Late Quaternary Evolution of Matakana Island, Bay of Plenty, New Zealand

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Frontispiece: Oblique aerial view of Matakana Island and Tauranga Harbour from above Mount Maunganui township.

Abstract

Matakana Island consists of two main parts - an area of mainly Pleistocene materials to the southwest and a *c*.24 km long Holocene barrier to the northeast. Together with the tombolo systems of Bowentown Heads and Mount Maunganui, Matakana Island encloses the *c*.200 km^2 Tauranga Harbour.

This study establishes the late Quaternary geomorphological history of Matakana Island, focussing primarily on the evolution of the Holocene barrier. The barrier consists largely of relict foredunes, with relict parabolic dunes, lakes/wetland areas, washover deposits and estuarine flats also present. A detailed geomorphological map provides a foundation for palaeoenvironmental reconstructions. The landform information is supplemented with details of the sedimentology, tephrochronology, pedology, archaeology and palynology of the barrier in order to identify and describe past environmental changes.

The Pleistocene part of the island contains remnants of at least three late Pleistocene terraces, mantled by thick beds of tephra and ignimbrite. The lowest terrace, which retains some coastal landforms, originated as a relict foredune plain which probably formed during the Last Interglacial maximum (*c*.125 000 years ago). The older, higher terraces are likely to have originated during earlier interglacial periods.

The barrier consists primarily of moderately well sorted to well sorted medium to fine sand. The dominance of quartz, feldspar and hypersthene indicate that much of the sediment was originally derived from the active Taupo Volcanic Zone. Following the end of the Postglacial Marine Transgression *c*.7 000 cal BP, deposits of these materials on the continental shelf were reworked and transported shoreward to form the Holocene barrier.

Barrier formation commenced by around *c*.6 000 cal BP. The barrier initially formed in at least two separate parts, separated by a tidal inlet at present-day Blue Gum Bay. The entrance migrated southeastward as the barrier prograded and was closed off *c*.3 750 cal BP. Following the closure of the entrance, foredunes became larger and more irregular, suggesting a major change to the coastal sediment budget.

Progradation rates, calculated from shoreline ages determined by airfall tephra deposits, radiocarbon ages and sea-rafted pumice deposits, generally decreased with time, from about 0.46 metres/year initially to about 0.18 metres/year over the last *c*.650 years. Significant erosion of the southeastern end of the barrier culminated shortly after the Kaharoa eruption (*c*.650 cal BP), at which time the barrier was approximately 83 percent of its present length. Subsequently, both ends of the barrier extended rapidly. The coarse texture of sand comprising the barrier ends and anomalously old radiocarbon ages of incorporated shells suggests that, as the entrances narrowed, sediment from adjacent ebb-tidal deltas was reworked to form the barrier ends. The barrier also underwent considerable change following the first arrival of humans on Matakana Island sometime after the Kaharoa eruption. Widespread vegetation clearance and soil disturbance are likely to have contributed to dune instability.

Matakana Island appears to have developed in a similar fashion to many Holocene barrier systems of southeastern Australia in terms of a predominant shelf sediment source, onshore sediment transport following the end of the Postglacial Marine Transgression and decreasing progradation rates through time.

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Chapter One: *Introduction*

1.1 INTRODUCTION

1.1.1 Background

Matakana Island (Figure 1.1) is New Zealand's largest barrier island. Together with the tombolos of Mount Maunganui and Bowentown Heads the 24 kilometre long barrier, which comprises the larger part of Matakana Island, encloses the *c*.200 km^2 Tauranga Harbour (Healy and de Lange 1988). Locations referred to in this study are shown in Figure 1.2.

The island consists of two major geological units: (1) an area to the southwest which formed during Pleistocene time; and (2) the Holocene barrier to the northeast (Figure 1.3). The Matakana Island barrier is a major component of the Bay of Plenty coast and littoral system and has played an important role in the evolution of Tauranga Harbour. It has, however, received comparatively little attention from researchers and its geomorphology was poorly known. Detailed investigations of the contemporary dynamics of Tauranga Harbour have been undertaken by a number of workers (e.g., the Wallingford Hydraulics Research Station 1963, Davies-Colley 1976, Dahm 1983), but the nature and chronology of harbour formation has largely been ignored. This study attempts to redress this imbalance.

The research for this project was carried out as part of a broader study concerned with the archaeology and environmental history of the island, involving the Department of Conservation and the Anthropology Department at the University of Auckland.

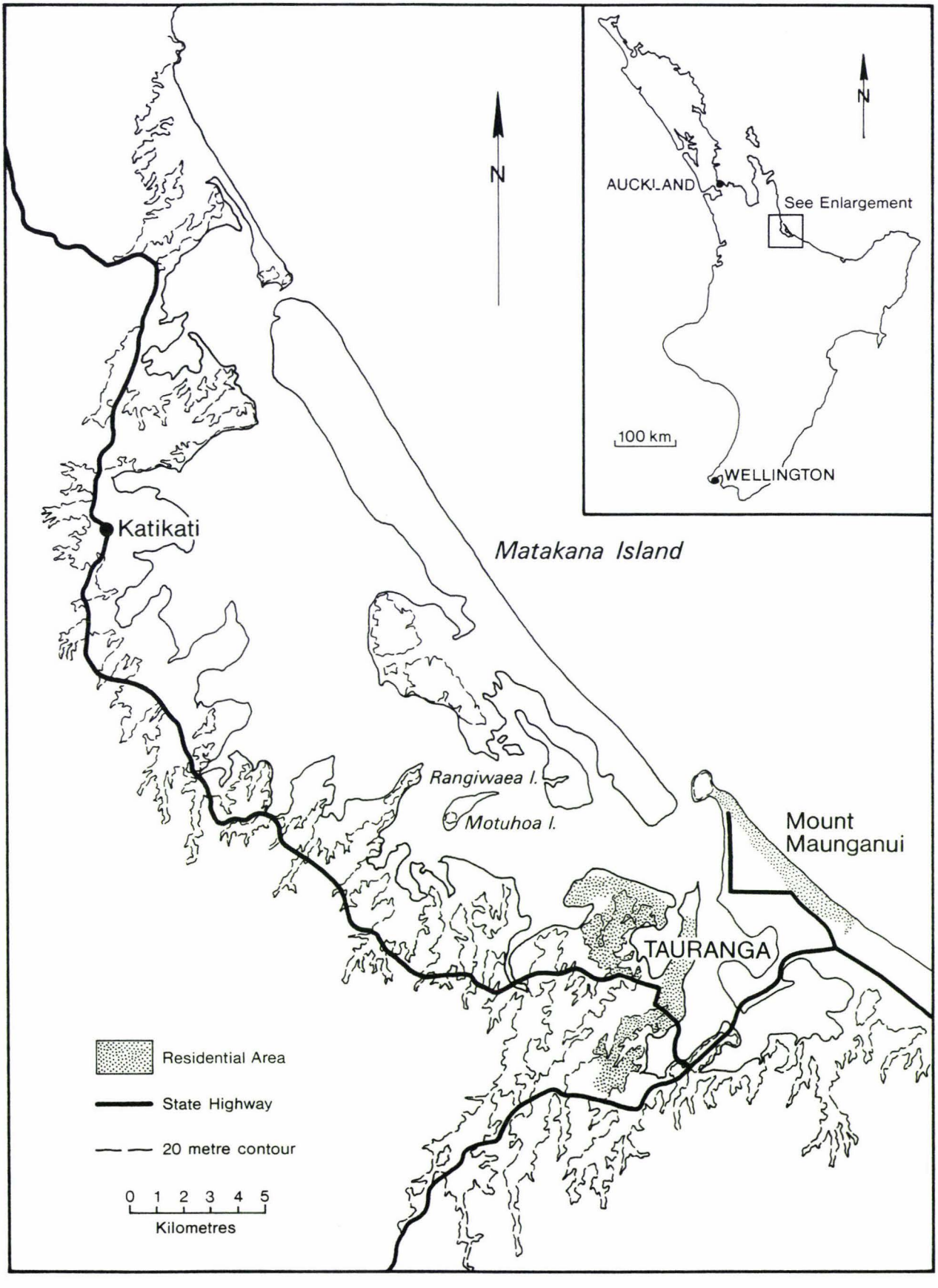


Figure 1.1: Location of Matakana Island.

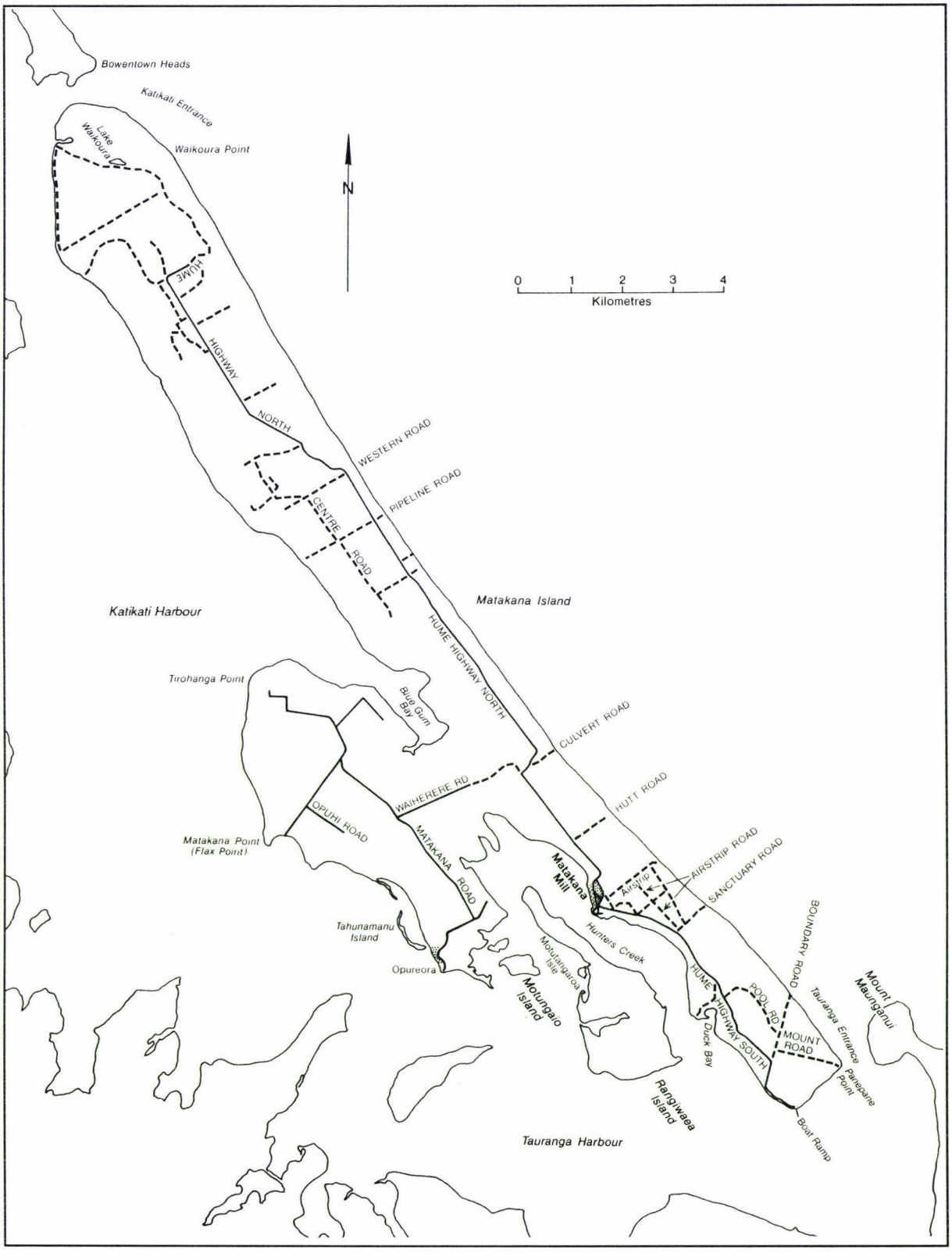


Figure 1.2: Locations referred to in the text.

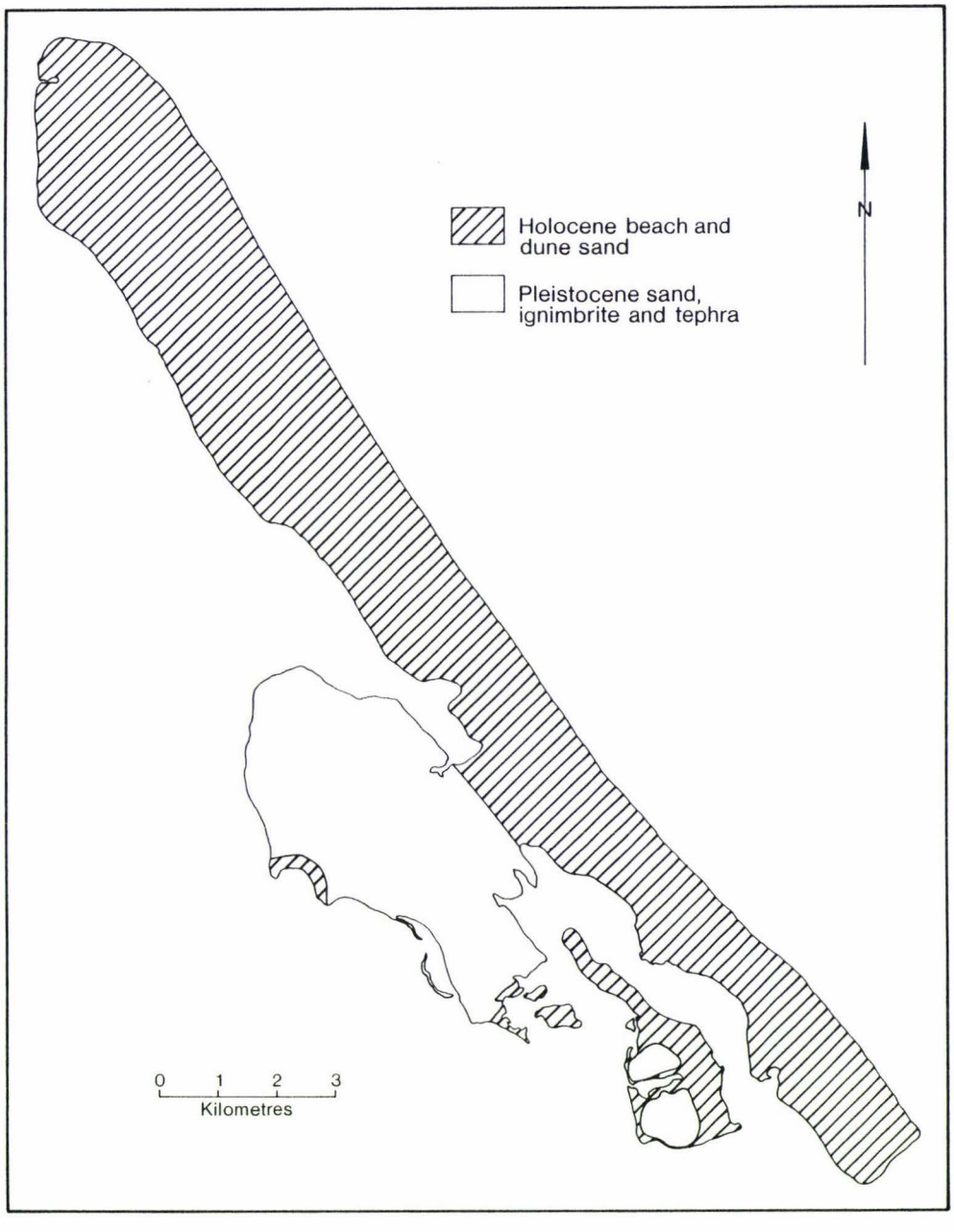


Figure 1.3: Major geological units on Matakana Island.

1.1.2 Objectives

The research carried out in this thesis has the following objectives:

(1) Mapping of the landforms of the barrier, using information derived primarily from aerial photographs with confirmation by ground checking, and explanations as to the origins of the landforms;

(2) Analysis of sediment size parameters and mineralogy, in order to identify sediment sources, transport processes, environments of deposition and possible changes in these environments over mid- to late Holocene time;

(3) Determination of the stratigraphy of the barrier, through the examination of stratigraphic sections and the excavation of drill holes and test pits;

(4) Definition of the age structure of the barrier, by means of radiocarbon dating, tephrochronology, historical records and archaeology;

(5) A reconstruction of the evolutionary history of the island.

While a detailed study of the contemporary dynamics of active landforms such as the beach and foredune system would have been desirable, this was beyond the scope of this thesis. However, observations of contemporary landforms and processes contributed to the interpretation of older features.

1.1.3 Thesis format

The thesis is divided into six chapters:

Chapter One introduces the topic and study area and outlines the main objectives. Previous work by other researchers is reviewed and methods of investigation and analysis are described.

Chapter Two describes the morphology of Matakana Island, with particular emphasis on the Holocene barrier. A map showing the landforms of the barrier is included, together with levelled profiles across the barrier and its shoreline. Explanations of the origins of the landforms are suggested.

Chapter Three describes the texture and mineralogy of the barrier sediments and discusses likely sediment sources and transport patterns.

Chapter Four outlines the chronology of the Matakana Island barrier, drawing on tephrochronology, soil development and radiocarbon dates.

Chapter Five reconstructs the late Quaternary evolutionary history of Matakana Island with particular emphasis on the Holocene barrier, based on the data described in Chapters Two to Four. The sequence of events is described in the context of present and past processes and is related to published models of coastal barrier development, particularly those from southeastern Australia.

Chapter Six summarises the results, presents conclusions and makes suggestions for further work.

A palynological investigation into palaeoenvironmental changes on Matakana Island is detailed in Appendix 1. Inferences are made with respect to climatic and human influences on the vegetation and on the morphological development of the Matakana Island barrier. Investigations into a soil chronosequence on the Matakana Island barrier, as part of an associated project, are described in Appendix 2.

Radiocarbon ages described in this thesis (see Table 4.1) are calibrated as follows: 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 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). The apparent offset of radiocarbon between the Northern and Southern Hemispheres (Vogel *et al.* 1993) is not compensated for in this thesis. Conventional radiocarbon ages are indicated in the text as "^{14}C years BP" (radiocarbon years before present where "present" = 1950AD). Calibrated ages are expressed as "cal BP".

Adopted calibrated ages for sea-rafted pumice and airfall tephra deposits are determined by calibrating the mean published radiocarbon ages for each (Froggatt and Lowe 1990, Alloway *et al.* 1994), taking the midpoint of the calibrated 95 percent confidence interval and rounding the midpoint to the nearest 50 years. The endpoints of hypothesised time intervals during early barrier formation discussed in Chapter 5 are similarly calibrated.

1.1.4 Previous work

Relatively little work has been carried out into the geomorphology of coastal barrier systems in New Zealand, although barrier systems of eastern Australia, with a similar microtidal swell wave environment, have been extensively studied. Thom (1984) defines coastal barriers as:

> "...bodies of detrital sediment, which rise above present sea level and block off or impound drainage from the hinterland. Typically, they are elongate sand bodies, parallel to the shore, and separated from the "mainland" in whole or in part by an estuary or lagoon, swamp or marsh, or sand or mud flat" (Thom 1984, pp.233-234).

Detailed studies of Australian Holocene barrier systems have led to a number of models of barrier evolution, such as those of Roy *et al.* (1980), Roy and Thom (1981) and Chapman *et al.* (1982). Other investigations into the morphology, stratigraphy and sedimentology of Australian barrier systems include Shepherd (1970, 1981), Thom (1984) and Thom *et al.* (1992), among others. The receding barrier systems of the United States have also received considerable attention in recent decades, with studies including Schwartz (1971), Dolan *et al.* (1980) and Nummedal (1983) describing the washover processes which commonly operate on these barriers.

