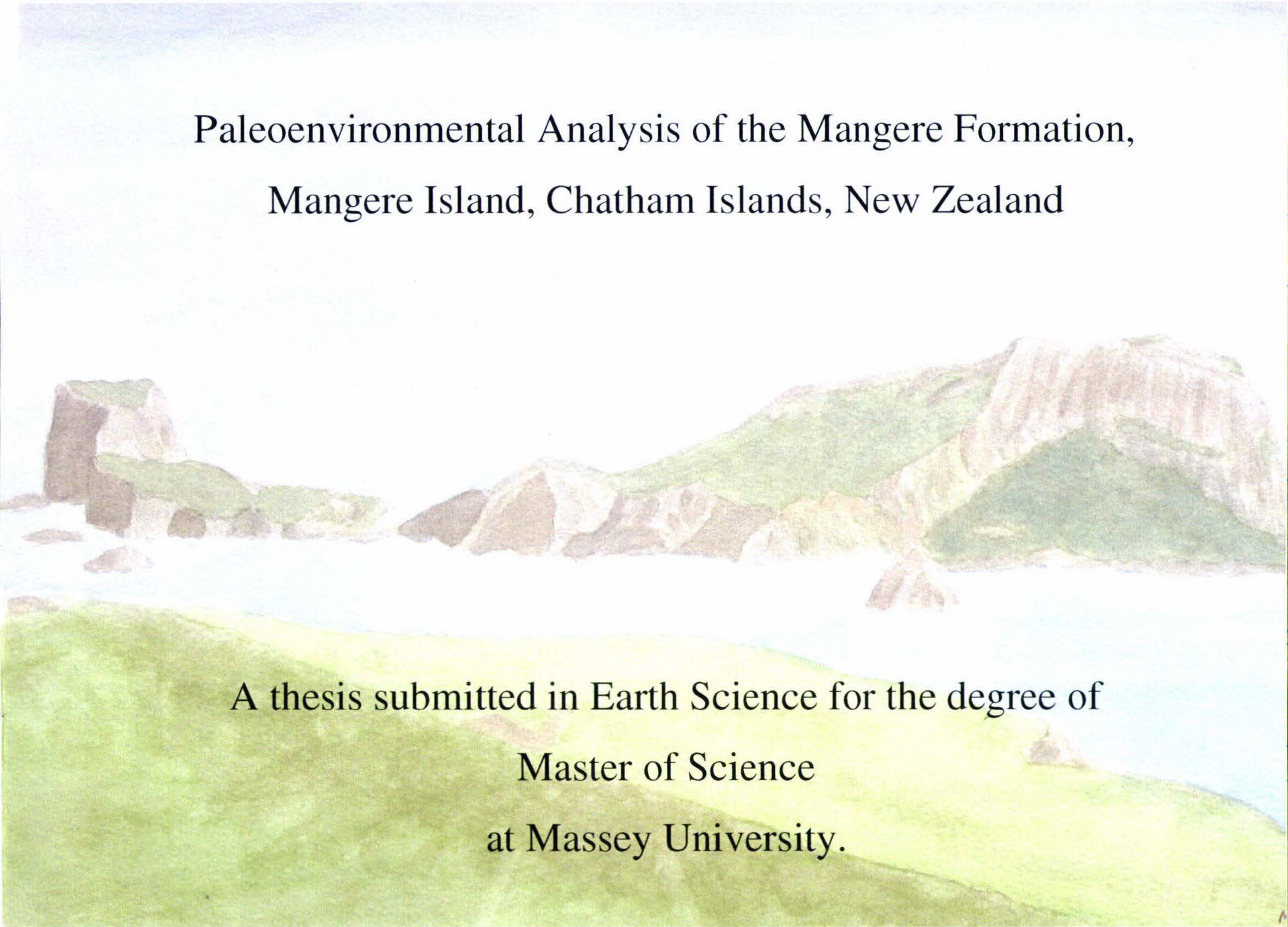

Paleoenvironmental Analysis of the Mangere Formation, Mangere Island, Chatham Islands, New Zealand

A thesis submitted in Earth Science for the degree of

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Abstract.

Mangere Island consists almost entirely of alkali basalt of the late Miocene early Pliocene Rangiauria Formation (Campbell et al., 1993) with outcrops of the sedimentary Tupuangi Formation on the east coast and the Mangere Formation (Campbell, et al., 1993), a sedimentary remnant, mainly lacustrine but also partly marine, lying between the northeastern and southwestern groups of volcanic vents of Mangere Island:

As a result of the present work the sedimentary Mangere Formation of Campbell *et al.* (1993) has been divided into two formations, Mangere Formation and the overlying Parakeet Formation. Mangere Formation consists of (1) a Basal member (32m of mudstone), and (2) a Cyclic member (12.6m of alternating sandstones and mudstones). Parakeet Formation has (1) a Carbonaceous member (0.6m 0f organic rich mudstones), (2) a Skua member (16.8m of tuffaceous siltstone), and (3) a capping rhyolitic tephra. The Basal member of the Mangere Formation is underlain by a breccia that is texturally extremely variable (Bag End breccia).

A sedimentary outcrop on the eastern coast of Mangere Island is lithologically and mineralogically identical to Tupuangi Formation on Pitt Island as well as having the same Cretaceous pollen suite. Thus it is inferred that, at the time of Rangiauria volcanism, Tupuangi Formation and its overlying Tertiary strata extended from Pitt Island at least as far as Mangere Island.

An arm of the sea between two Mangere Island volcanic centres extended towards Waihere Bay, Pitt Island. At some time in the late Pliocene, volcanic debris avalanches from the northeast and southwest groups of vents formed a debris dam that blocked off the seaward side of the sea arm, resulting in the formation an oligotrophic fresh water lake. As a result of a low energy regime and vegetated slopes, the lake filled to *ca.* 30m with very fine sediment (the Basal member) from both the volcanics of Mangere Island and the quartzofelspathic Tupuangi Formation of Pitt/Mangere Island.

Following this a debris dam, formed by volcanic debris avalanches, was breached by a rising sea. Local marine influence in storms destablised the slopes surrounding the then shallow lake resulting in the influx of coarse sands which alternated with mudstones deposited during quieter periods (the Cyclic Member).

At the end of this period there was a eustatic fall of sea level or tectonic uplift or both, probably resulting in subaerial erosion and an unconformity between the Cyclic and Carbonaceous Members.

A second shallow fresh water lake (the Carbonaceous member) was established on the top of the Cyclic member. This lake was later overwhelmed by wind-blown material derived from a deposit of Paleocene Red Bluff Tuff exposed probably by a falling sea level or marine erosion. The reworked Red Bluff Tuff was later covered by a layer of rhyolitic tephra probably from the Taupo Volcanic Zone (TVZ), North Island, New Zealand.

The distinctive jointing pattern seen in the sandstone units of the Cyclic member resulted from doming with a principal stress directed northwest-southeast. This probably correlates with tectonic uplift in the Castlecliffian.

The lack of any positive time markers makes dating the formation rather indeterminate, but the Basal and Cyclic members (Mangere Formation) are probably upper Mangapanian and the Skua member probably Quaternary. The sequence is generally lacking in fossils, except for palynomorphs which occur throughout, and ostracods which occur only in the Cyclic member. Neither proved useful for dating the sequence.

The pollen diagrams show a consistent coastal plant association of small trees, shrubs, herbs and ferns throughout the history of the sequence, with the implication that climate during this time did not vary greatly from a mild, moist, equable mean.

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Chapter 1.

Introduction.

1.0.0 Aims.

The primary aims of this study were to:

- Provide a detailed description of the stratigraphy of the Mangere Formation (as defined by Campbell *et al*. (1993).
- Determine the areal extent of the Mangere Formation
- Determine the provenance of the Mangere Formation
- Explain the palaeohistory of the Mangere Formation
- Determine the palaeoclimate at the time of deposition of the Mangere Formation, using palynology and other microfossils
- Determine the time of deposition of the Mangere Formation.

1.1.0. Thesis structure.

This thesis comprises five chapters. Chapter 1 is an introduction to the study area. It covers the aims of the study, and the location of the study area, together with notes on the history and physiography of Mangere Island, plus some background on Mangere Island's conservation importance. The regional geology of the Chatham Islands, and especially Pitt Island, is briefly covered as this is relevant to the Mangere Island study. Finally, in Chapter 1, previous geological work on Mangere Island is covered. Chapter 2 details and explains the methods of field and laboratory work used in the study. Chapter 3 details the results of field and laboratory work and includes stratigraphic columns of the Tupuangi and Mangere Formations on Mangere Island. Chapter 4 discusses the results of field and laboratory work given in chapters 2 and 3, and reconstructs the palaeohistory of the Mangere Formation as a series of maps. Chapter 5 details the conclusions of the study and relates them to the Haq *et al*, (1987) sea level curve.

1.1.1. Location of the study area.

The Chatham Islands are located approximately 850 km east of Christchurch (Fig. 1). The main economic activity is fishing (blue cod, crayfish, paua) and sheep farming for wool. The islands were originally inhabited by the Moriori. In the midnineteenth century they were settled by Europeans and in 1835 the Moriori were largely displaced as a result of a Maori invasion from mainland New Zealand (King, 1990).

