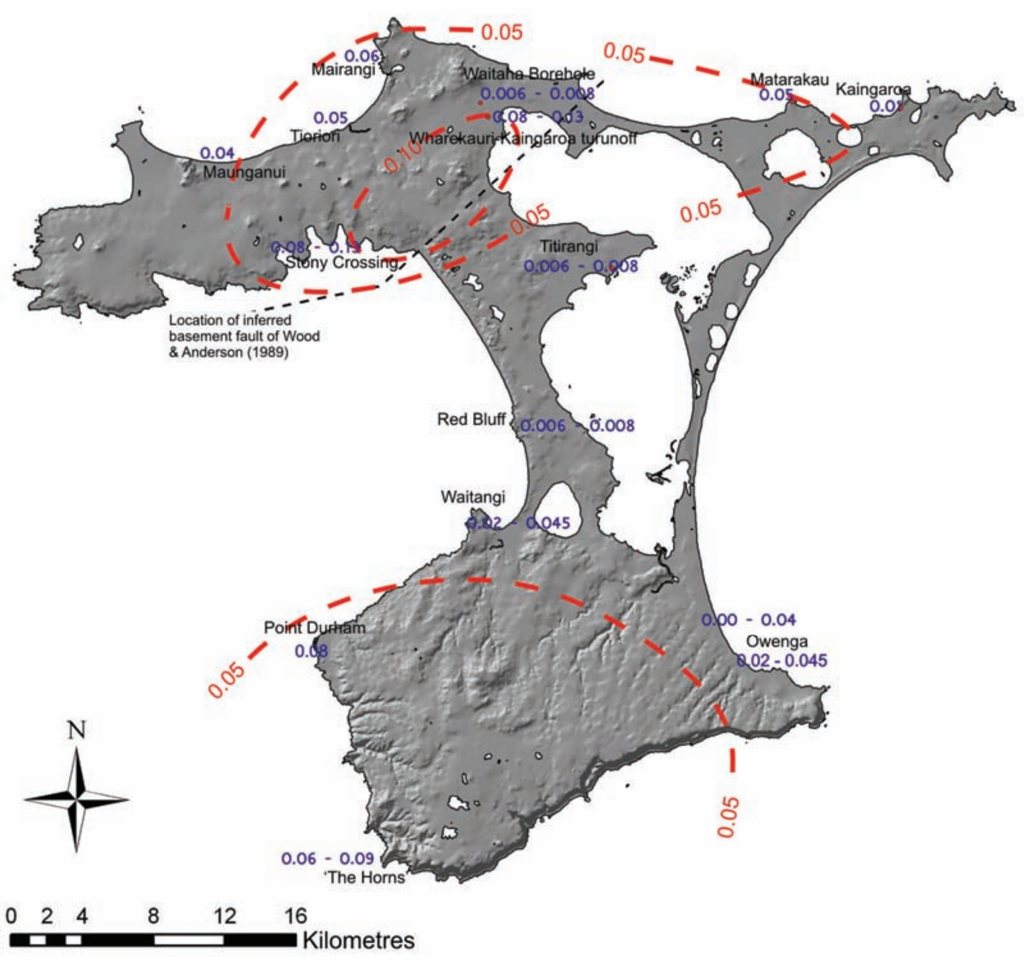
6.5 Terraces and uplift on Chatham Island

Marine terraces are often used in elucidating relative or absolute rates of tectonic uplift and deformation (Wellman 1972, 1979, Pillans 1990). Pillans (1990) describes the simple formula to determine uplift rates from terrace heights:

$$U = (H - E - S) / T$$

Where H is the height of the terrace surface (i.e. wave cut surface + cover beds), E is the difference in height between some feature, e.g. the strandline and the terrace surface, and S is the height of sea level at the time of terrace formation relative to present sea level. T is the time of formation or age of the terrace. This principle is applied to the marine terraces and wave-cut surfaces investigated in this work to provide preliminary uplift rates for Chatham Island (Figure 6.2).

Figure 6.2: Preliminary uplift rates for Chatham Island in mm/yr.



Pillans (1990) demonstrated that the height position of the strandline is the best method for determining uplift rates for a marine terrace (i.e. to provide factor E). However, at many locations on Chatham Island the position of the strandline is obscured by younger deposits, e.g. peat accumulations etc, so the maximum height of the wave-cut surface relative to modern day sea level is used, (thus providing minimum uplift rates).

Sea level at the presumed time of terrace formation (S) can be regarded as zero, because most high sea level stands over the last ~750 ka are generally considered to not have exceeded that of the present day (Pillans 1990), with the exception of the Last Interglacial (OIS 5e) which may have exceeded the present level by c. +5 metres

(Chappell and Veeh 1978) and OIS 11, which has been shown to have been particularly long interglacial (Droxler *et al.* 2003), with sea level rise exceeding 13 metres above present (Hearty *et al*. 1999, Poore and Dowsett 2001).

Age control of terraces (T) is from correlation of cover-bed deposits, particularly rhyolitic tephra beds and thus again provides minimum uplift rates for certain locations. A full description of how the values presented in Figure 6.2 were generated is contained within Appendix 12.

All of the uplift rates presented within Figure 6.2 are relatively low when compared with the more tectonically active regions of New Zealand. Most of the uplift values are around 0.04 – 0.08 mm/yr, with the (notable) exception of two surfaces: the ~16m surface at Stony Crossing and Wharekauri-Kaingaroa turn-off quarry; and the 7 - 14 m surface exposed at the North Red Bluff Quaternary sequence and within the CHA 65R borehole, near Waitaha Creek.

As discussed above, there are at least two possible age scenarios for the 16 m surface – a Last Interglacial (OIS 5e) age, or penultimate Interglacial (OIS 7) age. Rates of uplift calculated using the younger Last Interglacial age of 125 ka are 0.128 mm/yr, the highest calculated for the island, and 3 times greater than the rates calculated for the 3-5 m interglacial marine terrace in the Owenga region. While the older OIS 7 age ~200 ka, which is based largely on pollen evidence, yields rates of ~0.08 mm/yr, which is more in keeping with rates for the rest of the island but is still double that of the Last Interglacial marine bench at Owenga.

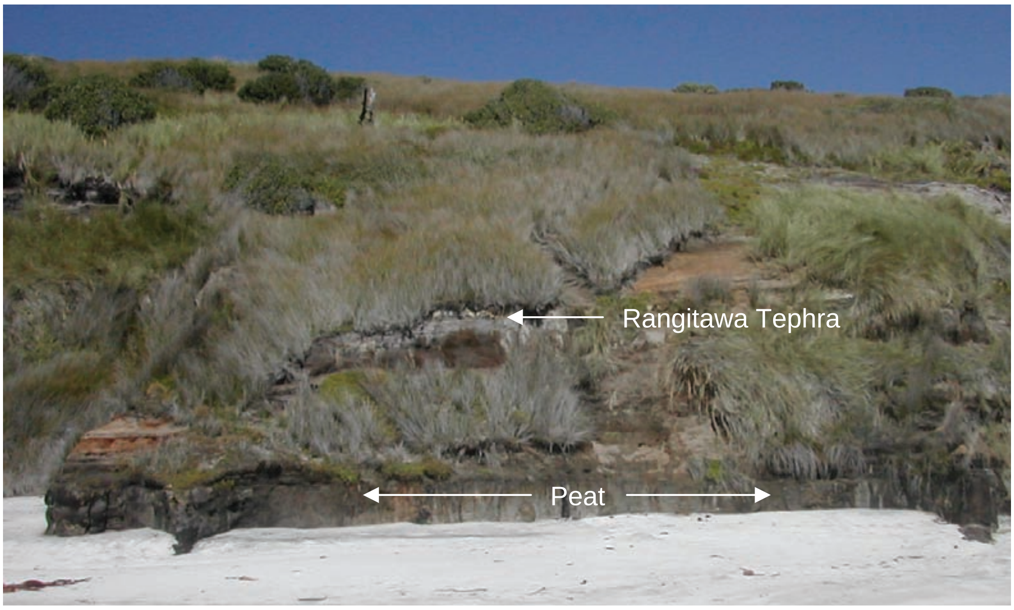
The 7 - 14 m late Pliocene-Early Quaternary surface gives rates of an order of magnitude lower than other sites on the island, which when considering its age, is rather perplexing. As discussed earlier in this chapter, it seems probable that this surface (and overlying deposits) must have been transgressed over subsequent to its initial formation during Nukumaruan times, most recently during OIS 11 as indicated by the cover-bed sequence exposed in the bay north of Red Bluff.

Nevertheless, the fact that the Titirangi Sand occurs today within 15 metres or less above modern day sea level indicates that there has not been more than 15 metres of uplift in the Wharekauri - central Chatham region at least, since its deposition during the Nukumaruan. This suggests that following the initial emergence of Chatham Island sometime between 2 – 3 Ma, (i.e. when the Titirangi Sand was deposited over the older Tertiary limestones) there was no further uplift, or uplift ceased or slowed to miniscule rates (~0.0001 mm/yr?) in the central Chatham region until sometime during the mid-late Pleistocene when uplift responsible for raising the younger surfaces began and rates increased to ~0.04 – 0.08 mm/yr. However this hiatus in tectonic uplift must have been limited to the central Chatham Island region, as there is strong evidence that other parts of the island have experienced greater rates of uplift over the Late Pliocene – Pleistocene. Recent work has found through both biological and geological lines of evidence, that a tectonic uplift event drove the Chatham Islands to become emergent during the late Pliocene – Early Quaternary, 3 - 2 Ma ago and no earlier (H. Campbell pers. comm.). The driving forces behind this uplift are not yet fully known. However, based on the position of a late Pliocene-aged fossiliferous marine conglomerate that now lies c.180m a.s.l. in south-west Chatham Island (H. Campbell pers. comm.), uplift rates of c. 0.06 – 0.09 mm/yr can be calculated for the southern uplands region at least, which are an order of magnitude higher than those of central Chatham Island region as indicated by the 7 – 14 m surface.

The position of the Rangitawa Tephra has provided an indication of very low uplift rates in other parts of Chatham Island. As mentioned above, in the Kaingaroa region the Rangitawa Tephra occurs within peat deposits that underlie a planation surface, apparently of marine origin, and lies within c.3 m of modern sea level. The tephra is also exposed 100 m to the north, within a similar but more lithologically variable sequence exposed in the modern beach cliff face. Peat outcrops at sea level and extends below the depth of the modern beach surface. A sharp planar surface is again apparently ‘cut’ into the top of this peat (Plate 6.6) which is overlain by a beach deposit comprising coarse, horizontally laminated, well rounded pebbly sands. This beach deposit is in turn overlain by 1 to 2 metres of inter-bedded (increasingly terrestrial) sandy layers, weak soils and thin peat beds. The Rangitawa Tephra is preserved within a peat bed at the top of this sequence (at ~3m a.s.l.), which is overlain by several metres of poorly to non-bedded peaty dune sand. Two more thin peat beds occur within the sequence, the upper of which contains the Kawakawa

Tephra. Pollen analysis of these peat beds suggests they both accumulated during glacial periods (Chapter 4, section 4.6.4.). The sharp upper contacts of the peat units

Plate 6.6: Pre-Rangitawa Tephra peat exposed at beach level at Kaingaroa, note sharp planar surface at the top of the peat



at both the beach front section and the slump section in the Kaingaroa area have been generated by wave action during interglacial sea level rise. During glacial periods, sea level fall exposed a considerable area of shelf to the east of the present day coast (Figure 4.2), which supported peat forming-vegetation. During post-glacial sea level rise the sea transgressed over the glacial peat and the interglacial beach was cut into this peat. This process is presently occurring and has been occurring over the Holocene in the southern Hanson Bay coast area where the modern day beach surface is underlain by LGCP-aged peat. This peat contains in-situ tree and shrub stumps which can be seen protruding from the beach surface at low tide, forming an LGCP buried forest.

The position of the Rangitawa Tephra in the Kaingaroa area has implications for uplift rates in the Kaingaroa region. Taking the Tephra's position of c.5 m a.s.l. implies <5m of uplift max. over 345 ka, which gives an uplift rate of 0.01 mm/yr. If the tephra was deposited at a position below modern sea level, i.e. in peat developed on the shelf exposed during the OIS 10 glacial, and survived the following sea level rise during

OIS 9, and was simply buried to be subsequently uplifted, then the uplift rate would of course be higher. However the lack of variation in the deposits overlying the Rangitawa Tephra at both the beach front and slump exposures, and particularly the lack of marine deposits, makes drawing any further conclusions about sea level relationships very difficult.

Several explanations for the variable rates of uplift across Chatham Island are possible. Variable rates of uplift derived from differences in heights of the same aged terrace from other regions in New Zealand are often attributed to simple models of styles of uplift e.g. tilting or doming (e.g. Pillans 1983). However the distribution of uplift rates observed on Chatham Island, particularly between the 7 - 14 m latest Pliocene – Early Quaternary surface in the CHA 65R borehole and the 16 m late Pleistocene surface at the adjacent Wharekauri-Kaingaroa turn-off area cannot be explained by these mechanisms, as apparent rates of uplift vary from 0.01 mm/yr to 0.08 - 0.13 mm/yr over a distance of 400 metres.

Faulting is one mechanism often invoked to explain such abrupt variations in observed uplift rates. There is no geomorphic or seismic evidence for the existence of a fault in the region between these two sites. However the large basement fault that juxtaposes the Chatham Schist against younger Cretaceous and Tertiary rocks (Wood & Anderson 1989) occurs within 3 km of the site. It is possible that there may be more than one fault paralleling this major geophysical gravity anomaly, and these may be responsible for progressive block faulting along the contact.

6.6 Concluding remarks

Marine terraces have been identified at several different heights on Chatham Island. However in several cases, firm evidence of marine origin for the surfaces is absent. Using the height of underlying wave-cut surfaces and the inferred age (based on tephrochronology and/or biostratigraphy) of the terrace, preliminary rates of uplift of Chatham Island have been calculated to be within 0.04 – 0.08 mm/yr. Overall these uplift rates are very low when compared with mainland New Zealand but are what would be expected from an area so distal from the zone of active deformation along the Australia/Pacific plate boundary. However there is considerable variation in rates across the island, and also over very short distances. These variations cannot yet be fully explained. They do indicate that following the initial emergence of Chatham Island during the Late Pliocene – Early Quaternary, uplift in the central portion of the island slowed considerably or ceased altogether, while the southern uplands continued rising at a rate of ~0.06 - 0.09 mm/yr. This makes sense as the central portion of Chatham Island essentially sits over a half graben between the upthrown schist basement to the north, and the Southern Volcanics in the south. However, this cannot satisfactorily explain all the observed variations in uplift rates, particularly in the region near the Wharekauri-Kaingaroa roads intersection.

What has become very clear is that considerably more work is required on Chatham Island marine terraces, most notably on more reliable age control. Radiometric ages on the deposits immediately overlying the wave cut surfaces is highly desirable but is unfortunately beyond the scope of this project. Luminescence dating of quartzose beach/dune sands has been applied with some success in dating marine terraces in New Zealand and other parts of the world, and would probably be appropriate for use on Chatham Island considering the most common type of covering deposit is quartzose beach/dune sand. Also the lack of fossiliferous marine cover-bed deposits precludes biostratigraphic age control and thus uranium/thorium dating of shell material.

CHAPTER 7
DISCUSSION

The preceding chapters have presented information on the Quaternary stratigraphy, vegetational history and interpreted marine terraces of Chatham Island. This chapter attempts to draw together a comprehensive synthesis of Chatham Island Quaternary history.

7.1 Uplift

One of the most significant issues in understanding Chatham Island's Quaternary history is the question of uplift. At first glance the Chatham region would seem to be relatively stable tectonically because it is located so far from the active Australia-Pacific plate boundary. The apparent lack of substantial tectonic uplift has prompted some to suggest that the Chatham Islands may be the ideal place to study eustatic sea level change (Campbell and Edwards 1988). In areas where geomorphic evidence of sea level change has been studied in detail, determining the magnitude of sea level rise is often complicated by the effects of tectonic uplift. So Chatham Island could be considered ideal for studying sea level rise during the Last Interglacial. Assuming no uplift on Chatham Island over the last 125 ka, the position of the strandline of the Last Interglacial marine bench would indicate that sea level rise during OIS 5e was around 5 metres, which approximates to values presented by Chappell and Veeh (1978).

But the lack of uplift makes Chatham Island less useful for studying older cycles. Without the influence of uplift, the stratigraphic record of one cycle is at great risk of marine removal by sea level rise during later cycles. More of the Quaternary record is absent from Chatham Island than is present, principally due to non-deposition and erosion. Campbell *et al.* (1993) summed up this point particularly well by stating that ' *a thick sedimentary succession within an area with an active but resolvable tectonic history can probably reveal more about eustatic sea level change* (over the Quaternary) *than the Chathams can*'. At this stage, Chatham Island tectonic history is not resolved. Most evidence (in this work) suggests that rates of uplift on Chatham are exceptionally low. However, the relationships between certain key (lithologic) formations and geomorphic features on Chatham Island imply that uplift has occurred, and that the tectonic history may be quite complicated.

What is apparent from the uplift data is that the northern, central and southern regions of Chatham Island behave differently in terms of deformation. This is understandable when considering what is known about the geophysical characteristics of the region. The central portion of the island is underlain by a half-graben formed between a large basement fault juxtaposing the Mesozoic Chatham Schist to the north against younger Cretaceous-Tertiary lithologies to the south, and the gently northward-dipping fault block composed of Southern Volcanics in the south. Consequently, rates of uplift are higher in the northern and southern portions of the island and lower in the central portion (Figure 6.2).

It is becoming acknowledged that there was a major period of uplift in the Chatham region sometime during 3-2 Ma, which resulted in the emergence of subaerial land in the Chatham region (Campbell *et al.* 2006). This period of uplift is represented in a few exposures on Chatham Island, which contain deep water (mid – outer shelf) bioclastic sediments with minimal terrestrial input (Motorata and Te Whanga Limestones) which are directly overlain by very shallow water (inner shelf – littoral) sediments with a significant component of terrestrial material (Titirangi Sand). Evidence for shallowing at this time has also been found within Late Pliocene sediments of the Mangere and Parakeet Formations on Mangere Island, to the south of Chatham Island (Davies 2006).

The timing of this shallowing is broadly consistent with global sea level fall towards the end of the Pliocene (Haq *et al*. 1987), and also with increased compression at the northern Alpine Fault, at the western end of the Chatham Rise during the Kaikoura Orogeny. Herzer and Wood (1992) attributed all of the Neogene shallowing to eustatic sea level change, with no tectonic influence. Grindley *et al.* (1977) also found no evidence for tectonic uplift of the Islands at this time. However, according to Campbell *et al.* (1993) the stark change in water depths represented by the juxtaposition of the two formations cannot be completely accounted for by eustatic sea level change alone, and that some component of tectonic uplift must be involved.

What is not known is whether uplift continued following this initial phase, and if so, at what rate? The physiographic position of the oldest post-emergence sediments on Chatham Island – namely the Titirangi Sand – has significant implications for this question. Today all known outcrops of the Titirangi Sand occur within 14 m or less of modern sea level, which implies that tectonic uplift cannot have been more than (an average of) 0.007 mm/yr since the deposition of the Sand, assuming that it was deposited at or around modern sea level. This rate is at least an order of magnitude lower than the rates calculated for Chatham Island from other geomorphic and stratigraphic lines of evidence (refer to Chapter 6). Also, deposition of the formation was coincident with the onset of Northern Hemisphere glaciation and the beginning of pronounced cyclicity in global climate and sea level. If uplift slowed or ceased soon after the accumulation of the Sand then presumably it would have been at risk from erosion during Pleistocene sea level transgressions.

A possible explanation for these features could involve the major structural features underlying Chatham Island. The area in which the Titirangi Sand occurs is underlain by the previously described half-graben. The Sand would have accumulated within a basin formed over this structure which may have approximated to a proto-Te Whanga Lagoon or shallow estuarine environment. Gradual subsidence within this basin over the Quaternary period would have allowed continued sedimentation in the basin, resulting in preservation of the Titirangi Sand beneath a sequence of younger deposits. Uplift of the northern and southern portions of Chatham may have persisted after the deposition of the Sand, but at very slow rates. Sometime later, uplift across the greater Chatham region resumed or increased to rates that exceeded rates of subsidence within the graben. This resulted in the uplift of sediments within the basin. Eustatic sea level change then led to the cutting of wave-cut surfaces at levels physiographically higher than the Titirangi Sand, which are preserved, at 30 - 40 m, 20 m and 16 m. The sediments overlying the Titirangi Sand within the basin have been partially eroded during subsequent uplift and sea level transgressions. It is simply fortuitous that the Sand has not been completely eroded away. This hypothesis would explain why at all known outcrops of Titirangi Sand, the deposits are unconformably overlain by much younger terrestrial Quaternary deposits.

7.2 OIS 11 transgression

Another feature of Chatham Island Quaternary history that warrants further discussion is the conspicuous gap in the record between early Quaternary and late Castlecliffian deposits. This unconformity has been recognised within coastal and low-lying inland sequences in both northern and central Chatham Island. A lack of stratigraphic variability within sediments in drill holes extracted from licence areas in northern Chatham during the Fletcher Challenge drilling program (Richards 1987) suggests that this unconformity is widespread.

As proposed in Chapters 5 and 6 the unconformity was generated during the interglacial of OIS 11, which is regarded by some as a ‘super-interglacial’. Although there is disagreement between terrestrial records and ice core records as to whether the climate during OIS 11 was the *warmest* (e.g. Rousseau 2003, Petit *et al.* 1999), what is agreed upon is that it was clearly the *longest* interglacial of the entire Pleistocene epoch (Droxler *et al.* 2003). Maximum interglacial warmth, low ice volume and low rates of accumulation of ice-rafted debris persisted for at least 30,000 years, which is considerably longer than the OIS 5e and 7c interglacials, or the elapsed part of the Holocene (Droxler *et al.* 2003). Sea level is estimated to have risen between 13 to 20 metres above present (Hearty *et al*. 1999, 2007, Poore and Dowsett 2001), and sea surface temperatures were 1 degree warmer than typical interglacial temperatures (Lea *et al.* 2000, Droxler *et al*. 2003).

Supporting evidence from the New Zealand-South Pacific region is largely restricted to oceanic records. There is a major and prolonged peak in $CaCO_3$ within DSDP 594 at the time of OIS 11, representing increased productivity associated with warmer temperatures. Sea surface temperatures in the South Pacific region during OIS 11 were the warmest throughout the last ~1 Ma, 2 - 4 degrees warmer than present (Wilson *et al.* 2005, Schafer *et al.* 2005).

The combination of a particularly high sea level persisting for a prolonged period of time would have promoted extensive marine erosion of Chatham Island. Presumably the sea transgressed over a considerable portion of northern and central Chatham Island when most of the pre-OIS 11 deposits were removed by the sea.

For the OIS 11 transgression to have removed ALL pre-OIS 11 Quaternary sediments in northern and central Chatham, the land surface must have been at a lower altitude than it is today. Most of northern and central Chatham Island is within 60 to 80 m of modern sea level, with the exception of the distinctive hills and headlands formed from Tertiary volcanics. The thickness of sediments overlying pre-Quaternary bedrock is around 20 m maximum (Richards 1987). Assuming that all of these sediments are post-OIS 11 in age, and taking into account a maximum sea level rise during OIS 11 of 20 m, the land surface would have had to have been on average 20 – 40 m lower than at present. Conversely, this implies that there would have had to have been 20 – 40 m of uplift over the last 400 ka, which corresponds to uplift rates of 0.05 – 0.1 mm/yr. This is in keeping with those uplift rates generated from other marine terraces on Chatham Island. If this is the case, then at the height of OIS 11, Chatham Island would have been reduced to a group of several small islands in the north and one large island to the south.

The OIS 11 transgression over much of the northern and central portions of the island implies that the 30 – 40 m surface present in the Mairangi area must be younger than initially thought. Formation of this surface had been assigned to OIS 13, based on its position above a surface at 20m assigned to OIS 11 (section 6.3). However, if the OIS 11 transgression hypothesis is valid, then both the 30 – 40 m and 20 m surfaces must be from OIS 11. Two OIS 11 surfaces have also been recognised in the Taranaki – Wanganui region (Pillans 1990). On Chatham Island the 30 – 40 m bench could have been cut following the initial peak in sea level of OIS 11, then when sea level fell slightly but interglacial conditions persisted, the 20 m bench was cut. Or alternatively, there was a short-lived period of rapid uplift in (this part of) Chatham Island during OIS 11. These hypotheses explain why there are no deposits on the 30 – 40 m surface that demonstratably pre-date OIS 11. I interpret the 30 – 40 m and 20 m surfaces to be correlatives of the Rangatatau and Ararata Terraces of Pillans (1983), respectively.

A major erosional transgression event of this nature at this particular point in time serves to explain the absence of significant tephra marker beds (other than the Kawakawa and Rangitawa) from Chatham Island. As discussed in Chapter 3, at least three other tephra beds occur within deep-sea cores proximal to Chatham Island

(Carter *et al.* 2004), and thus should be present on Chatham Island but have not yet been encountered.

However, there is certain stratigraphic evidence that conflicts with the concept of a major transgression over northern and central Chatham. At Kaingaroa, peat interpreted to predate OIS 11 occurs very close to sea level (Chapter 6, section 6.5). How did this peat survive the sea level rise of OIS 11, and why has it not been uplifted higher since OIS 11? The Kaingaroa sequence can be made to fit with the transgression scenario if the Kaingaroa area is subsiding. Very low uplift rates of 0.01 mm/yr have been calculated for Kaingaroa (Chapter 6, section 6.5) but if subsidence is occurring then these are of course invalid. According to Wood and Anderson (1989) Kaingaroa is on the down-thrown side of the basement fault. However, schist also forms the basement in the Kaingaroa area, which implies that the area must have initially been uplifted along with the rest of north Chatham, in which case a new fault has since developed between north-eastern and north/north-western Chatham. This concept is supported by strong differences in the metamorphic grade of the schist between north-eastern and north/north-western localities, which support the existence of a fault within the schist basement.

Sedimentary sequences that do pre-date OIS 11 on Chatham Island are most likely to be preserved in the topographically higher, southern reaches of the island. There are very few exposures through the Quaternary sequence in this area. Only one site in this region was examined in detail during this work - the Boundary Rock cliff site. Here the sequence comprises approximately 4 m of inter-bedded clayey silts and peat of the Maipito and Moorland Peat Formations, respectively. Palynological and stratigraphic lines of evidence suggest that this particular site may pre-date OIS 11 (Chapter 4, section 4.6.6), but further constraints on the age of the deposits are required before this can be confirmed.

Observations at relatively poor exposures on the western side of the southern uplands have indicated that the sedimentary cover may be quite thin. At one location (GR 388390) less than 2 metres of peat with the Kawakawa Tephra near the base, rests directly on Cretaceous-Tertiary volcanics. Elsewhere, particularly along the coast, 2 - 3 metres of Maipito Formation sediments rest directly on these volcanics.

The Fletcher Challenge drilling program found thicknesses of Quaternary sediments on the southern uplands in excess of 17 metres. On average, the sequences comprised 5 -10 m of peat overlying sand, sandy clay and clay, with the thickness of the clay exceeding 8 metres in some cases (Richards 1987). All of the peat examined during the project was regarded as being of Last Interglacial age or younger. However, Richards (1987) noted that peat extracted from deep in the drill holes in the southern uplands had a strong hydrogen sulphide smell. During this work, all peats presenting this odour occur below the Rangitawa Tephra, and are at least ~345,000 years old. So it is possible that the basal peats on parts of the southern uplands are >345,000 years old.

Chatham Island Soil Bureau Drill Hole 11 at Oropuke, located near one of the highest points of Chatham Island, contained some 12 metres of sediments. The upper 10 metres are peat, all of which is interpreted as Last Glacial-Holocene in age, based on the position of the Kawakawa Tephra near the base of the peat (Mildenhall 1994a). This peat overlies deposits described as tuffaceous siltstone, which may be Tertiary volcanics i.e. Red Bluff Tuff, or may in fact be much younger aeolian deposits of the Maipito Formation, formed from reworking of tuffaceous volcanics.

Neither the Fletcher Challenge nor Oropuke drill holes provide any conclusive indication of the maximum age of the Quaternary sediment cover over the southern uplands. Unfortunately the original core sediments have since been discarded, precluding any detailed re-examination in the hope of firmly establishing the age of the basal sediments.

The limited data and observations seem to imply that, like the lower reaches of Chatham Island, the uplands also contain a fragmentary record of Quaternary sedimentation. It is possible that prolonged exposure to aeolian/terrestrial conditions has resulted in limited sedimentation over this area. Both Richards (1987) and Mildenhall (1994a) imply that peat accumulation has only occurred on the (higher reaches of the) uplands relatively recently, which is supported by observations made during this work.

Explaining some of the spatial and temporal relationships between deposits and land forms on Chatham Island has required invoking a rather chequered uplift history for Chatham Island, including:

- Initial rapid uplift of the wider Chatham Islands area, probably accompanied by eustatic sea level fall,
- subsidence within central Chatham and slowing or cessation of uplift in northern and southern Chatham,
- resumption or increase of uplift during the mid-late Quaternary, particularly in the north-west,
- and subsidence in the north-east.

A full investigation into the driving forces underlying these proposed events is beyond the scope of this project. However, initial (post-Tertiary) uplift of the Chatham Islands is possibly related to movement and activity on the Australia-Pacific plate boundary translocated along the Chatham Rise. Translocation of compressional forces from collision zones can result in uplift and deformation in distal areas, for example the formation of the Wealden anticline in South East England, which was driven by continental collision between Europe and Africa some 800 km away, in the early Cenozoic (Nowell 2007).

Structurally, the Chatham Rise is dominated by large east-west-striking half-grabens formed by south-dipping listric faults which formed in response to late Cretaceous rifting and the formation of the Bounty Trough (Wood and Anderson 1989, Herzer and Wood 1992). Little deformation of the Rise occurred following the Late Cretaceous rifting phase, with the exception of renewed normal movement on Cretaceous faults in the Eocene (Herzer and Wood 1992). This stability is reflected in palinspatic reconstructions of the New Zealand plate boundary (King, P.R. 2000), in which the Rise is depicted as behaving as a single structural entity.

The stability of the Rise persisted presumably until the events that resulted in the uplift of the Chathams began. The timing of uplift of the Islands at ~3 - 2 Ma is broadly coincident with notable changes in the rate and azimuth of plate motion at the Australian-Pacific plate boundary. During the mid-Nukumaruan at ~2 Ma, the direction of relative motion of the Pacific plate with respect to the Australian plate, shifted from south-westward to westward, which lead to increased convergence along the northern portion of the Alpine Fault (King, P.R. 2000). This caused increased compression of the continental crust of the north-eastern South Island and its Chatham Rise continuity against the Australian Plate. Translocation of this compression along the Rise could have lead to buckling and deformation of the Rise, which may have driven uplift of the Chatham Islands. However, there is no other current evidence for broad-scale deformation of the Rise at this time. At present, activity associated with the change in plate motion at ~2 Ma is recognised only at its north-western end, between Mernoo Bank and the Southern Alps at the North Mernoo Fault Zone, where many new normal faults developed, and some Cretaceous faults reactivated in a normal sense (Herzer and Wood 1992, Barnes 1994). No post-Tertiary/Eocene deformational features are currently recognised anywhere else along the Rise. If the changes at the plate boundary did affect the eastern end of the Chatham Rise, then we would expect some evidence of it along the length of the Rise i.e. folding, and faulting of the mid-late Cenozoic sediment cover. We would also expect some degree of ongoing seismicity, yet very little seismic activity has been recorded from the Rise (Wood *et al.* 1989). However, the structural data obtained from the Rise (i.e. seismic profiling) are limited to regional reconnaissance surveys (Herzer and Wood 1992), so it is possible that minor structural features associated with Plio-Pleistocene deformation of the Rise may have not have been recognised. Also, the apparent lack of seismic activity may in part, result from a lack of sufficient instrumentation, in that as the Rise is too far away from most seismic stations for small magnitude (<5) earthquakes to be recorded (Campbell *et al.* 1993). Small earthquakes (magnitude ~4.6) have been felt on the Chatham Islands within the last 40 years (Campbell *et al.* 1993).

7.3 Influence of glacial climate

It was suggested in Chapter 4 that climatic deterioration during glacial periods did not have the same influence on the environments in the Chathams as it did on mainland New Zealand. The most compelling evidence for this lies within the vegetation records, which suggest that Chatham Island has always retained forest or bush cover, and when compared with New Zealand pollen records, changes have been less dramatic. The maritime influence on the Chatham climate would have moderated the effect of any drop in sea surface temperatures in the region, which are believed to be ~4 ºC in the area south of the Chatham Rise (Nelson *et al.* 1993, Wilson *et al.* 2005) and as little as 0 ºC to the north of the Rise (Fenner *et al.* 1992, Weaver *et al*. 1998). The drop in sea level would have served to increase the altitudinal range of the island to ~400 m a.s.l., however this is still relatively low lying. Perhaps the biggest impact glacial cooling and sea level fall had was to increase the land area of the Chathams (Figure 4.2) and to cause a drop in the level of the water table. Both of these factors would have, in general, decreased moisture availability on the island, except in low-lying areas around the coastline.

7.4 Synthesis

Quaternary sedimentation on Chatham Island began following the rapid emergence of the island from the sea, at around 2-3 million years ago. In these early stages, Chatham would have initially comprised a group of separate, smaller islands. To the north, these islands were formed by the resistant upstanding remnants of the Tertiary-aged Northern Volcanics and Rangitihi Volcanics. To the south, the large, broad plateau formed from Cretaceous-Tertiary-aged Southern Volcanics would have formed one large island. The central Chatham region would have comprised a relatively sheltered, shallow-marine area, with abundant molluscan life, into which debris freshly eroded off the newly exposed older schist and Tertiary lithologies was deposited. It was in this environment that the Titirangi Sand accumulated.