The geomorphology and dynamics of tidal inlets associated with barrier systems have been extensively researched, particularly along the eastern United States coast. Patterns of sediment transport in and around tidal inlets have been described by Oertel (1972), Hubbard *et al.* (1979) and Boothroyd (1985), while interactions between ebb-tidal deltas and adjacent shorelines have been described by Oertel (1977) and Fitzgerald (1984). The application of sedimentological principles to the detection study of relict tidal inlets preserved within coastal barriers is described by Moslow and Heron (1978).

Previous research in the Bay of Plenty region, directly and indirectly related to the study of the Matakana Island barrier, can be loosely grouped as follows:

(1) Studies providing details of the geomorphology and environmental setting of the Bay

of Plenty coast and its hinterland;

(2) Studies relating to the contemporary dynamics of the beaches and harbours of the Bay of Plenty.

Research specific to the Matakana Island barrier is limited: it includes Healy (1977) who described historical shoreline changes at Panepane Point; Dahm (1983) who investigated the geomorphic development, stability and sediment dynamics of the Tauranga Harbour near the Tauranga Entrance; and the studies of Munro (1994) and Munro *et al.* (1994) which used principles of tephrochronology and pedology to determine the evolution of the northwestern end of the Matakana Island barrier.

The geological and tectonic environment of the western Bay of Plenty region was first described by Henderson and Bartrum (1913: cited in Dahm 1983), who broadly referred to the Pleistocene sediments occurring within the Tauranga Basin at the "Tauranga Beds". Later studies by Shaw and Healy (1962); Healy (1964) and Cole (1978, 1979) described the general volcanic and tectonic history of the region, while Kear and Waterhouse (1961) and Chappell (1974) described Pleistocene marine terraces occurring within the Tauranga Basin. The University of Waikato has recently produced a number of Masterate theses describing the Quaternary stratigraphy and volcanic geology of the Tauranga Basin, including Harmsworth (1983), Hughes (1993), Hall (1994) and Whitbread-Edwards (1994).

Early studies of tephra deposits occurring in the Bay of Plenty include Vucetich and Pullar (1969), Pullar and Selby (1971) and Pullar (1972). Later work by Birrell *et al.* (1977), Hogg (1979), Froggatt (1981) and Hogg and McCraw (1983), among others, described the tephrostratigraphy of the region in greater detail. These were followed by a comprehensive review of late Quaternary tephra formations by Froggatt and Lowe (1990). The first detailed study of Holocene tephra deposits in the Western Bay of Plenty was carried out by Wigley (1990). Particularly relevant to this thesis is the work of Pullar *et al.* (1977), who describe air-fall Kaharoa Tephra, Taupo Lapilli and sea-rafted Loisels Pumice and Taupo Pumice, all of which occur on the Matakana Island barrier. Kaharoa Tephra and Taupo Lapilli were used to date palaeoshorelines on northwestern Matakana Island by Munro (1994) and Munro *et al.*

(1994).

A soil chronosequence present on the Mount Maunganui tombolo adjacent to Matakana Island has been described and interpreted by Pullar and Cowie (1967), and the soils of the Matakana Island barrier are described by Dahm (1983) Harmsworth (1983) and Munro (1994).

The sediment dynamics of Tauranga Harbour and its entrances were first described by the Wallingford Hydraulics Research Station (1963), which simulated harbour dynamics by means of scale models. Further investigations into the sediment dynamics of the harbour included White (1979), de Lange (1988) and de Lange and Healy (1991). In particular, empirical models of sediment circulation in and adjacent to the Tauranga Entrance were produced by Davies-Colley (1976), Davies-Colley and Healy (1978a,b) and Dahm (1983). Historical shoreline changes at the Tauranga Entrance have been documented by Healy (1977), while Hicks and Hume (1991, 1993), Hume and Herendorf (1992), Hume and Hicks (1993) and Munro (1994) provide details of past shoreline changes and the contemporary dynamics of the Katikati Entrance.

Studies of shelf sediments in the wider Bay of Plenty region include Godfriaux (1973), with detailed investigations into the dynamics of the inner shelf near the Tauranga Entrance carried out by Harms (1989), Foster *et al.* (1991), Healy *et al.* (1991) and Warren *et al.* (1991), among others. Harray (1977) and Harray and Healy (1978) investigated the sediments and erosion of Waihi Beach, while Gibb (1978) investigated rates of coastal erosion and accretion in this and other parts of New Zealand. A series of detailed investigations into the morphology, sedimentology and dynamics of the Bay of Plenty coast was produced by Healy *et al.* 1977 and Healy (1978a,b,c), followed by a further description of coastal erosion and sediment transport in this region by Healy (1980).

Studies specific to the evolutionary history of parts of the Bay of Plenty sandy coast include Pullar and Cowie (1967) on the Mount Maunganui tombolo and Pullar and Selby (1971) on the Rangitaiki Plains. Lowe *et al.* (1992) and Wigley (1990) describe the evolution of the Papamoa-Te Puke lowlands and Dahm *et al.* (1994) propose a model of Holocene coastal evolution for the Bay of Plenty-Coromandel region, based on tephrochronology. Munro

(1994) and Munro *et al.* (1994) applied tephrochronology and soil chronosequence principles to their studies of the evolution of the northwestern end of Matakana Island. Tephrochronology has also been applied to an investigation into the Holocene progradation of the Gisborne Plains by Pullar and Penhale (1970) and to various other parts of the North Island coast by Wellman (1962).

1.2 ENVIRONMENTAL SETTING

1.2.1 Pleistocene geology

Tauranga Harbour occupies the "Tauranga Basin" (Shaw and Healy 1962), which formed as a result of subsidence and late Pleistocene warping due to crustal spreading associated with the active Taupo Volcanic Zone (Shaw and Healy 1962, Chappell 1974, Cole 1979). The basin is part of a tensional graben structure (Cole 1979, Dahm 1983, Harmsworth 1983) aligned approximately northeast to southwest and Tauranga Harbour lies where this structure, the Ngatoro Basin (Cole 1979), intersects the Bay of Plenty coast (Figure 1.4). Whitbread-Edwards (1994) suggests an age of two to four million years for the Tauranga Basin.

The Tauranga Basin is thought to be either stable (Selby *et al.* 1971, Pillans 1986, Wigley 1990) or subsiding (Schofield 1968, Cole 1978). At least two calderas are suggested to exist in the Tauranga Basin (Hughes 1993, Whitbread-Edwards 1994). A proposed "Katikati caldera", up to perhaps nine kilometres in diameter, is thought to be centred approximately two kilometres west-northwest of Flax Point (Whitbread-Edwards 1994: Figure 6.3) A larger caldera about 25 kilometres in diameter is thought to be centred about 32 kilometres south of Mount Maunganui (Hughes 1993: Figure 6.4). These calderas have little or no surface expression, but their existence is supported by subcircular negative gravity anomalies and stratigraphic evidence as detailed by Hughes (1993) and Whitbread-Edwards (1994). No age is suggested for these features.

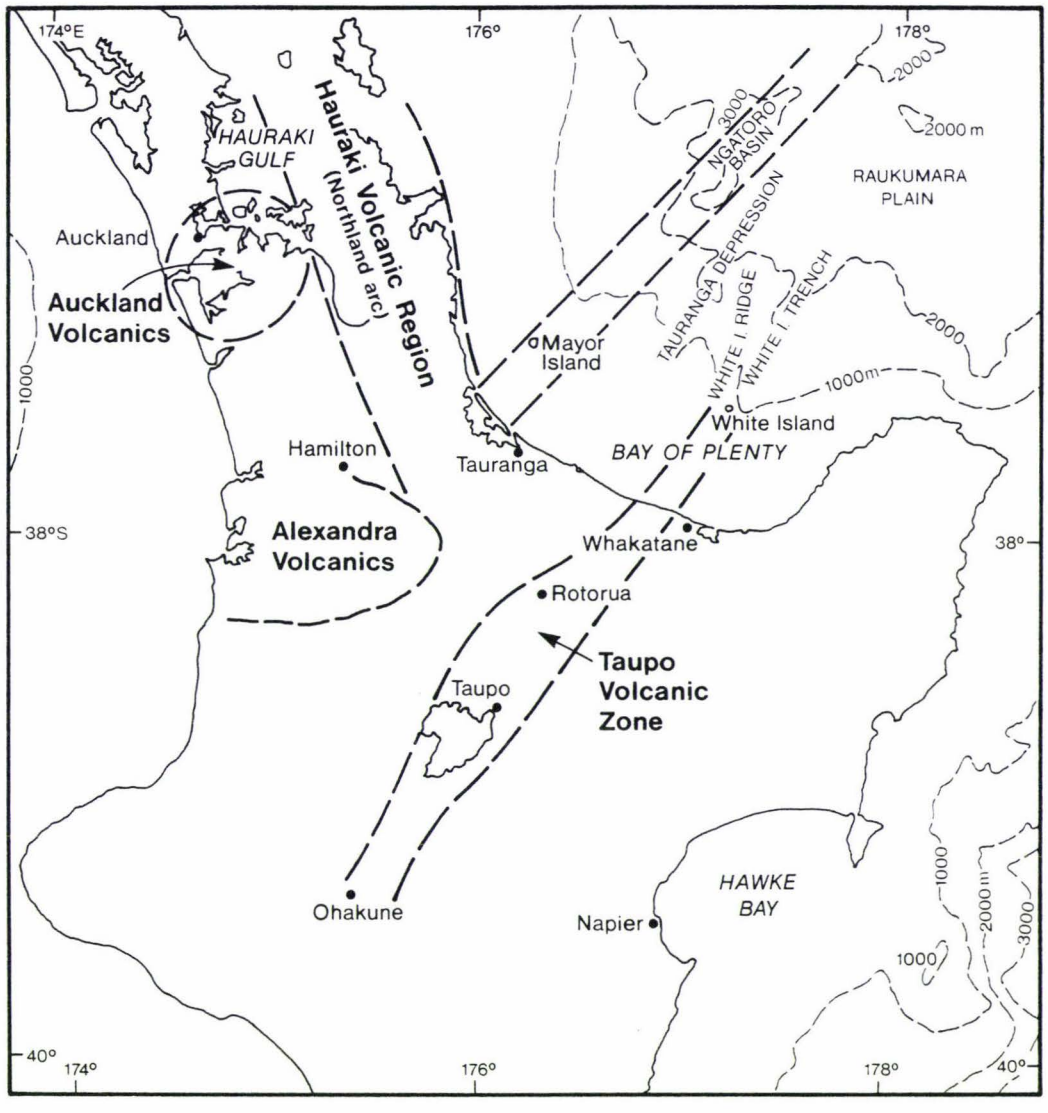


Figure 1.4: Tectonic setting of the Tauranga Basin (Cole 1979: Figure 1).

Considerable thicknesses of Pleistocene sediments, broadly grouped as the "Tauranga Beds" (Henderson and Bartrum 1913: cited in Dahm 1983), cover the Tauranga Basin. These sediments consist of mid- to late Quaternary tephra deposits (Selby *et al.* 1971, Pullar and Birrell 1973, Hogg 1979) in their upper part (Dahm 1983) and probably overlie either fluviatile (Healy 1964) or fluviatile-estuarine (Davies-Colley 1976) sediments. An isolated outcrop of pyroxene andesite (Henderson and Bartrum 1913: cited in Dahm 1983), known locally as Ratahi Rock, occurs near Flax Point on Matakana Island and is the only known occurrence of bedrock on the island.

It is suggested by Healy (1964), Davies-Colley (1976), Dahm (1983) and Munro (1994) that

Tauranga Harbour occupies palaeo-valley systems which were fluvially incised into the "Tauranga Beds" during the last period of glacially-lowered sea level and drowned by the Postglacial Marine Transgression. The Pleistocene parts of Matakana and Rangiwaea Islands are underlain by "Tauranga Beds", which are exposed in coastal cliffs. These isolated areas of Pleistocene material are now separated from the mainland as a result of fluvial erosion during the last period of low sea level (Healy and de Lange 1988, Munro 1994), becoming islands when the sea rose to its present level. Palaeo-valleys underlying Tauranga Harbour have been suggested as controls for the present configuration of tidal channels in the harbour (Dahm 1983, Healy and de Lange 1988). The Matakana Island sand barrier, consisting primarily of marine and aeolian sediment, developed during Holocene time.

1.2.2 Tephra deposits and soils

Volcanic activity since Miocene times has deposited large volumes of rhyolitic flow material and unwelded tephras in the Tauranga Basin (Davies-Colley 1976). Holocene tephra deposits occurring in the western Bay of Plenty are listed in Table 1.1 below.

Two of these have been previously recorded on the Matakana Island barrier (Dahm 1983, Harmsworth 1983, Munro 1994): Taupo Lapilli (Healy *et al.* 1964) dated at 1 850 ± 10 ^{14}C years BP (Froggatt and Lowe 1990), and Kaharoa Tephra (Vucetich and Pullar 1964) with a radiocarbon age of 665 ± 15 ^{14}C years BP calculated from available radiocarbon dates (B.G. McFadgen, pers. comm. 1995). The adopted calibrated radiocarbon age of Taupo Lapilli is 1 750 cal BP, while an age of 650 cal BP is adopted for Kaharoa Tephra. Kaharoa Tephra occurs on the Matakana barrier as a fine, powdery white ash, varying in thickness from six to 20 centimetres in undisturbed profiles. It is normally graded, with a coarse basal unit of pumiceous sand overlain by fine sand approximately three centimetres in thickness, and has a characteristic biotite-rich ferromagnesian assemblage (Pullar *et al.* 1977). The deposit is commonly referred to in the literature as "Kaharoa Ash". Taupo Lapilli ranges up to about eight centimetres in thickness, is mauve in colour, with abundant pumice lapilli up to about 1.5 centimetres in diameter. These tephras are shown in section in Figure 1.5 below.

Table 1.1: Holocene tephra deposits occurring in the western Bay of Plenty.

Tephra	Age (^{14}C years BP)	Calibrated age (approximate years BP)	Volcanic Centre
Kaharoa Tephra Formation[1]	665 ± 15[2]	650	Okataina
Taupo Tephra Formation[1]	1 850 ± 10	1 750	Taupo
Mapara Tephra Formation[1]	2 160 ± 25	2 150	Taupo
Whakaipo Tephra Formation[1]	2 685 ± 20	2 800	Taupo
Stent tephra[3]	3 970 ± 31	4 300	Taupo
Hinemaiaia Tephra Formation[1]	4 510 ± 20	5 150	Taupo

Footnotes:
[1] Nomenclature after Froggatt and Lowe (1990).
[2] B.G. McFadgen, pers. comm. (1995).
[3] Described by Alloway *et al.* (1994); tentatively identified on Matakana Island.

Older Holocene tephras are likely to have been deposited on the Matakana Island barrier, but they are either very thin and/or poorly preserved (e.g., Munro 1994) and their identification is uncertain. They include Stent tephra, which occurs as a yellowish-coloured deposit less than one centimetre thick and is tentatively identified near the Matakana Mill. It has a mean radiocarbon age of 3 970 ± 31 ^{14}C years BP (Alloway *et al* 1994); the adopted calibrated age for this deposit is 4 300 cal BP. This is described further in Section 4.1.2.

Three sea-rafted pumices (Waimihia Pumice, Taupo Pumice and Loisels Pumice) have been positively identified on the Matakana Island barrier. Waimihia Pumice is a highly vesicular, frothy pumice, similar to Taupo Pumice (described below). It is soft and easily broken, although it tends to be harder than Taupo Pumice. A distinguishing feature of the pumice is the grey banding or complete greyness of about 10-20 percent of clasts. Some of the grey clasts appear similar to Loisels Pumice (described below), but the latter is harder and contain more crystals. Waimihia Pumice contains only about five percent crystals, predominantly plagioclase feldspar and hypersthene with very minor amounts of quartz, augite and

hornblende (P.C. Froggatt, pers. comm. 1995). Waimihia Pumice was erupted at 3 280 ± 20 ^{14}C years BP (Froggatt and Lowe 1990) and has an adopted calibrated age of 3 450 cal BP.

Figure 1.5: A typical section on the Holocene barrier showing a disturbed peaty soil overlying Kaharoa Tephra (Ka), which directly overlies Taupo Lapilli (Tp).

Taupo Pumice is light yellow-brown in colour with characteristic abundant, large, elongated vesicles and is softer than Waimihia Pumice. Individual pumice clasts of up to 30 centimetres in diameter have been observed in deposits on the barrier. Taupo Pumice originates from the Taupo eruption of 1 850 ± 10 ^{14}C years BP (Froggatt and Lowe 1990), or 1 750 cal BP.

Loisels Pumice is generally dense, hard and grey in colour, with light and dark banding (Wellman 1962, Pullar *et al.* 1977). Its source is unknown (McFadgen 1994) and it has a hypersthene-augite-labradorite mineralogy which is unknown from New Zealand volcanoes (Froggatt and Lowe 1990). The age and stratigraphic relationship of Loisels Pumice to the Kaharoa Tephra Formation is a contentious issue (Pullar *et al.* 1977, Froggatt and Lowe 1990,

Felgate 1992, McFadgen 1994). It is generally thought that primary sea-rafted Loisels Pumice is younger than the Kaharoa Tephra Formation (Pullar *et al.* 1977, McFadgen 1982). Osborne *et al.* (1991) consider it to be older, although McFadgen (1994) rejects their argument on the grounds that it is based on an unreliable sample. The best calibrated radiocarbon age currently available for the first appearance of Loisels Pumice on New Zealand beaches is *c.*590 cal BP (McFadgen 1994).

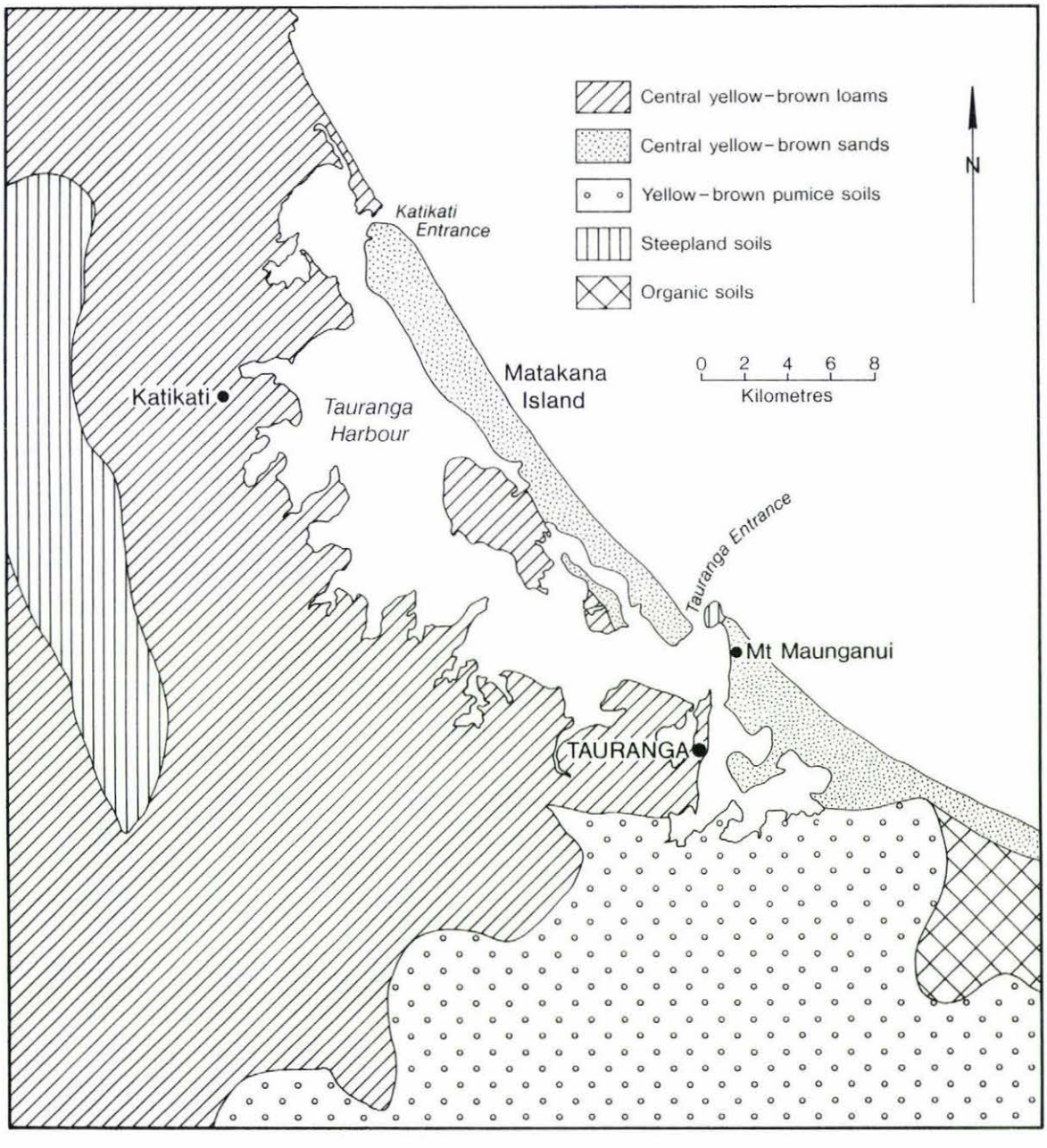


Figure 1.6: Major soil classes of the Tauranga district (after Gibbs *et al.* 1968).