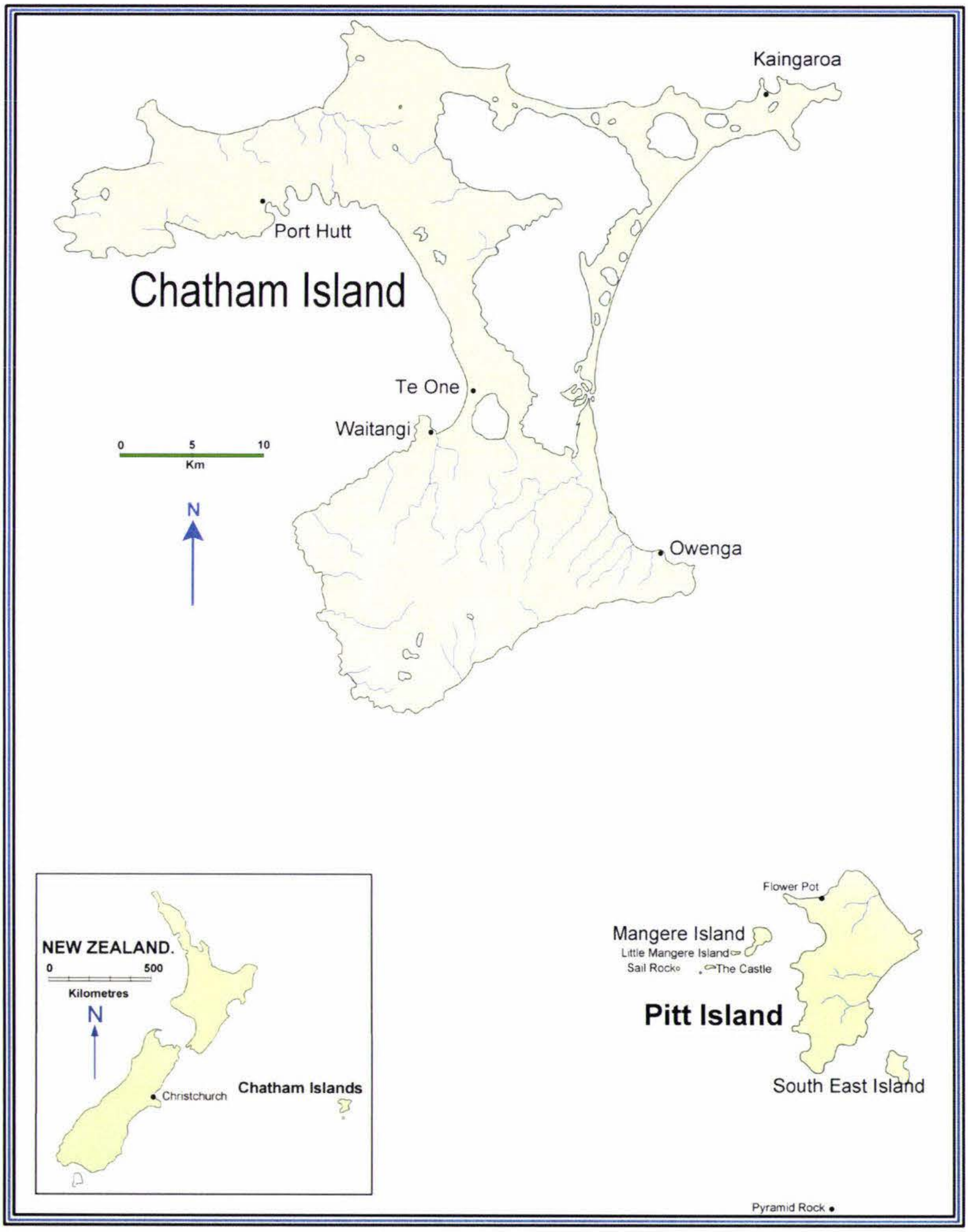

Figure 1. Chatham Islands location map.

The largest island is Chatham Island, over 50% of which is covered in blanket peat, followed in order of decreasing size by Pitt Island, South East Island, and Mangere Island (the object of this study), as well as many smaller islands, rocks, and reefs.Mangere Island lies 2.3 km off the west coast of Pitt Island. It is approximately 2.3 km long and 1.2 km at its widest (Fig. 2). Associated with it are a number of smaller islands, the most prominent of which are Little Mangere Island, The Castle, Pyramid Rock, and Sail Rock (Fig. 1), as well as a number of small rocks and reefs. These islands and rocks are all volcanic and of Late Miocene or Early Pliocene age, except for the sedimentary Tupuangi (Cretaceous) and Mangere Formations (upper Pliocene) on Mangere Island.

1.1.2. Mangere Island, historical and biological background.

Mangere Island was largely forested until the 1890's when the forest was cleared for sheep farming which continued until 1966 (Atkinson 2003). The island was made a nature reserve in 1967 (Atkinson, 2003), and an extensive reafforestation programme of mainly Chatham Island akeake (*Olearia traversii*) was initiated. The present vegetation is broadly, akeake forest, koromiko scrub, flaxland, herbfields, and introduced grasses. Between 1970 and 1989 (Atkinson 2003) Chatham Island snipe, black robins, shore plover, and Chatham Island tomtits were reintroduced. The Island is also important for several threatened species of invertebrate; the Rangatira spider, the coxella weevil which lives on the last remaining area of Dieffenbach's speargrass found only on Mangere Island, the giant click beetle (*Amychus candezei*) as well as a flightless carabid beetle (*Mecodema alterans*), a nocturnal flightless stag beetle (*Geodorcus capito*), plus a number of moths. Skinks are abundant on the island. In addition to the above mentioned birds there are sooty shearwaters, fairy prions, broad billed prions, black-winged petrels, blue penguins, Chatham Island oyster catchers, Pitt Island shags, red-billed gulls and white-fronted terns. Land birds include brown skua, Forbes parakeet, and Chatham Islands warblers, tuis, and parakeets.

1.1.3. Mangere Island Physiography (Figs.2 and 3).

The Island can be divided into 3 major topographic units:

1. A top plateau to the north, bounded on its northern and western sides by 200 metre-high cliffs of massive resistant breccia which rise almost vertically from the sea. The eastern side of the plateau falls precipitously to Black Robin Bush where huge blocks fallen from the cliff above are scattered on a colluvial footslope that extends to the shoreline.
2. To the south, the top plateau gives way to the more gently sloping Douglas Basin and this merges into:
3. A long narrow, generally steep sided southwest-trending peninsula with a central ridge attaining a height of no more than 100 m. The lowest part of this peninsula is occupied by the Mangere Formation (as defined by Campbell *et al.* 1993), a flat lying sedimentary sequence, 350 metres long and averaging about 175 metres wide with the highest point at 72 m.a.s.l.(metres above sea level) (Figs. 2 and 3). The lower part of the formation is a skirt sloping away from a layered sequence at about 40° (Figs. 4 and 5). The cliff face of the layered sequence slopes at about 60° and the upper part is near vertical.

Although the prevailing wind direction is southwest, northwesterlies are frequent. The western side of the island is thus subject to a high frequency of rough seas which account for the steep cliffs of the indurated northern massif of Mangere Island and Little Mangere Island, as well as wave-cut platforms which occur only on the southwest-trending peninsula and are also partly a consequence of its much less consolidated lithology.

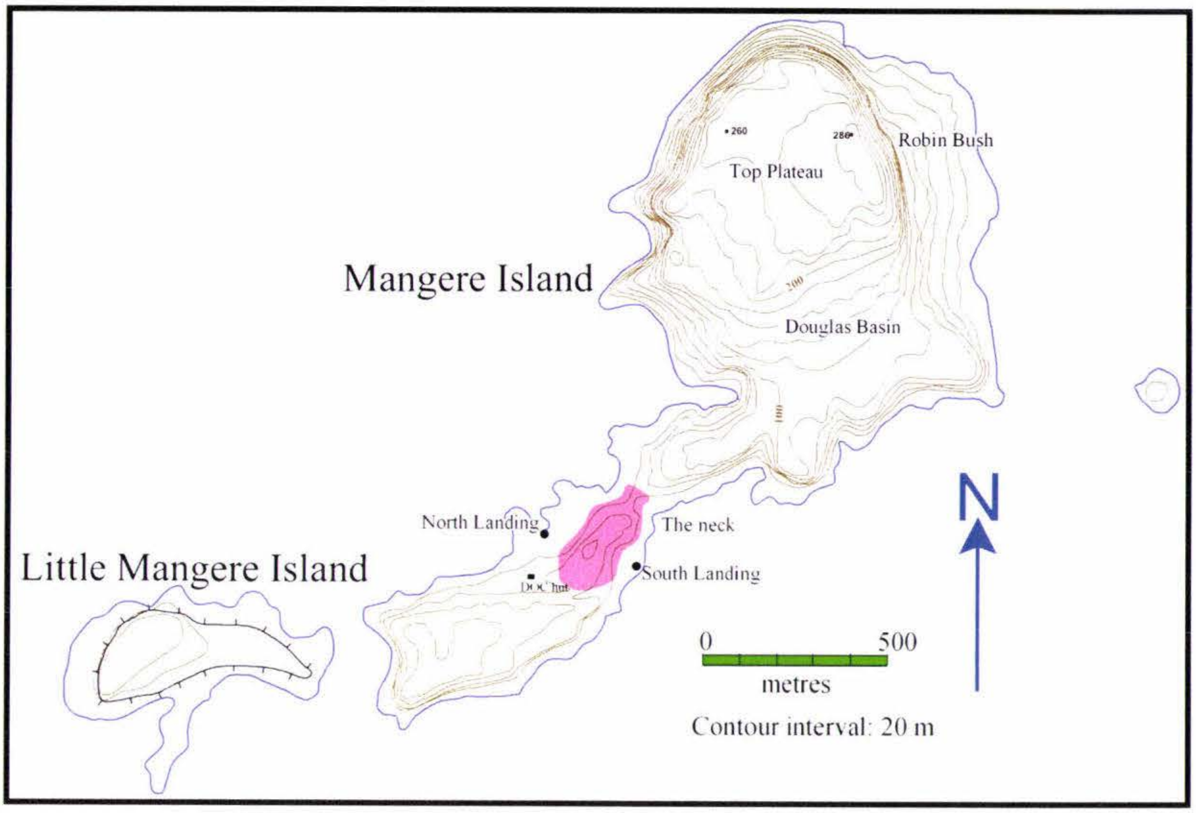

Figure 2. Location map for Mangere Island showing the extent of Mangere Formation (maroon colour). The place names on Mangere Island are informal names used by local people and the Department of Conservation.

The "tick" symbol on little Mangere Island indicates a vertical rock face.

