Formation, landforms and palaeoenvironment of Matakana Island and implications for archaeology

Formation, landforms and palaeoenvironment of Matakana Island and implications for archaeology

SCIENCE & RESEARCH SERIES NO.102

Mike J. Shepherd[1], Bruce G. McFadgen[2], Harley D. Betts 1, Douglas G. Sutton[3]

[1] Department of Geography, Massey University, Private Bag 11222, Palmerston North.

[2] Science and Research Division, 1 Department of Conservation, PO Box 10420, Wellington.

[3] Department of Anthropology, University of Auckland, Private Bag 92019, Auckland.

Published by
Department of Conservation
P.O. Box 10-420
Wellington, New Zealand

Frontispiece: oblique photograph of Matakana Island. View to the northwest with Mount Maunganui in the foreground.

Science & Research Series is a fully reviewed irregular monograph series reporting the investigations conducted by DoC staff.

ISSN 0113-3713
ISBN 0-478-018320

Cataloguing-in-Publication data

Formation, landforms and palaeoenvironment of Matakana Island and implications for archaeology / Mike J. Shepherd ... {et al.}.
Wellington, N.Z. : Dept. of Conservation, 1997.
1 v. ; 30 cm. (Science & Research series, 0113-3713 ; no.102.)
Includes bibliographical references.
ISBN 0478018320
1. Archaeological geology- -New Zealand- -Matakana Island. 2. Geomorphology--New Zealand- -Matakana Island. 3. Matakana Island (N.Z.)
I. Shepherd, Mike. II . Series: Science & research series ; no. 102.
551.42099321 20
zbn97-028036

CONTENTS

Abstract

Matakana Island, in the western Bay of Plenty, is a barrier island which encloses Tauranga Harbour. It comprises two distinct parts: an older area of tephra-covered Pleistocene terraces and, to seaward, a large Holocene sand barrier. Vestiges of shore-parallel relict foredunes indicate that the lowest Pleistocene terrace originated as a prograding coastal plain,

The Holocene sand barrier initially formed in at least two separate parts about 6000 cal (calendar years) BP. Its environmental history was determined by means of geomorphological, sedimentological, tephrochronological, pedological and palynological techniques, together with radiocarbon dating. The northwestern part of the Holocene barrier originated as a migrating washover ridge, whereas the southeastern part abutted the cliffed edge of the lowest Pleistocene terrace.

The barrier grew by means of southeasterly spit extension, the accretion of successive foredune ridges along the ocean shoreline, and progradation along the harbour shoreline. By about 3500 cal BP the tidal inlet which separated the two parts had closed. During the past 600 years the ends of the Holocene barrier adjacent to the present tidal inlets have been particularly dynamic features which extended rapidly as the harbour entrances narrowed.

The Holocene barrier has undergone major environmental change throughout its history. Parts of the relict foredune topography of the Holocene barrier were modified by migrating dunes. Parabolic and blowout dunes developed prior to human settlement and a variety of dunes has developed since. Since 600 cal BP natural changes have been augmented by human impact, including modification of the vegetation and soil by Maori and, more recently, farming and plantation forestry. Future planning and management decisions should take into account the dynamic nature of the island.

1. Introduction

Matakana Island forms part of a wave-dominated sedimentary coast located at the western end of the Bay of Plenty (Fig. 1). The older part of the island, which we call *Matakana Core* (Fig. 1), is composed mainly of Pleistocene sands mantled by thick tephra deposits. It adjoins the younger *Matakana Barrier* which is composed mainly of Holocene sands with minimal tephra cover. Rangiwaea Island, which lies to the southeast of Matakana Core (Fig. 1), has a similar geological structure to Matakana Island and a closely associated geological history.

Matakana Island is 24 km long and is New Zealand's largest barrier island. Its development, together with that of the tombolos adjoining Mount Maunganui and Bowentown Heads, formed Tauranga Harbour, a *c*. 200 km^2 estuarine lagoon.

Matakana Island has a Bay of Plenty climate which is mild and sunny, with a moderate rainfall of *c.* 1300 mm/year (Quayle 1984). It is very favourable for human settlement, and suitable for Maori gardening which was based on subtropical plants. The climate is complemented on Matakana Core by friable, easily-worked volcanic loams, on Matakana Barrier by light, sandy soils, and in the adjacent harbour and ocean by abundant fish and shellfish.

The island was extensively occupied in pre-European tunes. Its favourable environment is reflected in the large number of archaeological sites, especially fortifications, on Matakana Core, and in old garden soils and large numbers of shell middens on Matakana Barrier (Marshall *et al.* 1994). Radiocarbon dates indicate a history of occupation from at least 500 years ago. Moa bones found in the sandhills on Matakana Island in 1885 along with other archaeological remains (Bay of Plenty Times, 17 Jan 1885) suggest that initial occupation may have occurred before moa became extinct.

Since the 1920s the barrier has been used almost entirely for exotic forestry, which has had a detrimental effect on the archaeological sites and has modified the barrier soils, topography and drainage. Concern within the local Maori community for their heritage resulted in an approach to the Department of Conservation for information about the barrier history, which led to this interdisciplinary palaeoenvironmental and archaeological study.

Palaeoenvironmental studies are important for two reasons. Firstly, they provide an environmental context for archaeology; secondly, they provide an understanding of barrier landforms and the evolution of the barrier itself. Past studies have covered aspects of the geological, geomorphological, and environmental history of the Bay of Plenty (e.g., Kear and Waterhouse 1961, Wallingford Hydraulics Research Station 1963, Chappell 1974, Davies-Colley 1976, Healy *et al.* 1977, Dahm 1983, and Pullar and Cowie 1967) but Matakana Barrier has received comparatively little attention. This study was carried out between 1992 and 1995.

The objectives of the study are:

1. To map the landforms of the barrier.
2. To carry out geomorphological, sedimentological and stratigraphic studies in order to explain the origin of the barrier and its landforms.
3. To establish a time-frame for barrier development.
4. To determine the nature of the barrier and its environment before and after human settlement.
5. To determine the interrelationships between human activities and the barrier environment and their implications for the archaeological study of the barrier.

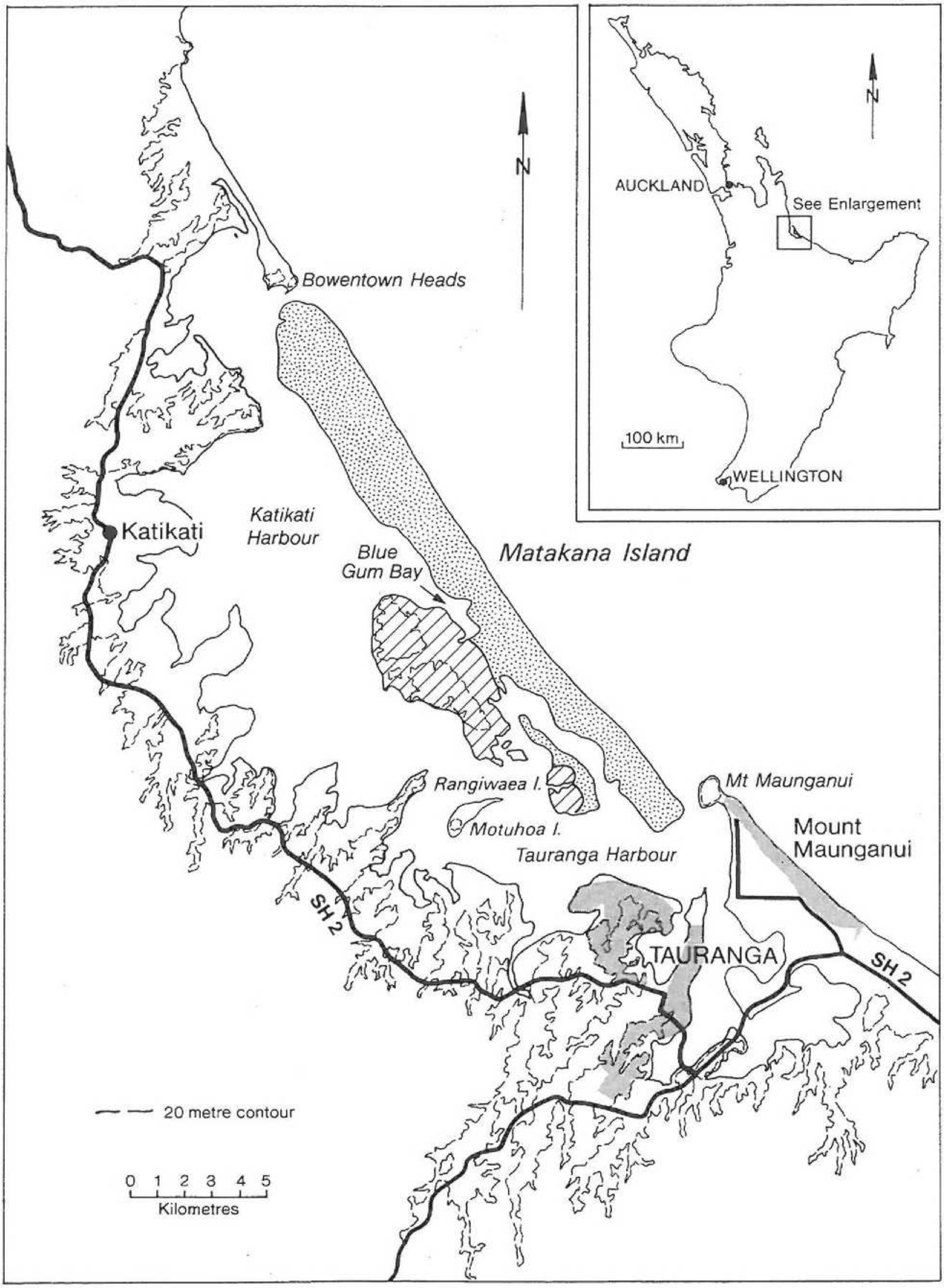


FIGURE 1. LOCALITY MAP FOR MATAKANA ISLAND. HOLOCENE BARRIER INDICATED WITH STIPPLING, PLEISTOCENE CORE OF ISLAND WITH DIAGONAL SHADING. NOTE ALSO THE HOLOCENE BARRIER AND PLEISTOCENE CORE OF RANGIWAEA ISLAND SH 2 = STATE HIGHWAY 2.

1.1 GEOLOGICAL SETTING

Matakana Island and Tauranga Harbour are located within the Tauranga Basin, which was formed during the last 2 to 4 million years by subsidence (Shaw and Healy 1962; Whitbread-Edwards 1994). At the present time the Tauranga Basin is thought to be either stable (Selby *et al*. 1971; Wigley 1990) or subsiding (Schofield 1968; Cole 1978). At times of high sea level the basin forms an embayment into which both fluvial sediment from the hinterland (Healy *et al.* 1964, Davies-Colley 1976) and marine sediment accumulates. During times of low sea level, the Pleistocene deposits, including thick tephra deposits (Selby *et al*. 1971; Pullar and Birrell 1973; Hogg 1979; Dahm 1983), have been dissected by streams and rivers. The Matakana and Rangiwaea cores are old interfluves isolated from the mainland by the rise in sea level following the Last Glacial.

It has been suggested that the valley systems, drowned during the Postglacial Marine Transgression (Healy *et al*. 1964; Davies-Colley 1976), control the present configuration of tidal channels in the harbour (Dahm 1983; Healy and de Lange 1988) and possibly the position of the Tauranga Entrance (Dahm 1983). The locations of the present entrances are also influenced by the isolated outcrops of volcanic rock at Bowentown Heads and Mount Maunganui. A small volcanic outcrop, Ratahi Rock (NZMS 260 788953), also occurs near Flax Point on the harbour side of Matakana Core.

1.2 FACTORS CONTROLLING THE GROWTH OF MATAKANA BARRIER

Factors controlling the growth of Matakana Barrier following the Postglacial Marine Transgression include sea level, offshore bathymetry, wave and tidal environments, sediment supply, wind climate and vegetation.

1.2.1 Sea level

Barrier development is closely associated with sea level change (Zenkovich 1967; Roy et al. 1994). In New South Wales, most Holocene barriers began prograding soon after c. 6500 yr (radiocarbon years) BP when the sea reached its present level at the end of the Postglacial Marine Transgression. A Holocene eustatic sea level curve for New Zealand (Gibb 1986) indicates that in New Zealand modern sea level was also reached c. 6500 yr BP. As the Tauranga region is fairly stable tectonically (Pillans 1986), the relative sea level curve for Matakana Island is unlikely to differ significantly from Gibb's curve and our fieldwork on the island has provided no evidence to the contrary.

1.2.2 Offshore bathymetry

The continental shelf off Matakana Island is generally uniform and smooth, except near Karewa Island and Steels Reef, and has a gradient of about 1:300 (Pantin *et al.* 1973; Hume and Hicks 1993).

The uniformity of the inner shelf has been modified near the entrances to Tauranga Harbour by strong tidal currents. Longshore sediment transport paths have been disrupted and large ebb-tidal deltas have formed (Davies-Colley and Healy 1978a). The deltas are major sub-tidal stores of sediment (Boothroyd 1985; Hicks and Hume 1993; Hume and Hicks 1993) and have played an important role in the development of Matakana Island.

1.2.3 Wave and tidal environment

The western Bay of Plenty coast, with its northeasterly aspect and prevailing offshore winds, has a lower-energy wave climate than most other New Zealand coasts. Swell waves dominate over locally-generated waves and the Bay of Plenty wave climate has thus been classified as a "mild-meso energy swell wave environment" (Healy *et al.* 1977). The offshore and nearshore significant wave heights are 1.5 m and 0.6 m respectively (Healy *et al.* 1977). The predominant wave approach direction, from the north to northeast, is approximately normal to the coast (Fig. 2), with low northerly swell (usually less than 1 m high) particularly frequent. Higher waves, which generally approach from the east or northeast (Davies-Colley and Healy 1978a), are associated with extra-tropical storms and winter depressions (de Lisle 1962; Heath 1985).

Tidal range is important for barrier development. The relatively low tidal range of 1.8 m-2.0 m (Healy *et al.* 1977) for the Tauranga Entrance is classified as "microtidal", which is conducive to barrier development (Davies 1980). The Tauranga and Katikati entrances would be classed as "tidally-dominated" (Hubbard et al. 1979) by reason of their morphology and extensive ebb-tidal deltas, which reflect the dominant influence of their large tidal prisms (130.8 x 10^6 m^3 and 95.8 x 106 m^3 respectively (Hume and Herdendorf 1992)) relative to the moderate wave energy of the ocean coast. The deltas store large amounts of sediment (the ebb-tidal delta at Tauranga has a volume of c. 47 x 10^6 m^3 and at Katikati c. 30 x 106 m^3 (Hicks and Hume 1991)), which may otherwise have been added to the shore. The ebb-tidal deltas also appear to have provided sediment to the barrier at certain times in its development, and their presence modifies the incoming waves by refraction and energy dissipation.

1.2.4 Sediment supply

Healy *et al.* (1977) used wave data from Davies-Colley (1976) to calculate a wave approach resultant of 4° north of normal to the coast, suggesting nett littoral drift from northwest to southeast. They estimated littoral drift along the Matakana Island barrier to be at least 40 000 m^3 per year based on observations of long-term progradation at Panepane Point.

Tidal inlets are the most dynamic parts of a barrier system (Hayes 1991). The convergence of tidal currents at the harbour entrances has scoured deep inlet gorges with depths that exceed 24 m at the Katikati Entrance and 30 m at the larger Tauranga Entrance (Hydrographic Office 1993). Interaction between the ebb-tide deltas and the beach on Matakana Barrier is demonstrated by bulges at the northwestern and southeastern ends of the barrier (Fig. 1), which are related to the ebb-tidal deltas of the Bowentown Bar and Matakana Bank respectively (Healy et al. 1977). Marine sediment carried into the harbour is deposited in flood-tide deltas which contribute to the inflling of the harbour.

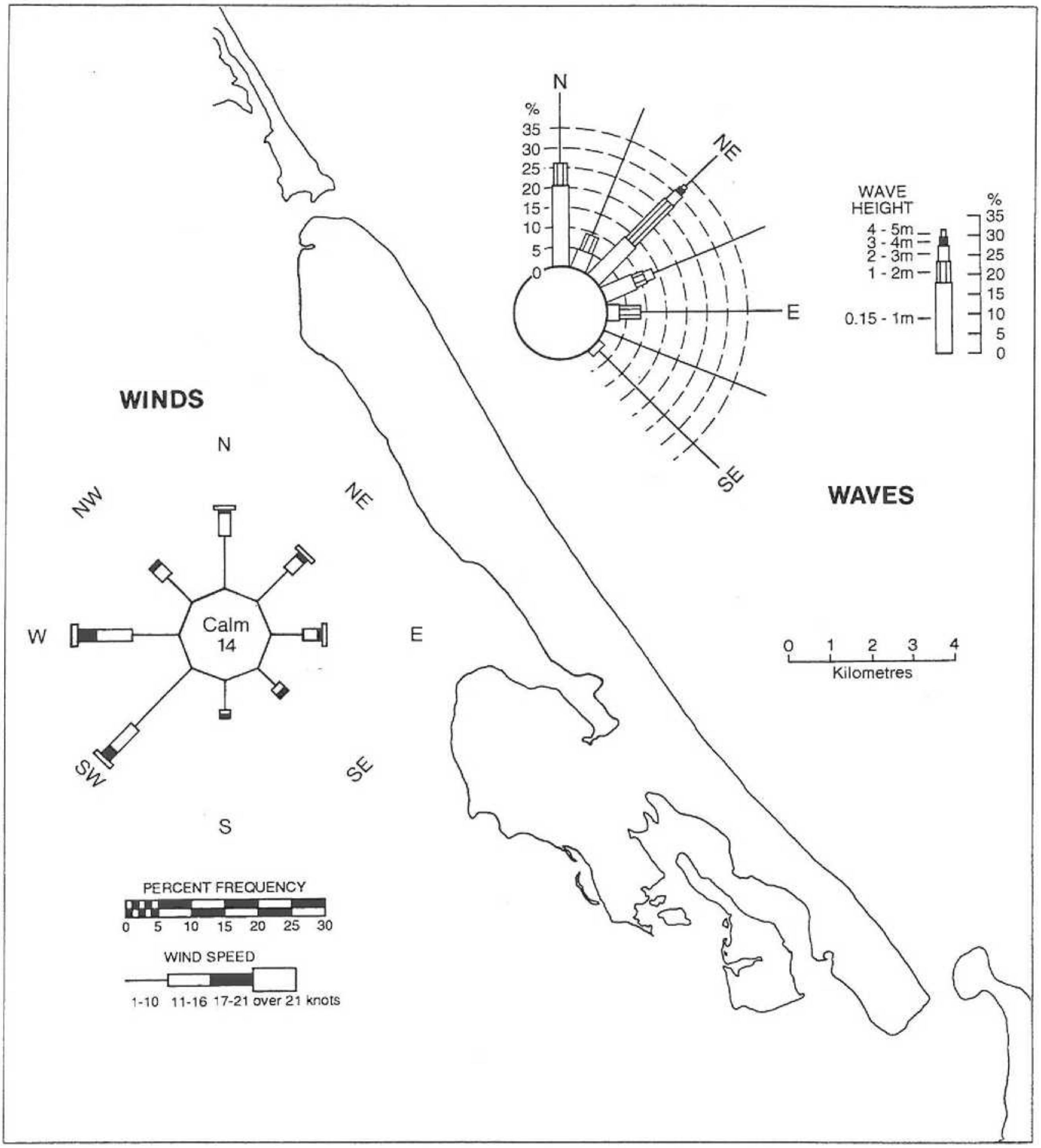


FIGURE 2. WAVE AND WIND CLIMATE FOR MATAKANA ISLAND. (SOURCES: WIND DATA FROM DE LISLE, 1962; WAVE DATA FROM HARRAY AND HEALY, 1978).

1.2.5 Wind climate

Although the Bay of Plenty is sheltered by high country to the west, south and east, westerly and southwesterly winds predominate at Tauranga Airport (de Lisle 1962; Quayle 1984). Gales, generally from the northeast or southwest, occur infrequently; such winds are more common near the coast and about the ranges than in other parts of the region (Quayle 1984). Whilst the coastal region is considerably less windy than other parts of New Zealand (Quayle 1984), the northeasterly and southwesterly winds are sufficiently strong to initiate the development of blowout and parabolic dunes following vegetation disturbance, and determine their orientation. Wind directions for Tauranga Airport are summarised by Fig. 2.

1.2.6 Vegetation

Vegetation today plays a role in the development of the barrier by trapping sand to accrete the foredune, by trapping sand, silt and clay on the estuarine flats, and by infilling lakes and swamps. The vegetation would have played a similar role in the past.

The contemporary vegetation on Matakana Island has been studied by Beadel (1989a,b) and a summary is provided in Appendix 1. Well-developed primary vegetation successions are evident on the island today at prograding shorelines, with pioneering communities on younger surfaces and more advanced communities on older surfaces. The vegetation pattern in the past would have shown similar successions as the island grew in size. The climax vegetation would have been forest, but little of the original forest remains owing to the planting of exotic forests. The largest remaining area of natural vegetation is adjacent to the harbour shoreline of the northwest part of the barrier, where well-developed swamp forest is present on relict estuarine flats.

1.3 DATING THE GROWTH OF MATAKANA ISLAND

At the end of the Postglacial Marine Transgression, Matakana Barrier began to prograde seawards, forming from sediments derived primarily from offshore. The growth of the barrier is marked by a succession of foredune ridges. The seaward edge of each ridge marks the position of a shoreline and each ridge is considered to be the same age along its entire length. The succession of ridges records the growth of the island through time. The ridges alone, however, record only the sequence of growth, but not the ages of the ridges or rates of barrier growth. To establish the ages of the ridges, and hence growth rates, two methods are used: radiocarbon dating and tephrochronology.

1.3.1 Radiocarbon dating

The interpretation of radiocarbon ages depends upon their stratigraphic relationship to the event to be dated and upon the inbuilt age of the samples. Samples may be within strata older than the event, contemporaneous with the event, or younger than the event. Inbuilt age is the length of time between the death of the organism dated and its arrival in the place from which it was collected (McFadgen 1982).

Inbuilt age is comprised of two parts: growth age and storage age (McFadgen 1982). For shells, the important component is storage age, i.e., the period between the death of the shellfish and their deposition within the deposits in which they were found. This could be many hundreds or even thousands of years for shells which were stored in ebb-tidal deltas before being transported onshore. Bivalves found in position of articulation are assumed to have negligible inbuilt age. Single bivalve shells and gastropods have unknown, and

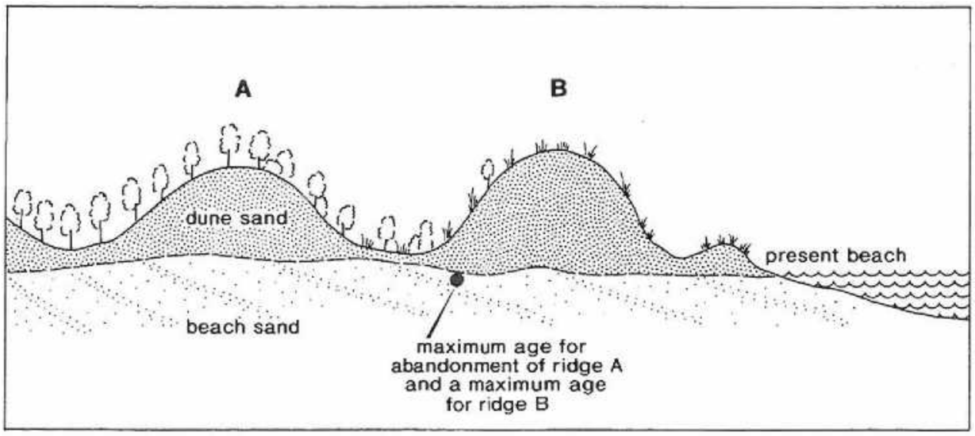


FIGURE 3. DIAGRAM ILLUSTRATING THE AGE RELATIONSHIP BETWEEN SHELL SAMPLES AND BARRIER STRATIGRAPHY. FOR EXPLANATION SEE TEXT.

possibly large, inbuilt age because there is no way of knowing their past transportational history. For midden shells, storage age is assumed to be negligible where the species dated are food species.

The relationship of shell samples to barrier sediments and the interpretation of their radiocarbon ages is illustrated by Fig. 3 which shows two foredune ridges A and B and their associated beach sand deposits. Shells from all barrier samples were either gastropods, or bivalves which were not in position of articulation when found. The shells therefore have an unknown and possibly large inbuilt age. Foredune ridge B forms above beach sand deposited while foredune ridge A was growing. Shells in beach sand immediately seaward of dune ridge A provide a maximum age for foredune ridge B because they are harbourward of ridge B. The shells are in sand which formed the beach while ridge A was forming and therefore provide a maximum age for the retreat of the sea from the beach in front of ridge A.

The shells are considered to be unsuitable for determination of the age of ridge A. This is because they have an unknown and possibly large inbuilt age. The shellfish may have died some considerable time before the formation of ridge A and only later transported into the position in which they were found.

Radiocarbon ages in this report (Table 1) are calibrated as follows: marine calibrations are based on the carbon cycle model calibration curve of Stuiver and Braziunas (1993), together with geographic offset delta-R set to -30 ± 15 years as recommended by McFadgen and Manning (1990). Terrestrial calibrations are based on a compilation of 20 year tree ring data by Stuiver and Reimer (1993). We do not apply a correction to compensate for the apparent offset of radiocarbon between the northern and southern hemispheres (Vogel *et al.* 1993). Conventional radiocarbon ages are indicated in the text as "yr BP" (years before present, where present = 1950 AD). Calibrated ages are expressed as a 95% confidence interval and indicated in the text as "cal BP".

Adopted ages in cal BP for airfall tephra deposits other than the Kaharoa Tephra are determined by calibrating the mean published radiocarbon ages for each tephra (Froggatt and Lowe 1990; Alloway *et al.* 1994), taking the mid-point of the calibrated 95% confidence interval and rounding the mid-point to the nearest 50 years. The age of the Kaharoa Tephra has recently been determined. (D.J. Lowe, pers. comm.)

LABORATORY NO.	δ ^{13}C ‰	CONVENTIONAL RADIOCARBON AGE YEARS BP (1950)	CALIBRATED AGE, YEARS BP[1] (95 % CONFIDENCE INTERVAL)	MATERIAL DATED	NZMS 260 GRID REFERENCE	DEPTH BELOW GROUND SURFACE (m)
NZA-3878	+1.91	5635 ± 69	6205-5905	Marine shells (*Zethalia zelandica*)	U13 775037	5.90-6.40
NZA-3879	+1.74	7697 ± 70	8295-7975	Marine shells (*Zethalia zelandica*)	U13 775037	9.50-10.10
NZA-3880	+1.39	8703 ± 72	9490-9195	Marine shells (*Zethalia zelandica*)	U13 796016	8.00-8.20
NZA-4654	-38.85	10991 ± 94	13110-12700	Estuarine sediment	U14 807973	1.90
NZA-4833	-31.23	8243 ± 88	9425-8985	Plant material	U14 807973	2.93
NZ-7997	+1.60	2114 ± 46	1830-1590	Marine shells (*Paphies ventricosa/ subtriangulata, Maurea tigris, Spisula aequilateralis, Paphies australis, Tawera spissa, Chione stutchburyi, Myadora boltina*)	U14 879917	0.45-1.40
NZ-8021	+1.70	701 ±31	435-295	Marine shells (*Struthiolaria papulosa, Paphies australis*)	U14 884920	0.70-1.20
NZ-8125	+1.50	667 ± 36	415-270	Midden shells (*Paphies subtriangulata*)	U14 855940	1.30
NZ-8187	+0.10	677 ±29	415-280	Marine shells (*Paphies subtriangulata*)	U13 863933	0.30
NZ-8235	+1.30	4914 ± 65	5435-5050	Marine shells (*Zethalia zelandica, Spisula aequilateralis, Paphies subtriangulata*)	U14 800006	0.90-1.10
NZ-8236	+1.50	5462 ± 68	6015-5695	Marine shells (*Zethalia zelandica*)	U14 820988	4.35-4.45
NZ-8294	-25.50	1449 ± 51	1415-1270	Kauri gum (*Agathis australis*)	U13 753071	0.10
NZ-8311	-0.10	751 ± 37	480-315	Midden shells (*Paphies australis*)	U14 882905	2.15

1. New Zealand marine calibrations are based on the carbon cycle model calibration curve of Stuiver and Braziunas (1993), with geographic offset delta-R set to -30 ± 15 as recommended by McFadgen and Manning (1990). Terrestrial calibrations (samples NZA-4654, NZA-4833 and NZ-8294) are based on a compilation of 20-year tree ring data by Stuiver and Reimer (1993).

TABLE 1. RADIOCARBON DATES FOR MATAKANA ISLAND.

1.3.2 Airfall tephra deposits and sea-rafted pumices

Volcanic activity since Miocene time has deposited material in the Tauranga Basin in the form of rhyolitic flows and unwelded tephras (Davies-Colley 1976).

Airfall tephras of Holocene age are widespread in the Western Bay of Plenty (Froggatt and Lowe 1990; Wigley 1990). Two previously recorded on Matakana Barrier are "Taupo Lapilli" and "Kaharoa Ash" (Dahm 1983; Harmsworth 1983; Munro 1994), and we provisionally record the Stent tephra (Alloway *et al.* 1994).

Tephras are derived from relatively short-lived events and therefore make good marker horizons for correlation and dating. However, the tephra deposits are patchy and often difficult to find on the island because of the history of Maori gardening and forest disturbance and, possibly, a longer history of tree throw. Maori gardening characteristically mixes Taupo Lapilli and Kaharoa Tephra into the soil together with shells and charcoal, destroying the tephra stratigraphy. In more recent times, v-blading for forestry has had an even more devastating effect (Sutton 1994).

The provisionally-identified Stent tephra is found at only two places on the barrier. The Taupo Lapilli and Kaharoa Tephra (Froggatt and Lowe 1990) are relatively widespread on the barrier, and because the barrier has a more or less steadily prograding shoreline, the seaward boundaries of the two tephras give a reasonable indication of the shoreline at the time of their eruption.

Stent tephra (Alloway *et al.* 1994) occurs as a yellowish-coloured deposit less than 1 cm thick. It has a mean radiocarbon age of c. 3970 ± 31 yr BP (Alloway *et al.* 1994); which gives a calibrated age of 4520-4300 cal BP. Our adopted age is 4450 cal BP.

Taupo Lapilli is part of the Taupo Tephra Formation (Froggatt and Lowe 1990). It ranges up to c. 8 cm in thickness, is mauve in colour, with abundant pumice lapilli up to c. 1.5 cm in diameter. The mean radiocarbon age for the Taupo Tephra Formation is 1850 ± 10 yr BP (Froggatt and Lowe 1990); which gives a calibrated age of 1815-1725 cal BP. Our adopted age is 1750 cal BP.

Kaharoa Tephra (Froggatt and Lowe 1990) is a basal unit of pumiceous sand c. 3 cm in thickness containing rare lapilli, overlain by a fine, powdery white ash. The tephra varies in thickness from 6 cm to c. 20 cm. It can be identified by its characteristic biotite-rich ferromagnesian assemblage (Pullar *et al.* 1977). We adopt a calibrated age for Kaharoa Tephra of 600 cal BP (D.J. Lowe, pers. comm.).

Sea-rafted pumices disperse quickly and are washed up on beaches soon after their eruption (Coombs and Landis 1966). Identification of primary sea-rafted deposits is always uncertain because all sea-rafted deposits are subject to possible reworking. Nevertheless, they do provide maximum ages for stratigraphically younger deposits.

Sea-rafted pumice deposits useful for correlation on Matakana Barrier are the Waimihia, Taupo and Loisels pumices. None of the three pumice deposits are independently dated, but each occurs in quantity as a pure deposit, and is in its correct stratigraphy order with respect to the others and to the airfall tephras. Taupo Pumice is on the seaward margin of the distribution of Taupo Lapilli on the Relict Foredune Plain (see section 2.2), and Loisels Pumice is on the seaward edge of the Purakau Shoreline (see section 2.2) which post-dates Kaharoa Tephra; the pumices were therefore probably washed ashore not long after they were erupted.

Waimibia pumice is part of the Waimihia Tephra Formation (Froggatt and Lowe 1990). The pumice occurs as rounded clasts up to 5 cm in diameter and was identified by Dr. P. Froggatt, Victoria University, Wellington. It has a mean radiocarbon age of 3280 ± 20 yr BP (Froggatt and Lowe 1990), which gives a calibrated age of 3565-3460 yr BP. Our adopted age is 3500 cal BP.

Taupo Pumice is part of the Taupo Tephra Formation (Froggatt and Lowe 1990). The pumice appears as rounded clasts up to 20 cm in diameter. Its adopted age is 1750 cal BP.