Soils of the Tauranga Basin are of two main types: *yellow-brown pumice soils* developed on Kaharoa Tephra and Taupo Lapilli, and *yellow-brown loams* developed on late Pleistocene Waihi Ashes (the upper constituent of the "Tauranga Beds" described in Section 1.2.1) (Harmsworth 1983). The latter predominate on the Pleistocene part of Matakana Island, with *central yellow-brown sands* occurring on the barrier. Munro (1994) described a soil chronosequence from the barrier near Waikoura Point. A similar chronosequence is described and discussed in Appendix 2 and summarised in Chapter 4 of this study. The distributions of the main soil types of the Tauranga area are shown in Figure 1.6.

1.2.3 Climate

The Bay of Plenty has a mild, sunny, temperate climate, with moderate rainfall. Westerly and southwesterly winds predominate at Tauranga Airport (Figure 1.7) (de Lisle 1962, Quayle 1984), although the Bay of Plenty, being sheltered by high country to the west, south and east, is considerably less windy than other parts of New Zealand (Quayle 1984). Gales, generally from the northeast or southwest, occur infrequently and are more common near the coast and about the ranges than in other parts of the region (Quayle 1984). The mean annual percentage frequency of wind direction for Tauranga Airport, which is located on the coastal plain near Mount Maunganui, is shown in Figure 1.7.

Mean annual rainfall is 1 349 millimetres at Tauranga Airport (Quayle 1984). A pronounced rainshadow effect in the lee of high ground to the south and west results in only a relatively small proportion of the region's rainfall being delivered by the prevailing winds. The greater part of mean annual rainfall occurs in association with less frequent, onshore north to northeast winds. Such airstreams have commonly traversed large areas of warm ocean to the north of New Zealand and are consequently very humid. Widespread and heavy rain often results when these air masses are orographically forced over the inland ranges (Quayle 1984).

The coastal margin of the region, including Matakana Island, commonly experiences summer dry spells (Quayle 1984). Soils moisture falls below field capacity for as much as 60 percent of the time from September to April, and soil moisture deficits of the equivalent of at least 75 millimetres of rainfall last for at least two months in about one year in four (de Lisle 1962).

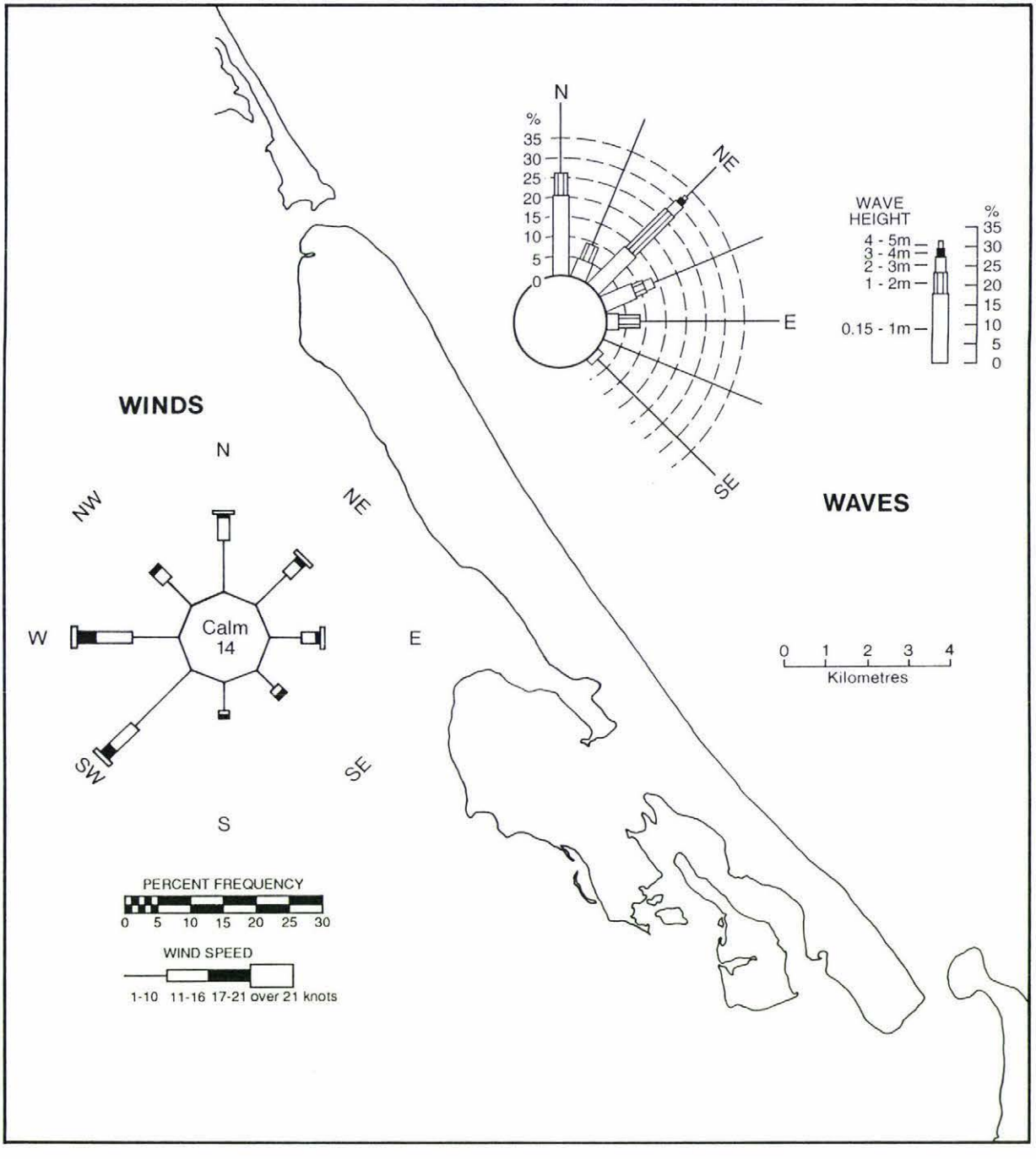


Figure 1.7: Wind regime at Tauranga Airport (Quayle 1984) and wave climate near the Tauranga Entrance (Davies-Colley and Healy 1978a).

1.2.4 Marine environment

1.2.4.1 Bathymetry

Bathymetric charts show the inner continental shelf off Matakana Island to be generally uniform and smooth (Pantin *et al.* 1973), with the exception of nearby Karewa Island and Steels Reef (Hume and Hicks 1993). The inner continental shelf has a gradient of about 1:130 (Davies-Colley 1976, Harms 1989); this decreases to about 1:300 on the outer shelf (Pantin *et al.* 1973).

The uniformity of the inner shelf is disrupted in the vicinity of the entrances to Tauranga Harbour, where large sand bodies, or *ebb-tidal deltas*, are present (Davies-Colley and Healy 1978a). These represent large stores of coastal sediment (Fitzgerald 1984, Boothroyd 1985, Hayes 1991, Hicks and Hume 1993, Hume and Hicks 1993) and their formation results from the transport of sediment out of tidal entrances by strong ebb-tidal currents. The convergence of tidal currents within the narrow harbour entrances leads to deep scouring of the inlet gorges. The Katikati Entrance has a maximum depth exceeding 24 metres (Hydrographic Office 1993), with maximum current velocities exceeding 3.9 knots (Hume and Hicks 1993). Peak current velocities in excess of 6.8 knots have been recorded in the larger Tauranga Entrance (Davies-Colley and Healy 1978b) and the inlet throat has been scoured to a depth of over 30 metres (Davies-Colley 1976, Dahm 1983, Hydrographic Office 1993).

Tidal inlets are the most dynamic parts of a barrier system (Hayes 1991) and, as is discussed in Chapter 5, this is clearly the case with Matakana Island. Interaction between the ebb-tidal deltas and the beach is demonstrated by the presence of rounded bulges, or *accretion cusps* (Healy and Kirk 1992) at the northwest and southeast ends of the barrier, which are related to the ebb-tidal deltas of the Bowentown Bar and Matakana Bank respectively (Healy *et al.* 1977). Detailed studies of the Tauranga Entrance and its associated flood- and ebb-tidal deltas are numerous and include the Wallingford Hydraulics Research Station (1963), Davies-Colley (1976), Davies-Colley and Healy (1978a,b), Dahm (1983), de Lange (1988), de Lange and Healy (1991) and Hume and Herendorf (1992). The morphology and dynamics of the Katikati Entrance has been specifically studied by Hume and Herendorf (1992), Hicks and Hume

(1993) and Hume and Hicks (1993).

1.2.4.2 Wave and tidal environment

The western Bay of Plenty coast, with a northeasterly aspect and prevailing offshore winds, has a generally lower energy wave climate than most other New Zealand coasts with a dominance of swell waves over locally-generated waves. The Bay of Plenty wave climate has been classified as a "mild-meso energy swell wave environment" by Healy *et al.* (1977), typical of a sheltered lee coast (Pickrill and Mitchell 1979). The offshore significant wave height has been reported by Healy *et al.* (1977) to be 1.5 metres, with a nearshore significant wave height of 0.6 metres. The predominant wave approach direction is from the north to northeast, approximately normal to the coast, as shown in Figure 1.7.

A low northerly swell, usually less than one metre in height, is particularly frequent. Higher waves generally approach from the east or northeast (Davies-Colley and Healy 1978a) and are associated with extra-tropical storms and winter depressions which occasionally track across the seas to the north of the region (de Lisle 1962, Heath 1985). Healy *et al.* (1977) treated available wave data from Davies-Colley (1976) similarly to wind data in calculating a wave approach resultant of 4° north of normal to the coast, suggesting nett littoral drift from northwest to southeast (Healy *et al.* 1977, Davies-Colley and Healy 1978b, Harray and Healy 1978, Dahm 1983, Wigley 1990).

Healy *et al.* (1977) observed considerable variation in both magnitude and direction of littoral drift, but 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. A probable range of 70 000 ± 20 000 m^3 per year is suggested (Healy *et al.* 1977, Healy 1980). However, the onshore movement of ebb-tidal delta sediments, consequent on a recent narrowing of the Tauranga entrance, could account for some of this progradation (see Chapter 5).

The tidal range of 1.8 - 2.0 metres (Dahm 1983, Healy *et al.* 1977) is near the upper limit of the "microtidal" category of Davies (1964), which is conducive to barrier development (Davies 1980). However, the Tauranga and Katikati Entrances can be classified as tidally-dominated

(Carter 1988), owing to the influence of their large tidal prisms (130.8 x 10^4 m^3 and 95.8 x 10^4 m^3 respectively (Hume and Herendorf 1992)) compared to the moderate wave energy climate. Both entrances possess morphological features characteristic of tidally-dominated inlets, viz. a deep, narrow inlet throat and an extensive ebb-tidal delta complex which extends beyond the shoreline (Carter 1988).

1.2.5 Land use

Land use on Matakana Island primarily involves horticulture, agriculture and commercial forestry. The suitability of these land uses to different parts of the island is governed to a large degree by soil development and fertility. Soils on the Holocene barrier are of low fertility (see Appendix 2) and productivity. Agricultural activities, consisting of beef and dairy farming, occupy the more productive soils of the Pleistocene part of the island. Horticulture, primarily in the form of kiwifruit orchards, occurs primarily in the vicinity of Opureora, the main settlement on the island (Figure 1.2).

An attempt to establish a sheep and cattle run on the Holocene barrier early this century was unsuccessful (Faulkner 1955). However, *Pinus radiata* seedlings were observed to thrive on the barrier, leading to the establishment of commercial forestry activities from 1925 (Faulkner 1955). Today the barrier is almost entirely devoted to commercial forestry, with the exception of some wetland areas near the Katikati Entrance and along the inner margin of the barrier around and northwest of Blue Gum Bay which have largely been left in their natural state. Other wetland areas were drained in the past to meet the growing demand for land suitable for forestry (Munro 1994).

1.2.6 Vegetation

Much of the natural vegetation which would have existed on the barrier before human settlement has been destroyed by human activity. The largest remaining area of natural vegetation occurs along the harbour shoreline of the northwestern part of the barrier, where mature swamp forest occupies relict estuarine flats. The vegetation of Tauranga Harbour and its margins has been surveyed in detail by Beadel (1989a).

With the exception of isolated areas of shoreline recession, 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 occur 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 (Figure 1.2). Individuals are generally small (30-50 centimetres tall), being close to the southern limit of their geographic range (Kuchler 1972, Dingwall 1980, Crisp *et al.* 1990).

Several wetland areas are present at the northwest end of the barrier, often containing lakes (see Chapter 2). Wetland vegetation is typically characterised by *Typha orientalis*, *Baumea juncea*, *Baumea articulata* (jointed twig-rush), *Schoenoplectus validus* (lake club-rush) and *Carex secta* (niggerheads) (Beadel 1989a). The rare ferns *Cyclosorus interruptus* and *Thelyptens confluens* (swamp fern) have also been observed by Beadel (1989a). *Leptospermum scoparium* shrubland and *Salix* spp. (willow) with an understorey characterised by *Baumea juncea* and *Phormium tenax* are common around the outer margins of the wetlands.

A well-established sand dune vegetation succession is present on the contemporary incipient foredune and foredune system of the ocean side of the barrier, between the mean high water spring mark and the plantation Pinus radiata forest to landward. Beadel (1989b) classifies the vegetation into the following broad zones:

Zone 1, adjacent to the mean high water spring mark, is characterised by *Spinifex sericeus* (spinifex), *Desmoschoenus spiralis* (pingao) and uncolonised bare sand.

Zone 2, immediately landward of Zone 1, consists of *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).

Zone 3 borders the plantation pine forest on the barrier, is less common than Zones 1 and 2 and is typically shrubland comprising *Isolepis nodosa*, *Calystegia soldanella*, *Deyeuxia billardierii*, *Spinifex sericeus*, *Desmoschoenus spiralis* and the exotics *Pinus radiata* and *Leptospermum laevigatum* (coast tea tree) (after Beadel 1989b).

Some or all of these zones, Zones 1 and 2 in particular, are absent where shoreline recession has destroyed part or all of the foredune system. This has occurred particularly in the vicinity of Boundary Road and Waikoura Point (located on Figure 1.2), where *Pinus radiata* occur immediately adjacent to the shoreline and are being removed by erosion.

1.3 METHODOLOGY

The study of the Matakana Island barrier involved a number of field and laboratory techniques:

1.3.1 Compilation of landform map

A map showing the landforms of the Matakana Island barrier, based primarily on aerial photographs, is located in the folder at the rear of this thesis. The map is classified into landform categories and discussed in Chapter 2. Details of photographs used in the compilation of the map are provided in Appendix 3.

A major obstacle to the extraction of landform information from the aerial photographs was the extent to which the barrier is covered by plantation pine forest. All but the most prominent landforms were virtually impossible to detect under mature forest and just a few years of growth following replanting was sufficient to considerably obscure the surface morphology. This was overcome with the use of aerial photographs taken at different time intervals ranging over a period of thirteen years from August 1981 to August 1994, when different parts of the barrier had been clear felled. This enabled most of the landforms of the

barrier to be mapped using a variety of aerial photographs.

Aerial photographs used in this study were at scales of 1:10 000, 1:15 000 and 1:25 000. The 1:25 000 photographs were first used to construct a base map on tracing paper, showing the shoreline and the location of forestry roads. This base map served as a "template" on to which the landform information gained from the aerial photographs was superimposed.

The landform information was visually derived from the aerial photographs with mirror stereoscopes, under which relict foredune crests and relict transgressive dunes were marked on the photographs in chinagraph pencil. The locations of relict transgressive dunes and relict foredunes were transferred directly onto tracing paper, along with information on forestry roads, vegetation boundaries and the shoreline. The information on the tracing paper was then photo-reduced to a scale of 1:25 000 and traced directly onto the base map, using the forestry roads, prominent relict foredunes and the shoreline as controls.

Landforms over most parts of the island were ground-checked during the course of the research, with particular attention given to forest blocks which were not clear in any of the photographs. The inner margin of the northwestern half of the barrier, occupied by dense swamp forest, was also ground checked, as were clear felled areas in which the surface morphology was obscure on the photographs. Information gained in this way was pencilled on relevant aerial photographs and added to the map where necessary.

1.3.2 Sediment sampling

Sediment samples were recovered from a variety of depositional environments and their textural, mineralogical and in some cases chemical properties analysed. Owing to the fine nature of the much of the sand, individual laminae could not be identified and specifically sampled so composite samples were collected, with the exception of estuary flat sediments as described below. Details of sampling procedures are outlined below:

1.3.2.1 Beach sediments

Ocean beach sand samples, of dry weight roughly 200-400 grams, were collected by trowel from the mid-foreshore to a maximum depth of approximately five centimetres. Harbour beach samples of similar weight and depth were taken from the high water mark, this being clearly defined by a narrow zone of debris along the shoreline.

1.3.2.2 Estuary flat sediments

Sediments of the estuary flats along the Katikati and Tauranga Harbour shorelines were sampled at very shallow depths (less than two centimetres), following the recommendations of MacPherson and Lewis (1978) regarding the variable nature of estuarine sediments with depth. Sampling at such shallow depths limits the sample to the "active layer" of the sediment, which is more likely to reflect contemporary environmental processes than deeper sediments (MacPherson and Lewis 1978). Sample weights were approximately 200-350 grams when dried.

Where possible, the samples were collected from estuarine flats below the estuarine beaches. However, for the Tauranga Harbour estuary flat samples in particular, an extensive flat was not always present owing to the close proximity of tidal channels to the shoreline, such as at Hunter's Creek. In these situations, samples were collected from the lowest part of the beach, although the steeper slopes and stronger tidal currents in these environments have certainly influenced the nature of the sediments.

1.3.2.3 Sampling of foredunes and relict foredunes

Samples were collected from relict foredune crests along four shore-normal transects across the barrier and one shore-parallel transect, using a hand auger. Samples were taken at a depth of one metre in order to avoid sand modified by soil forming processes. Dry sample weights were approximately 100-200 grams.

Sampling along the contemporary foredune consisted of surface samples to a maximum depth

of about 20 centimetres, with dry sample weights being about 100-200 grams. The foredune samples taken along five beach-foredune transects were collected in a similar fashion.