After time, with uplift continuing at very slow rates, and with the build up of sediment, these smaller islands would have become joined into one low-lying landmass. Small freshwater and brackish lakes and lagoons would have developed behind newly formed sand dunes. These have probably been a feature common to Chatham throughout its Quaternary history, although they are probably ephemeral in nature, moving and changing position with the movement of dune sands, or being invaded and opened to the sea during sea level transgression. Reconnaissance sampling of lake beds in many of the Chatham Island lakes has indicated that most contain relatively little sediment, which is dominated by sand, suggesting present lakes on the island are all relatively young.

Enclosure of Te Whanga Lagoon would have begun following exposure of sufficient land in the north-east of the island, i.e. in the Kaingaroa area. These areas would have acted as loci for sedimentation and the formation of sand spits and tombolos to join together the Mt Chudleigh, Matarakau and Kaingaroa headlands and islands in the north, and to join Kaingaroa to the Te Matarae and Rangihapainga Hill areas to the south, forming the northern and eastern borders of the lagoon, respectively.

Upon emergence, vegetation would have established on the island. All Chatham plants (and animals) have a strong affinity to the New Zealand mainland flora and fauna. At this stage it is not known exactly how flora or fauna reached Chatham Island. There are two main possibilities: a land bridge existed between Chatham and New Zealand, along the Chatham Rise, allowing the spread of species from mainland New Zealand out to the island; or species reached the Islands by other means of dispersal, i.e. rafting of seeds. The absence of prominent mainland species such as Kiwi, Moa and Tuatara from Chatham Island tends to favour the latter hypothesis.

Once vegetation cover was established, peat swamps would have begun to develop. The existence of peat which pre-dates the Rangitawa Tephra clearly demonstrates that peat-forming vegetation has been common place on Chatham for at least 350 ka, and probably longer. The conditions that make Chatham such a favourable environment for peat formation i.e. a relatively cool maritime climate and abundant salt spray which act together in retarding the decomposition of plant matter, have probably persisted throughout the Quaternary on Chatham Island. These peats developed into the large oligotrophic blanket peats of the Moorland Peat. The higher, more exposed parts of the island, coastal headlands, and exposed volcanic mounds were subject to aeolian erosion and most of the deposits accumulating in these areas are relatively discontinuous and were short-lived.

The emergence of Chatham Island is almost coincident with the onset of Northern Hemisphere glaciations and the beginning of pronounced cyclicity of global climate and sea level change. Hence, following the initial phases of landscape formation in the Late Pliocene and Early Pleistocene, sedimentation proceeded in a distinct pattern governed by global climate and eustatic sea level changes.

During an interglacial, the relative rise in sea level resulted in the landward migration of coastal environments (as it does everywhere). As the sea rose, increased erosion of the coast generated significant quantities of sediment which became available for transport, and sand dune construction. Thus, the onset of an interglacial is recorded within the Chatham Island peat sequences in several ways depending on proximity to the coast. Those deposits nearest the coast are incised and eroded by wave action as the sea transgresses landward. In certain circumstances, a wave-cut surface generated by the rising sea is cut into the peat, with this peat then underlying the interglacial beach surface. Examples of this can be seen in the Kaingaroa area, where at one location (GR 676785) peat pre-dating the Rangitawa Tephra is truncated by a sharp erosional surface overlain by horizontally laminated pebbly beach deposits, while at another the Last Interglacial marine bench is cut into OIS 10-aged peat. This process is also currently occurring in the southern Hanson Bay area, where LGCP-aged peat underlies the modern beach surface (Chapter 6, section 6.5).

Peat beyond the area of maximum landward transgression, but still relatively proximal to the coast, became overwhelmed by advancing sand dunes, (e.g. within the section exposed along the coast north of Owenga). Those that are even further inland still receive an increase in aeolian sand input, but peat growth continues.

Peat also records climatic amelioration associated with interglacials through fossil pollen. Under interglacial conditions, vegetation is dominated by broad-leaved and *Dracophyllum* forest species. Changes within mainland New Zealand vegetation are represented within Chatham peats by an increase in the levels of exotic/long distance Podocarp pollen, notably from *Podocarpus totara* or *Prumnopitys taxifolia*, and *Dacrydium cupressinum* (Chapter 4). Peat begins to accumulate in areas that were previously sites of aeolian deposition, particularly areas in the higher, more exposed reaches of the island. This is represented in areas like the Boundary Rock cliff site, where thin peat beds with interglacial flora occur within aeolian silts.

During interglacials, Te Whanga Lagoon would have been open to the ocean, at both its northern and eastern margins. These areas of the lagoon margin are not formed by pre-Quaternary, compacted lithologies, rather being constructed of relatively loose Quaternary unconsolidated sediments, which would have been easily eroded by the rising sea. This is reflected by the lack of deposits that predate the Last Interglacial (OIS 5e) in the northern and eastern arms of the Lagoon shore today. The deposits in this area comprise a Last Interglacial- Last Glacial succession of dune and beach sand (Wharekauri Sand) overlain by Moorland Peat containing the Kawakawa Tephra. The only Quaternary deposits in the north-eastern region of Chatham Island, that pre-date OIS 5e occur in the topographically higher areas of Kaingaroa and Matarakau, which would have been islands during the previous interglacials.

Towards the close of an interglacial, sea level begins to fall and the climate begins to cool towards the onset of a glacial period. As the sea recedes, a significant portion of the continental shelf around Chatham Island is exposed. Figure 4.2 demonstrates just how much broader Chatham Island could have been during glacial periods, with all islands within the group joined into one larger landmass.

During the initial stages of sea level fall, aeolian erosion of the sediments on the exposed shelf resulted in the deposition of silt-rich sands in coastal areas. Peat accumulation continues in inland areas, while aeolian erosion and reworking occurs in regions of higher altitude where increased exposure leads to local retreat of forest cover. After time, the exposed shelf area becomes vegetated, and peat formation occurs. Local fisherman on Chatham have reported hauling up large lumps of peat from the sea floor around Chatham Island. Once vegetated, the shelf area ceases to be a source of sediment (for ‘coastal’ areas) and soil development occurs in the reworked shelf sediments that were deposited inland.

Peat accumulation in inland areas continued for most of the duration of the glacial periods; however rates probably slowed somewhat during the coldest phases. Accumulation may have ceased altogether during the LGCP (Mildenhall 1994a), particularly in higher inland regions. However, accumulation probably continued at moderate rates in low areas and on the shelf area where conditions were more equable.

This concept of peat accumulation and soil development in coastal and lowland areas, and aeolian erosion, reworking and deposition in inland, undulating and high areas during glacial climates is reinforced by the stratigraphic associations of the two rhyolitic tephra markers. Both the Rangitawa Tephra and the Kawakawa Tephra fell during glacial periods, (OIS 10 and OIS 2, respectively). Where occurring in coastal and low-lying areas, both tephras were deposited in peat, or occur in close association with an overlying paleosol or peat bed. While in regions of greater relief and/or higher altitude they are found almost exclusively within aeolian deposits.

Glacial conditions are represented in the peat by an increase in the levels of fine silt-sized material of aeolian origin, creating silt-rich horizons. These horizons result from a combination of an increase in windblown sediments, derived from the shelf during initial regression, and a decline in peat accumulation which allows concentration of clastic material within the peat. Glacial conditions are reflected in the pollen record by a decrease in pollen of broadleaved forest species, and a rise in grass and Asteraceae pollen. Long distance pollen from mainland New Zealand becomes dominated by *Nothofagus* (Fusca type) and to a lesser extent, *Phyllocladus*, representing a reduction in warm climate podocarp forest and a relative increase of higher altitude forest species, as the tree line migrates to lower altitudinal levels.

During glacial periods Te Whanga Lagoon probably drained completely. It is possible that several smaller separate lakes in the northern, central and southern areas of the lagoon continued to exist. As was the case on the continental shelf, peat-forming vegetation would have dominated the exposed lagoon bed. Locals report that peat forms the lagoon bed in the area under the old ford between Karewa Point and Rangiauri Hill, which today forms some of the shallowest water of Te Whanga Lagoon.

CHAPTER 8

CONCLUDING REMARKS AND DIRECTIONS FOR FUTURE RESEARCH

This thesis presents the most focussed investigation on the Quaternary of Chatham Island to date. A range of techniques have been applied to the island's Quaternary deposits to constrain their age and to determine their relationship to Quaternary climatic fluctuations. These techniques include tephrochronology, palynology, stratigraphy and geomorphology.

Some of the major findings of the project include:

- Recognition and identification of the 345 ka Rangitawa Tephra on Chatham Island. The Tephra provides a significant marker horizon within Quaternary sequences on Chatham Island, in addition to the previously recognised 27.1 ka Kawakawa Tephra

- Definition of new Quaternary formations and members, resulting in a more comprehensive Quaternary stratigraphy for Chatham Island.

- Obtaining a late Castlecliffian paleovegetation record for Chatham Island, a time period from which few records exist on mainland New Zealand

- Recognition of marine terraces at various heights on Chatham Island, and applying their heights and interpreted ages to generate the first rates of uplift and deformation for the island

Certain logistical and environmental factors have limited the conclusiveness of some findings in this project; some of which have been touched upon in the previous chapters. These include:

- A lack of control on the ages of deposits and surfaces apart from the two rhyolitic tephra beds – 27.1 ka Kawakawa and 345 ka Rangitawa Tephras.

- A paucity of good exposures spanning extended periods of time. The combination of low uplift rates, repeated eustatic sea level rises, and a dominantly terrestrial depositional environment has resulted in poor preservation potential for long sequences on Chatham Island.

- Young (<125ka) peat and sand obscures much of the older deposits and land form features (e.g. strandlines).

- Poor understanding of the characteristics and history of tectonics and uplift of the Chatham Islands area.

Although this work is the first that deals specifically with Chatham Island Quaternary geology, the thesis essentially presents only a relatively broad overview, with many aspects requiring further and more detailed study. Research investigations that would make significant contributions to a fuller and more comprehensive knowledge of Quaternary history and environmental change on Chatham Island are described in the following text.

<u>A drilling/coring programme dedicated to Quaternary stratigraphy.</u>

Although drilling projects have been undertaken on the island previously, (e.g. Fletcher Challenge, Soil Bureau), these were largely for the purposes of economic reconnaissance (Chapter 2). The stratigraphy, in terms of the age of sediments and relationship to Quaternary climatic fluctuations, and OIS chronology were not investigated in any detail. Much of the information and data produced remains largely unpublished and the original cores have now been discarded, precluding any renewed investigation. A new drilling and coring expedition with particular focus on Quaternary sediments and stratigraphy is highly desirable. This would involve obtaining drill cores from strategic locations, particularly from cover-bed sequences of marine terraces, representative locations on the southern table lands, Te Whanga Lagoon, and from near shore areas of the sea bed around Chatham Island, i.e. the continental shelf.

Numerical age dating of Chatham sediments

As discussed previously, the conclusions of this work are significantly limited by a lack of numerical dating and solid age control. Obtaining numerical ages on key deposits, particularly those directly overlying wave-cut platforms, would confirm the ages of these surfaces and correlations with OIS chronology. The most suitable dating techniques for use on Chatham Island sediments (older than 60,000 yrs) would be luminescence dating and possibly amino-acid racemisation dating. Luminescence dating could be applied to date the quartzose sands that typically overly wave-cut surfaces on Chatham Island. This has been applied elsewhere with some success, although there is still some doubt over the reliability of OSl/TL dating. Amino-acid racemisation (AAR) dating could be applied to plant remains within the older peat deposits that are older than the maximum age range of radiocarbon dating. The maximum age limit for AAR varies depending on the type of material, and ambient temperatures under which the material has existed, but it has been used to date plant materials in excess of 190 ka (Pillans 1981). Thus, AAR would be useful in pin-pointing the timing of shifts in vegetation composition represented by fossil pollen within some pre-Last Interglacial peat sequences.

Further paleovegetational work

High resolution sampling of peat sections from a wider range of locations across Chatham Island would produce a more detailed picture of vegetation dynamics over the Quaternary and would identify other changes occurring in response to global climate fluctuations that may have previously been overlooked due to large sampling intervals. A dedicated study into long-distance pollen rain on Chatham Island is necessary to gain an enhanced understanding of the significance of this fraction of the pollen record. In combination with high-resolution sampling described above, the variations in levels and species composition within fossil pollen sequences could be examined for short (100 yr) periods. A comprehensive modern pollen rain study carried out over several years is necessary to examine the seasonal variations in levels and species composition of long-distance pollen; identify primary source areas and investigate if the location of source areas changes seasonally; and also to examine variations associated with ENSO patterns i.e. El –Niño vs. La Niña years.

To briefly summarise, Chatham Island has probably been a relatively low-lying landmass for most of its sub-aerial existence. Sedimentation has followed a general pattern governed largely by eustatic sea level change associated with global climatic fluctuations of the Quaternary. Low uplift rates and a terrestrial depositional environment result in low preservation potential for Quaternary sediments on Chatham Island, which in turn has resulted in a relatively poor Quaternary record on the Island.

To conclude, Chatham Island is a most unique environment to work in, and offers so much, not only for the geologist, but also for ecologists, botanists, entomologists, anthropologists, to name but a few. I hope that the information presented within this thesis will stimulate other scientists to make the pilgrimage out to the raw and stunning environment that is Chathams, to witness first hand the myriad of possibilities for research projects in all disciplines of natural science.

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APPENDICES

APPENDIX 1

Electron Mircoprobe Analyses

Appendix 1A: Rhyolitic/volcanic glass

Section 1.1: Kawakawa Tephra correlatives

Section 1.2: Rangitawa Tephra correlatives

Section 1.3: Pumice and reworked volcanic glass samples

Appendix 1B: Ilmenite

(Note: The sample code listed along side the analyses is the field code given to the sample at the time of collection. The site name, grid reference, date of collection and stratigraphic position or depth within the sequence of the sample are also given. Total iron is presented as FeO).

Appendix 1A: section 1.1

Kawakawa Tephra
Raw Analyses

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cl	NiO	Cr_2O_3	SO_3	P_2O_5	TOTAL
Kawakawa Tephra		70.77	0.17	11.09	1.08	0.05	0.07	0.99	3.87	2.80	0.22			0.02		91.13
Type section (Aokautere Ash, Manawatu)		70.57	0.17	11.03	1.07	0.04		0.98	3.55	2.86	0.17		0.12			90.56
		71.46	0.19	11.40	1.05		0.17	1.03	3.87	2.66	0.14	0.21				92.18
		71.03	0.17	11.35	1.21		0.11	1.05	3.74	2.72	0.17	0.08				91.63
		71.16	0.22	11.31	1.11	0.09	0.11	1.06	3.68	2.71	0.20	0.03	0.01	0.04		91.73
		70.84	0.28	11.09	1.18	0.11	0.06	1.13	3.72	2.86	0.19	0.07		0.08		91.61
		71.59	0.17	11.15	1.08		0.01	1.05	3.57	2.88	0.15	0.14				91.79
		72.16	0.34	10.49	1.01		0.07	0.93	5.09	2.23	0.30		0.34	0.37		93.33
		72.31	0.15	11.32	1.03	0.10	0.19	1.02	3.69	3.12	0.22		0.02	0.11		93.28
		70.89		11.28	1.17			1.10	3.73	2.57	0.15	0.15		0.08		91.11
KAWAKAWA CORRELATIVES - CHATHAM ISLAND																
Sample code	**KCh-9**	72.27	0.16	11.42	1.16	0.02	0.08	0.94	3.93	3.11	0.18	0.06				93.33
Site name or area of collection	Stony Crossing	72.30	0.10	11.27	1.13	0.07	0.11	1.08	3.68	2.96	0.19		0.04		0.17	93.10
Grid reference	382721	71.66	0.18	11.45	1.07	0.03	0.20	1.05	3.59	2.90	0.21	0.01		0.04		92.39
Sample depth	51-61 cm	71.76	0.13	11.34	1.05		0.19	1.11	3.74	2.94	0.17					92.43
Date collected	10/03/2004	72.00	0.14	11.10	1.19		0.11	0.99	3.53	3.24	0.20	0.08				92.58
		71.77	0.23	11.39	1.08	0.07	0.01	0.94	3.75	3.02	0.19	0.09	0.02			92.56
		71.68	0.14	11.08	1.11	0.01	0.07	1.06	3.71	2.97	0.21		0.01	0.06	0.07	92.18
		71.25	0.01	11.22	1.01	0.01	0.13	0.98	3.62	2.86	0.11			0.06	0.11	91.37
		69.77	0.20	11.81	1.67		0.14	1.06	4.11	3.28	0.17	0.07		0.02	0.18	92.48
		69.42	0.18	11.87	1.77	0.05	0.08	1.03	3.84	3.31	0.19			0.09	0.09	91.92
		71.14	0.21	11.12	1.06		0.12	0.99	3.71	2.79	0.16			0.16		91.46
		70.98	0.09	11.36	1.00	0.03	0.05	1.08	3.46	2.73	0.21			0.08		91.07
		71.27	0.13	11.48	1.18	0.09	0.20	1.10	3.79	2.99	0.23				0.14	92.60
		71.49	0.17	11.41	1.20		0.09	1.13	3.51	2.89	0.16		0.05			92.10
Sample code	**KCh14**	72.48	0.12	11.17	1.21	0.05	0.07	0.95	3.96	3.00	0.15		0.01		0.13	93.30
Site name or area of collection	Henga	72.14	0.23	11.35	1.16	0.09	0.07	1.00	3.71	2.98	0.17			0.01		92.91
Grid reference	452653	71.10	0.20	11.04	0.84	0.03	0.15	1.01	3.91	3.04	0.16	0.04	0.06		0.05	91.63
Sample depth	n/a	71.41		11.21	1.07	0.03	0.08	1.02	3.88	3.01	0.24		0.01	0.10		92.06
Date collected	11/03/2004	70.71	0.22	11.23	1.22		0.13	1.05	3.79	2.70	0.18			0.02		91.25
		72.09	0.16	11.31	1.04		0.20	0.96	3.91	3.00	0.20					92.87
		71.99	0.15	11.18	1.10		0.10	1.11	3.81	2.86	0.25	0.03		0.08		92.59
		72.04	0.15	11.19	1.10		0.10	1.11	3.81	2.86	0.25	0.03		0.08		92.65
		71.50	0.14	11.19	0.95		0.06	0.98	3.45	2.93	0.20	0.04	0.07	0.09		91.60
		70.91	0.01	11.25	1.18		0.15	1.12	3.79	2.70	0.25		0.03			91.39
		72.41	0.14	11.32	1.03		0.08	1.07	3.87	2.92	0.25			0.05		93.07
Sample code	**KCh28**	70.76	0.14	11.13	1.10			0.96	3.55	2.94	0.22	0.03				90.83
Site name or area of collection	North Red Bluff	71.89	0.04	11.14	1.14		0.07	0.91	3.73	3.00	0.23	0.07			0.01	92.23
Grid reference	465620	71.25	0.03	11.28	1.01		0.18	0.96	3.98	3.03	0.19		0.05			91.96
Sample depth	140 -150 cm (pocketing)	71.64	0.13	11.14	1.10	0.15	0.11	1.11	3.90	2.74	0.23		0.02	0.16	0.02	92.45
Date collected	14/03/2004	71.54	0.19	11.33	1.01		0.03	1.04	3.75	2.81	0.18			0.08	0.04	92.00

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cl	NiO	Cr_2O_3	SO_3	P_2O_5	TOTAL
	KCh28 contd.	71.09	0.27	11.23	1.06		0.08	1.06	3.79	2.71	0.15	0.08				91.52
		72.31	0.17	11.25	1.01	0.15	0.11	1.02	4.00	2.90	0.22				0.04	93.18
		70.73	0.16	11.10	1.03	0.09	0.16	1.10	3.88	2.76	0.13					91.14
		71.04	0.14	11.13	1.03	0.02	0.04	1.06	3.43	2.80	0.23					90.92
		71.59	0.13	11.40	1.29		0.20	1.20	3.96	2.81	0.21	0.15		0.01		92.95
		72.85	0.23	11.54	0.81		0.17	0.77	4.11	3.08	0.22	0.11				93.89
		72.69	0.05	11.47	0.74		0.12	0.87	4.10	3.01	0.28		0.03	0.11		93.47
		72.43	0.16	11.22	0.79	0.02	0.12	0.77	4.04	3.14	0.20	0.10	0.02			93.01
		72.31	0.16	11.72	0.89	0.01	0.10	0.85	3.86	3.15	0.14		0.01	0.11	0.02	93.33
		73.33	0.07	11.59	0.91		0.08	0.81	4.17	3.11	0.22	0.11				94.40
Sample code	**KCh29**	71.83	0.20	11.11	1.00	0.01	0.12	1.00	3.70	2.97	0.16	0.16		0.01		92.27
Site name or area of collection	Boundary Rock cliff site	72.39	0.16	11.23	1.10			1.01	3.89	3.05	0.18					93.01
Grid reference	586440	71.01	0.10	11.19	1.13		0.05	0.97	3.75	2.87	0.22	0.11		0.05	0.01	91.46
Sample depth	126-131 cm	71.33	0.08	11.30	1.15		0.18	1.01	3.91	2.87	0.17		0.04		0.15	92.19
Date collected	15/03/2004	72.11	0.21	11.24	1.06	0.02	0.08	0.92	3.93	3.05	0.23			0.11		92.96
		72.45	0.11	11.28	1.07		0.14	0.96	3.82	3.07	0.15			0.14		93.19
		71.59	0.19	11.16	0.91	0.02	0.15	0.92	3.96	2.90	0.14		0.03			91.97
		72.17	0.10	11.28	1.21	0.04	0.06	0.94	3.85	3.00	0.20	0.03				92.88
		70.05	0.15	11.04	0.96			1.01	3.88	2.63	0.17			0.12	0.01	90.02
		71.85		11.36	1.18		0.04	1.13	1.27	2.23	0.13				0.04	89.23
		72.35	0.14	11.42	1.14		0.21	1.17	4.16	2.85	0.15			0.16		93.75
		71.84		11.31	1.22		0.12	1.11	3.83	2.71	0.17	0.14		0.04		92.49
Sample code	**KCh33**	72.17	0.08	11.33	1.00		0.16	1.00	3.98	2.76	0.20			0.10	0.09	92.87
Site name or area of collection	Owenga Coast	71.59	0.27	11.13	0.94	0.07	0.15	0.99	3.73	2.84	0.16		0.01		0.05	91.93
Grid reference	570534	71.96	0.21	11.38	1.06		0.09	1.04	3.59	2.76	0.22			0.13	0.09	92.53
Sample depth	500-510 cm	71.02	0.11	11.19	0.96	0.10	0.12	1.03	3.89	2.95	0.22			0.14		91.73
Date collected	15/03/2004	71.58	0.24	11.32	1.18		0.11	1.06	3.73	2.74	0.20		0.12	0.06		92.34
		71.96	0.17	11.33	1.04	0.04	0.17	0.97	4.02	2.99	0.27	0.10		0.18	0.02	93.26
		71.19	0.19	11.41	1.00		0.17	1.09	3.76	2.74	0.17		0.06			91.78
		71.73	0.01	11.44	1.19	0.04	0.20	1.18	4.06	2.87	0.15	0.11				92.98
		71.27	0.20	11.31	1.22		0.15	0.96	3.56	3.05	0.18					91.90
		71.11	0.13	11.12	1.05		0.09	0.91	3.66	3.08	0.20			0.06		91.41
Sample code	**KCh05-43**	71.80	0.21	13.07	2.86	0.01		1.71	4.02	3.65	0.08	0.04	0.06	0.04		97.50
Site name or area of collection	South Coast	73.88	0.10	11.33	1.12			1.00	4.17	2.81			0.20			94.27
Grid reference	361473	72.23	0.01	11.28	1.04	0.09	0.06	1.09	3.77	2.84			0.18		0.05	92.46
Sample depth	25-38cm	72.23	0.01	11.28	1.04	0.09	0.06	1.09	3.77	2.84			0.18		0.05	92.46
Date collected	6/02/2005	71.68		11.18	1.16	0.19	0.17	1.03	3.67	2.78			0.13	0.08		91.56
		71.85	0.02	11.34	1.27	0.05	0.10	1.04	3.62	2.82			0.13	0.02		92.11
		72.66	0.20	11.40	1.15	0.14	0.01	1.15	3.99	2.69		0.09	0.18	0.10		93.61
		71.69	0.22	11.27	1.24	0.05	0.15	1.08	3.78	2.71		0.02	0.17	0.02	0.03	92.39
		72.70	0.32	11.32	0.90			1.00	3.81	2.89			0.12			92.58
		72.06	0.09	11.32	1.23	0.16	0.16	1.07	3.89	2.85			0.14		0.04	92.88

		SiO$_2$	TiO$_2$	Al$_2$O$_3$	FeO	MnO	MgO	CaO	Na$_2$O	K$_2$O	Cl	NiO	Cr$_2$O$_3$	SO$_3$	P$_2$O$_5$	TOTAL
	KCh05-43 contd.	72.30	0.14	11.27	1.00			1.12	3.92	2.84		0.01	0.17	0.03	0.06	92.66
		72.45	0.10	11.39	1.07	0.09	0.15	1.02	3.94	2.70			0.16	0.08		93.15
		72.10		11.34	1.12		0.26	1.07	3.94	2.74			0.15	0.08	0.08	92.88
		72.38	0.24	11.44	1.15	0.03	0.07	1.06	4.14	2.77			0.17			93.45
		71.82	0.21	11.29	0.95	0.05	0.01	0.85	3.96	2.86			0.19		0.14	92.33
		71.52	0.17	11.06	1.06	0.06	0.10	0.90	3.82	2.81			0.23		0.03	91.76
		71.57	0.15	11.08	1.03	0.10		0.81	3.82	2.73			0.16			91.45
		72.23	0.09	11.56	1.07			1.11	3.92	2.73			0.14	0.04		92.89
Sample code	**Mairangi SSB**	72.50	0.12	11.56	1.20	0.08	0.11	1.16	4.05	2.67	0.09	0.02	0.26	0.02		93.84
Site name or area of collection	South of Paua Cove	70.81	0.11	12.38	1.96	0.13	0.07	0.96	4.04	3.95	0.09	0.11	0.27			94.88
Grid reference	392818	70.86	0.20	11.22	1.09		0.08	1.04	3.80	2.89	0.04		0.17			91.39
Sample depth	85 - 90 cm	71.35	0.23	11.26	0.82		0.09	0.92	4.12	2.71	0.05	0.05	0.27	0.01	0.31	92.19
Date collected	2/02/2006	71.57	0.24	11.12	1.18	0.12	0.03	1.06	4.05	2.77	0.04		0.24		0.28	92.70
		72.38	0.18	11.36	1.26	0.07	0.17	1.14	4.10	2.98			0.25	0.06		93.95
		73.07	0.20	11.30	0.83	0.10	0.10	0.94	3.99	2.88			0.25		0.24	93.90
		71.59	0.19	11.16	0.91	0.02	0.15	0.92	3.96	2.90	0.14		0.03			91.97
		73.07	0.11	11.56	1.23	0.24	0.16	1.01	4.14	3.01		0.05	0.33		0.08	94.99
		72.22	0.11	11.34	1.07	0.11	0.12	0.87	3.97	3.01	0.01	0.11	0.34	0.08	0.11	93.47
Sample code	**MR12**	71.76	0.17	11.29	1.35	0.17	0.09	1.09	3.94	2.84			0.12			92.57
Site name or area of collection	Mairangi	71.13	0.22	10.83	1.29	0.09		0.98	3.69	2.81		0.01	0.17		0.07	91.14
Grid reference	391826	73.24	0.15	11.53	1.13	0.13		0.97	4.17	2.90		0.02	0.21		0.08	94.42
Sample depth	150-158 cm	72.05	0.17	11.20	1.03	0.09	0.05	1.09	4.04	2.88			0.19			92.46
Date collected	11/02/2005	71.21	0.07	11.39	1.28	0.06	0.23	1.02	3.76	2.75	0.04	0.08	0.23	0.07		92.11
		69.90	0.13	11.75	1.22	0.01	0.08	1.03	3.68	2.71			0.21	0.08		90.54
		71.96	0.14	11.15	1.08	0.02	0.06	1.14	3.54	2.72			0.12			91.70
		72.96	0.11	11.30	1.02	0.07	0.08	0.89	3.91	3.04	0.02	0.05	0.22			93.54
		73.56	0.18	11.52	1.04	0.09	0.25	1.07	3.90	3.18	0.05	0.02	0.24			95.00
		73.56	0.18	11.52	1.04	0.09	0.25	1.07	3.90	3.18	0.05	0.02	0.24			95.00
		72.62	0.11	11.22	1.25	0.06		1.05	3.77	2.98			0.18	0.01	0.03	93.06
		72.04	0.11	11.25	0.99	0.16	0.01	0.90	3.73	2.97			0.15	0.02		92.33
		72.40	0.22	11.26	1.13		0.04	0.98	3.96	3.10		0.06	0.14			93.29
		73.20	0.16	11.33	1.25	0.05	0.07	0.94	3.96	2.78		0.04	0.16	0.01		93.95
		71.55	0.12	11.03	1.18		0.11	0.96	4.05	2.93		0.11	0.20		0.30	92.54
		72.24	0.11	11.21	1.08	0.10	0.27	1.18	4.05	2.72			0.20		0.02	93.18
		72.30	0.25	11.19	1.27	0.09	0.10	1.12	3.91	2.79			0.21			93.23
		73.32	0.13	11.57	1.08	0.13	0.05	0.73	3.95	3.93			0.29	0.02		95.20
		71.49	0.15	11.24	1.25	0.16	0.28	1.10	3.89	2.84			0.19			92.59
		72.41	0.19	11.34	1.19	0.14	0.16	1.02	3.98	2.70			0.18	0.06	0.22	93.59
Sample code	**MR 21**	73.42	0.19	11.41	0.96	0.17	0.05	1.07	4.26	2.81			0.13	0.03	0.11	94.49
Site name or area of collection	Mairangi	72.01	0.11	11.12	0.93	0.08	0.05	0.95	3.67	2.82			0.18			91.78
Grid reference	392825	73.37	0.07	11.44	1.10	0.05		1.10	3.88	2.94	0.02		0.11		0.03	93.89
Sample depth	n/a	72.97	0.12	11.51	1.16	0.05	0.14	1.08	3.93	2.84	0.06	0.06	0.22		0.15	94.26
Date collected	11/02/2005	72.77	0.11	11.42	1.09	0.01	0.24	1.09	3.96	2.88			0.19			93.49
		70.97	0.01	11.07	0.97	0.16		0.90	3.62	2.80		0.04	0.18			90.50