Loisels Pumice (Wellman 1962) is from an unknown source. The pumice occurs as rounded clasts up to 15 cm in diameter. It has a calibrated age range of 660-510 cal BP (McFadgen 1994). Following McFadgen (1994) we adopt an age for the pumice of 590 cal BP.

2. Matakana Island geomorphology

2.1 LANDFORMS OF MATAKANA CORE

2.1.1 Pleistocene terraces

Matakana Core comprises Pleistocene terraces (Fig. 4) mantled with volcanic deposits. Marine deposits exposed in a cliff at Flax Point (Fig. 4) on the harbour side of the island are about 1 m above present sea level, and underlie at least ten metres of tephra and pyroclastic flow material. It appears likely that all terraces of Matakana Core are underlain by marine deposits.

Interglacial relict foredune plain

The lowest Pleistocene terrace is present on both Matakana and Rangiwaea Islands. It appears to have originated as a coastal strandplain in the same fashion as the Holocene barrier to seaward. Its original topography is subdued by Late

FIGURE 4. MAP OF MATAKANA AND RANGIWAEA CORES SHOWING MAIN PLEISTOCENE GEOMORPHOLOGICAL FEATURES. HEAVY DASHED LINE IS THE RELICT PLEISTOCENE MARINE CLIFF. NUMBERS 1-5 ARE WELL-HEAD LOCATIONS. H HIGHER PLEISTOCENE TERRACES; L = LOWEST PLEISTOCENE TERRACE (INTERGLACIAL COASTAL PLAIN SHOWING RELICT FOREDUNE TRENDS); P = PLEISTOCENE PARABOLIC DUNES; BGB = BLUE GUM BAY SECTION.

Pleistocene tephra. Well logs and a section at Blue Gum Bay (GR NZMS 260 U14802987) indicate more than 10 m of tephra overlying sand. The terrace surface is between *c.* 8 m and 10 m above present sea level, and the original surface below the cover beds is at or below sea level. Old ridges and swales aligned roughly parallel to the riser of the older terrace, and to the trend of the present ocean shoreline (Fig. 4), are clearly discernable from the air (Fig. 5, see page 43) and have influenced the development of drainage patterns on the terrace.

We tentatively correlate the lowest terrace with the "BOP2" terrace of Chappell (1974) on the basis of the elevation of its underlying surface (Table 2). The terrace probably formed during the Last Interglacial sea level maximum of c. 125 000 years BP (Chappell 1974), but in view of the thickness of its tephra cover, a greater age cannot be discounted.

Last Interglacial sea level stood c. 4 m to 6 m above present sea level (Roy and Thom 1981; Gibb 1986). Well log data (Table 2) shows the sand surface of the interglacial coastal plain to be now as much as 3 m below present sea level. The average elevation of the Holocene barrier is about 6 m and if of Last Interglacial age, the Pleistocene sand surface would therefore have been about 10 m to 12 m above present mean sea level (the elevation of the Holocene barrier added to the height of the Last Interglacial sea level maximum). For the last 125 000 years, a maximum mean subsidence rate of between 104 mm and 120 mm/1000 years is therefore indicated.

Relict Pleistocene transgressive dunes

Large relict transgressive dunes mantled by Pleistocene tephra occur on the Lowest Pleistocene terrace at Blue Gum Bay (Fig. 6, see page 43) and at Opureora. Their similar orientation to the Holocene relict parabolic dunes indicates that the interglacial wind directions in this region were probably similar to those of the Holocene.

TABLE 2. WELL-HEAD ELEVATIONS, THICKNESSES OF TEPHRA COVER DEPOSITS AND ELEVATIONS OF UNDERLYING SAND SURFACES FOR THE WELLS LOCATED IN FIG. 4.

Source: S. Halliday, Whakatane Regional Council, pers. comm. 1995; M. Carlyle, well driller, pers. comm. 1995.

WELL ID (FIG. 4)	NZMS 260 GRID REFERENCE*	ELEVATION ABOVE MEAN SEA LEVEL (m)*	TEPHRA THICKNESS (m)	ELEVATION OF UNDERLYING SAND SURFACE (m)
1	U14 798968	15.1	12.2	2.9
2	U14 824946	8.5	*c.* 20.0**	*c.* -11.5**
3	U14 824942	11.0	*c.* 12.0	*c.* -1.0
4	U14 819940	12.4	13.0	-0.6
5	U14 817932	10.8	14.9	-4.1

Footnotes:

NZMS 260 grid references and elevations for the well heads were obtained by use of a Trimble Pro-XI. GPS system.

Tephra thickness at well 3 is provisional on account of possible inaccuracies in available well log data.

2.2 LANDFORMS OF MATAKANA BARRIER

Matakana Barrier is an accumulation of coastal sediments, predominantly sand, which has prograded seaward from the earliest Holocene shoreline cut into the Pleistocene cores of Matakana and Rangiwaea Islands, and from a washover ridge southeast of Katikati Entrance (Fig. 7). It is characterised by a series of relict foredunes cut off from the beach as the shoreline prograded, and by relict transgressive sand dunes which formed as a result of erosion of the relict foredunes. The main part of the barrier is a relict foredune plain which shows no visible evidence for any major reversal of steady progradation from the time of its initial formation to the present day, but landforms at each end of the barrier, where the progradational history is more complex, have different characteristics. The *Northwestern End* (Fig. 7) is lower, contains wetlands, and has many ridges which often converge and diverge reflecting past changes in the outline of the harbour entrance. The *Southeastern End* also is lower than most of the barrier and is characterised by hummocky dunes and few indistinct broad shoreline ridges.

Major geomorphological features of the barrier useful for correlating landform features are a prominent continuous relict foredune ridge we call *Long Ridge* which extends almost the entire length of the barrier (Fig. 7), and an erosional shoreline we call *Purakau Shoreline,* after the Maori name of the land block through which it passes, which cuts obliquely across the southern part of the barrier from near the present ocean beach to Duck Bay (Fig. 7). Both features are continuous. Each is thought to have formed along its entire length at the same time, and therefore to represent a chronological marker. Long Ridge we correlate with ridge D1 mapped near the northwestern end of the barrier by Munro (1994).

The Purakau Shoreline separates the regular relict foredune ridges to the northwest from an irregular collection of hummocky and parabolic dunes to the southeast. The area to the southeast narrows towards the northwest and merges with a narrow strip of parabolic dunes which extends continuously to the northwestern end of the barrier (Fig. 7). The strip separates the older relict foredunes from one or two younger relict foredunes immediately behind the present-day foredune.

Progradation of the harbour shoreline in the shelter of the growing barrier resulted in the formation of extensive backbarrier flats. They are best developed to the northwest of the barrier where swampy flats extend between the harbour shore and the washover slope.

The landforms discussed below are, in order. the Earliest Holocene Shoreline, Backbarrier Washover Slope, Relict Foredune Plain, the Contemporary Foredune and Ocean Beach, Barrier Ends, Relict Transgressive Dunes, and Backbarrier Flats. The locations of landforms other than the Relict Transgressive Dunes are shown in Fig. 7.

2.2.1 Earliest Holocene Shoreline

The Earliest Holocene Shoreline is the relict wave-cut cliff along the northeastern side of the Pleistocene core of Matakana and Rangiwaea Islands(Fig. 7). It is more or less parallel with the Holocene relict foredunes and present shoreline of the barrier. The Earliest Holocene Shoreline was formed at the end of the Postglacial Marine Transgression which ended c. 6500 yr BP (Gibb 1986).

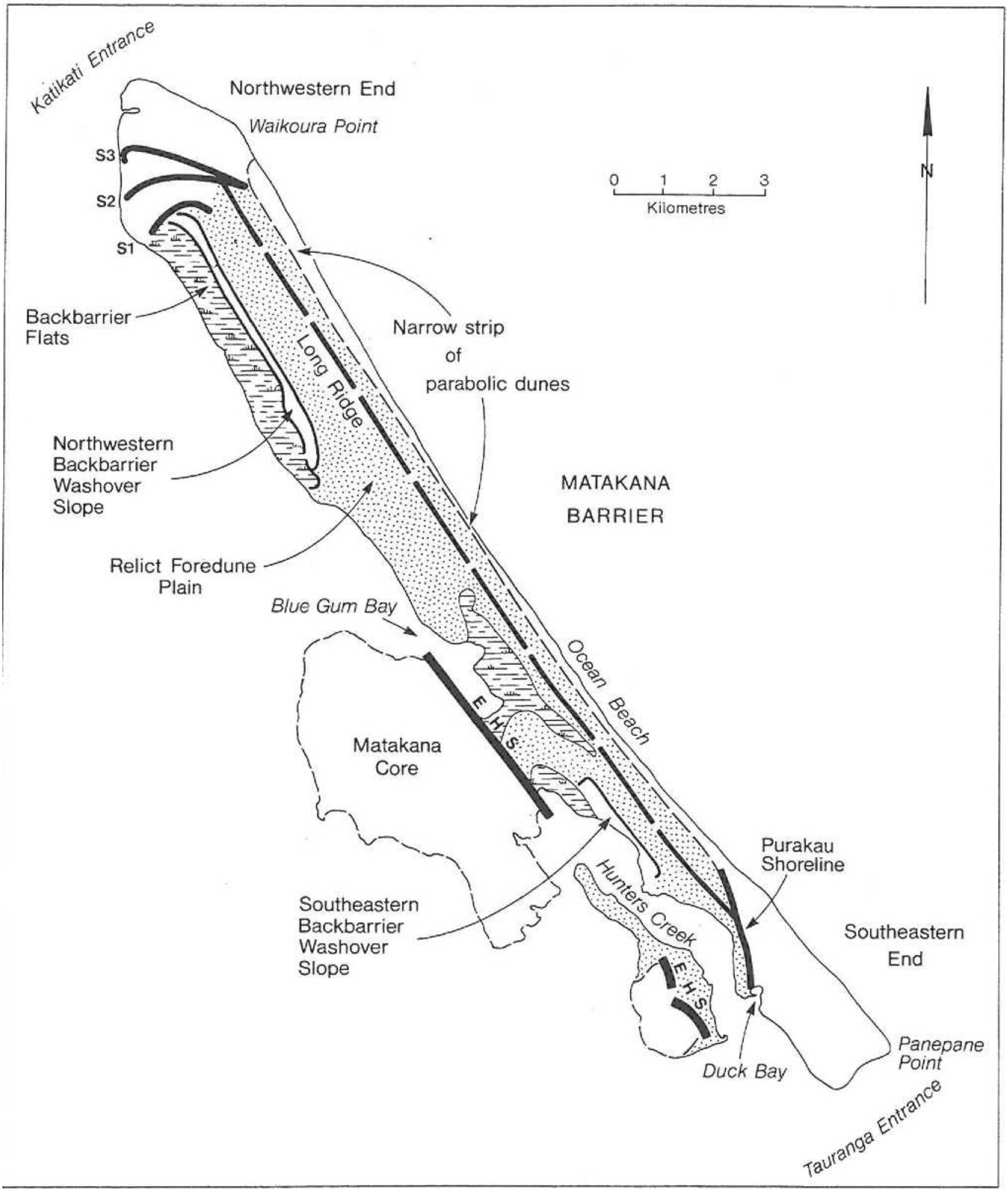


FIGURE 7. MAP OF MATAKANA BARRIER SHOWING LANDFORMS AND FORMER SHORELINES. EHS = EARLIEST HOLOCENE SHORELINE; S1 AND S2 = ERODED SHORELINES; S3 = KAHAROA SHORELINE.

2.2.2 Backbarrier washover slope

The backbarrier washover slope (Tanner 1988) is a surface along the inner margin of the barrier (Fig. 7) which slopes gently harbourward from the back of the innermost relict foredune to the backbarrier flats. It is between 180 m and

360 m wide. The Northwestern Backbarrier Washover Slope is to the northwest of Blue Gum Bay; the Southwestern Backbarrier Washover Slope borders Hunter's Creek.

Washover commonly occurs where a narrow barrier separating an estuary or lagoon from the ocean coast is subjected to large storm waves or a rising sea level (Tanner 1988). Overtopping of the barrier by storm waves (washover) removes sediment from the ocean beach, redepositing it as washover lobes on the landward side of the barrier. A backbarrier washover slope forms where numerous washover lobes coalesce into a regular slope on the inner margin of the barrier.

The processes of erosion and overtopping may cause a narrow barrier to migrate shoreward over the surface of former estuarine or low energy deposits (Dolan *et al.* 1980). The final position of the washover ridge marks the line from which subsequent progradation begins. A borehole through the Northwestern Backbarrier Washover Slope (borehole 1, Fig. 8, Fig. 9a) encountered silty sand at a depth of c. 2 m below mean sea level, and a 0.2 m clay horizon at a depth of c, 3 m overlying poorly sorted silty sand (Fig. 9a). As sediment derived from the ocean beach contains neither silt nor clay, it is apparent that at this site the washover deposits are overlying harbour (estuarine) sediment.

The innermost barrier beach in front of the backbarrier washover slope is comprised of coarse shelly sediments with heavy mineral seams. Two samples of marine shells from the sediments are dated: NZA3879 from 3-4 m below present high water level is 7697 ± 70 yr BP; NZA3878 from about present high water level is 5635 ± 69 yr BP (Table 1). NZA3879 is probably from material carried up with the rising sea level and is a maximum age for the innermost barrier beach and hence backbarrier washover deposits. NZA3878 is a maximum age for the growth of the relict foredune immediately in front of the washover slope.

Kaud gum from peaty soil near the bottom of the backbarrier slope at the northwestern end of the island has an age of 1449 ± 51 yr BP (NZ 8294, Table 1).

2.2.3 Relict foredune plain

Relict foredunes are cut off from the beach as a shoreline progrades and indicate the positions of former shorelines. They are the dominant landform on Matakana island and occupy a wide zone with up to 35 parallel ridges which extends for almost the entire length of the barrier (Fig. 8). They are modified by the formation of transgressive dunes, which are considered separately below.

The relict foredune plain extends from the furakau Shoreline at the southeastern end of the barrier to where the ridges begin to curve at the Katikati Entrance. It excludes the recurved ridges at the Katikati Entrance, but includes recurved ridges formed during coastal progradation along a former entrance through the inner part of the barrier adjacent to Blue Gum Bay.

A narrow band of relict foredunes is present on Rangiwaea island between the Pleistocene core and Hunter's Creek (Fig. 8).

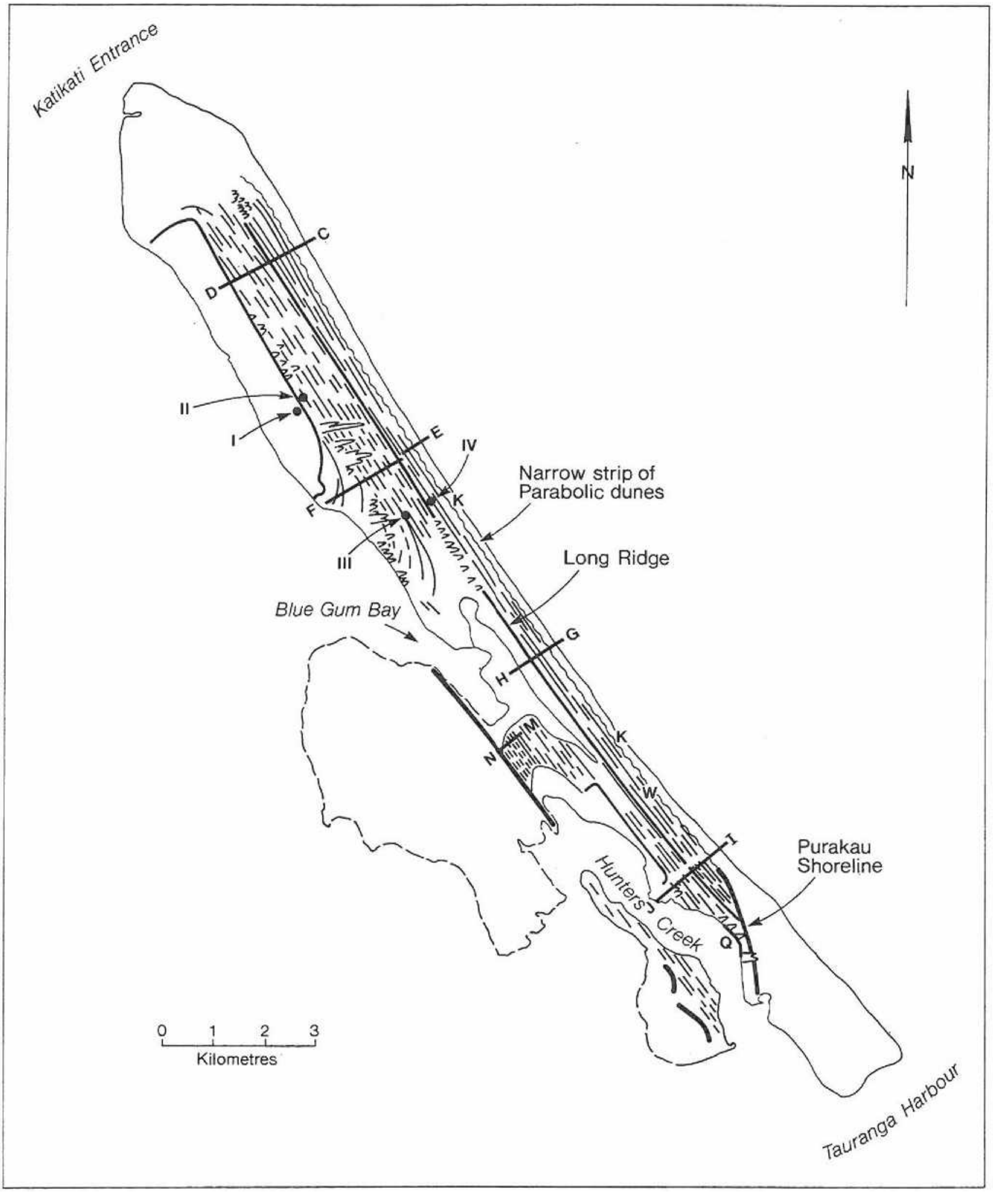


FIGURE S. MAP OF RELICT FOREDUNE PLAIN SHOWING DEEP BOREHOLE LOCATIONS (I, II, III, IV) AND PROFILES (C-D, E-F, G-H, I-J, M-N). K = LOCATIONS OF KAHAROA TEPHRA BENEATH PARABOLIC DUNES OF THE COASTAL STRIP; W = SEA-RAFTED WAIMIHIA PUMICE; Q = HUNTER'S CREEK SECTION WITH PROVISIONALLY IDENTIFIED STENT TEPHRA.

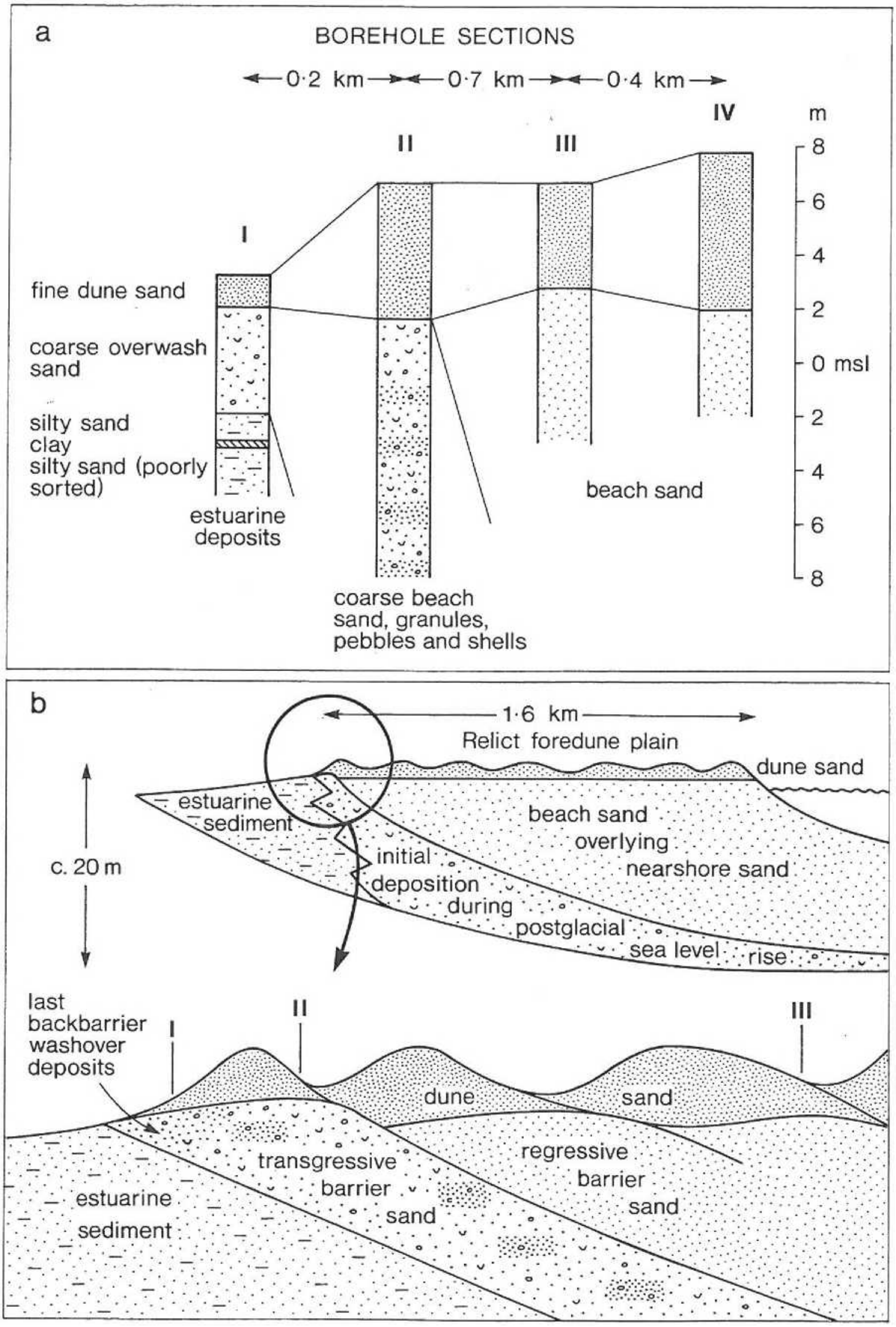


FIGURE 9. BARRIER STRATIGRAPHY:

a. BOREHOLES I-IV (FIG. 8) SHOWING STRATIGRAPHY DETERMINED BY DRILLING. HEIGHTS IN METRES RELATIVE TO MEAN SEA LEVEL.

b. INFERRED BARRIER STRATIGRAPHY BASED ON BOREHOLE DATA.

Foredune formation is an aeolian process whereby sand blown landward from the beach is trapped by sand-binding vegetation. The vegetation germinates from. wave-deposited seeds at the level of spring tide swash, or spreads by rhizome/stolon or shoot growth from an existing vegetated area (Hesp 1984). This process results in the construction of a foredune, which continues to accumulate sand until progradation of the beach allows a new sand vegetation zone to become established to seaward. This new zone becomes the primary zone of accumulation, causing the original foredune to become inactive (relict). Swales are low areas between the dune ridges where deposition is non-existent because most available sand is trapped by seaward vegetation (Hesp 1984).

The heights of the relict foredunes which comprise the main zone of ridges on Matakana Barrier vary from less than 2 m to about 14 m, with spacing between successive foredunes of *c*. 20 m to X100 m (Profiles C-D to I-J, Fig. 8 and 10). Despite the height of the highest dunes, few have been affected by large-scale wind erosion and most ridges have been stable since their formation (Fig. 11).

Sediment texture and mineralogy (Appendix 2; for full details see Betts 1996) are remarkably uniform throughout the relict foredune sequence. The mean grain size of each of 26 foredune sand samples from Profiles C-D to I-J (Figs. 8 and 10) and 9 samples from points along Long Ridge is between 1.9 and 2.7 phi (0.27 mm and 0.15 mm) and all are well-sorted (Fig. 12). The Long Ridge samples tend to coarsen towards the southeast (Fig. 13).

The heavy mineral content of the profile samples (Fig. 14) is generally below 10% but rises to 20-35% towards the inner margin of the barrier along Profiles C-D to G-H. Neither the inner margin of the barrier along Profile I-J nor Long Ridge were sampled. The heavy mineral suite was fairly uniform throughout with hypersthene dominant (50-70%).

The larger light mineral fraction (Fig. 15) is fairly uniform and dominated by quartz (50-70%) and feldspar (20-30%). Except for the Taupo Foredune at Profile E-F, where the glass content is 30%, in all other samples the glass content is less than 7%. Also significant are the lower proportions of rock fragments and glass near the inner margin of the barrier.

Sand in the relict foredunes is finer in three boreholes (II, III , IV, Fig. 8) than the underlying beach and nearshore sand. Borehole II is at the oldest beach on the barrier just seaward of the innermost ridge, III is 0.8 km seaward of the innermost ridge and IV is 0.4 km further seaward. The holes were drilled to depths below mean sea level of 5 m, 3 m and 2 m respectively (Fig. 9a). Beach and nearshore sand in the two seaward holes is only slightly coarser than the dune sand and contained only rare shell fragments; beach and nearshore sand in the innermost hole is very much coarser with heavy mineral seams, abundant shell fragments and rock granules.

Ground disturbance caused by forestry operations has almost completely destroyed the original topsoil and subsoil on the relict foredunes and in many of the Swales. In some Swales, however, the original soil profile is present beneath layers of recently deposited sand and may be podzolised (Table 3; Fig. A7.1, Appendix 7). Some Swales also contain primary deposits of Kaharoa Tephra and Taupo Lapilli, charcoals, undisturbed shell midden and garden soils (Appendix 3). On older parts of the barrier the subsoil shows considerable weathering indicated by strong iron-cementation.

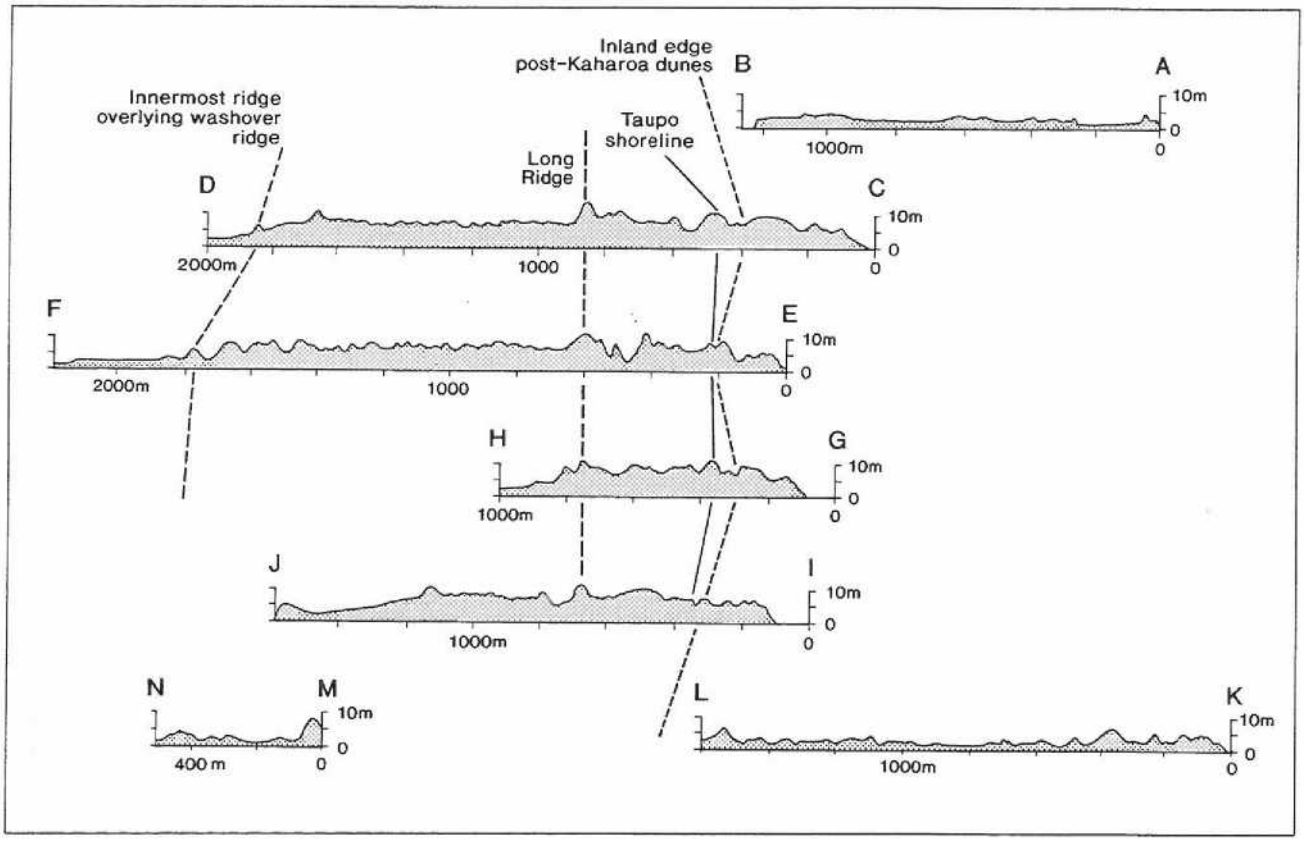


FIGURE 10. LEVELLED PROFILES ACROSS THE HOLOCENE BARRIER SHOWING RELICT FOREDUNES AND SWALES. CORRELATION BETWEEN PROFILES SHOWN BY DASHED LINES. LOCATION OF PROFILES SHOWN ON FIGS 8 AND 17. DISTANCES IN METRES FOR ALL PROFILES EXCEPT M-N ARE MEASURED HARBOURWARD FROM THE PRESENT OCEAN BEACH. M-N SHOWS THE INNERMOST 500m OF THE BARRIER.

TABLE 3. DESCRIPTION OF SOIL PROFILE IN SWALE 150m HARBOURWARDS OF THE TAUPO FOREDUNE ALONG TRANSECT G-H.

DEPTH (cm)	DESCRIPTION
0-37 [Forestry-disturbed soil]	Brownish-black (10YR2/2) sandy loam with faint, medium and coarse dark brown (10YR3/3) mottles, few increasing downwards to abundant at the boundary with the underlying Kaharoa Tephra. Weakly developed fine to very fine nut structure. Firm. Few roots, few fine charcoal fragments, few fine lapilli. Sharp to distinct irregular boundary.
37-47 [Kaharoa Tephra]	Kaharoa Tephra. Fine component (ca 2cm thick layer) generally on top with coarse at the bottom, but also mixed in places. Dull yellow (2.5Y6/3). Firm. Distinct wavy boundary.
47-52 [Buried topsoil]	Dull yellowish-brown (10YR5/3) sand. Weakly developed fine to very fine nut structure. Friable. Few roots, few coarse rounded pumice fragments up to 10cm long, many fine and very fine lapilli, few fine charcoal fragments. Indistinct wavy boundary.
52-69 [Leached horizon]	Dull yellow-orange (10YR7/3) sand with few faint medium dull yellow-orange (10YR6/3) mottles. Single grain. Very friable. Few roots. Distinct smooth boundary.
69-81 [B horizon]	Dull yellowish-brown (10YR5/3 loamy sand with many fine and medium faint brown (10YR4/4) mottles. Weakly developed very fine to coarse nut and blocky structure. Firm. Few roots. Indistinct smooth boundary.
81-100 [Parent material]	Dull yellowish-brown (10YR5/4) sand with many medium and coarse distinct brown (7.5YR4/4) mottles. Single grain. Very friable. Few Roots. Distinct irregular boundary.
100-110+ [Parent material]	Dark reddish-brown (5YR3/3) sand with profuse faint medium brown (7.5YR4/4) mottles. Weakly developed very fine to fine nut and fine blocky structure with single grain. Firm.

FIGURE 11. OBLIQUE PHOTOGRAPH OF THE NORTHWESTERN END OF THE RELICT FOREDUNE PLAIN SHOWING RELICT FOREDUNES AND SWALES. VIEW TO THE NORTHWEST.

Stent tephra is tentatively identified in relict foredune deposits in a section at Hunter's Creek (Q, Fig. 8). Sea-rafted Waimihia Pumice was found as abundant rounded pumice clasts up to c. 5 cm diameter in beach sand below the Swale 50 m seaward of Long Ridge (W, Fig. 8).

Taupo Lapilli is in stratigraphic position immediately below Kaharoa Tephra in many swales. It is present as a lag deposit on many of the relict foredune surfaces where it has been concentrated by wind erosion following forestry operations. The Taupo foredune is identified near Profile G-H (Figs. 8 and 10) by abundant Taupo Lapilli mixed with the sand on its seaward slope. It is a short distance inland of the strip of parabolic dunes. Near Profile E-F (Figs. 8 and 10) there is a marked increase in the proportion of volcanic glass in the Taupo foredune compared with relict foredunes on either side (Fig. 15). No Taupo Lapilli has been found seawards of this ridge.