1.3.2.4 Vertical sampling

Vertical sequences of samples were collected from several locations in order to examine changes in depositional environments over time. This was carried out with the use of a hand auger for relict transgressive dunes and a trailer-mounted mechanical drilling rig, supplied by the Department of Civil Engineering of the University of Auckland, for deeper sampling of the barrier sediments. Samples obtained by the 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. Samples recovered were of approximately 100-150 grams in weight when dry.

1.3.2.5 Radiocarbon samples

Material suitable for radiocarbon dating was recovered from several locations. Shell material was recovered from holes drilled by the trailer-mounted rig, from auger holes and from prehistoric Maori shell middens; unabraded shells were submitted to the Institute of Geological and Nuclear Sciences (Lower Hutt) for dating. Two samples from a swamp core (see Appendix 1), one of charcoal-bearing sediment and one of preserved plant material, were also submitted. Details of radiocarbon samples are listed in Table 4.1.

1.3.2.6 Soil samples

A shore-normal transect of test pits was excavated near Blue Gum Bay (Section 4.1.4; Appendix 2). A soil sample was collected from each of the A_1, A_2 and B horizons in each test pit, with the exception of one pit where the A_1 and A_2 horizons were indistinguishable and one sample was taken to represent an A horizon. Dry sample weights were approximately 50-100 grams.

1.3.3 Levelling of profiles

Seven topographic profiles across the Holocene barrier, one across part of the Pleistocene part of the island and fourteen beach profiles were levelled.

The beach profiles were levelled from landward of the foredune crest (where present) to the water line with a maximum interval of ten metres between points. Profiles across the barrier included the heights of every foredune crest and swale. A known point on each cross section across the barrier was obtained with a Trimble GeoExplorer GPS and the height data of all the cross sections reduced to mean sea level. The heights of the ocean beach and harbour entrance beach profiles were plotted relative to the height of the seaward limit of foredune vegetation and the harbour beach profiles relative to the high water strandline.

1.3.4 35mm aerial photographs

An aircraft was chartered for an aerial photograph run over Matakana Island on July 31, 1994. Most photographs were taken from a low altitude of 200-250 metres, with an additional higher-altitude run at about 1700 metres.

1.3.5 Sediment sample preparation and analysis

Sediment samples were prepared for laboratory analysis using the following procedures:

1.3.5.1 Sediment size analysis

Samples collected from the harbour beach, ocean beach and ocean foredune were first decanted several times with distilled water to remove salt where necessary, then oven dried. Roots and other coarse organic matter such as shells were removed prior to analysis.

The dried samples were then subsampled, using a sample divider in order to avoid introducing bias to the results of sediment size analyses. The subsamples were mechanically sieved at ¼ϕ

intervals for 20 minutes. Errors in the total weight for all sieve fractions were generally less than 0.5 percent and did not exceed 2.0 percent. Calculation of sediment size parameters was carried out using the PC-GRAN computer software package. The Folk-Ward (Folk 1974) sediment size parameters used in this study are: (1) mean size; (2) deviation (sorting); (3) skewness; and (4) kurtosis. Raw data from these analyses are provided in Appendix 5.

The samples recovered from the estuary flats of Tauranga and Katikati Harbours were examined for their silt/clay fractions only. The samples were wet-sieved through a 4ϕ (63μm) sieve with distilled water. The coarse fractions retained were dried and weighed and the fines were decanted, dried and weighed after being allowed to settle for approximately one day. Sediment losses during the wet sieving procedure were generally higher than those for dry sieving, the maximum error being 2.1 percent. However, this was not considered significant in the context of the wide variation in silt/clay content of the samples analysed.

The soil samples from the Blue Gum Bay Transect were subdivided, with one half undergoing wet sieving to determine percentage silt/clay content, the other half being sent to the Soil Science Department, Massey University, for full chemical analysis. The subsamples retained for wet sieving were processed following the same procedure as for the estuary flat samples. However, a generally higher content of silt- and clay-sized material in these samples required a longer settling time of several days before the fines were decanted and dried.

1.3.5.2 Mineralogy

After sieving the 2ϕ-4ϕ fraction was retained for mineralogical analysis, following the procedure of Healy (1978c). 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 were counted for each slide, with the exception of one sample for which the heavy fraction comprised only 259 grains. Grains were counted along parallel transects across each slide.

Chapter Two:
Matakana Island Geomorphology

Introduction

In this chapter the landforms of Matakana Island are described and discussed, with emphasis on the Holocene barrier.

The landforms of the two broad geological units identified in Figure 1.3 are treated separately. However, the subdivision of the island into a Pleistocene and an Holocene section is complicated by the occurrence of landforms of Holocene age on the Pleistocene part of the island. These are identified and discussed with the Pleistocene landforms in Section 2.1.1.4 below.

Section 2.1.2 deals with the landforms of the Holocene barrier, combining levelled profiles with information from landform mapping in a detailed description and discussion of barrier morphology. The chapter is then summarised in Section 2.2.

2.1 LANDFORM IDENTIFICATION AND MAPPING

A map showing the landforms of the barrier (Map 1) is located in the folder at the rear of this thesis. This is the first detailed map of the landforms of the barrier. A summary of this map (Figure 2.1) shows major landform categories on the both the Pleistocene part of the island and the Holocene barrier.

Landform categories identified on this map are described and discussed below:

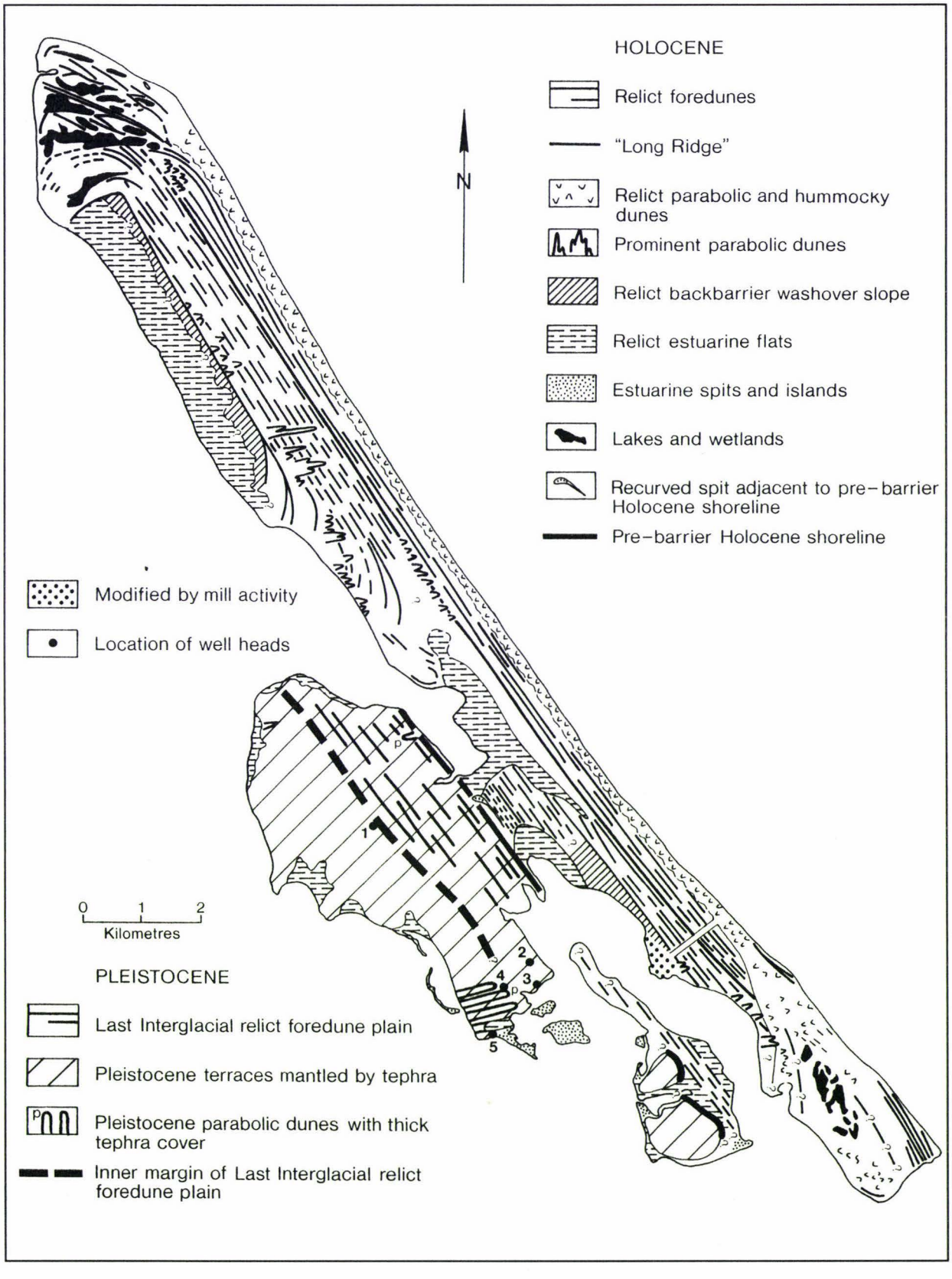


Figure 2.1: Geomorphological map of Matakana Island. Numbers shown on the Pleistocene part of the island refer to well head locations discussed in Section 2.1.1.2.

2.1.1 Landforms of the Pleistocene part of the island

2.1.1.1 Pleistocene terraces mantled with tephra

The Pleistocene part of Matakana Island comprises at least three Pleistocene terraces (Figure 2.2(a)), overlain by tephra. Terrace heights are approximately ten metres, 40 metres and 70 metres above present sea level and all terraces probably overlie marine or fluviatile sediments. At Flax Point, a marine deposit containing shells is exposed in a cliff section at the back of the highest terrace. The shells are about one metre above present mean sea level.

It is thought that the equivalent of Chappell's "BOP3" terrace (Chappell 1974: Figure 8), occurs on the higher parts of this part of Matakana Island, although correlations are tentative. This terrace represents the Penultimate Interglacial sea level peak of *c.*210 000 years ago (oxygen isotope stage 7 (Selby 1985, Pillans 1987)). However, it is possible that the highest terrace may be as old as *c.*300 000 years (oxygen isotope stage 9).

The lowest terrace probably represents the Last Interglacial sea level maximum of about 125 000 years ago (oxygen isotope stage 5 (Selby 1985, Pillans 1987)). Its surface is between about eight and ten metres above present sea level, although its original surface prior to the deposition of cover beds is mainly below sea level (see Section 2.1.1.2). The terrace is tentatively correlated with the "BOP2" terrace of Chappell (1974) on the basis of the height of its original surface (Table 2.1). Remnants of a Pleistocene terrace at a slightly higher elevation are also present on Rangiwaea Island.

2.1.1.2 Last Interglacial relict foredune plain

The lowest Pleistocene terrace appears to have originated as a coastal strandplain in the same manner as the Holocene barrier. The overlying tephra (Table 2.1) has preserved the original topography of the lower terrace and has prevented its destruction by marine erosion during the Postglacial Marine Transgression. On its surface, a pattern of old shoreline ridges and swales aligned roughly parallel to the riser of the older terrace and the present shoreline is clearly discernable from the air (Figure 2.2(b)). A profile (Figure 2.3) levelled across the

Figure 2.2(a): Oblique aerial photograph showing the eroded remains of marine terraces on the Pleistocene part of Matakana Island.

Figure 2.2(b): Near-vertical aerial photograph of the lowest Pleistocene terrace shown in Figure 2.2(a). Note the ridge-swale topography and elements of a rectangular drainage system.

terrace, from the shoreline at Blue Gum Bay to the riser of the higher Pleistocene terrace, clearly shows the undulating topography. The old ridges are spaced an average 80 metres apart, although they occur as close together as 40 metres. This spacing is greater than that of the Holocene relict foredunes described below, a phenomenon also reported from Pleistocene barrier systems of southeastern Australia where slope degradational processes and the "cannibalism" of certain swales are thought to be responsible (Shepherd 1970). Similar processes may account for the wider spacing of the Pleistocene ridges on Matakana Island, although the surface expression of the smaller swales there may have been obliterated by the thick tephra cover.

Table 2.1: Well head elevations, thicknesses of cover deposits and elevations of underlying sand surfaces for the wells located in Figure 2.1.
Source: Halliday pers. comm. (1995)

Well ID (Figure 2.1)	NZMS 260 Grid Reference[1]	Elevation Above Mean Sea Level (m)[1]	Tephra Thickness (m)	Elevation of underlying sand surface (m)
1	U14 798968	15.1	12.2	2.9
2	U14 824942	11.0	*c.*12.0	*c.*-1.0
3	U14 824946	8.5	*c.*20.0[2]	*c.*-11.5[2]
4	U14 819940	12.4	13.0	-0.6
5	U14 817932	10.8	14.9	-4.1
Mean:		11.6	14.4	-2.8

Footnotes: [1] NZMS 260 grid references and elevations for the well heads were obtained by use of a Trimble Pro-XL GPS system.
[2] Tephra thickness at Well 3 is provisional on account of possible inaccuracies in available well log data. Excluding this figure, the mean tephra thickness is recalculated at 13.0 metres.

Elements of a rectangular drainage pattern in this area (Figure 2.2(b)), apparently controlled by the pattern of former swales, further supports a strandplain origin (Thom 1970, 1975). The surface elevation increases near the riser of the older terrace where a colluvial slope has developed.

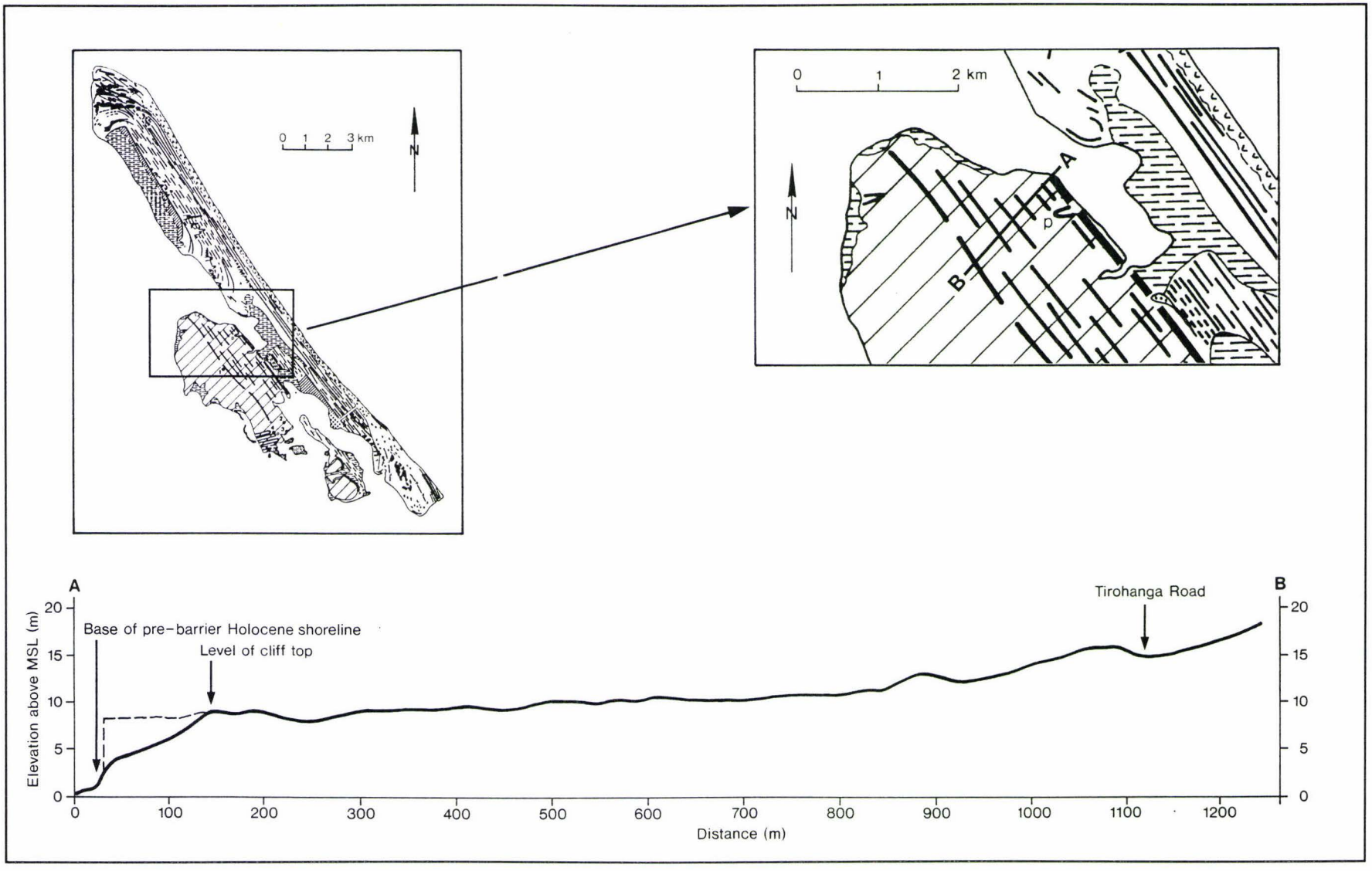


Figure 2.3: Topographic profile across the lowest Pleistocene terrace. A subdued, undulating ridge-swale topography is apparent, suggesting a former coastal strandplain.

A strandplain origin is further supported by well records, which indicated the presence of sandy beds underlying *c.*13 metres of tephra (Table 2.1). A cliff section eroded into the lowest terrace at Blue Gum Bay (grid reference NZMS 260 U14 802987) shows tephra deposits extending to below the present beach level and the original sand surface now appears to be below present sea level at this point. Well log data indicate the original sand surface is now up to perhaps three metres below present sea level, inferred from the thickness of the tephra cover beds and well head elevations. As the Last Interglacial sea level stood some four to six metres above present sea level (Roy and Thom 1981, Gibb 1986), the present height of the sand surface is evidence for local subsidence. Assuming an average elevation of the Holocene barrier of six metres (from Profiles 2-5 in Section 2.1.2.2 below) and that the Pleistocene sand surface was originally at about 10-12 metres above present mean sea level (the elevation of the Holocene barrier added to the height of the Last Interglacial sea level maximum), the mean subsidence rate for the last 125 000 years is about 104-120mm/1 000 years. This subsidence contrasts with Figure 8 in Chappell (1974), which suggests that terraces in the Tauranga area have been slowly uplifted.

The older terraces may also have originated as coastal strandplains, although the cover beds on these older surfaces are sufficiently thick to obscure any surface expression of the underlying topography.

2.1.1.3 Pleistocene relict transgressive dunes

Large relict transgressive dunes of Pleistocene age occur on the southeastern part of this Last Interglacial surface at Opureora. As with the rest of the terrace, these features are mantled with several metres of tephra but are clearly visible, particularly from the air (Figure 2.4(a)). The Postglacial Marine Transgression led to partial erosion of these dunes and flooded their basins, which may have been previously occupied by consequent stream valleys. A relict Pleistocene parabolic dune at Blue Gum Bay, also mantled with Pleistocene tephra, is truncated by the pre-barrier Holocene shoreline (see Section 2.1.1.5) approximately 2.0 kilometres northwest of where Waiherere Road crosses this shoreline (Figure 2.4(b)).

Figure 2.4(a): Oblique aerial photograph showing eroded remains of Pleistocene transgressive dunes, orientated in a seaward direction, at Opureora.

Figure 2.4(b): Oblique aerial photograph of a Pleistocene parabolic dune, orientated in a landward direction, breaching the northwestern part of the pre-barrier wave-cut Holocene shoreline.

The orientations of these and other parabolic dunes on Matakana Island are discussed with respect to the regional wind climate in Section 2.1.2.3 below.