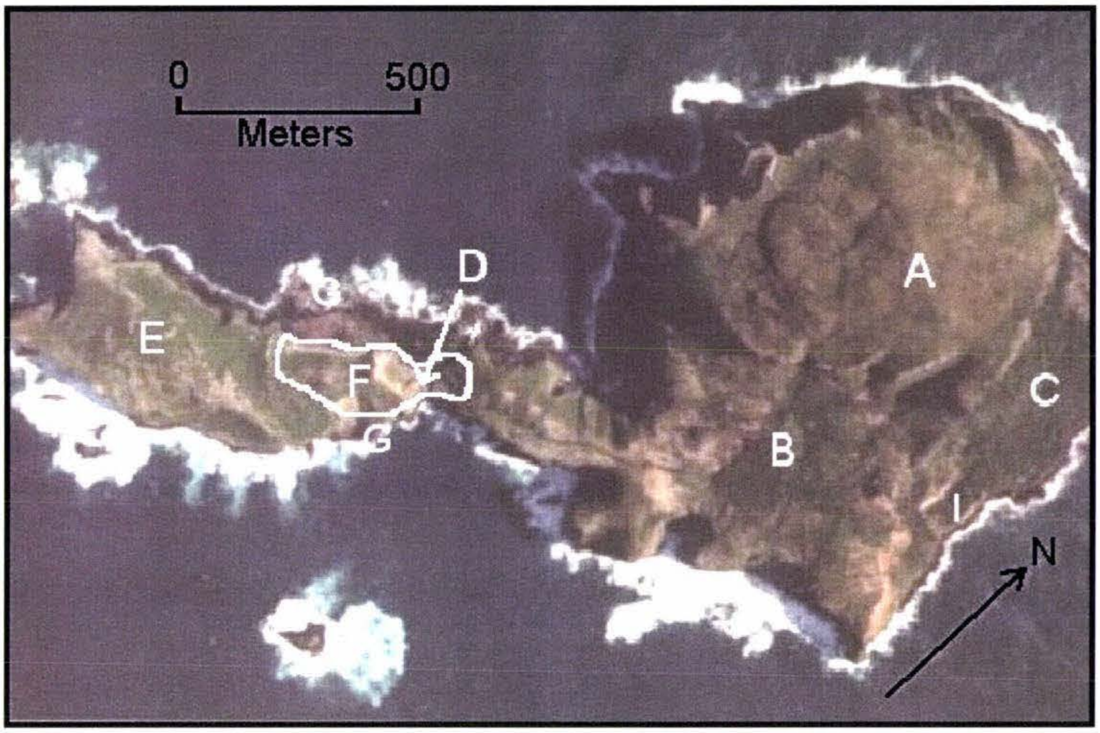

Figure 3. Aerial photo of Mangere Island showing: A; Top Plateau, B; Douglas Basin, C; rockfall footslope (covered by Robin Bush), D; The Neck, E; the lower peninsula, F; the extent of the Mangere Formation, G; wave cut platform, I; Tupuangi Formation. The green lines on the Top Plateau and the lower peninsula are akeake hedges planted as part of a Department of Conservation (DOC) reafforestation programme. Photo: Dept. of Lands and Survey.

Figure 4. View of Mangere Formation taken from the North Landing. The DOC hut is the white object at the extreme centre right of the photograph and The Neck is at the extreme left. The North Landing is marked by the "X"at centre foreground. The South Landing is opposite this on the other side of the Mangere Formation. The photograph was taken from the seaward edge of the wave-cut platform.

Figure 5. View of Mangere Formation taken from Douglas Basin looking southwest along the lower peninsula. The Mangere Formation remnant is the hill in the centre of the photograph. The North Landing is marked with an "X" at the end of the inlet in the wave-cut platform just below the hut at the centre right. The South Landing, "Y", is on the wave-cut platform at the centre left of the photograph. Little Mangere Island is at the top right hand corner. (Photo: Mark Bellingham).

1.2.0. Regional Geology.

Introduction.

The Chatham Islands lie on the easternmost emergent structural high of the Chatham Rise. The Chatham Rise is a shallowly submerged (to about 400 m along its crest) block of continental crust which was probably formed at the edge of the proto-Pacific plate when it was Gondwana (Campbell *et al.* 1993, p. 29). Structurally the Chatham Rise extends about 250 km to the east of the Chatham Islands and 950 km west to the Alpine Fault and is about 100 km wide. The Rise was originally part of Gondwana and probably adjacent to Antarctica. The Rise is bounded to the north by the Hikurangi Plateau and to the south by the Bounty Trough. The Mernoo Gap at the western end of the Rise is part of a foreland basin which includes the Canterbury Plains and shelf and which developed during Late Miocene time (Fig. 6). The Chatham Islands is the only emergent area on the Rise. There is no satisfactory explanation for this at present although the Islands themselves may be the result of thermal uplift associated with Late Cretaceous volcanism. In the past the Veryan and Mernoo Banks may have been emergent as there is evidence of erosion on them (Campbell *et al.* 1993).

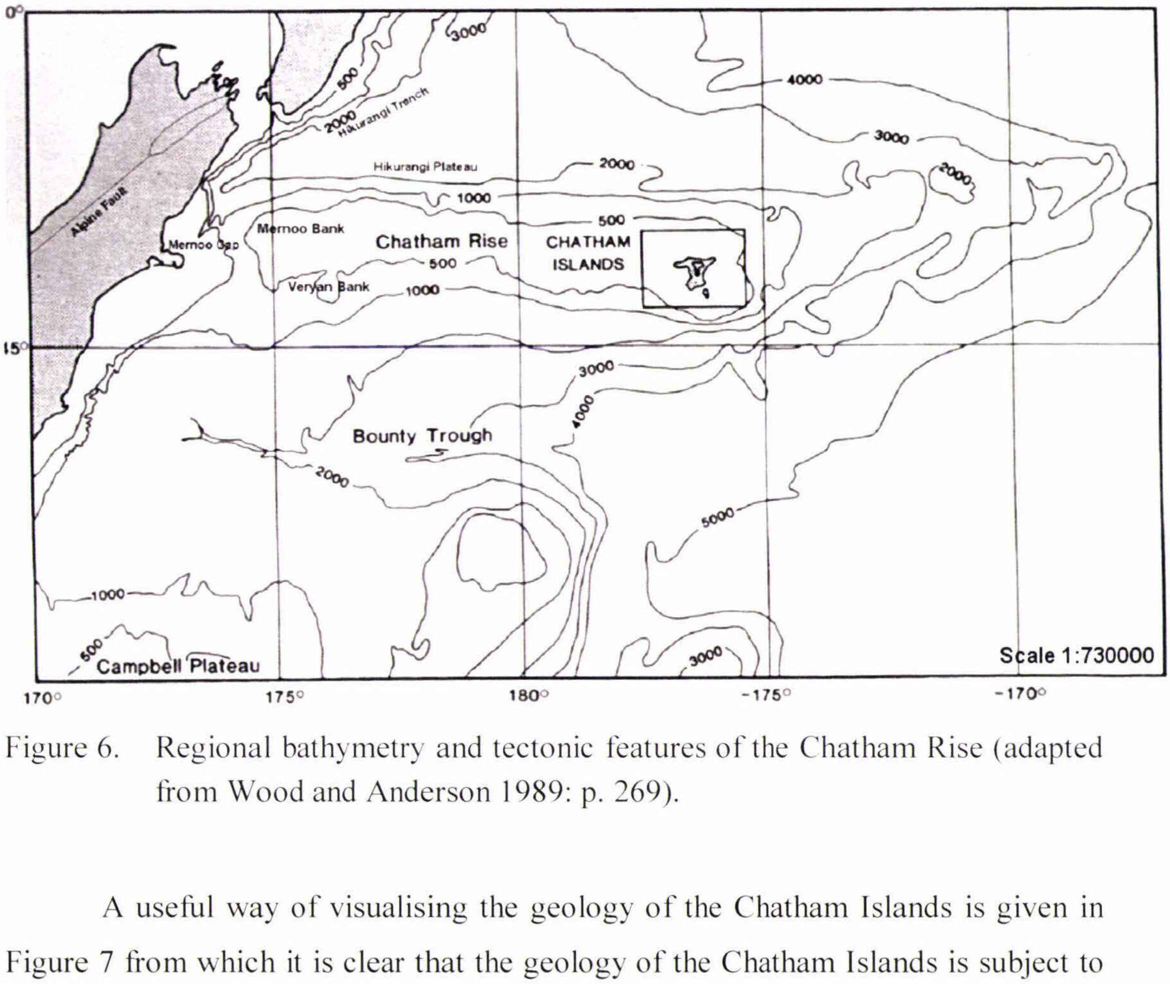

Figure 6. Regional bathymetry and tectonic features of the Chatham Rise (adapted from Wood and Anderson 1989: p. 269).

A useful way of visualising the geology of the Chatham Islands is given in Figure 7 from which it is clear that the geology of the Chatham Islands is subject to many hiatuses. The stratigraphic abbreviations used in the text refer to the geological map (Campbell *et al.* 1993) of the Chathams and its key (Figs. 8 and 9). A number of minor stratigraphic units which do not occur on either Pitt Island or Mangere Island will be only briefly discussed for completeness. Much of what follows is adapted from Campbell *et al.* (1993).