Kaharoa Tephra once covered most of the relict foredunes and is present today in many swales as an undisturbed airfall deposit right up to the inner margin of the strip of parabolic dunes along the present coast. It has been located about 120 m from the present shoreline at two places (K, Fig. 8) where it is buried by the parabolic dunes. Swales containing undisturbed Kaharoa Tephra are truncated by the Purakau Shoreline. Kaharoa Tephra is absent from the ocean side of the shoreline. There are abundant and extensive deposits of sea-rafted Loisels Pumice on the immediate ocean side of the Purakau Shoreline.

The radiocarbon age of shells from Shelly beach sand in a swale between two recurved ridges to the north of the old Blue Gum Bay harbour entrance is 4914 65 yr BP (NZ8235) (Fig. 16). Further along the same Swale to the north the age of shell fragments from Shelly beach sand is 8703 ± 72 yr BP (NZA3880). Beneath the backslope of Long Ridge, where it crosses the Blue Gum Bay

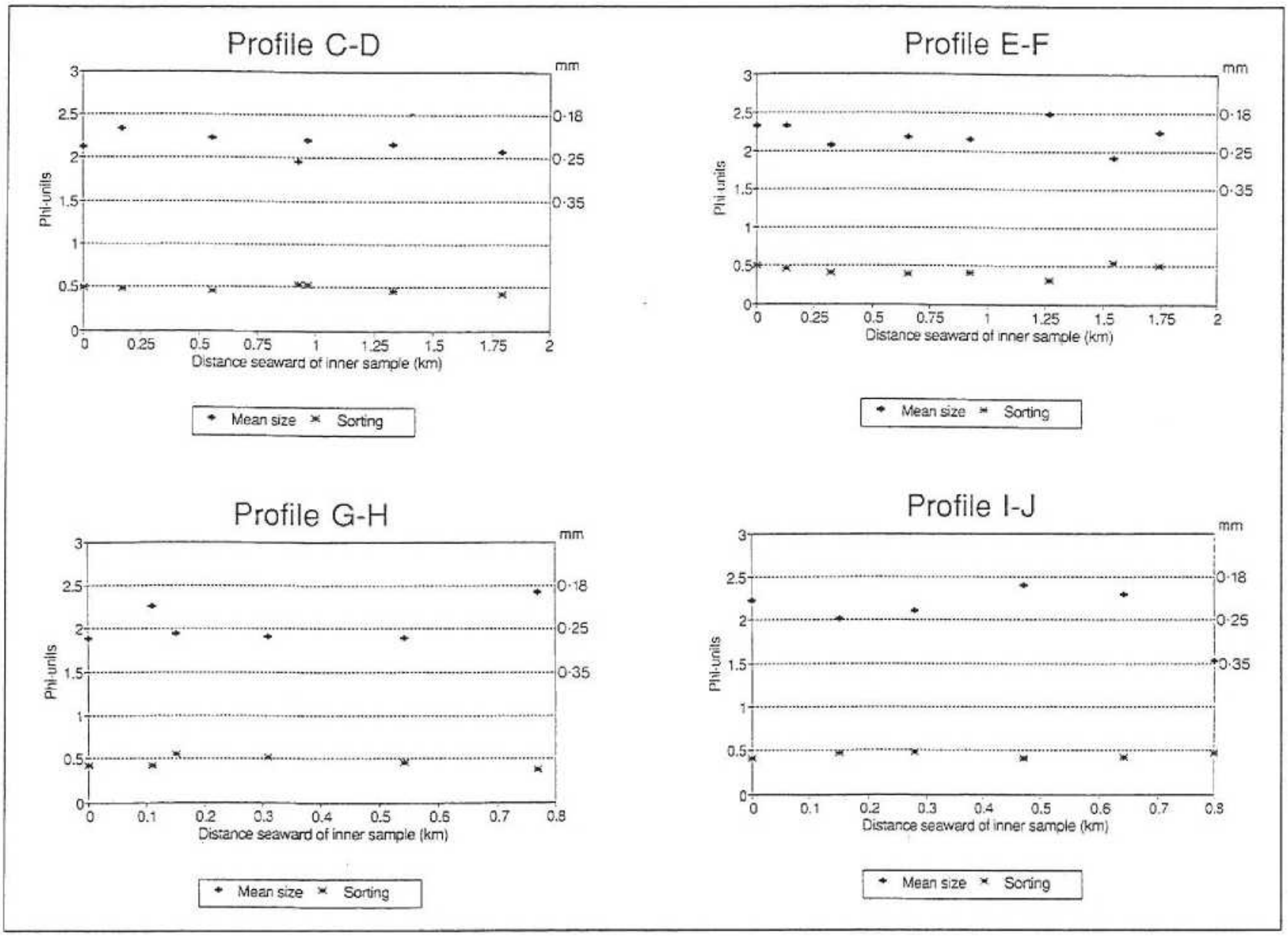
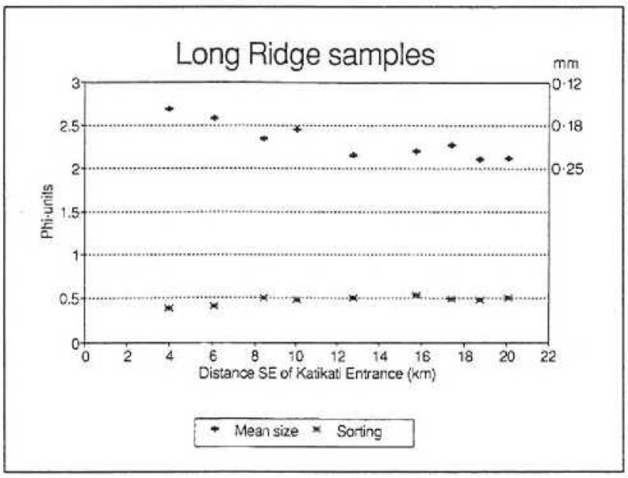


FIGURE 12. MEAN SIZE AND SORTING OF RELICT FOREDUNE SAND SAMPLED ALONG PROFILES C-D, E-F, G-H, I-J (FIG. 8). MEAN SIZE SHOWN IN PHI UNITS AND MILLIMETRES. SORTING SHOWN IN PHI UNITS ONLY. FOR LOCATION OF SAMPLING POINTS SEE APPENDIX 2.

FIGURE 13. MEAN SIZE AND SORTING OF RELICT FOREDUNE SAND SAMPLED ALONG LONG RIDGE (FIG. 7). MEAN SIZE SHOWN IN PHI UNITS AND MILLIMETRES. SORTING SHOWN IN PHI UNITS ONLY. FOR LOCATION OF SAMPLING POINTS SEE APPENDIX 2.



harbour entrance, the age of shells from coarse beach sand is 5462 ± 68 yr BP (NZS236).

Sea-rafted Taupo Pumice is present at the northeastern boundary of the relict Rangiwaea foredunes and estuarine flats (Fig. 16).

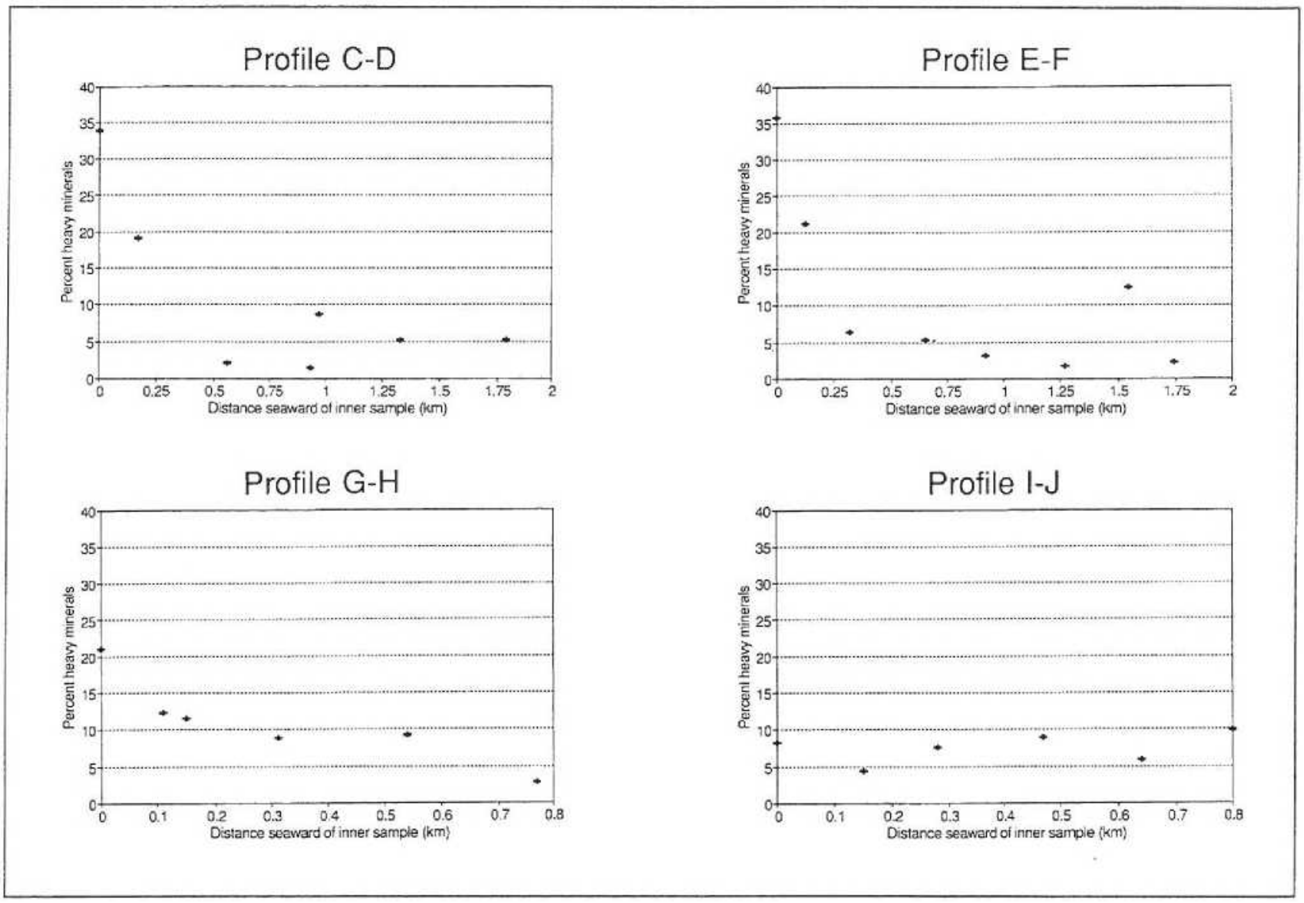


FIGURE 14. HEAVY MINERAL CONTENT OF RELICT FOREDUNE SAND SAMPLED ALONG PROFILES C-D, E-F, G-H, I-J (FIG. 8).

2.2.4 Barrier ends

At the barrier ends the relict foredunes curve to follow previous shorelines of the harbour entrances (Fig. 17). The Northwestern End of the barrier extends northwestward to the Katikati Entrance from where the curves of the relict foredune ridges begin. The Southeastern End is located east and south of the Purakau Shoreline.

Northwestern End

Two recurved ridges, formed following coastal erosion, truncate older ridges; one ridge begins on the harbour side of Long Ridge, and one begins on the seaward side (S1 and S2, Figs. 17 and 18). The older (S1) is a massive ridge indicating that the harbour shoreline was relatively stable early in the history of the barrier. Younger recurved ridges including S3, the Kaharoa shoreline, diverge and converge and are far lower in height (A-B, Figs. 10 and 17). Dune cover is discontinuous and in some places the underlying beach sand, often containing abundant shells and shell fragments, is exposed at the surface.

Lakes and wetlands fill the swales between some of the ridges. At least seven wetlands exist between the ridges, of which six include small lakes (Fig. 18). The wetlands are typically small and elongated, with their long axes aligned

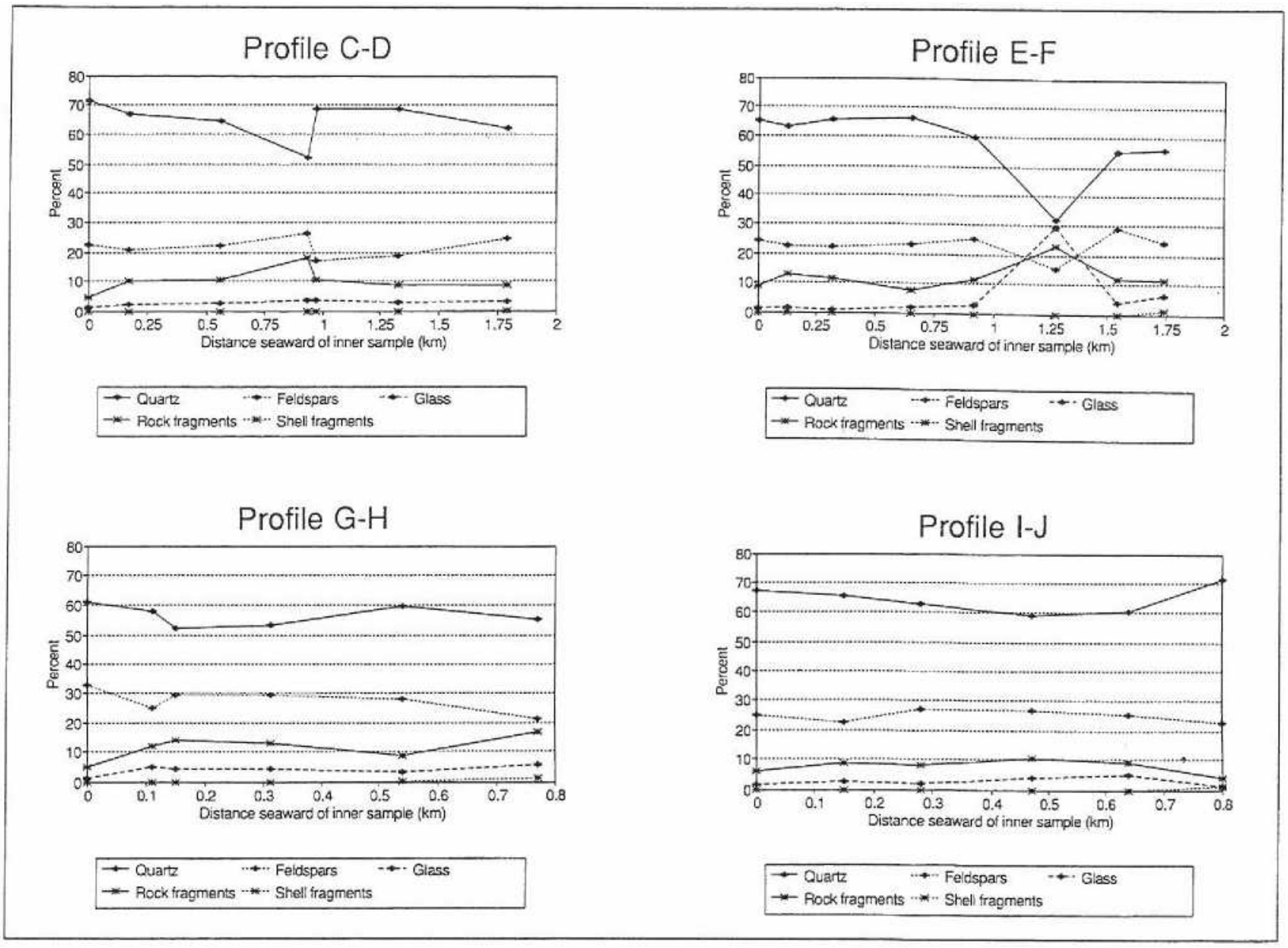


FIGURE 15. MINERALOGY OF THE LIGHT FRACTION OF RELICT FOREDUNE SAND SAMPLED ALONG PROFILES C-D, E-F, G-H, I-J (FIG. 8). E-F SHOWS THE REDUCTION IN QUARTZ AND FELDSPAR AND INCREASE IN VOLCANIC GLASS WITHIN THE RELICT TAUPO FOREDUNE *c.* 1.25 km SEAWARD OF THE INNERMOST SAMPLE.

roughly parallel to the ocean shoreline and the relict foredune ridges which have impounded there. The largest lake is about 460 m long and up to 60 m wide. Some lane floors are at or below mean sea level and therefore cannot have been formed by deflation. They appear to have been impounded by spit extension. The 1870 shoreline (Fig. 19a) shows lakes in the process of being formed in this way. The lakes have been studied in detail by Munro (1994) who obtained radiocarbon dates for the lake deposits and ridges.

Wetlands in these settings generally begin as lakes, becoming wetlands as the lakes infill with sediments and peat. Kaharoa Tephra is found in peat in the wetland immediately landwards of the S3 shoreline (Figs. 17 and 18), but not in wetlands or lakes further north.

Southeastern End

The Southeastern End consists of a low plain, on which are hummocky and parabolic transgressive dunes. In general, the Southeastern End is slightly higher than the Northwestern End (A-B, K-L, Figs. 10 and 17) and therefore contains fewer, less extensive wetlands. Coarse sand is present at or near the surface in many places.

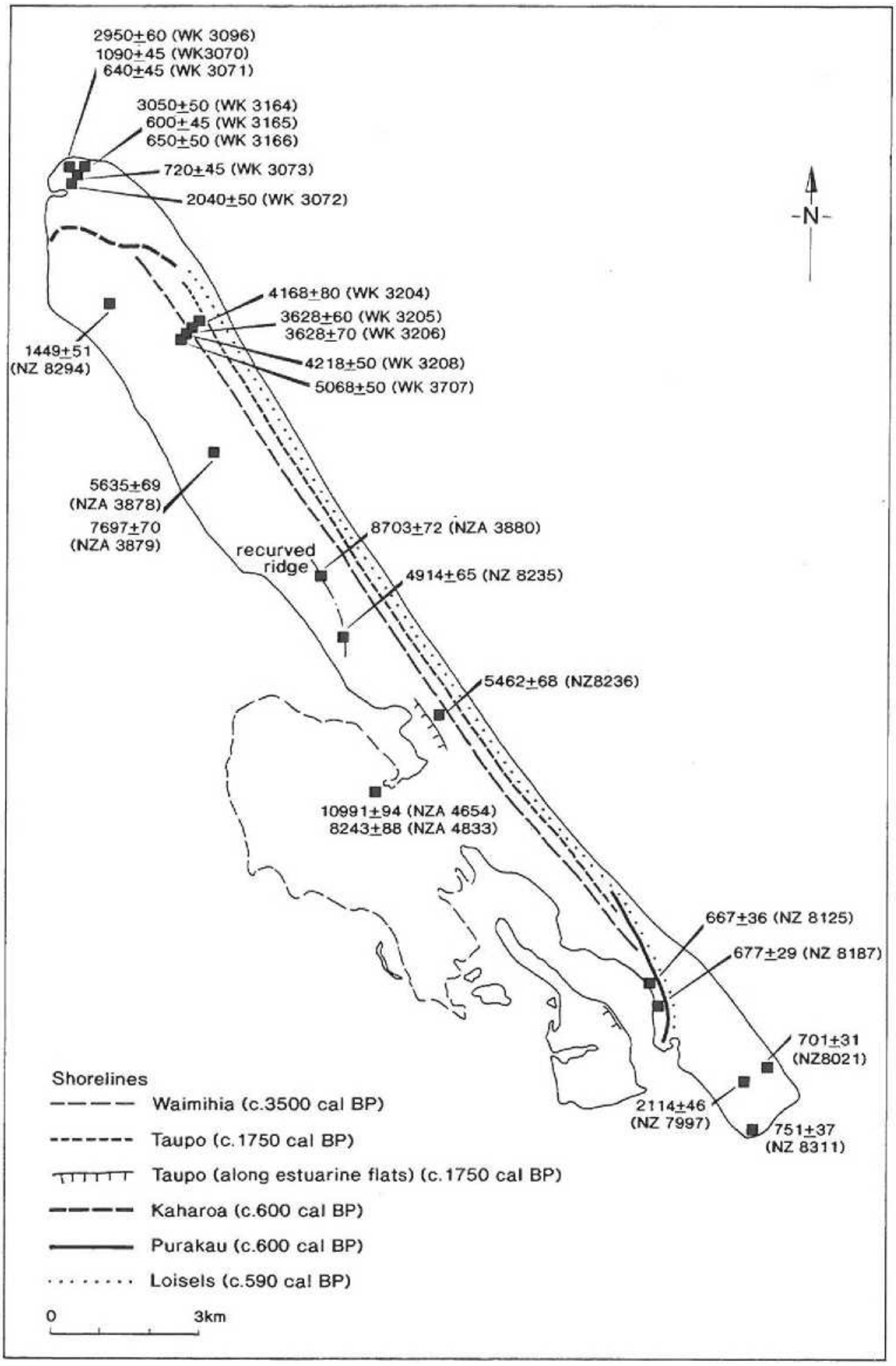


FIGURE 16. MAP OF MATAKANA ISLAND SHOWING LOCATIONS OF RADIOCARBON SAMPLES, RADIOCARBON AGES, AND PALAEO-SHORELINES DATED BY TEPHRA AND SEA-RAFTED PUMICES. LABORATORY NUMBERS IN BRACKETS. LABORATORY NUMBERS PREFIXED "WK" FROM MUNRO (1994). FOR DETAILS OF RADIOCARBON DATES SEE TABLE 1.

No tephras were found at the Southeastern End but there are extensive deposits of sea-rafted Loisels Pumice close to the foot of the Purakau Shoreline at several locations (Fig.17). The pumice covered hundreds of square metres, with waterworn lumps up to 10 cm in diameter.

FIGURE 17. MAP OF BARRIER ENDS,

a) NORTHWESTERN END. S1, S2 = ERODED SHORELINES; S3 = KAHAROA SHORELINE; K" = KAHAROA TEPHRA IN WETLAND DEPOSITS; K = KAHAROA TEPHRA IN DUNE DEPRESSION; A-B = PROFILE SHOWN IN FIG. 10.

b) SOUTHEASTERN END. LP = LOCATIONS OF LOISELS PUMICE; L-K = PROFILE SHOWN IN FIG.10; NZ NUMBERS REFER TO RADIOCARBON-DATED SAMPLE LOCATIONS (TABLE 1). APPARENT LOW BROAD RIDGES SHOWN AS "-?-?-".

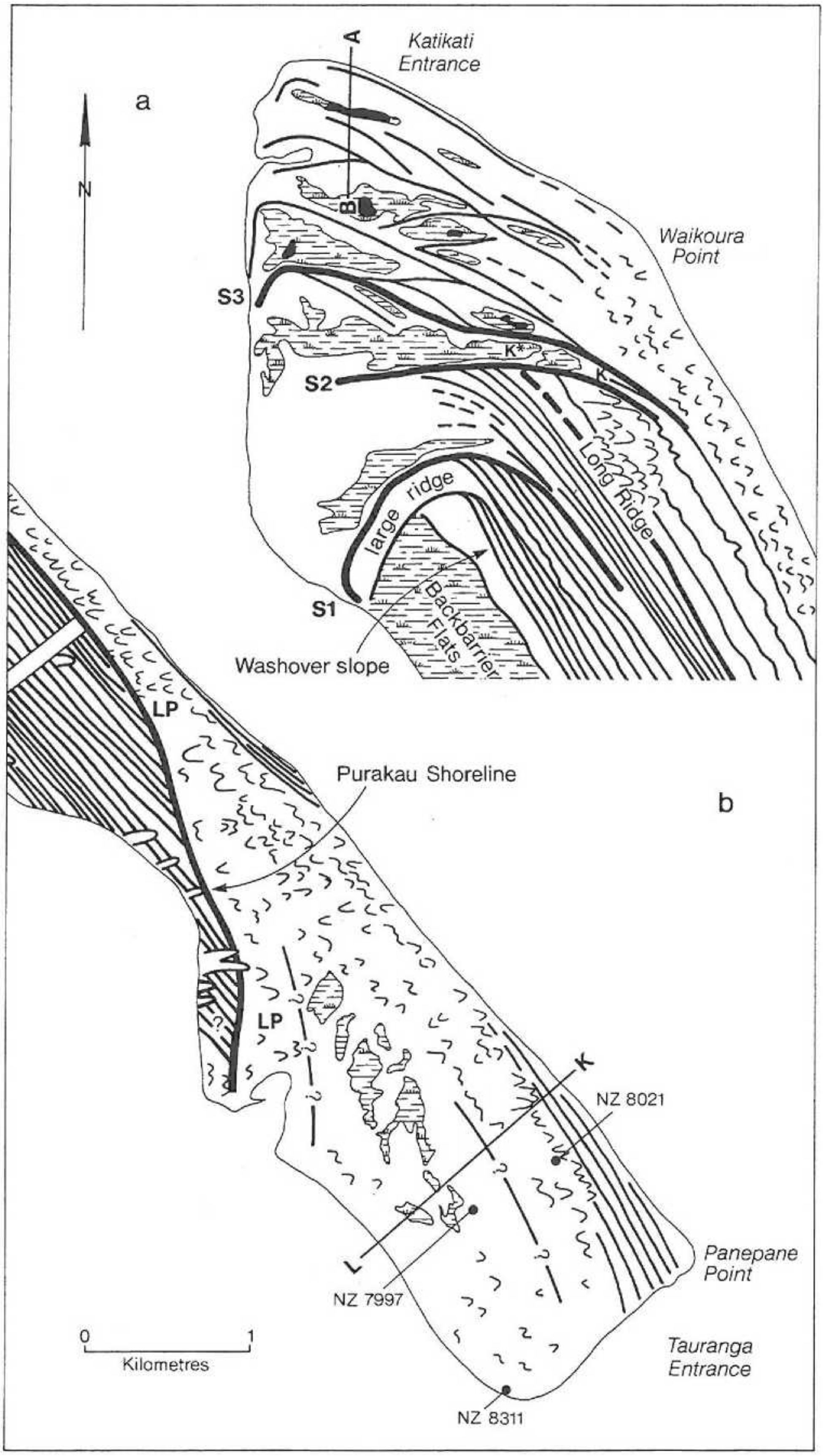


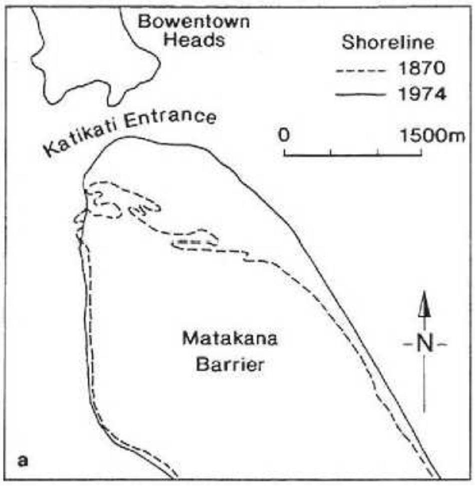
FIGURE 18. VERTICAL AERIAL PHOTOGRAPH OF RECURVED RIDGES AT THE NORTHWESTERN END OF THE ISLAND. PHOTOGRAPH COURTESY OF AIR MAPS (NZ) LTD.

Parallel relict foredunes are present near Panepane Point and in a small area about 4 km northwest of Panepane Point. There appear, however, to be low broad ridges (Fig. 17), separating depressions and wetlands. From the relict foredunes and the low, broad ridges we infer the growth of the Southeastern End of the island from the Purakau Shoreline to the present shoreline (Fig. 20).

The ages of shells from the coarse sand at c. 1.0m below present high water level are 701 ± 31 yr BP (NZ8021) and 2114 ± 46 yr BP (NZ7997) (Table 1). The older shells are from near the middle of the Southeastern End, the younger from near the ocean coast (Fig. 19b). The age of midden shells from the boat ramp corner of the Southeastern End is 751 ± 37 yr BP.

2.2.5 Contemporary foredune and beach

There is a regular foredune along much of the ocean shoreline. Its vegetation is described by Beadel (1989b). The foredune height above the seaward limit of



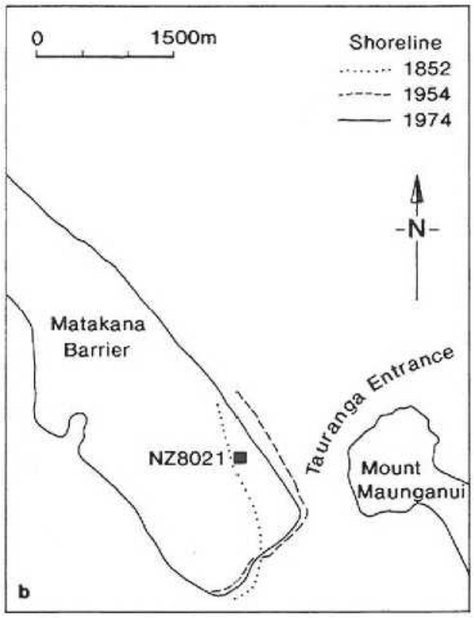


FIGURE 19. HISTORICAL SHORELINE CHANGES AT THE ENDS OF MATAKANA BARRIER:

a) THE NORTHWESTERN END OPPOSITE BOWENTOWN HEADS. DATA FOR 1870 SHORELINE FROM CADASTRAL MAP (SO 9385) AND 19-4 SHORELINE FROM TOPOGRAPHIC MAP NZMS 260 U13 1ST ED., 1979).

b) THE SOUTHEASTERN END OPPOSITE MT. MAUNGANUI. DATA FOR THE 1852, 1954 AND 1972 SHORELINES FROM HEALY (197.').

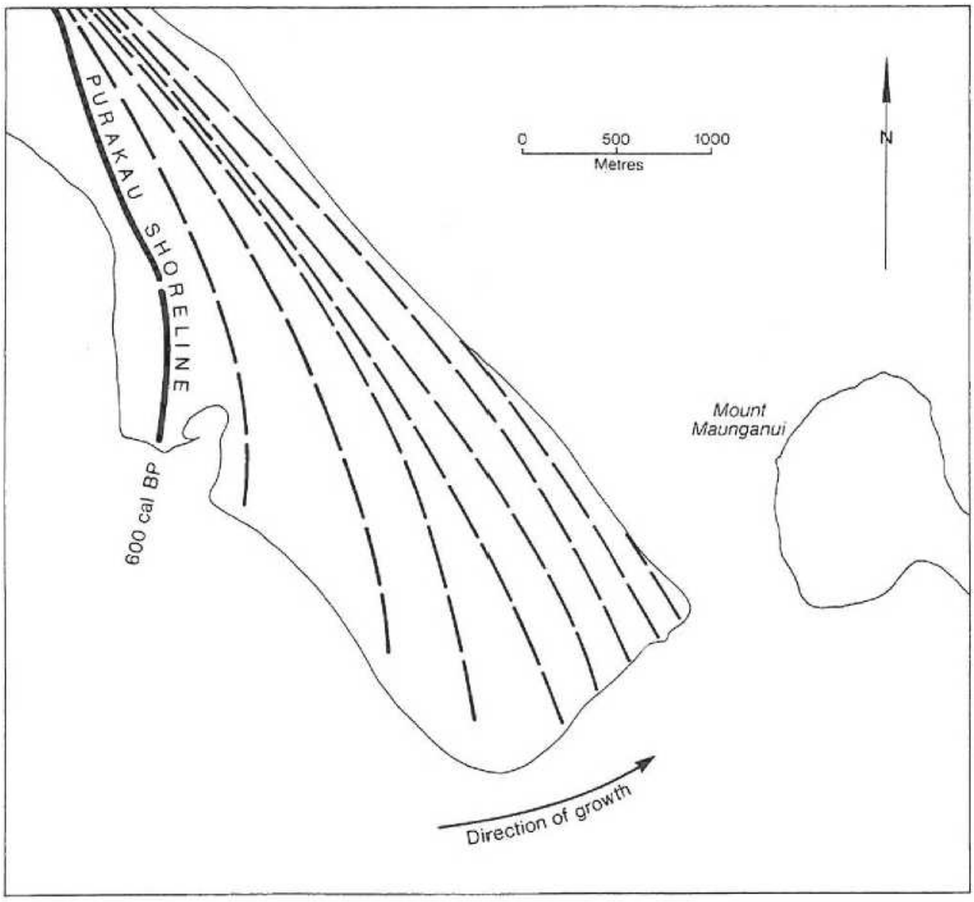


FIGURE 20. INFERRED GROWTH OF THE SOUTHEASTERN END.