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cl	NiO	Cr_2O_3	SO_3	P_2O_5	TOTAL
	MR 21 contd.	72.77	0.17	11.37	1.21	0.04	0.17	1.07	3.81	2.96			0.15			93.49
		72.43	0.18	11.30	1.08	0.15	0.04	1.25	3.93	2.76		0.02	0.14	0.05	0.01	93.20
		71.77	0.18	11.30	1.09	0.09	0.26	0.91	3.62	2.90			0.16	0.11	0.02	92.29
		73.01	0.19	11.34	1.15	0.12	0.06	1.08	4.17	2.67	0.09	0.06	0.13	0.01		94.05
Sample code	**MR 22**	73.74	0.12	11.48	1.12	0.25	0.06	1.07	3.91	2.89		0.02	0.15	0.07	0.15	94.89
Site name or area of collection	Mairangi	72.59		11.53	1.12	0.21	0.03	1.04	4.03	2.85			0.19	0.04	0.04	93.51
Grid reference	392825	73.06	0.23	11.42	1.18	0.15	0.08	1.00	4.10	2.99		0.02	0.21		0.04	94.33
Sample depth	n/a	72.48	0.18	11.30	0.90		0.11	1.00	3.96	2.95	0.08		0.16	0.04		93.13
Date collected	11/02/2005	72.45	0.19	11.31	0.98	0.02	0.07	1.01	3.46	3.02		0.01	0.15			92.59
		73.35	0.23	11.20	1.11	0.20	0.18	1.15	4.09	2.87			0.20			94.39
		71.60	0.17	11.01	1.03		0.10	0.96	3.80	2.84			0.21	0.03	0.06	91.62
		72.93	0.12	11.33	1.09	0.24		0.98	4.06	3.36			0.14		0.17	94.17
		72.77	0.14	11.49	1.03		0.08	1.00	3.80	3.05			0.21			93.17
		72.07	0.18	11.15	1.04	0.05	0.14	0.94	4.13	2.80		0.01	0.16	0.05		92.58
Sample code	**MRsw**	72.82	0.16	11.50	1.01	0.08	0.16	0.91	4.02	3.06		0.05	0.23	0.05	0.06	94.11
Site name or area of collection	south of Paua Cove	72.73	0.02	11.63	1.08	0.03	0.01	1.05	3.95	2.90	0.01		0.25	0.03	0.27	93.96
Grid reference	392818	72.61	0.12	11.34	1.22	0.03	0.07	1.08	4.05	2.76			0.24			93.52
Sample depth	c. 1m	76.04	0.16	11.96	1.23	0.07	0.13	1.13	4.27	2.83	0.26		0.25			98.33
Date collected	2/02/2006	74.38	0.12	11.55	1.00	0.02	0.04	0.94	4.20	2.80			0.25			95.30
		73.04	0.08	11.43	0.99		0.06	1.06	4.07	2.89			0.27	0.11	0.03	94.03
		72.50	0.18	11.44	1.21	0.06	0.08	1.11	4.03	2.73	0.09		0.27	0.01	0.01	93.72
		71.94	0.12	11.19	1.07	0.10	0.11	0.92	3.97	2.81	0.08	0.01	0.30	0.07		92.69
		73.19	0.14	11.31	1.03		0.05	0.94	3.80	2.99		0.10	0.25			93.80
		71.34	0.11	11.19	1.12	0.03	0.14	1.00	3.76	2.65	0.07	0.09	0.29		0.03	91.82
		72.15	0.07	11.34	0.99	0.10		1.08	3.93	2.83	0.09		0.30			92.88
Sample code	**PC 290-300 cm**	71.65	0.13	11.20	0.99	0.10	0.12	0.92	3.74	2.97	0.06		0.23			92.11
Site name or area of collection	Paua Cove	72.07	0.11	11.24	1.07	0.17	0.14	0.99	3.73	2.90	0.18		0.26		0.16	93.02
Grid reference	391821	71.76	0.12	11.38	1.14	0.05	0.13	1.09	4.25	2.64		0.02	0.22		0.01	92.81
		71.16	0.17	11.26	1.15		0.18	1.00	4.05	2.86	0.18			0.07	0.13	92.21
Sample depth	290-300 cm	71.63	0.08	11.17	1.08	0.17	0.10	0.90	3.74	2.89	0.12		0.28	0.03	0.08	92.27
Date collected	31/01/2006	72.45	0.12	11.45	1.12	0.05	0.23	0.96	3.87	2.77	0.06		0.25			93.33
		72.24	0.11	11.21	1.08	0.10	0.27	1.18	4.05	2.72			0.20		0.02	93.18
		72.03	0.12	11.22	0.99	0.06	0.14	0.95	3.70	3.01	0.15		0.24		0.07	92.68
		71.76	0.16	11.27	1.15	0.03	0.08	1.03	4.12	2.88			0.21	0.01	0.05	92.75
		72.38	0.21	11.42	1.09	0.10	0.11	1.16	4.06	2.85	0.04	0.02	0.28	0.07	0.13	93.92
Sample code	**SMKK**	71.83	0.20	11.31	1.04	0.24	0.11	0.97	4.16	2.93		0.02	0.25		0.06	93.12
Site name or area of collection	South Mairangi	71.64	0.13	11.25	1.05	0.12	0.06	0.98	3.83	2.82			0.23			92.11
Grid reference	392811	72.53	0.13	11.36	1.18	0.17	0.10	1.10	4.13	2.89	0.05	0.10	0.26		0.02	94.02
Sample depth	54-58 cm	72.39	0.20	11.46	1.03	0.04	0.08	1.03	4.02	2.96		0.07	0.24	0.04	0.02	93.58
Date collected	5/02/2006	72.17	0.15	11.22	1.12	0.09	0.20	0.85	4.08	2.91		0.05	0.24	0.06	0.01	93.15

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cl	NiO	Cr_2O_3	SO_3	P_2O_5	TOTAL
	SMKK contd.	71.85	0.26	11.38	1.15	0.10	0.07	1.05	4.00	2.79			0.28	0.05	0.05	93.03
		71.66	0.24	11.14	1.20	0.07		0.89	3.49	2.62		0.01	0.11		0.13	91.56
		72.19	0.16	11.45	1.09	0.10	0.08	1.00	3.99	2.77			0.18	0.03	0.05	93.09
		72.35	0.16	11.34	0.98		0.12	1.03	4.00	2.89		0.02	0.16	0.03		93.08
		71.25	0.10	11.12	1.01	0.10	0.16	0.99	3.95	2.82			0.25	0.06		91.81
Sample code	**WB**	71.28	0.15	11.37	1.04	0.04	0.07	1.06	3.88	2.77	0.01		0.21			91.88
Site name or area of collection	Waitangi Beach	72.36	0.14	11.28	0.99	0.18	0.16	1.07	4.05	2.72	0.05		0.26			93.26
Grid reference	451553	71.95	0.19	11.22	1.20	0.04	0.01	0.96	3.83	2.94			0.21	0.01	0.23	92.79
Sample depth	c 1.2m above wave-cut surface	72.82	0.06	11.40	1.15		0.12	0.98	4.09	3.03	0.25	0.07	0.27		0.15	94.39
Date collected	28/01/2006	71.79	0.19	11.31	1.23		0.11	1.00	3.84	2.84			0.23	0.08		92.62
		72.14	0.07	11.26	1.02	0.08	0.07	0.96	4.10	2.93			0.23		0.10	92.96
		72.38	0.18	11.36	1.26	0.07	0.17	1.14	4.10	2.98			0.25	0.06		93.95
		72.33	0.19	11.27	1.12		0.19	0.96	3.90	2.94			0.27	0.06	0.05	93.28
		72.33	0.19	11.27	1.12		0.19	0.96	3.90	2.94			0.27	0.06	0.05	93.28
		72.50	0.21	11.18	0.99	0.10	0.03	0.94	3.85	3.02			0.22	0.09		93.13
		71.96	0.13	11.19	1.10	0.08	0.04	1.11	4.03	2.92			0.30		0.15	93.01
Sample code	**WQ**	71.16	0.17	11.26	1.26	0.06	0.17	1.12	3.72	2.86	0.18					91.96
Site name or area of collection	Wharekauri-Kaingaroa turnoff	70.92	0.09	11.35	0.99	0.15	0.12	1.08	3.86	2.87	0.24	0.15				91.82
Grid reference	452787	71.88	0.17	11.21	1.12		0.14	0.89	3.48	3.01	0.25		0.01		0.07	92.23
Sample depth	100-110cm	72.86	0.15	11.25	1.11		0.14	1.05	3.82	3.09	0.22					93.69
Date collected	22/03/2004	70.85	0.32	11.14	1.18		0.15	1.07	3.56	2.89	0.14					91.30
		71.85	0.12	11.29	1.06	0.14	0.11	0.95	3.66	2.94	0.21	0.09		0.13	0.07	92.62
		73.52	0.14	11.43	1.05	0.16	0.15	0.95	4.31	2.92	0.19					94.82
		73.29	0.13	11.39	1.03	0.05	0.11	1.02	3.81	3.01	0.20			0.08	0.08	94.20
		71.16	0.17	11.26	1.15		0.18	1.00	4.05	2.86	0.18			0.07	0.13	92.21
		72.16	0.12	11.19	1.05		0.07	0.94	4.07	2.93	0.22		0.01	0.10	0.05	92.91
		69.89	0.14	11.10	0.99		0.00	1.04	3.33	2.90	0.14					89.50

Kawakawa Tephra

Normalised analyses recalculated to 100% water free

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cl	NiO	Cr_2O_3	SO_3	P_2O_5	TOTAL
Kawakawa Tephra		77.66	0.19	12.17	1.19	0.05	0.08	1.09	4.25	3.07	0.24			0.02		100.00
Type section (Aokautere Ash, Manawatu)		77.93	0.19	12.18	1.18	0.04		1.08	3.92	3.16	0.19		0.13			100.00
		77.52	0.21	12.37	1.14		0.18	1.12	4.20	2.89	0.15	0.23				100.00
		77.52	0.19	12.39	1.32		0.12	1.15	4.08	2.97	0.19	0.09				100.00
		77.58	0.24	12.33	1.21	0.10	0.12	1.16	4.01	2.95	0.22	0.03	0.01	0.04		100.00
		77.33	0.31	12.11	1.29	0.12	0.07	1.23	4.06	3.12	0.21	0.08		0.09		100.00
		77.99	0.19	12.15	1.18		0.01	1.14	3.89	3.14	0.16	0.15				100.00
		77.32	0.36	11.24	1.08		0.08	1.00	5.45	2.39	0.32		0.36	0.40		100.00
		77.52	0.16	12.14	1.10	0.11	0.20	1.09	3.96	3.34	0.24		0.02	0.12		100.00
		77.81		12.38	1.28			1.21	4.09	2.82	0.16	0.16		0.09		100.00

KAWAKAWA CORRELATIVES - CHATHAM ISLAND

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cl	NiO	Cr_2O_3	SO_3	P_2O_5	TOTAL
Sample code	**KCh-9**	77.43	0.17	12.24	1.24	0.02	0.09	1.01	4.21	3.33	0.19	0.06				100.00
Site name or area of collection	Stony Crossing	77.66	0.11	12.11	1.21	0.08	0.12	1.16	3.95	3.18	0.20		0.04		0.18	100.00
Grid reference	382721	77.56	0.19	12.39	1.16	0.03	0.22	1.14	3.89	3.14	0.23	0.01		0.04		100.00
Sample depth	51-61 cm	77.64	0.14	12.27	1.14		0.21	1.20	4.05	3.18	0.18					100.00
Date collected	10/03/2004	77.77	0.15	11.99	1.29		0.12	1.07	3.81	3.50	0.22	0.09				100.00
		77.54	0.25	12.31	1.17	0.08	0.01	1.02	4.05	3.26	0.21	0.10	0.02			100.00
		77.76	0.15	12.02	1.20	0.01	0.08	1.15	4.02	3.22	0.23		0.01	0.07	0.08	100.00
		77.98	0.01	12.28	1.11	0.01	0.14	1.07	3.96	3.13	0.12			0.07	0.12	100.00
		75.44	0.22	12.77	1.81		0.15	1.15	4.44	3.55	0.18	0.08		0.02	0.19	100.00
		75.52	0.20	12.91	1.93	0.05	0.09	1.12	4.18	3.60	0.21			0.10	0.10	100.00
		77.78	0.23	12.16	1.16		0.13	1.08	4.06	3.05	0.17			0.17		100.00
		77.94	0.10	12.47	1.10	0.03	0.05	1.19	3.80	3.00	0.23			0.09		100.00
		76.97	0.14	12.40	1.27	0.10	0.22	1.19	4.09	3.23	0.25				0.15	100.00
		77.62	0.18	12.39	1.30		0.10	1.23	3.81	3.14	0.17		0.05			100.00
Sample code	**KCh14**	77.68	0.13	11.97	1.30	0.05	0.08	1.02	4.24	3.22	0.16		0.01		0.14	100.00
Site name or area of collection	Henga	77.65	0.25	12.22	1.25	0.10	0.08	1.08	3.99	3.21	0.18			0.01		100.00
Grid reference	452653	77.59	0.22	12.05	0.92	0.03	0.16	1.10	4.27	3.32	0.17	0.04	0.07		0.05	100.00
Sample depth	n/a	77.57		12.18	1.16	0.03	0.09	1.11	4.21	3.27	0.26		0.01	0.11		100.00
Date collected	11/03/2004	77.49	0.24	12.31	1.34		0.14	1.15	4.15	2.96	0.20			0.02		100.00
		77.62	0.17	12.18	1.12		0.22	1.03	4.21	3.23	0.22					100.00
		77.75	0.16	12.07	1.19		0.11	1.20	4.11	3.09	0.27	0.03		0.09		100.00
		77.75	0.16	12.08	1.19		0.11	1.20	4.11	3.09	0.27	0.03		0.09		100.00
		78.06	0.15	12.22	1.04		0.07	1.07	3.77	3.20	0.22	0.04	0.08	0.10		100.00
		77.59	0.01	12.31	1.29		0.16	1.23	4.15	2.95	0.27		0.03			100.00
		77.80	0.15	12.16	1.11		0.09	1.15	4.16	3.14	0.27			0.05		100.00
Sample code	**KCh28**	77.90	0.15	12.25	1.21			1.06	3.91	3.24	0.24	0.03				100.00
Site name or area of collection	North Red Bluff	77.95	0.04	12.08	1.24		0.08	0.99	4.04	3.25	0.25	0.08			0.01	100.00
Grid reference	465620	77.48	0.03	12.27	1.10		0.20	1.04	4.33	3.29	0.21		0.05			100.00
Sample depth	140 -150 cm (pocketing)	77.49	0.14	12.05	1.19	0.16	0.12	1.20	4.22	2.96	0.25		0.02	0.17	0.02	100.00
Date collected	14/03/2004	77.76	0.21	12.32	1.10		0.03	1.13	4.08	3.05	0.20			0.09	0.04	100.00

		SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	Cl	NiO	Cr2O3	SO3	P2O5	TOTAL
	KCh28 contd.	77.68	0.30	12.27	1.16		0.09	1.16	4.14	2.96	0.16	0.09				100.00
		77.60	0.18	12.07	1.08	0.16	0.12	1.09	4.29	3.11	0.24				0.04	100.00
		77.61	0.18	12.18	1.13	0.10	0.18	1.21	4.26	3.03	0.14					100.00
		78.13	0.15	12.24	1.13	0.02	0.04	1.17	3.77	3.08	0.25					100.00
		77.02	0.14	12.26	1.39		0.22	1.29	4.26	3.02	0.23	0.16		0.01		100.00
		77.59	0.24	12.29	0.86		0.18	0.82	4.38	3.28	0.23	0.12				100.00
		77.77	0.05	12.27	0.79		0.13	0.93	4.39	3.22	0.30		0.03	0.12		100.00
		77.87	0.17	12.06	0.85	0.02	0.13	0.83	4.34	3.38	0.22	0.11	0.02			100.00
		77.48	0.17	12.56	0.95	0.01	0.11	0.91	4.14	3.38	0.15		0.01	0.12	0.02	100.00
		77.68	0.07	12.28	0.96		0.08	0.86	4.42	3.29	0.23	0.12				100.00
Sample code	**KCh29**	77.85	0.22	12.04	1.08	0.01	0.13	1.08	4.01	3.22	0.17	0.17		0.01		100.00
Site name or area of collection	Boundary Rock cliff site	77.83	0.17	12.07	1.18			1.09	4.18	3.28	0.19					100.00
Grid reference	586440	77.64	0.11	12.23	1.24		0.05	1.06	4.10	3.14	0.24	0.12		0.05	0.01	100.00
Sample depth	126-131 cm	77.37	0.09	12.26	1.25		0.20	1.10	4.24	3.11	0.18		0.04		0.16	100.00
Date collected	15/03/2004	77.57	0.23	12.09	1.14	0.02	0.09	0.99	4.23	3.28	0.25			0.12		100.00
		77.74	0.12	12.10	1.15		0.15	1.03	4.10	3.29	0.16			0.15		100.00
		77.84	0.21	12.13	0.99	0.02	0.16	1.00	4.31	3.15	0.15		0.03			100.00
		77.70	0.11	12.14	1.30	0.04	0.06	1.01	4.15	3.23	0.22	0.03				100.00
		77.82	0.17	12.26	1.07			1.12	4.31	2.92	0.19			0.13	0.01	100.00
		80.52		12.73	1.32		0.04	1.27	1.42	2.50	0.15				0.04	100.00
		77.17	0.15	12.18	1.22		0.22	1.25	4.44	3.04	0.16			0.17		100.00
		77.67		12.23	1.32		0.13	1.20	4.14	2.93	0.18	0.15		0.04		100.00
Sample code	**KCh33**	77.71	0.09	12.20	1.08		0.17	1.08	4.29	2.97	0.22			0.11	0.10	100.00
Site name or area of collection	Owenga Coast	77.87	0.29	12.11	1.02	0.08	0.16	1.08	4.06	3.09	0.17		0.01		0.05	100.00
Grid reference	570534	77.77	0.23	12.30	1.15		0.10	1.12	3.88	2.98	0.24			0.14	0.10	100.00
Sample depth	500-510 cm	77.42	0.12	12.20	1.05	0.11	0.13	1.12	4.24	3.22	0.24			0.15		100.00
Date collected	15/03/2004	77.52	0.26	12.26	1.28		0.12	1.15	4.04	2.97	0.22		0.13	0.06		100.00
		77.16	0.18	12.15	1.12	0.04	0.18	1.04	4.31	3.21	0.29	0.11		0.19	0.02	100.00
		77.57	0.21	12.43	1.09		0.19	1.19	4.10	2.99	0.19		0.07			100.00
		77.15	0.01	12.30	1.28	0.04	0.22	1.27	4.37	3.09	0.16	0.12				100.00
		77.55	0.22	12.31	1.33		0.16	1.04	3.87	3.32	0.20					100.00
		77.79	0.14	12.16	1.15		0.10	1.00	4.00	3.37	0.22			0.07		100.00
Sample code	**KCh05-43**	73.64	0.22	13.41	2.93	0.01		1.75	4.12	3.74	0.08	0.04	0.06	0.04		100.00
Site name or area of collection	South Coast	78.37	0.11	12.02	1.19			1.06	4.42	2.98			0.21			100.00
Grid reference	361473	78.12	0.01	12.20	1.12	0.10	0.06	1.18	4.08	3.07			0.19		0.05	100.00
Sample depth	25-38cm	78.12	0.01	12.20	1.12	0.10	0.06	1.18	4.08	3.07			0.19		0.05	100.00
Date collected	6/02/2005	78.29		12.21	1.27	0.21	0.19	1.12	4.01	3.04			0.14	0.09		100.00
		78.00	0.02	12.31	1.38	0.05	0.11	1.13	3.93	3.06			0.14	0.02		100.00
		77.62	0.21	12.18	1.23	0.15	0.01	1.23	4.26	2.87		0.10	0.19	0.11		100.00
		77.59	0.24	12.20	1.34	0.05	0.16	1.17	4.09	2.93		0.02	0.18	0.02	0.03	100.00
		78.53	0.35	12.23	0.97			1.08	4.12	3.12			0.13			100.00
		77.58	0.10	12.19	1.32	0.17	0.17	1.15	4.19	3.07			0.15		0.04	100.00

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cl	NiO	Cr_2O_3	SO_3	P_2O_5	TOTAL
	KCh05-43 contd.	78.03	0.15	12.16	1.08			1.21	4.23	3.06		0.01	0.18	0.03	0.06	100.00
		77.78	0.11	12.23	1.15	0.10	0.16	1.10	4.23	2.90			0.17	0.09		100.00
		77.63		12.21	1.21		0.28	1.15	4.24	2.95			0.16	0.09	0.09	100.00
		77.45	0.26	12.24	1.23	0.03	0.07	1.13	4.43	2.96			0.18			100.00
		77.79	0.23	12.23	1.03	0.05	0.01	0.92	4.29	3.10			0.21		0.15	100.00
		77.94	0.19	12.05	1.16	0.07	0.11	0.98	4.16	3.06			0.25		0.03	100.00
		78.26	0.16	12.12	1.13	0.11		0.89	4.18	2.99			0.17			100.00
		77.76	0.10	12.44	1.15			1.19	4.22	2.94			0.15	0.04		100.00
Sample code	**Mairangi SSB**	77.26	0.13	12.32	1.28	0.09	0.12	1.24	4.32	2.85	0.10	0.02	0.28	0.02		100.00
Site name or area of collection	South of Paua Cove	74.63	0.12	13.05	2.07	0.14	0.07	1.01	4.26	4.16	0.09	0.12	0.28			100.00
Grid reference	392818	77.54	0.22	12.28	1.19		0.09	1.14	4.16	3.16	0.04		0.19			100.00
Sample depth	85 - 90 cm	77.39	0.25	12.21	0.89		0.10	1.00	4.47	2.94	0.05	0.05	0.29	0.01	0.34	100.00
Date collected	2/02/2006	77.21	0.26	12.00	1.27	0.13	0.03	1.14	4.37	2.99	0.04		0.26		0.30	100.00
		77.04	0.19	12.09	1.34	0.07	0.18	1.21	4.36	3.17			0.27	0.06		100.00
		77.82	0.21	12.03	0.88	0.11	0.11	1.00	4.25	3.07			0.27		0.26	100.00
		77.84	0.21	12.13	0.99	0.02	0.16	1.00	4.31	3.15	0.15		0.03			100.00
		76.92	0.12	12.17	1.29	0.25	0.17	1.06	4.36	3.17		0.05	0.35		0.08	100.00
		77.27	0.12	12.13	1.14	0.12	0.13	0.93	4.25	3.22	0.01	0.12	0.36	0.09	0.12	100.00
Sample code	**MR12**	77.52	0.18	12.20	1.46	0.18	0.10	1.18	4.26	3.07			0.13			100.00
Site name or area of collection	Mairangi	78.04	0.24	11.88	1.42	0.10		1.08	4.05	3.08		0.01	0.19		0.08	100.00
Grid reference	391826	77.57	0.16	12.21	1.20	0.14		1.03	4.42	3.07		0.02	0.22		0.08	100.00
Sample depth	150-158 cm	77.93	0.18	12.11	1.11	0.10	0.05	1.18	4.37	3.11			0.21			100.00
Date collected	11/02/2005	77.31	0.08	12.37	1.39	0.07	0.25	1.11	4.08	2.99	0.04	0.09	0.25	0.08		100.00
		77.20	0.14	12.98	1.35	0.01	0.09	1.14	4.06	2.99			0.23	0.09		100.00
		78.47	0.15	12.16	1.18	0.02	0.07	1.24	3.86	2.97			0.13			100.00
		78.00	0.12	12.08	1.09	0.07	0.09	0.95	4.18	3.25	0.02	0.05	0.24			100.00
		77.43	0.19	12.13	1.09	0.09	0.26	1.13	4.11	3.35	0.05	0.02	0.25			100.00
		77.43	0.19	12.13	1.09	0.09	0.26	1.13	4.11	3.35	0.05	0.02	0.25			100.00
		78.04	0.12	12.06	1.34	0.06		1.13	4.05	3.20			0.19	0.01	0.03	100.00
		78.02	0.12	12.18	1.07	0.17	0.01	0.97	4.04	3.22			0.16	0.02		100.00
		77.61	0.24	12.07	1.21		0.04	1.05	4.24	3.32		0.06	0.15			100.00
		77.91	0.17	12.06	1.33	0.05	0.07	1.00	4.22	2.96		0.04	0.17	0.01		100.00
		77.32	0.13	11.92	1.28		0.12	1.04	4.38	3.17		0.12	0.22		0.32	100.00
		77.53	0.12	12.03	1.16	0.11	0.29	1.27	4.35	2.92			0.21		0.02	100.00
		77.55	0.27	12.00	1.36	0.10	0.11	1.20	4.19	2.99			0.23			100.00
		77.02	0.14	12.15	1.13	0.14	0.05	0.77	4.15	4.13			0.30	0.02		100.00
		77.21	0.16	12.14	1.35	0.17	0.30	1.19	4.20	3.07			0.21			100.00
		77.37	0.20	12.12	1.27	0.15	0.17	1.09	4.25	2.88			0.19	0.06	0.24	100.00
Sample code	**MR 21**	77.70	0.20	12.08	1.02	0.18	0.05	1.13	4.51	2.97			0.14	0.03	0.12	100.00
Site name or area of collection	Mairangi	78.46	0.12	12.12	1.01	0.09	0.05	1.04	4.00	3.07			0.20			100.00
Grid reference	392825	78.14	0.07	12.18	1.17	0.05		1.17	4.13	3.13	0.02		0.12		0.03	100.00
Sample depth	n/a	77.41	0.13	12.21	1.23	0.05	0.15	1.15	4.17	3.01	0.06	0.06	0.23		0.16	100.00
Date collected	11/02/2005	77.84	0.12	12.22	1.17	0.01	0.26	1.17	4.24	3.08			0.20			100.00
		78.42	0.01	12.23	1.07	0.18		0.99	4.00	3.09		0.04	0.20			100.00

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cl	NiO	Cr_2O_3	SO_3	P_2O_5	TOTAL
	MR 21 contd.	77.84	0.18	12.16	1.29	0.04	0.18	1.14	4.08	3.17			0.16			100.00
		77.71	0.19	12.12	1.16	0.16	0.04	1.34	4.22	2.96		0.02	0.15	0.05	0.01	100.00
		77.77	0.20	12.24	1.18	0.10	0.28	0.99	3.92	3.14			0.17	0.12	0.02	100.00
		77.63	0.20	12.06	1.22	0.13	0.06	1.15	4.43	2.84	0.10	0.06	0.14	0.01		100.00
Sample code	**MR 22**	77.71	0.13	12.10	1.18	0.26	0.06	1.13	4.12	3.05		0.02	0.16	0.07	0.16	100.00
Site name or area of collection	Mairangi	77.63		12.33	1.20	0.22	0.03	1.11	4.31	3.05			0.20	0.04	0.04	100.00
Grid reference	392825	77.45	0.24	12.11	1.25	0.16	0.08	1.06	4.35	3.17		0.02	0.22		0.04	100.00
Sample depth	n/a	77.83	0.19	12.13	0.97		0.12	1.07	4.25	3.17	0.09		0.17	0.04		100.00
Date collected	11/02/2005	78.25	0.21	12.22	1.06	0.02	0.08	1.09	3.74	3.26		0.01	0.16			100.00
		77.71	0.24	11.87	1.18	0.21	0.19	1.22	4.33	3.04			0.21			100.00
		78.15	0.19	12.02	1.12		0.11	1.05	4.15	3.10			0.23	0.03	0.07	100.00
		77.45	0.13	12.03	1.16	0.25		1.04	4.31	3.57			0.15		0.18	100.00
		78.10	0.15	12.33	1.11		0.09	1.07	4.08	3.27			0.23			100.00
		77.85	0.19	12.04	1.12	0.05	0.15	1.02	4.46	3.02		0.01	0.17	0.05		100.00
Sample code	**MRsw**	77.38	0.17	12.22	1.07	0.09	0.17	0.97	4.27	3.25		0.05	0.24	0.05	0.06	100.00
Site name or area of collection	south of Paua Cove	77.41	0.02	12.38	1.15	0.03	0.01	1.12	4.20	3.09	0.01		0.27	0.03	0.29	100.00
Grid reference	392818	77.64	0.13	12.13	1.30	0.03	0.07	1.15	4.33	2.95			0.26			100.00
Sample depth	c. 1m	77.33	0.16	12.16	1.25	0.07	0.13	1.15	4.34	2.88	0.26		0.25			100.00
Date collected	2/02/2006	78.05	0.13	12.12	1.05	0.02	0.04	0.99	4.41	2.94			0.26			100.00
		77.68	0.09	12.16	1.05		0.06	1.13	4.33	3.07			0.29	0.12	0.03	100.00
		77.36	0.19	12.21	1.29	0.06	0.09	1.18	4.30	2.91	0.10		0.29	0.01	0.01	100.00
		77.61	0.13	12.07	1.15	0.11	0.12	0.99	4.28	3.03	0.09	0.01	0.32	0.08		100.00
		78.03	0.15	12.06	1.10		0.05	1.00	4.05	3.19		0.11	0.27			100.00
		77.70	0.12	12.19	1.22	0.03	0.15	1.09	4.09	2.89	0.08	0.10	0.32		0.03	100.00
		77.68	0.08	12.21	1.07	0.11		1.16	4.23	3.05	0.10		0.32			100.00
Sample code	**PC 290-300 cm**	77.79	0.14	12.16	1.07	0.11	0.13	1.00	4.06	3.22	0.07		0.25			100.00
Site name or area of collection	Paua Cove	77.48	0.12	12.08	1.15	0.18	0.15	1.06	4.01	3.12	0.19		0.28		0.17	100.00
Grid reference	391821	77.32	0.13	12.26	1.23	0.05	0.14	1.17	4.58	2.84		0.02	0.24		0.01	100.00
		77.17	0.18	12.21	1.25		0.20	1.08	4.39	3.10	0.20			0.08	0.14	100.00
Sample depth	290-300 cm	77.63	0.09	12.11	1.17	0.18	0.11	0.98	4.05	3.13	0.13		0.30	0.03	0.09	100.00
Date collected	31/01/2006	77.63	0.13	12.27	1.20	0.05	0.25	1.03	4.15	2.97	0.06		0.27			100.00
		77.53	0.12	12.03	1.16	0.11	0.29	1.27	4.35	2.92			0.21		0.02	100.00
		77.72	0.13	12.11	1.07	0.06	0.15	1.03	3.99	3.25	0.16		0.26		0.08	100.00
		77.37	0.17	12.15	1.24	0.03	0.09	1.11	4.44	3.11			0.23	0.01	0.05	100.00
		77.07	0.22	12.16	1.16	0.11	0.12	1.24	4.32	3.03	0.04	0.02	0.30	0.07	0.14	100.00
Sample code	**SMKK**	77.14	0.21	12.15	1.12	0.26	0.12	1.04	4.47	3.15		0.02	0.27		0.06	100.00
Site name or area of collection	South Mairangi	77.78	0.14	12.21	1.14	0.13	0.07	1.06	4.16	3.06			0.25			100.00
Grid reference	392811	77.14	0.14	12.08	1.26	0.18	0.11	1.17	4.39	3.07	0.05	0.11	0.28		0.02	100.00
Sample depth	54-58 cm	77.36	0.21	12.25	1.10	0.04	0.09	1.10	4.30	3.16		0.07	0.26	0.04	0.02	100.00
Date collected	5/02/2006	77.48	0.16	12.05	1.20	0.10	0.21	0.91	4.38	3.12		0.05	0.26	0.06	0.01	100.00

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cl	NiO	Cr_2O_3	SO_3	P_2O_5	TOTAL
	SMKK contd.	77.23	0.28	12.23	1.24	0.11	0.08	1.13	4.30	3.00			0.30	0.05	0.05	100.00
		78.27	0.26	12.17	1.31	0.08		0.97	3.81	2.86		0.01	0.12		0.14	100.00
		77.55	0.17	12.30	1.17	0.11	0.09	1.07	4.29	2.98			0.19	0.03	0.05	100.00
		77.73	0.17	12.18	1.05		0.13	1.11	4.30	3.10		0.02	0.17	0.03		100.00
		77.61	0.11	12.11	1.10	0.11	0.17	1.08	4.30	3.07			0.27	0.07		100.00
Sample code	**WB**	77.58	0.16	12.37	1.13	0.04	0.08	1.15	4.22	3.01	0.01		0.23			100.00
Site name or area of collection	Waitangi Beach	77.59	0.15	12.10	1.06	0.19	0.17	1.15	4.34	2.92	0.05		0.28			100.00
Grid reference	451553	77.54	0.20	12.09	1.29	0.04	0.01	1.03	4.13	3.17			0.23	0.01	0.25	100.00
Sample depth	c 1.2m above wave-cut surface	77.15	0.06	12.08	1.22		0.13	1.04	4.33	3.21	0.26	0.07	0.29		0.16	100.00
Date collected	28/01/2006	77.51	0.21	12.21	1.33		0.12	1.08	4.15	3.07			0.25	0.09		100.00
		77.60	0.08	12.11	1.10	0.09	0.08	1.03	4.41	3.15			0.25		0.11	100.00
		77.04	0.19	12.09	1.34	0.07	0.18	1.21	4.36	3.17			0.27	0.06		100.00
		77.54	0.20	12.08	1.20		0.20	1.03	4.18	3.15			0.29	0.06	0.05	100.00
		77.54	0.20	12.08	1.20		0.20	1.03	4.18	3.15			0.29	0.06	0.05	100.00
		77.85	0.23	12.00	1.06	0.11	0.03	1.01	4.13	3.24			0.24	0.10		100.00
		77.37	0.14	12.03	1.18	0.09	0.04	1.19	4.33	3.14			0.32		0.16	100.00
Sample code	**WQ**	77.38	0.18	12.24	1.37	0.07	0.18	1.22	4.05	3.11	0.20					100.00
Site name or area of collection	Wharekauri-Kaingaroa turnoff	77.24	0.10	12.36	1.08	0.16	0.13	1.18	4.20	3.13	0.26	0.16				100.00
Grid reference	452787	77.94	0.18	12.15	1.21		0.15	0.96	3.77	3.26	0.27		0.01		0.08	100.00
Sample depth	100-110cm	77.77	0.16	12.01	1.18		0.15	1.12	4.08	3.30	0.23					100.00
Date collected	22/03/2004	77.60	0.35	12.20	1.29		0.16	1.17	3.90	3.17	0.15					100.00
		77.58	0.13	12.19	1.14	0.15	0.12	1.03	3.95	3.17	0.23			0.14	0.08	100.00
		77.54	0.15	12.05	1.11	0.17	0.16	1.00	4.55	3.08	0.20					100.00
		77.80	0.14	12.09	1.09	0.05	0.12	1.08	4.04	3.20	0.21			0.08	0.08	100.00
		77.17	0.18	12.21	1.25		0.20	1.08	4.39	3.10	0.20			0.08	0.14	100.00
		77.67	0.13	12.04	1.13		0.08	1.01	4.38	3.15	0.24		0.01	0.11	0.05	100.00
		78.09	0.16	12.40	1.11			1.16	3.72	3.24	0.16					100.00