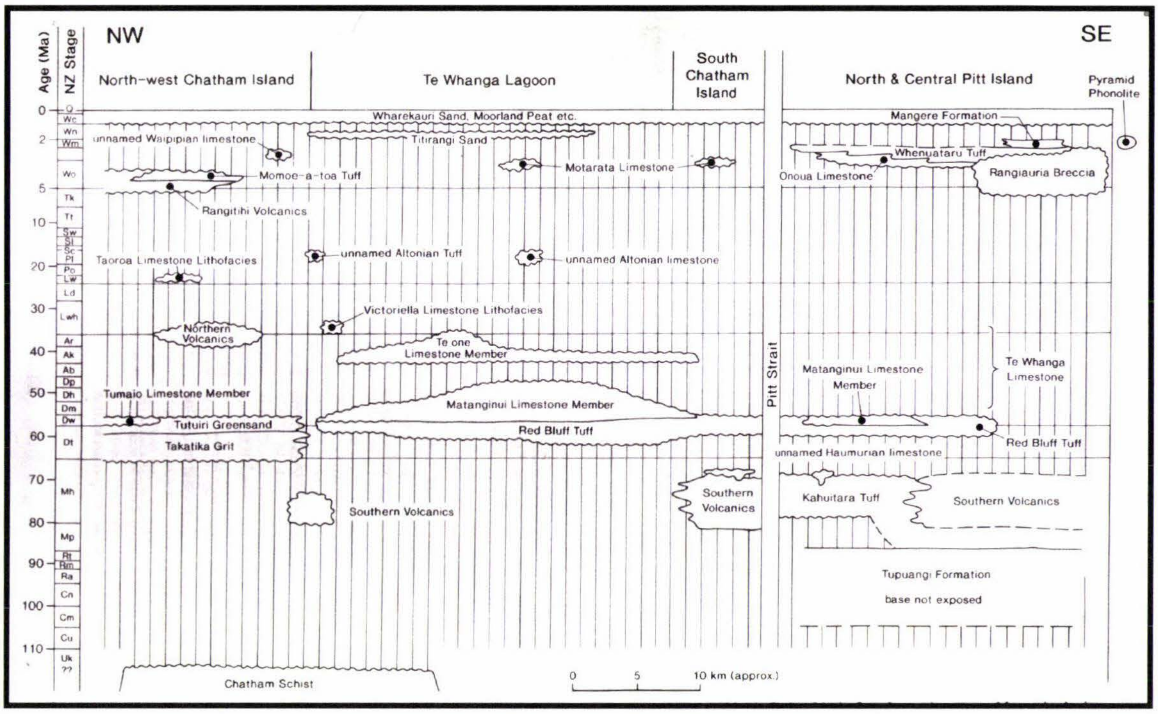

Figure 7. Space-time diagram showing the general relationships of known stratigraphic units in the Chatham Islands. (From Campbell *et al.* 1993, p12).

Chatham Schist (bc).

During the Permian and Triassic (perhaps earlier), volcanic and quartzofeldspathic sediments were deposited in a deep marine environment on the margin of the proto-Pacific plate where burial transformed them into greywacke and argillite. During the Mid-Jurassic (*ca.* 164 Ma) they were largely metamorphosed to schist (Adams and Robinson 1977, p. 296) as a result of a major collision between these quartzofeldspathic Torlesse terrain sediments and the Caples/ Aspiring and Murihiku terrains thus forming the future basement of the Chatham Rise and Chatham Islands. This basement also underlies Mangere Island as is demonstrated by schist xenoliths in the Rangiauria Breccia.

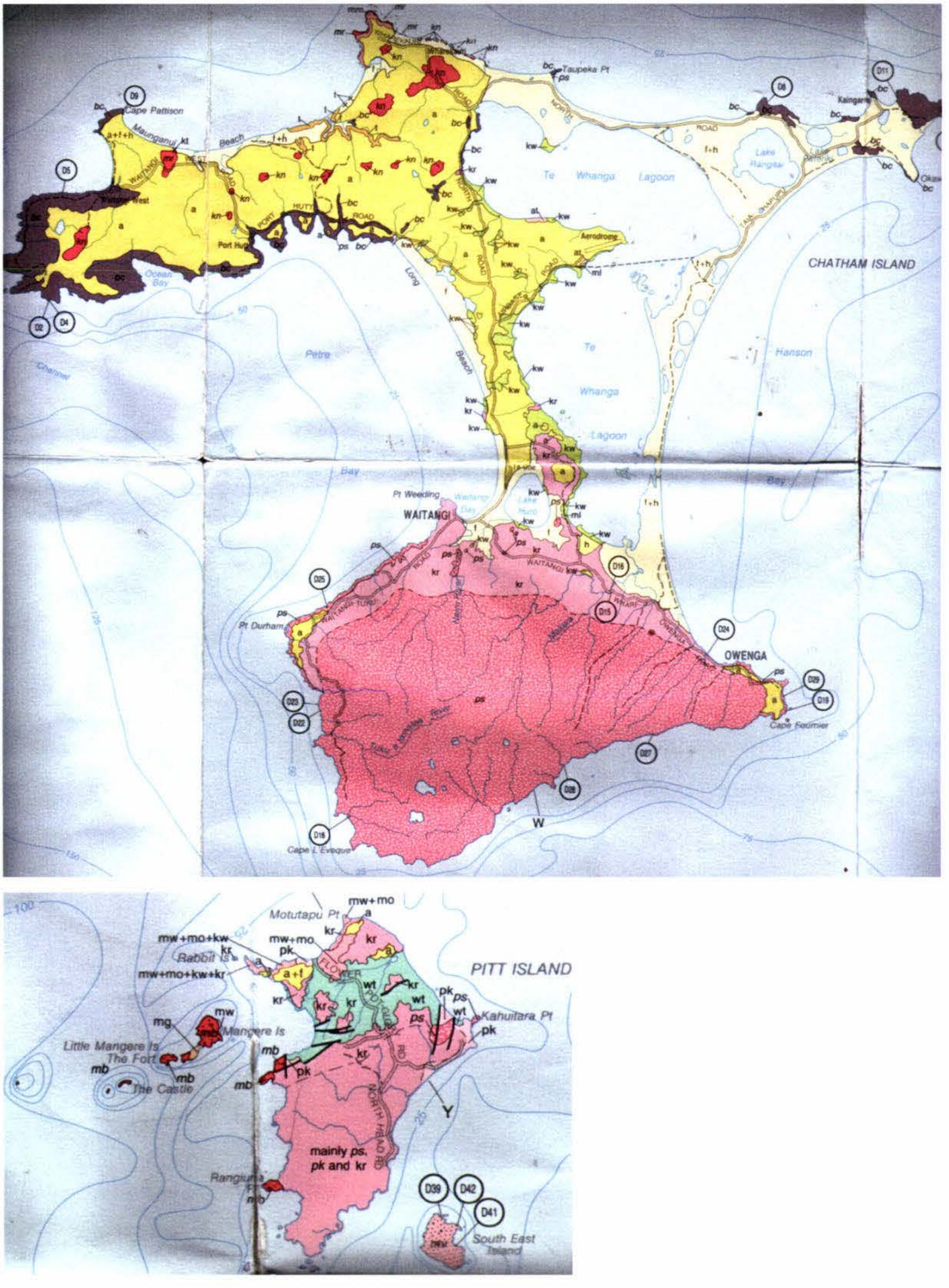

Figure 8. Geological map of the Chatham Islands. (from Campbell *et al.* 1993).

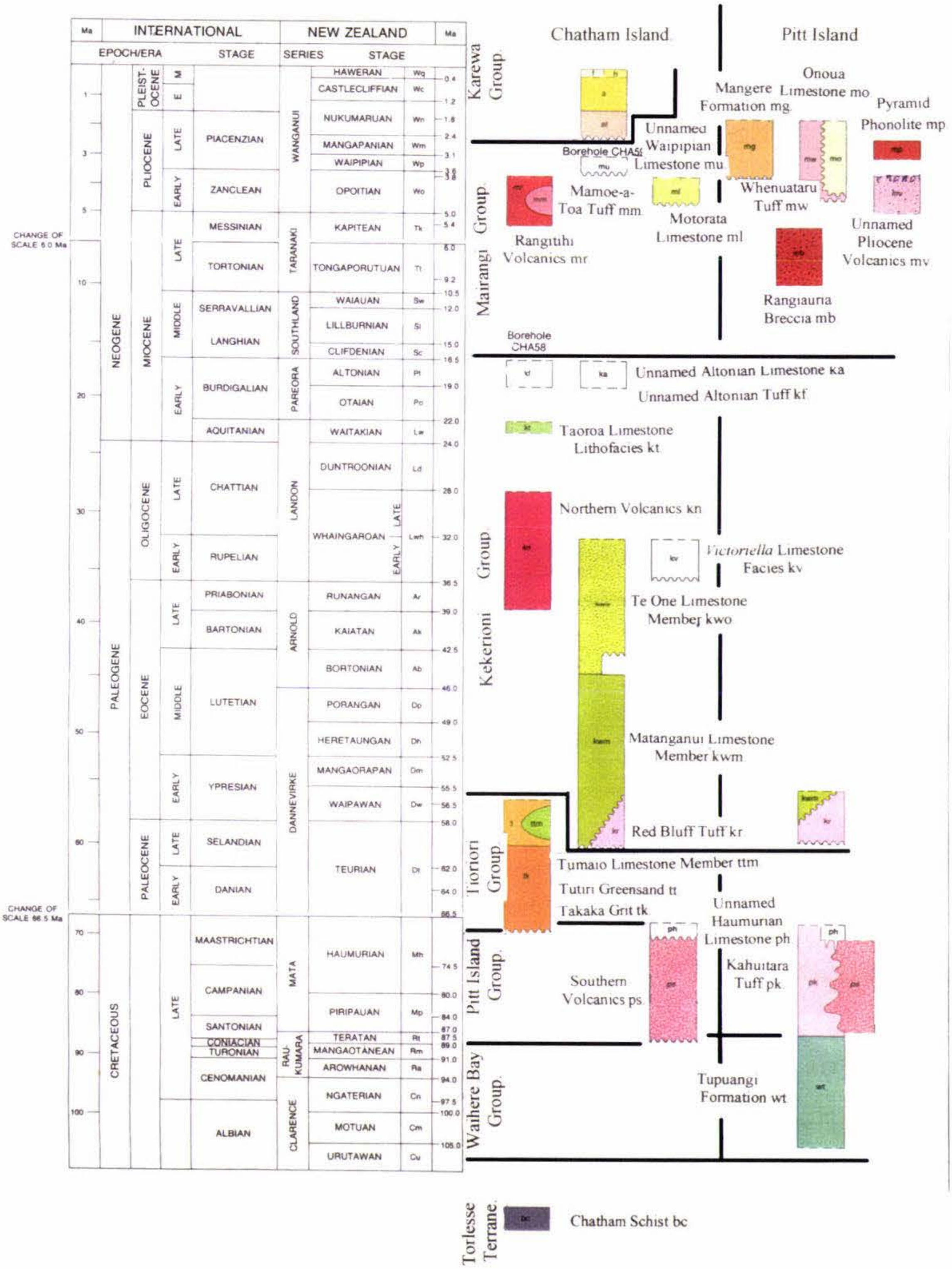

Figure 9. Key to geological map of Chatham Islands (Fig. 8). (modified from Campbell *et al.* 1993).