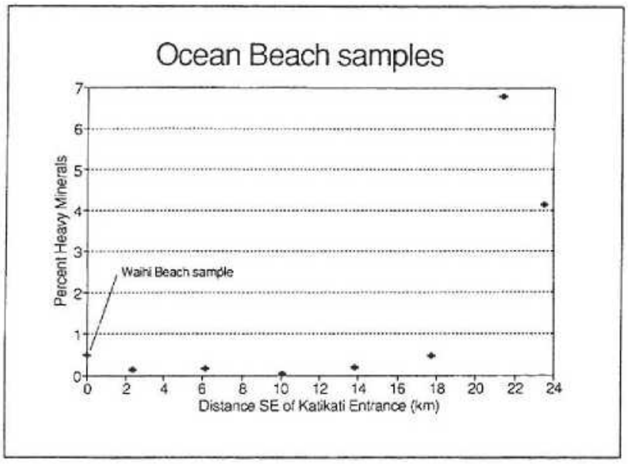


FIGURE 21. HEAVY MINERAL CONTENT OF OCEAN BEACH SAND SAMPLED AT THE MID-TIDE LEVEL IN 1993- WAIHI BEACH SAMPLE, TAKEN 8km NORTHWEST OF KATIKATI ENTRANCE SHOWN FOR COMPARISON,

vegetation varies from *c*. 1.7 m near the central part of the barrier to *c*. 4 m near the harbour entrances, and it is generally 5 m to 10 m wide. It is absent from c. 1.6 km to 3.7 km northwest of Panepane Point (Fig. 17), where the shoreline has eroded by more than 100 m since reaching its maximum seaward position in 1954 (Healy 1977). Shoreline erosion at the Katikati Entrance has removed the foredune and destroyed an area of Pinus radiata forest. Two or three additional ridges are present in a narrow strip behind much of the present ocean foredune. The additional ridges are lower and more closely spaced than ridges on the relict foredune plain, and are about the same height as the foredune. The small size of the foredune, where present, suggests that it is young.

Beach morphology around the barrier varies according to exposure. The ocean beach is wider and extends higher above mean sea level than beaches at the entrances and adjacent to the harbour. Dark seams of heavy minerals concentrated by storm waves sometimes occur on the upper part of the beach and are generally thicker, richer and more extensive than wind-blown heavy mineral seams in the foredune. When sampled in 1993, the heavy mineral content of mid-tide level sand was <1% in all samples except those near the Tauranga Entrance, where the sand contained up to 7% heavy minerals (Fig. 21).

Beach sand from near mid-tide level was collected twice, during January 1993 and August 1994, and foredune sand once during August 1994, along the entire ocean beach. Both sets of samples from Waikoura Point to a point c. 7 km from the Tauranga Entrance show uniform grain size (2.0-2.7 phi, 0.25-0.15 mm) and sorting almost identical to sand forming the relict foredunes on the main part of the barrier. Within 7 km of the Tauranga Entrance the beach sand coarsens markedly to c, 1.5 phi (0.35 mm) (Fig. 22a) and is more poorly sorted; foredune sand coarsens but its sorting shows little change (Fig. 22b).

2.2.6 Relict transgressive dunes

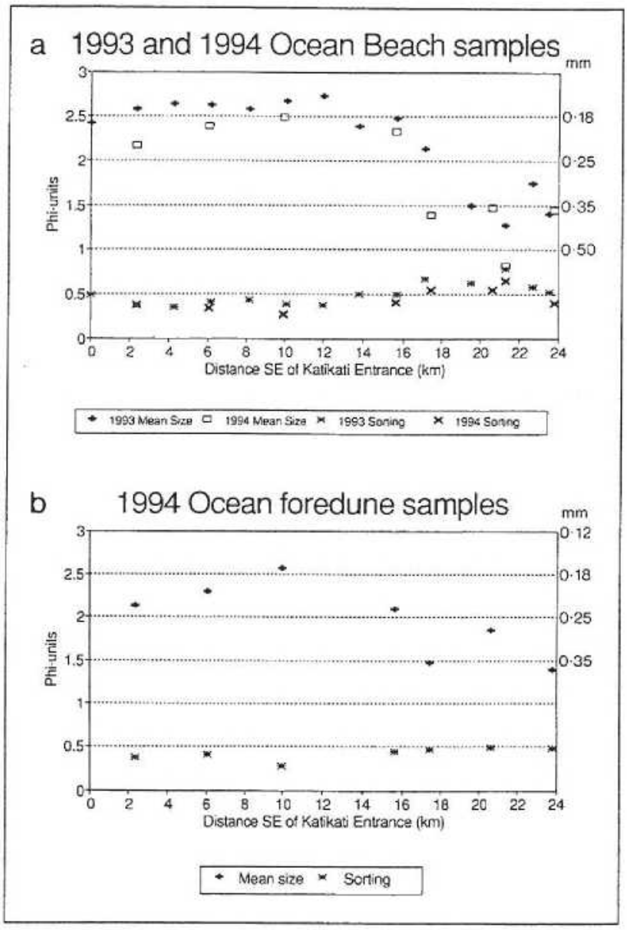
Relict transgressive dunes are common on Matakana Barrier. Blowout and parabolic dunes develop in response to disturbance of dune vegetation which exposes unconsolidated sand to wind erosion. Disturbance can include erosion by waves, increased wind, fire, tephra deposition, and damage by animals, including humans.

Once the vegetation is destabilised, a blowout dune may form as a lobe of sand aligned downwind- If the dune migrates further downwind it may evolve into a

FIGURE 22. MEAN SIZE AND SORTING OF BEACH AND FOREDUNE SAND. MEAN SIZE SHOWN IN PHI UNITS AND MILLIMETRES. SORTING SHOWN IN PHI UNITS ONLY. FOR LOCATION OF SAMPLING POINTS SEE APPENDIX 2.

a) OCEAN BEACH, JANUARY 1993 AND AUGUST 1994.

b) FOREDUNE SAND, AUGUST 1994.



parabolic dune with an advancing nose, a central deflation basin and two trailing arms aligned upwind. Sand is supplied to the nose by winds which are funnelled between the trailing arms.

Large parabolic dunes 2 km to 5 km northwest of the entrance to Blue Gum Bay (B, Fig. 23), and adjacent to Hunters Creek (E, Fig. 23), have mean directions of movement from 256° and 262° respectively. Blowouts and parabolic dunes are normally aligned with winds from a *geomorphically significant* wind resultant (Landsberg 1956). The geomorphically significant resultant for the harbour shore of Matakana Barrier (257°-259°) we calculate from winds at Waihi Beach (Harray 1977) and at Tauranga (Healy et al. 1977) using the method of Landsberg (1956) modified by Jennings (1957). The resultant agrees well with the alignment of the large parabolic dunes.

Not all dunes on the barrier, however, are aligned with the dominant wind directions; those which show no particular alignment are termed hummocky dunes.

The dunes on Matakana Barrier are described in three groups:

a) Blowout dunes and small parabolic dunes associated with relict foredunes;
b) Large parabolic dunes which have migrated across a number of relict foredunes;
c) Parabolic dunes in a narrow strip near the foredune along the ocean coast. This strip widens to include the southeastern end of the barrier, where hummocky dunes are present.

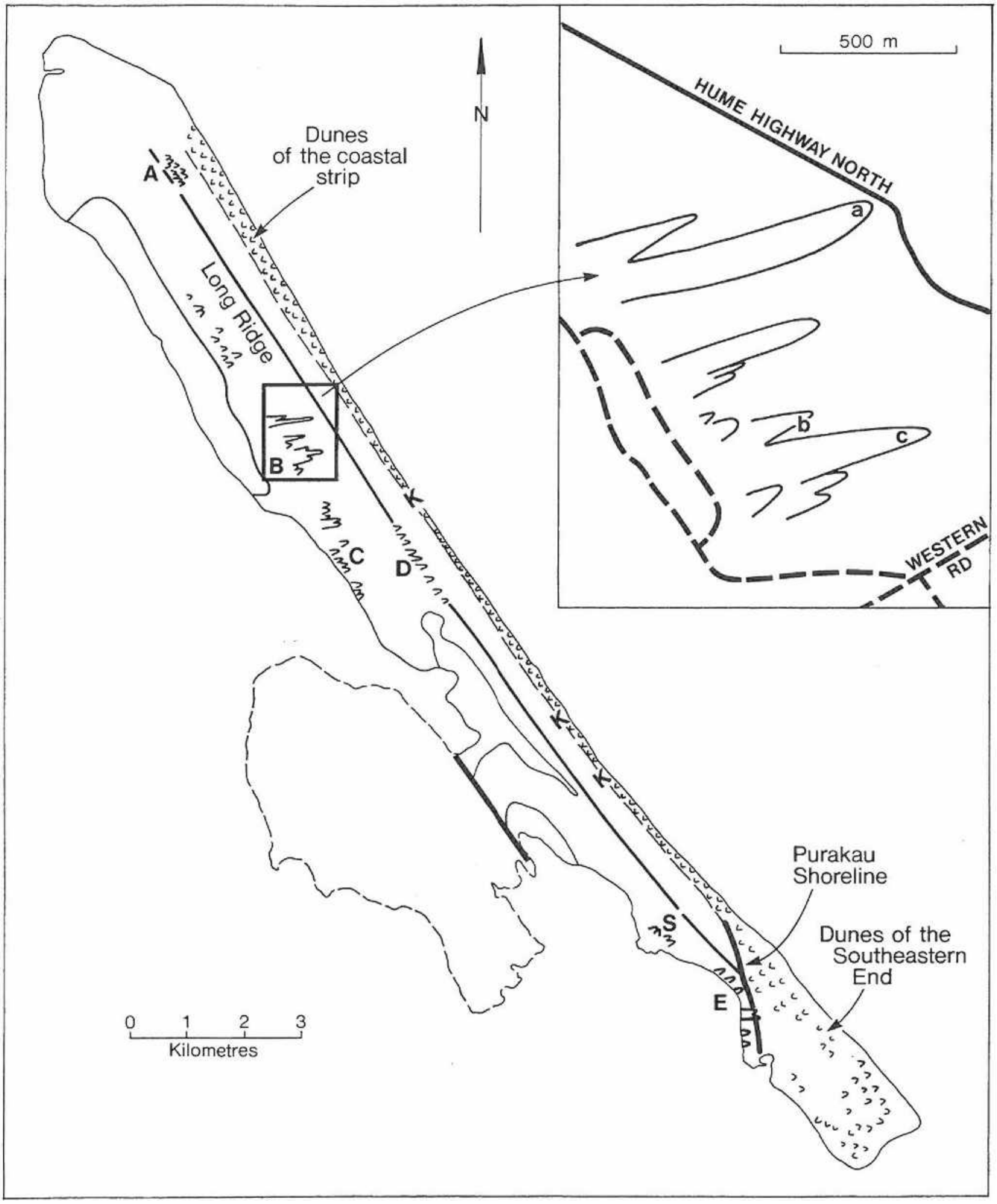


FIGURE 23. MATAKANA BARRIER SHOWING LOCATION OF LARGER TRANSGRESSIVE DUNES. LARGE PARABOLICS LABELLED A-E; S = STENT TEPHRA SITE NEAR THE MILL; K = LOCATIONS OF KAHAROA TEPHRA BENEATH PARABOLIC DUNES OF THE COASTAL STRIP.

INSET: ENLARGEMENT OF LARGE PARABOLIC DUNES AT B. LOCATIONS MENTIONED IN THE TEXT LABELLED a-c.

FIGURE 24. VERTICAL PHOTOGRAPH SHOWING THE DEVELOPMENT OF SMALL PARABOLIC DUNES FROM BLOWOUTS IN A LARGE RELICT FOREDUNE NORTHWEST OF HUNTER'S CREEK. PHOTOGRAPH COURTESY OF CAR'T'ER HOLT HARVEY FORESTS LTD.

a) Dunes associated with relict foredunes

In many parts of the barrier, small blowout and parabolic dunes have modified foredune ridges (Fig. 24), particularly the high foredunes which would have been exposed to higher wind velocities. Dune orientation indicates that most developed in response to onshore northeasterly winds, and others to offshore winds. The blowout and parabolic dunes are morphologically and stratigraphically continuous with their parent foredunes. The continuity indicates that the blowout and parabolic dunes are similar in age to their parent foredunes.

b) Large parabolic dunes

Large parabolic dunes are present in at least five locations on the barrier (A-E, Fig. 23). They developed either through enlargement of the blowouts of formerly stable (relict) foredune ridges or from wind erosion of bare sand cliffs along receding sections of the harbour shoreline, as at Hunter's Creek. Some dunes (B, Fig. 23) have migrated up to 730 m over otherwise unmodified relict foredunes. We include as large parabolic dunes the noses of parabolic dunes adjacent to Hunter's Creek (E, Fig. 23, Fig. 27); these migrated from former relict foredunes west of the Hunter's Creek shoreline. Both the trailing arms of the parabolic dunes and the relict foredunes from which they were derived have been eroded away by Hunter's Creek.

The oldest parabolic dunes occur near the inner margin of the barrier. A Taupo-sourced rhyolitic tephra, tentatively identified as Stent tephra, is interbedded with dune sand near the Matakana Mill (S, Fig. 23), indicating dune migration probably commenced about 4000 yr BP at that site.

The large parabolic dunes which migrated eastward across the inner part of the Relict Foredune Plain 2-5 km northwest of the entrance to Blue Gum Bay (inset, Fig. 23) have Taupo Lapilli on their arms and were initiated prior to the Taupo eruption. They cross relict foredune ridges on the surface of which are old Maori garden soils (b, inset, Fig. 23), indicating reactivation after human settlement. The eastern parts of two of the larger dunes (a and c, inset, Fig. 23; Fig. 25, see page 45) overlie Kabaroa Tephra, confirming that they were reactivated during the past 600 years. The ash below one (c, inset, Fig. 23) was in a dark peaty soil with Taupo Lapilli. Pollen from the soil did not include Pinus pollen (Appendix 4), which suggests that the dune covered the site prior to European arrival.

Large relict parabolic dunes occur along and harbourward of Long Ridge on the ocean side of the recurved ridges at the former Blue Gum Bay entrance (D, Fig. 23). Their steep slip faces and the absences of soil profile development and a tephra cover from their surfaces strongly suggests they are also post-Kaharoa in age. The extent of these dunes has not been defined, owing to a thick vegetation cover and lack of suitable aerial photographs. It is possible that they are reactivated dunes similar to those 2-5 km northwest of the entrance to Blue Gum Bay, and were originally formed prior to the Taupo eruption.

At the northern end of the barrier, 1 km south of Waikoura Point (A, Fig. 23), undisturbed Kaharoa Tephra lies directly on clean sand in the deflation basin of one of the large parabolic dunes. The lack of a soil profile indicates the ash fell soon after the deflation basin had formed. The age for the parabolic dune is therefore little more than 600 years. Adjacent dunes are likely to be of similar age.

Relict post-Kaharoa transgressive dunes are common in places along the inner barrier northwest of Blue Gum Bay (C, Fig. 23). These younger dunes are generally smaller, have steeper slopes, show little or no soil profile development, and lack surface tephra deposits.

A series of parabolic dunes (E, Fig. 23) is present along Hunter's Creek. Continuing shoreline erosion by Hunter's Creek has exposed sections across the noses of several parabolic dunes. One section shows three phases of aeolian sand deposition separated by poorly formed buried topsoils (Fig. 27, Table 4).

TABLE 4. DESCRIPTION OF SECTION EXPOSED BY EROSION AT HUNTER'S CREEK.

DEPTH (m)	DESCRIPTION
0-0.10	Poorly-developed, discontinuous topsoil on sand.
0.10-1.75	Wind blown sand with poorly-developed buried topsoils on old dune surfaces and occasional shell fragments.
1.75-2.35	Buried topsoil, gardened, with sparse charcoals, shells, Taupo Lapilli, and lumps of Kaharoa Tephra well-mixed through it. Intact shell midden deposits on upper surface.
2.35-3.15	Iron-stained sand.
3.15-4.65	Cross-bedded dune sand with traces of Stent (?) tephra near base.
4.65-6.00	Horizontally-bedded beach sand with bands of heavy minerals.

The dunes had advanced over Maori garden soils formed on relict foredunns. The garden soils contained Taupo Lapilli and pockets of Kaharoa Tephra. A shell midden on the Maori garden soil has a radiocarbon age of 667 ± 36 yr BP (NZ 8125, Table 1).

The most recent dune advance is probably at the southeastern end of the section where two parabolic dunes have advanced from the present shoreline to beyond the Purakau shoreline (Fig. 26, see page 45). They cut through a Maori garden soil and their basins have been deflated almost to present sea level. A shell midden in the Maori garden soil has a radiocarbon age of 677 ± 29 yr BP (NZ8187, Table 1).

c) Dunes of the coastal strip and Southeastern End of the barrier

Relict, largely parabolic, dunes form a narrow continuous strip near the ocean coast. This extends along much of the barrier's length and obscures the former relict foredune topography. The strip is mostly 100-200 m wide with its seaward limit within 100 m of the foredune. However, it widens to the southeast to include most of the southeastern part of the barrier which has a generally low, hummocky topography. The parabolic dunes near the ocean coast are more numerous and extensive than the other two groups.

These dunes show little or no soil profile development. Limited foredune development seaward of them suggests a relatively young age. They overlie Kaharoa Tephra at three locations (K, Fig. 23) but nowhere does the tephra overlie the dunes. They therefore appear to postdate the Kaharoa Eruption and may have originated following damage to the foredune vegetation, possibly due to human activity or volcanic ash. Historical records provide no conclusive evidence that these dunes were active at the time of early European settlement on the island, but it should be noted that Cockayne (1909), in his study of active dunefields in New Zealand, referred to a strip of dunes adjacent to the Bay of Plenty coast extending from Tauranga Harbour to beyond Opotiki.

2.2.7 Backbarrier flats

Backbarrier flats supporting swamp forest are common at the heads of Hunter's Creek, Blue Gum Bay, and the inner margin of the northwestern part of the barrier (Fig. 7). Their boundary with the backbarrier washover slope is poorly defined. The flats have extremely low relief compared to the rest of the barrier and are up to 750 m wide. In the northwestern part of the barrier they incorporate former estuarine channels.

The backbarrier flats developed along the sheltered harbour shoreline of the barrier and originated as estuarine flats which ceased to be inundated by tides as the harbour shore prograded. They are commonly fringed by a zone of active estuarine flats with a well-developed vegetation succession e.g., at the northwestern end of Blue Gum Bay. In contrast to sediment derived directly from the ocean beach, sediment of the backbarrier flat and active intertidal flats contains a small proportion of fine mud.

Sedimentation rates on estuarine flats are enhanced by salt marsh vegetation, such as that described by Beadel (1989x), which gives greater protection from harbour waves by lowering energy levels (White 1979). Accretion rates tend to decrease with time as the surface elevation approaches that of the highest spring tide (Pethick 1981). Accretion above this level results mainly from the accumulation of organic platter and airfall tephra.

Kaharoa Tephra and sea-rafted Taupo Pumice are present at the northwestern margin of the flats along Blue Gum Bay. Kaharoa Tephra only was observed on the flats at the northwestern end of the barrier but field investigations were limited. Nevertheless, our impression is that the greater part of these flats are young.

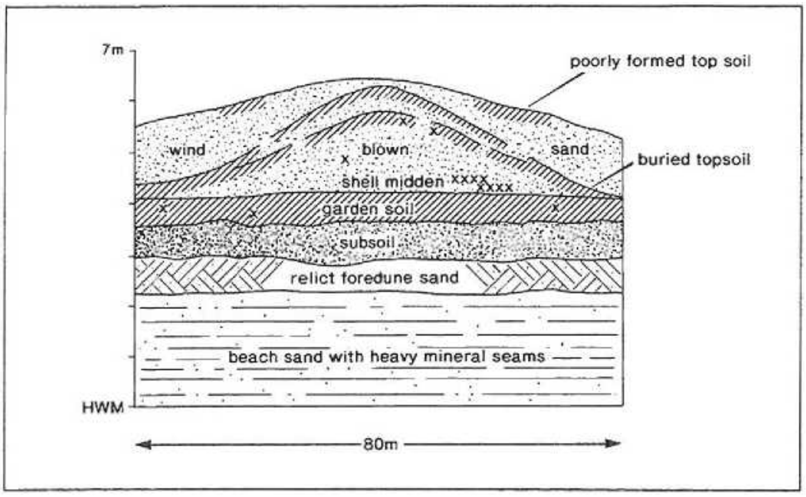


FIGURE 27. STRATIGRAPHY OF DUNES EXPOSED IN AN ESTUARINE CLIFF ADJACENT TO HUNTER'S CREEK. GARDEN SOIL ON RELICT FOREDUNE SAND IS OVERLAIN BY THREE LAYERS OF DUNE SAND ASSOCIATED WITH PARABOLIC DUNE ADVANCES. THE PARABOLIC DUNE SAND LAYERS ARE SEPARATED BY BURIED SOILS.

FIGURE 5 PHOTO OF THE LOWEST PLEISTOCENE TERRACF ON MATAKANA CORE. BLUE GUM BAY AT TOP LEFT. THE INTERGALACIAL. COASTAL PLAIN WITH TRACES OF THE ORIGINAL RIDGE/SWALE TOPOGRAPHY AT CENTRE, AND THE. OUTER MARGIN OF AN OLDER PLEISTOCENE TERRACE AT BOTTOM RIGHT. VIEW TO THE EAST.

FIGURE 6. PLEISTOCENE PARABOLIC DUNE (CENTRE OF PHOTO) ADJACENT TO BLUE GUM BAY (FIG. 4). VIEW TO THE NORTHWEST.

FIGURE 25. THE NOSE OF A PARABOLIC DUNE (c, INSET, FIG. 23) WHICH HAS MIGRATED ACROSS THE RELICT FOREDUNE PLAIN NORTH OF BLUE GUM BAY.

FIGURE 26. PARABOLIC DUNES WHICH HAVE MIGRATED FROM HUNTER'S CREEK (CENTRE LEFT) ACROSS THE PURAKAU SHORELINE. VIEW TO THE NORTH.

3 Sequence of barrier formation

Immediately prior to formation of Matakana Barrier, the Pleistocene cores of Matakana and Rangiwaea Islands lay offshore in a large bay with the volcanic outcrops at Bowentown and Mt Maunganui forming islands to the northwest and southeast respectively (Fig. 28a). Ocean waves eroded the northeast-facing coasts of Matakana and Rangiwaea Islands to form wave-cut cliffs, and to the northwest shelf sediment was being transported shoreward to eventually form a washover ridge (Fig. 28a).

The Holocene barrier began forming in at least three parts: a northwestern; a central; and a southeastern part. The three parts were separated by entrances at Blue Gum Bay and between Matakana and Rangiwaea Islands (Fig. 28b). The northwestern part consisted initially of the washover ridge. The heavy mineral content and size of the marine sediment beneath the innermost foredune ridge of the northwestern part indicates a high degree of reworking consistent with a washover origin. This ridge stabilised after about 6000 cal BP (NZA3878, Table 1), more than 1000 years after the end of the Postglacial Marine Transgression which ended about 7000 cal BP.

The central part of the barrier began forming against the low wave-cut cliff eroded into the Pleistocene deposits of Matakana Core, and the southeastern part against the wave-cut cliff cut into the Pleistocene deposits of the Rangiwaea Core. Spit extension enabled the northwestern part to grow southeastwards at the same time as it prograded seawards, deflecting the Blue Gum Bay entrance to the southeast (Fig. 28c). The Katikati entrance was more stable, enabling a recurved spit to develop into a large ridge by aeolian accretion (Fig. 17). There is clear evidence for at least one erosional episode (S1, Fig. 17) which truncated relict foredunes at the Northwestern End (Fig. 28c).

The Blue Gum Bay entrance was eventually closed off by, and the northwestern and central parts joined by, the prominent Long Ridge. The formation of Long Ridge is dated by radiocarbon samples of shells from harbourward and seaward of the ridge.

Samples from the harbour side of Long Ridge provide a maximum age for its formation and include NZ8236, NZ8235 (Table 1) and WK3207 (Munro 1994)(Fig. 16). The youngest maximum age (NZ8235) is from the recurved ridges and provides a maximum age for beginning of formation of 5435-5050 cal BP. The sample site, however, is separated from Long Ridge by more than six relict foredune ridges over a distance of c. 400 m and Long Ridge will therefore be considerably younger than the sample. Stent tephra is provisionally identified on the harbour side of Long Ridge at Hunter's Creek and in the Mill section, and provides a maximum possible age of 4520-4300 cal BP.

Samples from the seaward side of Long Ridge will provide maximum ages for the formation of the ridge provided they are from the beach deposits immediately seawards of the ridge. Only one sample, WK3208 (Munro 1994), meets this condition and it provides a maximum age of 4870-4605 cal BP. The sea-rafted Waimihia Pumice, located at a site (NZMS 260 U14 845960) which is *c.* 50 m seawards of Long Ridge, provides a minimum age for the ridge only if the pumice is a primary sea-rafted deposit. If this is the case, then Long Ridge would have stopped accreting by about 3500 cal BP. Considering the above ages we provisionally adopt an age for Long Ridge of 4000-3500 cal BP.

As with the Blue Gum Bay entrance, the entrance between Matakana and Rangiwaea islands was deflected to the southeast. It has, however, maintained a channel, Hunter's Creek, which separates the two islands and now connects with the harbour near the Tauranga Entrance. Hunter's Creek has eroded into the back of Matakana Barrier, removing the older foredune ridges.

The barrier appears to have grown more slowly after the Blue Gum Bay entrance was closed, suggested by the somewhat higher relict foredune ridges from Long Ridge seawards compared with those harbourwards from Long Ridge. There is clear evidence for at least one further erosional episode at the Northwestern End (S2, Fig. 17) which truncated relict foredunes shortly after the Taupo Pumice eruption 1750 cal BP (Fig. 28d). At the Southeastern End, a major period of erosion, which ended shortly after the Kaharoa Eruption 600 cal BP, resulted in the formation of the Purakau Shoreline which obliquely truncates relict foredunes (Fig. 28e).

Following truncation, the southeastern end of the barrier grew quickly as a series of low, ill-defined broad ridges and swales (Fig. 20) partially covered with hummocky dunes. In historical time a sequence of better-defined low relict foredunes has developed at Panepane Point.

Following its truncation, the northwestern end of the barrier has grown less than the southeastern end. The growth has formed a series of diverging and converging ridges enclosing lakes and swamps (Fig. 28f). The growth appears to have greatly accelerated during historical time (Fig. 19a).

Transgressive dunes formed throughout the history of the barrier and range from relatively minor blowouts of the relict foredunes to large parabolic dunes which extend across several relict foredunes. Whilst the larger parabolic dunes were initiated in discrete areas and migrated seaward in the direction of the prevailing winds, the more recent parabolic dunes form a continuous strip adjacent to the present ocean foredune and have blown inland from the coast.

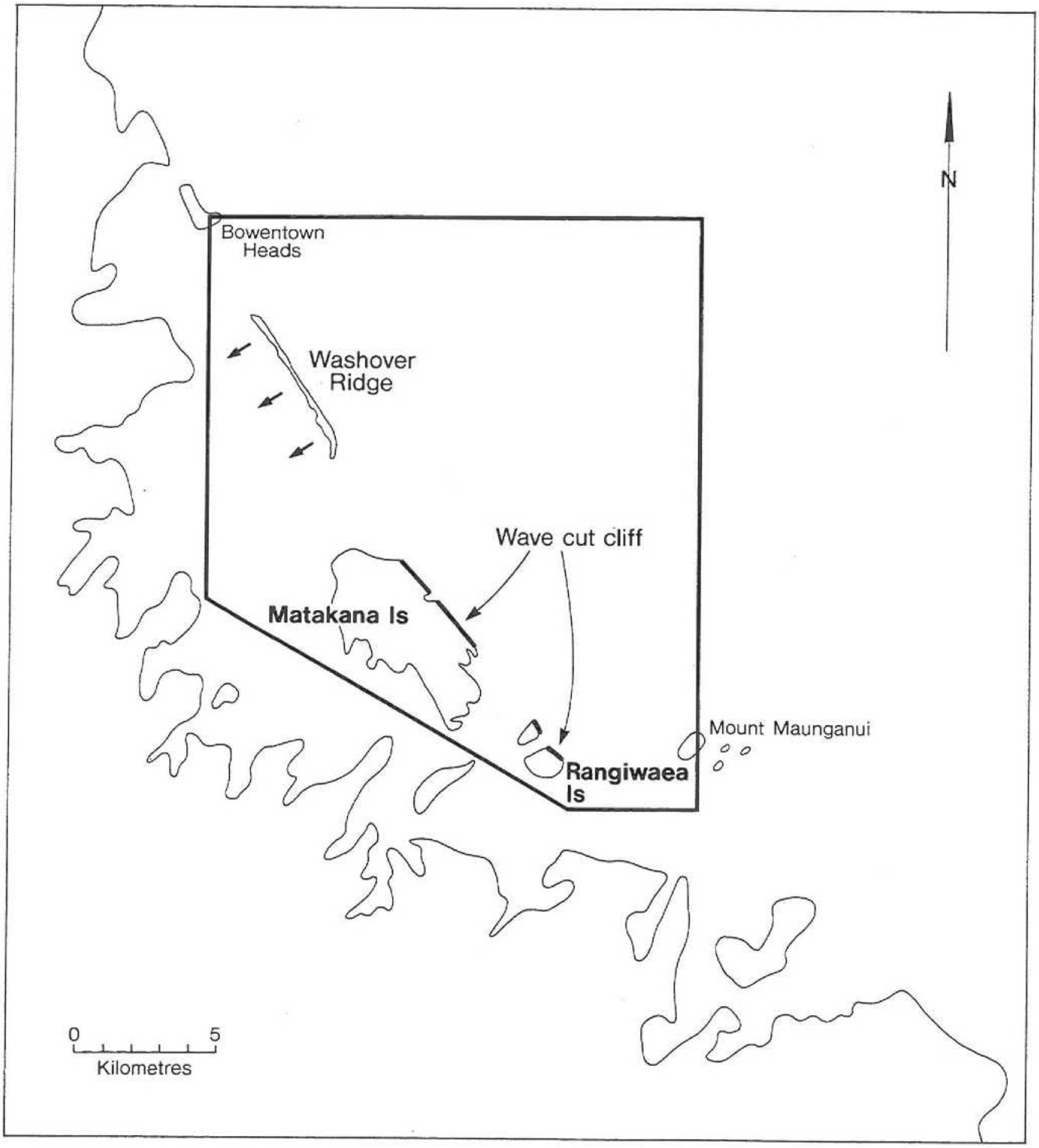


FIGURE 28. FIVE STAGES IN THE HOLOCENE DEVELOPMENT OF MATAKANA BARRIER (FIGS. a-e). INFILLING OF ESTUARINE EMBAYMENTS ADJACENT TO THE HOLOCENE BARRIER (FIGS. c-e) HAS BEEN ESTIMATED. INFILLING OF HOLOCENE EMBAYMENTS OF MATAKANA CORE NOT SHOWN.

a) c. 6500 CAL BP. COASTLINES ADAPTED FROM DAHM (1983) POSSIBLE WASHOVER RIDGE SHOWN MIGRATING LANDWARDS TOWARDS ITS FINAL POSITION AS SHOWN IN FIG. b. NOTE THE SMALLER SCALE COMPARED TO FIGS. b-f.