Appendix 1A: section 1.2

Rangitawa Tephra
Raw Analyses

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cl	NiO	Cr_2O_3	SO_3	P_2O_5	TOTAL
Rangitawa Tephra		73.04	0.17	11.32	1.01		0.11	0.71	3.20	4.35			0.19		0.01	93.92
Type section, Rangitikei River Valley		73.02	0.11	11.35	1.10	0.11		0.90	3.91	3.29			0.19	0.08	0.07	94.02
		73.15	0.16	11.47	1.04		0.11	0.84	3.58	4.08			0.22	0.05		94.41
		73.03	0.17	11.50	1.08		0.01	0.77	3.85	4.23			0.12	0.06		94.61
		72.71	0.21	11.50	1.11		0.05	0.72	3.13	4.19			0.25			93.62
		72.98	0.08	11.43	1.07		0.09	0.69	3.45	4.18			0.26			94.03
		72.81	0.19	11.36	1.01	0.10	0.01	0.69	3.47	4.20			0.23	0.03	0.07	94.07
		72.75	0.03	11.33	1.06	0.13	0.10	0.75	4.03	3.44			0.13	0.01		93.41
		73.25	0.15	11.60	0.98	0.05	0.08	0.83	3.49	4.13			0.17	0.07	0.07	94.68
		72.82	0.23	11.42	1.07	0.13		0.73	3.52	4.34			0.22		0.06	94.34
RANGITAWA CORRELATIVES - CHATHAM ISLAND																
Sample code	**KCh15**	73.22	0.28	11.58	0.97		0.14	0.80	1.80	3.51	0.24	0.05				92.59
Site name or area of collection	Matarakau	73.72	0.29	11.64	1.05	0.03	0.07	0.90	1.59	3.32	0.25	0.05				92.91
Grid reference	623791	71.64	0.30	11.35	0.87	0.07	0.16	0.72	3.43	4.30	0.25	0.04		0.04		93.17
Sample depth	138-149cm	71.87	0.32	11.37	0.94	0.13	0.08	0.79	3.41	4.29	0.29			0.13		93.62
Date collected	12/03/2004	71.72	0.16	11.34	0.89		0.11	0.80	3.37	4.34	0.26			0.05	0.02	93.06
		72.50	0.12	11.50	1.10		0.19	0.75	3.19	4.30	0.22			0.09		93.96
		72.43	0.31	11.52	0.88	0.17	0.15	0.73	3.57	4.25	0.26			0.11		94.38
		72.13	0.15	11.51	0.59	0.18		0.59	3.40	4.27	0.23	0.12		0.09	0.21	93.44
		72.34	0.11	11.46	0.91	0.02	0.09	0.57	3.69	4.51	0.21	0.03		0.02		93.96
		72.84	0.22	11.22	1.07	0.08		0.85	3.35	4.13	0.23			0.07		94.06
		71.79	0.23	11.45	0.98	0.04	0.15	0.78	3.38	4.14	0.24	0.04		0.07		93.29
		72.41	0.22	11.56	0.82	0.07	0.15	0.71	3.49	4.17		0.02	0.26	0.04		93.92
		70.96	0.21	11.20	0.96		0.05	0.79	3.26	4.07		0.04	0.24	0.12		91.90
		71.39	0.09	11.41	1.10	0.06	0.14	0.69	3.41	4.03			0.19			92.51
		72.99	0.06	11.42	0.81			0.71	3.54	4.31			0.25	0.06	0.07	94.22
		72.87	0.09	11.10	1.03		0.05	0.84	3.34	4.00			0.16			93.48
		72.92	0.17	11.35	1.00	0.04		0.71	3.35	4.18	0.05	0.17	0.24		0.04	94.22
		72.38	0.26	11.33	1.10	0.06	0.25	0.65	3.42	3.97			0.24		0.06	93.72
		72.43	0.07	11.30	1.04			0.71	3.30	4.20			0.20	0.03		93.28
		72.72	0.10	10.99	1.01	0.11		0.74	3.51	4.17		0.01	0.24		0.02	93.62
Sample code	**KCh05-7**	73.07	0.18	11.52	0.94	0.10		0.82	3.64	4.51	0.06		0.30	0.02	0.01	95.17
Site name or area of collection	Kaingaroa Beach	73.22	0.23	11.61	0.88	0.15	0.10	0.73	3.57	4.41	0.20		0.32			95.42
Grid reference	676785	71.58	0.21	11.12	0.85			0.79	3.75	3.92	0.21		0.24			92.67
Sample depth	692 -702 cm	71.32	0.25	11.28	0.98	0.03	0.06	0.81	3.44	4.10	0.08	0.09	0.22		0.13	92.79
Date collected	22/01/2006	71.49	0.20	11.29	0.98		0.08	0.75	3.45	4.06	0.25	0.16	0.36		0.02	93.09
		72.17	0.18	11.38	0.88	0.07	0.06	0.79	3.89	3.95	0.19		0.39			93.95
		71.82	0.22	11.39	0.98		0.16	0.73	3.50	4.06	0.11		0.25			93.22
		72.12	0.12	11.31	1.06	0.01	0.12	0.75	3.89	3.96			0.28	0.02		93.64
		71.25	0.27	11.16	0.93	0.19	0.06	0.79	3.69	3.89	0.23	0.02	0.31			92.79
		71.69	0.23	11.12	0.90		0.16	0.72	3.75	3.82	0.25		0.33		0.18	93.15
		72.35	0.20	11.24	0.85	0.04	0.15	0.88	3.58	3.83	0.01	0.08	0.33		0.04	93.58

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cl	NiO	Cr_2O_3	SO_3	P_2O_5	TOTAL
	KCh05-7 contd.	71.69	0.09	11.32	1.01	0.02	0.11	0.73	3.69	3.96	0.04		0.32		0.10	93.08
		71.03	0.25	11.21	0.87	0.06	0.08	0.63	3.64	3.92	0.16		0.29		0.03	92.17
		71.46	0.30	11.24	0.89	0.12	0.09	0.71	3.80	3.96	0.10		0.30		0.11	93.08
		71.82	0.17	11.36	0.81	0.07	0.09	0.87	3.53	3.92	0.13		0.31	0.07		93.15
		73.52	0.13	11.65	1.12	0.15	0.03	0.72	3.59	4.42	0.16	0.04	0.31			95.84
Sample code	**KRM**															
Site name or area of collection	Kaingaroa Beach															
Grid reference	676785	73.61	0.23	11.41	0.95	0.15	0.05	0.85	3.49	4.40	0.15		0.28	0.03	0.06	95.66
Sample depth	686-696cm	73.36	0.17	11.67	1.06		0.04	0.80	3.58	4.40	0.12	0.02	0.24	0.06	0.09	95.61
Date collected	22/01/2006	72.06	0.18	11.60	0.96	0.05	0.25	0.70	3.69	4.03	0.06		0.29		0.16	94.03
		72.22	0.09	11.36	0.97	0.02	0.24	0.74	3.88	3.99	0.14	0.02	0.30	0.03	0.07	94.07
		71.54	0.25	11.15	0.97		0.08	0.85	3.50	3.97		0.05	0.26	0.04		92.66
		71.90	0.28	11.27	0.85	0.02	0.16	0.77	3.67	3.98	0.13		0.28	0.03	0.08	93.42
		72.18	0.15	11.17	0.97			0.73	3.56	4.09			0.25	0.04	0.17	93.31
		71.75	0.11	11.15	1.00		0.11	0.79	3.56	3.97	0.08	0.08	0.29			92.89
		72.45	0.06	11.47	1.01	0.05	0.11	0.78	3.65	4.03	0.09	0.05	0.31	0.03		94.09
		72.21	0.02	11.17	0.75	0.11	0.09	0.53	4.00	3.87			0.23	0.05	0.04	93.07
		72.33	0.15	11.52	0.90	0.14	0.07	0.80	3.58	3.95	0.08		0.29			93.81
		71.74	0.14	11.21	0.98	0.02	0.11	0.79	3.45	3.97	0.04		0.23	0.07	0.02	92.77
		71.72	0.21	11.33	0.87		0.11	0.76	3.68	3.80	0.12	0.01	0.29	0.03		92.93
		71.86	0.26	11.32	0.84	0.07	0.14	0.72	3.77	3.84	0.15	0.12	0.32		0.24	93.65
		72.73	0.07	11.68	0.66	0.09		0.57	3.87	4.12	0.24		0.29		0.01	94.33
		71.77	0.22	11.40	0.86	0.10	0.13	0.79	3.50	4.10	0.07	0.03	0.26			93.23
		71.13	0.12	11.20	0.93	0.16	0.07	0.77	3.57	3.90			0.30			92.15
		71.25	0.20	11.31	0.92	0.07	0.12	0.72	3.58	3.97	0.11	0.12	0.34		0.09	92.80
		72.35	0.20	11.40	0.95	0.03		0.91	3.34	4.33		0.05	0.23		0.01	93.68
		70.34	0.11	11.16	0.90		0.20	0.78	3.51	3.88		0.05	0.20			91.00
		72.41	0.18	11.28	1.08		0.06	0.84	3.48	3.91		0.13	0.25		0.05	93.55
		72.58	0.21	11.47	0.84	0.14	0.01	0.71	3.36	4.04			0.23		0.02	93.36
		72.85	0.25	11.38	1.11	0.02	0.10	0.94	3.43	4.04			0.25	0.03		94.20
		72.86	0.01	11.57	1.07	0.06		0.84	3.40	4.47			0.27			94.40
		71.82	0.37	11.15	1.03		0.01	0.82	2.99	3.89			0.15	0.07		91.83
		72.60	0.17	11.41	1.00		0.02	0.80	3.53	4.09			0.22			93.69
		72.49	0.22	11.30	1.08	0.03	0.07	0.65	3.65	4.01			0.21			93.48
		72.68	0.18	11.55	0.97	0.17		0.82	2.83	4.20			0.18		0.08	93.46
Sample code	**KRS**	73.93	0.02	11.75	0.76	0.09		0.54	3.54	4.77			0.16	0.01	0.04	95.61
Site name or area of collection	Kaingaroa Slump	72.67		11.25	0.80		0.12	0.79	3.60	3.29			0.15	0.04		92.71
Grid reference	679788	71.73	0.05	11.24	0.99	0.04		0.85	3.87	3.33			0.18			92.28
Sample depth	220-230cm	73.39	0.13	11.47	0.94	0.14		0.83	3.52	3.75			0.24		0.18	94.59
Date collected	26/01/2005	74.17	0.17	11.93	1.10	0.09	0.19	0.87	3.74	3.98			0.19			96.43
		72.90	0.13	11.35	0.85	0.16	0.02	0.77	4.08	3.34		0.01	0.18	0.03	0.10	93.92
		73.27	0.10	11.46	1.00	0.11		0.75	3.61	3.54			0.17		0.02	94.03
		73.27	0.11	11.41	0.86	0.12	0.01	0.77	4.04	3.50			0.11		0.12	94.32
		73.17	0.16	11.27	0.98	0.10		0.74	3.75	3.47	0.04		0.19	0.03		93.90
		73.86	0.13	11.83	1.10	0.08	0.27	1.04	4.00	3.31		0.06	0.14		0.26	96.08
		72.90	0.14	11.47	0.92			0.75	3.81	3.32			0.12	0.07	0.04	93.54

		SiO$_2$	TiO$_2$	Al$_2$O$_3$	FeO	MnO	MgO	CaO	Na$_2$O	K$_2$O	Cl	NiO	Cr$_2$O$_3$	SO$_3$	P$_2$O$_5$	TOTAL
	KRS contd.	72.69	0.07	11.38	0.92	0.03	0.03	0.82	3.88	3.23		0.01	0.12	0.01	0.23	93.42
		72.18		11.28	0.94	0.28	0.10	0.84	3.75	3.18		0.02	0.23		0.16	92.96
		73.80	0.28	11.81	1.07	0.10	0.04	0.87	3.82	3.60			0.17			95.56
		72.90		11.65	1.02	0.13	0.12	0.80	3.83	3.31			0.19	0.04	0.16	94.15
		72.32	0.13	11.56	1.01	0.14	0.09	0.82	3.62	3.53		0.01	0.16		0.02	93.41
		73.18	0.13	11.83	1.01	0.02	0.06	0.84	4.20	3.36			0.15	0.02	0.21	95.01
		72.91	0.06	11.52	0.85	0.04	0.12	0.77	3.81	3.40		0.10	0.19	0.07		93.84
		72.71	0.08	11.33	0.89	0.23	0.17	0.76	3.65	3.39			0.16	0.01		93.38
		73.64	0.15	11.63	1.01	0.08	0.09	1.18	3.96	2.89			0.13		0.06	94.82
Sample code	**MR9**	72.34	0.14	11.43	0.97	0.04		0.82	3.42	4.31		0.12	0.23		0.07	93.73
Site name or area of collection	Mairangi	73.38	0.18	11.48	1.02			0.75	3.49	4.35			0.17		0.01	94.59
Grid reference	391826	72.69	0.21	11.40	0.93	0.07		0.87	3.75	4.03			0.19	0.11	0.14	94.22
Sample depth	390-400cm	72.56	0.13	11.46	0.97	0.09	0.07	0.79	3.47	4.16			0.27	0.02	0.01	93.70
Date collected	11/02/2005	72.94	0.13	11.51	0.90	0.11		0.79	3.50	4.16			0.23			94.05
		72.77	0.34	11.26	1.12	0.04		0.80	3.65	4.13		0.04	0.20			94.13
		72.24	0.24	11.14	1.07		0.08	0.77	3.53	3.93			0.22		0.21	93.12
		72.20	0.22	11.24	1.00		0.12	0.77	3.34	3.91			0.24	0.09		92.82
		72.56	0.26	11.53	1.08	0.11	0.08	0.68	3.63	4.19			0.17		0.02	93.89
		73.38	0.20	11.25	1.04	0.08	0.03	0.74	3.45	4.10		0.06	0.28	0.01		94.50
		72.74	0.06	11.15	1.16	0.16		0.71	3.72	3.99			0.24	0.01		93.94
		72.40	0.13	11.26	1.00		0.11	0.75	3.61	4.23		0.08	0.21		0.04	93.82
		72.22	0.16	11.53	0.91	0.13		0.82	3.63	4.01			0.23	0.03	0.07	93.74
		72.43	0.17	11.22	1.01	0.16		0.67	3.77	4.12			0.22			93.77
		72.57	0.23	11.55	1.01	0.04	0.19	0.66	3.61	4.13		0.06	0.24		0.03	94.32
		73.03	0.17	11.65	1.23	0.03	0.18	0.75	3.61	4.14			0.23	0.02	0.19	95.23
		72.05	0.23	11.12	0.88	0.07		0.83	3.59	3.79			0.22			92.78
		72.80	0.16	11.42	0.92	0.07	0.20	0.75	3.50	4.00			0.28	0.02	0.02	94.14
		72.50		11.32	1.04	0.10	0.18	0.74	3.71	4.19		0.06	0.19			94.03
		72.23	0.24	11.45	1.04	0.06	0.25	0.84	3.43	3.86		0.04	0.23	0.05		93.72
Sample code	**MRO**	72.16	0.11	11.34	0.92	0.01	0.06	0.75	3.74	4.06		0.04	0.30	0.12	0.03	93.64
Site name or area of collection	South Mairangi	73.50	0.05	11.41	0.91	0.12	0.17	0.54	4.10	3.93	0.12	0.01	0.20	0.02		95.08
Grid reference	392811	73.15	0.12	11.22	0.77			0.60	4.07	3.84	0.01		0.27	0.03		94.08
Sample depth	256-286cm	73.33	0.23	11.10	1.06	0.06	0.10	0.71	4.15	3.79	0.20	0.08	0.20		0.10	95.11
Date collected	5/02/2006	72.83	0.05	11.19	0.93	0.11	0.03	0.50	3.90	3.91	0.20		0.31		0.07	94.03
		72.47	0.17	11.41	1.27		0.08	1.04	4.07	2.89	0.18		0.22	0.02	0.08	93.90
		71.78	0.21	11.41	0.99	0.03	0.12	0.76	3.55	4.04	0.24	0.05	0.31	0.01		93.50
		73.05	0.14	11.30	0.99	0.07		0.59	4.15	3.66		0.10	0.25			94.30
		73.09	0.02	11.40	0.89	0.09	0.07	0.65	4.19	3.72	0.08		0.24			94.44
		73.23	0.21	11.46	0.97	0.04	0.14	0.94	4.36	3.04	0.21	0.06	0.23	0.03		94.92
		71.12	0.06	11.08	1.17	0.05	0.07	1.03	3.97	2.87		0.04	0.19		0.07	91.72
		72.84	0.10	11.19	1.06	0.11		0.46	4.05	3.96	0.02	0.06	0.24		0.01	94.10
		72.84	0.17	11.16	0.89	0.07		0.52	3.93	4.02	0.09		0.24			93.93
		72.75	0.19	11.49	0.99		0.03	0.81	4.02	2.99	0.12	0.05	0.23		0.03	93.70

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cl	NiO	Cr_2O_3	SO_3	P_2O_5	TOTAL
	MRO contd.	70.18	0.20	11.13	0.99	0.07	0.05	0.76	3.63	4.03	0.14		0.30		0.20	91.68
		71.63	0.26	11.26	0.98	0.05	0.08	0.81	3.57	4.02	0.13		0.28	0.08	0.37	93.52
		72.92	0.13	11.38	1.08	0.09		0.58	3.85	3.96	0.11		0.18		0.12	94.40
		73.17	0.11	11.16	0.94		0.01	0.54	4.03	3.90	0.08	0.01	0.25			94.20
Sample code	**NRB**	72.76	0.19	11.41	1.03		0.11	0.72	3.68	4.06	0.15	0.01	0.27		0.16	94.55
Site name or area of collection	North Red Bluff	72.01	0.11	11.42	0.96	0.16	0.07	0.76	3.64	4.17	0.14		0.30			93.74
Grid reference	465620	72.60	0.24	11.46	0.89	0.15	0.22	0.82	3.65	4.23	0.01	0.06	0.27	0.10	0.22	94.92
Sample depth	1000 -1010cm	71.68	0.15	11.38	0.91	0.07	0.17	0.78	3.50	3.97	0.10		0.28			92.99
Date collected	28/01/2006	73.06	0.11	11.67	1.06	0.04	0.08	0.79	3.69	4.15			0.28		0.11	95.04
		72.49	0.22	11.41	1.02		0.01	0.78	3.59	4.32			0.37		0.09	94.30
		71.49	0.17	11.46	0.78	0.04	0.08	0.72	3.41	4.26		0.02	0.34		0.01	92.78
		73.00	0.07	11.60	1.03		0.08	0.81	3.66	4.17	0.07	0.08	0.36		0.12	95.05
		73.00	0.07	11.60	1.03		0.08	0.81	3.66	4.17	0.07	0.08	0.36		0.12	95.05
		73.00	0.15	11.43	1.12	0.05	0.06	0.75	3.54	4.22			0.31			94.63
		72.95	0.21	11.65	0.98	0.04	0.15	0.84	3.59	4.19	0.02	0.05	0.26		0.19	95.12
		71.92	0.19	11.32	0.98		0.12	0.92	3.51	4.03	0.09		0.28		0.05	93.41
		72.78	0.10	11.43	0.91	0.09	0.07	0.76	3.37	4.15		0.04	0.36		0.21	94.27
		72.82	0.14	11.44	0.91	0.02	0.10	0.72	3.56	4.18			0.32			94.21
		72.79	0.13	11.54	0.92	0.04	0.15	0.71	3.35	4.45	0.02	0.05	0.30	0.03	0.03	94.51
		72.98	0.13	11.37	0.95	0.14	0.06	0.70	3.28	4.24	0.20	0.18	0.32			94.55
Sample code	**UCY**	71.75	0.25	11.42	0.84	0.02	0.14	0.78	3.58	4.01	0.28	0.03		0.10		93.20
Site name or area of collection	Cape Young	71.72	0.13	11.46	1.12		0.07	0.70	3.23	4.18	0.22	0.10		0.01		92.94
Grid reference	403836	72.36	0.19	11.49	1.13	0.02	0.03	0.70	1.64	3.42	0.27	0.08		0.08	0.02	91.43
Sample depth	c. 1m from surface	72.04	0.20	11.41	0.99		0.05	0.74	3.48	4.13	0.26			0.14	0.12	93.56
Date collected	23/03/2004	71.74	0.21	10.96	1.05		0.13	0.85	3.45	3.87	0.25				0.01	92.52
		71.36	0.03	11.31	0.91	0.05	0.01	0.80	3.43	4.15	0.35	0.04		0.21	0.04	92.69
		71.70	0.18	11.20	1.00			0.80	3.48	4.05	0.22	0.02		0.06	0.19	92.90
		72.00	0.15	11.30	0.90		0.13	0.84	3.53	3.98	0.25	0.14		0.02	0.10	93.34
		72.74	0.26	11.66	0.93	0.04	0.12	0.72	1.68	3.40	0.26	0.01			0.07	91.89
		71.68	0.23	11.27	0.98		0.08	0.75	3.41	4.02		0.01	0.24	0.01		92.68
		71.82	0.33	11.26	0.94	0.10	0.14	0.81	3.37	4.01			0.24	0.09		93.11
		72.61	0.22	11.21	0.95	0.17	0.09	0.83	3.38	3.76			0.20	0.12	0.22	93.76
		72.15	0.13	11.38	0.98		0.09	0.77	3.53	4.01			0.14			93.18
		71.82	0.23	11.29	1.00	0.03		0.76	3.76	3.89			0.26		0.14	93.18
		71.83		11.93	0.91		0.14	0.66	3.38	3.82	0.26	0.02	0.22	0.10		93.27
		72.67	0.24	11.48	0.88	0.07	0.13	0.83	3.53	4.01			0.22		0.03	94.09
		73.33	0.26	11.16	1.07	0.19	0.10	0.88	3.46	4.11		0.02	0.14	0.04		94.76
		72.26	0.25	11.28	0.86	0.05	0.10	0.60	3.28	3.94			0.18	0.02		92.82
		72.12	0.12	11.25	0.90		0.14	0.71	3.30	4.03			0.21			92.78

Rangitawa Tephra
Normalised analyses recalculated to 100% water free

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cl	NiO	Cr_2O_3	SO_3	P_2O_5	TOTAL
Rangitawa Tephra		77.77	0.18	12.05	1.08		0.12	0.76	3.41	4.63			0.20		0.01	100.00
Type section, Rangitikei River Valley		77.66	0.12	12.07	1.17	0.12		0.96	4.16	3.50			0.20	0.09	0.07	100.00
		77.48	0.17	12.15	1.10		0.12	0.89	3.79	4.32			0.23	0.05		100.00
		77.19	0.18	12.16	1.14		0.01	0.81	4.07	4.47			0.13	0.06		100.00
		77.67	0.22	12.28	1.19		0.05	0.77	3.34	4.48			0.27			100.00
		77.61	0.09	12.16	1.14		0.10	0.73	3.67	4.45			0.28			100.00
		77.40	0.20	12.08	1.07	0.11	0.01	0.73	3.69	4.46			0.24	0.03	0.07	100.00
		77.88	0.03	12.13	1.13	0.14	0.11	0.80	4.31	3.68			0.14	0.01		100.00
		77.37	0.16	12.25	1.04	0.05	0.08	0.88	3.69	4.36			0.18	0.07	0.07	100.00
		77.19	0.24	12.11	1.13	0.14		0.77	3.73	4.60			0.23		0.06	100.00
RANGITAWA CORRELATIVES - CHATHAM ISLAND																
Sample code	**KCh15**	79.08	0.30	12.51	1.05		0.15	0.86	1.94	3.79	0.26	0.05				100.00
Site name or area of collection	Matarakau	79.35	0.31	12.53	1.13	0.03	0.08	0.97	1.71	3.57	0.27	0.05				100.00
Grid reference	623791	76.89	0.32	12.18	0.93	0.08	0.17	0.77	3.68	4.62	0.27	0.04		0.04		100.00
Sample depth	138-149cm	76.77	0.34	12.14	1.00	0.14	0.09	0.84	3.64	4.58	0.31			0.14		100.00
Date collected	12/03/2004	77.07	0.17	12.19	0.96		0.12	0.86	3.62	4.66	0.28			0.05		100.00
		77.16	0.13	12.24	1.17		0.20	0.80	3.40	4.58	0.23			0.10		100.00
		76.74	0.33	12.21	0.93	0.18	0.16	0.77	3.78	4.50	0.28			0.12		100.00
		77.19	0.16	12.32	0.63	0.19		0.63	3.64	4.57	0.25	0.13		0.10	0.22	100.00
		76.99	0.12	12.20	0.97	0.02	0.10	0.61	3.93	4.80	0.22	0.03		0.02		100.00
		77.44	0.23	11.93	1.14	0.09		0.90	3.56	4.39	0.24			0.07		100.00
		76.95	0.25	12.27	1.05	0.04	0.16	0.84	3.62	4.44	0.26	0.04		0.08		100.00
		77.10	0.23	12.31	0.87	0.07	0.16	0.76	3.72	4.44		0.02	0.28	0.04		100.00
		77.21	0.23	12.19	1.04		0.05	0.86	3.55	4.43		0.04	0.26	0.13		100.00
		77.17	0.10	12.33	1.19	0.06	0.15	0.75	3.69	4.36			0.21			100.00
		77.47	0.06	12.12	0.86			0.75	3.76	4.57			0.27	0.06	0.07	100.00
		77.95	0.10	11.87	1.10		0.05	0.90	3.57	4.28			0.17			100.00
		77.39	0.18	12.05	1.06	0.04		0.75	3.56	4.44	0.05	0.18	0.25		0.04	100.00
		77.23	0.28	12.09	1.17	0.06	0.27	0.69	3.65	4.24			0.26		0.06	100.00
		77.65	0.08	12.11	1.11			0.76	3.54	4.50			0.21	0.03		100.00
		77.68	0.11	11.74	1.08	0.12		0.79	3.75	4.45		0.01	0.26		0.02	100.00
Sample code	**KCh05-7**	76.78	0.19	12.10	0.99	0.11		0.86	3.82	4.74	0.06		0.32	0.02	0.01	100.00
Site name or area of collection	Kaingaroa Beach	76.73	0.24	12.17	0.92	0.16	0.10	0.77	3.74	4.62	0.21		0.34			100.00
Grid reference	676785	77.24	0.23	12.00	0.92			0.85	4.05	4.23	0.23		0.26			100.00
Sample depth	692 -702 cm	76.86	0.27	12.16	1.06	0.03	0.06	0.87	3.71	4.42	0.09	0.10	0.24		0.14	100.00
Date collected	22/01/2006	76.80	0.21	12.13	1.05		0.09	0.81	3.71	4.36	0.27	0.17	0.39		0.02	100.00
		76.82	0.19	12.11	0.94	0.07	0.06	0.84	4.14	4.20	0.20		0.42			100.00
		77.04	0.24	12.22	1.05		0.17	0.78	3.75	4.36	0.12		0.27			100.00
		77.02	0.13	12.08	1.13	0.01	0.13	0.80	4.15	4.23			0.30	0.02		100.00
		76.79	0.29	12.03	1.00	0.20	0.06	0.85	3.98	4.19	0.25	0.02	0.33			100.00
		76.96	0.25	11.94	0.97		0.17	0.77	4.03	4.10	0.27		0.35		0.19	100.00
		77.31	0.21	12.01	0.91	0.04	0.16	0.94	3.83	4.09	0.01	0.09	0.35		0.04	100.00

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cl	NiO	Cr_2O_3	SO_3	P_2O_5	TOTAL
	KCh05-7 contd.	77.02	0.10	12.16	1.09	0.02	0.12	0.78	3.96	4.25	0.04		0.34		0.11	100.00
		77.06	0.27	12.16	0.94	0.07	0.09	0.68	3.95	4.25	0.17		0.31		0.03	100.00
		76.77	0.32	12.08	0.96	0.13	0.10	0.76	4.08	4.25	0.11		0.32		0.12	100.00
		77.10	0.18	12.20	0.87	0.08	0.10	0.93	3.79	4.21	0.14		0.33	0.08		100.00
		76.71	0.14	12.16	1.17	0.16	0.03	0.75	3.75	4.61	0.17	0.04	0.32			100.00
Sample code	**KRM**															
Site name or area of collection	Kaingaroa Beach															
Grid reference	676785	76.95	0.24	11.93	0.99	0.16	0.05	0.89	3.65	4.60	0.16		0.29	0.03	0.06	100.00
Sample depth	686-696cm	76.73	0.18	12.21	1.11		0.04	0.84	3.74	4.60	0.13	0.02	0.25	0.06	0.09	100.00
Date collected	22/01/2006	76.64	0.19	12.34	1.02	0.05	0.27	0.74	3.92	4.29	0.06		0.31		0.17	100.00
		76.77	0.10	12.08	1.03	0.02	0.26	0.79	4.12	4.24	0.15	0.02	0.32	0.03	0.07	100.00
		77.21	0.27	12.03	1.05		0.09	0.92	3.78	4.28		0.05	0.28	0.04		100.00
		76.96	0.30	12.06	0.91	0.02	0.17	0.82	3.93	4.26	0.14		0.30	0.03	0.09	100.00
		77.36	0.16	11.97	1.04			0.78	3.82	4.38			0.27	0.04	0.18	100.00
		77.24	0.12	12.00	1.08		0.12	0.85	3.83	4.27	0.09	0.09	0.31			100.00
		77.00	0.06	12.19	1.07	0.05	0.12	0.83	3.88	4.28	0.10	0.05	0.33	0.03		100.00
		77.59	0.02	12.00	0.81	0.12	0.10	0.57	4.30	4.16			0.25	0.05	0.04	100.00
		77.10	0.16	12.28	0.96	0.15	0.07	0.85	3.82	4.21	0.09		0.31			100.00
		77.33	0.15	12.08	1.06	0.02	0.12	0.85	3.72	4.28	0.04		0.25	0.08	0.02	100.00
		77.18	0.23	12.19	0.94		0.12	0.82	3.96	4.09	0.13	0.01	0.31	0.03		100.00
		76.73	0.28	12.09	0.90	0.07	0.15	0.77	4.03	4.10	0.16	0.13	0.34		0.26	100.00
		77.10	0.07	12.38	0.70	0.10		0.60	4.10	4.37	0.25		0.31		0.01	100.00
		76.98	0.24	12.23	0.92	0.11	0.14	0.85	3.75	4.40	0.08	0.03	0.28			100.00
		77.19	0.13	12.15	1.01	0.17	0.08	0.84	3.87	4.23			0.33			100.00
		76.78	0.22	12.19	0.99	0.08	0.13	0.78	3.86	4.28	0.12	0.13	0.37		0.10	100.00
		77.23	0.21	12.17	1.01	0.03		0.97	3.57	4.62		0.05	0.25		0.01	100.00
		77.30	0.12	12.26	0.99		0.22	0.86	3.86	4.26		0.05	0.22			100.00
		77.40	0.19	12.06	1.15		0.06	0.90	3.72	4.18		0.14	0.27		0.05	100.00
		77.74	0.22	12.29	0.90	0.15	0.01	0.76	3.60	4.33			0.25	0.00	0.02	100.00
		77.34	0.27	12.08	1.18	0.02	0.11	1.00	3.64	4.29			0.27	0.03		100.00
		77.18	0.01	12.26	1.13	0.06		0.89	3.60	4.74			0.29			100.00
		78.21	0.40	12.14	1.12		0.01	0.89	3.26	4.24			0.16	0.08		100.00
		77.49	0.18	12.18	1.07		0.02	0.85	3.77	4.37			0.23			100.00
		77.55	0.24	12.09	1.16	0.03	0.07	0.70	3.90	4.29			0.22			100.00
		77.77	0.19	12.36	1.04	0.18		0.88	3.03	4.49			0.19		0.09	100.00
Sample code	**KRS**	77.32	0.02	12.29	0.79	0.09		0.56	3.70	4.99			0.17	0.01	0.04	100.00
Site name or area of collection	Kaingaroa Slump	78.38		12.13	0.86		0.13	0.85	3.88	3.55			0.16	0.04		100.00
Grid reference	679788	77.73	0.05	12.18	1.07	0.04		0.92	4.19	3.61			0.20			100.00
Sample depth	220-230cm	77.59	0.14	12.13	0.99	0.15		0.88	3.72	3.96			0.25		0.19	100.00
Date collected	26/01/2005	76.92	0.18	12.37	1.14	0.09	0.20	0.90	3.88	4.13			0.20			100.00
		77.62	0.14	12.08	0.91	0.17	0.02	0.82	4.34	3.56		0.01	0.19	0.03	0.11	100.00
		77.92	0.11	12.19	1.06	0.12		0.80	3.84	3.76			0.18		0.02	100.00
		77.68	0.12	12.10	0.91	0.13	0.01	0.82	4.28	3.71			0.12		0.13	100.00
		77.92	0.17	12.00	1.04	0.11		0.79	3.99	3.70	0.04		0.20	0.03		100.00
		76.87	0.14	12.31	1.14	0.08	0.28	1.08	4.16	3.45		0.06	0.15		0.27	100.00
		77.93	0.15	12.26	0.98			0.80	4.07	3.55			0.13	0.07	0.04	100.00