Based on an assumption that there is no fault in Pitt Strait and with a uniform dip of 1° of the schist surface from Chatham Island, Campbell *et al.* (1993, p 128) estimated the schist would be 830-900 m below sea level at Mangere Island. However, the situation is more complicated at Pitt and Mangere Islands since (a) the well exposed Tupuangi Formation on Pitt Island suggests there is a fault in Pitt Strait and (b) as a result of faulting and doming in the Pitt/Mangere area, the Tupuangi Formation dips generally somewhat less than 20° to the southeast on Pitt Island and 14° to the northwest on Mangere Island. Further, the Tupuangi Formation on Mangere Island is faulted with an unknown downthrow to the south where it underlies the Mangere Formation. Thus, under the northern part of Mangere Island the schist is probably considerably nearer the surface but dipping to the west, and under the southern part of the island the schist is an unknown amount deeper, but presumably with a similar attitude.

It is probable that the whole Chatham Rise has always been proximal to the Pacific Plate boundary (Campbell *et al.*, 1993, p 29). There is seismic reflection evidence that the basement of the Hikurangi Plateau may dip beneath the Chatham Rise with the possibility that it was once a convergent margin (Bradshaw *et al*, 1981, Campbell *et al.*, 1993, p 30). However this is not upheld by King (2000) who shows no convergence along the northern margin of the Chatham Rise in his series of reconstructions of the New Zealand area. The southern margin of the Rise borders the Bounty Trough which was formed by rifting in mid-to-late Cretaceous times (105 to 75 Ma), (Wood *et al.*, 1989, p 281) accompanied by rifting and tensional crustal thinning. This tension, in turn, resulted in east-west horst and half-graben structures on the eastern Rise which are major controls on the present geology of the Chatham Islands. The rifting which began in the Lower Cretaceous resulted in the separation of the New Zealand continental area from Gondwana in the Upper Cretaceous (85 to 87 Ma). The Chatham Rise, as part of the Pacific Plate, began its rotation to its present position at this time.

Waihere Bay Group (w).

While still part of Gondwana the half grabens were mainly filled (87 to 105 Ma) with horizontal quartzofeldspathic sediments of Tupuangi Formation which now dip gently south to southeast (Fig. 8). Tupuangi sediments are generally grey to dark grey and poorly consolidated with an estimated thickness of at least 700 m (Campbell *et al.*, 1993, p 37).

They are best exposed as a series of fault blocks in Waihere Bay opposite Mangere Island. The sediments include conglomerate with discoid pebbles near the base, silty sandstones, sandy siltstones and lignite with some basalt and rhyolite volcaniclastics. They are generally rich in pollen, leaves, and wood with rare macrofossils at the base. They are tuffaceous near the top and gradually grade into the massive Kahuitara Tuff. From palaeocurrent trends (Campbell *et al.* 1993) the sediments appear to have been derived mainly from the slowly prograding delta of an emergent landmass the north northeast (Fig. 10). These sediments appear to have come from a Permian–Triassic source, as reworked Permian–Triassic palynomorphs are found in both the Tupuangi Formation and the Kahuitara Tuff (Mildenhall and Crosbie 1981 pp.2-23; Mildenhall 1983 p.165). At this time it is thought that much of the Rise was emergent (Campbell *et al.* 1993 pp. 29, 41, 43). The Tupuangi Formation is nowhere exposed on Chatham Island and its base is not exposed on Pitt Island. Offshore seismic evidence and velocity data (Austin *et al.* 1973; Wood and Ingham 1981; Campbell *et al.* 1993 p. 35) suggest that older unexposed sedimentary sequences of inferred Cretaceous age underlie the Tupuangi Formation and may be the provenance from which the lowest units of the Tupuangi Formation are partly derived. These studies also show that there is an unconformity between these units and the Chatham Schist. The Tupuangi Formation is shown in this study to be present on Mangere Island.

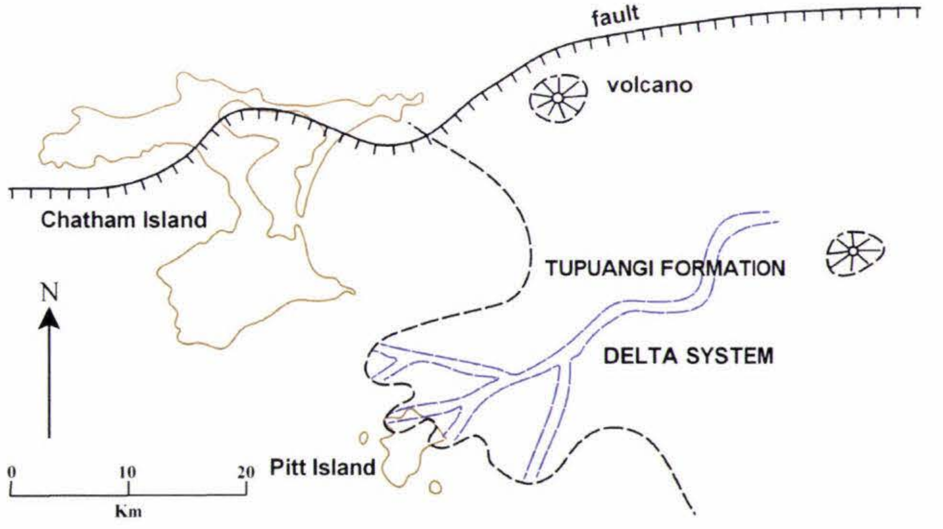

Figure 10. Paleogeographic reconstruction of the Chatham Island area during Tupuangi time (from Campbell *et al.* 1993 p. 41). This study shows that Tupuangi Formation extended at least as far west as Mangere Island.

Pitt Island Group (p).

Introduction.

The Pitt Island Group immediately, and mainly conformably, followed the deposition of the Tupuangi Formation. It represents a prolonged episode of volcanism which occurred from *ca.* 87 to 70 Ma in the Upper Cretaceous (Campbell *et al.* 1993, p. 54). It consisted of basaltic flows together with the deposition of Kahuitara Tuff and an unnamed Haumurian limestone. These lithologies consist of the southern portions of Chatham Island and Pitt Island and probably underlie or extend out towards Mangere Island. It was at this time that crustal extension finally separated the New Zealand continental area from Gondwana. Thermal uplift from late Cretaceous volcanism resulted in the raising and emergence of fault blocks. Evidence for this includes the basement horsts which are exposed in Chatham Schist, northwestern Chatham Island, and graben fill on Pitt Island. Graben filling ceased during latest Cretaceous time with minor folding, peneplanation, thermal subsidence and eruption of the Southern Volcanics in the form of several large alkaline volcanoes (Campbell *et al.* 1993 p. 29). Following this there was a period of widespread mild tectonism in the Palaeocene/Eocene when Cretaceous normal faults were reactivated, especially to the west, and the clastic Red Bluff Tuff was deposited. Through most of the Tertiary, periods of limestone deposition (xenoliths from some of these are common in the Rangiauria Breccia on Mangere Island), alternated with periods of volcanism interspersed with prolonged periods of non-deposition or erosion between episodes as is shown in Figure 7. Little appears to be known of what happened during these non-depositional periods.

Kahuitara Tuff (pk).

There are no known outcrops of Kahuitara Tuff on Chatham Island. The Tuff is brown-grey and massive to well bedded. It consists of volcaniclastic sandstone, scoriaceous conglomerate, and lapilli tuff of basaltic composition, with bombs in the basal units. Its thickness is *ca.* 225 m and it is unconformable with the Tupuangi Formation to the northeast but is conformable in northwestern Pitt Island (Campbell *et al.* 1993 pp. 50,55). Fissure fill of an unnamed Haumurian limestone contains foraminifera of outer shelf depth (100 – 200 m). The Kahuitara Tuff contains macrofossils and a shallow water (5 to 50 m) foraminifera fauna which indicates deepening in Haumurian time (Strong and Edwards 1979 p. 615; Campbell *et al.* 1993 p. 50). Faulting in the tuff is probably associated with the late Miocene/early Pliocene volcanism that produced Mangere Volcano, and Waihere and Rangiauria Heads (Campbell *et al.* 1993 p. 53). At eastern Pitt Island, deposition of Kahuitara Tuff was interrupted at *ca.* 80 Ma (middle Piripauan; early Campanian) by the extrusion of a thick olivine basalt (Southern Volcanics). In northwestern Pitt Island deposition of Kahuitara Tuff continued contemporaneously with the extrusive volcanism, both ceasing at about 70 Ma (late Haumurian; early Maastrichtian) (Campbell *et al.* 1993 p. 55).

Southern Volcanics (ps).

Extensive areas of Southern Volcanics are found in the south of Chatham Island where they attain a thickness of 300 m, and also to the south and east of Pitt Island where they attain a thickness of at least 150 m. The volcanics consist essentially of alkaline olivine basalt hawaiites, (Morris, 1985a, p 255) dominated by flows 5-10 m thick on Chatham Island, and 5-20 m thick on Pitt Island, where tuff and scoria deposits alternate with the flows. Columnar jointing, pillow basalt, agglomerate, breccia, hyaloclastite, trachyte and basalt dikes are common. There is no fossil content (Campbell *et al.* 1993 p. 57). This unit is of Haumurian age, and is subaerial and shallow marine. Volcanism ceased at about 70 Ma (late Haumurian) and a period of non-deposition or erosion that lasted 4 m.y. ensued (Campbell *et al.* 1993 p. 57). The source of the Kahuitara Tuff and Southern Volcanics is in southern Chatham Island or beneath Pitt Strait. This has been determined from flow sequences (Hay *et al.* 1970; Morris 1985a p. 254) and magnetic survey data (Austin *et al.* 1973; Yakunin and Schoernharting 1971 (quoted in Campbell *et al*, 1993); Campbell *et al.* 1993 p. 57 Strong and Edwards 1979 p. 615). Associated with the tuff are the carbonate minerals dolomite, ankerite and siderite. Its age is late Haumurian.