2.1.1.4 Holocene relict transgressive dunes, relict flats, estuarine spits and islands

An Holocene relict parabolic dune overlying Pleistocene tephra occurs just south of Tirohanga Point. The contemporary shoreline adjacent to the dune has very little sediment available for dune building at the present time, suggesting the sediment supply to this part of the shoreline has diminished since the dune formed. Reasons for this are discussed in Section 5.1.7.

Relict estuarine flats generally occupy old fluvial channels and shallow embayments drowned by the Postglacial Marine Transgression. They are common along the southwestern margin of the island and also occur in the central part of Rangiwaea Island. Many of these areas on Matakana Island have been drained and converted into dairy pasture.

Estuarine spits and islands are restricted to the southern part of the island near Opureora, the shallow estuarine flats between Opureora and Rangiwaea Island and the southern and eastern shores of Rangiwaea Island. These features occur where convergence or a loss of competence of tidal currents creates a locus for deposition. Littoral drift processes may also operate, particularly around high tide, in association with locally-generated harbour waves where the fetch is sufficiently large. The superposition of tidal currents and sediment stirring by harbour waves can lead to sediment transport in what is generally a low energy environment (de Lange 1988), forming spits and islands where these sediments are deposited.

Estuarine spits are generally either parallel with or form an extension of an estuarine shoreline, the spit forming the eastern extremity of Rangiwaea Island, and the spit extending southeastward towards Tahunamanu Island being examples. This suggests they have probably formed as a result of shore-parallel sediment transport by combined wave and current action as described above. These features are often dynamic and susceptible to rapid change, and many of them are sparsely vegetated. Tahunamanu Island, for example, has been eroded substantially in recent years (D. McCoubrie, pers. comm. 1995).

2.1.1.5 The pre-barrier Holocene shoreline

A relict wave-cut escarpment or "fossil sea cliff" (Pillans 1990) clearly delineates this shoreline on Matakana Island (Figure 2.5). It is aligned sub-parallel to the Holocene relict foredunes and the contemporary shoreline to seaward and is straight and regular except where it is breached by two infilled fluvial channels at the head of Blue Gum Bay.

Figure 2.5: The pre-barrier Holocene shoreline (at left), eroded into Pleistocene sediments.

A similar, less well-defined relict cliff is present on Rangiwaea Island. This escarpment is also breached by an infilled fluvial channel (see Section 2.1.2.3), which separates the Pleistocene part of the island into two sections.

These cliffs were probably formed during the mid-Holocene. The Postglacial Marine Transgression which ended *c.*6 500 ^{14}C years BP (Dahm 1983, Gibb 1986, Wigley 1990,

Munro 1994) initially caused shorelines to recede, with no barrier formation occurring apparently until after sea level stabilised (Dahm 1983). This pre-barrier shoreline erosion led to the formation of wave-cut escarpments, such as those on Matakana and Rangiwaea Islands, which mark the position of the former shoreline at the end of the transgression.

2.1.2 Landforms of the Holocene barrier

2.1.2.1 Beach morphology

The beaches of the Holocene barrier are grouped into three categories: (1) ocean beach; (2) harbour beach; and (3) transitional (within the harbour entrances). Locations of the beach profiles are shown in Figure 2.6 below.

2.1.2.1.1 Ocean beach profiles

The eight annotated profiles are shown in Figure 2.7. With the exception of Beach Profiles 1 and 2, the incipient foredune was included in each profile. Photographs of Beach Profiles 1 and 5 are shown in Figure 2.8.

Beach profiles are most variable near the ends of the barrier, as illustrated by Beach Profiles 1 and 2 in particular. The beach at Panepane Point (Beach Profile 1) is currently prograding, reflected in the double berm profile and extensive berm terrace present behind the beach. In contrast, Beach Profile 2, approximately 2.5 kilometres to the northwest, shows a beach in a state of active erosion. The incipient foredune and foredune have been completely removed and a *c.*4 metre high active escarpment, cut into relict transgressive dunes, occurs at the top of the beach. Beach erosion has also occurred at the northwestern end of the barrier, as indicated by the scarps in Beach Profiles 7 and 8.

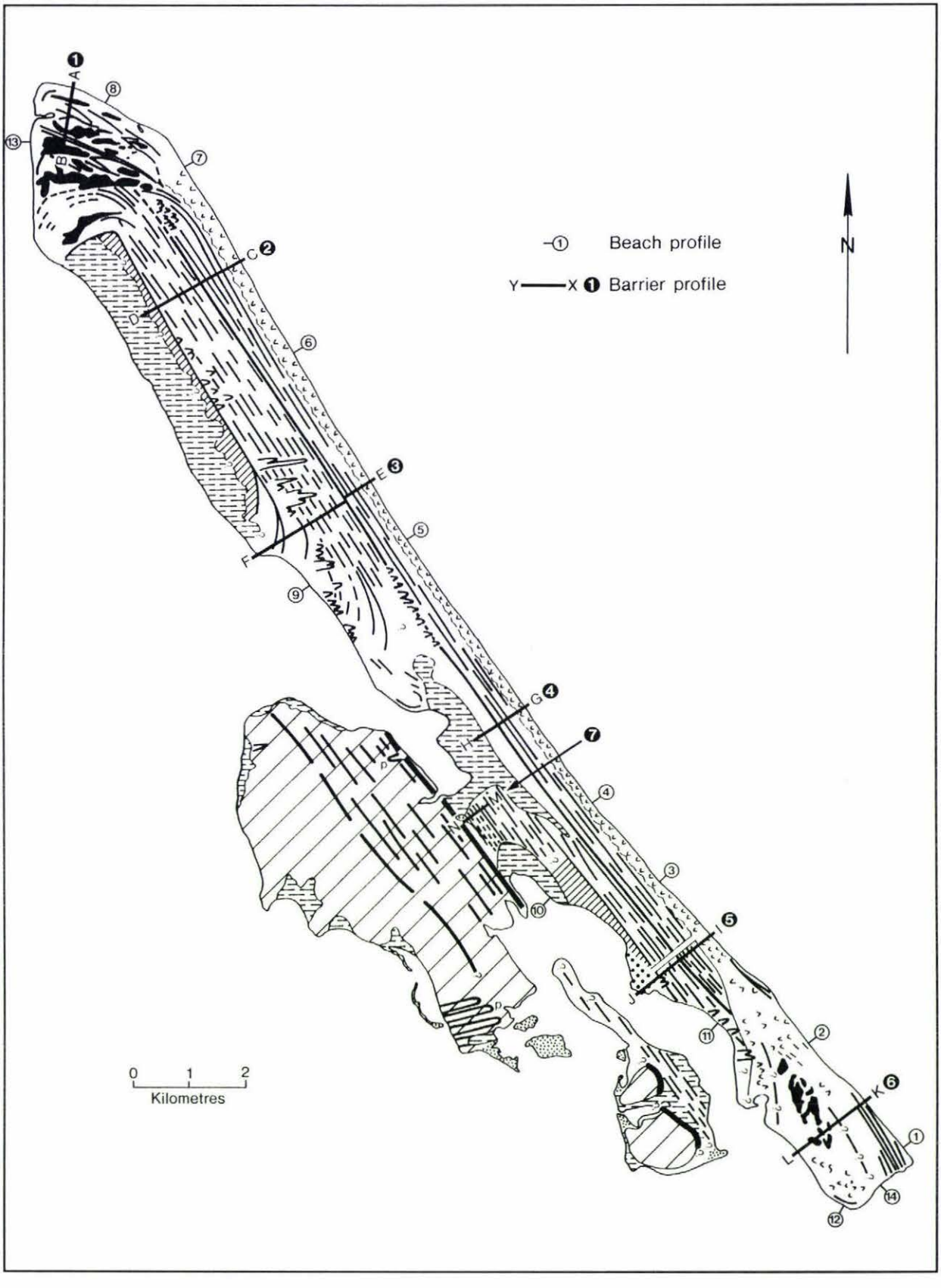


Figure 2.6: Locations of beach profiles (Section 2.1.2.1) and barrier profiles (Section 2.1.2.2)

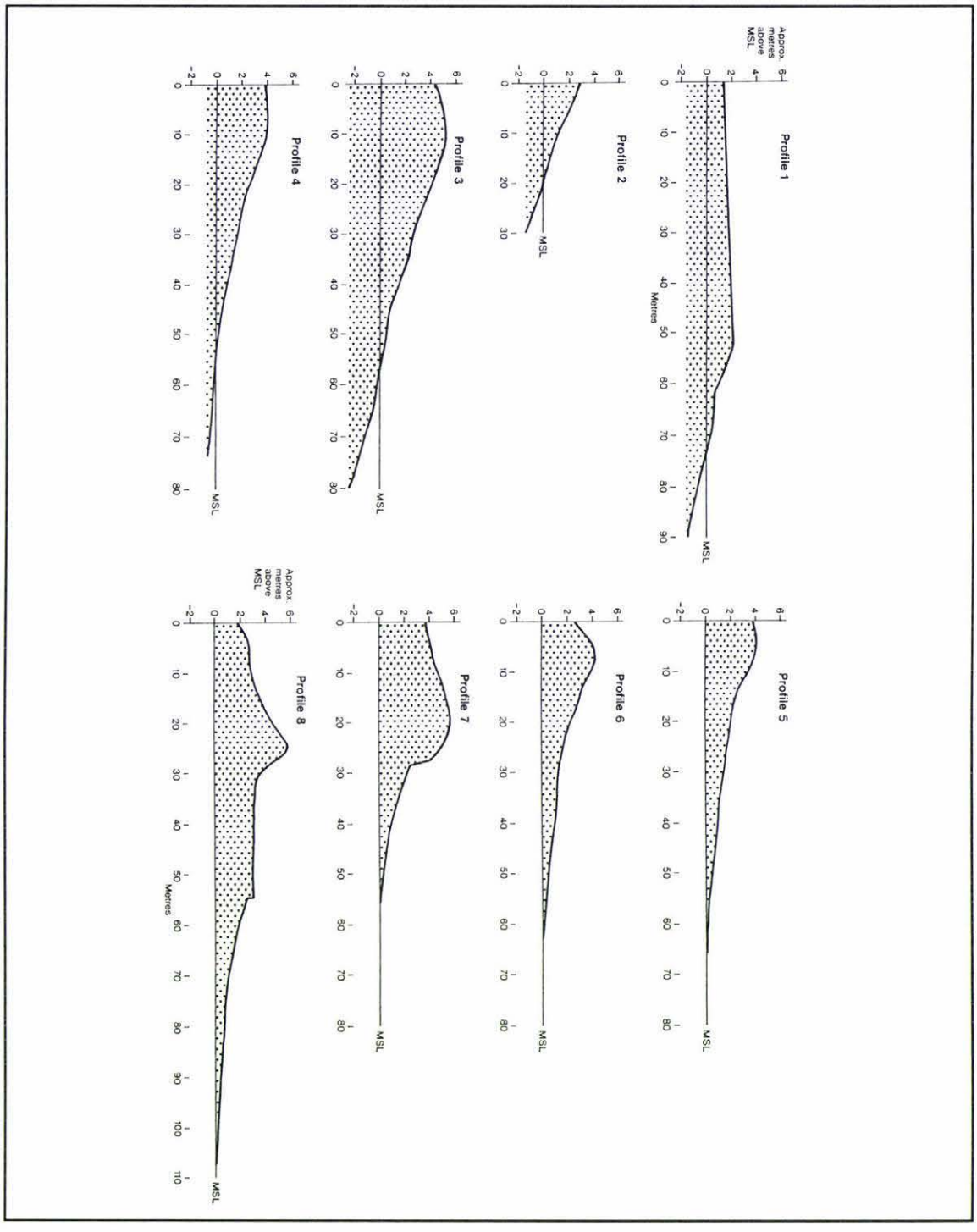


Figure 2.7: Ocean beach profiles.

Beach profiles away from the ends of the barrier (Beach Profiles 3-6) are less variable. The beach in these locations is characteristically uniform in slope, with a regular incipient foredune, poor berm development and generally lower gradients. Levelling carried out at Pipeline Road (located on Figure 1.2) showed that the top of the beach occurs at

Figure 2.8(a): The ocean beach at Panepane Point (Beach Profile 1), showing a double berm system. View to the northwest.

Figure 2.8(b): The ocean beach at the more exposed central part of the barrier (Beach Profile 5), showing a typical low-relief "post-storm" profile. View to the southeast.

approximately 2.9 metres above mean sea level, which is taken to represent the upper limit of contemporary marine deposits on the barrier.

2.1.2.1.2 Harbour beach profiles

Four harbour beach profiles (Beach Profiles 9-12) are located in Figure 2.6 and plotted in Figure 2.9. Photographs of Beach Profiles 9 and 11 are provided in Figure 2.10.

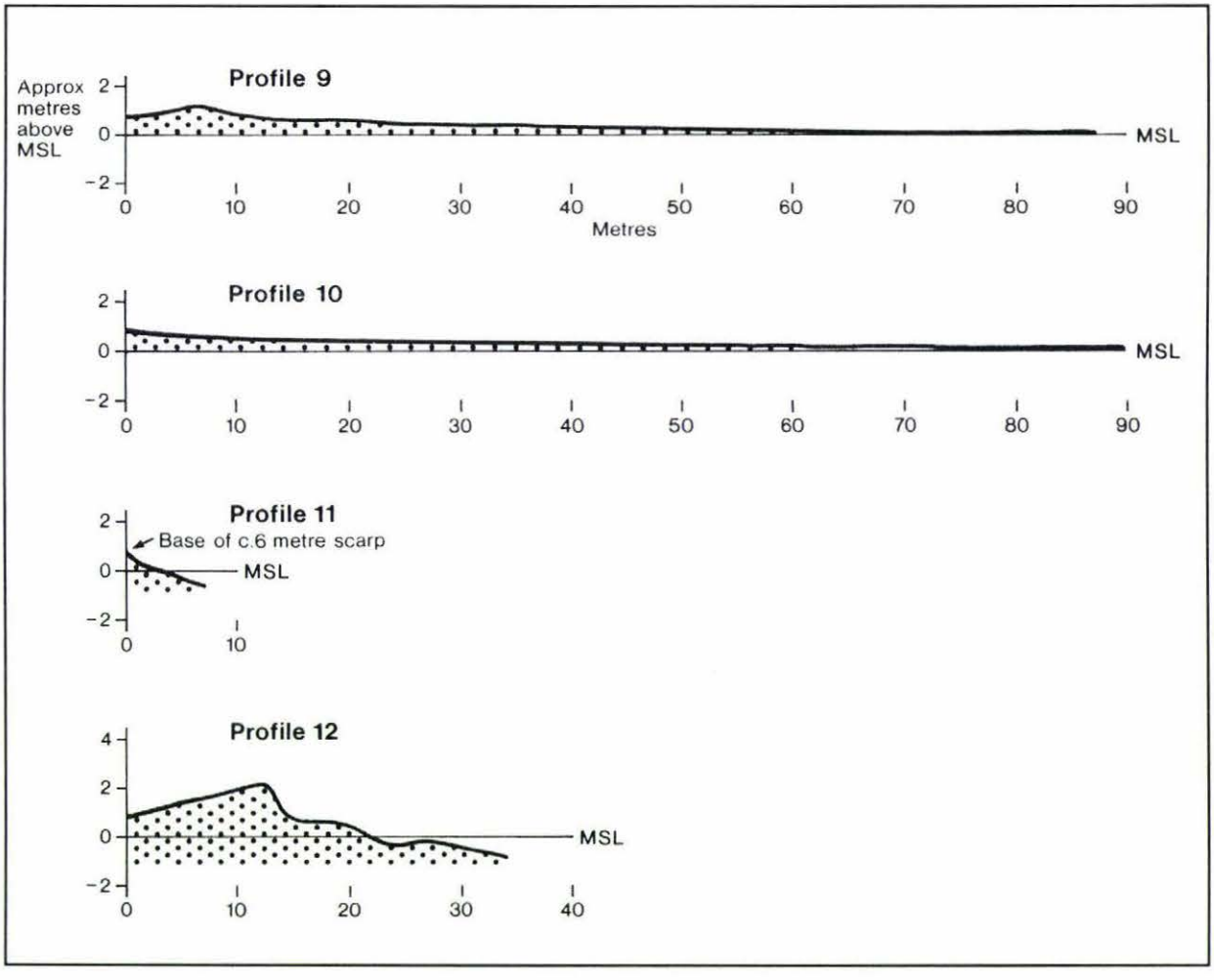


Figure 2.9: Harbour beach profiles.

Harbour beaches vary considerably in morphology. Very low gradients and uniform slopes prevail at Pipeline Road (Beach Profile 9) and the head of Hunter's Creek (Beach Profile 10). A low incipient foredune occurs behind the beach at Pipeline Road and isolated mangroves

Figure 2.10(a): Harbour shoreline at Pipeline Road (Beach Profile 9) showing extensive intertidal flats occupied by mangroves. View to the northwest.

Figure 2.10(b): Severe erosion of the harbour shoreline at Hunter's Creek (Beach Profile 11). View to the southeast.

are common. There is no foredune present along the shoreline at the head of Hunter's Creek, where an extensive mangrove community occurs.

These contrast sharply with the harbour beaches represented by Beach Profiles 11 and 12. Both of these are narrow, steep and in a state of erosion, which is particularly severe at Hunter's Creek southeast of the Mill (Beach Profile 11; Figure 2.10(b)). The relationship between harbour beach gradient and tidal channel proximity is shown in Figure 2.11.

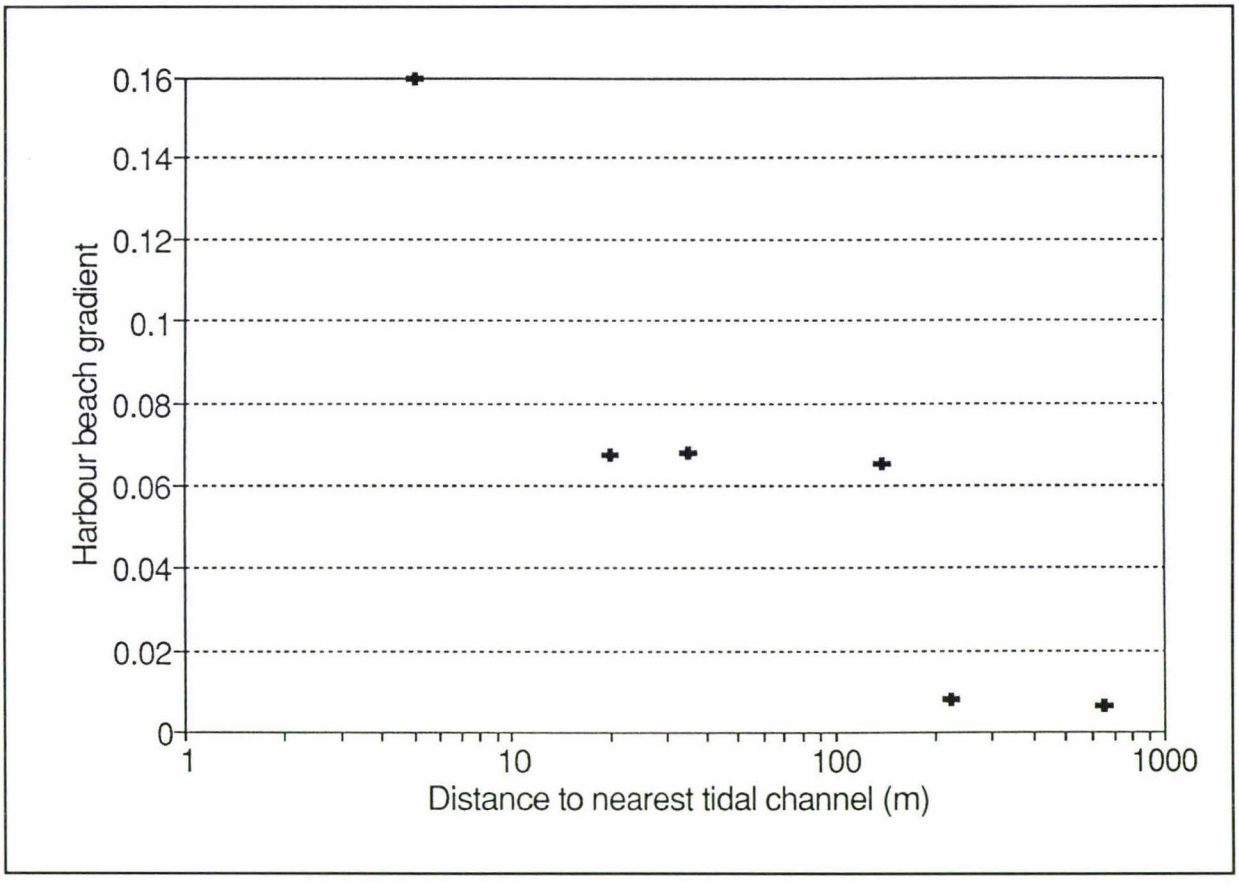


Figure 2.11: Plot of harbour beach gradient against tidal channel proximity, showing an inverse logarithmic relationship. Linear regression of beach gradient against $\log_e$(distance to nearest tidal channel) yielded an r^2 value of 0.83.