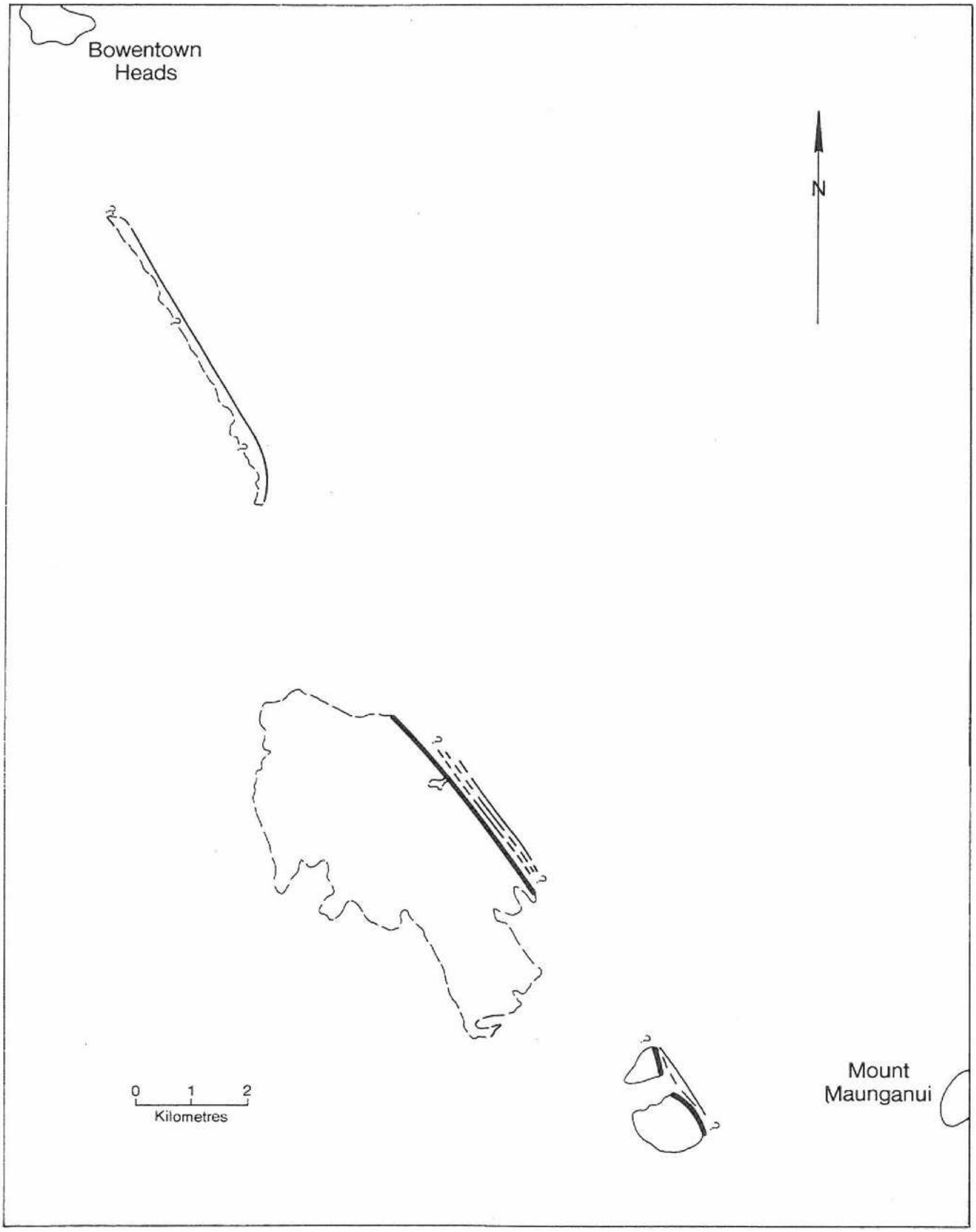


FIGURE 28b. *c*. 6000 GAL BP.

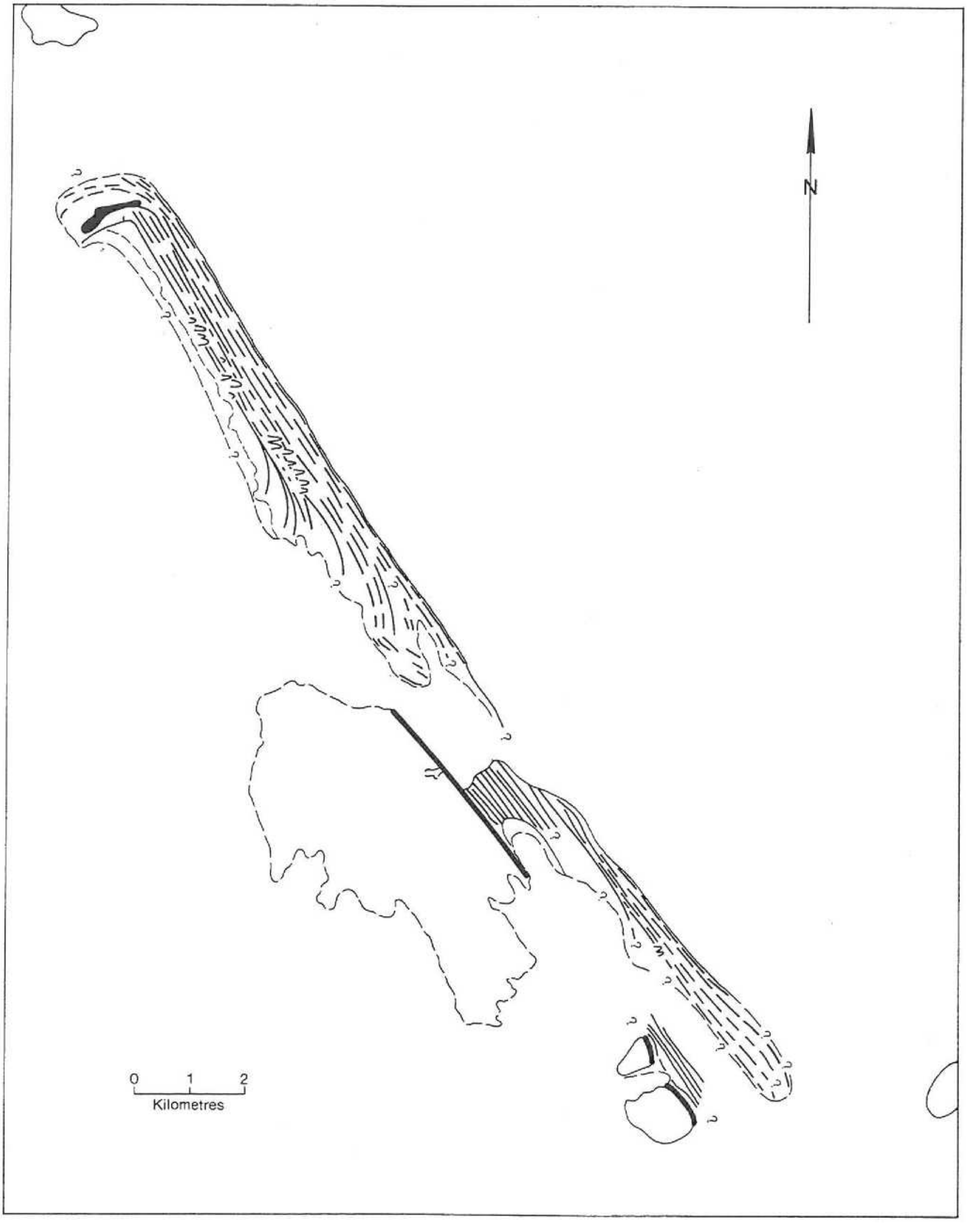


FIGURE 28c. *c*. 4000 CAL BP.

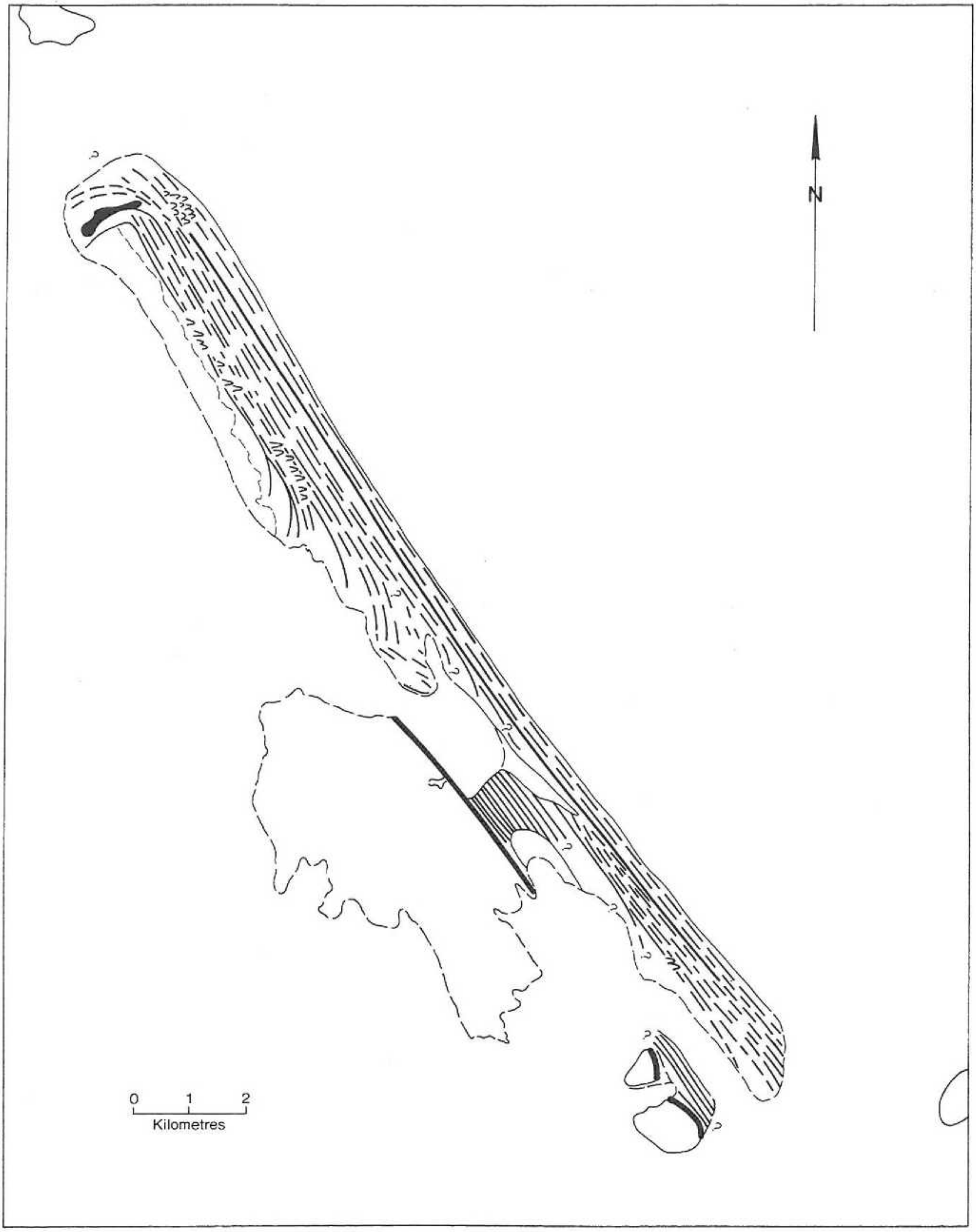


FIGURE 28d. *c*. 1750 CAL BP.

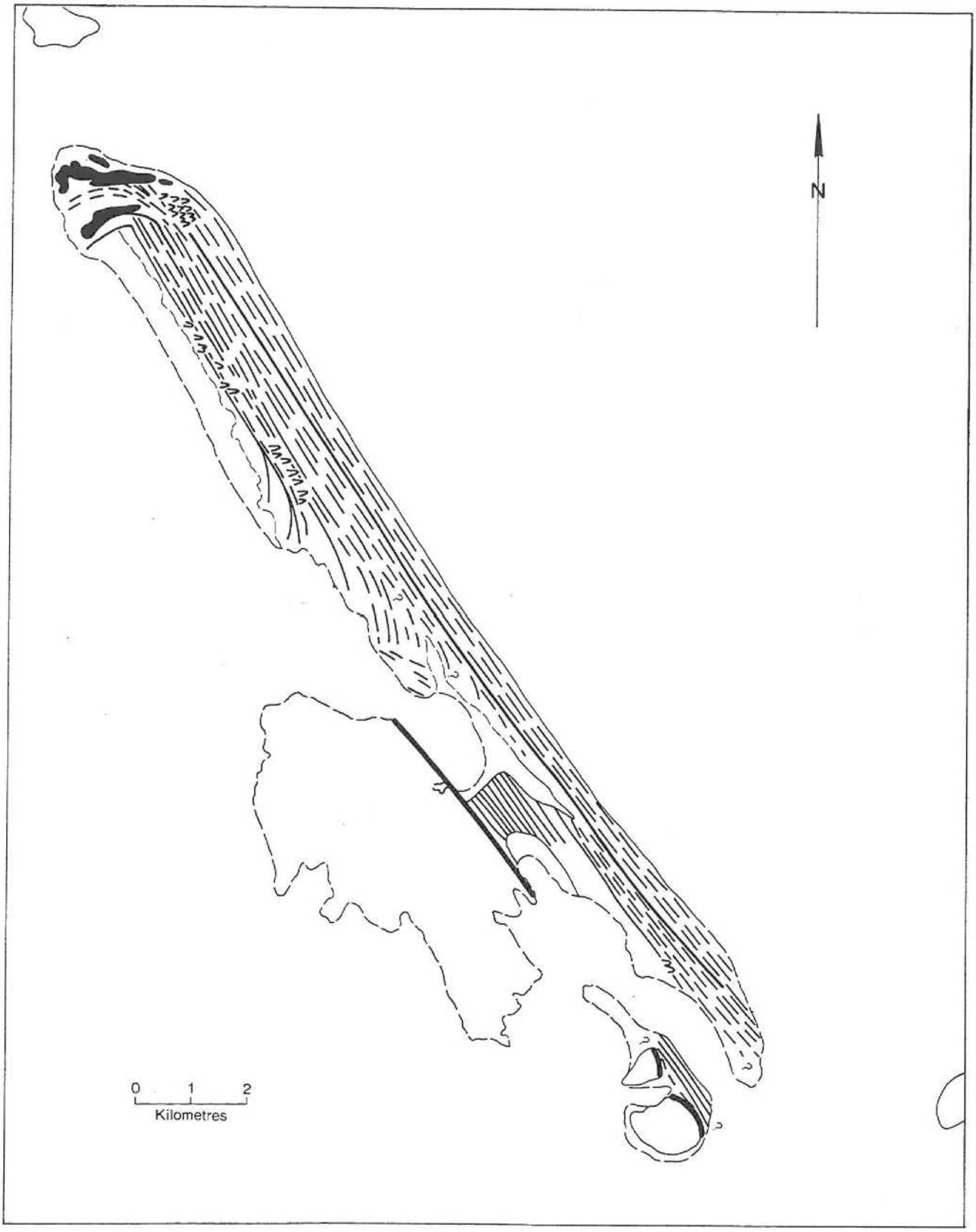


FIGURE 28e. c. 600 CAI. BF.

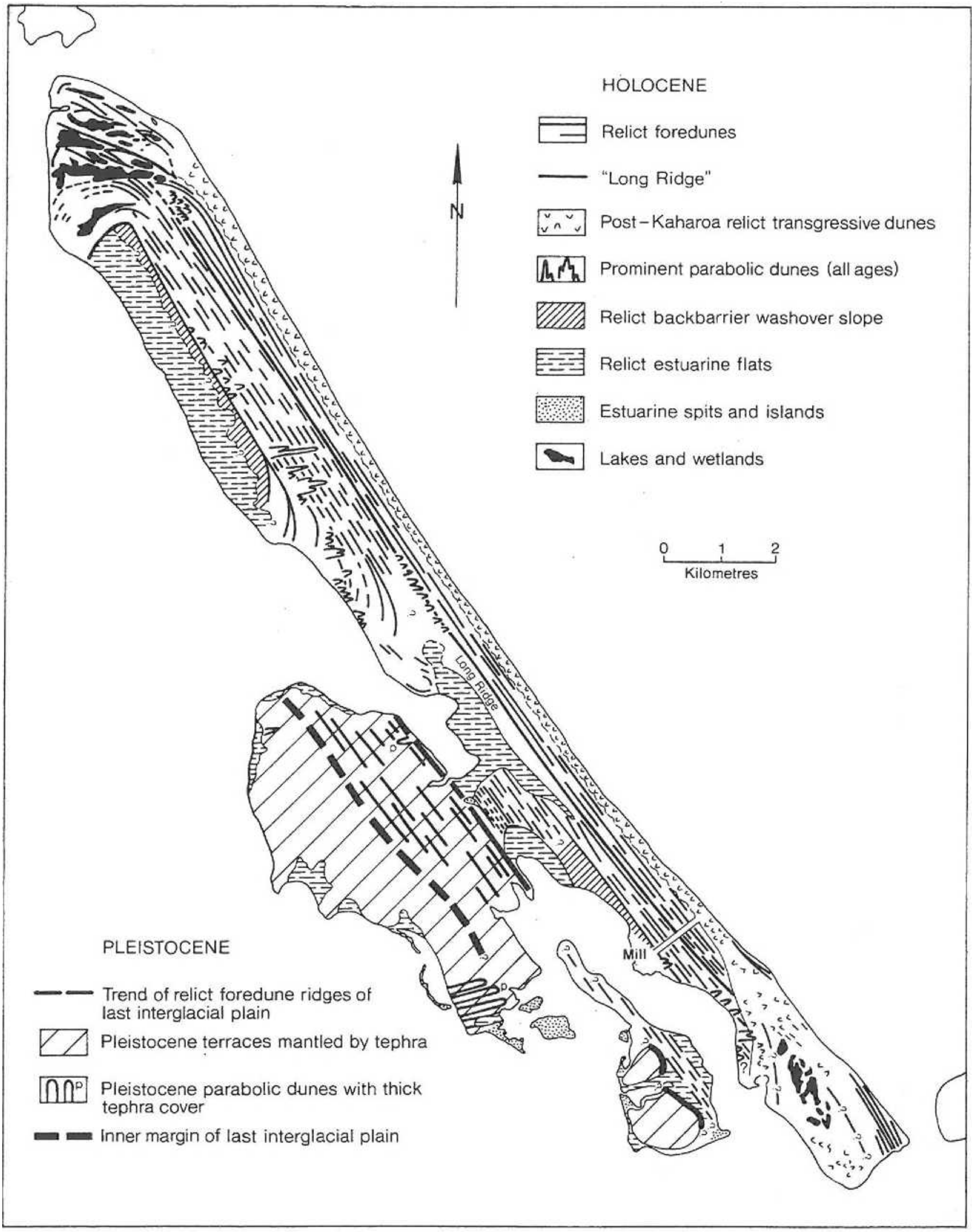


FIGURE 28f. PRESENT DAY.

4. Rates of barrier progradation

Rates of progradation are determined from the 6000 cal BP shoreline, and three shorelines defined by tephra or sea-rafted pumice deposits: the 3500 cal BP Waimihia shoreline; the 1750 cal BP Taupo shoreline, and the 600 cal BP Kaharoa shoreline. Progradation rates varied along the barrier depending upon proximity to present and former harbour entrances. Full sets of ridges possibly exist only in two places: where the Holocene Barrier joins Matakana Core and between the former Blue Gum Bay harbour entrance and the northwestern end of the barrier.

Although a full set of ridges appears to exist where the barrier joins Matakana Core, it does not form a continuous sequence along a line normal to the ocean coast owing to the presence of the former Blue Gum Bay Entrance. Progradation rates listed in the following table are therefore determined between the former Blue Gum Bay entrance and the northwestern end of the barrier. Because the 600 cal BP Kaharoa shoreline is obscured by the parabolic dunes along the coast, the distance between it and the sea is assumed to be 120 m, based on its distance inland at two locations to the south (Fig. 8).

Table 5 indicates that *c.* 65% of the progradation occurred during the first 2550 years of barrier development, which is consistent with the findings of Lowe et at. (1992) for the Papamoa-Te Puke coastal plain to the southeast.

TABLE 5. PROGRADATION RATES FOR MATAKANA BARRIER BASED ON THE INFERRED AGE OF THE EARLIEST RELICT FOREDUNE AND SHORELINES DEFINED BY TEPHRA OR SEA-RAFTED PUMICE.

PERIOD (Cal years BP)	PROGRADATION DISTANCE (m)	PROGRADATION RATE (m/yr)
c. 6000 - *c.* 3500	*c.* 1050	*c.* 0.42
c. 3500 - *c.* 1750	*c.* 325	*c.* 0.19
c. 1750 - *c.* 600	*c.* 125	*c.* 0.11
c. 600 - present	*c.* 120	*c.* 0.20

The change in progradation rate with time is graphed in Fig. 29, which adds two additional points to those shown by Table 5. These are the Long Ridge shoreline and the Stent tephra shoreline. The Long Ridge shoreline has an inferred age of 4000-3500 cal BP which is less precise than the tephra ages. The Stent tephra is only found near the southeast end of the barrier, where it is interbedded with relict foredune sand along Hunter's Creek. Its position in the sequence of relict foredunes at the northwest end of the barrier has been inferred in two ways. The first is based on the number of ridges harbourward from Long Ridge, and the second on the distance in metres harbourward from Long Ridge. Fig. 29 shows a general trend, which may disguise shorter-term fluctuations, of an initial rapid rate of progradation which diminishes gradually with time.

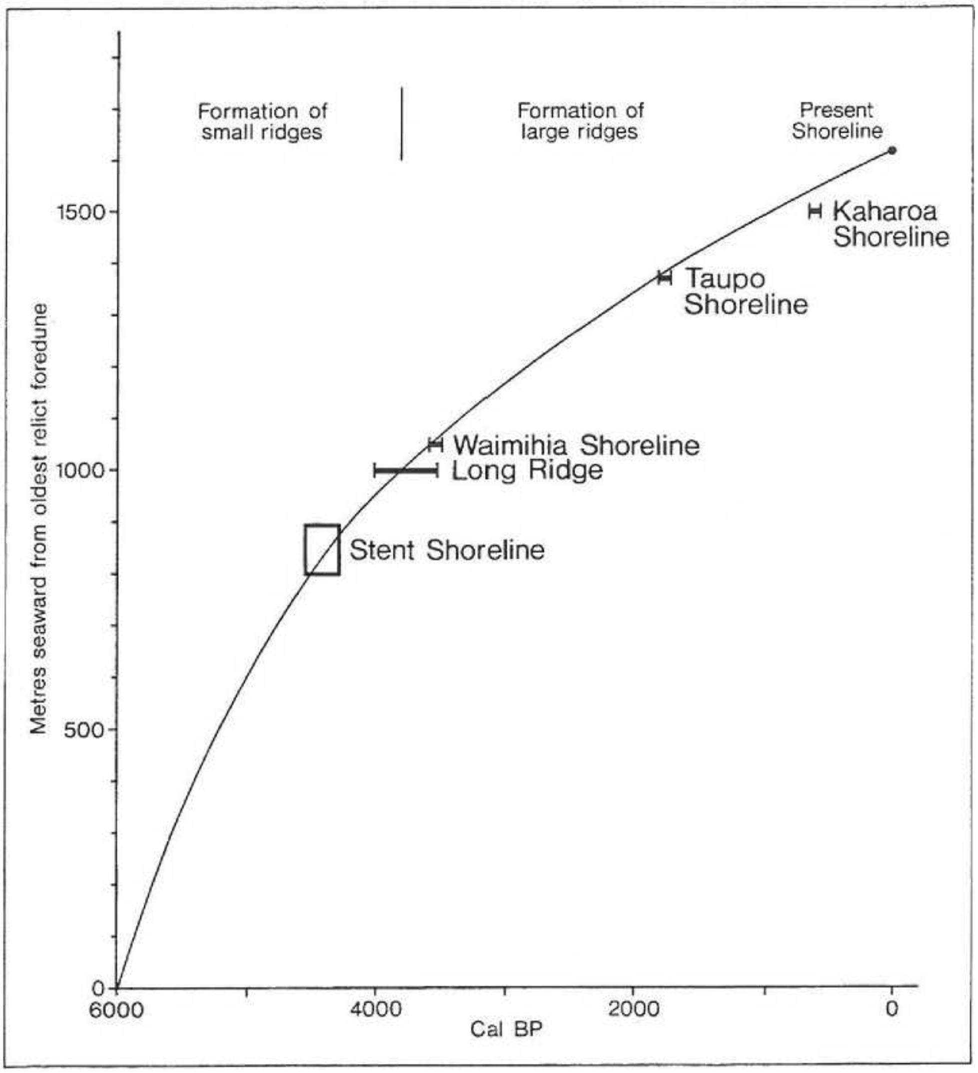


FIGURE 29. RATES OF PROGRADATION FOR MATAKANA BARRIER BASED ON DATED SHORELINE POSITIONS. UNCERTAINTY OF AGES AND POSITIONS SHOWN BY ERROR BARS.

Substantial progradation occurred at both ends of the barrier following the Kaharoa eruption 600 cal BP. The Purakau Shoreline marks the limit of shoreline retreat (Fig. 20) at the southeastern end, which ended shortly after c. 600 cal BP. Subsequent progradation was rapid, causing the Tauranga Entrance to narrow by more than 80%, from c. 3.2 km to the present 0.5 km, at an average rate little different to that of the last 140 years (Healy *et al.* 1977) (Fig. 19b). Similarly, the Katikati Entrance narrowed by some 70% from c. 2.0 km to the present 0.4 km. Fig. 19a indicates that most of this progradation (up to 1 km) occurred between 1870 and 1974.

5. Structure and origin of Matakana Barrier

At the end of the Postglacial Marine Transgression, the sea cut a cliff into the Pleistocene cores of Matakana and Rangiwaea Islands, following which the shoreline began to prograde. At about the same time a washover ridge formed to the northwest. The underlying structure of the upper barrier is inferred from four boreholes drilled into the barrier, one (I, Fig. 9a) through the Northwestern Backbarrier Washover Slope and three (II-IV, Fig. 9a) through the Relict Foredune Plain (Fig. 8).

All four boreholes show fine dune sand overlying coarser sand. At the innermost borehole, (1, Fig. 9a) the coarse sand overlies estuarine deposits of silty sand and clay which are absent from, or not reached by, the boreholes further seaward. The coarsest sand was in borehole II which was drilled on the immediate seaward side of the innermost relict foredune. The sand was strongly bedded and contained shells and shell fragments, granules and small pebbles, and seams of heavy minerals. At borehole I, the coarse sand was slightly bedded and occurred in a thinner layer. It was not as coarse as in borehole II, and lacked the whole shells, granules and small pebbles.

The coarsest sand at borehole II has the characteristics of a basal transgressive layer of strongly reworked sediment which accumulated during and shortly after the Postglacial Marine Transgression (Thorn 1984). The coarse sand at borehole I has the characteristics of a backbarrier washover deposit (Fig. 9b) derived from reworked sediment to seaward. Its washover origin is further supported by the silty and clayey estuarine sediments immediately below.

The "coarser" sand in III and IV was much finer and better sorted than the coarse sand in boreholes I and II (Fig. 30) and lacked the shells, shell fragments, granules and pebbles. It was almost as fine as the fine sand above it, but was distinguished from the fine sand in borehole III by heavy mineral seams that probably indicate the upper level of a former beach. The coarser sand in boreholes III and IV is relatively uniform, similar in size to the present foreshore sand, and probably representative of foreshore sand underlying the main part of the barrier. This is consistent with the characteristics of regressive sands deposited during progradation (Thom 1984).

In all four boreholes, the surface morphology and sediment size parameters indicate that the upper layer of fine sand is dune sand. The dune sand covering the backbarrier washover slope is only about 1 m thick, but increases in thickness to *c.* 5 m in swales to seaward and >5 m beneath the intervening relict foredune ridges.

The inferred relationship of the sediments in the boreholes to the barrier growth is shown in Fig. 9b. Transgressive sand was deposited on top of estuarine sediments which accumulated in the more sheltered environment behind the washover ridge as it migrated landward. Once the migration ceased, the shoreline prograded seaward with the deposition of finer beach and foredune sand.

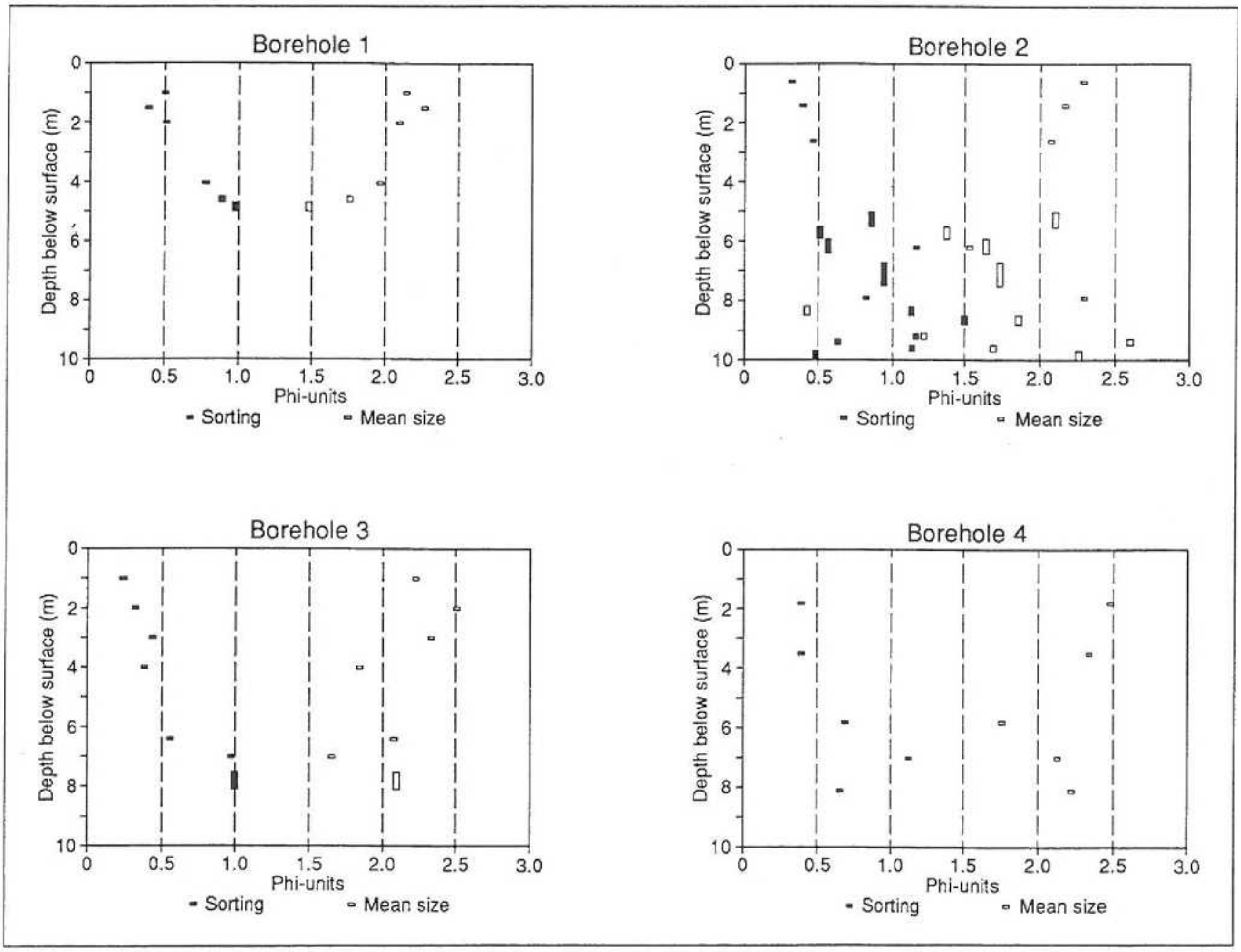


FIGURE 30. MEAN SIZE AND SOR'T'ING OF SAND SAMPLES FROM BOREHOLES I-IV (FIG. 8). VERTICAL BAR LENGTHS INDICATE DEPTHS OVER WHICH SAMPLES WERE COLLECTED.

The evolution of Matakana Barrier, as indicated by borehole stratigraphy and rates of barrier progradation (Fig. 29), is broadly similar to that of prograded barriers in New South Wales where the stratigraphy and age structure have been studied in detail and summarised by Chapman *et al*. (1982). Both locations have a similar Holocene sea level history with the Postglacial Marine Transgression ending *c*. 7000 cal BP, followed by a stillstand with relatively stable sea levels until the present (Thom and Chappell 1975; Gibb 1986). Although each barrier has a unique chronology, the progradation rate of many New South Wales barriers, in common with Matakana Barrier, was rapid after *c*. 7000-6000 cal BP but declined after *c*. 3000 cal BP. In New South Wales, most sediment now comprising the barriers was transported onshore by wave action as offshore profiles began to adjust to a stable sea level during the Holocene stillstand. When the offshore profiles reached equilibrium, progradation diminished or ceased entirely (Chapman *et al*. 1982).

Similar processes are likely to have affected Matakana Island. If the present average gradient offshore from the island (Pantin *et al*. 1973) is an indication of substrate gradient, then according to simulation modelling reported by Roy *et al*. (1994), onshore sediment flows would have accompanied and followed the

Postglacial Marine Transgression. The modelling indicates that nett onshore sediment transport occurs when the initial substrate gradient is less than 0.8°: the Matakana offshore gradient is less than half this figure.

However, at Matakana Island the sediment supply from offshore must have been augmented by an alongshore supply from the northwest. An alongshore supply is indicated by the southerly extension of the recurved shoreline ridges which diverted the former Blue Gum Bay harbour entrance 8 km to the southeast and also the southeasterly extension of the barrier seaward of Rangiwaea Island. It is also consistent with the prediction by Healy *et al.* (1977), based on the wave approach resultant, of nett littoral drift from northwest to southeast along the ocean coast in the vicinity of Matakana Island. The continuing but slower progradation of Matakana Barrier may thus indicate a diminishing offshore sediment supply superimposed upon a relatively constant alongshore supply. If this is the case, then Fig. 29 could be interpreted as illustrating a gradual change from a dominant onshore to a dominant longshore sediment supply. The sediment of Matakana Barrier is mineralogically very uniform and did not enable the two sources to be distinguished.

Further information about barrier development is derived from the morphology of the relict foredunes between the washover slope and the present ocean beach. Foredune morphology and coastal sand budget are related (Davies 1957; Shepherd 1987; Psuty 1992): smaller foredunes develop during periods of rapid coastal progradation; large foredunes develop in association with a relatively stable shoreline position where the foredune remains adjacent to the beach for a longer period.