Tioriori Group (t).

Introduction.

This group is not related to Pitt or Mangere Island stratigraphy but is mentioned briefly for completeness. The Tioriori Group is Haumurian to early Waipawan in age and includes Takitika Grit, Tutuiri Greensand, and Tumaio

Limestone Member. It is restricted to northwestern Chatham Island and rests unconformably on Chatham Schist. It consists essentially of a thin sequence of non-tuffaceous, quartzofelspathic, schist-derived very coarse sandstone, sometimes rich in authigenic minerals, and includes minor bioclastic limestone bodies (Campbell *et al.* 1993 p. 60).

Kekerione Group (k).

Introduction.

Kekerione Group (represented on Mangere Island as xenoliths in Rangiauria Breccia) is "...a widespread but discontinuous, essentially volcaniclastic succession of fossiliferous marine palagonitic tuff, tuff breccia, minor basalt flows, and associated bioclastic limestone which ranges in age from Paleocene to Oligocene. The group includes nine units: Red Bluff Tuff; TeWhanga Limestone with at least two members- Matanginui Limestone and Te One Limestone; Northern volcanics; two restricted limestone lithofacies lenses – *Victoriella* Limestone and Taoroa Limestone; an unnamed Altonian tuff and an unnamed Altonian limestone" (Campbell *et al.* 1993 p. 73).

Red Bluff Tuff (kr).

Red Bluff Tuff is at least 100 m thick and covers large areas of Chatham and Pitt Islands. It is fossiliferous and largely marine. It was possibly derived from Surtseyian-type volcanism (Campbell *et al* 1993 p. 88) and this study shows that it may have supplied material to the Mangere Formation as defined by Campbell *et al.* (1993). It is essentially a calcareous tuff of basaltic composition containing beds of lapillistone and tuff-breccia. It is generally a yellow-brown to brick-red colour but basal parts are dark green and grey-brown. It is generally well bedded with cross bedding and graded bedding indicative of water sorting. Red Bluff Tuff unconformably overlies the Southern Volcanics and Kahuitara Tuff and is unconformably overlain by all units younger than the Matanginui Member. Fossil evidence shows it to be coeval with Tutiri Greensand. Its age is late Paleocene to early Eocene. It has a rich fossil content of spores, pollen, foraminifera, calcareous nanofossils, sponges, corals, bryozoans, brachiopods, bivalves, nautiloids, echinoderms, teeth, and trace fossils from many localities, giving an age of late

Teurian to late Waipawan. Cross-bedding is common suggesting shallow marine deposition with a northeast-southwest current regime. On the other hand the fossil evidence suggests a mid-shelf to bathyl environment (Campbell *et al.* 1993 pp. 74, 75, 88).

Te Whanga Limestone (kw).

Introduction.

Te Whanga Limestone includes Matanginui Limestone Member, Te One Limestone Member and Undifferentiated Te Whanga limestones (some outcrops are undifferentiated and cannot be assigned to either member).

Matanginui Limestone Member (kwm).

Matanginui Limestone is, "... a soft, white, poorly bedded bryozoan-echinoid-formaminiferal-bivalve packstone" (Campbell *et al.* 1993 p. 89). It is at least 35 m thick and is the lower member of Te Whanga Limestone. It is conformable, or interfingers with Red Bluff Tuff and is disconformable with overlying units. It was deposited in the Waipawan-Bortonian in moderately deep oceanic water, although the presence of *Asterocyclina*, a warm relatively shallow water species in some beds may indicate changes in water depth (Campbell *et al.* 1993 p. 95). On Mangere Island it appears as large xenoliths in the Rangiauria Breccia.

Te One Limestone Member (kwo).

Te One Limestone Member is a pale, soft, massive, porous bryozoan grainstone. It is pale yellow to medium orange-grey and is found only on Chatham Island. It was deposited in the Kaiatan to early Whaingaroan and is greater than 25 m thick. It disconformably overlies the Red Bluff Tuff and the Matanginui Limestone. It is also disconformably overlain by Motorata Limestone and the Karewa Group. The fossil assemblage is mid-to-outer shelf and includes vertebrate bones and teeth, bryozoans, brachiopods, bivalves, barnacles, and echinoderms (Campbell *et al.* 1993 pp. 88, 89, 95, 98, 102).

Northern Volcanics (kn).

This group is not directly related to Pitt or Mangere Island but is briefly mentioned for completeness.

Northern volcanics are made up of cones up to 140 m high standing directly on the Chatham Schist, and are overlain by Karewa Group sediments. The cones are made up of massive, extrusive, limburgitic basalt, plus extrusive agglomeritic and scoriaceous deposits. The massive flows are pale grey to black when unweathered but are usually weathered to brown. Accompanying volcaniclastic deposits are strong reds and browns. The deposits are unfossiliferous but radiometric dating shows them to be of Eocene- Oligocene age. The volcanic products suggest Strombolian type episodic flow and diatreme volcanism (Morris 1985b; Campbell *et al.* 1993 p. 107).

Mairangi Group (m).

Introduction.

Mairangi Group is largely volcanic limburgitic basalt with richly fossiliferous volaniclastics and tuffs as well as some bioclastic limestone. The group includes Rangitahi Volcanics, Momoe-a-toa Tuff, Rangiauria Breccia, Mangere Formation, Whenuataru Tuff, Onoua Limestone, Motorata Limestone, Pyramid Phonolite, an unnamed Waipipian limestone and unnamed Pliocene volcanics.

Rangitihi Volcanics (mr).

The limbugitic, basaltic, Rangitihi Volcanics are composed of massive extrusive and intrusive rocks with associated agglomerate, scoriacious and tuffaceous deposits. They are at least 100 m thick and were initially submarine, with later pyroclastic deposits above sea level. The unit is unfossiliferous. Radiometric ages range from 4.54 ± 0.3 Ma to 5.3 ± 0.4 Ma (Campbell *et al.* 1993 p.117) and average 5 Ma. Thus the unit is Late Miocene to Early Pliocene in age.

Momoe-a-toa Tuff (mm).

Momoe-a-toa Tuff is made up of dark grey, medium yellow-brown and medium red-brown hornblende-rich, fine to coarse volcaniclastic sandstone and limburgitic basalt tuff. It appears to be greater than 120 m in thickness, is marine and richly fossiliferous. It rests unconformably on the Rangitihi Volcanics and is disconformably overlain by Rangitihi Volcanics and/or Kawera Group sediments. The macro-and micropaleontological evidence suggests a mid-to-inner shelf environment of deposition (Campbell *et al.* 1993).

Rangiauria Breccia (mb).

Rangiauria Breccia is found at Rangiauria and Waihere Heads, and at the south end of Pebbly Beach on Pitt Island and on Mangere Island. The Breccia is Late Miocene and comprises hard, dark grey-brown massive to crudely bedded, poorly sorted, coarse, pyroclastic breccia of limburgitic basalt composition. It contains very large crystals of hornblende and has an abundant xenolith component of igneous, metamorphic and sedimentary lithologies derived mainly from the Waihere Bay, Pitt Island, Kekerione, and Mairangi Groups. On Mangere Island it is the source of much of the material making up the Mangere Formation. Grain size is from large boulders to fine sand with highly vesicular smaller basalt clasts. Thickness is greater than 300 m. It is unconformable with all older units and is disconformably overlain by Whenuataru Tuff and units of the Quaternary Karewa Group. Often the clasts are set in a matrix of finely comminuted debris but elsewhere the clasts are surrounded by limburgite. It contains some wood fossils and fossiliferous limestone xenoliths Campbell *et al.* (1993).

Motarata Limestone (ml).

Motarata Limestone is early Pliocene in age and is pale yellow-brown, massive, soft, well sorted, sandy fine foraminiferal grainstone with a basal layer of phosphorite pebbles. It is more than 5 m thick and rests disconformably on Red Bluff Tuff. Fossil evidence shows it was deposited on the mid-to-outer shelf Campbell *et al.* (1993).

Onoua Limestone (mo).

Onoua Limestone, early (?) to late Pliocene, is a white to pale yellow, massive, soft, porous, well sorted, glauconitic fine bryozoan grainstone, composed of bryozoans, foraminifera, brachiopods, bivalves and echinoderm fragments. It is at least 26 m thick and is unconformable with the Red Bluff Tuff and Matanginui Limestone, but is conformably and gradationally overlain by Whenuataru Tuff and in places interfingers with it. It was deposited on the outer part of an oceanic platform at depths of mid-to-outer shelf (Campbell *et al.* 1993).

Whenuataru Tuff (mw).

Whenuataru Tuff is Early to Late Pliocene in age, brown-grey to red-brown, massive to well bedded, volcaniclastic sand, silt and palagonite tuff of limburgitic basalt composition with large hornblende crystals. It is marine, fossiliferous and some beds contain blocks and bombs. It is up to 50 m thick and overlies either Onoua Limestone conformably or Red Bluff Tuff unconformably. Whenuataru Tuff is very fossiliferous with abundant macro-and microfossils and was deposited between the outer and inner shelf. On Mangere Island the Tuff is thought to form part of the low-lying, northeastern coastal strip where it conformably overlies Rangiauria Breccia and is conformably overlain by Mangere Formation (Campbell *et al.* 1993 p. 136). On the northwestern shore of Mangere Island, in the vicinity of the North Landing, the "...Rangiauria Breccia is overlain, apparently conformably, by about 7.5 m of coarse tuffaceous sandstone with thin lensing beds of well stratified Whenuataru Tuff which in turn is overlain by the Mangere Formation...On the evidence available the tuff was laid down immediately after the formation of the Rangiauria Breccia on Mangere Island following collapse of the central part of the volcano and incursion of the sea" (Campbell *et al.* 1993 p. 148). (In this study the unit underlying the Mangere Formation is not considered to be Whenuataru Tuff and has been renamed "Bag End Breccia" from the name of an informal site in Black Robin Bush).