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cl	NiO	Cr_2O_3	SO_3	P_2O_5	TOTAL
	KRS contd.	77.81	0.07	12.18	0.98	0.03	0.03	0.88	4.15	3.46		0.01	0.13	0.01	0.25	100.00
		77.65		12.13	1.01	0.30	0.11	0.90	4.03	3.42		0.02	0.25		0.17	100.00
		77.23	0.29	12.36	1.12	0.10	0.04	0.91	4.00	3.77			0.18			100.00
		77.43		12.37	1.08	0.14	0.13	0.85	4.07	3.52			0.20	0.04	0.17	100.00
		77.42	0.14	12.38	1.08	0.15	0.10	0.88	3.88	3.78		0.01	0.17		0.02	100.00
		77.02	0.14	12.45	1.06	0.02	0.06	0.88	4.42	3.54			0.16	0.02	0.22	100.00
		77.70	0.06	12.28	0.91	0.04	0.13	0.82	4.06	3.62		0.11	0.20	0.07		100.00
		77.86	0.09	12.13	0.95	0.25	0.18	0.81	3.91	3.63			0.17	0.01		100.00
		77.66	0.16	12.27	1.07	0.08	0.09	1.24	4.18	3.05			0.14		0.06	100.00
Sample code	**MR9**	77.18	0.15	12.19	1.03	0.04		0.87	3.65	4.60		0.13	0.25		0.07	100.00
Site name or area of collection	Mairangi	77.58	0.19	12.14	1.08			0.79	3.69	4.60			0.18		0.01	100.00
Grid reference	391826	77.15	0.22	12.10	0.99	0.07		0.92	3.98	4.28			0.20	0.12	0.15	100.00
Sample depth	390-400cm	77.44	0.14	12.23	1.04	0.10	0.07	0.84	3.70	4.44			0.29	0.02	0.01	100.00
Date collected	11/02/2005	77.55	0.14	12.24	0.96	0.12		0.84	3.72	4.42			0.24			100.00
		77.31	0.36	11.96	1.19	0.04		0.85	3.88	4.39		0.04	0.21			100.00
		77.58	0.26	11.96	1.15		0.09	0.83	3.79	4.22			0.24		0.23	100.00
		77.78	0.24	12.11	1.08		0.13	0.83	3.60	4.21			0.26	0.10		100.00
		77.28	0.28	12.28	1.15	0.12	0.09	0.72	3.87	4.46			0.18		0.02	100.00
		77.65	0.21	11.90	1.10	0.08	0.03	0.78	3.65	4.34		0.06	0.30	0.01		100.00
		77.43	0.06	11.87	1.23	0.17		0.76	3.96	4.25			0.26	0.01		100.00
		77.17	0.14	12.00	1.07		0.12	0.80	3.85	4.51		0.09	0.22		0.04	100.00
		77.04	0.17	12.30	0.97	0.14		0.87	3.87	4.28			0.25	0.03	0.07	100.00
		77.24	0.18	11.97	1.08	0.17		0.71	4.02	4.39			0.23			100.00
		76.94	0.24	12.25	1.07	0.04	0.20	0.70	3.83	4.38		0.06	0.25		0.03	100.00
		76.69	0.18	12.23	1.29	0.03	0.19	0.79	3.79	4.35			0.24	0.02	0.20	100.00
		77.66	0.25	11.99	0.95	0.08		0.89	3.87	4.08			0.24			100.00
		77.33	0.17	12.13	0.98	0.07	0.21	0.80	3.72	4.25			0.30	0.02	0.02	100.00
		77.10		12.04	1.11	0.11	0.19	0.79	3.95	4.46		0.06	0.20			100.00
		77.07	0.26	12.22	1.11	0.06	0.27	0.90	3.66	4.12		0.04	0.25	0.05		100.00
Sample code	**MRO**	77.06	0.12	12.11	0.98	0.01	0.06	0.80	3.99	4.34		0.04	0.32	0.13	0.03	100.00
Site name or area of collection	South Mairangi	77.30	0.05	12.00	0.96	0.13	0.18	0.57	4.31	4.13	0.13	0.01	0.21	0.02		100.00
Grid reference	392811	77.75	0.13	11.93	0.82			0.64	4.33	4.08	0.01		0.29	0.03		100.00
Sample depth	256-286cm	77.10	0.24	11.67	1.11	0.06	0.11	0.75	4.36	3.98	0.21	0.08	0.21		0.11	100.00
Date collected	5/02/2006	77.45	0.05	11.90	0.99	0.12	0.03	0.53	4.15	4.16	0.21		0.33		0.07	100.00
		77.18	0.18	12.15	1.35		0.09	1.11	4.33	3.08	0.19		0.23	0.02	0.09	100.00
		76.77	0.22	12.20	1.06	0.03	0.13	0.81	3.80	4.32	0.26	0.05	0.33	0.01		100.00
		77.47	0.15	11.98	1.05	0.07		0.63	4.40	3.88		0.11	0.27			100.00
		77.39	0.02	12.07	0.94	0.10	0.07	0.69	4.44	3.94	0.08		0.25			100.00
		77.15	0.22	12.07	1.02	0.04	0.15	0.99	4.59	3.20	0.22	0.06	0.24	0.03		100.00
		77.54	0.07	12.08	1.28	0.05	0.08	1.12	4.33	3.13		0.04	0.21		0.08	100.00
		77.41	0.11	11.89	1.13	0.12		0.49	4.30	4.21	0.02	0.06	0.26		0.01	100.00
		77.55	0.18	11.88	0.95	0.07		0.55	4.18	4.28	0.10		0.26			100.00
		77.64	0.20	12.26	1.06		0.03	0.86	4.29	3.19	0.13	0.05	0.25		0.03	100.00

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cl	NiO	Cr_2O_3	SO_3	P_2O_5	TOTAL
	MRO contd.	76.55	0.22	12.14	1.08	0.08	0.05	0.83	3.96	4.40	0.15		0.33		0.22	100.00
		76.59	0.28	12.04	1.05	0.05	0.09	0.87	3.82	4.30	0.14		0.30	0.09	0.40	100.00
		77.25	0.14	12.06	1.14	0.10		0.61	4.08	4.19	0.12		0.19		0.13	100.00
		77.68	0.12	11.85	1.00		0.01	0.57	4.28	4.14	0.08	0.01	0.27			100.00
Sample code	**NRB**	76.95	0.20	12.07	1.09		0.12	0.76	3.89	4.29	0.16	0.01	0.29		0.17	100.00
Site name or area of collection	North Red Bluff	76.82	0.12	12.18	1.02	0.17	0.07	0.81	3.88	4.45	0.15		0.32			100.00
Grid reference	465620	76.49	0.25	12.07	0.94	0.16	0.23	0.86	3.85	4.46	0.01	0.06	0.28	0.11	0.23	100.00
Sample depth	1000 -1010cm	77.08	0.16	12.24	0.98	0.08	0.18	0.84	3.76	4.27	0.11		0.30			100.00
Date collected	28/01/2006	76.87	0.12	12.28	1.12	0.04	0.08	0.83	3.88	4.37			0.29		0.12	100.00
		76.87	0.23	12.10	1.08		0.01	0.83	3.81	4.58			0.39		0.10	100.00
		77.05	0.18	12.35	0.84	0.04	0.09	0.78	3.68	4.59		0.02	0.37		0.01	100.00
		76.80	0.07	12.20	1.08		0.08	0.85	3.85	4.39	0.07	0.08	0.38		0.13	100.00
		76.80	0.07	12.20	1.08		0.08	0.85	3.85	4.39	0.07	0.08	0.38		0.13	100.00
		77.14	0.16	12.08	1.18	0.05	0.06	0.79	3.74	4.46			0.33			100.00
		76.69	0.22	12.25	1.03	0.04	0.16	0.88	3.77	4.40	0.02	0.05	0.27		0.20	100.00
		76.99	0.20	12.12	1.05		0.13	0.98	3.76	4.31	0.10		0.30		0.05	100.00
		77.20	0.11	12.12	0.97	0.10	0.07	0.81	3.57	4.40		0.04	0.38		0.22	100.00
		77.30	0.15	12.14	0.97	0.02	0.11	0.76	3.78	4.44			0.34			100.00
		77.02	0.14	12.21	0.97	0.04	0.16	0.75	3.54	4.71	0.02	0.05	0.32	0.03	0.03	100.00
		77.19	0.14	12.03	1.00	0.15	0.06	0.74	3.47	4.48	0.21	0.19	0.34			100.00
Sample code	**UCY**	76.98	0.27	12.25	0.90	0.02	0.15	0.84	3.84	4.30	0.30	0.03		0.11	0.00	100.00
Site name or area of collection	Cape Young	77.17	0.14	12.33	1.21		0.08	0.75	3.48	4.50	0.24	0.11		0.01	0.00	100.00
Grid reference	403836	79.14	0.21	12.57	1.24	0.02	0.03	0.77	1.79	3.74	0.30	0.09		0.09	0.02	100.00
Sample depth	c. 1m from surface	77.00	0.21	12.20	1.06		0.05	0.79	3.72	4.41	0.28			0.15	0.13	100.00
Date collected	23/03/2004	77.54	0.23	11.85	1.13		0.14	0.92	3.73	4.18	0.27			0.00	0.01	100.00
		76.99	0.03	12.20	0.98	0.05	0.01	0.86	3.70	4.48	0.38	0.04		0.23	0.04	100.00
		77.18	0.19	12.06	1.08			0.86	3.75	4.36	0.24	0.02		0.06	0.20	100.00
		77.14	0.16	12.11	0.96		0.14	0.90	3.78	4.26	0.27	0.15		0.02	0.11	100.00
		79.16	0.28	12.69	1.01	0.04	0.13	0.78	1.83	3.70	0.28	0.01		0.00	0.08	100.00
		77.34	0.25	12.16	1.06		0.09	0.81	3.68	4.34		0.01	0.26	0.01	0.00	100.00
		77.13	0.35	12.09	1.01	0.11	0.15	0.87	3.62	4.31			0.26	0.10	0.00	100.00
		77.44	0.23	11.96	1.01	0.18	0.10	0.89	3.60	4.01			0.21	0.13	0.23	100.00
		77.43	0.14	12.21	1.05		0.10	0.83	3.79	4.30			0.15	0.00	0.00	100.00
		77.08	0.25	12.12	1.07	0.03		0.82	4.04	4.17			0.28	0.00	0.15	100.00
		77.01	0.00	12.79	0.98		0.15	0.71	3.62	4.10	0.28	0.02	0.24	0.11	0.00	100.00
		77.23	0.26	12.20	0.94	0.07	0.14	0.88	3.75	4.26			0.23	0.00	0.03	100.00
		77.38	0.27	11.78	1.13	0.20	0.11	0.93	3.65	4.34		0.02	0.15	0.04	0.00	100.00
		77.85	0.27	12.15	0.93	0.05	0.11	0.65	3.53	4.24			0.19	0.02	0.00	100.00
		77.73	0.13	12.13	0.97		0.15	0.77	3.56	4.34			0.23	0.00	0.00	100.00

Appendix 1A: section 1.3:

Pumice and reworked volcanic glass
Raw Analyses

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cl	NiO	Cr_2O_3	SO_3	P_2O_5	TOTAL
Sample code	**KCh05-16**	73.10	0.24	12.70	1.85	0.04	0.13	1.45	4.55	2.94			0.16			96.84
Site name or area of collection	Owenga coast	73.65	0.22	12.47	1.74	0.10	0.19	1.48	4.42	2.85			0.19		0.02	97.06
Grid Reference	578502	73.56	0.47	12.59	1.84		0.29	1.42	4.43	2.81			0.13	0.12	0.02	97.61
Sample depth	290 cm	73.56	0.47	12.59	1.84		0.29	1.42	4.43	2.81			0.13	0.12	0.02	97.61
Date collected	28/01/2005	72.42	0.17	12.33	1.84	0.16	0.17	1.33	4.38	2.81		0.06	0.16		0.09	95.87
		73.73	0.26	12.82	1.87	0.20	0.18	1.50	4.69	2.79			0.10		0.09	97.98
		73.53	0.34	12.86	1.94	0.04	0.17	1.50	4.70	2.88			0.17	0.04		97.95
		73.33	0.41	12.67	1.99	0.11	0.17	1.47	4.40	2.77			0.20			97.19
		73.80	0.29	12.62	1.91	0.12	0.18	1.57	4.78	2.85			0.17		0.06	98.19
		73.46	0.11	12.70	1.90	0.18	0.12	1.47	4.53	2.86			0.20	0.03		97.34
		71.56	0.32	12.37	1.95		0.29	1.49	4.60	2.73		0.06	0.12	0.09		95.45
		71.56	0.32	12.37	1.95		0.29	1.49	4.60	2.73		0.06	0.12	0.09		95.45
		74.18	0.31	12.89	2.01	0.04	0.20	1.53	4.49	2.79			0.20			98.64
		74.26	0.27	12.75	1.98	0.03	0.19	1.48	4.40	2.90			0.18		0.13	98.57
		73.43	0.32	13.01	1.87	0.10	0.37	1.41	4.35	2.83		0.11	0.17	0.15	0.03	98.15
		74.84	0.14	12.72	1.90		0.17	1.49	4.67	2.85	0.06	0.05	0.21	0.12	0.09	99.31
		73.58	0.38	12.61	2.08	0.10	0.24	1.45	4.61	2.80			0.15			98.00
		74.42	0.20	12.83	1.83	0.22	0.18	1.43	4.64	2.96			0.19		0.03	98.93
		74.00	0.33	12.77	1.89	0.19	0.14	1.33	4.47	2.77			0.14		0.09	98.12
		73.64	0.35	12.58	1.97	0.16	0.14	1.36	4.46	2.92			0.14		0.19	97.91
		73.82	0.30	12.76	1.79	0.11	0.19	1.47	4.32	2.86			0.15	0.03		97.80
Sample code	**MKTU**	72.28	0.14	11.05	1.10	0.01	0.17	0.95	3.95	2.62			0.15			92.42
Site name or area of collection	Matakatau, Waitangi-Tuku Road	71.25	0.14	11.16	1.03	0.14		1.00	3.57	2.74			0.21		0.21	91.45
Grid Reference	419521	72.18	0.10	11.43	1.02	0.17	0.13	1.00	3.91	2.84		0.02	0.17		0.05	93.02
Sample depth	23-35cm	72.12	0.23	11.17	1.09	0.13	0.12	0.91	3.70	2.80			0.16			92.43
Date collected	12/11/2005	71.80	0.24	11.37	1.02	0.06	0.10	1.17	4.03	2.69			0.16			92.64
		74.24	0.05	11.81	0.83	0.18	0.08	0.79	3.67	3.69			0.12		0.01	95.47
		72.00	0.13	11.12	1.17	0.12	0.25	0.94	3.94	2.87		0.04	0.16		0.20	92.94
		71.39	0.11	10.98	0.99	0.06	0.09	0.95	3.33	2.73			0.13	0.08		90.84
		71.45	0.15	11.34	1.16	0.16	0.12	1.11	3.99	2.65			0.17	0.03	0.04	92.37
		72.10	0.24	11.19	0.99	0.10		0.97	3.82	2.94			0.21	0.03	0.22	92.81
		70.93	0.11	11.22	1.17	0.16	0.15	1.12	3.61	2.60			0.17	0.07	0.11	91.42
		73.36	0.20	11.24	1.15	0.06	0.01	0.91	3.68	3.11			0.21	0.04		93.97
		70.96	0.21	11.37	1.17	0.01	0.08	1.05	3.53	2.61			0.13			91.12
		71.68	0.17	11.21	1.02	0.05	0.16	0.99	3.67	2.94			0.19			92.08
		72.12	0.24	11.25	1.16	0.03	0.09	1.02	3.81	2.67		0.01	0.20		0.06	92.66
		72.33	0.19	11.16	1.16		0.06	1.00	3.81	2.77			0.13		0.18	92.79
		72.15	0.09	11.41	1.11	0.07	0.14	1.04	3.87	2.84		0.04	0.18	0.06	0.03	93.03
		70.87	0.16	11.07	0.97	0.08	0.04	0.98	3.57	2.70			0.17			90.61
		70.66	0.08	10.77	1.00	0.15	0.01	0.89	3.44	2.93		0.08	0.21	0.10		90.32
		72.42	0.15	11.19	1.04	0.09	0.12	0.97	3.91	3.00			0.20		0.11	93.20

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cl	NiO	Cr_2O_3	SO_3	P_2O_5	TOTAL
Sample code	**KCh-30**	72.68	0.22	11.33	1.15	0.12		0.71	3.89	3.29		0.02	0.31	0.01		93.70
Site name or area of collection	Boundary Rock cliff site	72.93	0.20	11.21	1.21	0.11	0.03	0.74	3.85	3.27			0.24	0.06	0.14	93.99
Grid Reference	586440	72.23		11.17	1.06	0.05	0.06	0.82	3.68	3.27			0.15		0.04	92.53
Sample depth	208-218	72.27	0.10	11.28	1.20		0.25	0.79	3.53	3.37			0.22	0.03		93.04
Date collected	2/02/2005	71.84	0.17	11.29	0.94	0.15		0.75	3.44	3.27			0.14		0.21	92.20
		72.49	0.14	11.00	1.00	0.01	0.01	0.85	3.61	3.27			0.23	0.01		92.62
		72.44		11.08	1.15		0.01	0.70	3.92	3.17		0.01	0.20		0.01	92.69
		72.83	0.21	11.33	1.12	0.14	0.03	0.64	3.97	3.34			0.22	0.02		93.85
		72.00	0.08	11.33	1.05			0.78	3.38	3.43			0.25	0.10	0.03	92.43
		72.37	0.13	11.32	1.03		0.19	1.01	3.86	2.87			0.20	0.03		93.01
		72.78	0.06	11.24	1.15	0.07	0.09	0.74	3.79	3.24		0.01	0.20	0.05	0.04	93.46
		73.18	0.21	11.30	1.08		0.09	0.70	3.77	3.23	0.05		0.17			93.78
		71.28	0.17	11.41	1.08	0.11	0.17	0.99	3.53	2.59			0.17		0.04	91.54
		71.66	0.15	11.13	1.08	0.03	0.06	0.73	3.88	3.17			0.19			92.08
		71.39	0.10	11.07	0.91	0.20		0.74	3.49	3.37		0.10	0.17		0.05	91.59
		72.51	0.13	11.28	1.11	0.06	0.03	0.79	3.69	3.21			0.21			93.02
		72.68	0.17	11.30	1.08	0.10	0.08	0.67	3.34	3.89			0.17		0.04	93.52
		72.41	0.18	11.10	1.20	0.01		0.81	3.58	3.28			0.28	0.08	0.04	92.97
		71.76	0.11	11.09	1.16	0.16	0.01	0.72	3.82	3.30			0.18			92.31
		73.73	0.15	11.61	0.97	0.02	0.08	0.86	3.97	3.23			0.15		0.05	94.82
Sample code	**KRS-UPL**	71.25	0.22	11.00	0.95	0.01	0.27	1.09	3.58	2.90		0.01	0.17	0.10		91.55
Site name or area of collection	Kaingaroa Slump section	73.09	0.12	11.45	0.94	0.14	0.13	0.86	3.64	3.40		0.02	0.18	0.02	0.06	94.05
Grid Reference	679788	72.20	0.08	11.11	0.90	0.04	0.11	0.77	3.78	3.57		0.07	0.14			92.77
Sample depth	100-102cm	71.92	0.25	11.15	0.89	0.08	0.11	0.71	3.43	3.46			0.11			92.11
Date collected	26/01/2005	71.56	0.32	11.16	0.93	0.08	0.01	1.02	3.61	3.13			0.18	0.01		92.01
		71.89	0.17	11.31	0.93			1.01	3.94	3.07		0.06	0.16	0.01		92.55
		72.86	0.14	11.23	0.96	0.20	0.08	0.74	3.71	3.47			0.19			93.58
		73.70	0.16	11.32	1.01	0.08	0.15	0.98	3.55	3.60			0.20		0.19	94.94
		72.87	0.15	11.31	0.89	0.15	0.16	0.68	3.87	3.46			0.21		0.01	93.76
Sample code	**OwWh**	73.28	0.14	11.61	1.05	0.11	0.07	0.74	3.42	4.64	0.18	0.07	0.32			95.63
Site name or area of collection	Owenga wharf	73.53	0.32	11.64	0.72		0.13	0.78	3.36	4.80	0.01		0.30		0.10	95.69
Grid Reference	605472	72.98	0.17	11.49	0.94		0.09	0.76	3.38	4.56	0.11	0.12	0.29			94.89
Sample depth	130-200 cm	73.32	0.11	11.29	0.87	0.13	0.09	0.81	3.17	4.61	0.05	0.01	0.32	0.02	0.08	94.88
Date collected	12/11/2005	73.63	0.11	11.50	0.88	0.06	0.09	0.81	3.42	4.76	0.04		0.33			95.63
		73.37	0.19	11.54	1.02	0.08	0.15	0.81	3.26	4.58	0.07		0.36		0.02	95.45
		73.05	0.24	11.41	1.02	0.08	0.09	0.85	3.43	4.49	0.06		0.32		0.03	95.07
		74.13	0.16	11.50	1.03	0.05	0.10	0.80	3.28	4.57	0.13	0.05	0.31		0.05	96.16
		73.29	0.20	11.76	1.13	0.07	0.13	0.78	3.39	4.60	0.01	0.02	0.23			95.61
		73.79	0.11	11.51	1.08	0.08	0.15	0.82	3.44	4.55	0.28		0.28	0.02	0.09	96.20
		72.86	0.15	11.55	1.12		0.14	0.85	3.22	4.65	0.06		0.29	0.01	0.15	95.05
		73.37	0.13	11.67	1.11	0.04	0.07	0.79	3.32	4.61	0.14	0.06	0.37		0.03	95.71
		73.51	0.24	11.57	0.87		0.07	0.81	3.25	4.80	0.02		0.34		0.05	95.53
		73.39	0.15	11.57	0.88	0.11	0.09	0.67	3.53	4.62			0.35		0.07	95.43
		73.33	0.20	11.53	0.93	0.06	0.16	0.79	3.44	4.64	0.17	0.06	0.27		0.13	95.71

Pumice and reworked volcanic glass
Normalised analyses recalculated to 100% water free

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cl	NiO	Cr_2O_3	SO_3	P_2O_5	TOTAL
Sample code	**KCh05-16**	75.49	0.25	13.11	1.91	0.04	0.13	1.50	4.70	3.04			0.17			100.00
Site name or area of collection	Owenga coast	75.88	0.23	12.85	1.79	0.10	0.20	1.52	4.55	2.94			0.20		0.02	100.00
Grid Reference	578502	75.36	0.48	12.90	1.89		0.30	1.45	4.54	2.88			0.13	0.12	0.02	100.00
Sample depth	290 cm	75.36	0.48	12.90	1.89		0.30	1.45	4.54	2.88			0.13	0.12	0.02	100.00
Date collected	28/01/2005	75.54	0.18	12.86	1.92	0.17	0.18	1.39	4.57	2.93		0.06	0.17		0.09	100.00
		75.25	0.27	13.08	1.91	0.20	0.18	1.53	4.79	2.85			0.10		0.09	100.00
		75.07	0.35	13.13	1.98	0.04	0.17	1.53	4.80	2.94			0.17	0.04		100.00
		75.45	0.42	13.04	2.05	0.11	0.17	1.51	4.53	2.85			0.21			100.00
		75.16	0.30	12.85	1.95	0.12	0.18	1.60	4.87	2.90			0.17		0.06	100.00
		75.47	0.11	13.05	1.95	0.18	0.12	1.51	4.65	2.94			0.21	0.03		100.00
		74.97	0.34	12.96	2.04		0.30	1.56	4.82	2.86		0.06	0.13	0.09		100.00
		74.97	0.34	12.96	2.04		0.30	1.56	4.82	2.86		0.06	0.13	0.09		100.00
		75.20	0.31	13.07	2.04	0.04	0.20	1.55	4.55	2.83			0.20			100.00
		75.34	0.27	12.93	2.01	0.03	0.19	1.50	4.46	2.94			0.18		0.13	100.00
		74.81	0.33	13.26	1.91	0.10	0.38	1.44	4.43	2.88		0.11	0.17	0.15	0.03	100.00
		75.36	0.14	12.81	1.91		0.17	1.50	4.70	2.87	0.06	0.05	0.21	0.12	0.09	100.00
		75.08	0.39	12.87	2.12	0.10	0.24	1.48	4.70	2.86			0.15			100.00
		75.22	0.20	12.97	1.85	0.22	0.18	1.45	4.69	2.99			0.19		0.03	100.00
		75.42	0.34	13.01	1.93	0.19	0.14	1.36	4.56	2.82			0.14		0.09	100.00
		75.21	0.36	12.85	2.01	0.16	0.14	1.39	4.56	2.98			0.14		0.19	100.00
		75.48	0.31	13.05	1.83	0.11	0.19	1.50	4.42	2.92			0.15	0.03		100.00
Sample code	**MKTU**	78.21	0.15	11.96	1.19	0.01	0.18	1.03	4.27	2.83			0.16			100.00
Site name or area of collection	Matakatau, Waitangi-Tuku Road	77.91	0.15	12.20	1.13	0.15	0.00	1.09	3.90	3.00			0.23		0.23	100.00
Grid Reference	419521	77.60	0.11	12.29	1.10	0.18	0.14	1.08	4.20	3.05		0.02	0.18		0.05	100.00
Sample depth	23-35cm	78.03	0.25	12.08	1.18	0.14	0.13	0.98	4.00	3.03			0.17			100.00
Date collected	12/11/2005	77.50	0.26	12.27	1.10	0.06	0.11	1.26	4.35	2.90			0.17			100.00
		77.76	0.05	12.37	0.87	0.19	0.08	0.83	3.84	3.87			0.13		0.01	100.00
		77.47	0.14	11.96	1.26	0.13	0.27	1.01	4.24	3.09		0.04	0.17		0.22	100.00
		78.59	0.12	12.09	1.09	0.07	0.10	1.05	3.67	3.01			0.14	0.09		100.00
		77.35	0.16	12.28	1.26	0.17	0.13	1.20	4.32	2.87			0.18	0.03	0.04	100.00
		77.69	0.26	12.06	1.07	0.11	0.00	1.05	4.12	3.17			0.23	0.03	0.24	100.00
		77.59	0.12	12.27	1.28	0.18	0.16	1.23	3.95	2.84			0.19	0.08	0.12	100.00
		78.07	0.21	11.96	1.22	0.06	0.01	0.97	3.92	3.31			0.22	0.04		100.00
		77.88	0.23	12.48	1.28	0.01	0.09	1.15	3.87	2.86			0.14			100.00
		77.85	0.18	12.17	1.11	0.05	0.17	1.08	3.99	3.19			0.21			100.00
		77.83	0.26	12.14	1.25	0.03	0.10	1.10	4.11	2.88		0.01	0.22		0.06	100.00
		77.95	0.20	12.03	1.25		0.06	1.08	4.11	2.99			0.14		0.19	100.00
		77.56	0.10	12.26	1.19	0.08	0.15	1.12	4.16	3.05		0.04	0.19	0.06	0.03	100.00
		78.21	0.18	12.22	1.07	0.09	0.04	1.08	3.94	2.98			0.19			100.00
		78.23	0.09	11.92	1.11	0.17	0.01	0.99	3.81	3.24		0.09	0.23	0.11		100.00
		77.70	0.16	12.01	1.12	0.10	0.13	1.04	4.20	3.22			0.21		0.12	100.00

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cl	NiO	Cr_2O_3	SO_3	P_2O_5	TOTAL
Sample code	**KCh-30**	77.57	0.23	12.09	1.23	0.13		0.76	4.15	3.51		0.02	0.33	0.01		100.00
Site name or area of collection	Boundary Rock cliff site	77.59	0.21	11.93	1.29	0.12	0.03	0.79	4.10	3.48			0.26	0.06	0.15	100.00
Grid Reference	586440	78.06		12.07	1.15	0.05	0.06	0.89	3.98	3.53			0.16		0.04	100.00
Sample depth	208-218	77.68	0.11	12.12	1.29		0.27	0.85	3.79	3.62			0.24	0.03		100.00
Date collected	2/02/2005	77.92	0.18	12.25	1.02	0.16		0.81	3.73	3.55			0.15		0.23	100.00
		78.27	0.15	11.88	1.08	0.01	0.01	0.92	3.90	3.53			0.25	0.01		100.00
		78.15		11.95	1.24		0.01	0.76	4.23	3.42		0.01	0.22		0.01	100.00
		77.60	0.22	12.07	1.19	0.15	0.03	0.68	4.23	3.56			0.23	0.02		100.00
		77.90	0.09	12.26	1.14			0.84	3.66	3.71			0.27	0.11	0.03	100.00
		77.81	0.14	12.17	1.11		0.20	1.09	4.15	3.09			0.22	0.03		100.00
		77.87	0.06	12.03	1.23	0.07	0.10	0.79	4.06	3.47		0.01	0.21	0.05	0.04	100.00
		78.03	0.22	12.05	1.15		0.10	0.75	4.02	3.44	0.05		0.18			100.00
		77.87	0.19	12.46	1.18	0.12	0.19	1.08	3.86	2.83			0.19		0.04	100.00
		77.82	0.16	12.09	1.17	0.03	0.07	0.79	4.21	3.44			0.21			100.00
		77.95	0.11	12.09	0.99	0.22		0.81	3.81	3.68		0.11	0.19		0.05	100.00
		77.95	0.14	12.13	1.19	0.06	0.03	0.85	3.97	3.45			0.23			100.00
		77.72	0.18	12.08	1.15	0.11	0.09	0.72	3.57	4.16			0.18		0.04	100.00
		77.89	0.19	11.94	1.29	0.01		0.87	3.85	3.53			0.30	0.09	0.04	100.00
		77.74	0.12	12.01	1.26	0.17	0.01	0.78	4.14	3.57			0.19			100.00
		77.76	0.16	12.24	1.02	0.02	0.08	0.91	4.19	3.41			0.16		0.05	100.00

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cl	NiO	Cr_2O_3	SO_3	P_2O_5	TOTAL
Sample code	**KRS-UPL**	77.83	0.24	12.02	1.04	0.01	0.29	1.19	3.91	3.17		0.01	0.19	0.11		100.00
Site name or area of collection	Kaingaroa Slump section	77.71	0.13	12.17	1.00	0.15	0.14	0.91	3.87	3.62		0.02	0.19	0.02	0.06	100.00
Grid Reference	679788	77.83	0.09	11.98	0.97	0.04	0.12	0.83	4.07	3.85		0.08	0.15			100.00
Sample depth	100-102cm	78.08	0.27	12.11	0.97	0.09	0.12	0.77	3.72	3.76			0.12			100.00
Date collected	26/01/2005	77.77	0.35	12.13	1.01	0.09	0.01	1.11	3.92	3.40			0.20	0.01		100.00
		77.68	0.18	12.22	1.00			1.09	4.26	3.32		0.06	0.17	0.01		100.00
		77.86	0.15	12.00	1.03	0.21	0.09	0.79	3.96	3.71			0.20			100.00
		77.63	0.17	11.92	1.06	0.08	0.16	1.03	3.74	3.79			0.21		0.20	100.00
		77.72	0.16	12.06	0.95	0.16	0.17	0.73	4.13	3.69			0.22		0.01	100.00

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cl	NiO	Cr_2O_3	SO_3	P_2O_5	TOTAL
Sample code	**OwWh**	76.63	0.15	12.14	1.10	0.12	0.07	0.77	3.58	4.85	0.19	0.07	0.33			100.00
Site name or area of collection	Owenga wharf	76.84	0.33	12.16	0.75		0.14	0.82	3.51	5.02	0.01		0.31		0.10	100.00
Grid Reference	605472	76.91	0.18	12.11	0.99		0.09	0.80	3.56	4.81	0.12	0.13	0.31			100.00
Sample depth	30-131cm	77.28	0.12	11.90	0.92	0.14	0.09	0.85	3.34	4.86	0.05	0.01	0.34	0.02	0.08	100.00
Date collected	12/11/2005	76.99	0.12	12.03	0.92	0.06	0.09	0.85	3.58	4.98	0.04		0.35			100.00
		76.87	0.20	12.09	1.07	0.08	0.16	0.85	3.42	4.80	0.07		0.38		0.02	100.00
		76.84	0.25	12.00	1.07	0.08	0.09	0.89	3.61	4.72	0.06		0.34		0.03	100.00
		77.09	0.17	11.96	1.07	0.05	0.10	0.83	3.41	4.75	0.14	0.05	0.32		0.05	100.00
		76.66	0.21	12.30	1.18	0.07	0.14	0.82	3.55	4.81	0.01	0.02	0.24			100.00
		76.70	0.11	11.96	1.12	0.08	0.16	0.85	3.58	4.73	0.29		0.29	0.02	0.09	100.00
		76.65	0.16	12.15	1.18		0.15	0.89	3.39	4.89	0.06		0.31	0.01	0.16	100.00
		76.66	0.14	12.19	1.16	0.04	0.07	0.83	3.47	4.82	0.15	0.06	0.39		0.03	100.00
		76.95	0.25	12.11	0.91		0.07	0.85	3.40	5.02	0.02		0.36		0.05	100.00
		76.90	0.16	12.12	0.92	0.12	0.09	0.70	3.70	4.84			0.37		0.07	100.00
		76.62	0.21	12.05	0.97	0.06	0.17	0.83	3.59	4.85	0.18	0.06	0.28		0.14	100.00

Appendix 1B: Electron microprobe analyses of ilmenites from Rangitawa tephra and tephra-like layers on Chatham Island