2.1.2.1.3 Transitional beach profiles

Profiles were levelled across the shoreline inside each of the entrances to Tauranga Harbour (Figure 2.6) and are shown in Figure 2.12. The beach at Beach Profile 14 is illustrated in Figure 2.13.

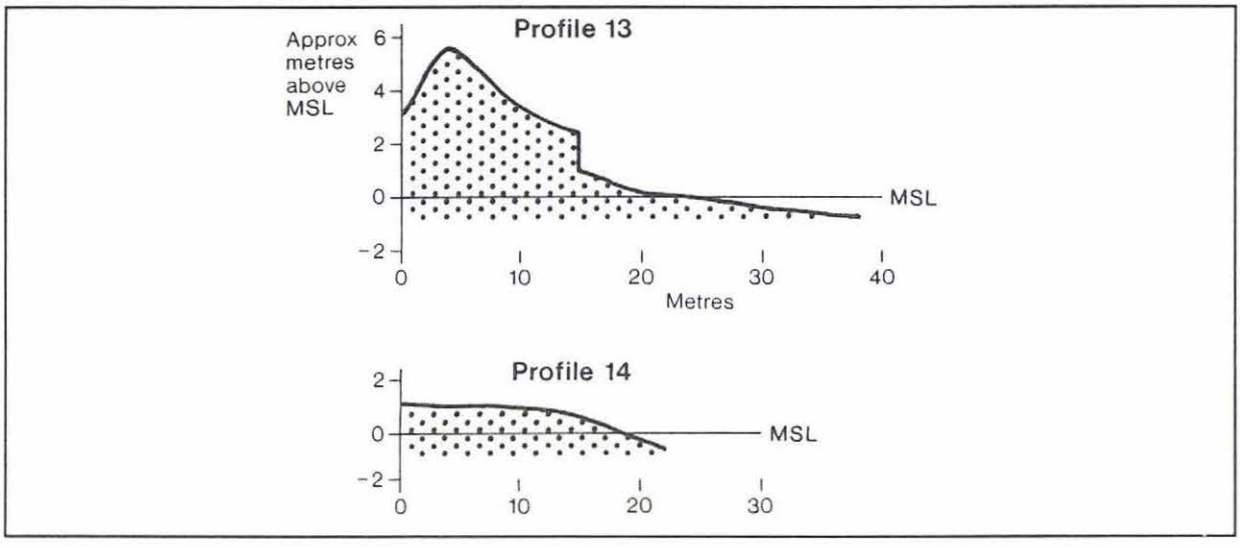


Figure 2.12: Harbour entrance beach profiles.

Figure 2.13: The beach at Beach Profile 14. Note the steep gradient related to the adjacent major tidal channel. View to the northeast.

The scarp in Beach Profile 13, levelled inside the Katikati Entrance, illustrates an episode of shoreline recession. The steeper gradient of Beach Profile 14 inside the Tauranga Entrance

relates to the presence of a major tidal channel adjacent to the shoreline, although there is no evidence for shoreline recession.

2.1.2.1.4 Discussion

Ocean beach morphology becomes more variable towards the ends of the barrier, probably in relation to variations in the offshore profile as a consequence of processes operating on the ebb-tidal deltas present at the Tauranga Harbour entrances. For example, the western swash platform adjacent to the Tauranga Entrance (the Matakana Bank) narrowed significantly between 1970 and 1977 (Dahm 1983), causing beach erosion. Aerial photographs taken in 1992 indicate further erosion of this part of the shoreline has occurred since 1977 (such as at Beach Profile 2). In contrast, Panepane Point (Beach Profile 1) has prograded rapidly in recent times. Dahm (1983) and Davies-Colley and Healy (1978b) identified converging sediment transport pathways at Panepane Point and suggested this as a cause of progradation.

Away from the harbour entrances, the ocean beach was less variable in profile at the time of levelling. A northeasterly storm had occurred in the region four days prior to levelling and consequently the beach showed a typical "post-storm" eroded profile (Healy *et al.* 1977) with uniform slopes and little or no berm development. A poorly developed berm occurs in Beach Profiles 3 and 6. This indicates the beach was in a state of "recovery" following the storm event, where sediments mobilised and moved offshore during the storm were being returned to the beach under swell wave conditions. Well-developed berms were observed but not levelled by the author during previous field trips when swell wave conditions prevailed. Also observed at other times have been well-defined breaks in slope on the lower shoreface coinciding with the "outcropping" of the beach groundwater table, a phenomenon also reported from the macrotidal central Queensland coast by Turner (1993).

The persistence of berms at Panepane Point, despite their poor development elsewhere at the time of levelling, is a consequence of the sheltering of this part of the barrier from the northeasterly storm by Mount Maunganui. This sheltering effect is likely to contribute to the long-term progradation of the Point, since most storms in this region are from the easterly quarter.

Harbour entrance beaches tend to be narrow and steep, particularly inside the Tauranga Entrance (Beach Profile 14). There is a clear inverse logarithmic relationship between the harbour beach gradient and the proximity of tidal channels (Figure 2.11). Beach morphology is also influenced by vegetation where combined wave and tidal current energy is very low, as at the head of Hunter's Creek (Beach Profile 10). Mangroves are abundant here and no true beach is present: estuarine flats extend directly to Holocene backbarrier sediments. Abandoned beaches, isolated from open water by the spread of mangrove communities along the flats, were observed along the upper reaches of Hunter's Creek northwest of the Mill.

Foredune development is limited to the ocean beach and parts of the harbour entrances, although a very low incipient foredune is present behind the harbour beach at Pipeline Road (Beach Profile 9). As discussed in Section 2.1.2.2, sediment supply is an important factor in foredune development. The greater vertical extent of the ocean beaches results in the beach sediments being more likely to dry out and be entrained by wind between successive tides. The lower amplitude harbour beaches were rarely observed to dry out between tides, sharply reducing the potential for aeolian sediment transport. A near-absence of mud in the ocean beach sediments also contributes to rapid drying, whereas the mud fraction of the harbour sediments tends to retain water and cause some cohesion of the surface sediments, further inhibiting drying and entrainment by wind.

Wave-built beaches, as distinct from intertidal flats, are uncommon along the harbour shoreline and are restricted to areas where the available fetch for locally-generated harbour waves formed by the prevailing west to southwest winds is sufficiently long. The harbour shoreline at Pipeline Road (Beach Profile 10) has a fetch of up to 10 kilometres at high tide for the prevailing winds, while the shoreline at the Panepane Point jetty has a similar fetch. These are also the only harbour profiles to include a wave-built beach and low foredune, which has been scarped at the Panepane Point jetty. A combination of fetch distance and tidal channel proximity, with emphasis on the latter, is therefore suggested as the major control on harbour beach morphology.

2.1.2.2 Relict foredunes and foredunes

Relict foredunes (Hesp 1984), also termed "dune ridges" (McKenzie 1958), "parallel dunes" (Bird 1968) and "beach ridges" (Shepherd 1981, 1987, Thom *et al.* 1992), have previously been recognised on Matakana Island by Dahm (1983), Harms (1989), Healy and Kirk (1992), Munro (1994) and Munro *et al.* (1994). Relict foredunes make up a large proportion of the landforms of the barrier. The greatest number of relict foredunes in any cross section is approximately 35, in the vicinity of Cottage Road. Healy and Kirk (1992) estimate there to be as many as 70 relict foredunes on the barrier, although this number is far higher than that recorded by any of the profiles levelled for this study (see Figure 2.17).

A narrow zone comprising the incipient foredune and two or three relict foredunes is separated from the larger area of relict foredunes of the central and inner barrier by a strip of relict transgressive dunes (see Section 2.1.2.3). This zone widens at about 3.9 kilometres northwest of Panepane Point (Map 1), but has been removed by shoreline recession from between about 1.6 and 3.7 kilometres northwest of Panepane Point and at the Katikati Entrance. The ridges are low and closely spaced, as illustrated by Profile 2 in Figure 2.17. The older relict foredunes of the central and inner barrier are generally aligned sub-parallel to the ocean shoreline. However, at the northwestern end of the barrier they curve westward towards Katikati Harbour. This curvature is particularly abrupt on the inner part of the barrier, where a large recurved ridge truncates older, shore-parallel relict foredunes and forms the northwestern boundary of the backbarrier washover slope described below (see Figure 2.1). Toward the ocean shoreline at the northwestern end of the barrier, the relict foredunes merge and diverge in an irregular fashion and frequently enclose wetland areas or small lakes (see Section 2.1.2.4). The western margin of this end of the barrier features shore-parallel relict foredunes aligned approximately at right angles to the recurved relict foredunes just described. A contemporary harbour entrance foredune is shown in Figure 2.14(a).

Recurved ridges are also present on the inner part of the barrier from approximately Western Road to southeast of Pipeline Road near Blue Gum Bay. Ground checking indicated that the innermost parallel relict foredunes in that area terminated as recurves at their southeastern ends, whilst more than one recurve diverged from some relict foredunes, particularly the

Figure 2.14(a): An actively accreting foredune inside the Katikati Entrance. View to the southeast.

Figure 2.14(b): A regular, well vegetated incipient foredune typical of the ocean beach away from the harbour entrances. View to the northwest. Note the abundant *Spinifex* seed heads.

innermost ridge (Map 1). The significance of these recurved ridges in terms of the early history of the barrier is discussed further in Chapter 5.

Between the Mill and Duck Bay, the relict foredunes of the barrier are truncated by a north-northwest aligned wave-cut cliff. This scarp extends from the harbour shoreline immediately west of Duck Bay towards the ocean shoreline northeast of the Mill, where it becomes obscured by relict transgressive dunes about 150 metres from the beach. Shoreline recession along Hunter's Creek has removed the innermost relict foredunes from this part of the barrier (Figure 2.10(b)).

Relict foredunes are also truncated in two places at the northwestern end of the barrier, at approximately 2.0 and 2.6 kilometres south-southeast of the Katikati Entrance. These mark earlier episodes of shoreline erosion at this end of the barrier. Relict foredune truncation at the ends of the barrier is discussed in the context of barrier evolution in Chapter 5.

Relict foredune morphology varies considerably. An abrupt seaward transition from low, regular relict foredunes to larger, irregular relict foredunes is apparent, particularly from the air (Figure 2.15). This change is more pronounced on the northwestern half of the barrier. The innermost of these ridges closed off a former third tidal entrance to Tauranga Harbour (see Section 2.1.2.6), a process which may have contributed to the change in relict foredune size.

Larger relict foredunes have usually been modified by the development of small blowouts (see Section 2.1.2.2.1). Smaller relict foredunes, particularly those in the vicinity of Cottage, Western and Pipeline Roads and also near the Mill, appear not to have been modified by aeolian processes to the same degree.

A regular incipient foredune occurs along much of the ocean shoreline and is well vegetated (Figure 2.14(b)) as described by Beadel (1989b). Incipient foredune height above the seaward limit of vegetation varies from about 1.7 metres near the central barrier to about four metres near the harbour entrances and the foredune is generally five to ten metres in width. As with the relict foredunes immediately adjacent to these, it is absent from between approximately

Figure 2.15: Vertical aerial photograph of the barrier immediately southeastward of Waikoura Point, showing the abrupt change seaward to larger, less regular relict foredunes. Scale = 1:10 000. Photograph courtesy of PF Olsen and Company Limited.

1.6 and 3.7 kilometres northwest of Panepane Point (Figure 2.16), where the shoreline has retreated markedly since it reached its maximum seaward position in 1954 (see Section 4.1.3.1). Shoreline recession has also removed the incipient foredune and destroyed an area of *Pinus radiata* forest at the Katikati Entrance.

Figure 2.16: Removal of the contemporary foredune by shoreline recession, *c*.2.5 kilometres northwest of Panepane Point. An active washover lobe extends into *Pinus radiata* forest behind the beach and relict transgressive dunes are being eroded as the shoreline continues to retreat.

Very low ridges occur on the inner barrier adjacent to the pre-barrier Holocene shoreline shown in Figure 2.1, forming a zone about 400 metres wide (Profile 7 in Figure 2.17). Side slope angles of 4°-8° measured from four of these ridges are consistent with wave-built beach ridges, which generally have side slope angles in the 3°-10° range (Tanner 1988). However, the ridges described here are often irregular and hummocky which does not support a beach ridge origin. Where progradation is rapid, relict foredunes can be very low in height with gentle side slopes (P.A. Hesp, pers. comm. 1995) and the ridges described here are thus

interpreted as being relict foredunes. The innermost of these ridges forms a recurving spit at the northwestern corner of this zone, with small washover lobes present on its inner slope. This ridge, at about 90 metres wide, is the largest of the sequence described here (see Figure 2.17).

Rangiwaea Island also contains relict foredunes, clearly visible on aerial photographs, on its seaward part (Map 1; Figure 2.1). They have not been investigated in detail in this study, although their presence indicates that the island was exposed to the open ocean for a period sufficient to form the foredunes prior to the formation of the Matakana Island barrier to seaward (see Chapter 5).

Seven topographic profiles levelled across the barrier, located in Figure 2.6, are plotted in Figure 2.17. The overall elevation of the surface in Profiles 2 to 6 across the barrier shows no evidence for significant tectonic movement since the barrier began forming, although probable slow subsidence proposed in Section 2.1.1.2 is not ruled out as discussed below. Lower elevations occur at Profiles 1, 6 and 7 which have different progradational histories to the rest of the barrier (see Chapter 5).

Profile 7 illustrates the subdued relict foredunes adjacent to the pre-barrier Holocene shoreline described above, which are distinct from the surface morphology indicated by the rest of the profiles. The transition from a relict (possibly dune-capped) berm with evidence of washover through low relict foredunes to higher relict foredunes indicates the pattern of former relative progradation rates for this part of the barrier. The five major morphological units occurring in Profiles 1 to 6 are:

(1) *A backbarrier washover slope* (see Section 2.1.2.5) which occurs along the inner margin of the barrier and is bounded on the harbour side by relict estuarine flats. Recession of the harbour shoreline has removed this unit in some places, such as at Hunter's Creek (Figure 2.10(b)). This unit does not occur on Profile 6, although this part of the barrier does not appear to have been significantly eroded from the harbour side. Profile 1 was not levelled to the inner margin of the barrier.

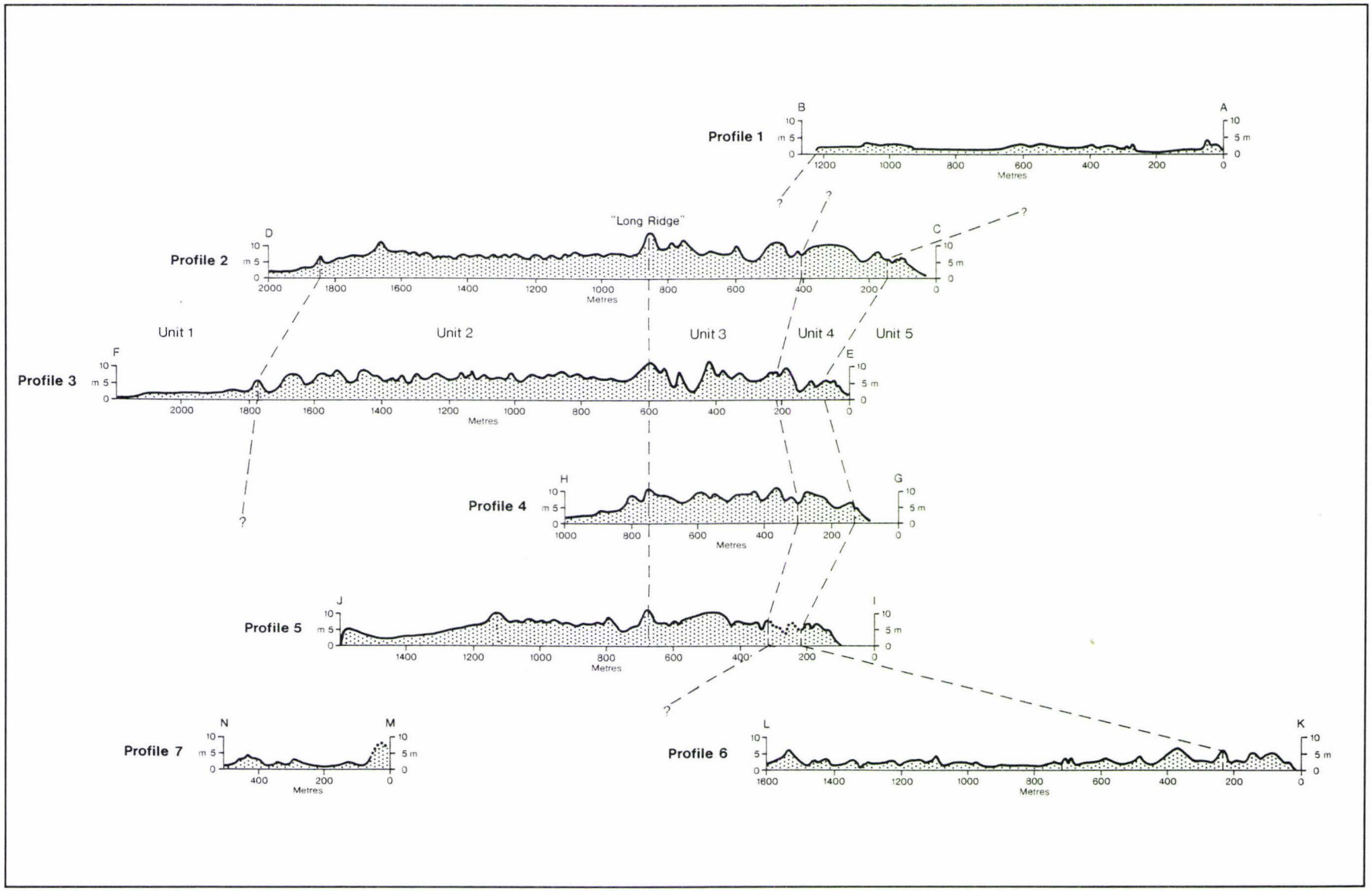


Figure 2.17: Topographic profiles levelled across the barrier. Five major morphological units are identified on the barrier, indicated by the dashed lines linking Profiles 1 to 6. Profile 7 is not correlated to the other profiles as described in the text. The dotted portions of Profiles 6 and 7 were heavily vegetated and not levelled in detail.

(2) *Low relict foredunes* which are generally present seaward of the backbarrier washover slope, with the exception of Profile 4 where this unit is not present. Relict foredune spacing is within the range 42-50 metres. Profile 6 has a wide zone of low relief, but the topography is chaotic and does not correspond to the regular relict foredunes present in this unit in the other profiles. Relict foredune amplitude tends to decrease seaward along Profiles 2 and 3, particularly the latter.