Mangere Formation mg. (as defined by Campbell *et al.* 1993).

Mangere Formation is of Late Pliocene age and is made up of flat-lying, well bedded, well sorted, generally fine-grained sediments of partly volcaniclastic and tuffaceous limburgitic basalt, and partly terrigenous quartzofeldspathic composition. The Formation is fossiliferous, non-marine and thought to occur only on Mangere Island although, according to Campbell *et al.*, (1993, p 149), a thin poorly exposed tuffaceous sandstone on the summit of Kaingaroa Hill, Pitt Island, may belong to the

Formation. It conformably overlies Bag End breccia (Campbell *et al*'s. 1993 Whenuataru Tuff) and is approximately 60 m thick. The Formation contains fossil wood fragments, spores, pollen, dinoflagellates and acritarchs especially in the lower part, which is also concretionary. To date no foraminifera, calcareous nanofossils, diatoms or sponge spicules have been found (Campbell *et al*. 1993 p. 149). Most of the pollen and dinoflagellates are reworked and derived from the Tupuangi Formation. The extinct Mangapanian pollen, *Rhoipites alveolatus*, puts an upper limit on the age of the Formation (Mildenhall in Campbell *et al*. 1993 p. 150) though it is not clear exactly where in the Formation *R. alveolatus* was found. Also the possible occurrence of *Epilobium* (again, it is not clear exactly where in the Formation this was found) puts a lower limit on the Formation of Opoitian age (Campbell, *et al*. 1993 p.150). Only reworked marine fossils have been found in this Formation suggesting that most of the Formation was deposited under terrestrial conditions in the collapsed crater of the Mangere Volcano with periods of lacustrine deposition. It is thought that the formation is a remnant that was once spread over part of the area west of Pitt Island (Campbell *et al*. 1993 p. 150).

Pyramid Phonolite (mp).

Pyramid Phonolite is a hard dark green-grey fine grained alkaline rock. It forms a single plug 9 km south of Pitt Island rising to 174 m above sea level and radiometrically dated at 3.9 Ma Campbell *et al*. (1993).

Unnamed Pliocene volcanics (mv).

These occur on South East and Round Islands as a result of submarine eruptions. They are bedded, dark pyroclastic rock of basaltic composition and dominated by lapilli tuff breccia with xenoliths of Southern Volcanics and Te Whanga Limestone. Their thickness is more than 150 m Campbell *et al*. (1993).

Karewa Group (a).

These are all Late Pliocene to Recent deposits and consist of sands, peat, shell beds and tephra. They occur almost entirely on Chatham Island although small areas are found in the vicinity of Kaingaroa and Moffett trig on Pitt Island.

1.3.0. Previous work on Mangere Island.

Prior to this study very little geological work had been done on Mangere Island and even less on the Mangere Formation. The geology was first described in Hay *et al.* (1957) who made "...two visits of a week each to Pitt Island, and a brief landing on Mangere..." (p 7). They recognised two formations on Mangere Island: the Rangiauria Agglomerate, (named after the precipitous "hard, dark massive agglomerate" at Rangiauria and Waihere Heads on Pitt Island as well as at the southern end of Pebbly Beach and the Mangere Agglomerate (on Mangere Island only) which made up, "...the low lying south-west part of Mangere Island." (Fig. 11).

Hay *et al.* (1970 p. 42) described the Whenuataru Tuff from Pitt Island as beds consisting of "...brown calcareous palagonite tuff with occasional pillow lava near the base. The tuff is richly fossiliferous, displays prominent current bedding and contains abundant hornblende crystals." No mention is made of Whenuataru Tuff on Mangere Island. Campbell *et al.* (1993 p. 136) describes it as, "...brown-grey to red-brown, massive to well bedded volcaniclastic sand, silt and palagonite tuff (crystal, lithic) of limburgitic basalt composition. Some beds are calcareous. Some are locally coarse, containing blocks and bombs. It is richly fossiliferous, marine, and restricted to Pitt Island and its adjacent islets."

Watters (in Campbell *et al.* 1993 p. 148) reports, "Whenuataru Tuff is believed to form part of the low-lying coastal strip in the northeastern part of Mangere Island...(and)... Along the northwestern shore of the narrow part of Mangere Island, the Rangiauria Breccia is overlain, apparently conformably, by about 7.5 m of coarse tuffaceous sandstone with thin (<20 cm) lensing beds of well stratified tuff." This in turn is overlain by the Mangere Formation. Watters (in Hay *et al.* 1970 p. 71) interpreted the volcanism as explosive and short lived, noting that there were no lava flows. He gave a detailed account of the petrography of these formations (Hay *et al.* 1970 pp. 69-71) and the relationship between the two agglomerates was interpreted as "...the low lying Mangere Agglomerate" being "the collapsed central portion of a wide volcanic vent, the outer part of which is represented by the two high remnants of Rangiauria Agglomerate forming Little Mangere Island and the high north-east part of Mangere." (Fig. 12). It is noteworthy that Hay *et al.* (1970 p. 69) did not recognise the Mangere Formation (Campbell *et al.* 1993) in the lowest part of Mangere Island as being distinct from the Mangere Agglomerate.

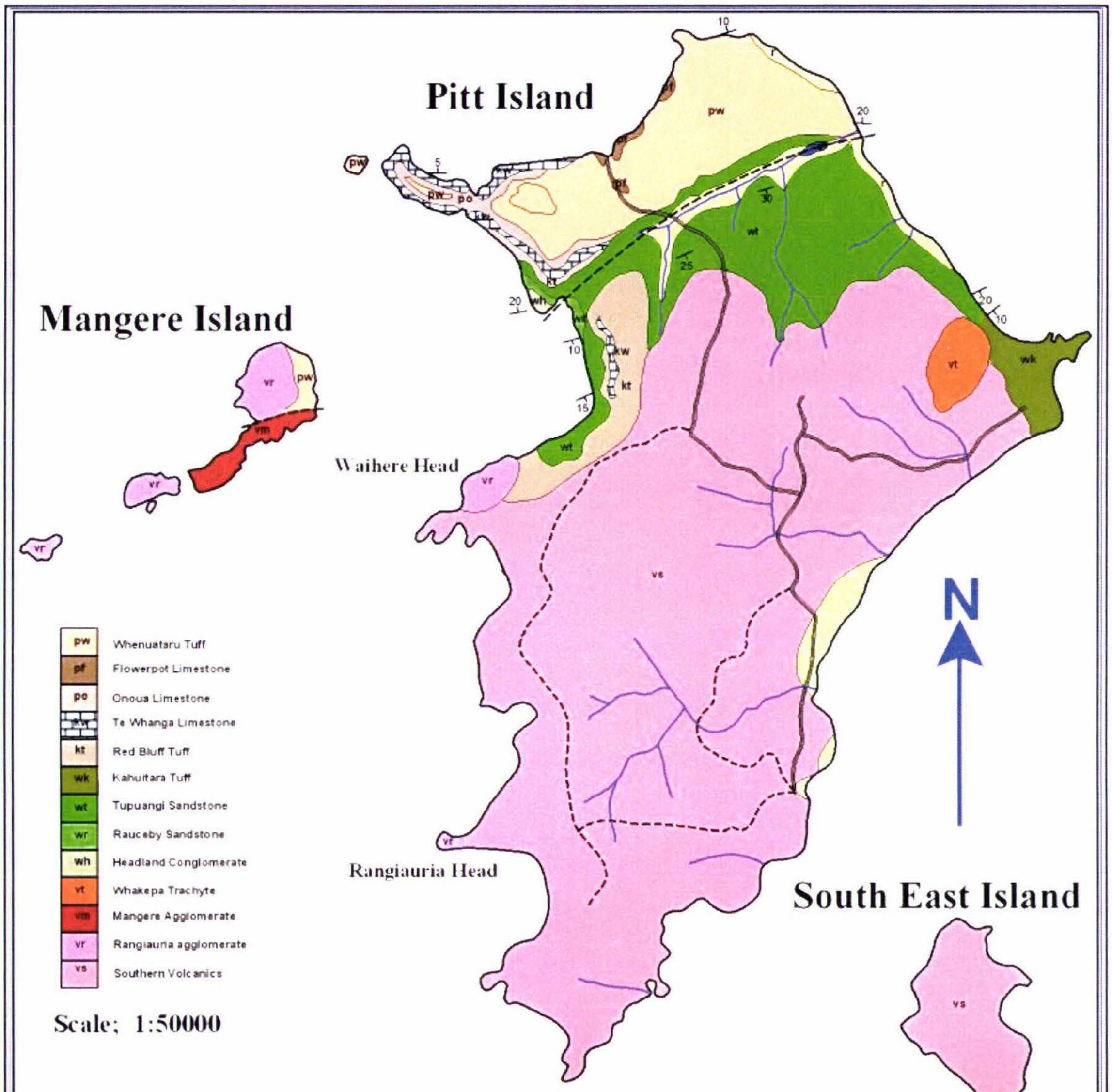

Figure. 11. Map of Pitt and Mangere Islands redrawn from Hay *et al.* 1970. The Headland Conglomerate, and the Tupuangi and Rauceby Sandstones are now assimilated in the Tupuangi Formation and the Mangere Agglomerate is assimilated in the Rangiauria Formation (Campbell *et al.* 1988).