The seven levelled profiles across the barrier (Figs. 8 and 10) illustrate considerable variation in relict foredune morphology. Small relict foredunes, with a spacing of c. 30-50 m, are generally present between the backbarrier washover slope and Long Ridge. An abrupt change to much larger relict foredunes is apparent seaward of Long Ridge along Profiles C-D to I-J. Relict foredunes seaward of Long Ridge have a spacing of *c.* 50-70 m and some exceed 13 m in height (Fig. 31).

The change in the relict foredune dimensions would thus appear to indicate a change in the progradation rate: the smaller ridges harbourward of Long Ridge being formed during rapid coastal progradation; the larger ridges seaward of Long Ridge being formed during slower progradation. This is consistent with calculated rates described in Table 5.

At the northwestern end of the barrier, however, the large ridges seaward of Long Ridge increase in size but diverge to the northwest (Fig. 34, see end of report) and would appear to contradict the relationship between foredune morphology and sand budget. The phenomenon is localised and therefore unlikely to be related to the general supply of sediment from offshore. It has already been suggested that longshore sediment transport is occurring and we think that changes in longshore transport are responsible for the phenomenon.. It is shown below that sediment from the ebb-tidal deltas can be rapidly transported shoreward and such a process occurring intermittently may account for the formation and diverging nature of the large ridges.

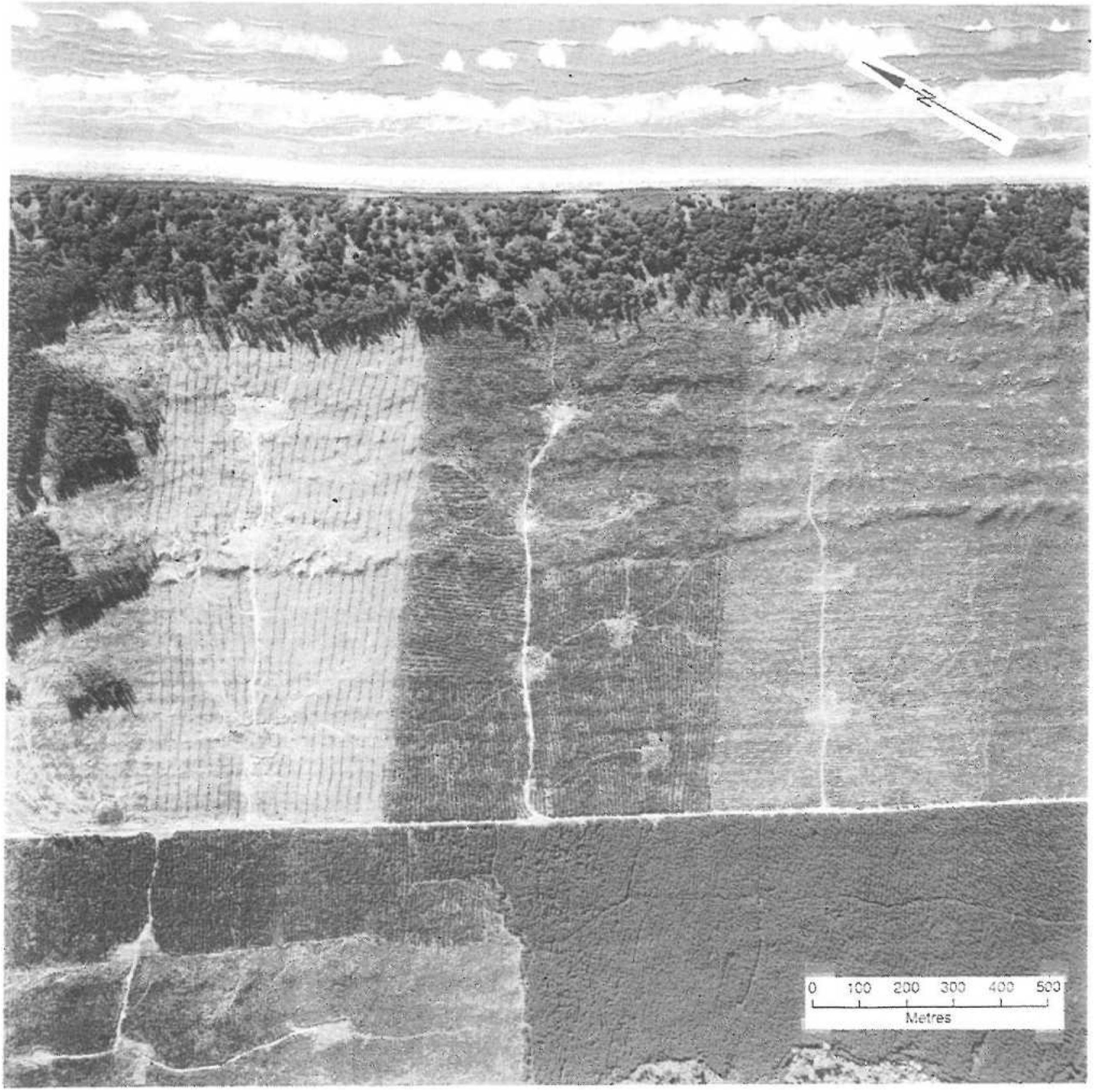


FIGURE 31. VERTICAL AERIAL PHOTOGRAPH OF THE BARRIER *c*. 3km SOUTH-SOUTHEAST OF WAIKOURA POINT, SHOWING THE ABRUPT CHANGE SEAWARD TO LARGER, LESS REGULAR RELICT FOREDUNES. PHOTOGRAPH COURTESY OF P.F. OLSEN AND CO. LTD.

5.1 TRANSGRESSIVE DUNES

The upper part of the barrier is mantled in places by aeolian sand of varying thickness associated with transgressive dune development.

5.2 GROWTH OF THE BARRIER ENDS

Sand comprising the barrier ends is very shelly and the age of the shells predates the deposition of the sand. The Southeastern End is younger than the

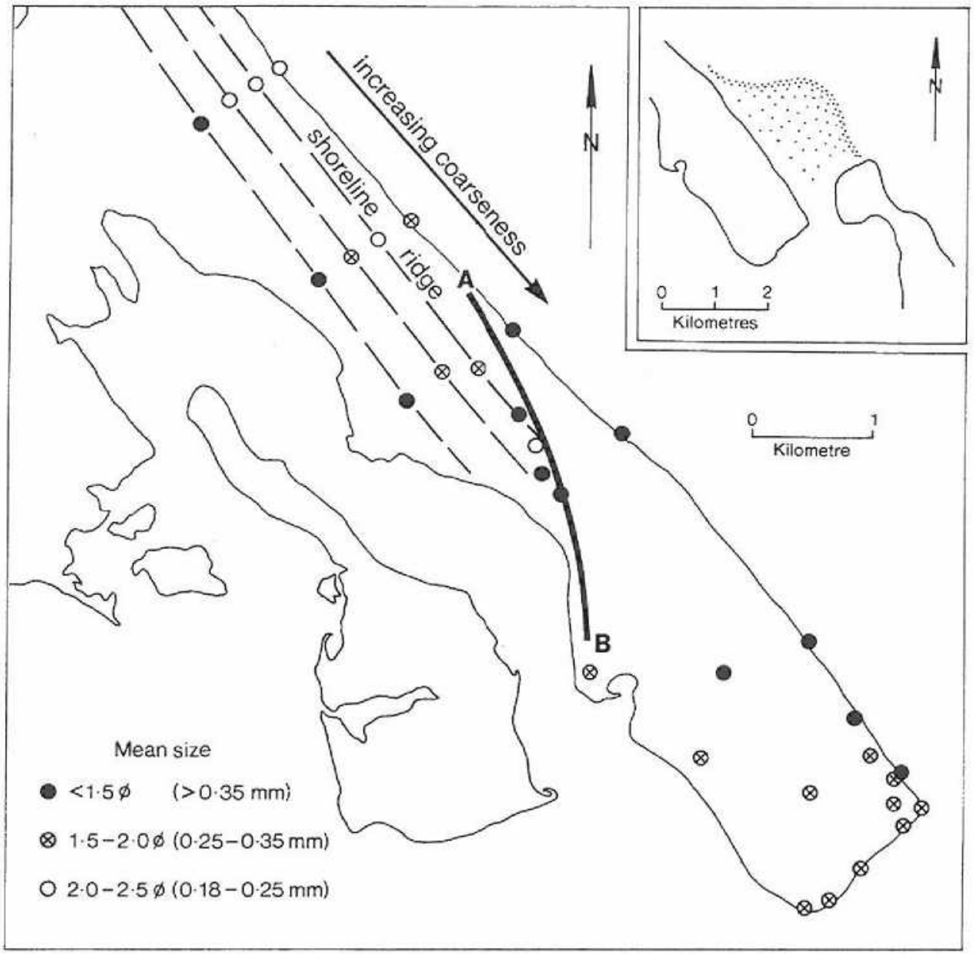


FIGURE 32. MAP OF SOUTHEASTERN MATAKANA BARRIER SHOWING THE COARSENING OF BEACH SEDIMENT TOWARDS THE TAURANGA HARBOUR ENTRANCE. THE INSET SHOWS THE LOCATION OF THE PRESENT EBB-TIDAL DELTA ADJACENT TO THE TAURANGA ENTRANCE.

Purakau Shoreline (*c.* 600 cal BP). The age of shells from sediments c. 1 m below high water level near the middle of the Southeastern End (Fig. 17(b)) is 1830-1591 cal BP (NZ7997, Table 1). Near Panepane Point, the barrier has grown rapidly since 1852 AD. The age of shells from sediments 1 m below high water level on the seaward side of the 1852 AD shoreline and 300 m from the ocean beach (Fig. 17(b)) is 435-295 cal BP (NZ8021 Table 1). The shells dated were the least abraded of those recovered. Dates for shells from the northern end, obtained by Munro (1994), are between 300 and 3000 cal BP for parts of the northern end, which did not exist until after 1870 AD (Figs. 16, 19a). The dates for the shells indicate that the sediment of which they are part has been reworked from older deposits.

Davies-Colley and Healy (1978b) describe the transfer of coarse sediment from the Tauranga Entrance ebb-tidal delta to the southeastern end of the barrier. Coarse sand from within the entrance is transported to the ebb-tidal delta by the ebb jet and then moved landward by wave action (Barnett 1985). The anomalously old shell dates from the Southeastern End suggest that such transfer may have occurred throughout its formation. Shells recovered from the sediments include estuarine species, consistent with the transfer process. The sediment is generally coarser, with more heavy minerals, than the beach sand

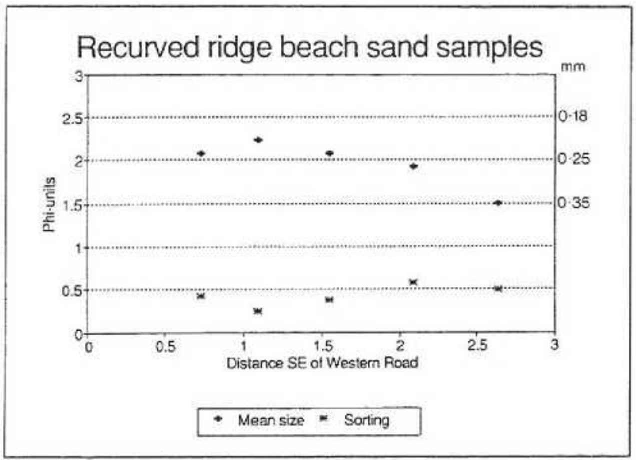


FIGURE 33. MEAN SIZE AND SORTING OF BEACH SAND BENEATH A RECURVED RIDGE ADJACENT TO BLUE GUM BAY. MEAN SIZE SHOWN IN PHI UNITS AND MILLIMETRES. SORTING SHOWN IN PHI UNITS ONLY. SAMPLED POINTS SHOWN IN APPENDIX 2. FOR LOCATION OF WESTERN ROAD SEE APPENDIX 7.

beneath the Relict Foredune Plain. The shell ages indicate that the sediment transferred may have been deposited in the delta nearly 2000 years ago, but as only the least abraded shells were selected for dating, even older sediment may be present.

Adjacent to the ebb-tidal delta the sand on the present beach coarsens and becomes less well-sorted as a result of the exchange of sand between the delta and the beach (Figs. 22a and 32). A similar trend of coarsening and poorer sorting of beach sand toward the southeast is observed in beach sand under the older shoreline ridges, including Long Ridge (Figs. 13 and 32). Under these and on the present beach (Fig. 22a) the coarsening and poorer sorting begins *c.* 7 km northwest of Panepane Point, slightly northwest of the bulge on the present coast which is located adjacent to the terminal lobe of the delta. The coarsening and poorer sorting under the older ridges suggests the close proximity of an ebb-tidal delta for at least 3500 years while these ridges were forming.

5.3 BLUE GUM BAY HARBOUR ENTRANCE

A trend of coarsening and poorer sorting of beach sand toward the southeast is observed under one of the recurved ridges on the northwestern side of the former Blue Gum Bay Entrance (Fig. 33), but the trend is less pronounced than at the Tauranga Entrance. This trend suggests that an ebb-tidal delta was present at the former Blue Gum Bay Entrance. With the closure of the entrance *c.* 4000 cal BP, it is likely that the sediment forming the ebb-tidal delta would have been redistributed along the barrier. It may also have resulted in increased tidal flows through the Katikati Entrance, affecting entrance dimensions, development of the Katikati ebb-tidal delta and the adjacent ocean beach/dune system.

6. Palaeoenvironment and human settlement

The earliest available evidence for human occupation of Matakana Barrier postdates the Kaharoa Eruption. Despite extensive searching, we have found no evidence for human occupation below the Kaharoa Tephra, nor was any found by Marshall *et al.* (1994). Our radiocarbon dates of three shell middens indicate occupation less than 500 cal BP (Table 1). Charcoal is present below the tephra and is also found below the Taupo Lapilli. Charcoal on its own is not evidence for human occcupation and its presence within soils on the barrier can be accounted for by natural fires. On the basis of the current age for the Kaharoa Tephra, and the absence of any archaeological remains below the tephra, the earliest evidence for human occupation of the barrier is younger than 600 cal BP, and human impact on the barrier environment probably began some time between 600 and 550 cal BP. This is consistent with recent analyses of radiocarbon dates for New Zealand pre-history (Anderson 1991; McFadgen *et al.* 1994), but does not entirely preclude the possibility of earlier human visits (see also papers in Sutton 1994).

At around 600 cal BP, Matakana Barrier was about 85% of its present length, having been shortened by erosion at each end. At the Northwestern End, the shape of the barrier was little different from that of today, but there would have been fewer wetlands. At the Southeastern End, a narrow spit would have adjoined a much wider harbour entrance. The young age of the barrier ends indicates there is little point in looking in these areas for evidence of early occupation. It is likely, however, that early settlers would have been attracted to wetlands at the northern end which may have held fresh water.

The soils on the barrier are severely disturbed by forestry. The best preserved soils are in the swales where they have been buried by pre-European Maori, by dune advance, or by forestry operations. Soils are well-developed in the older swales and are less well-developed in the younger swales.

The soils indicate that the barrier supported a mature forest cover, particularly on the older parts. Soils in the older swales immediately below the Kaharoa Tephra contain charcoals of totara, matai, vine rata, tanekaha and a small amount of bracken (Table 6). The charcoals were sparse and too few for firm conclusions to be drawn, but they are consistent with identifications of charcoals made by Wallace (1994) from samples taken elsewhere on the barrier. Kauri gum recovered from a peaty soil near the foot of the backbarrier washover slope has an age of 1270-1415 cal BP (Table 1). The forest vegetation was similar to the post-Taupo/pre-Kaharoa forest cover at Papamoa, as inferred from the pollen record from the Papamoa Bog (Newnham *et al.* 1995). Younger parts of the barrier, towards the ocean beach, would have supported coastal scrub. Shortly before human settlement, the vegetation was likely to have been modified by Kaharoa Tephra.

TABLE G. IDENTIFICATIONS* OF CHARCOAL FROM SOILS.

AGE	MILL SECTION**
Pre-Kaharoa Tephra	Vine rata (*Metrosideros robusta*) Tanekaha (*Phyllocladus trichomanoides*) Matai (*Prumnopitys spicatus*) Totara (*Podocarpus totara*)
	PROFILE G-H***
Pre-Kaharoa Tephra	Matai (*Prumnopitys spicatus*) Maire (*Nestegis* sp.) Totara (*Podocarpus totara*) Tanekaha (*Phyllocladus trichomanoides*) Bracken fern (*Pteridium esculentum*) undetermined conifer undetermined broadleaf
Post-Kaharoa Tephra (Garden soil)	Bracken fern (*Pteridium esculentum*) Totara (*Podocarpus totara*)

* All identifications carried out by Dr R. T. Wallace, Department of Anthropology, the University of Auckland.

** Samples from a section exposed in a road cutting near the Mill (Appendix 6).

*** Samples from 5 soil pits dug along transect G-H between Long Ridge and the Taupo foredune. All soil pits contained Kaharoa Tephra, buried soils, and charcoals.

The fine texture of the Kaharoa Tephra, in contrast to the sandy soils below it, may have altered the drainage in the swales and induced the formation of peaty soils. This may account for the young peats at the northwestern end of the Relict Foredune Plain dated by Munro (1994).

After humans arrived, much of the forest was cleared for a range of purposes, including gardening. Pollen from Matakana Core (Appendix 5) shows that bracken fern became widespread as tree species declined (Appendix 5). Charcoal from a garden soil (Table 6) was dominantly bracken fern, characteristic of vegetation regrowth following forest clearance, and a small amount of totara. This again is consistent with charcoal identifications from archaeological sites made by Wallace (1994).

Forest clearance appears to have influenced the formation of parabolic dunes. Some very large parabolic dunes formed or were reactivated after human settlement. Whilst their initiation was possibly caused by natural processes, once the forest was cleared an area of migrating dunes could expand and move further downwind.

The parabolic dunes are important for archaeology because some of those that became active after Maori settlement and before forestry began have buried and protected archaeological sites from damage by forestry operations. For instance, parabolic dunes along Hunters Creek advanced seaward *c.* 350-400 cal BP (NZ8125 and NZ8187, Table 1) and buried gardens and middens under more than 2 m of dune sand (Fig. 27). We anticipate that many of the other large parabolic dunes on Matakana Barrier may also cover undisturbed archaeological remains.

We recognise gardens by their topsoils, through which are mixed shells, shell fragments, charcoal, Taupo hapilli, and recognisable pieces of Kaharoa Tephra.

Extent is important when identifying garden soils in order to distinguish gardening from localised non-gardening soil disturbances such as pit excavation, cut and fill terrace formation for houses etc., and tree throw. Garden soils along Hunter's Creek are exposed in at least two places, where they occur over a distance of more than 80 rn. Test pits reported by Marshall *et al.* (1994), together with many pits dug by us, contained buried mixed topsoils similar to those along Hunter's Creek. It would appear that gardening was widespread on Matakana Barrier.

Forestry operations on the barricr have damaged many archaeological sites (Sutton 1994) and completely removed many of the old garden soils. Only those preserved by burial are available for study and these are not always in the most suitable places. A relict foredune plain environment similar to that at Matakana is present at Papamoa 15 km southeast of Matakana Barrier. The dunes at Papamoa show evidence of extensive gardening, probably analogous to that carried out on Matakana Barrier (B. McFadgen and A. Walton, pers. comm.).

Only the higher Papamoa relict foredune ridges were gardened. Gardening began at the foot of the dune on each side of the ridge. The dune slope was dug into and the topsoil moved downslope. The digging proceeded up the dune until the crest of the ridge was reached. In this way, the original topsoil and the Kaharoa Tephra were incorporated into the garden soil. At the same time, the dune slope was decreased and the dune crest reduced in height.

The Papamoa gardens included large shell middens, fireplaces, pits and possibly the remains of houses. The middens at Papamoa were generally distributed to the rear of the foredune ridges and in the swales where subsequent gardening activities covered them with sand. On Matakana Barrier we found undisturbed shell middens in swales buried by sand derived either from Maori gardening or from forestry operations. It is rarely possible to predict which swales are likely to contain undisturbed archaeological remains and to find them will require excavation or augering. Like the Papamoa middens, the many shell middens on the main part of Matakana Barrier are likely to be associated with gardening.

Matakana Barrier today, however, has a generally poor availability of fresh water, except at the two ends where there are wetlands. If the poor availability of fresh water prevailed in the past, then the many shell middens on the main part of Matakana Barrier are likely to have been deposited by people who were gardening on the barrier but living on Matakana Core.

If Matakana Barrier was gardened in the same way as at Papamoa, then the dune ridges on Matakana Barrier appear to be remarkably stable. Despite the disturbance of the soils on either side of the ridges and the removal of soil from ridge crests, there are very few blowouts of the ridges, apart from those which developed when the ridges initially formed. This is consistent with observations at Papamoa.

Shell deposits are very widespread on Matakana Barrier. Over most of the barrier the deposits are old shell middens (Marshall *et al.* 1994), but many shell deposits at the barrier ends are of natural origin. The barrier ends are low in elevation, young in age and only partially dune-covered. This explains the presence of much coarse beach material, including reworked shells, at the ground surface. The shells include open coast and estuarine species, and such deposits could be misinterpreted as shell middens. Natural shell deposits may differ from shell midden deposits in the following ways:

1. abraded shell fragments are present;
2. very small shells and species which would be unsuitable as a food source may be abundant;
3. whole unabraded shells sometimes in position of articulation will be absent from or near the surface;
4. cultural remains such as fire-cracked stones, fish scales, or bones will be absent.

It should be noted, however, that any one of these criteria alone is insufficient to distinguish between shell middens and natural deposits. The shell deposit should be assessed in its environmental context.

7. Conclusions

1. The Matakana Holocene barrier began forming *c.* 6000 cal BP as a result of similar processes to those which caused the older part of Matakana Island to prograde during a late Pleistocene interglacial.

2. The barrier began forming in at least two parts. The southeastern part abutted the Pleistocene core of the island, the other partially enclosed Katikati Arm of Tauranga Harbour to the northwest. The parts were separated by an early entrance to Tauranga Harbour located near Blue Gum Bay.

3. The southeastern part formed against a Holocene wave-cut cliff. The northwestern part began as a landward-migrating washover ridge. Subsequent development of both parts occurred by spit extension and the formation of successive foredunes as the shoreline prograded seawards. The entrance had closed by 3500 cal BP.

4. The closure was followed by a change in the morphology of the foredunes, which became larger and less regular and the average rate of progradation slowed.

5. The barrier ends have a more complex history and underwent periods of erosion. The most recent erosion of the Northwestern End ended shortly after 1750 cal BP and was followed by erosion of the Southeastern End which ceased shortly after 600 cal BP. Both the Katikati and Tauranga entrances have narrowed rapidly during the last 600 years.

6. Transgressive dunes are present on many parts of the barrier and have formed throughout the history of the barrier. The largest began forming before human settlement, migrating as parabolic dunes in an easterly direction, and some were reactivated following human settlement.

7. Significant transgressive dune formation during the past 600 years occurred adjacent to the present ocean beach, Hunter's Creek, and at the southeastern end of the barrier.

8. No evidence of human settlement prior to the Kaharoa eruption 600 cal BP was found. When humans arrived the barrier was forested. The forest was progressively removed and replaced by bracken fern and scrub.

9. Undisturbed archaeological sites will most likely be found beneath transgressive dunes, and in swales where they have been buried by sand from subsequent pre-historic Maori activities or forestry operations. These will be a valuable complement to the few remaining areas of undisturbed sites on the present ground surface.

10. Earliest archaeological sites will be found on the main part of the barrier between the Purakau Shoreline at the southeastern end and the Kaharoa Shoreline at the northwestern end. Archaeological sites outside of these two shorelines will date from the latter part of the prehistoric period.

11. This study has demonstrated the dynamic nature of Matakana Barrier. Over the last 6000 years, but more especially during the last 600 years, the barrier

has undergone substantial change brought about by the natural processes of erosion and deposition. Parts of the shoreline particularly susceptible to change are the barrier ends, the harbour shoreline, and those parts of the ocean beach adjacent to the ebb-tidal deltas. Such processes have caused the shoreline at the northwestern end of the barrier to advance more than a kilometre in less than 100 years, and have initiated the formation of transgressive dunes on several parts of the barrier. Erosion and deposition are likely to continue into the forseeable future and careful planning will be necessary if the barrier's resources are to be further developed.

8. Acknowledgements

Research upon which this report is based was carried out as part of two Department of Conservation Research Investigations: "Archaeological Conservation Assessment of Matakana Island" (Science and Research Investigation 1480), which included environmental history as one of its principal objectives, and "Palaeoenvironmental Research on Matakana Island" (Science and Research Investigation 1771). The two investigations were set up and funded by the Conservation Sciences Centre of the Department of Conservation at the request of the Bay of Plenty Conservancy. The Conservancy was responding to a request from the Maori community on Matakana Island for assistance to recover part of their cultural heritage before it was irretrievably lost by the development of the Matakana Island sand barrier.

Investigation 1480 was administered by Auckland UniServices Ltd. Investigation 1771 was administered by the Conservation Sciences Centre, Wellington. We acknowledge the assistance of Niels Gedge, Uniservices Ltd., Auckland, and Mark Stephens, Conservation Sciences Centre, Wellington, for efficicient administrative support. The research was carried out in conjunction with the Geography Department of Massey University and Centre for Archaeological Research, the University of Auckland. Funding was also provided by the Department of Conservation Bay of Plenty Conservancy, Auckland University Research Committee, the University of Auckland Anthropology Department, Massey University Research Fund, Massey University Graduate Research Fund, Massey University Department of Geography, a Massey University Masterate Scholarship and a grant from the Royal Society of New Zealand Skinner Fund.

We are grateful to the Matakana Islanders for their hospitality, accommodation, and assistance in kind. We are especially grateful to: Enoka, Adelaide and Mark Ngatai; Dave, Piri and Russell McCoubrie; Awhina and Jim White; and Waata and Annie Smith. For their help in the field we would also like to thank Mike Paama and Jimmy Peene.

Our scientific colleagues and friends provided valuable assistance and advice at various stages of the project and for this we thank: Alan Beu, Dennis Eden, John Fienley, Paul Froggatt, Jeremy Gibb, Andrew Hammond, Bill McLea, Alan Palmer, Matai Power, Richard Sadleir, Bernd Striewski, Andrea Thom, and Rod Wallace.

A drilling rig was provided and operated respectively by Professor Michael Pender and Graham Duske of Civil and Resources Engineering, the University of Auckland.

Access to forestry land was kindly provided by Blakely Pacific Ltd., Ernslaw One Ltd., FAR Forestry Ltd., ITT Rayonier Ltd., P.F. Olsen and Co. Ltd., and Te Kotukutuku Corporation. Ltd. Our thanks to Carter Holt Harvey Ltd., P.F. Olsen and Co. Ltd., and Air Maps (NZ) Ltd for generously providing aerial photographs of the island, and to Carter Holt Harvey Ltd. P.F. Olsen and Co. Ltd., and New Zealand Aerial Mapping Ltd., for permission to use their photographs in this report.

The following persons and/or organisations kindly provided data or assistance in kind: Don Shaw, Te Kotukutuku Corporation Ltd.; Stuart Halliday, Say of Plenty District Council (well logs); Dave Montgomery, Geosystems (NZ) Ltd. (GPS equipment); Dave Douglas, Matakana Island. Figures were drafted by Karen Puklowski (Massey University Department of Geography) and Sean Hutton and Chris Edkins (Conservation Sciences Centre). Our radiocarbon dates were measured by the Institute of Geological and Nuclear Sciences, Gracefield.

Oblique photographs were taken by H. Betts and M. Shepherd.

9. References

Alloway, B., Lowe, D.J., Chan, R.P.K., Eden, D. and Proggatt, P.C. 1994. Stratigraphy and chronology of the Stent tephra, a c. 4 000 year old distal silicic tephra from Taupo Volcanic Centre, New Zealand. New *Zealand Journal of Geology and Geophysics* 37, 37-47.

Anderson, A.J. 1991. The chronology of colonisation in New Zealand. *Antiquity* 65, 767-795.

Barnett, A.G. 1985. Tauranga Harbour study. Part 1 - Overview. Report to the Bay of Plenty Harbour Board.

Beadel, S.M. 1989a. Notes on the vegetation and flora of Tauranga Harbour and Little Waihi Estuary, Bay of Plenty. Report prepared by Wildland Consultants Ltd for the Department of Conservation, Eastern Region.

Beadel, S.M. 1989b. Notes on the vegetation and flora of the foredune system, seaward side of Matakana Island. Report prepared by Wildland Consultants Ltd for the Department of Conservation, Rotorua.

Betts, H.D. 1996. Late Quaternary evolution of Matakana Island, Bay of Plenty, New Zealand. Unpublished M.Sc. Thesis, Dept. of Geography, Massey University, Palmerston North.

Boothroyd, J.C. 1985. Tidal inlets and tidal deltas. *In:* Davis, R.A. ed., Coastal sedimentary environments. Springer-Verlag, New York, 716 p.

Chapman, D.M., Geary, M., Roy, P.S. and Thom, B.G. 1982. Coastal evolution and coastal erosion in New South Wales. Report prepared for the Coastal Council of New South Wales. David Ell Press, New South Wales, Australia, 341 p.

Chappell, J. 1974. Upper Quaternary warping and uplift rates in the Bay of Plenty and West Coast, North Island, New Zealand. *New Zealand journal of Geology and Geophysics* 18, 129-155.

Cockayne, L. 1909. Report on the sand dunes of New Zealand: The geology and botany- with their economic bearing. Section C-13 *in:* New Zealand appendix to the journals of the House of Representatives. Government Printer, Wellington.

Cole, J,W. 1978. Tectonic setting of Mayor Island volcano (note). New *Zealand Journal of Geology and Geophysics* 21, 645-647.

Coombs, D.S. and Landis, C.A. 1966. Pumice from the South Sandwich eruption of March 1962 reaches New Zealand. *Nature* 209, 289-290.

Dahm, J. 1983. The geomorphic development, bathymetric stability and sediment dynamics of Tauranga Harbour. Unpublished M.Sc. Thesis, University of Waikato, Hamilton.

Davies, J.L. 1957. The importance of cut and fill in the development of sand beach ridges. *Australian Journal of Science* 20, 105-111.

Davies, J.L. 1980. Geographical variation in coastal development. 2nd ed. Longman, London; New York, 212 p,

Davies-Colley, R.J. 1976. Sediment dynamics of Tauranga Harbour and the Tauranga Inlet. Unpublished M.Sc. Thesis, University of Waikato, Hamilton.

Davies-Colley, R.J. and Healy, T.R. 1978a. Sediment and hydrodynamics of the Tauranga Entrance to Tauranga Harbour. *New Zealand Journal of Marine and Freshwater Research* 12, 225-236.

Davies-Colley, R.J. and Healy, T.R. 1978b. Sediment transport near the Tauranga Entrance to Tauranga Harbour. *New Zealand Journal of Marine and Freshwater Research* 12, 237-243.

de Lisle, J.F. 1962. Climate and weather. Ch. 4 in: National Resources Survey, 11, Bay of Plenty Region. Town and Country Planning Branch, Ministry of Works, N.Z. Pp. *45-56.*

Dolan, R., Hayden, B. and Lins, H. 1980. Barrier islands. *American Scientist 68, 16-25.*

Froggatt, P.C. and Lowe, D.J. 1990. A review of late Quaternary silicic and some other tephra formations from New Zealand: their stratigraphy, nomenclature, distribution, volume, and age. *New Zealand Journal of Geology and Geophysics* 33, 89-109.

Gibb, J.G. 1986. A New Zealand regional Holocene eustatic sea level curve and its application to determination of vertical tectonic movements. A contribution to IGCP-project 200. Proceedings of the International Symposium on Recent Crustal Movements from the Pacific Region, Wellington, New Zealand. *Journal of the Royal Society of New Zealand Bulletin* 24, 377-395.

Harmsworth, G.R. 1983. Quaternary stratigraphy of the Tauranga Basin. Unpublished M.Sc. Thesis, University of Waikato, Hamilton.

Harray, K.G. 1977. Beach erosion and sediments of Waihi Beach. Unpublished M.Sc.. Thesis, University of Waikato, Hamilton.

Harray, K.G. and Healy, T.R. 1978. Beach erosion at Waihi Beach, Bay of Plenty, New Zealand. *New Zealand journal ofMarine and Freshwater Research* 12, 99-107.

Hayes, M.O. 1991. Geomorphology and sedimentation patterns of tidal inlets: a review. Coastal Sediments '91: Proceedings of a specialty conference on quantitative approaches to coastal sediment processes, Seattle, Washington, June 25-27, 1991. Pp. 1343-1355.