(3) A zone of *higher relict foredunes* which abruptly succeeds Unit 2 occurs in Profiles 2-5 (Figure 2.15). The innermost ridge in this zone is referred to as the "Long Ridge", and is correlated to ridge "D1" mapped near the northwestern end of the barrier by Munro (1994). This ridge can be traced along much of the barrier. Some blowouts occur in this unit, particularly in the vicinity of Profiles 2 and 4. Relict foredunes of this unit contain some of the highest relief on the barrier with elevations exceeding 13 metres above mean sea level occurring along Profile 2. Relict foredune spacing often exceeds 100 metres (Figures 2.15 and 2.17). They diverge as they recurve westward toward the Katikati Entrance and become lower in elevation, as shown in Profile 1 which crosses part of this unit. Lakes and wetland areas (described below) occur between some of these ridges in this area.

(4) A zone of *inactive transgressive dunes* which occurs near the ocean coast in Profiles 2-6 consists of parabolic dunes and blowouts. Deflation has lowered the surface to the level of the contemporary beach in some parts of this zone, as has occurred about 100 metres landward of the incipient foredune at Profile 3. This zone narrows from 230 metres to 100 metres between Profiles 2 and 5, then widens southeastward to include the entire barrier at Profile 6 where low irregular dunes predominate. It is absent from Profile 1.

(5) A zone of *intact relict foredunes* which occurs immediately behind a regular incipient foredune at all locations profiled except for Profile 1, where a contemporary foredune occurs immediately seaward of a relict berm terrace.

Illustrated here is a series of changes in relict foredune morphology from the inner barrier toward the contemporary beach, which are replicated on several parts of the barrier. These are illustrated by the aerial photograph shown in Figure 2.18. However, the relief of the

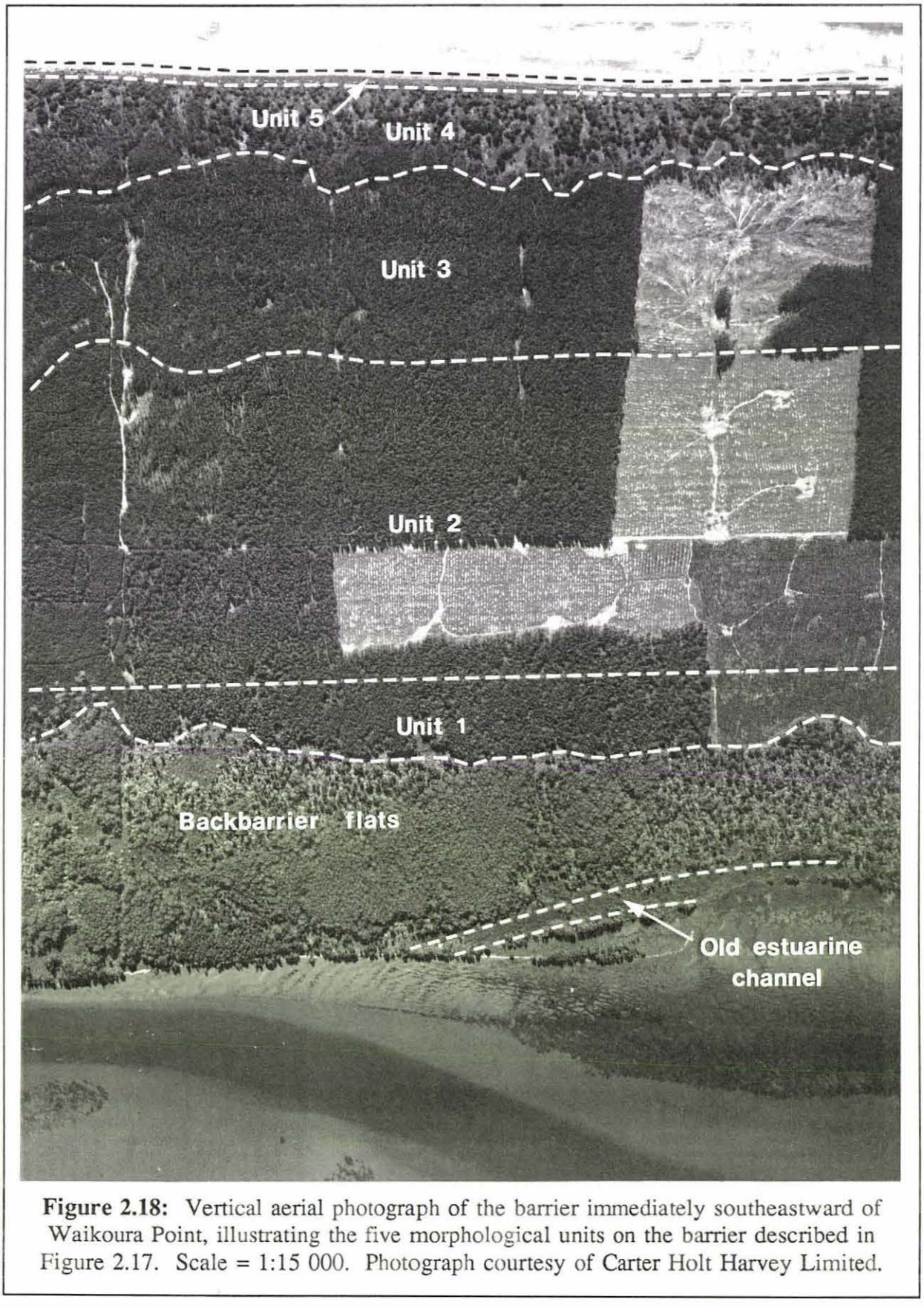


Figure 2.18: Vertical aerial photograph of the barrier immediately southeastward of Waikoura Point, illustrating the five morphological units on the barrier described in Figure 2.17. Scale = 1:15 000. Photograph courtesy of Carter Holt Harvey Limited.

southeastern part of the barrier (Profile 6) does not correspond closely to the general pattern outlined above. The northwestern end of the barrier also has a distinctive morphology as indicated by Profile 1. Profile 7 is not correlated with any of the other profiles for reasons outlined above and discussed further in Chapter 5.

2.1.2.2.1 Discussion

The morphological variation identified within and between barrier profiles is likely to be related to past progradation rates.

Foredune formation has been attributed to a number of processes by various workers in the past. Early work by Davies (1957) associated foredune development with beach cut and fill cycles and proposed that berm formation during periods of fill, followed by an extended period of poor cut and good fill, is sufficient for the new berm to accumulate a capping of aeolian sand and become established as a new foredune. Continued onshore sediment movement under fill conditions was suggested to form a new berm to seaward and, if not eroded by cut, eventually another foredune. Bird (1968) attributed the separation of relict foredunes by swales to scarping by storm waves.

More recently, Hesp (1984) suggested that foredune formation is a purely aeolian process. Under his hypothesis, sand blown landward from the beach is trapped by sand-binding vegetation, which 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 were identified as areas of low or non-deposition, where a seaward vegetation zone traps most available aeolian sand (Hesp 1984). This mode of foredune formation is now widely accepted.

The morphology of foredunes and relict foredunes is controlled by a number of factors, including sediment supply and type, vegetation type and extent, the subaerial beach profile and

the wind and wave climate (Shepherd 1987). The size of a foredune is determined by the amount of sediment it has received; this in turn is a function of the time for which the foredune receives sand from the beach. Shepherd (1987) related foredune size to the sediment budget of a coast, through its control on progradation rates.

Four scenarios were identified by Shepherd (1987) (Figure 2.19).

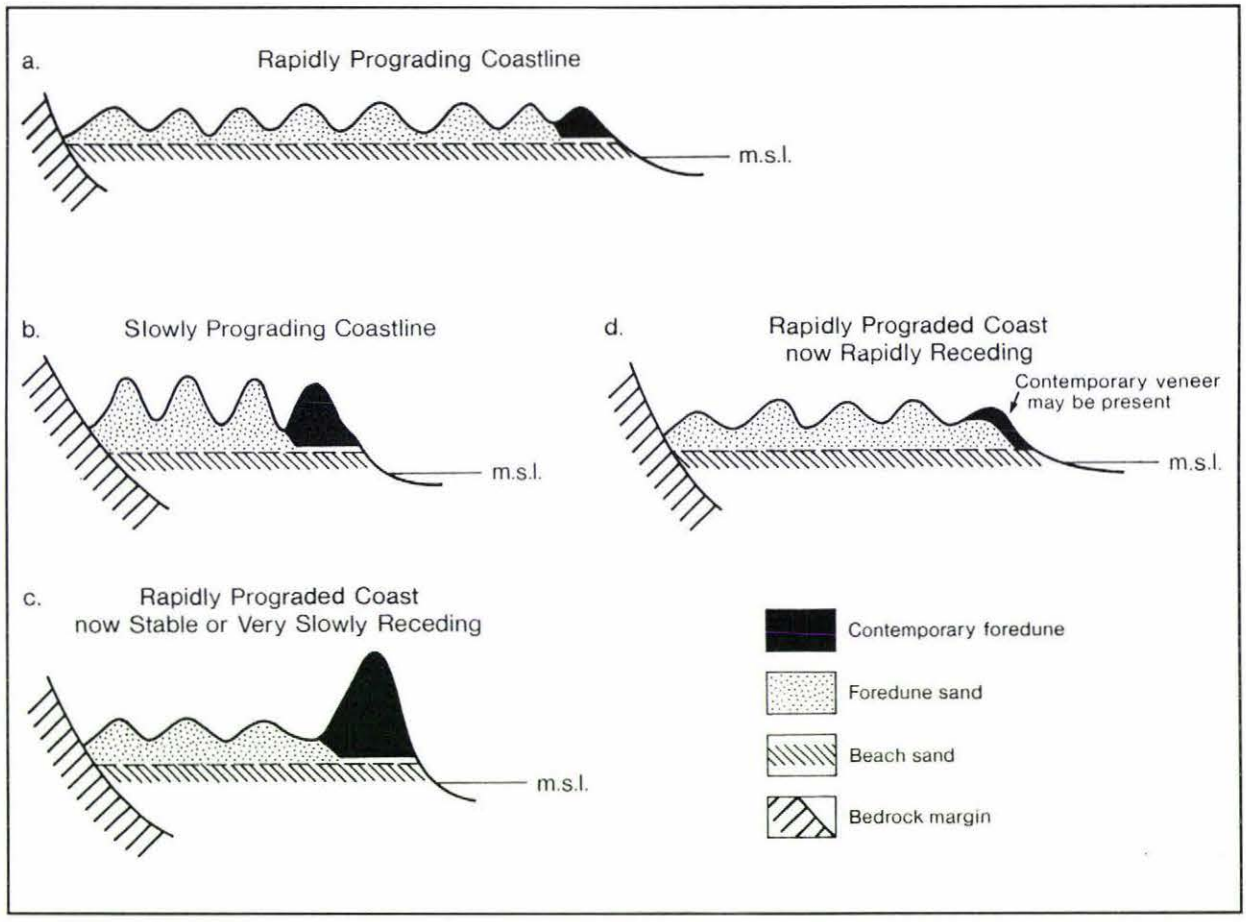


Figure 2.19: Four examples of the relationship between foredune size and the coastal sediment budget (Shepherd 1987: p.106).

A rapidly prograding coast is associated with low, closely spaced foredunes, each of which was quickly rendered inactive in turn by the formation of a new foredune to seaward. Larger foredunes are associated with a slowly prograding coast, where each foredune receives sediment for a longer period of time before it is succeeded by a new one.

A cessation of progradation, or a change to very slow recession, results in the contemporary foredune receiving sediment for long periods of time. Consequently it may become very large, to the point where increased wind stresses across its crest lead to its destabilisation and subsequent modification by blowouts (Shepherd 1981). Established foredunes along the New South Wales coast are rarely higher than 30 metres, which appears to be a threshold height above which increased wind shear results in the dominance of aeolian erosion over accretion (Hesp and Thom 1990). Finally, a coast with a strongly negative sediment budget often shows poor contemporary foredune development and older sediments, veneered with contemporary foredune sand, may be exposed behind the beach.

Psuty (1992) proposes a model for foredune development based on separate sediment budgets for the beach and foredune systems (Figure 2.20):

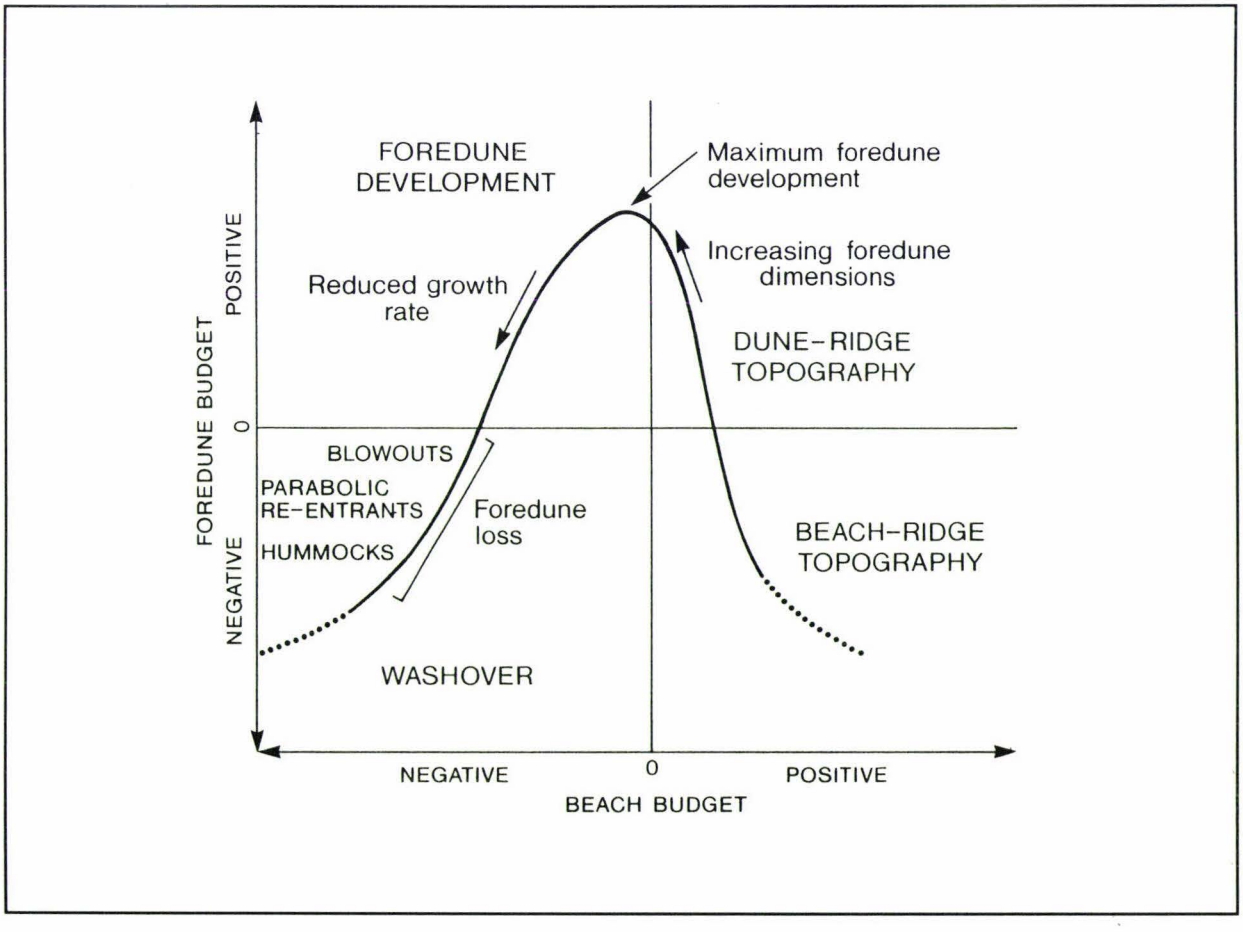


Figure 2.20: Psuty's model of foredune development in terms of the beach sediment budget (Psuty 1992: p.5).

Optimal foredune development is suggested to occur near the threshold between a negative and positive beach sediment budget (Psuty 1992, 1993), where occasional wave-scarping of the foredune creates a free sand transport surface and promotes the inland transfer of the foredune crestline (Psuty 1992). With an increasingly negative beach sediment budget, a foredune tends to lose mass and become modified by marine and aeolian erosion. A strongly positive beach sediment budget limits the duration of sediment accumulation at a single foredune location, leading to a series of low foredunes of limited development (Psuty 1992). This model, showing the continuum from low foredunes through maximum development to foredune attenuation with a decreasing beach sediment budget, is shown in Figure 2.20.

The main controls on foredune development are clearly sediment supply and progradation rate. The pattern of varying degrees of foredune development on the barrier illustrated in Figure 2.17 therefore indicates progradation rates on the barrier have varied considerably throughout the history of the barrier.

Evidence from the Papamoa coastal plain to the southeast (B.G. McFadgen, pers. comm. 1995) suggests considerable modification of relict foredune topography by prehistoric Maori. This appears to have involved the excavation of "benches" into the flanks of relict foredunes for cultivation purposes, a process which may have reduced the heights of the dune crests by up to a metre as successive benches were excavated higher up the slopes of the dunes. This appears to have been restricted to only the larger relict foredunes. Similar modifications may have occurred on the relict foredunes of the Matakana Island barrier, suggesting that natural processes may not be entirely responsible for the present morphology of relict foredunes. Despite this possibility, the general pattern of foredune morphology is clearly the product of natural processes described above.

2.1.2.3 Relict transgressive dunes

Relict transgressive dunes are common on the Matakana Island barrier. A narrow strip consisting entirely of hummocky, relict, largely parabolic dunes is present near the ocean coast, extending along much of the barrier's length and obscuring the former relict foredune topography. This zone widens southeastward of the Mill to include most of the southeastern

Figure 2.21(a): Oblique aerial photograph of a large parabolic dune, *c.*350 metres northwest of the intersection of Western and Centre Roads. View to the northwest. Note the intact relict foredunes transgressed by the parabolic dune.

Figure 2.21(b): Oblique aerial photograph of parabolic dunes adjacent to Hunter's Creek (at left). The relict wave-cut cliff transgressed by these dunes at centre left is discussed in Section 5.1.11. View to the north.

part of the barrier, with the exception of an incipient foredune on parts of the ocean coast and intact relict foredunes at Panepane Point and about 3.9 kilometres to the northwest. The terrain of the southeastern part of the barrier is generally low, hummocky and chaotic, although topographic lows and swampy areas in the vicinity of Duck Bay are generally aligned from north to south. This is discussed further in Section 5.1.11.

Larger parabolic dunes occur towards the inner part of the barrier immediately northwest of Western Road (Figure 2.21(a)), in the vicinity of the southwestern end of Pipeline Road and along Hunter's Creek southeast of the Mill (Figure 2.21(b)). The dunes northwest of Western Road in particular have moved a considerable distance over otherwise unmodified relict foredunes (Figure 2.21(a)); the northernmost parabolic dune has moved a maximum distance of about 730 metres over such terrain.

Transgressive dunes often form in response to the disturbance of a previously vegetated sand surface, leading to the exposure of unconsolidated sand to aeolian processes and the consequent formation of blowouts and parabolic dunes. Initiating factors include the disruption or destruction of stabilising vegetation, scarping of a foredune by waves, or an increase in the frequency, duration and/or strength of sand-moving winds. Once initiated, a blowout dune may evolve into a parabolic dune unless it is stabilised by sand-binding vegetation or otherwise impeded. Parabolic dunes are typically elongated and consist of a "nose" of advancing, unvegetated sand, flanked by two trailing, partly vegetated "arms" which enclose a basin. Sand is supplied to the nose via the long axis of the dune, where winds are channelled between the trailing arms. This funnelling effect creates an environment hostile to vegetation (Muckersie 1989), which contributes to dune mobility. The basic form of a parabolic dune is illustrated in Figure 2.22 below.