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	SO_3	Cl	Cr_2O_3	NiO	TOTAL
Rangitawa Tephra		0.05	46.66	0.09	49.14	0.98	1.62						0.06	0.05		98.65
Type Section		0.15	46.80	0.07	48.84	0.97	1.73		0.01			0.05	0.01			98.63
			47.10	0.07	48.78	0.83	1.64	0.03		0.06	0.01				0.09	98.61
		0.16	46.70	0.19	48.54	0.82	1.71	0.03				0.02			0.07	98.24
		0.23	46.70	0.27	49.10	0.90	1.74	0.07	0.09	0.07	0.06		0.01		0.04	99.28
		0.18	46.27	0.19	48.75	0.87	1.66	0.05		0.05	0.03	0.03	0.04		0.19	98.31
		0.04	46.79	0.11	49.12	0.84	1.76		0.12			0.04		0.09		98.91
			47.48	0.08	47.44	0.98	1.96					0.05	0.12		0.03	98.14
			46.49	0.06	49.16	0.97	1.70	0.01	0.01			0.01	0.04	0.09		98.54
			46.80	0.07	49.36	0.79	1.69	0.04					0.07			98.82
			50.14	0.28	44.46	0.31	3.32		0.05	0.04		0.06	0.02		0.12	98.80
Local' detrital ilmenites extracted			48.89	0.27	44.27	0.54	4.76	0.08	0.06		0.01		0.01		0.11	99.00
from Te Awapatiki Shelly Sand at the		0.06	48.02	0.42	44.21	0.53	4.27					0.04	0.01	0.14		97.70
type section (GR 569536).		0.10	50.28	0.24	42.92	0.45	5.64	0.04	0.14	0.01		0.05	0.09	0.11		100.07
		0.06	50.51	0.28	42.96	0.59	4.40	0.02		0.11	0.01				0.12	99.06
		0.01	50.56		43.31	0.60	3.19			0.05	0.01			0.07		97.80
		0.11	50.53	0.08	43.86	0.65	3.04			0.01	0.02		0.02	0.01	0.01	98.34
			50.24		44.55	0.70	3.02		0.01		0.08	0.04	0.02	0.09	0.08	98.83
		0.03	48.73	0.38	44.28	0.37	3.52	0.01			0.04			0.18		97.54
			50.52	0.24	43.10	0.62	3.78	0.07	0.10		0.11			0.08		98.62
			50.81	0.26	42.79	0.60	3.80	0.20	0.30	0.01			0.02	0.11		98.90
		0.02	49.64	0.67	40.39	0.51	6.92	0.11	0.01						0.17	98.44
			49.37	0.42	41.72	0.45	5.73				0.04	0.04	0.05		0.05	97.87
		0.21	50.93	0.34	42.36	0.29	4.06		0.05	0.04	0.17	0.07	0.03	0.47	0.09	99.11
		0.07	48.20	0.65	42.01	0.47	6.21				0.09	0.02	0.02	0.09		97.83
KNOWN RANGITAWA CORRELATIVES - CHATHAM ISLAND																
Sample code:	**KRS**		48.83	0.05	48.07	1.06	1.18	0.07	0.31	0.08			0.06		0.21	99.92
Site name or area of collection:	Kaingaroa Slump	0.12	47.10	0.02	49.31	0.87	1.57			0.04	0.02	0.08	0.05	0.15	0.01	99.34
Grid reference:	679788		46.62	0.16	49.01	0.91	2.14	0.06		0.06			0.02	0.02		99.00
Sample depth:	220-230cm	0.06	48.30	0.02	47.89	1.78	1.05		0.26							99.36
Date collected:	26/01/2005		48.57		48.51	0.98	1.39	0.06		0.04				0.11		99.66
		0.03	45.69	0.01	49.97	0.89	1.76	0.07	0.20	0.08		0.05			0.09	98.84
Sample code:	**NRB**	0.06	46.43	0.01	48.61	0.95	1.49			0.02					0.02	97.59
Site name or area of collection:	North Red Bluff	0.08	46.40	0.05	48.34	0.76	1.68			0.02	0.12	0.06				97.51
Grid reference:	465620	0.12	47.86	0.05	47.14	1.11	1.18	0.07		0.03					0.02	97.58
Sample depth:	1000 -1010cm		48.19		47.88	1.30	1.41						0.04	0.03		98.85
Date collected:	28/01/2006	0.05	46.45	0.07	48.75	0.95	1.71	0.03			0.02	0.01	0.05	0.06		98.15
		0.06	46.41		49.21	0.86	1.60			0.03	0.01		0.02		0.05	98.25
		0.05	48.45	0.09	46.79	1.27	1.44						0.02	0.04	0.06	98.21
			46.38		48.14	0.88	1.84		0.21	0.01		0.06		0.13	0.03	97.68
		0.18	46.50	0.16	47.80	1.23	1.73				0.09		0.01	0.02		97.72
			46.37	0.06	48.57	0.90	1.81		0.05			0.03	0.04		0.14	97.97

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	SO_3	Cl	Cr_2O_3	NiO	TOTAL
DEVITRIFIED TEPHRA (RANGITAWA) CORRELATIVES																
Sample code:	**KCh05-7**	0.08	46.35		48.88	0.78	1.68	0.07	0.08					0.05		97.97
Site name or area of collection:	22/01/2006		46.61		48.28	1.85	1.09	0.11		0.06	0.13				0.05	98.18
Grid reference:	Kaingaroa Beach		46.40		48.82	1.59	1.09		0.01	0.01	0.07		0.07	0.01		98.07
Sample depth:	676785		46.48	0.15	47.38	0.95	1.83			0.02				0.04		96.85
Date collected:	692 -702 cm	0.05	45.57	0.07	48.66	0.87	1.74		0.08		0.08	0.11				97.23
Sample code:	**KCh05-44**		46.94	0.08	48.25	0.97	1.59		0.11		0.06	0.08	0.07	0.10	0.08	98.33
Site name or area of collection:	6/02/2005	0.01	46.21	0.11	48.92	0.90	1.90	0.05	0.24	0.03					0.02	98.39
Grid reference:	Waitangi-Tuku Road		46.54	0.01	48.34	0.86	1.72	0.11		0.02						97.60
Sample depth:	381501		46.71	0.08	48.64	0.82	1.66	0.01	0.23	0.06		0.08	0.08			98.37
Date collected:	c.1m from surface	0.02	46.05		49.01	0.81	1.63	0.11	0.15	0.05	0.04		0.01	0.10	0.02	98.00
			46.07	0.11	48.84	0.75	1.63	0.02		0.07			0.04		0.11	97.64
			46.12		48.54	1.03	1.61		0.11	0.03	0.01					97.45
		0.06	46.27	0.14	48.58	0.94	1.82	0.04	0.06	0.01				0.04		97.96
		0.08	46.95	0.05	48.33	0.84	1.69			0.02			0.04	0.05	0.01	98.06
NON-VOLCANIC 'PALE LAYERS'																
Sample code:	**KCh05-1**	0.04	51.07	0.41	42.31	0.66	4.35	0.02						0.12		98.98
Site name or area of collection:	Waitangi-Owenga Road		50.57	1.62	43.13	0.44	4.79	0.22					0.45	1.34	1.14	103.70
Grid reference:	474537	0.06	51.08	0.22	40.83	0.75	5.63			0.06	0.11	0.12	0.04			98.90
Sample depth:	c. 1m from surface	0.12	50.68	0.19	41.29	0.69	5.88			0.01	0.07	0.09	0.01			99.03
Date collected:	24/01/2005		48.83	0.64	42.92	0.35	5.39		0.05		0.05	0.15	0.03	0.05		98.46
		0.04	50.30	0.40	41.46	0.53	6.09		0.14	0.01				0.09		99.06
			51.15	0.14	41.04	0.67	5.71			0.07		0.10		0.07	0.11	99.06
Sample code:	**KCh05-2**	0.13	49.82	0.20	42.18	0.37	5.85			0.05		0.06		0.04		98.70
Site name or area of collection:	25/01/2005		50.57	0.19	43.22	0.53	4.97		0.05				0.04	0.05	0.08	99.70
Grid reference:	Radio statio cliff	0.07	52.32	0.11	40.71	0.68	5.32	0.08		0.06			0.03	0.04		99.42
Sample depth:	439544	0.04	50.24	0.24	41.13	0.57	6.97	0.04	0.33		0.02		0.01	0.18	0.04	99.81
Date collected:	c. 1.5m from surface	0.04	52.09	0.07	41.95	0.65	4.33			0.04				0.01	0.10	99.28
		0.18	50.27	0.11	42.33	0.71	4.59			0.03		0.01		0.09	0.02	98.34
		0.15	48.92	0.59	43.84	0.51	5.12			0.03	0.05		0.08	0.01		99.30
		0.14	49.14	0.47	44.07	0.50	4.87	0.06	0.09	0.01				0.06		99.41
		0.13	50.73	0.43	39.66	0.63	8.25		0.16	0.02	0.05	0.02	0.03	0.03		100.14
Sample code:	**KCh-30**	0.08	49.34	0.36	44.42	0.44	4.80		0.10		0.03		0.04	0.11	0.06	99.78
Site name or area of collection:	15/03/2004		49.97	0.46	42.53	0.40	6.04	0.01		0.08		0.05	0.04	0.03		99.61
Grid reference:	Boundary Rock cliff site	0.03	49.57	0.31	44.79	0.53	3.38	0.03				0.14	0.02	0.10	0.02	98.92
Sample depth:	586440	0.15	51.09	0.07	42.38	0.54	4.84	0.06	0.06			0.04	0.04			99.27
Date collected:	126-131cm	0.09	49.36	0.45	42.17	0.51	6.03	0.03		0.01		0.05		0.02		98.72
		0.04	49.87	0.49	41.90	0.39	6.22	0.07	0.20	0.02			0.09			99.29
		0.09	50.10	0.46	42.64	0.58	5.53			0.14			0.07	0.05	0.07	99.73

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	SO_3	Cl	Cr_2O_3	NiO	TOTAL
	KCh-30 contd.	0.01	53.26		40.37	0.50	5.15	0.03			0.14		0.02	0.01	0.07	99.56
			52.66		42.48	0.69	4.17			0.06		0.03	0.01	0.12		100.22
			53.55	0.23	40.28	0.44	5.44			0.08		0.10	0.08			100.20
Sample code:	**LCY**	0.21	45.44	0.43	46.92	0.32	4.59	0.13					0.06	0.15		98.25
Site name or area of collection:	Cape Young	0.12	46.11	0.49	47.16	0.29	4.51	0.03		0.04			0.05	0.01	0.14	98.95
Grid reference:	403836	0.22	50.70	0.26	43.58	0.83	3.91				0.02	0.01		0.02	0.03	99.58
Sample depth:	c.5m from surface	0.24	52.62	0.26	41.47	0.82	4.05	0.04	0.18	0.04	0.01		0.01	0.01		99.75
Date collected:	23/03/2004	0.10	47.31	0.96	43.39	0.50	5.79	0.29			0.10		0.03	0.04		98.51
		0.08	47.93	0.51	45.47	0.43	4.38						0.02	0.13		98.95
		0.10	41.33	0.48	52.58	0.10	2.75	0.04			0.04	0.05	0.06	0.05		97.58
		0.15	49.30	0.64	40.46	0.19	7.55	0.09					0.03	0.08	0.18	98.67
Sample code:	**MKT upper**		53.49	0.23	34.94	0.61	5.88		0.12	0.02			0.04	0.01		95.34
Site name or area of collection:	Waitangi-Tuku Road	0.06	52.31	0.18	41.88	0.43	4.31	0.03						0.04		99.24
Grid reference:	419521	0.11	46.47	1.34	45.53	0.25	5.48	0.06					0.06	0.08	0.04	99.42
Sample depth:	23-35cm	0.08	49.33	0.62	43.42	0.41	5.87		0.23	0.07	0.04		0.07	0.12		100.26
Date collected:	12/02/2005		51.88	0.06	42.94	0.69	3.54	0.03		0.03				0.12	0.04	99.33
Sample code:	**MKT lower**	0.22	49.31	0.62	40.37	0.42	6.93	0.05		0.03			0.11	0.10		98.16
Site name or area of collection:	Waitangi-Tuku Road	0.13	49.59	0.15	41.96	0.89	6.52				0.06	0.02	0.03	0.09	0.03	99.47
Grid reference:	419521	0.08	49.42	0.15	42.07	0.75	6.65	0.02	0.11	0.02	0.06	0.01	0.01			99.35
Sample depth:	74-89cm	0.16	48.96	0.78	44.88	0.45	3.97	0.05				0.15	0.05	0.11	0.01	99.57
Date collected:	12/02/2005	0.12	49.80	0.70	40.45	0.31	7.21	0.09		0.02		0.01	0.01	0.05	0.17	98.94
		0.15	48.62	0.73	42.62	0.59	5.87	0.03		0.05			0.05		0.06	98.77
			50.19	0.51	41.52	0.49	6.93		0.15	0.01	0.06			0.16	0.18	100.20
			50.60	0.52	40.28	0.30	7.31	0.06		0.02		0.06		0.09		99.24
		0.06	49.31	0.35	42.64	0.30	6.03	0.01		0.09		0.11	0.06			98.96
		0.05	49.24	0.39	41.95	0.30	6.25			0.06	0.01		0.01			98.26

APPENDIX 2

Locations where Kawakawa Tephra has been observed on Chatham Island (this work).

Location	**Grid ref** (NZTM 260, Ch. Is. Sheets 1 & 2)	**Depth**	**Surrounding seds** (above/below, where relevant)	**Sample No.** (if collected). Samples on grey have been chemically analysed.
Airbase Road	514698	20 - 27 cm	Moorland Peat	**KCh-6**
Boundary Rock cliff sequence	586440	126 - 131 cm	Maipito Fm.	**KCh29**
Faheys Pit	513557	30 - 36 cm	Maipito Fm.	**KCh25**
Henga	452653	at surface	Wharekauri Sand	**KCh14**
Kaingaroa Beach	676785	259 - 266 cm	Moorland Peat/Wharekauri Sand	**KRB**
Mairangi	391826	150 - 158 cm	Maipito Fm.	**MR12,21,22**
Mairangi cone	400822	20 - 28 cm	Moorland Peat	
Matarakau	620791	c. 50 - 55 cm	Moorland Peat	**KCh19**
North Red Bluff	465620	140 - 150 cm (pocketing)	Wharekauri Sand	**KCh28**
North Road	624785	*c.* 80 - 85 cm	Moorland Peat/Wharekauri Sand	
Lake Kaingarahu	596700	*c.* 45 - 70 cm	Soil	
Paua cove	391821	290 - 300 cm	Maipito Fm.	**PC 290-200cm**
Port Hutt rubbish dump	*c.* 321721	*c.* 50 - 60 cm	Moorland Peat	
Radio station cliff sequence	439544	*c.* 0.5 m from surface	Maipito Fm.	**KCh-1**
Southern Hanson Bay coastline	570534	500 - 510 cm	Moorland Peat	**KCh33**
South Mairangi	392811	50 - 60 cm	Maipito Fm.	**SMKK**
South of Paua cove	391820	85 - 90 cm	Maipito Fm.	**Mairangi SSB**
South of Paua cove	392818	*c.* 100 - 110 cm	Maipito Fm.	**MrSw**
South-west coast (lowland)	361473	25 - 38 cm	Maipito Fm.	**KCh05-43**
South-west coast (upland)	*c.* 386442	*c.* 80 - 86 cm	Moorland Peat	
Stony Crossing	382721	51 - 61 cm	Moorland Peat	**KCh-9**
The crossing/Moutapu Point	518696	at surface	Moorland Peat	
Waitangi Beach	451553	101 - 112 cm	Maipito Fm.	**WB**
Waitangi-Owenga Road	472542	*c.* 105 - 114 cm	Maipito Fm.	**OwRd 1**
Waitangi West	198682	*c.* 20 - 24 cm	Moorland Peat	**KCh05-12**
Waitangi West Road (SE of Maunganui Bluff)	298752	*c.* 50 - 60 cm	Moorland Peat/Wharekauri Sand	
Waitangi West Road (SW of Maunganui Bluff)	267741	70 - 75 cm	Moorland Peat/Wharekauri Sand	
Wharekauri-Kaingaroa turnoff quarry	452787	0-100 cm	Moorland Peat	**WQ**

APPENDIX 3

Raw grain-size data of Kawakawa and Rangitawa Tephras

	Kawakawa Tephra (sample **MR12**)	Rangitawa Tephra (sample **KRS**)
Initial sample weight (g)	155.56	156.74
Grain size		
>180μm		
125 - 180 μm	0.24	1.19
90 - 125 μm	3.2	7.24
63 - 90 μm	13.23	17.14
45 - 63 μm	17.56	25.73
32 - 45 μm	75.14	67.55
<32μm	43.78	36.38
Total (g)	153.15	155.23
loss on sieve	2.41	1.51

APPENDIX 4

Heavy mineral point counts of tephras and 'pale layers' from Chatham Island.

All performed on grain mounts of 63-125 micron fraction of minerals with specific gravity >3.

4A: Kawakawa Tephra correlatives

4B: Rangitawa Tephra correlatives

4C: ‘Pale layers’

Appendix 4A: Kawakawa Tephra correlatives (opx = orthopyroxene, hbl = hornblende, opaque = magnetite, ilmenite etc, mica = biotite/phlogopite).

		Mineral					
		opx	hbl	opaque	zircon	mica	**Total**
Sample							
Sample code:	**KCh-9**	254	34	27	1		316
Site name or area of collection:	Stony Crossing						
Grid reference:	382721						
Sample depth	51-61cm						
Date collected:	10/03/2004						
Sample code:	**KCh-28**	249	39	19	7		314
Site name or area of collection:	North Red Bluff						
Grid reference:	465620						
Sample depth	140 150 cm (pocketing)						
Date collected:	14/03/2004						
Sample code:	**KCh-29**	261	45	29	3		338
Site name or area of collection:	Boundary Rock cliff site						
Grid reference:	586440						
Sample depth	126-131cm						
Date collected:	15/03/2004						
Sample code:	**KCh-33**	231	40	15	5	1	292
Site name or area of collection:	Owenga Coast						
Grid reference:	570534						
Sample depth	500-510cm						
Date collected:	15/03/2004						
Sample code:	**KCh-14**	232	40	23	3		298
Site name or area of collection:	Henga						
Grid reference:	452653						
Sample depth	n/a						
Date collected:	11/03/2004						
Sample code:	**KCh05-43**	252	51	27	8		338
Site name or area of collection:	south coast						
Grid reference:	361473						
Sample depth	25-38cm						
Date collected:	6/02/2005						
Sample code:	**Mairangi SSB**	201	54	39	7		301
Site name or area of collection:	south of Paua cove						
Grid reference:	392819						
Sample depth	85 - 90 cm						
Date collected:	2/02/2006						
Sample code:	**MR 12**	180	59	61	4		304
Site name or area of collection:	Mairangi						
Grid reference:	391826						
Sample depth	150-158cm						
Date collected:	11/02/2005						
Sample code:	**MR 21**	214	37	18	4		273
Site name or area of collection:	Mairangi						
Grid reference:	392825						
Sample depth	n/a						
Date collected:	11/02/2005						
Sample code:	**MR 22**	220	33	15	4		272
Site name or area of collection:	Mairangi						
Grid reference:	392825						
Sample depth	n/a						
Date collected:	11/02/2005						
Sample code:	**MRsw**	197	50	43	3		293
Site name or area of collection:	south of Paua cove						
Grid reference:	392818						
Sample depth	c. 1m						
Date collected:	2/02/2006						

		Mineral					
		opx	hbl	opaque	zircon	mica	**Total**
Sample							
Sample code:	**PC 290-300 cm**	224	61	29	6		320
Site name or area of collection:	Paua cove						
Grid reference:	391821						
Sample depth	290-300cm						
Date collected:	31/01/2006						
Sample code:	**SMKK**	220	61	34	6		321
Site name or area of collection:	South Mairangi						
Grid reference:	392811						
Sample depth	54-58cm						
Date collected:	5/02/2005						
Sample code:	**WB**	220	40	50	1		311
Site name or area of collection:	Waitangi Beach						
Grid reference:	451553						
Sample depth	c 1.2m above wave-cut surface						
Date collected:	28/01/2006						
Sample code:	**WQ**	235	44	25	4		308
Site name or area of collection:	Wharekauri-Kaingaroa turnoff quarry						
Grid reference:	452787						
Sample depth	100-110cm						
Date collected:	22/03/2004						

Appendix 4B: Rangitawa Tephra correlatives
(opx = orthopyroxene, hbl = hornblende, opaque = magnetite, ilmenite etc, mica = biotite/phlogopite).

		Mineral					
		opx	hbl	opaque	zircon	mica	**Total**
Sample							
Sample code:	**UCY**	124	33	52	16	3	228
Site name or area of collection:	Cape Young						
Grid reference:	403836						
Sample depth	c. 1m from surface						
Date collected:	23/03/2004						
Sample code:	**KCh15**	156	63	61	27	2	309
Site name or area of collection:	Matarakau						
Grid reference:	623791						
Sample depth	138-149cm						
Date collected:	12/03/2004						
Sample code:	**MR9**	119	51	92	16	12	290
Site name or area of collection:	Mairangi						
Grid reference:	391826						
Sample depth	390-400cm						
Date collected:	11/02/2005						
Sample code:	**KRS**	129	142	103	29	27	430
Site name or area of collection:	Kaingaroa Slump						
Grid reference:	679788						
Sample depth	220 - 230 cm						
Date collected:	26/01/2005						
Sample code:	**KCh05-7**	26	45	242	10	1	324
Site name or area of collection:	Kaingaroa Beach						
Grid reference:	676785						
Sample depth	692 -702 cm						
Date collected:	22/01/2006						
Sample code:	**NRB**	157	65	91	7	4	324
Site name or area of collection:	North Red Bluff						
Grid reference:	465620						
Sample depth	1000 -1010cm						
Date collected:	28/01/2006						
Sample code:	**MRO**	128	104	73	5	7	317
Site name or area of collection:	South Mairangi						
Grid reference:	392811						
Sample depth	256-286cm						
Date collected:	5/02/2005						
Sample code:	**KCh05-44**	19	12	168	51		250
Site name or area of collection:	Waitangi-Tuku Road						
Grid reference:	381501						
Sample depth	c. 1m from surface						
Date collected:	6/02/2005						

Appendix 4C: Tephra-like layers
(opx = orthopyroxene, hbl = hornblende, opaque = magnetite, ilmenite etc, mica = biotite/phlogopite).

				Mineral			
		opx	hbl	opaque	zircon	mica	TOTAL
Sample							
Sample code:	**KCh05-1**			100			100
Site name or area of collection:	Waitangi-Owenga Road						
Grid reference:	474537						
Sample depth	c.1 m from surface						
Date collected:	24/01/2005						
Sample code:	**KCh05-2**			100			100
Site name or area of collection:	Radio station cliff section						
Grid reference:	439544						
Sample depth	c. 1.5 m from surface						
Date collected:	25/01/2005						
Sample code:	**KCh05-30**		19	181			200
Site name or area of collection:	Boundary Rock cliff site						
Grid reference:	586440						
Sample depth	208 - 218 cm						
Date collected:	2/02/2005						
Sample code:	**LCY**	12		175	45		232
Site name or area of collection:	Cape Young						
Grid reference:	403836						
Sample depth	c. 1 m from surface						
Date collected:	23/0/2004						
Sample code:	**MKTU**	9		188	39		236
Site name or area of collection:	Matakatau						
Grid reference:	419521						
Sample depth	23 - 35 cm						
Date collected:	12/02/2005						
Sample code:	**MKTL**	4		195	44		243
Site name or area of collection:	Matakatau						
Grid reference:	419521						
Sample depth	74 - 89 cm						
Date collected:	12/02/2005						
Sample code:	**OwWh**	16	9	176	35	3	239
Site name or area of collection:	Owenga wharf						
Grid reference:	605472						
Sample depth	130-200 cm						
Date collected:	12/02/2005						

APPENDIX 5

Zircon fission track data from tephra at the North Red Bluff Quaternary sequence, Chatham Island.

Sample	Lithology	Mineral	No. of grains	Standard track density (x10^5 cm^{-2})	Fossil track density (x$10^5$$cm^{-2}$)	Induced track density (x$10^6$$cm^{-2}$)	Uranium content (ppm)	Chi -square probability %	Age dispersion %	*Fission track age, ka (± 1 σ)
NRB	Rhyolitic tephra	zircon	42	3.480 (2877)	0.536 (59)	3.340 (3677)	374	49.4	18.04	350 ± 50

Brackets show number of tracks counted or measured. Standard and induced track densities measured on external mica detectors (g= 0.5) and fossil track densities on internal mica surfaces.

**Central age.*

Age determined at Fission Track Geochronometrey Lab, Earth Science Department, University of Melbourne, by A. Raza, calculated using zeta = 125 ± 3 for dosimeter glass Corning-1.

APPENDIX 6

Raw pollen counts

6A: Wharekauri-Kaingaroa turnoff quarry

6B: Stony Crossing basalt quarry

6C: Kaingaroa Slump section

6D: Kaingaroa Beach section

6E: Mairangi section

6F: Boundary Rock cliff section

6G: North Red Bluff

6A

Site name: Wharekauri-Kaingaroa turn-off quarry Grid reference: 452787

Depth (cm)	0-1	9-10	19-20	29-30	39-40	49-50	59-60	69-70	79-80	89-90	99-100	109-110	119-120	129-130
Taxa														
Poaceae	50	33	9	74	24	5	5	3	2	3	6	2	2	7
Small trees and shrubs														
Apiaceae	1	3		1	2	1	4	2	1	2	4	1	2	2
Asteraceae														
-*Olearia travesii*			2	5	4									
-*Olearia semidentata*	101	164	58	136	183	13	38	58	84	51	103	62	156	154
-other	34	6		25								3	9	
Coprosma	47	14	8	16	31	23	30	37	43	34	68	35	41	20
Epacridaceae	143	61	131	91	83	161	209	209	213	231	462	186	132	169
Melicytus				1	1		1		1	1	12	1	1	2
Myrsine	9	2	4	4	5	15	6	5	3	8	16	12	6	12
Palmae										1	2			
Plagianthus	6	1	2	1	7	3	2	2	3	2	4	2	2	1
Pseudopanax chathamicus		1	2	2	1	2	1	6	2	3	7	2	3	1
Herbs														
Astelia chathamica									7			2	4	
Gentiana chathamica		2	2	2									1	
Pteridophytes														
Cyathea	6	2	4	5	12	5			2			20	1	2
Dicksonia		5	13				9	2	1				1	1
Hymenophyllum			1	1		1	1	2	2	1	2		1	
Lycopodiales		9	11	4	3	17						5	1	2
Microsorum pustulatum	4								1	1	2		1	1
monolete fern spores - textured	3					6	7			1	2		3	
monolete fern spores - psilate	5	4	5		2	8	8	9	2	10	20	2	2	6
other trilete fern spores	30	23	28	8	14	69	27	19	20	17	31	14	8	26
Pteris		1			1		1	2	3		4	4	1	1
Wetland														
Cyperaceae	6					7							5	
Gleichenia dicarpa	255	108	160	58	67	120	76	61	28	26	52	71	24	25
Haloragaceae										2	4			
Restionaceae	165	213	57	243	72	995	108	56	17	35	70	10	14	6
Long distance														
Dacrydium cupressinum		2		1		17	7	1	2	1	2	6		
Dodonea viscosa						2								
Nothofagus (Fuscospora)	9	6	6	6	2	53	18	6	16	14	28	2	8	7
Phyllocladus	12	2		2		8			4	2	4			
Podocarpus/*Prumnopitys*	27	2	4	1	4	23	8	4	7	2	4	8	18	10
Charcoal fragments														
small		116		90										
medium		28		34										
large				12										

6B

Site Name: Stony Crossing	Grid reference: 382721															
Depth (cm)	**0-1**	**24-25**	**49-50**	**64-65**	**89-90**	**134-135**	**144-145**	**160-161**	**180-181**	**194-195**	**214-215**	**229-230**	**249-250**	**284-285**	**319-320**	**354-355**
Taxa																
Poaceae	17	27	39	17	31	11		23	11	4	7	16	29	21	9	3
Small trees and shrubs																
Apiaceae	2	1	2	1	1	2		2	1	2						6
Asteraceae																
-*Olearia semidentata*	43	85	67	62	75	59	80	43	58	37	24	44	21	14		1
-*Olearia travesii*									1							1
-other	2	6	10	9	6	4	13		4	5		7	12	9	6	12
Coprosma	2	5	2	19	20	25	5	26	15	16	8	23	24	32	47	27
Epacridaceae	142	140	150	149	143	122	92	143	124	141	142	147	123	177	114	176
Hebe					3						5					2
Melicytus chathamicus	1	1					1	1	1		1		1	3	9	6
Myrsine	2	3	7	24	20	29	6	11	14	17	21	21	58	62	89	46
Palmae								2								21
Plagianthus	1	1	4	2	3			5	1		1			5		1
Pseudopanax chathamicus	2	3	1	1	5		2	1	2	6	1		2	10	1	2
Herbs																
Astelia chathamica									1				4	5	2	2
Chenopodiaceae									1							
Gentiana chathamica									1							
Pteridophytes																
Cyathea	2	4	4	4	8	12		6	7	18	1	23	41	33	56	49
Dicksonia	43	11	1	13	3	25	2	16	31	6	2	13	20	20	17	21
Hymenophyllum		4		1	2				2	2		3		2		2
Lycopodiales	13	13				3			1	4		3				4
Microsorum putsulatum		2		1	3	5	3		2	13	3	7	5	9	11	15
monolete fern spore - textured	14	28	37	24	12	28	6	31		23	2	26	26	32	10	
monolete fern spores - psilate	2	5	7	5	8	2	3	7	4	1	1		11	15	15	12
other trilete fern spores	9	4	1	16	27		26	9	23	6	9	16	5	4	19	7
Pteridium	84	42				2		2	1							
Pteris	3	1	6	7	39	2			2	5	4		10	16	2	2
Wetland																
Gleichenia dicarpa	108	68	62	53	135	98	202	126	140	107	253	141	47	60	53	63
Cyperaceae	8		14		11	14		2	2	7	3		8	2	2	
Haloragaceae					3			4		5				2	2	
Restionaceae	43	59	120	23	51	34	23	25	26	48	20	63	40	9	12	12
Long distance																
Dacrydium cupressinum		3	2	2	2											
Halocarpus														2		
Nothofagus (fuscospora)		7	6		6		2	2	2			5	2	6	4	2
Metrosiderous			1													
Podocarpus/Prumnopitys	5	17	11	7	9	23	2	8	18	4	7	12			2	
Charcoal fragments																
small	77	26	4		5			5	14	4		5	2			
medium	96	68	18	9	12	3	6	8	4	18	4	21	11		4	2
large	89	67	3	12	11	18	4	10	12	9	2	9	9	6	4	4

6C

Site name: Kaingaroa Slump section **Location:** Kaingaroa **Grid reference:** 679788

Depth (cm)	0-1	10-11	20-21	30-31	40-41	50-51	60-61	70-71	80-81	90-91	100-101	200-201	204-205	208-209	239-240
Taxa															
Poaceae	2					1					1	30	16		15
Small trees and shrubs															
Apiaceae	3	3	5		3	4	3	11	3	5	4				6
Asteraceae															
- *Olearia semidentata*	110	108					8					22	60	36	
-*Olearia travesii*	24			31	7	4	4	4	4	2	4				
other		28	3	36	25	97		47	21	11	37				
Coprosma	82	112	70	107	120	159	76	134	171	247	28	13	12	20	16
Epacridaceae	214	140	93	114	141	45	50	115	75	29	4	76	47	87	215
Melicytus chathamicus	1	3	4	4	19	10	20	6	2	10		1			3
Myrsine	5	12	40	17	24	14	222	29	24	12		2		6	21
Plagianthus				2	4	15	3	2	3	2					3
Pseudopanax chathamica	3	2	5	7	11		6	2	3	7	14	2			4
Herbs															
Astelia chathamica	2	1	2			4				0					
Pteridophytes															
Cyathea		6	40	17	104	314	120	14	6	8	5	22	4	4	13
Dicksonia		4	225	123	487	123	87	40	28	26	4			8	6
Lycopodiales								2	1	1		3		15	3
Microsorum pustulatum					7	29	3		1	2					
monolete - textured		1			4	52	2	4	2	8	292		23	1	99
monolete - psilate		1	90	14	44	33	7	19	1	2	60				8
other trilete ferns spores			5	10	17			4	2	4	7	354	320	298	41
Wetland															
Cyperaceae															5
Gleichenia		3				3	2	8	7	34	3	14	48	39	153
Haloragaceae								2		16	3				
Restionaceae	16	1		6	8			2	2	6			24	25	330
Long distance															
Dacrydium cupressinum	2		6	4	6			6	4	2	4				
Nothofagus		3										2	2		3
Phyllocladus	1					6									
Podocarpus/Prumnopitys	1	3	3	4	8	2	2	2	4	8	6		1		26
Charcoal fragments															
small															1443
medium															891
large															202

6C contd.