Healy, J. , Schofield, J.C. and Thompson, B.N. 1964. Sheet 5 Rotorua, Geological Map of New Zealand 1:250,000. New Zealand D.S.I.R., Wellington.

Healy, T.R. 1977. Progradation at the entrance, Tauranga Harbour, Bay of Plenty. *New Zealand Geographer* 33, *90-92.*

Healy, T.R. and de Lange, W.P. 1988. Field Trip 3 (intra-conference): Coastal sedimentology of the Tauranga and Maketu Basins. *Geological Society of New Zealand*, pp. 65-74.

Healy, T.R., Hamay, K.G. and Richmond, B. 1977. Bay of Plenty coastal erosion survey, *Occasional Report No-3.* Department of Earth Sciences, University of Waikato, Hamilton.

Heath, R.A. 1985. A review of the physical oceanography of the seas around New Zealand - 1982. *New Zealand journal of Marine and Freshwater Research* 19, 79-124.

Hesp, P.A. 1984. The formation of sand "beach ridges" and foredunes. *Search* 15, 289-291.

Hicks, D.M. and Hume, T.M. 1991. Sand storage at New Zealand's tidal inlets. *Proceedings of the 10th Australasian conference on coastal and ocean engineering, Auckland, 2-6 December, 1991,* pp. 213-219.

Hicks, D.M. and Hume, T.M. *1993.* Morphologies and sand volumes at flood and ebb tidal deltas on the New Zealand coast. *Proceedings of the 11th Australasian Conference on Coastal and Ocean Engineering, Townsville, Australia, 23-27 August, 1993.*

Hogg, A.G. 1979. Identification and correlation of late Quaternary tephras of Coromandel Peninsula. Unpublished Ph.D. Thesis, University of Waikato, Hamilton.

Hubbard, D.K., Oertel, G. and Nummedal, D. 1979. The role of waves and tidal currents in the development of tidal-inlet sedimentary structures and sand body geometry: examples from North Carolina, South Carolina, and Georgia. *Journal of Sedimentary Petrology* 49,1073-1092.

Hume, T.M. and Hicks, D.M. 1993. Shelf morphology and processes near an ebb tide delta, Katikati Inlet, New Zealand. *Proceedings of the 11th Australasian Conference on Coastal and Ocean Engineering, Townsville, Australia, 23-2 7 August, 1993.*

Hume, T.M. and Herdendorf, C.E. 1992. Factors controlling tidal inlet characteristics on low drift coasts. *Journal of Coastal Research 8,* 355-375.

Hydrographic Office 1993. Bathymetric chart, Tauranga Harbour: Katikati Entrance to Mount Maunganui. Hydrographic Office, Auckland.

Jennings, J.N. 1957. On the orientation of parabolic or U-dunes. *Geographic Journal* 123, 474-480.

Kear, D. and Waterhouse, B.C. 1961. Quaternary surfaces and sediments at Waihi Beach. *New Zealand Journal of Geology and Geophysics* 4, 434-445.

Landsberg, S.U. 1956. The orientation of dunes in Britain and Denmark in relation to the wind. *Geographic journal* 122, 76-89.

Lowe, D.J., Wigley, G.N.A., Dahm, J. and Nagatomo, Y. 1992. Late Quaternary tephrostratigraphy and Holocene dune development in the Papamoa-Te Puke area, Bay of Plenty. *In* Rijske, W.J, compiler: Field notes for the field days for the 1992 conference of the New Zealand Society of Soil Science, pp. 36-41.

Marshall, Y.M., Paama, M., Samuels, M., Sutton, D.G. and Taikato, T. 1994. Archaeological survey of Matakana Island forest compartment 3, stands 2-4; compartment 12, stands 1-5; compartment 14, stand 2 and compartment 20, stands 1-5: Final Report. Unpublished report prepared for ITT Rayonier NZ Ltd., Auckland Uniservices Limited.

McFadgen, B.G. 1982. Dating New Zealand archaeology by radiocarbon. *New Zealand Journal of Science* 25, 379-392.

McFadgen, B.G. 1994. Archaeology and Holocene sand dune stratigraphy on Chatham Island. *Journal of the Royal Society of New Zealand* 24, 17-44.

McFadgen, B.G., Knox, F.B. and Cole, T.R.L 1994. Radiocarbon calibration curve variations and their implications for the interpretation of New Zealand prehistory. *Radiocarbon* 36, 221-236.

McFadgen, B.G. and Manning, M.R. 1990. Calibrating New Zealand radiocarbon dates of marine shells. *Radiocarbon* 32, 229-232.

Munro, A.J. 1994. Holocene Evolution and Palaeolimnoiogy of a barrier spit, Matakana Island, Bay of Plenty, New Zealand. Unpublished M.Sc. Thesis, University of Waikato, Hamilton.

Newnham, R.M., Lowe, D.G., and Wigley, G.N.A 1995. Late Holocene palynology and palaeovegetation of tephra-bearing mires at Papamoa and Waihi Beach, western Bay of Plenty, North Island, New Zealand. *Journal of the Royal Society of New Zealand* 25, 283-200.

Pantin, H.M-, Herzer, R.H. and Glasby, G.P. 1973. Bay of Plenty Bathymetry. New Zealand Oceanographic Institute Chart, Coastal Series, 1:200 000.

Pethick, J.S. 1981. Long-term accretion rates on tidal salt marshes. *Journal of Sedimentary Petrology* 51, 571-577.

Pillans, B. 1986. A late Quaternary uplift map for North Island, New Zealand. *Royal Society of New Zealand Bulletin* 24, 409-417.

Psuty, N.P. 1992. Spatial variation in coastal foredune development. In: Carter, Curtis and Sheehy-Skeffington, eds., Coastal dunes. Balkerna, Rotterdam. Pp. 3-13.

Pullar, W.A. and Birrell, K.S. 1973. Age and distribution of late Quaternary pyroclastic and associated cover deposits of the Rotorua and Taupo area, North Island, New Zealand. *New Zealand Soil Survey Report I,* Department of Scientific and Industrial Research, Wellington, New Zealand.

Pullar, W.A. and Cowie, J.D. 1967- Morphology of subfulvic and related soils on dunelands at Mt. Maunganui, Bay of Plenty. *New Zealand Journal of Science* 10, 180-189.

Pullar, W.A., Kohn, B.P., and Cox, J.E. 1977. Air-fall Kaharoa Ash and Taupo Pumice, and sea-rafted Loisels Pumice, Taupo Pumice, and Leigh Pumice in northern and eastern parts of the North Island, New Zealand. *New Zealand Journal of Geology and Geophysics* 20,697-717.

Quayle, A.M. 1984: The climate and weather of the Bay of Plenty region. *New Zealand Meteorological Service Miscellaneous Publication 115, 1,* Second Edition. 56 p.

Roy, P.S. and Thom, B.G. 1981. Late Quaternary marine deposition in New South Wales and southern Queensland - an evolutionary model. *Journal of the Geological Society of Australia* 28, 471-489.

Roy, P.S., Cowell, P. J., Ferland M.A. and Thom, B.G. 1994. Wave-dominated coasts. *In:* Carter R.W.G. and Woodroffe C.D., eds., Coastal Evolution. Cambridge University Press, U.K, pp. 121-186.

Schofield, J.C. 1968. Dating of recent low sea-level and Maori rock carvings. Ongari Point. *Earth ScienceJournal* 2, 167-174.

Selby, M.J., Pullar, W.A. and McCraw, J,D. 1971. The age of Quaternary surfaces at Waihi Beach. *Earth Science journal* 5, 106-113.

Shaw, G.C. and Healy, J. 1962 Geology. Ch. 2 in: National Resources Survey, 11, Bay of Plenty Region. Town and Country Planning Branch, Ministry of Works, N.Z., pp. 10-25.

Shepherd, M.J. 1987. Sandy beach ridge system profiles as indicators of changing coastal processes. *In: Proceedings of the 14th New Zealand Geography Conference and 56th ANZAAS Conference, 1987.* New Zealand Geographical Society, pp. 106-112.

Stuiver, M. and Braziunas, T.F. 1993. Modelling atmospheric ^{14}C influences and ^{14}C ages of marine samples to 10 000 BC. *Radiocarbon* 35, 137-189.

Stuiver, M. and Reimer, P.J. 1993. Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. *Radiocarbon* 35, 215-229.

Sutton, D.G. 1994. Forestry site preparation and archaeological evidence. *Archaeology in New Zealand* 37, 141-144.

Sutton, D.G (ed). 1994. The Origins of the first New Zealanders. Auckland University Press, 269 p.

Tanner, W.F. 1988. Beach ridge data and sea level history from the Americas. *Journal of Coastal Research 4, 81-91.*

Thom, B.G. 1984. Sand barriers of eastern Australia: Gippsland - a case study, In: Thom, B.G., ed., Coastal geomorphology in Australia. Academic Press, Australia, pp. 233-261.

Thom, B.G. and Chappell, J. 1975. Holocene sea levels relative to Australia. *Search* 6, 90-93.

Vogel, J.C., Fuls, A. and Visser, E. 1993. Pretoria calibration curve for short-lived samples, 1930-3350 BC. *Radiocarbon* 35, 73-85.

Wallace, R. 1994. Charcoal identifications. Appendix 4 *in:* Marshall, Y.M., Paama, M., Samuels, M., Sutton, D.G. and Taikato, T. Archaeological survey of Matakana Island forest compartment 3, stands 2-4; compartment 12, stands 1-5; compartment 14, stand 2 and compartment 20, stands 1-5: Final Report. Unpublished report prepared for ITT Rayonier NZ Ltd., Auckland Uniservices Limited.

Wallingford Hydraulics Research Station. 1963. Tauranga Harbour investigation. Wallingford Hydraulics Research Station, Berkshire, England. Unpublished report on the first stage, Report No. Ex 201, 69 p.

Wellman, H.W. 1962. Holocene of the North Island of New Zealand: a coastal reconnaissance. *Transactions of the Royal Society of New Zealand Geology* 1, 29-99.

Whitbread-Edwards, A.N. 1994. The volcanic geology of the western Tauranga Basin. Unpublished M.Sc. Thesis, University of Waikato, Hamilton.

White, J.L. 1979. Recent sediments of Waikareao Estuary, Tauranga, North Island, New Zealand. Unpublished M.Sc. Thesis, University of Waikato, Hamilton.

Wigley, G.N.A. 1990 Holocene tephrochronology and evolution of the Te Puke Lowlands, Bay of Plenty, New Zealand. Unpublished M.Sc. Thesis, University of Waikato, Hamilton.

Zenkovich, V.P. 1967. Processes of coastal development. Oliver and Boyd, Edinburgh, London. 738 p.

Maps consulted

SO 9385 held by Department of Survey and Land Information, Hamilton.

NZMS 260 Sheet U13 1st Edition 1979.

NZMS 260 Sheet U14 1st Edition 1980.

Pantin, H.M., Herzer, R.H. and Glasby, G.P. 1973. Bay of Plenty Bathymetry. New Zealand Oceanographic Institute Chart, Coastal Series, 1:200 000.

Appendix 1

VEGETATION OF MATAKANA ISLAND

The following description refers to those parts of the island which have not been planted with pine trees.

Dunes

A well-established succession of sand dune vegetation is present on the contemporary incipient foredune and foredune system of the ocean side of the barrier between the mean high water spring tide mark and the *Pinus radiata* forest to landward. Beadel (1989b) recognises four zones. Zone 1, adjacent to the mean high water spring tide mark, is characterised by *Spinifex sericeus* (spinifex), *Desmoschoenus spiralis* (pingao) and uncolonised bare sand. Landward of zone 1 is zone 2, characterised by *Spinifex sericeus-Calystegia soldanella* (shore convolvulus)-*Desmoschoenus spiralis* grassland, with localised occurrences of *Hypochaeris radicata* (catsear), *Deyeuxia billardierii* (sand wind-grass), and *Isolepis nodosa* (knobby clubrush). Between zone 2 and the plantation forest zones 3 and 4 are sometimes present. Zone 3 consists of shrubland comprising the native species *Isolepis nodosa*, *Calystegia soldanella*, *Deyeuxia billardierii*, *Spinifex sericeus*, *Desmoschoenus spiralis* and the exotic species *Pinus radiata* and *Leptospermum laevigatum* (coastal tea tree). Zone 4 consists of *Muehlenbeckia complexa* vineland which often includes *Isolepis nodosa*, *Carex testacea* and *Calystegia soldanella* and local emergent radiata pine and coastal tea tree (after Beadel 1989b).

Some or all of these zones, particularly zones 1 and 2, are absent where coastal erosion has destroyed part or all of the foredune system. In. the vicinity of Boundary Road and Waikoura Point, for example, *Pinus radiata* trees which occur adjacent to the beach are being removed by erosion.

The harbour shoreline

Except for isolated areas with eroding shores, much of the Tauranga Harbour shoreline supports salt marsh vegetation, dominated by *Typha orientalis* (raupo), *Juncus maritimus* (sea rush), *Leptocarpus similis* (oioi), *Baumea juncea* (swamp twig-rush), and *Avicennia marina* (mangrove). *Leptospermum scoparium* (manuka) scrub with locally dominant *Phormium tenax* (flax) commonly occurs landward of the salt marsh vegetation (Beadel 1989a). Mangrove communities are common along the harbour shoreline in and northwest of Blue Gum Bay, and are particularly extensive at the heads of Blue Gum Bay, Hunter's Creek, and on the high tide flat off the harbour coast between Tirohanga Point and Flax Point. Individual plants are generally small (30-50 cm tall), being close to the southern limit of their geographical range (Kuchler 1972; Dingwall 1980; Crisp *et al.* 1990).

Wetlands

Several wetland areas, often containing lakes, are present at the northwestern end of the barrier. Wetland vegetation typically comprises *Typha orientalis*, *Baumea juncea*, *Baumea articulate* (jointed twig-rush), *Scboenoplectus validus* (lake club-rush), and *Carex secta* (niggerheads) (Beadel 19890). Around the outer margins of the wetlands are commonly *Leptospermum scoparium* shrubland and *Salix* spp. (willow) with an understorey characterised by *Baumea juncea* and *Phormium tenax*.

References

Beadel, S.M. 19890. Notes on the vegetation and flora of Tauranga Harbour and Little Waihi Estuary, Bay of Plenty. Report prepared by Wildlife Consultants Ltd for the Department of Conservation, Eastern Region.

Beadel, S.M. 1989b. Notes on the vegetation and flora of the foredune system, seaward side of Matakana Island. Report prepared by Wildlife Consultants Ltd for the Department of Conservation, Rotorua.

Crisp, P., Daniel, L. and Tortell, P. 1990. Mangroves in New Zealand: trees in the tide. GP Books.

Dingwall, P.R. 1980. Overcoming problems in the management of New Zealand mangrove forests. *In:* Teas, H.J. ed., Physiology and management of mangroves. Dr. W. Junk Publishers.

Kuchler, A.J. 1972. The mangrove in New Zealand. *New Zealand Geograpber* 28, 113-129.

Appendix 2

SEDIMENTARY TECHNIQUES

Sampling

Sample locations are shown by Fig. A2.1. Samples of contemporary beach sand were collected from the mid-foreshore to a maximum depth of *c.* 5 cm. Relict foredune sand was sampled at a depth of 1 m using a hand auger. Contemporary foredune samples were taken from the surface to a maximum depth of *c.* 20 cm.

Other samples to a depth of 6 m were collected using a hand auger, while four holes were drilled to a maximum depth of 14 m using a trailer-mounted mechanical drilling rig supplied and operated by the Department of Civil Engineering of the University of Auckland. Samples obtained by the drilling rig were collected in open barrel tubes above the water table, and in a double split coring barrel with extended tube below the water table. All samples exceeded 100 g dry weight.

Size analysis

Beach samples were decanted several times with distilled water to remove salt and then oven dried. Coarse organic matter, such as roots and whole shells, were removed from the samples prior to analysis. The dried samples were then subsampled using a sample divider. The subsamples were mechanically sieved at 0.25 phi intervals for 20 minutes.

Sediment size is expessed as phi units (ø), where $ø = -\log_2$ (grain diameter in mm).

Calculation of Folk-Ward size parameters (Folk and Ward 1957) was carried out using the PC-GRAN computer software package. The Folk-Ward grain size parameters are calculated as follows:

1. *GRAPHIC MEAN*

$$M_Z = \frac{ø_{16} + ø_{50} + ø_{84}}{3}$$

MZ (ø)	Millimetres	Wentworth Size Class
-1.0-0.0	2.00- 1.00	Very coarse sand
0.0- 1.0	1.00-0-50	Coarse sand
1.0- 2.0	0.50-0.25	Medium sand
2.0 - 3.0	0.25 -0.125	Fine sand
3.0-4.0	0.125 - 0.0625	Very fine sand

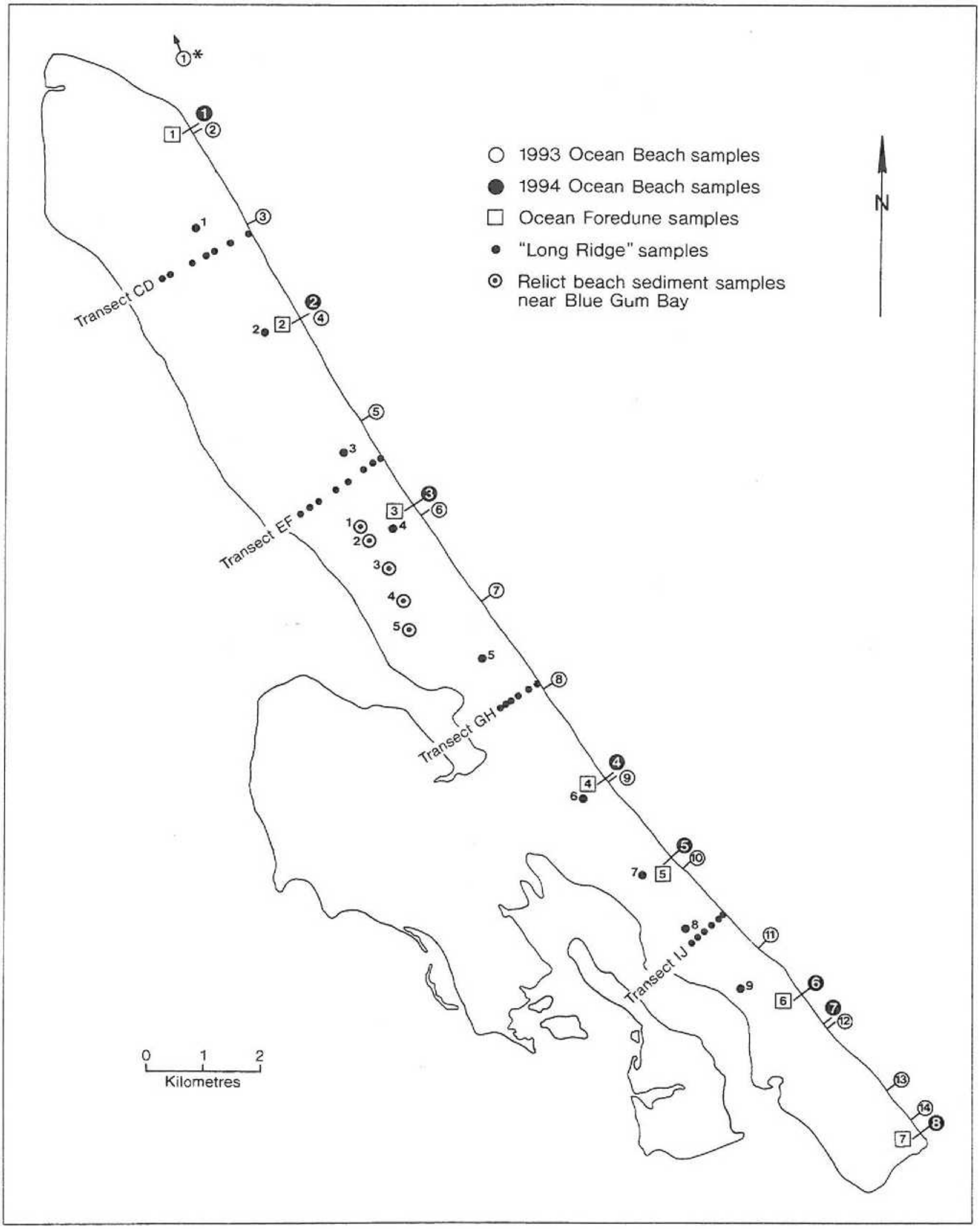


FIGURE A2.1. SEDIMENT SAMPLING SITES ON THE HOLOCENE. BARRIER. NOTE THAT LONG RIDGE SAMPLES ARE NUMBERED 1-9 TO DISTINGUISH THEM FROM TRANSECT SAMPLES.

2. *INCLUSIVE GRAPHIC STANDARD DEVIATION (SORTING)*

$$\sigma_I = \frac{\varnothing_{84} - \varnothing_{16}}{4} + \frac{\varnothing_{95} - \varnothing_5}{6.6}$$

σ_I (Ø)	Verbal Classification
Under 0.35	Very well sorted
0.35 - 0.50	Well sorted
0.50-0.71	Moderately well sorted
0.71 - 1.00	Moderately sorted
1.00-2.00	Poorly sorted
2.00-4.00	Very poorly sorted
over 4.00	Extremely poorly sorted

3. *INCLUSIVE GRAPHIC SKEWNESS*

$$Sk_I = \frac{\varnothing_{16} + \varnothing_{84} - 2\varnothing_{50}}{2(\varnothing_{84} - \varnothing_{16})}$$

SkI (ø)	Verbal Classification
-1.00 - -0.30	Strongly coarse-skewed
-0.30 - -0.10	Coarse-skewed
-0.10 - +0.10	Near symmetrical
+0.10 - +0.30	Fine-skewed
+0.30 - +1.00	Strongly fine-skewed

4. *GRAPHIC KURTOSIS*

$$K_G = \frac{\varnothing_{95} - \varnothing_5}{2.44(\varnothing_{75} - \varnothing_{25})}$$

KG (ø)	Verbal Classification
Under 0.67	Very platykurtic
0.67-0.90	Platykurtic
0.90 - 1.10	Mesokurtic
1.10-1,50	Leptokurtic
1.50 - 3.00	Very leptokurtic
Over 3.00	Extremely leptokurtic

Full details of size parameters for Matakana Barrier samples are included in Betts (1996).

Mineralogy

The 2ø-4ø sieve fraction was retained for mineralogical analysis, following the procedure of Healy (1978). Heavy minerals were separated from the samples by flotation in an aqueous solution of sodium polytungstate, of specific gravity 2.90 (Callahan 1987). The heavy and light fractions were mounted on slides in clove oil and examined under a petrographic microscope. A minimum of 300 grains was counted for each sample.

Full details of the sand mineralogy of Matakana Barrier samples are included in Betts (1996).

References

Betts, H.D. 1996. Late Quaternary evolution of Matakana Island, Bay of Plenty, New Zealand. Unpublished M.Sc. Thesis, Dept. of Geography, Massey University, Palmerston North.

Callahan, J. 1987. A nontoxic heavy liquid and inexpensive filters for separation of mineral grains. *Journal of Sedimentary Petrology* 57, 765-766.

Folk, R.L. and ward, W.C. 1957. Brazos River bar, a study in the significance of grain size parameters. *Journal of Sedimentary Petrology* 27, 3-27.

Healy, T.R. 1978. Some textural and mineralogical investigations of the Rangitaiki Plains foreshore and river sands. Bay of Plenty coastal erosion survey report 78/4. Bay of Plenty Catchment Commission, 74 p.

Appendix 3

STRATIGRAPHY AND SOILS OF TRANSECT G-H

Sections with soils and stratigraphy described in Table A3.1 are recorded from five swales on the outer part of the barrier along the transect line G-H (Fig. A3.1). The swales are numbered 1 to 5 in a harbourward direction. The youngest swale (1, Fig. A3.1) is *c.* 115 m harbourward of the Taupo foredune; the oldest swale (5, Fig. A3.1) is on the immediate seaward side of Long Ridge.

Airfall Kaharoa Tephra is present in all swales. In each swale the tephra buries a well-developed soil. In swales 1, 2, 3 and 5 the buried soil has the appearance of a podzol with a pale, apparently leached horizon separating a darkish topsoil from the subsoil. Podzolisation, however, is much less apparent from the soil profile descriptions (Table A3.1) and soil chemistry (Table A3.2).

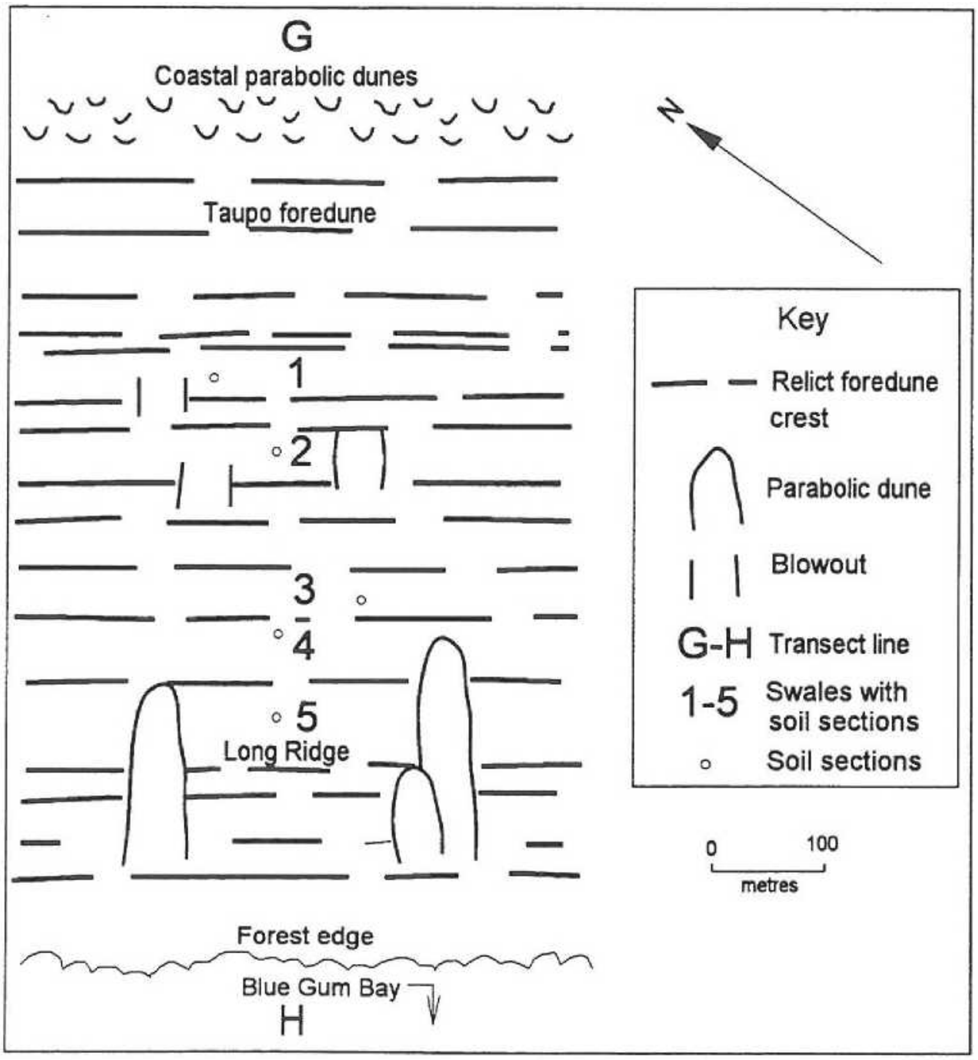


FIGURE A3.1. TRANSECT G-H SHOWING LOCATION OF SECTIONS DESCRIBED IN TABLE 1. FOR LOCATION OF TRANSECT SEE FIGURE 8 (MAIN TEXT).

Inspection pits seaward of the five swales show that immediately harbour ward of the Taupo foredune the Kaharoa Tephra fell on a very poorly-developed topsoil overlying whitish-grey sand, and seaward of the Taupo foredune it appears to have fallen on sand with little or no observable soil development.

In all five swales the tephra is buried by stratified sandy deposits up to 72 cm thick. Whether the overlying sand accumulated from natural processes following the Kaharoa eruption or from cultural processes is not clear. In Swale 4 the sandy deposit immediately above the tephra contains lenses of clean and dirty sand, together with shell and charcoal fragments, suggesting cultural processes at least played a part in its accumulation.

The sand layer immediately overlying the Kaharoa Tephra in swales 2 to 5 has lumps of the tephra and pieces of charcoal mixed through it and, in Swale 4, it also contains occasional shell fragments. The sand layer in swales 2, 3 and 5 is reasonably well mixed and there is no sign of the internal lenses present in swale 4. The layer is 27 cm thick in Swale 5 and 22 cm thick in Swale 4, but its thickness in swales 2 and 3 appears to have been reduced by subsequent forestry operations.

The lumps of Kaharoa Tephra in the sand layer in swales 2, 3, and 5 indicate disturbance of the underlying tephra after the sand layer had been deposited. This disturbance was also probably responsible for introducing charcoal into the layer from above. The disturbance is not attributed to forestry operations which produce a layer often containing pieces of pine wood and pine cones. The extent over which the disturbance occurs in each of the swales has not been investigated, although in Swale 5 where several pits were dug the disturbance occurs over an area of at least 10 m by 10 m.

Gardening in prehistoric tunes is thought to be the cause of the disturbance. The presence of the well-mixed sand layer in at least three of the swales, and its extent in Swale 5, supports gardening as a probable cause insofar as its occurrence suggests a reasonable areal extent for the mixed layer. The mixed layer is matched by a disturbed soil of similar thickness and content which extends over a distance of 80 m in the section along Hunter's Creek. It is similar to gardened soils on sand dunes at Papamoa 15 km southeast of Matakana Barrier (see main text) and has a thickness which is consistent with gardened soils elsewhere in New Zealand (McFadgen 1980).

The chemistry of the garden soil does not differ significantly from the chemistry of the soil beneath the Kaharoa Tephra (Table A3.2) suggesting that soil chemistry is unlikely to provide a useful means of identifying garden soils on the barrier.

References

McFadgen, B.G. 1980. Maori Plaggen Soils in New Zealand, Their Origin and Properties. *Journal of the Royal Society of New Zealand* 10, 3-18.

TABLE A3.1, DESCRIPTIONS OF SWALE STRATIGRAPHY AND BURIED SOILS.

SWALE 5

DEPTH (cm)	DESCRIPTION
0-25 (Sand from dug holes)	Brown (10YR4/4) sand. Very friable. Single grain with some weakly developed medium granular structure. Few roots. Sharp irregular boundary.
25-55 (Soil disturbed by forestry)	Brownish -black (10YR2/2) sand with many fine and few medium faint mottles. Very friable. Single grain with weakly developed fine and medium nut structure. Few roots, with charcoal fragments. Sharp irregular boundary.
55-72 (Garden soil) uAp	Black (10YR1.7/1) sandy loam with many fine and medium distinct and prominent mottles of greyish yellow brown (10YR6/2) in lower part of the horizon. Very friable to friable. Moderately developed fine nut and medium to coarse granular structure. Few roots, few fine charcoal fragments. Sharp irregular boundary.
72-76 (Kaharoa Tephra)	Kaharoa Tephra, dull-yellow (2.5Y6/3). Layer of variable thickness from 2 to 10cm comprising a basal coarse component 3-4cm thick overlain by fine component. Few to many distinct black fine and medium mottles. Upper part disturbed by gardening. Few roots. Sharp irregular boundary.
76-81 (Buried topsoil) uA1	Brownish-black (10YR2/2) sandy loam with few fine and coarse distinct mottles of Kaharoa Tephra. Very friable. Fine to medium granular structure with some fine nut. Few roots, many fine and medium angular pumice lapilli (Taupo), and few fine charcoal fragments. Distinct boundary.
81-95 uA_2(?)	Dull yellowish-brown (10YR4/3) sandy loam with many fine and medium faint greyish yellow brown (10YR4/2) mottles. Very friable. Weak to moderately developed very fine to medium nut structure. Few roots. Distinct boundary.
95-119 uB	Yellowish-brown (10YR5/6-5/8) sandy loam with many medium to coarse distinct brownish-black (10YR3/2) and dull yellow-orange (10YR6/3) mottles. Very friable. Moderately developed very fine to medium nut structure. Few roots. Distinct boundary.
119+ C	Brown (10YR4/4) sand with many large, irregular, faint dull yellowish-brown (10YR5/4) mottles. Loose to very friable. Single grain. Few roots.