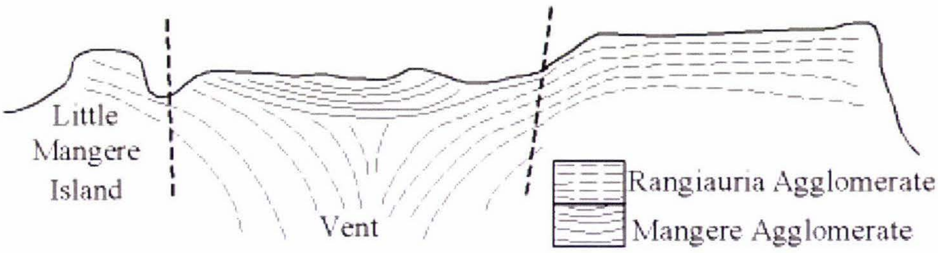

Figure 12. Diagram of Hay *et al's.* 1970 model "...showing the relationship between Rangiauria and Mangere Agglomerates at the suggested single volcanic vent at Mangere and Little Mangere Islands." (Drawn from Hay *et al.* 1970 p. 69).

The Mangere Agglomerate of Hay *et al.* (1970) was renamed as Mangere Beds by Watters (1978). Mildenhall and Wilson (1978) altered Mangere Agglomerate to Mangere Formation without change of definition. Campbell *et al.* (1988, 1993, p. 149) redefined Mangere Formation as consisting of, "flat lying, well bedded, well sorted generally fine grained sediments of partly volcaniclastic and tuffaceous limburgitic basalt composition and partly terriginous quartzofeldspathic composition. Some siltstone and claystone is concretionary. The formation is fossiliferous, non-marine, and thought to be restricted to southwestern Mangere Island (from which it is named), although thin, poorly exposed tuffaceous sandstone on the summit of Kaingaroa Hill, southwest of Flowerpot Harbour, Pitt Island may belong to the Mangere Formation or may be a correlative of it." This is the first detailed definition of the formation.

The type section of the Mangere Formation is given as CH/655194-CH/659198, Sheet 2, 1981. (All further grid references in this study refer to Land Information New Zealand Topographic Map 260, Edition 1 Sheet 2, 1998).

In November 1957, Watters collected four samples from the Mangere Agglomerate (Geological Survey Fossil serial numbers f 247 to 250). The actual location of these was in the above described sedimentary sequence, i.e. the Mangere Formation (though the precise localities could not be ascertained from the reports). In March 1977 Fleming and Billing collected ten samples from the same locality (Numbers f 445 to 553). All of the above samples were processed for pollen and dinoflagellates by Mildenhall and Wilson (1976b, 1977, 1978, 1981, 1994). They found abundant well preserved Cretaceous pollen and rare poorly preserved Pliocene pollen. Dinoflagellate cysts and acritarchs are, "... moderately abundant and diverse" (1978, p 661). Both Cretaceous taxa indicate a mid-to late Cretaceous age (1978). The Pliocene pollen gave an age of Opoitian to Mangapanian. The presence of the abundant Cretaceous palynomorphs showed "Clearly the source rocks for these fossils are the Waihere Bay group sediments of Pitt Island..." (Mildenhall and Wilson 1978 p. 661).

Several of Hay *et al's.* (1970) group and formation names were subject to revision by Austin *et al.* (1973); Mildenhall and Wilson (1978); Grindley *et al.* (1977), and finally by Campbell *et al.* (1988 and 1993) when revisions relevant to Mangere Island were made; i.e. Rangiauria Agglomerate and Mangere Agglomerate were subsumed under Rangiauria Formation, and Tupuangi Sandstone, Rauceby Sandstone and Headland Conglomerate became Tupuangi Formation.

This is summed up by (Fig. 13) showing the development of the stratigraphy of Mangere Island. (The changes in nomenclature shown in the right hand column have been adopted throughout the rest of this study. They are explained in Chapter 4).

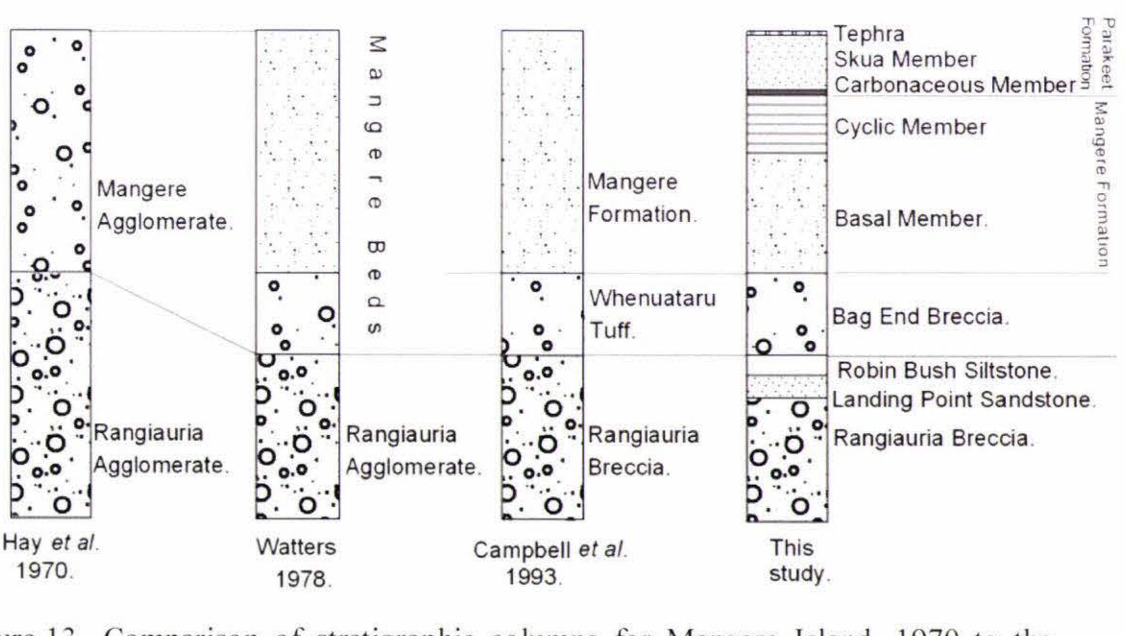

Figure 13. Comparison of stratigraphic columns for Mangere Island, 1970 to the present. (Not to scale).

In January/February 2005 G. Davies, V.E.Neall and R.C.Wallace visited Mangere Island to complete mapping for this project. Neall spent considerable time investigating the volcaniclastics under the Mangere Formation and, from the disposition of the bedding and types of deposits, was able to show that, rather than one vent on Mangere Island, there were at least eight vents (V.E.Neall, pers.com.). The general situation is illustrated in Fig 14. Further, Dr Neall named Robin Bush Siltstone and Landing Point Sandstone and recognised them as separate members within the Rangiauria Breccia (Neall, 2005).

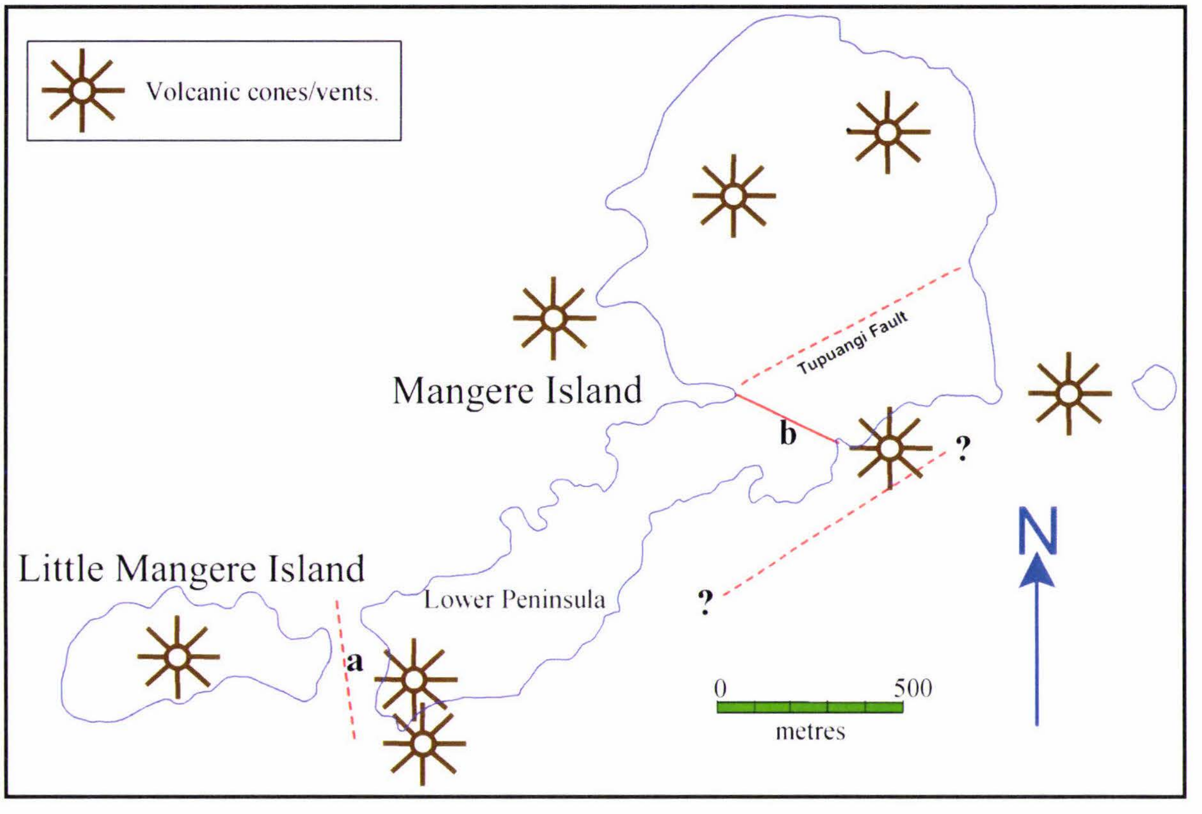

Figure 14. Sketch map showing inferred locations of a number of volcanic vents on Mangere Island (V. E. Neall, pers. com. 2005).