Site name: Kaingaroa Slump section contd.															
Depth (cm)	**249-250**	**259-260**	**286-287**	**306-307**	**326-327**	**346-347**	**366-367**	**386-387**	**406-407**	**416-417**	**447-448**	**467-468**	**487-488**	**507-508**	**517-518**
Taxa															
Poaceae	27	6						3	3	7	9	11	29	7	9
Small trees and shrubs															
Apiaceae	13	1	1		6		10				2	3	2	4	2
Asteraceae															
- *Olearia semidentata*		8	6		5	7		8	3	3	30	34	22	9	3
-*Olearia travesii*							7				2	7	0	2	
other															6
Coprosma	6	119	13		33	197	87	165	129	16	14	11	11	13	57
Epacridaceae	232	20	132		211	8	13	17	55	186	128	102	144	90	80
Melicytus chathamicus	8	10	4		13	14		5	3			1	1	2	2
Myrsine	17	67	153		17	37	120	65	35	8	33	43	39	123	111
Plagianthus	3	4	2			6	4		6	6	6	5	11	3	4
Pseudopanax chathamic	4	26	7		16	49		8	6			1	1	1	1
Herbs															
Astelia chathamica	0		19		6	12	8	3	6	9	4	3	6	6	24
Pteridophytes															
Cyathea	8	103	12			8		4	27	54			8	2	2
Dicksonia	33	217				24				7			13	6	63
Lycopodiales	1										4	3	4		
Microsorum pustulatum	4	12				29			13				6	20	18
monolete - textured		14			8				30	16	2	2	5	2	
monolete - psilate	1	34	15		30	428	491	204	219	171	2	2	6	7	33
other trilete ferns spores	1	8			7					86	4	10	4	20	4
Wetland															
Cyperaceae													4	2	
Gleichenia	472	108							15	6	16	12	122	125	59
Haloragaceae										6	2	2	4		
Restionaceae	676	111				4			4	20	46	53	33	34	
Long distance															
Dacrydium cupressinum		3			6				3						
Nothofagus			5			13		3	2			4	4		
Phyllocladus		8				11	1		2				2		
Podocarpus/Prumnopity	23	27	26		26	148	516	68	57	15				2	4
Charcoal fragments															
small	681	189							11	1360	103	109			
medium	522	60							20	722	73	64	3		
large	123	25							2	141	4	9			

6D

Site name: Kaingaroa beach section Grid reference: 676785

Depth (cm)	255-256	269-270	382-383	392-393	396-397	400-401	405-406	675-676	680-681	684-685	699-700	702-703
Taxa												
Poaceae	163	95	54	27	14	8	9	11	21	23	63	140
Small trees and shrubs												
Apiaceae						4						
Asteraceae												33
-*Olearia semidentata*	51	81	127	155	182	145	181		19	44	147	
-*Olearia travesii*			5									
-other	6		6	21	8		11	51		4		
Coprosma	7	8	67	8	9	21	3	15	41		38	5
Epacridaceae	15	21	8	7	2	32	6	52	14	57	93	39
Myrsine	2	3	6	3	1	13	2				4	
Melicytus chathamicus					1							
Plagianthus					1		1					
Pseudopanax chathamicus					1							
Herbs												
Astelia chathamica											4	
Gentiana chathamica												3
Pteridophytes												
Cyathea		1	19	2				356	184	95	5	
Dicksonia						1		5	1	24		
Hymenophyllum									3			
Lycopodiales	3	1		2				32		56		
Microsorum pustulatum	1	3				3						
monolete - textured	1	1	81					23				
monolete - psilate			56	3	1	5		12	8	12		1
other trilete fern spores				3				167	2	199	15	
Pteris										32		
Wetland												
Gleichenia dicarpa	2	10	42	25	4	4			1	56	47	
Restionaceae				10		19	10	20				
Long distance												
Nothofagus (fuscospora)	3	2	5	6	2	3	4	5	2	2	4	1
Phyllocladus								3				2
Podocarpus/Prumnopitys							1		1	1	2	

6E

Site name: Mairangi Grid reference: 391826

Depth (cm)	162-167	380-390	400-405	425-435	455-456	469-470	484-485	499-500	515-516
Taxa									
Poaceae	20	152	110	12	55	66	152	112	88
Small trees and shrubs									
Apiaceae		6		9	1	3	2	3	2
Asteraceae									
-*Olearia travesii*	10		11	4	3	4	6	4	5
-*Olearia semidentata*	134	76	87		38	10	16	13	60
-other	12	33			27			4	53
Coprosma	12	5		61	27	6	2	22	45
Epacridaceae	206	9	27	116	22	103	59	89	36
Hebe				2	2	2		1	2
Melicytus		1							
Myrsine	4	4	25	79	15	18	22	32	27
Palmae				10					
Plagianthus		16	2	3	3	8	2	7	
Pseudopanax chathamicus		1	1	2	3		1	2	3
Herbs									
Astelia chathamica		3							
Gentiana chathamica							10	6	
Pteridophytes									
Cyathea					18				32
Dicksonia		8	19	28	19	7	2	2	29
Hymenophyllum		1		2		2	1	4	
Lycopodiales		1				2	14		
Microsorum pustulatum		24					28	9	
monolete fern spores - textured		6		2	25	14			27
monolete fern spores - psilate		7	5	6		3	6	11	
other trilete fern spores	8	32		8	15	4	12	12	24
Pteris		2			1	1	2	2	
Wetland									
Cyperaceae					3			24	4
Gleichenia dicarpa	16	1397	1998	33	222	180	87	92	299
Restionaceae	54	264	484	42	147	172	90	151	388
Long distance									
Ascarina lucida				2					
Dacrydium cupressinum	2			2					
Nothofagus (Fuscospora)	4	8		8			4		
Phyllocladus							2		
Podocarpus/*Prumnopitys*	2			65	15	4		4	19
Charcoal fragments									
small	2		231						
medium	2	40	225				6	6	
large		16	11						

6F

Site name: Boundary Rock cliff section — Grid reference: 586440

Depth (cm)	155-156	161-162	168-169	194-195	202-203	207-208	218-219	229-230	239-240	268-269	278-279	288-289	298-299
Taxa													
Poaceae	23	4	5	8	2	2		7	59	11	57	7	
Small trees and shrubs													
Apiaceae		2	1		3	5		3	1			1	3
Asteraceae													
-*Olearia travesii*		3		5		3				3	3	1	
-*Olearia semidentata*	80	75	63	120	35	48			7	42		5	3
-other	12		3				63	45	70		9	21	2
Coprosma	5	20	13	37	73	60	45	30	25	22	25	28	45
Epacridaceae	122	161	158	59	135	113	98	149	57	143	153	161	133
Melicytus	1	1		1				1	1		3	3	5
Myrsine	5	4	10	3	11	3	9	7	7	7	3	7	20
Palmae	2												
Plagianthus	2	5	3	3	1	5	2	3	4	2	2	1	4
Pseudopanax chathamicus	4	5	2	2	5	1	1	1	1	3	1	2	1
Herbs													
Astelia chathamica		3	3	4	1	5	7		1				
Chenopodiaceae			5		1				1		1	1	
Gentiana chathamica			1		1				5	7		1	
Pteridophytes													
Cyathea	2	1	1	1	2		45	20	6	1	1	42	59
Dicksonia	2	5	3	2	1	2	161	30	25	4	3	49	4
Hymenophyllum	1			1	3	7		1			3		1
Lycopodiales	3	4	1	3	3				1		3	6	
Microsorum pustulatum	3		1	1	1	2		23	10	3	3	6	15
monolete fern spore - textured		3	1	1	1			7			1	7	33
monolete fern spores - psilate	5	2	5	23	22	14	27			3	3		2
other trilete fern spores			1	1	1	2			13		1	7	15
Pteris	1	1	1	1	1				1		1		
Wetland													
Cyperaceae		1			1				5				
Gleichenia dicarpa	3	1	3	3	1		399	577	299	9	39	357	199
Haloragaceae					1				5				
Restionaceae			3		6		18		5		422		5
Long distance													
Dacrydium cupressinum		1											
Nothofagus (Fuscospora)	3			2		7					3		
Phyllocladus	2			3							3		
Podocarpus/Prumnopitys	2			5	3	6	17						9
Charcoal fragments													
small										33	168		
medium										11	70		
large										18	72		

6F contd.

Site name: Boundary Rock cliff section contd.

Depth	308-309	318-319	323-324	330-331	337-338	338-339	342-343	358-359	368-369	378-379	388-389	398-399	403-404
Taxa													
Poaceae	4	3	15		17	13	23	32	23	11	7	71	21
Small trees and shrubs													
Apiaceae	3	39	0						14				4
Asteraceae			26	9								26	
-*Olearia travesii*		6								5			
-*Olearia semidentata*	24	45			28					21			
-other	6				20	15	39	63	31		23		21
Coprosma	17	23	25	63	17	32	56	54	38	51	25	19	53
Epacridaceae	32	127	151	135	176	130	120	127	145	123	197	108	145
Melicytus	1			18							8		
Myrsine	25	9	10	27		26	17			30		24	11
Palmae													
Plagianthus	16							10	7				
Pseudopanax chathamicus	1												
Herbs													
Astelia chathamica	1						7		7				
Chenopodiaceae	2												
Gentiana chathamica							7		6	8			
Pteridophytes													
Cyathea	2	3	4		18	13	24	9	9	10	39	2	9
Dicksonia	8		24	89	86	76	56	65	98	49	77	23	19
Hymenophyllum	43		5	9	8				12		7		
Lycopodiales	16			8	7			9	0		14		
Microsorum pustulatum			46	79	59	89	33	99	25	43	38	11	
monolete fern spore - textured		6											
monolete fern spores - psilate		6	5		24	7		21	51		30	12	4
other trilete fern spores		15	5	27		20	9		39	10		5	
Pteris						17				3			
Wetland													
Cyperaceae													
Gleichenia dicarpa	577	31	192	396	392	299	432	498	382	175	399	324	84
Haloragaceae													
Restionaceae	176	192	39	36		45		160	112		79	21	15
Long distance													
Dacrydium cupressinum						7							
Nothofagus (Fuscospora)			5								13		
Phyllocladus			3									5	
Podocarpus/*Prumnopitys*			1	15				18	7			11	3
Charcoal fragments													
small													
medium													
large													

6G

Site name: North Red Bluff		Grid reference: 465620		
Depth (cm)		**209-210cm**	**216-217cm**	**223-224cm**
Taxa				
Poaceae		7	3	3
Small trees and shrubs				
Apiaceae			2	
Asteraceae				
-*Olearia semidentata*		21	38	6
-*Olearia travesii*		305	187	121
-other		10	11	3
Coprosma		6	130	43
Epacridaceae		61	68	60
Myrsine		2	23	25
Palmae				6
Plagianthus				3
Herbs				
Astelia chathamica			2	
Pteridophytes				
Dicksonia				16
Lycopodiales		2		
Microsorum pustulatum				276
monolete fern spore - textured				23
monolete fern spores - psilate		8	8	36
other trilete fern spores				3
Wetland				
Gleichenia dicarpa				
Haloragaceae		2		
Restionaceae		8		
Long distance				
Nothofagus (Fuscospora)		8	4	3
Phyllocladus		4		
Podocarpus / Prumnopitys				3
Specific Long distance				
Nothofagus			79	
Podocarpus/Prumnopitys			3	
Phyllocladus			4	
Halocarpus			4	
Casuarina			1	

APPENDIX 7

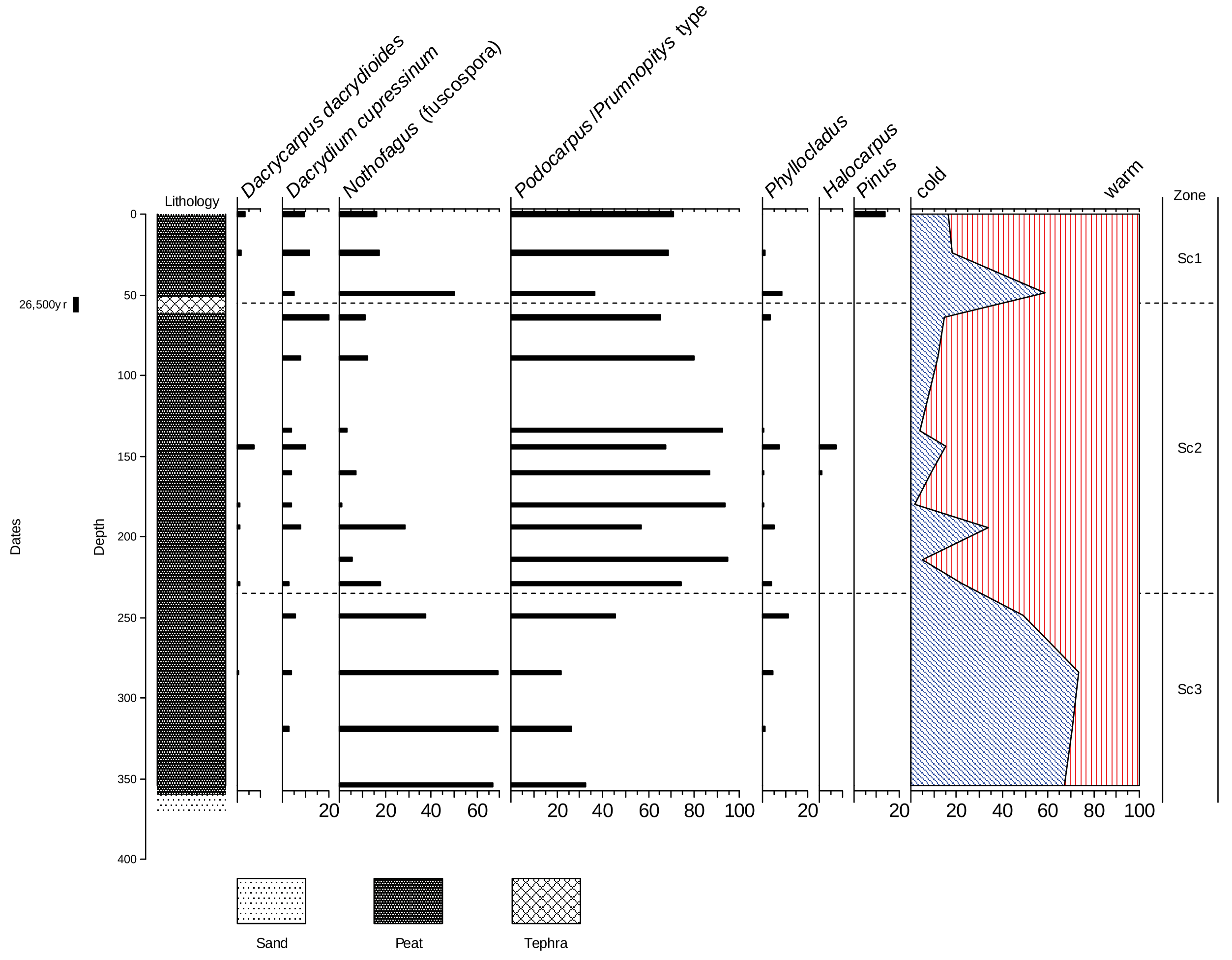
Specific long distance pollen counts

7A: Stony Crossing basalt quarry
Relative pollen diagram
Ratio of warm elements to cold elements
Raw count data

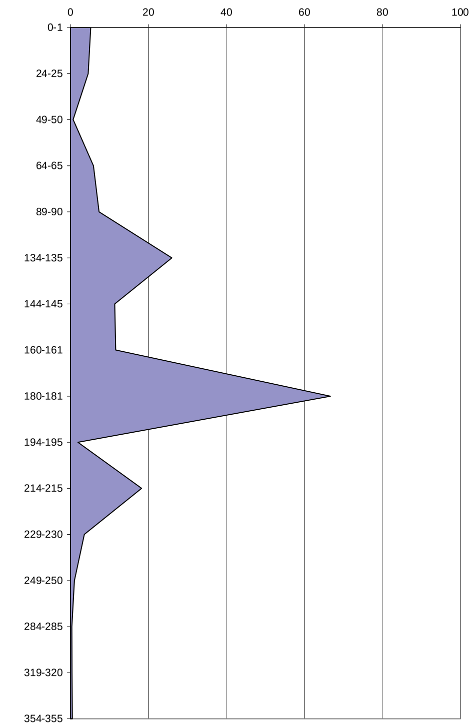
7B: Boundary Rock cliff section
Relative pollen diagram
Ratio of warm elements to cold elements
Raw count data

Appendix 7A: Stony Crossing

Stony Crossing specific long distance pollen count



Ratio of warm elements (Podocarps) to cold elements (*Nothfagus*, *Halocarpus* & *Phyllocldus*).



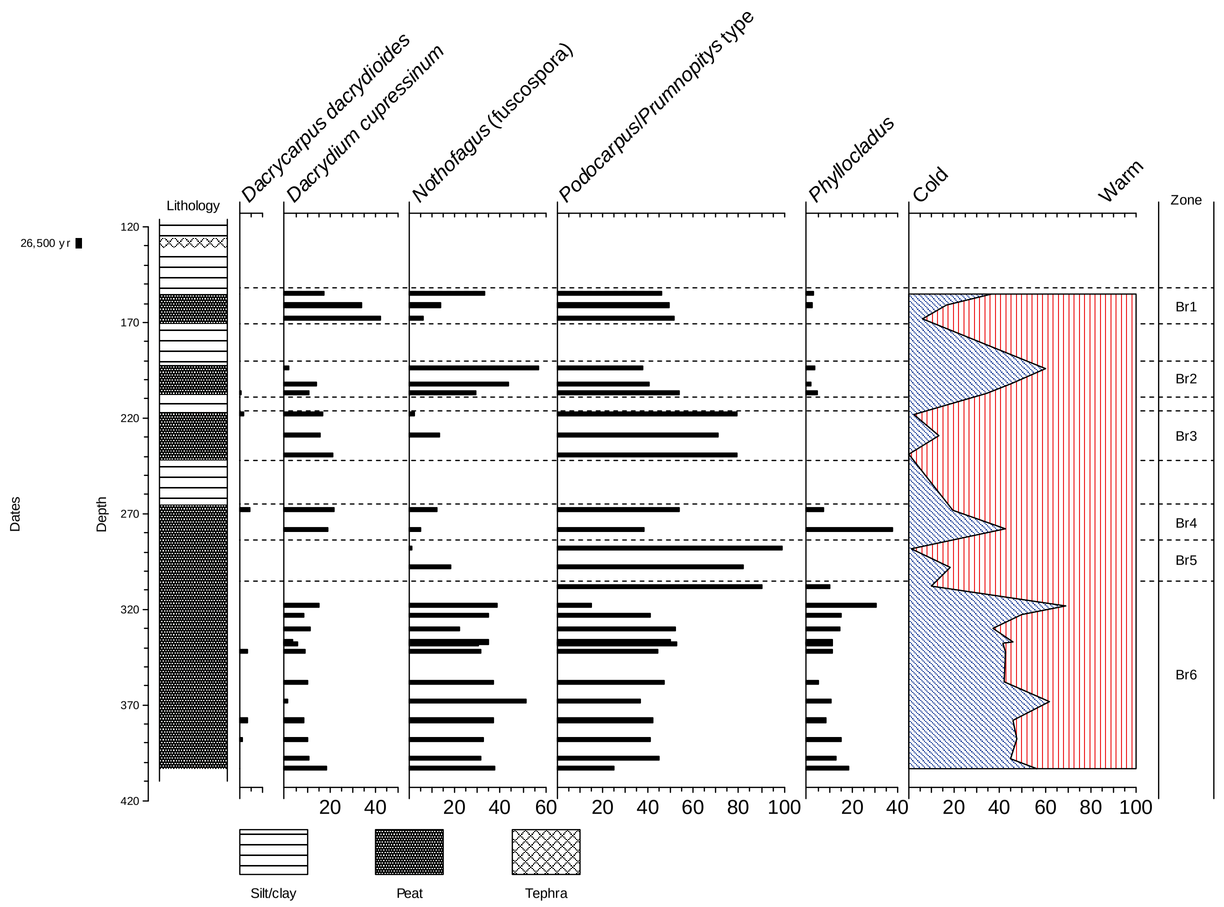
Specific long-distance pollen count

Site name: Stony Crossing **Grid reference**: 382721

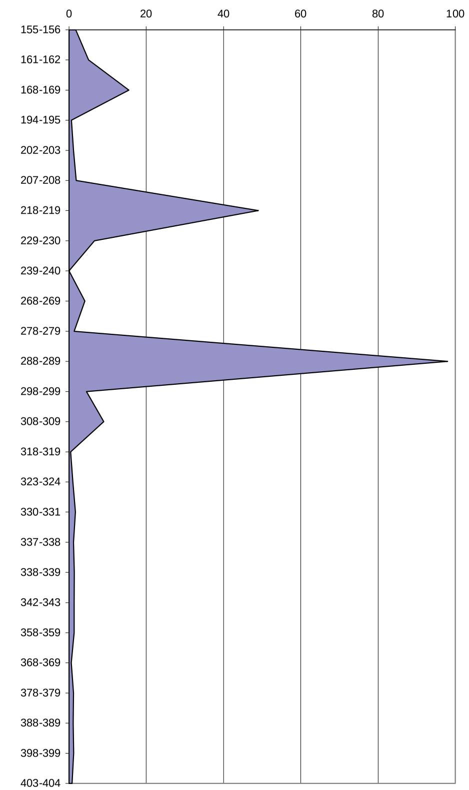
Depth (cm)	**0-1**	**24-25**	**49-50**	**64-65**	**89-90**	**134-135**	**144-145**	**160-161**	**180-181**	**194-195**	**214-215**	**229-230**
Taxa												
Dacrycarpus dacrydioides	1	3					3		2	2		2
Dacrydium cupressinum	3	24	5	18	8	10	4	15	8	12		5
Nothofagus (Fuscospora)	5	34	51	10	12	7		26	2	43	8	36
Podocarpus /Prumnopitys type	22	137	37	59	80	224	27	321	190	85	146	150
Phyllocladus		2	9	3		2	3	3	1	8		8
Halocarpus							3	4				
Pinus	5											
TOTAL	36	200	102	90	100	243	40	369	203	150	154	201

Appendix 7B: Boundary Rock cliff site

Boundary Rock cliff site specific long distance pollen count



Ratio of warm elements (Podocarps) to cold elements (*Nothofagus, Halocarpus* & *Phyllocladus*).



Specific long-distance pollen count

Site name: Boundary Rock cliff site **Grid reference:** 586440

Depth (cm)	155-156	161-162	168-169	194-195	202-203	207-208	218-219	229-230	239-240	268-269	278-279	288-289	298-299
Taxa													
Dacrycarpus dacrydioides						1	2			2			
Dacrydium cupressinum	11	25	14	1	14	11	17	6	4	9	4		
Nothofagus (fuscospora)	21	10	2	33	44	30	2	5		5	1	1	2
Podocarpus /*Prumnopitys* type	29	36	17	22	41	55	79	27	15	22	8	98	9
Phyllocladus	2	2		2	2	5				3	8		
TOTAL	63	73	33	58	101	102	100	38	19	41	21	99	11

Depth (cm)	308-309	318-319	323-324	330-331	337-338	338-339	342-343	358-359	368-369	378-379	388-389	398-399	403-404
Taxa													
Dacrycarpus dacrydioides							2			2	1		
Dacrydium cupressinum	0	2	7	6	2	3	5	10	1	5	8	4	3
Nothofagus (fuscospora)		5	28	12	18	16	17	36	43	22	26	12	6
Podocarpus /*Prumnopitys* type	9	2	33	28	26	28	24	46	31	25	33	17	4
Phyllocladus	1	4	12	8	6	6	6	5	9	5	12	5	3
TOTAL	10	13	80	54	52	53	54	97	84	59	80	38	16

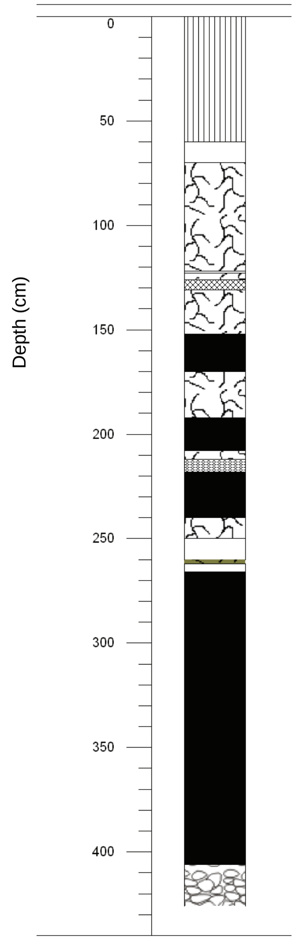
APPENDIX 8

Descriptions of stratigraphic sections and simplified stratigraphic columns

Codes in **bold** within brackets refer to tephra samples collected

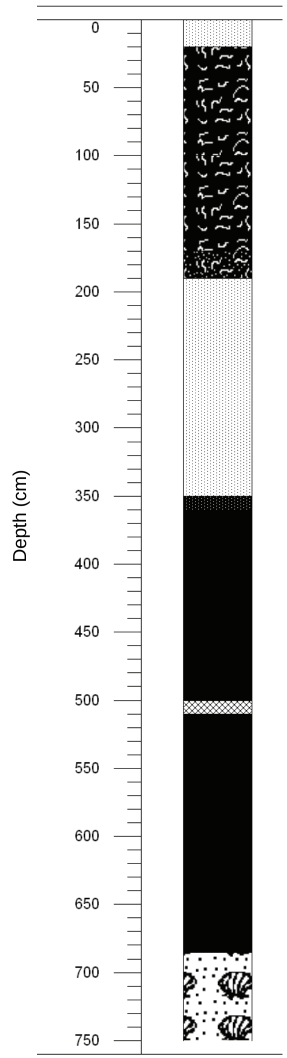
Boundary Rock cliff site

Grid ref:	586440
Notes:	This section is located above the south-eastern coast of Chatham Island, and over-looks the small offshore islet of Boundary Rock
Depth (cm)	
0 – 60	Brown silt loam, abundant fine grass rootlets.
60 – 70	Very firm silty clay with minor organic matter content and mottling/iron-staining.
70 – 122	Brown silt loam with abundant fine root channels and dark specks of organic matter.
122 - 123	Blue-grey clay.
123 - 126	Brown silt loam with abundant fine root channels and dark specks of organic matter.
126 - 131	Pale yellow coarse silt – fine sand – Kawakawa Tephra (**KCh-29**).
131 - 155	Pale-brown clayey silt with abundant root channels 2-5mm in diameter.
155 - 170	Very dark brown silty peat.
170 - 185	Brown silt loam with abundant fine root channels and dark specks of organic matter.
185 - 200	Very fine, highly decomposed black peat.
200 - 208	Pale brown silt loam with abundant clay and organic matter-lined root channels.
208 - 218	White-grey silt (**KCh-30**).
218 - 240	Very fine, highly decomposed dark brown to black peat with abundant clay-lined root channels.
240 - 250	Light brown silt loam with abundant peat and clay-lined root channels.
250 - 263	Orange – brown clay, abundant fine clay-lined root channels.
263 – 264	Dark grey-brown peaty clay.
264 - 266	Brown silt loam.
266 - 406	Very fine, highly decomposed black peat with abundant clay-lined root channels.
4060 onwards	orange-brown highly weathered gravel composed of basaltic pebbles



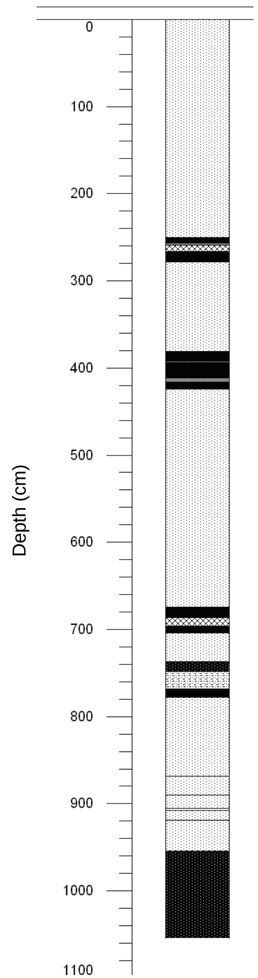
Hanson Bay coastline – south of Te Awapatiki

Grid ref:	570534
Notes:	This section is exposed in the present sea-cliff along the southern Hanson Bay coastline, ~1km south of the lagoon opening (Te Awapatiki). The lowest part of the section (520cm onwards) occurs below the modern beach surface, and was accessed by digging below the modern day beach.
Depth (cm)	
0 – 20	Quartzose dune sand.
20 - 100	Red-brown fibrous peat with in-situ tree stumps.
100 - 190	Red-brown fibrous peat, more decomposed than above.
190 - 350	Quartzose dune sand, stained brown with peaty organic matter.
350 – 360	Peaty sand.
360 - 490	Very fine highly decomposed black peat with abundant in-situ tree and shrub roots and trunks.
490 - 500	Very fine highly decomposed black peat.
500 - 510	Dark orange-brown coarse silt to fine sand – Kawakawa Tephra **(KCh-33).**
510 - 685	Very fine highly decomposed black peat with occasional in-situ wood from small trees or shrubs.
685- onwards	Strongly horizontally laminated black sands, with horizons of disarticulated bivalves and shelly fragments. Rich in ferromagnesian minerals, and also heavily stained by translocated peaty material and tannens.



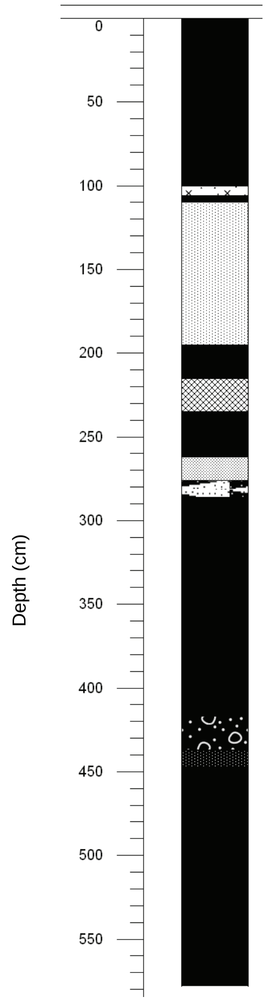
Kaingaroa Beach section

Grid Ref:	676785
Notes:	This section is exposed within the modern day beach cliff, and the base of the sequence is at modern sea level
Depth (cm)	
0 – 250	Unconsolidated quartzose dune sand.
250 – 257	Fine highly decomposed black peat.
257 – 259	Coarse grey silt.
259 – 266	Coarse orange silt-fine sand – Kawakawa Tephra.
266 – 278	Highly decomposed black peat.
278 – 381	Quartzose dune sand, becoming increasingly rich in organic matter with depth.
381 - 392	Very fine dark brown to black peat.
392 - 394	Pale grey silt.
394 - 401	Very fine dark-brown to reddish brown peat.
401 - 402	Pale grey silt.
402 - 403	Very fine dark reddish-brown peat.
403 - 404	Pale grey silt.
404 - 411	Very fine dark reddish brown peat.
411 - 416	Pale grey silt.
416 - 424	Very fine black peat.
424 - 674	Coarse quartzose dune sand, rich in peaty organic material.
674 - 692	Very fine highly decomposed black peat.
692 - 702	Pinky – brown silt with some ~5mm diameter peat filled sub-vertical rhizomorphs – Rangitawa Tephra (**KCh05-7).**
702 - 732	Very fine highly decomposed black peat.
732 - 737	Coarse yellow quartzose sands.
737 - 748	Dark-brown sandy peat.
748 - 768	Coarse silt rich sand.
768 - 778	Very fine highly decomposed black peat.
778 - 868	Pale yellow/white coarse quartzose sand.
868 - 890	Coarse brown quartzose sand.
890 - 891	Iron-stained quartzose sand.
891 - 905	Coarse brown sand.
905 - 908	Pale yellow, horizontally bedded quartzose coarse pebbly sand.
908 - 954	Pale yellow quartzose coarse sand.
954 - 1054	Very fine, highly decomposed black peat ,outcropping at modern sea level, upper contact with sands is very sharp and planar.



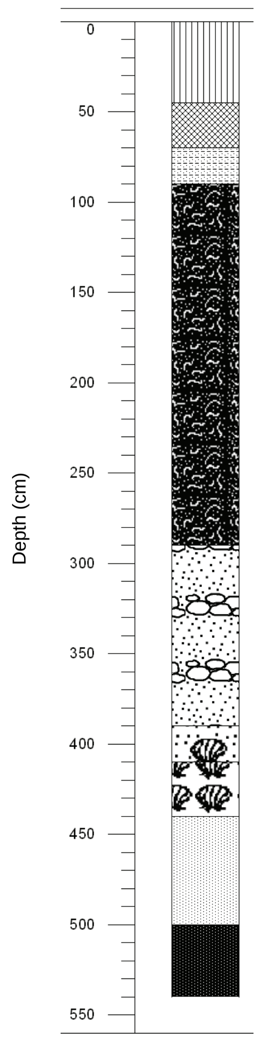
Kaingaroa Slump section

Grid ref:	679788
Notes:	This section occurs within metres of the present beach, and has been exposed by slumping along the outer margin of the Last Interglacial (?) marine bench.
Depth (cm)	
0 – 100	Very fine black nutty, crumbly peat.
100 -102	Firm pale yellow-pink silt (**KRS-UPL**).
102 - 110	Very fine black nutty crumbly peat.
110 - 195	Coarse quartzose sands, faint horizontal lamination.
195 - 215	Very fine, highly decomposed black peat..
220 - 230	Pink coarse silt-fine sand – Rangitawa Tephra (**KRS**).
235 - 262	Very fine highly decomposed black peat.
262 - 276	Pinky-brown sub-horizontally laminated quartzose sand, with many thin <10 mm peat-rich horizons.
276 - 286	Pinky – brown sands inter-fingering with very fine black peat.
286 - 417	Very fine, highly decomposed black peat with abundant in-situ woody material from small trees and shrubs.
417 - 437	Peaty coarse quartzose pebbly sand.
437 - 447	Peaty quartzose sand.
447 - 578	Very fine, highly decomposed black peat.
578 onwards	Water table.



Lake Kaingarahu section

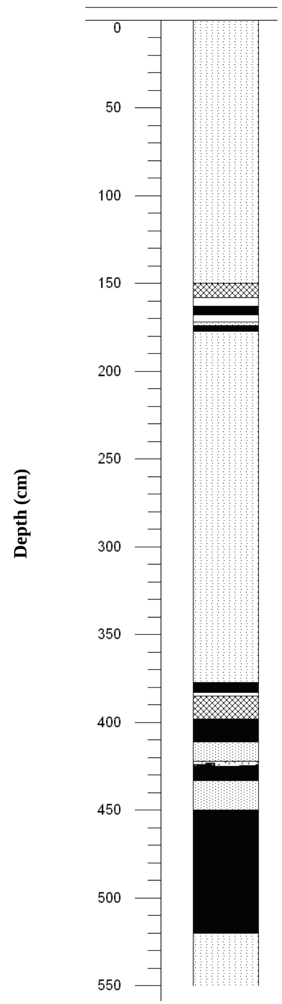
Grid reference:	596699
Notes:	This sequence is exposed in a bank above Lake Kaingarahu.
Depth (cm)	
0 - 45	Modern soil – grey-brown sandy silt loam with abundant fine rootlets.
45 - 70	Dark yellow-orange light fluffy fine sand - coarse silt –Kawakawa Tephra.
70 - 90	Brown loamy sand with old bracken roots.
90 - 290	Brown sandy fibrous peat .
290 - 390	Laminated quartzose pebbly sand.
390 - 410	Laminated quartzose pebbly sands containing abundant water-worn shell fragments.
410 - 440	Water-worn shell fragments.
410 - 440	Same as above but with many small quartzose pebbles.
440 - 540	Coarse quartzose sand with abundant water-worn shell fragments, and thin peaty ‘stringers’/horizons, becoming increasingly peaty with depth.
540 onwards	Water table/lake level.