SWALE 4

DEPTH (cm)	DESCRIPTION
0-14 (Soil disturbed by forestry)	Black to dark -grey sand with pine needles and wood overlying light brown sand with some charcoal fragments. Distinct irregular boundary.
14-25	Medium-brown to dark-brown sand with charcoal and shell fragments increasing in quantity towards bottom of layer. Rare lapilli. Distinct irregular boundary.
25-33	Light-brown sand with shell fragments and charcoal fragments. Occasional lapilli Distinct irregular boundary.
33-37	Dark-greyish-brown sand with abundant whole and fragmented shells and charcoals. Distinct wavy boundary.
37-43	Shell midden with abundant burnt and unburnt, whole and fragmented shells. Distinct wavy boundary.
43-66	Black sandy peat with patches of white Kaharoa Tephra, lenses of grey sand, occasional lapilli and fragments of charcoal and shell. Distinct irregular boundary.
66-74 (Kaharoa Tephra)	Layer of fine Kaharoa Tephra, 5cm thick, overlying 3cm of coarse tephra.

74-80 (Buried topsoil) uA1	Black (10YR1.7/1) sandy loam. Very friable. Moderately developed very fine to fine nut with some fine to very fine blocky structure. Few roots, few fine and medium charcoal fragments, many fine and few medium lapilli. Indistinct wavy boundary.
80-91 uB	Brownish-black (10YR3/2) sandy loam with many faint, medium to coarse mottles ranging in colour from dull yellow-brown (10YR5/4) to greyish yellow-brown (10YR4/2). Moderately developed very fine to fine nut with some very fine to fine blocky structure. Friable. Few roots, few lapilli. Distinct to diffuse wavy boundary.
91+ C	Dull yellow-orange (10YR6/3) sand with many fine to coarse distinct brown (10YR4/4) mottles. Single grain, loose. Few roots.

SWALE 3

DEPTH (cm)	DESCRIPTION
0-30 (Forestry disturbed deposits)	Well-defined layers and lenses of dark and light coloured sand. Sharp irregular boundary.
30-41 (Garden soil) uAp	Brownish-black (10YR2/3) sandy loam with many faint fine brownish-black (10YR3/2) and few distinct medium yellow-brown (2.5Y5/3) mottles. Moderately developed very fine to fine nut structure. Friable to firm. Few roots, few fine and medium charcoal fragments, few fine lapilli, many lumps of Kaharoa Tephra. Indistinct smooth boundary.
41-49 (Buried topsoil) uA1	Dull yellowish-brown (10YR4/3) sandy loam with many faint medium dull yellowish-brown (10YR4/3-5/3) mottles. Moderately developed very fine to fine nut structure. Friable. Few roots, few fine charcoal fragments, many fine lapilli near top of horizon. Indistinct wavy boundary.
49-58 uA_2(?)	Dull yellow-brown (10YR5/3) sandy loam with many faint fine to medium dull yellow-orange (10YR6/3) mottles. Moderately developed very fine to fine blocky and nut structure. Friable. Few roots. Distinct wavy boundary.
58-64 uB	Yellowish-brown (10YR5/6) loamy sand with many faint medium bright yellowish-brown (10YR6/6) mottles, grading down to sand. Loamy sand breaks to a moderately developed very fine to fine blocky and nut structure. Sand breaks to a weakly developed very fine to fine blocky and nut structure with single grain. Friable to loose. Few roots. Indistinct wavy boundary.
64-90+ C	Bright yellowish-brown (10YR6/6) sand with many faint medium to coarse brown (10YR4/6) mottles. Single grain. Loose. Few roots.

SWALE 2

DEPTH (cm)	DESCRIPTION
0-11 (Soil disturbed by forestry)	Brownish-black (10YR2/3) loamy sand, with many faint coarse dark brown (10YR3/3) mottles. Weakly developed medium granular and fine nut structure with single grain. Very friable. Few roots, pieces of wood (*Pinus* sp.). Sharp wavy boundary.
11-31 (Garden soil) uAp	Black (10YR2/1) sandy loam with few faint medium to coarse brownish-black (10YR3/2) and many distinct fine to coarse dull yellow (2.5Y6/3) mottles of Kaharoa Tephra. Moderately developed fine to medium blocky and very fine nut structure. Friable. Few roots. Few fine and medium charcoal fragments, few fine and medium lapilli. Sharp irregular boundary.
31-37 (Kaharoa Tephra)	Kaharoa Tephra. Discontinuous graded layer, fine at top and coarse at bottom. Dull yellow (2.5Y6/3). Distinct smooth boundary.
37-50 (Buried topsoil) uA1	Brownish-black (10YR3/2) paling downwards to greyish-yellow-brown (10YR4/2) sandy loam with many faint fine to medium brownish-black (10YR3/2) mottles. Moderately developed very fine to medium blocky and very fine nut structure. Friable. Few roots. Many fine lapilli, few fine charcoal fragments. Indistinct wavy boundary.

50-54 uA2(?)	Dull yellowish-brown (10YR5/3) sandy loam with many faint fine to medium dull yellow brown (10YR4/3) mottles. Moderately developed very fine blocky and fine nut structure. Very friable. Few roots. Indistinct smooth boundary.
54-63 uB	Yellowish-brown (10YR5/6) sandy loam with many distinct fine and medium dull yellow orange (10YR6/4) to dark brown (10YR3/4) mottles. Moderately developed very fine blocky and fine nut structure grading down to sand with weakly developed very fine and fine nut structure and single grain. Friable. Few roots. Indistinct smooth boundary.
63+ C	Dull yellowish-brown (10YR5/4) sand with many medium to coarse dull yellow-orange (10YR6/4) mottles. Single grain. Loose. Few roots.

SWALE 1

DEPTH (cm)	DESCRIPTION
0-37 Ap(?)	Brownish-black (10YR2/2) sandy loam with faint, medium and coarse dark brown (10YR3/3) mottles, few increasing downwards to abundant at the boundary with the underlying Kaharoa Tephra. Weakly developed fine to very fine nut structure. Firm. Few roots, few fine charcoal fragments, few fine lapilli. Sharp to distinct irregular boundary.
37-47 (Kaharoa Tephra)	Kaharoa Tephra. Fine component (*c.* 2cm thick layer) generally on top with coarse at the bottom, but also mixed in places. Dull yellow (2.5Y6/3). Firm. Distinct wavy boundary.
47-52 (Buried topsoil) uA1	Dull yellowish - brown (10YR5/3) sand. Weakly developed fine to very fine nut structure. Friable. Few roots, few coarse rounded pumice fragments up to 10cm long, many fine and very fine lapilli, few fine charcoal fragments. Indistinct wavy boundary.
52-69 uA2	Dull yellow - orange (10YR7/3) sand with few faint medium dull yellow - orange (10YR6/3) mottles. Single grain. Very friable. Few roots. Distinct smooth boundary.
69-81 uB	Dull yellowish-brown (10YR5/3) loamy sand with many fine and medium faint brown (10YR4/4) mottles. Weakly developed very fine to coarse nut and blocky structure. Firm. Few roots. Indistinct smooth boundary.
81-100 C	Dull yellowish-brown (10YR5/4) sand with many medium and coarse distinct brown (7.5YR4/4) mottles. Single grain. Very friable. Few roots. Distinct irregular boundary.
100-110+ D	Dark reddish-brown (5YR3/3) sand with profuse faint medium brown (7.5YR4/4) mottles. Weakly developed very fine to fine nut and fine blocky structure with single grain. Firm.

TABLE A3.2. CHEMISTRY' OF THE SOILS BURIED BY KAHAROA *TEPHRA IN* SWALES 1 TO 5, AND OF THE GARDEN SOIL IN SWALE 5.

PROPERTY	SOIL HORIZON	SWALE 1	SWALE 2	SWALE 3	SWALE 4	SWALE 5	SWALE 5 GARDEN SOIL
pH	A1	5.3	5.8	6.1	8.1	6.2	5.8
	A2	5.4	5.7	6.2		6.3	
	B	5.1	5.9	5.1	8.1	6.8	
Olsen P	A1	10	23	5	6	2	5
	A2	8	17	6		9	
	B	20	19	9	8	3	
SO4	A1	6.0	1.5	2.5	2.0	3.0	4.0
	A2	2.5	2.5	2.5		1.5	
	B	35.0	1.0	62.0	<1.0	33.5	
Exch K	A1	0.02	0.10	0.38	0.14	0.04	0.04
	A2	0.01	0.09	0.33		0.05	
	B	0.03	0.06	0.07	0.05	0.03	
Exch Ca	A1	1.0	0.9	1.2	13.3	3.4	3.2
	A2	0.6	1.2	0.5		1.8	
	B	0.2	0.9	0.5	8.1	5.3	
Exch Mg	A1	0.15	0.24	0.28	0.14	0.74	1.18
	A2	0.21	0.14	0.22		0.35	
	B	0.06	0.64	0.03	0.09	1.12	
Exch Na	A1	0.6	0.3	0.2	0.2	0.2	0.3
	A2	0.2	0.2	>0.1		0.1	
	B	0.3	0.3	>0.1	<0.1	0.1	
C E C	A1	10	9	13	16	10	16
	A2	8	10	7		7	
	B	10	9	7	10	11	
P retn.	A1	12	22	36	27	25	35
	A2	6	35	29		13	
	B	22	19	30	16	67	
Org matter	A1	1.8	2.9	3.7	3.9	4.2	5.3
	A2	0.5	3.4	3.1		3.2	
	B	2.4	2.4	2.4	1.9	3.2	

*Data provided by the Soil Science Department, Massey University, Palmerston North. Phosphate and sulphate values are expressed as micrograms per gram (air dry). Exchangeable cations and CEC values are expressed as meq/100g (air dry). Organic matter was determined as the percentage loss from an oven dry sample after ignition at 500°C. Phosphate retention is expressed as a percentage.

Appendix 4

POLLEN IDENTIFICATIONS AND COMMENTS PROVIDED BY DR W.L. McLEA FOR A POLLEN SAMPLE FROM PEAT BENEATH A PARABOLIC DUNE

The pollen sample is from peat beneath parabolic dune ridge c (Pig. 23 inset, main text).

Identifications:

Species	No.
Orchid ?	1
Poaceae	2
Gleichenia	3
Cyathea dealbata type	9
Cyathea smithii type	12
Monolete fern	2
Pteridium	5
Trilete fern	2
Nothofagus fusca type	1
Dacrydium cupressinum	27
Prumnopitys ferruginea	1
Prumnopitys taxifolia	4
unidentified podocarp pollen	10
Phyllocladus	2
Agathis	7
Laurelia ?	2

Comments:

The sample is from peat and identifications are from a slide measuring 22 x 32 mm. Preservation of some grains is poor, which probably means that they were present when the peat formed. Later pollen, deposited in anaerobic conditions, are better preserved. *Cyperaceae* belonging to several taxa were present. They were very abundant and were not counted. There was abundant charcoal which probably came from burning of the peat. No obvious wood fragments were seen.

An absence of *Pinus* pollen indicates that the deposit is probably pre-European.

Rimu and matai pollen can travel many kilometres from source and could have come from the mainland. Broadleaf pollen such as rata and kamahi are not usually dispersed very far by wind. The absence of rata and kamahi pollen from the sample suggests that these species were not growing near the site.

Appendix 5

POLLEN DIAGRAM FROM MATAKANA CORE

A swamp adjacent to a tidal creek on Matakana Core was sampled for pollen (NZMS 260 U14 80,'973). The swamp occupies a late Pleistocene-early Holocene fluvial course, drowned by the Postglacial Marine Transgression. A sediment core was taken from the swamp *c*. 200 m upstream of an active salt marsh (Betts 1996). Radiocarbon ages from the core (NZA4654 and NZA4833) are reversed and appear to be too old as the swamp would have formed near the end of the Postglacial Marine Transgression. Being an estuarine site some of the pollen and charcoal may have been transported to the site by water. No tephra deposits have been identified in the sediment core.

Results

The pollen diagram (Fig. A5.1, see end of report) is divided into three zones. The lower boundary, between Zone 1 and Zone 2, represents a change from scrubland to forest vegetation. The upper boundary, between Zone 2 and Zone 3, represents a change from predominantly forest vegetation to small trees, shrubs and bracken.

Zone 1 shows relatively low frequencies of podocarp pollen and high levels of *Cyathea* and monolete fern spores. After allowance is made for the high pollen production of *Dacrydium cupressinum*, the pollen of Zone 1 suggests that the vegetation was dominated by ferns and scrub. *Metrosideros* pollen appears at the top of this zone, possibly indicating the early stages of forest development. *Kunzea/Leptospermum* pollen, however, which are also indicators of forest regeneration, are absent. Aquatic pollen counts are very low.

Zone 2 shows considerable increase in the pollen of trees and shrubs, particularly podocarps. Small trees and shrubs exhibit a sharp peak, in particular, *Leguminosae*, *Metrosideros* robusta type and *Muehlenbeckia*, followed by a decline. *Cyathea* and monolete fern spores also increase. This increase may be an early successional change as a result of continuing development or recovery of the local vegetation. A small increase in *Nothofagus* possibly reflects an increase in *Nothofagus* populations in upland areas in the region, such as the Kaimai Ranges (*cf.* Newnham *et al.* 1995). No particular significance is attached to the increase because *Nothofagus* is a cooler climate species and its rise coincides with an increase in *Ascarina*, an indicator of warm, moist climates.

Charcoal counts rise sharply in this zone. High charcoal counts coinciding with dominant podocarp pollen suggests that the charcoal and pollen were derived from different sources. Alternatively, *Dacrydium cupressinum* can withstand most ground fires and can persist over long periods (Bray 1989), which may explain its occurrence with the high charcoal counts. The coincidence of other tree pollen and charcoal is probably due to natural fires caused by lightning strike or volcanic activity elsewhere in the Bay of Plenty.

The decline of *Ascarina* pollen at the top of zone 2 suggests that a cooler, drier climate then became established (cf. McGlone 1983; McGlone *et al.* 1977; 1984, McGlone 1988; Newnham *et al.* 1989).

Zone 3 contrasts sharply with Zone 2. The podocarp and *Nothofagus fusca* pollen drop substantially and *Pteridium* increases sharply. In the upper part of the zone, pollen of the modern adventive *Pinus radiates* first appears and Podocarp pollen declines, which reflects the clearance of native forest and the planting of exotic forest following European settlement. The first appearance of gorse pollen (Ulex) coincides with the first occurrence of exotic pine pollen.

Small trees and shrubs increase in this zone, especially *Kunzea/Leptospermum* and to a lesser extent *Metrosideros.* These are colonisers which follow vegetation disturbance and their failure to increase following the major charcoal peak in Zone 2 reinforces the suggestion made above that initial disturbance by burning occurred elsewhere in the Tauranga district.

The aquatics *Cyperaceae*, *Haloragaceae* and *Restionaceae* increase strongly to dominate the pollen spectrum in Zone 3. Herb species show a marked increase in this zone, including the adventive *Taraxacum*.

Interpretation of vegetation changes

Prior to the development of Matakana Barrier, the swamp site would have been adjacent to the open sea with exposure to considerably higher wave energy and salt-laden onshore winds than at present. Such environments do not favour well-developed forest vegetation, and scrubland would probably have been more dominant. Zone 1 and the lower part of Zone 2 appears to be consistent *with* this situation.

Formation of the barrier would have decreased exposure to wind-borne salt and reduced the overall strength of onshore winds. A change to a more sheltered, less saline environment would have allowed a transition from scrubland vegetation to lowland forest similar to the successional change described from Zone 2 above. The brief peak in *Leguminosae* possibly represents an early successional stage.

The lowered energy regime of the site following barrier development may have provided the conditions for the spread of local aquatic vegetation, indicated by the rise in *Restionaceae* in Zone 2. A further spread of aquatics is apparent in Zone 1 and possibly represents the transition from an active salt marsh to a freshwater swamp.

The virtual disappearance of indigenous trees, appearance of modern adventive pollen such as *Pinus*, *Ulex*, *Taraxacum* and increases in disturbance indicators such as *Pteridium* and *Kunzea/Leptospermum* all mark the destruction of natural vegetation and the introduction of exotic species by humans. *Pinus*, *Ulex* and *Taraxacum* were introduced by Europeans within the last 225 years. The initial increase in *Pteridium* and *Kunzea/Leptospermum* are probably a result of forest clearance following Maori settlement within the last 600-700 years.

References

Betts, H.D. 1996. Late Quaternary evolution of Matakana Island, Bay of Plenty, New Zealand. Unpublished M.Sc. thesis, Department of Geography, Massey University, Palmerston North.

Bray, J.R. 1989. The use of historical vegetation dynamics in interpreting prehistorical vegetation change. Journal of *the Royal Society of New Zealand* 19, 151-160.

McGlone, M.S. 1983. Holocene Pollen diagrams, Lake Rotorua, North Island, New Zealand. *Journal of the Royal Society of New Zealand* 13, 53-65.

McGlone, M.S. 1988. New Zealand. *In:* Huntley, B. and Webb T. eds. Vegetation History (3rd edition). Kluwer Academic Publishers.

McGlone, M.S. and Moar, N.T. 1977. The Ascarina decline and post-glacial climatic change in New Zealand. New *Zealand Journal of Botany* 15, 485-489.

McGlone, M.S., Nelson, C.S. and Todd, A.J. 1984. Vegetation history and environmental significance of pre-peat and surficial deposits at Ohinewai, Lower Waikato lowland. *Journal of the Royal Society of New Zealand* 14, 233-244.

Newnham, R.M., Lowe, D.J. and Green, J.D. 1989. Palynology, vegetation and climate of the Waikato lowlands, North Island, New Zealand, since *c.* 18 004 years ago. *Journal of the Royal Society of New Zealand* 19, 127-150.

Newnham, R.M., Lowe, D.J. and Wigley, G.N.A 1995. Late Holocene palynology and palaeovegetation of tephra-bearing mires at Papamoa and Waihi Beach, western Bay of Plenty, North Island, New Zealand. *Journal of the Royal Society of New Zealand* 25, 283-300.

Appendix 6

SECTION THROUGH SWALE NEAR MATAKANA MILL

SECTTON THROUGH SWALE NEAR THE MILL(PIG 28f, MAIN TEXT)SHOWING BURIED PODZOL (=P) OVERLAIN BY KAHAROA TEPHRA (=K).

Appendix 7

MATAKANA ROAD MAP

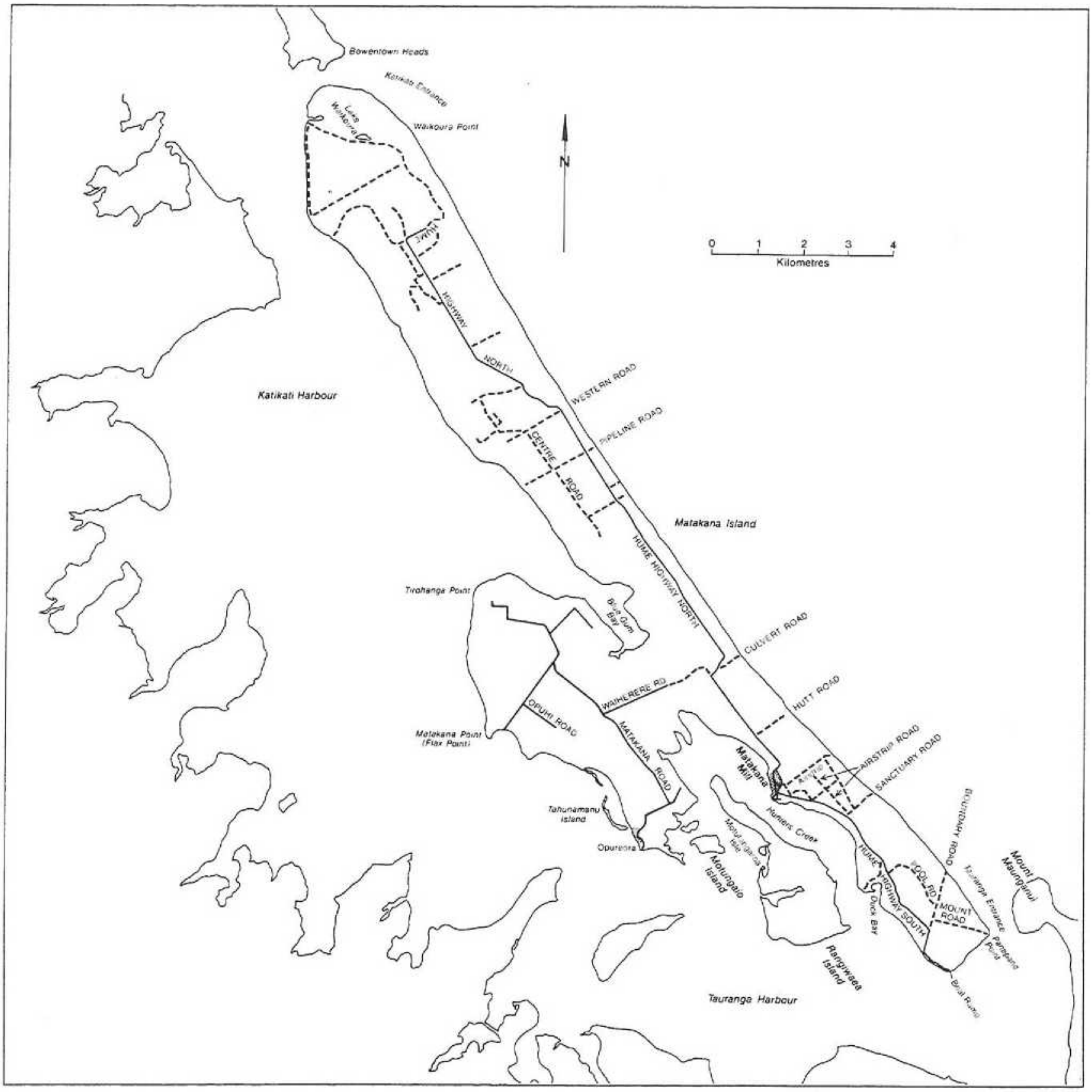


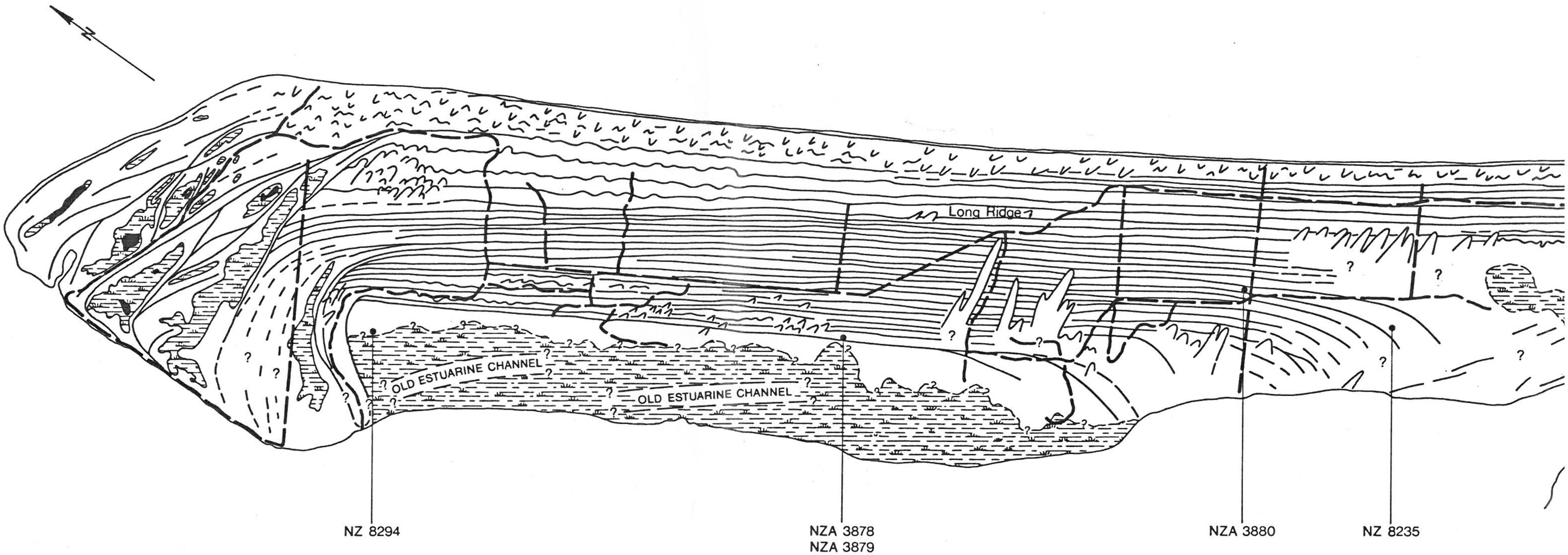
FIGURE 1. MATAKANA ISLAND ROAD MAP. FORMED METALLED ROADS SHOWN SOLID, SAND TRACKS SHOWN DASHED. DATA FROM TOPOGRAPHIC MAPS NZMS 260 SHEETS U13 AND U14, AND FROM AERIAL PHOTOGRAPHS.

FIGURE 34

LANDFORM MAP OF MATAKANA BARRIER COMPILED FROM AERIAL PHOTOGRAPHS WITH GROUND CHECKING. PHOTOGRAPHS PROVIDED BY CARTER HOLT HARVEY (1981-1992), AIR MAPS (NZ) LTD. (1982-1994) AND NEW ZEALAND AERIAL MAPPING LTD (1996). THICK DASHED LINES ARE ROADS MAPPED FROM AERIAL PHOTOGRAPHS AND MAY DIFFER FROM PRESENT-DAY ROADS.

FIGURE A5.1

POLLEN DIAGRAM FOR MATAKANA ISLAND.


N
Long Ridge
OLD ESTUARINE CHANNEL
OLD ESTUARINE CHANNEL
NZ 8294
NZA 3878
NZA 3879
NZA 3880
NZ 8235

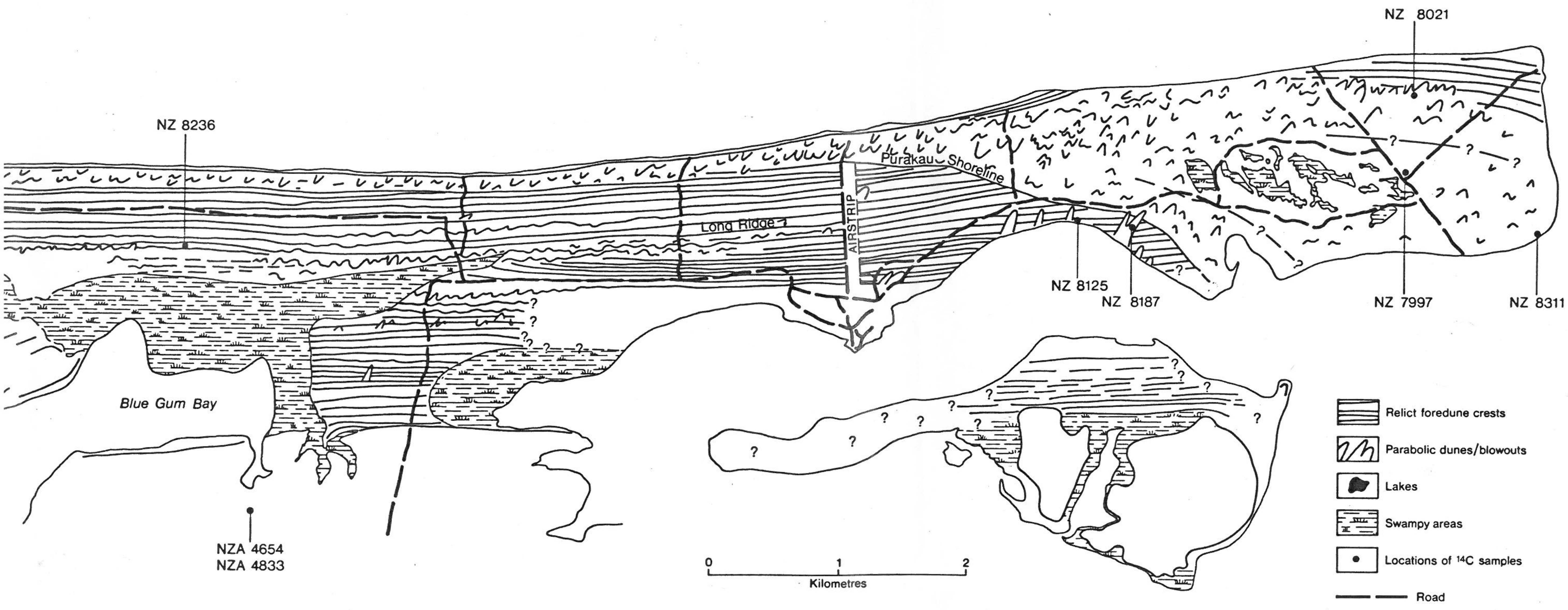


FIGURE 34
LANDFORM MAP OF MATAKANA BARRIER COMPILED FROM AERIAL PHOTOGRAPHS WITH GROUND CHECKING. PHOTOGRAPHS PROVIDED BY CARTER HOLT HARVEY (1981-1992), AIR MAPS (NZ) LTD. (1982-1994) AND NEW ZEALAND AERIAL MAPPING LTD (1996). THICK DASHED LINES ARE ROADS MAPPED FROM AERIAL PHOTOGRAPHS AND MAY DIFFER FROM PRESENT-DAY ROADS.

Matakana Island
Unnamed swamp (grid ref. NZMS 260 U14 807973)
Analyst: Harley Betts
(absolute pollen counts)

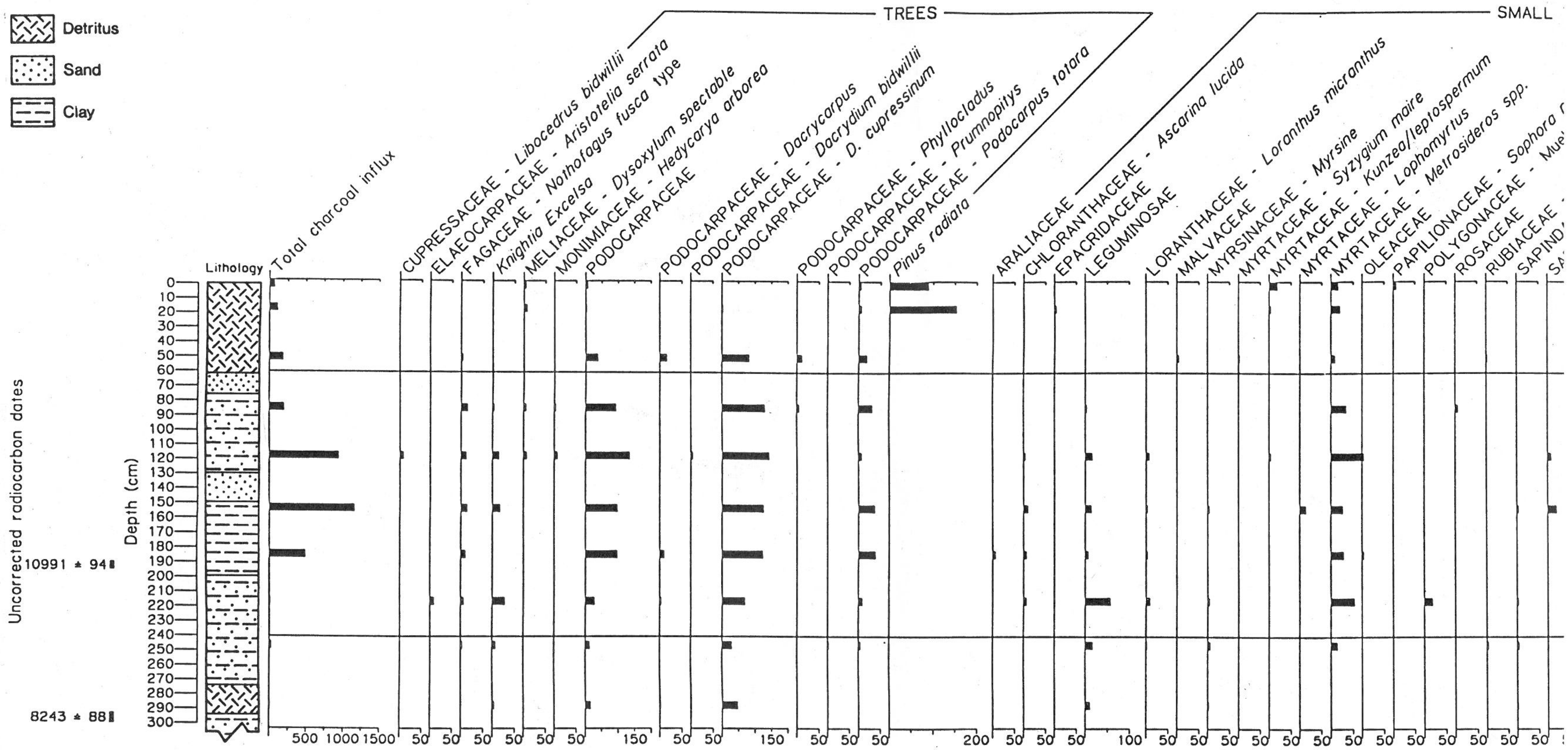


FIGURE A5.1
POLLEN DIAGRAM FOR MATAKANA ISLAND.