Mairangi

Grid ref: 391826

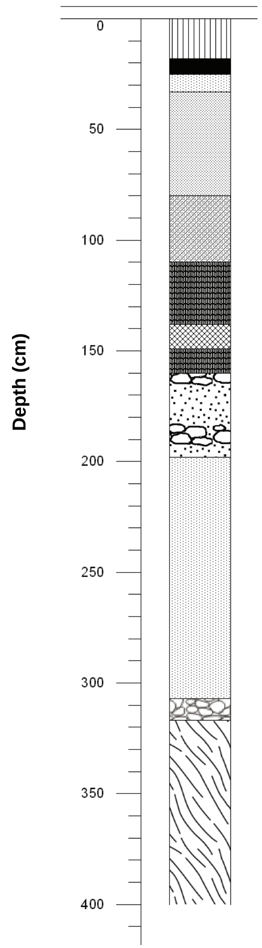
Depth (cm)	
0 - 150	Orange brown sandy silt, abundant root channels and fine rootlets.
150 - 158	Pale yellow-white fine sand/coarse silt –Kawakawa Tephra (**MR12**).
158 - 163	Pinky brown silty sandy clay.
163 - 168	Very fine, highly decomposed black peat.
168 - 172	Pinky brown silty sandy clay.
172 - 174	White silty sand.
174 - 177	Discontinuous 'pockets' of organic rich, peaty clay.
177 - 377	Brown sandy silt,.
377 - 383	Very fine, highly decomposed black peat.
383 - 385	Pinky-grey clay.
385 - 398	Pink coarse silt with sub-horizontal, clay-filled root channels ~5mm in diameter – Rangitawa Tephra (**MR9**).
398 - 411	Very fine, highly decomposed black peat.
411 - 422	Brown sand.
422 - 425	Inter-fingering peat and sand.
425 - 433	Very fine, highly decomposed black peat.
433 - 450	Medium-coarse quartzose sands, stained orange-brown from iron oxides and organic matter.
450 - 520	Very fine, highly decomposed black peat .
520 onwards	Brown sandy silt, over Momoe-a-toa Tuff and Rangitihi Volcanics.



Matarakau

Grid ref:	623791
Notes:	This sequence overlies the c. 20m marine bench at Matarakau

Depth (cm)	
0 - 18	Modern soil – sandy loam.
18 - 25	Very fine, highly decomposed black peat.
25 - 33	Quartzose sand.
33 - 80	Brown quartzose and, stained with organic matter.
80 - 110	Orange-brown quartzose sands, stained with iron oxides.
110 - 138	Brown sandy silt loam – paleosol.
138 - 149	Grey-white fine sand-coarse silt – Rangitawa Tephra (**KCh-15**).
149 - 160	Brown sandy silt loam – paleosol.
160 – 198	Horizontally laminated quartzose pebbly sand.
198 - 307	Quartzose sand.
307 - 317	Scattered quartzose and chert pebbles in sand.
317 onwards	Chatham Schist.

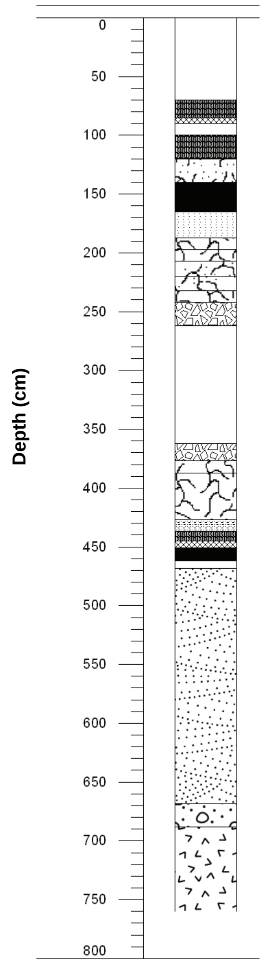


Mairangi - south of Paua cove

Grid ref: 392818

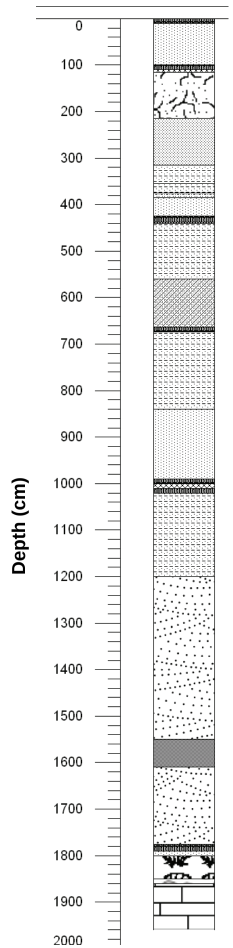
Notes: This section overlies the ~35m marine terrace which, at this location, is cut into pillow-basalts and tuff deposits of the Miocene-aged Rangitihi Volcanics.

Depth (cm)	
0 – 70	Sandy silt loam, abundant fine rootlets (from pasture grass).
70 – 85	Paleosol.
85 – 90	Pocketing pale orange silty sand - Kawakawa Tephra **(Mairangi SSB).**
90 – 100	Sandy silt.
100 - 120	Paleosol.
120 - 140	Brown sandy silt with many root channels and rootlets.
140 - 165	Peaty sandy silt – paleosol.
165 - 187	Brown sandy silt,.
187 - 197	Firm brown clayey silt.
197 - 207	Grey-brown clayey silt.
207 - 220	Brown sandy silt.
220 - 232	Brown-grey silty sand.
232 - 242	Firm brown-grey silt.
242 - 262	Colluvial unit of firm brown silty clay with angular fragments of highly weathered basaltic volcanic lithologies.
262 - 362	Firm brown silty clay.
362 - 377	Colluvial unit of firm brown silty clay with angular fragments of highly weathered basaltic volcanic lithologies, 2mm – 13mm in diameter..
377 - 387	Grey-brown firm silty clay.
387 - 427	Firm mauve-brown clayey silt.
427 - 437	Mauve-brown silty sand.
437 - 445	Firm fine highly decomposed peat.
445 - 451	Low-density orange clay with many fine clay and peat-filled Rhizomorphs – Rangitawa Tephra (devitrified).
451 - 462	Firm fine highly decomposed peat with abundant clay-lined rhizomorphs (1-5mm in diameter).
462 - 468	Brown clayey silt.
468 - 670	Coarse quartzose dune-bedded sand, many thin (5 -15mm) peaty/organic-rich horizons.
670 - 688	Scattered rounded basalt pebbles (30 – 125mm in diameter) in coarse quartzose sand.
688 onwards	Volcanics.



North Red Bluff Quaternary Sequence

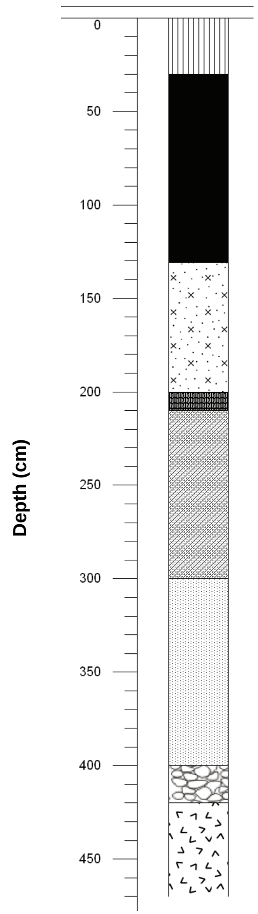
Grid ref:	465620
Notes:	This section overlies the 7-13m Pliocene surface, cut into Eocene-aged Matanganui Limestone.
Depth (cm)	
0 - 15	Light-brown unconsolidated sand, minor amounts of organic matter – modern-day soil, under marram grass.
15 - 25	Unconsolidated calcareous sand.
25 - 55	Unconsolidated calcareous sand containing evidence of human habitation – fish, bird and seal(?) bones, whale(?) teeth, shells and charcoal fragments.
55 - 125	Unconsolidated calcareous sand.
125 - 140	Firm mauve-grey organic-rich silty sand (paleosol).
140 - 150	Pocketing pale-orange silty-fine sand – Kawakawa Tephra **(KCh-28).**
150 - 245	Iron-stained quartzose silty sand with many rootlet impressions.
245 - 275	Grey-brown silty sand.
275 - 455	Unconsolidated calcareous sand.
455 - 467	Brown sandy organic-rich silt (paleosol).
467 - 470	Cemented iron pan.
470 - 590	Grey-brown silty sand.
590 - 694	Iron-stained unconsolidated dune bedded sand,.
694 - 704	Brown organic-rich silty sand (paleosol).
704 - 870	Grey-brown silty sand.
870 - 1020	Unconsolidated calcareous sand.
1020 - 1030	Firm grey silt with some root channels, 2-5 mm in diameter.
1030 - 1040	Pale cream-pinky silt – Rangitawa Tephra **(NRB)**.
1040 - 1050	Firm grey-brown sandy silt with few root channels, 2-5 mm diameter.
1050 - 1230	Grey-brown silty sand.
1230 - 1580	Unconsolidated dune-bedded calcareous sand.
1580 - 1640	Consolidated pale-pink silt.
1640 - 1806	Unconsolidated dune-bedded calcareous sand.
1806 - 1820	Dark-grey brown clay (paleosol).
1820 - 1830	Brown quartzose sand.
1830 - 1880	Laminated calcareous sand with several horizons of shells and shell fragments.
1880 - 1890	Horizon of scattered rounded chert, quartz and limestone pebbles 20 mm-200 mm in diameter.
1890 onwards	Wave cut surface in Matanganui Limestone, c. 7m above modern sea level.



Owenga Wharf

Grid ref: 605472
Notes: This sequence overlies the c.9m marine bench at the Owenga Wharf.

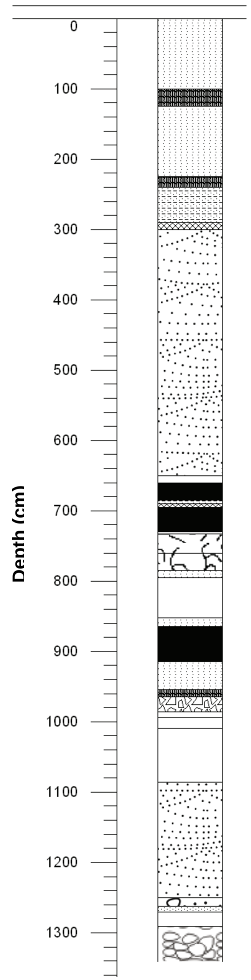
Depth (cm)	
0 - 30	Modern soil – brown silt loam.
30 - 130	Dark brown fibrous peat.
130 - 200	Dark yellow-orange light fluffy silty material, reworked Rangitawa Tephra (**OwWh**).
200 - 210	Peaty sandy paleosol.
210 – 300	Quartzose sand, stained orange - brown from iron oxides and peaty material.
300 - 400	Quartzose sand.
400 - 420	Horizon of scattered weathered basalt and tuff pebbles.
420 onwards	Red Bluff Tuff.



Paua cove

Grid ref: 391821

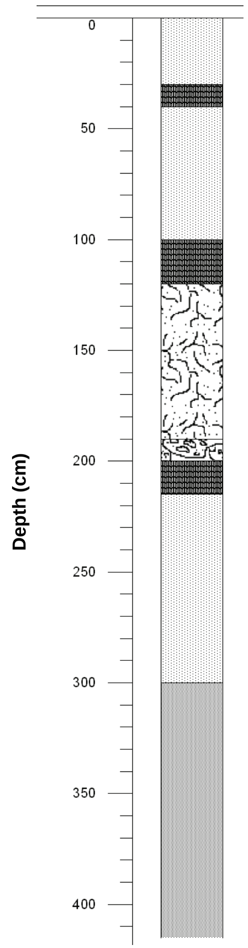
Depth (cm)	
0 - 100	Brown sandy silt loam, with abundant fine rootlets.
100 - 125	Dark brown sandy silt loam (paleosol).
125 - 225	Brown sandy silt loam, with abundant fine rootlets.
225 - 240	Dark brown sandy silt loam (paleosol).
240 - 290	Light brown silty sand.
290 - 300	Pale yellow-brown coarse silt-fine sand – Kawakawa Tephra **(PC 290-300cm).**
300 - 650	Pinky-brown coarse quartzose dune sand, with sub-vertical peat/OM filled root channels.
650 - 660	Sandy peat.
660 - 685	Very fine, highly decomposed black peat.
685 - 690	Silty sand.
690 - 695	Orange-pink silt.
695 - 730	Very fine, highly decomposed black peat.
730 - 733	Layer of very dry crumbly peat.
733 - 760	Brown silt with abundant root channels.
760 - 785	Dark grey brown silty clay with abundant root channels.
785 - 795	Firm sandy silt.
795 - 807	Firm silt.
807 - 817	Firm dark grey silt.
817 - 832	Peaty silt.
832 - 852	Firm silt.
852 - 864	Firm sandy silt.
864 - 914	Very fine, highly decomposed black peat.
914 - 954	Firm sandy silt.
954 - 964	Dark brown sandy silt loam (paleosol).
964 - 986	Colluvial unit of firm brown silty clay with angular fragments of highly weathered basaltic volcanic lithologies.
986 - 994	Firm dark grey silt.
994 - 1009	Coarse, laminated quartzose sand.
1009 - 1086	Firm dark grey silt.
1086 - 1250	Pinky-brown coarse quartzose dune sand, with sub-vertical peat/OM filled root channels.
1250 - 1262	Scattered weathered basalt and tuff pebbles in quartzose sand.
1262 - 1270	Pinky-brown coarse quartzose dune sand.
1270 - 1291	Peaty clay.
1291 - 1341	Highly weathered basaltic gravel.
1341 onwards	Tuffaceous volcanics (Rangitihi Volcanics).



Southern Hanson Bay coast

Grid ref: 578502

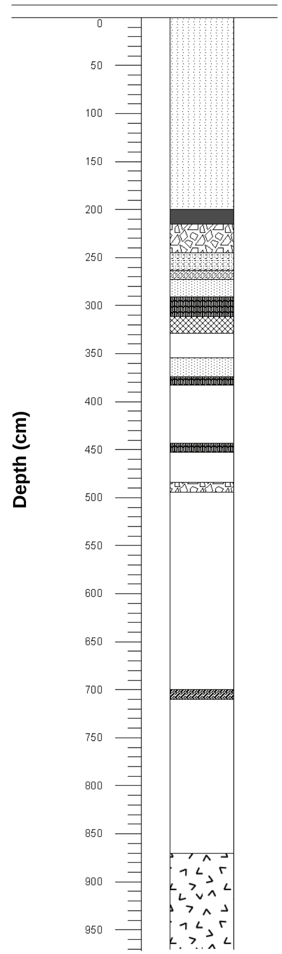
Depth (cm)	
0 - 30	Quartzose dune sand.
30 - 40	Slightly peaty sand (paleosol).
40 - 100	Quartzose dune sand.
100 - 120	Peaty sand (paleosol).
120 - 190	Brown quartzose dune sand stained brown by organic/peaty material.
190 - 200	Scattered rounded pumice clasts – Taupo Pumice (**KCh05-16**).
200 - 215	Peaty sand (paleosol).
215 - 300	Quartzose dune sand.
300 onwards	Strongly horizontally laminated black sand.



South Mairangi A

Grid reference: 391814

Depth (cm)	
0 – 200	Sandy silt loam with abundant fine rootlets.
200 – 215	Brown organic matter-rich silty clay (paleosol).
215 – 245	Brown sandy silt, containing colluvial fragments of highly weathered basalt.
245 – 263	Very firm, blue-grey silty sand.
263 – 273	Orange-brown silt.
273 – 291	Coarse white quartzose sand.
291 – 301	Brown silty sand (paleosol).
301 – 311	Peaty clay.
311 – 329	Light orange-yellow fine silt.
329 – 354	Organic-rich coarse brown clayey sand.
354 – 374	Light brown, medium to coarse sand with some mottling from organic matter.
374 – 383	Organic-rich sandy clay (paleosol).
383 – 443	Medium to coarse quartzose dune-sand.
443 – 453	Grey-brown clayey sand.
453 – 484	Grey-brown silt/clay.
484 – 494	Orange-brown clay-rich colluvial material.
494 – 700	Olive-brown silt/clay.
700 – 710	Cemented iron pan.
710 – 870	Medium quartzose dune-bedded sand.
870 onwards	Pillow basalts and tuff (Rangitihi Volcanics).

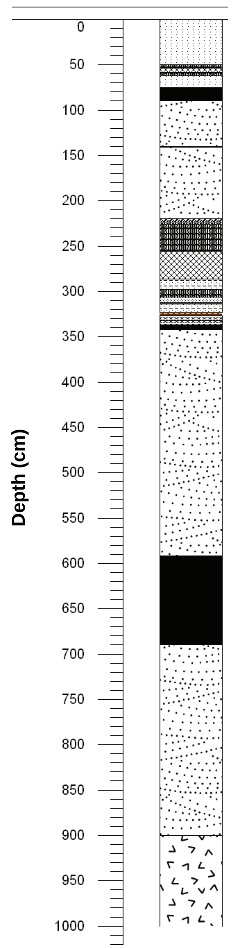


South Mairangi B

Grid ref: 392811

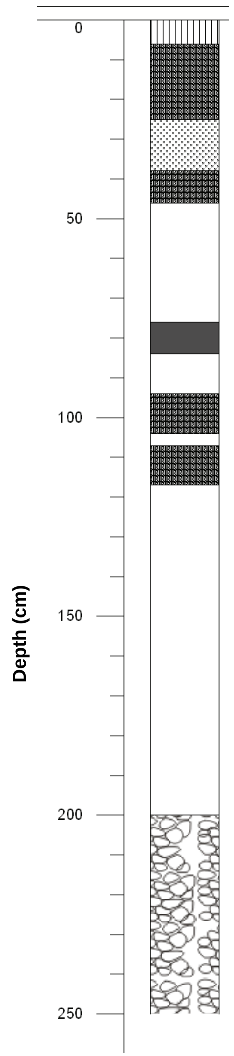
Notes: This sequence overlies the c.35m marine bench, overlooking the coast between Mairangi and Tioriori

Depth (cm)	
0 – 50	Sandy silt loam with abundant fine grass rootlets.
50 – 54	Paleosol.
54 – 58	Pocketing pale orange fine sand – coarse silt Kawakawa Tephra **(SMKK).**
58 – 62	Paleosol.
62 – 75	Sandy silt loam.
75 – 90	Fine, highly decomposed black peat.
90 – 140	Dune-bedded quartzose sand.
140 – 141	Silt.
141 – 220	Dune-bedded quartzose sand.
220 – 226	Cemented iron pan.
226 – 256	Paleosol.
256 – 286	Low-density orange clay with many fine clay and peat-filled rhizomorphs – Rangitawa Tephra **(MRO).**
286 – 298	Grey silty sand.
298 – 306	Paleosol.
306 – 312	Quartzose sand with abundant organic matter.
312 – 314	Peaty clay.
314 – 323	Grey silty sand.
323 – 332	Organic rich silty sand.
332 – 342	Highly decomposed fine black peat.
342 – 592	Dune-bedded quartzose sand.
592 – 690	Fine peat with abundant in-situ roots and wood of small trees and shrubs.
690 – 900	Dune-bedded quartzose sand.
900 onwards	Tuff and pillow lavas (Rangitihi Volcanics).



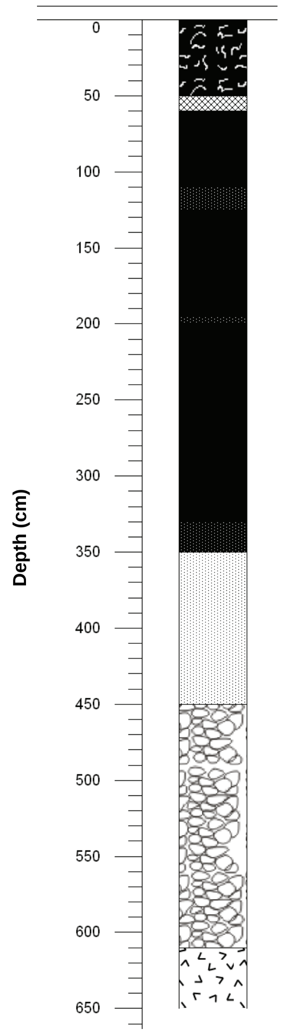
Southwest coast – lowlands

Grid ref:	361473
Notes:	This sequence overlies the 3 – 5 m marine bench on the south-west coast of Chatham Island, to the south of Point Durham
Depth (cm)	
0 - 6	Modern ‘a’ horizon – grey-brown silt loam with abundant fine rootlets
6 - 25	Peaty silt loam (paleosol)
25 - 38	Coarse silt-fine sand - Kawakawa Tephra - (**KCh05-43**)
38 - 46	Peaty silt loam (paleosol)
46 - 76	Firm grey brown silt loam
76 - 84	Peaty silt loam (paleosol)
84 - 94	Firm grey brown silt loam
94 - 104	Peaty silt loam (paleosol)
104 - 107	Firm grey brown silt loam
107 - 117	Peaty silt loam (paleosol)
117 - 200	Firm grey brown silt loam
200 onwards	Gravel composed of small rounded basalt pebbles



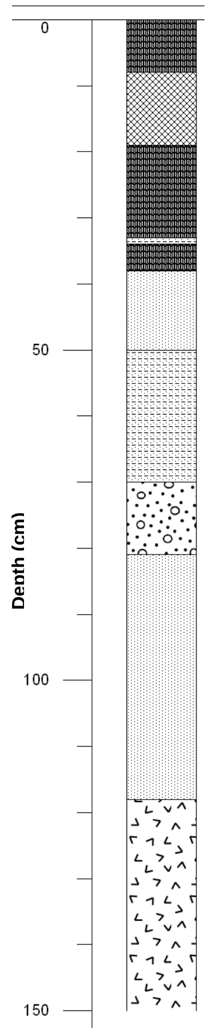
Stony Crossing basalt quarry

Grid ref:	382721
Notes:	This sequence is exposed in a basalt quarry at the ford known as Stony Crossing. The sequence overlies the 16m surface in the Ohira Bay area.
Depth (cm)	
0 - 50	Very fibrous peat.
50 - 60	Pale yellow-orange fine sand-coarse silt – Kawakawa Tephra (**KCh-9**).
60 - 110	Fibrous dark brown peat.
110 - 125	Dark brown sandy peat.
125 - 195	Very fine highly decomposed black peat.
195 - 200	Very fine highly decomposed sandy black peat.
200 - 330	Very fine highly decomposed black peat.
330 - 350	Very fine highly decomposed sandy black peat.
350 - 450	Coarse quartzose dune sand, stained brown from peaty material.
450 - 610	Boulder gravel deposit composed of large basalt boulders, with smaller chert, schist/quartz and limestone pebbled in a coarse sandy matrix.
610 onwards	Basaltic lavas (Southern Volcanics).



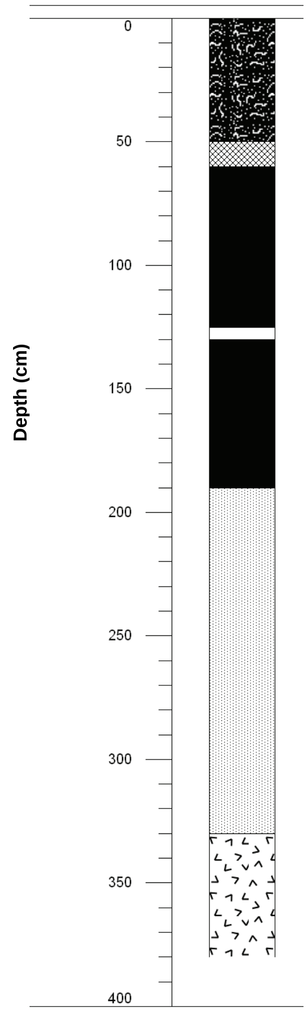
Waitangi Beach

Grid ref:	451553
Notes:	This section overlies the LIG marine bench, cut into Eocene Red Bluff Tuff, at Waitangi township. The section description begins below a massive unit of Maipito Fm. sediments, some of which may have been reworked during construction of the road and buildings of Waitangi township.
Depth (cm)	
0 – 8	Peaty silty sand.
8 – 19	Pale yellow – grey fine sand – coarse silt – Kawakawa Tephra (**WB**).
19 – 33	Peaty silt.
33 – 34	Light brown silt – fine sand.
34 - 38	Light brown silt loam with minor staining from iron oxides and organic matter.
38 - 50	Light brown quartzose sand with minor staining from iron oxides and organic matter.
50 - 70	Very firm clayey sand.
70 - 81	Light yellow-brown sand with scattered schist, basalt and limestone pebbles.
81 - 118	Orange sandy silt, with scattered schist, basalt and limestone pebbles at the base.
118 onwards	Red Bluff Tuff.



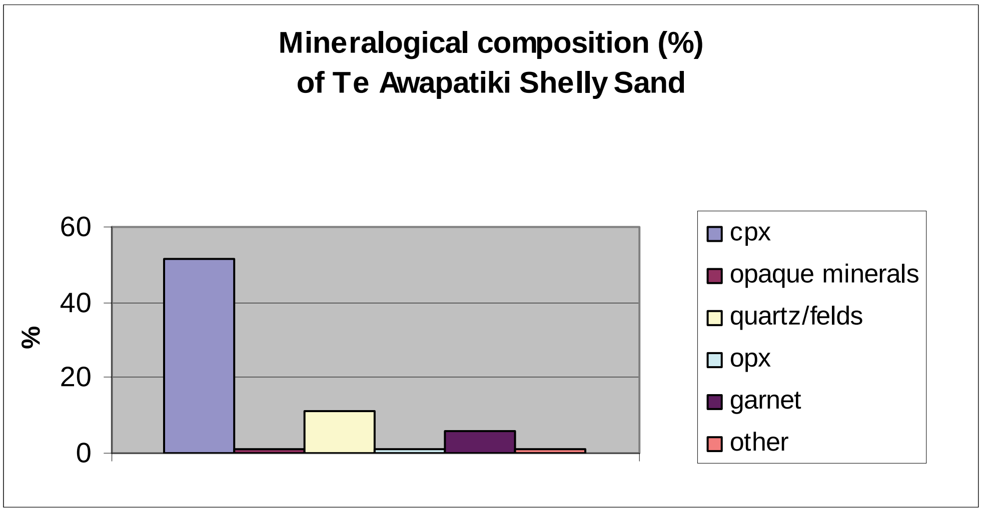
Wharekauri-Kaingaroa turnoff basalt quarry

Grid ref:	452787
Notes:	This sequence is exposed in a basalt quarry located adjacent to the Whaerkauri – Kaingaroa turnoff. The sequence overlies the 16m marine bench.
Depth (cm)	
0 - 50	Sandy fine fibrous peat.
50 - 60	Orange fine sand/coarse silt –Kawakawa Tephra (**WQ**).
60 - 75	Very fine, highly decomposed black peat.
75 - 125	Very fine, highly decomposed black peat with abundant in-situ wood of small trees and shrubs.
125 - 130	Pale orange silt.
130 - 190	Very fine, highly decomposed black peat with abundant in-situ wood of small trees and shrubs.
190 - 330	Brown coarse to medium, weakly bedded quartzose sand, increasingly coarse and pebbly towards the base.
330 onwards	Basaltic lavas (Southern Volcanics).



APPENDIX 9

Mineralogy of the Te Awapatiki shelly sand (63-125µm fraction)
(cpx = clinopyroxene, opx = orthopyroxene, opaque = magnetite, ilmenite etc, hbl = hornblende).



cpx	opaque	quartz/feldspar	opx	garnet	zircon	hbl?	Total
134	78	29	12	6	1	1	261

APPENDIX 10

Raw sieving data from the North Red Bluff Quaternary sequence

Depth (cm)	start weight (g)	>350µm	250 - 350 µm	180 - 250 µm	125 - 250 µm	90 - 125 µm	63 - 90 µm	<63µm	total (g)	loss on sieve
55 - 125	78.14	6.77	9.34	11.53	24.07	15.20	6.00	4.71	77.62	0.52
150 - 245	203.18	7.71	20.51	78.00	34.07	3.89	4.09	53.92	202.19	0.99
245 - 275	125.25	0.23	0.71	6.15	34.83	24.84	3.74	54.61	125.11	0.14
275 - 455	391.65	10.90	53.90	197.69	92.27	10.39	6.86	19.22	391.23	0.42
470 - 590	166.08	0.69	3.74	15.41	64.66	13.59	6.52	61.05	165.66	0.42
590 - 694	189.08	3.61	4.13	17.52	118.14	22.47	5.91	17.07	188.85	0.23
704 - 870	111.11	0.71	4.74	15.32	26.75	7.74	3.84	51.87	110.97	0.14
870 - 1020	290.96	0.51	31.18	135.94	96.06	11.98	3.23	11.90	290.80	0.16
1050 - 1230	257.06	1.26	11.96	59.26	43.84	16.87	4.60	118.53	256.32	0.74
1230 - 1580	440.83	23.01	94.50	151.87	126.78	11.37	3.86	27.97	439.36	1.47
1580 - 1806	438.10	22.46	94.32	153.48	125.82	10.20	3.61	27.26	437.15	0.95

APPENDIX 11

Point counts of 63-125um fraction of sand units from the North Red Bluff Quaternary sequence

(cpx = clinopyroxene, opx = orthopyroxene, opaque = magnetite, ilmenite etc.).

	Mineral					
	CaCO3/shell	opx	cpx	quartz/felds	opaque	**Total**
Depth (cm)						
55-125	141	4	26	29	4	204
150-245	8	1	19	170	4	202
245-275	16	0	16	168	2	202
275-455	153	7	37	18	8	223
470-590	4	0	8	228	0	240
590-694	88	2	18	90	4	202
704-870	26	0	5	192	2	225
870-1020	150	4	39	20	8	221
1050-1230	10	2	20	184	0	216
1230-1580	171	6	34	12	10	233
1640-1806	146	10	58	21	12	247

APPENDIX 12

Calculation of rates of uplift of Chatham Island, using marine terrace heights.

3-5m terrace

This surface is the Last Interglacial marine bench, preserved in the Southern Hanson Bay area, Manakau Point, Waitangi Township, Waitangi West and Kaingaroa(?).

Taking into account a +5 metre increase in sea level during OIS5e, rates of uplift for this area are practically nil:

(5m surface height – 5m sea level rise)/125ka = 0

However, researchers are not in agreement over LIG sea level rise, with some evidence suggesting that the LIG sea level was no higher than present. S (sea level at the time of formation of the surface, relative to present), H/T for the 3-5m surface (at Owenga) is:

5m/125ka = 0.04m/ka or 0.04mm/yr

Thus rates for (Owenga) are placed between **0.00 – 0.04 mm/yr**.

9 metre surface

This surface is preserved in the Owenga, Point Durham, Waitangi township and Waitangi West areas.

Two possible (age) scenarios:

A) Penultimate interglacial at ~200 ka (as proposed by Tonkin *et al.* unpublished) and as indicated by superposition/position above 3-5m Last Interglacial terrace.

Gives uplift rate of: 9m/200ka = 0.045 mm/yr

Other maximum possible age is OIS 11 @ ~400ka, based on tephric material possibly derived from the Rangitawa Tephra, within the cover bed sequence.

Gives uplift rate of: 9m/400ka = 0.02 mm/yr

Therefore uplift rates for this surface are placed at **0.02 – 0.045mm/yr**.

16 metre surface

This surface is preserved in the Ohira Bay and Wharekauri/Tuapeka regions

Again, there are two possible age scenarios:

A) Last Interglacial age, based upon the thickness of the cover-bed sequence, and pollen stratigraphy at Wharekauri Quarry.

Gives uplift rate of: 16m/125ka = 0.128mm/yr

B) Alternatively, if the surface is of penultimate interglacial age, as based on pollen stratigraphy at Ohira Bay, and thus correlates with the 9m surface in the Owenga region, then rates would be:

16m/200ka = 0.08mm/yr

Another possible scenario is that though the surfaces in the two areas are the same height, they are both different ages, and that uplift rates in the Wharekauri area are considerably higher than at Ohira Bay.

Therefore uplift rates for this surface are placed between **0.08 – 0.13mm/yr**.

<u>15 – 20 metre surface</u>

This surface is preserved in the Matarakau and Tioriori areas.

The minimum age for this surface is OIS 11, based on the occurrence of the Rangitawa Tephra within the cover bed sequence in these areas.

20m/400ka = **0.05 mm/yr**.

<u>30 – 40 metre surface</u>

This surface is preserved in the Mairangi area.

The minimum possible age for this surface is OIS 11, based on the occurrence of the Rangitawa Tephra within the cover-bed sequence. However, the relationship of this surface to the 15 – 20 metre surface in the adjacent Tioriori area which is also regarded as OIS 11 indicates that this terrace is probably older by at least 1 cycle. So taking the age of OIS 13 at *c.* 500kyr gives an uplift rate of:

35m/500ka = 0.07mm/yr

Alternativly, it may be that there are two OIS 11 surfaces in the Mairangi-Tioriori region (i.e. equivalent to the Rangatatau and Ararata marine surfaces in the Taranaki region, after Pillans 1990), in which case rates of uplift are higher for the 30-40m surface.

35m/400ka = 0.09 mm/yr

Thus rates for the 35m surface are placed between **0.07 – 0.09 mm/yr**.

7 – 13 metre latest Pliocene – Early Quaternary surface

This surface is exposed in the North Red Bluff area, and apparently preserved below younger Quaternary deposits in the Wharekauri region.

Biostratigraphic ages from the fauna contained within the Titirangi Sand overlying the planation surface give an age range of 1.8 – 2.4 Ma, which gives an uplift rate of:

14m/1800 – 2400kyr = **0.006 – 0.008 mm/yr**.