The development of blowout dunes on Matakana Island appears to be related to the initial height of the foredunes, with larger foredunes having undergone more modification than smaller ones. Blowout dunes and small parabolic dunes are particularly abundant near Waikoura Point, in places along the inner part of the barrier northwest of Blue Gum Bay and southwest of Hume Highway North in the vicinity of Blue Gum Bay. Being stabilised, the smaller blowouts associated with the relict foredunes indicate that conditions at the time of

blowout initiation were not conducive to continuing dune transgression.

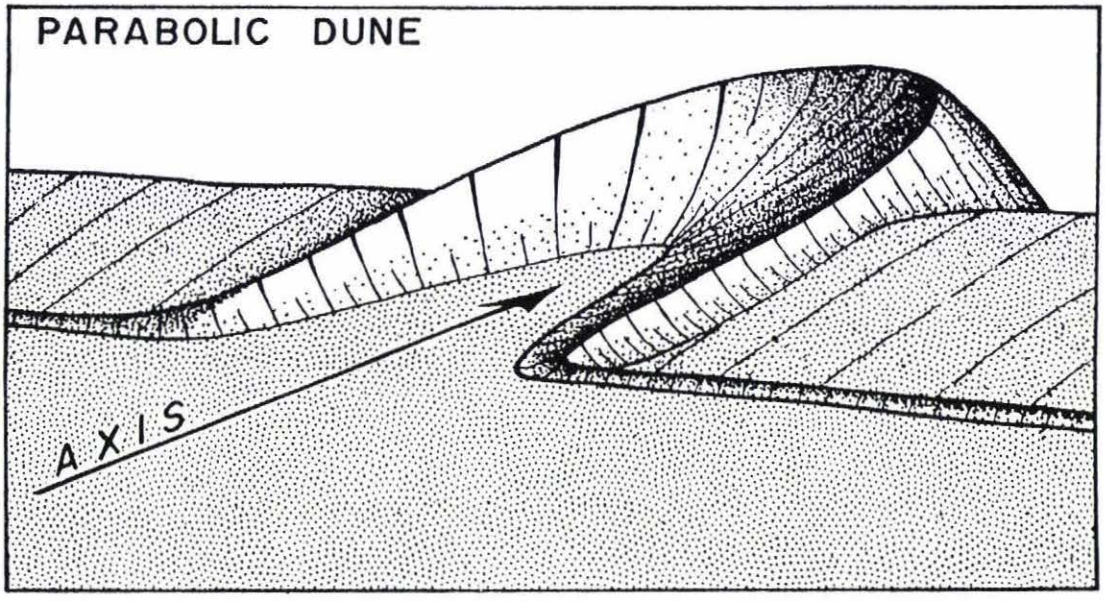


Figure 2.22: Generalised morphology of a parabolic dune (Bird 1972: p.139).

Relict blowouts and parabolic dunes are aligned in the direction of the most effective sand-moving winds (Davies 1980). This direction can be approximated by the Landsberg Method, which calculates the *geomorphically significant* wind resultant based on the cube of the wind velocity above a threshold of ten knots (*c*.5.1 m/s), the upper limit of 3 on the Beaufort Scale (Landsberg 1956).

Jennings (1957) suggests that the *onshore* wind resultant may be of more significance to the orientation of coastal relict transgressive dunes than the overall resultant, in that onshore winds transport sand from the beach and are less disrupted by vegetation and topography than offshore winds. This appears to be the case on King Island, Tasmania, where coastal dunes on the east coast are aligned to the onshore resultant rather than the overall westerly to southwesterly wind resultant (Jennings 1957). Consequently, Jennings recommends the Landsberg Method be modified to consider onshore winds in preference to offshore winds. This is illustrated by Bird (1972) in Figure 2.23.

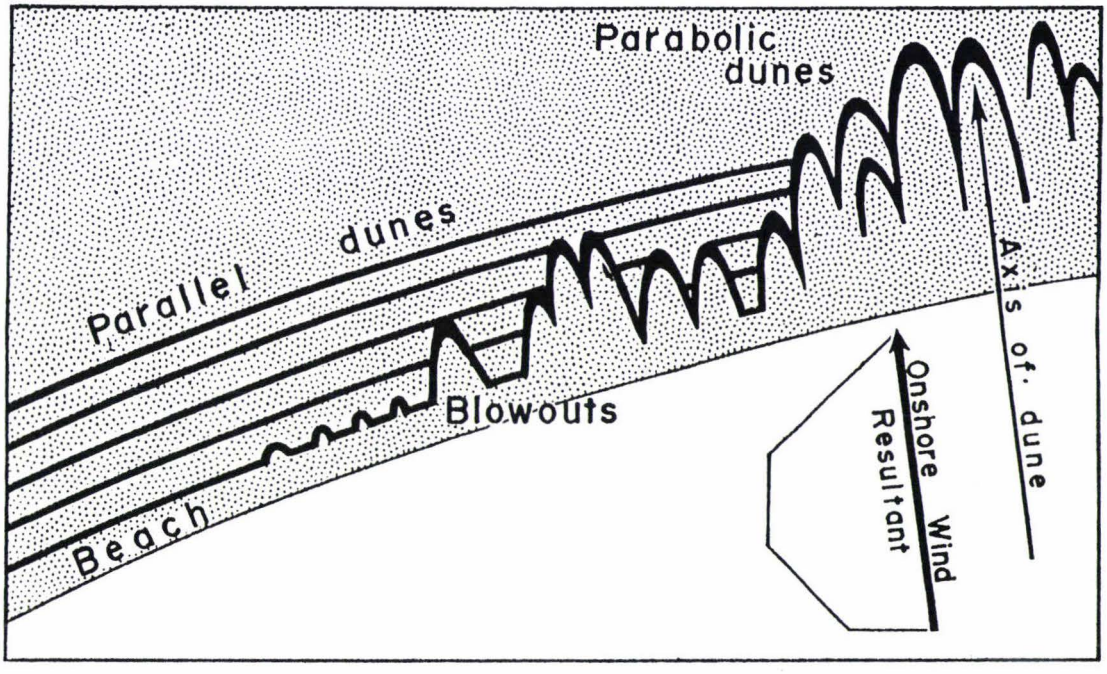


Figure 2.23: The development of blowouts and parabolic dunes in response to the onshore wind resultant (Bird 1972: p.139).

The geomorphically significant overall and onshore wind resultants have been calculated for Waihi Beach by Harray (1977) and for Tauranga by Healy *et al.* (1977) and are shown in Figure 2.24. Their diagrams have been modified to show also the onshore wind resultant for the harbour shoreline of the Matakana Island barrier.

The wind resultants differ slightly between Waihi Beach and Tauranga. The overall resultants fall between northwest and west (290° and 273° respectively), while the ocean onshore resultants are slightly north of northeast (38° and 42° respectively). The harbour onshore resultants calculated here are 259° and 257° respectively. Owing to the short period covered by available data (one year) and proximity to high ground to the northwest, the wind vectors for Waihi Beach calculated by Harray (1977) are regarded with caution. Consequently the following discussion is based on the Tauranga wind data.

Large parabolic dunes on the central barrier to the northwest of Western Road (Figure 2.21(a)) and along the margin of Hunter's Creek (Figure 2.21(b)) are orientated at an average 256° and

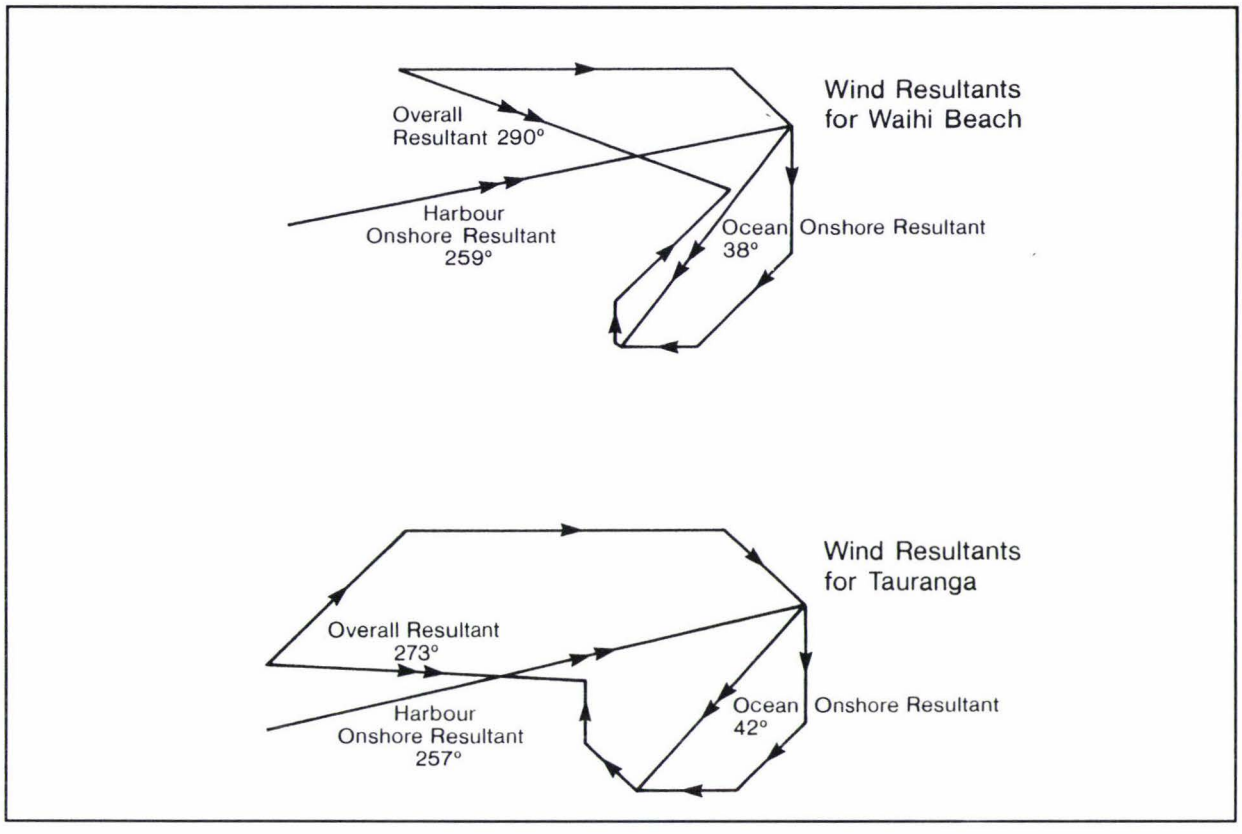


Figure 2.24: Geomorphically significant wind resultants for Waihi Beach (after Harray 1977) and Tauranga (after Healy *et al.* 1977).

262° respectively, bearing a close relationship to the harbour onshore resultants calculated from the Tauranga and Waihi Beach wind data in Figure 2.24. An Holocene parabolic dune occurring on the Pleistocene part of the island, approximately 500 metres south of Tirohanga Point (grid reference NZMS 260 U14 778975), is aligned at 249°; the small departure from the harbour onshore wind resultant may result from topographic influences on wind flow.

The ocean onshore resultant is not as closely related to the orientation of onshore-orientated dunes in the coastal strip of relict transgressive dunes mentioned above, which have an orientation of about 82°. Landward orientated blowouts, occurring on a large relict foredune southwest of Hume Highway near Culvert Road, are orientated at about 76°. This differs by up to 40° from the ocean onshore resultant of 42° for Tauranga (Figure 2.24).

A change in the alignment of the coastline may partially account for this discrepancy. The Matakana Island ocean beach is aligned about 15° more easterly than the Mount Maunganui

coastline near where the Tauranga wind data was collected: consequently the directional range of "onshore" winds would differ. The quality of available wind data may also be a factor. Muckersie (1989) reports an onshore resultant for Tauranga of 57°, compared to 42° in Healy *et al.* 1977. Jennings (1957: p.479) suggests a need for "meteorological data gathered specifically in relation to geomorphological problems" in discussing the departure of parabolic dune orientations from available onshore wind resultants.

Remnants of large Pleistocene relict transgressive dunes dominate the topography at Opureora (Figure 2.4(a)). Their alignment of 261° is consistent with that of the dunes northwest of Western Road and adjacent to Hunter's Creek and also with the harbour onshore wind resultants in Figure 2.24.

The small inlet which divides the Pleistocene part of Rangiwaea has an identical orientation. The inlet is elongated but irregular in outline and probably represents a former fluvial course. However, its alignment parallel to that of the Pleistocene relict parabolic dune remnants at Opureora suggests it originated as a transgressive dune which became fluvially incised. Such topographic control is also supported by the direction of the inlet with respect to the Pleistocene strandplain on Matakana Island. Streams draining the plain in the absence of parabolic dunes would tend to be aligned at right angles or parallel to the relict foredunes, whereas the inlet on Rangiwaea is aligned obliquely.

A Pleistocene parabolic dune truncated by the pre-barrier Holocene shoreline (Figure 2.4(b)) has an alignment of 72°, comparable to the Holocene harbourward-orientated parabolics described above. The similar orientations of both Pleistocene and Holocene relict parabolic dunes strongly indicates the Pleistocene wind climate of the region has been similar, at least during the Last Interglacial, to that of the Holocene.

Some relict foredunes appear to have been modified by the development of small parabolic dunes in response to both onshore and offshore winds. A relict erosional scarp about 160 metres landward of the contemporary foredune where crossed by Profile 6 (Figure 2.17) has been modified by blowouts - some having moved landward, often separated by others which had moved in the opposite, seaward, direction. They may be causally linked. For example,

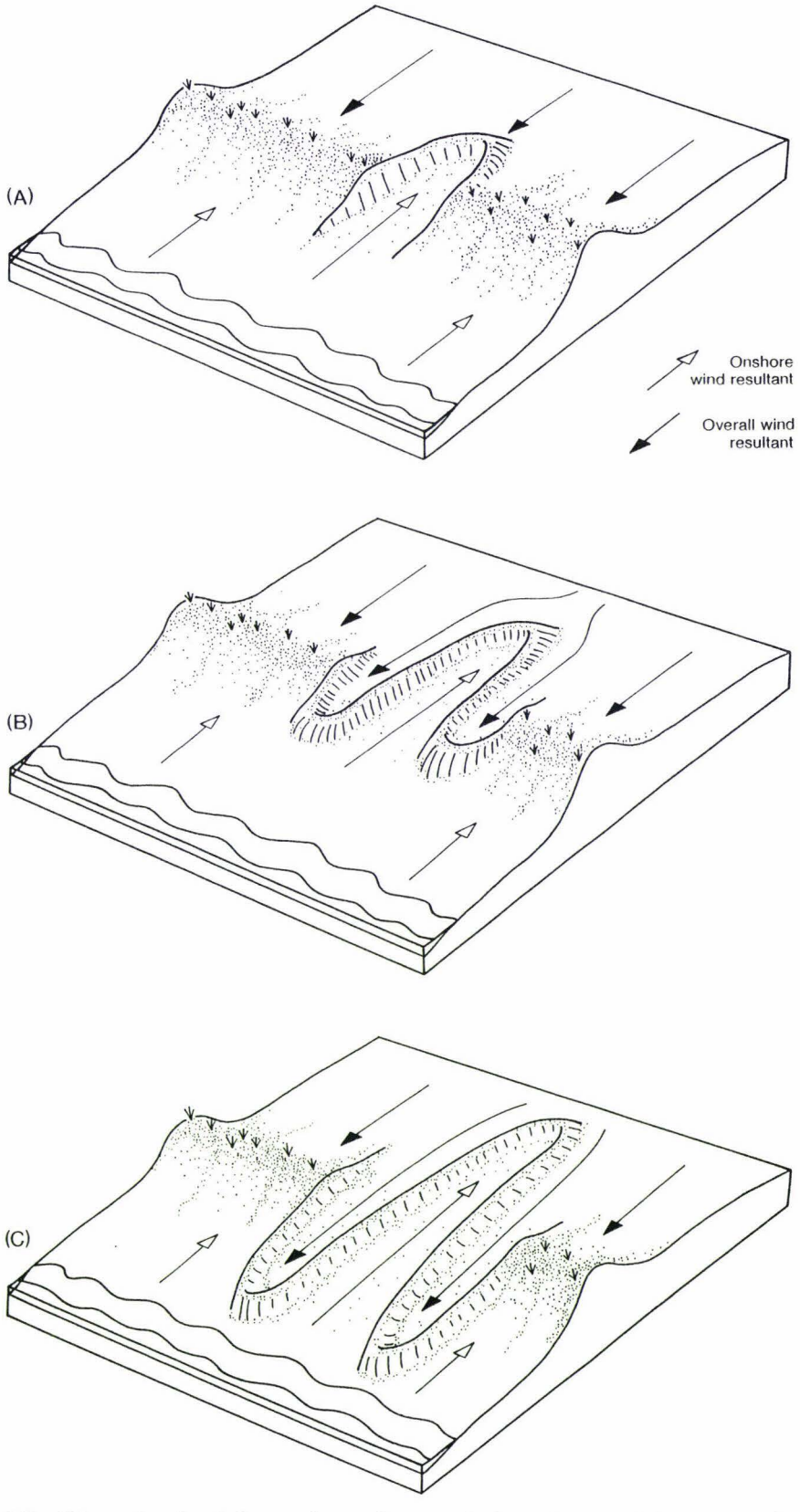


Figure 2.25: Hypothesised formation of oppositely-orientated blowouts in response to onshore and offshore winds: (A) blowout initiated by onshore winds; (B) overall resultant winds are channelled around the blowout, leading to blowout formation in the opposite direction; (C) blowouts develop into oppositely-orientated parabolic dunes.

blowouts moving landward, driven by onshore winds, may facilitate the development of adjacent blowouts moving in the opposite direction as prevailing offshore winds are channelled between the advancing dunes (Figure 2.25). To the knowledge of the author, this has not been reported elsewhere in the literature. The fact that winds capable of initiating blowouts blow from opposite directions may assist in this process.

Relict transgressive dunes on the barrier may have been initiated in a number of different ways and have been active at several stages throughout the barrier's history. Their origins and chronology are discussed in Chapter 4.

2.1.2.4 Lakes and wetlands

At least seven wetland areas occur at the northwestern end of the Matakana Island barrier, impounded by relict foredunes. Small lakes occur in six of these (e.g., Figure 2.26).

The wetland areas are typically small and elongated, with their long axes aligned sub-parallel to the ocean shoreline and the relict foredunes between which they are situated. The lakes have been studied in detail by Munro (1994) and their chronology is briefly discussed in Section 4.1.3.1. A topographic profile which includes three of these wetland areas has been discussed in Section 2.1.2.2 and associated vegetation has been summarised in Section 1.2.6.

Lakes and wetlands associated with prograding coastal plains, spits and barriers may form as a result of: (1) spit development and enclosure of coastal lagoons; (2) deflation and subsequent rise of the water table; or (3) impounding by encroaching transgressive dunes. The lakes and wetlands of northwestern Matakana Island are relatively small (the largest is about 460 metres long and a maximum 60 metres wide) and aligned sub-parallel to intervening relict foredunes. The absence of adjacent transgressive dunes and the depths of these lakes (the lake *c.*800 metres northwest of Lake Waikoura (Figure 2.26) exceeds two metres in depth - well below the maximum deflation level) suggests that they were formed by the first mechanism described above, rather than the second or third. This is supported by the configuration of the shoreline in 1870 shown in Chapter 4 (see Figure 4.2), which clearly shows some of these lakes in the process of being isolated from the sea by spit extension. The periodic welding of swash bars

Figure 2.26: A lake impounded by relict foredunes at the northwestern extremity of the barrier. View to the east.

to the shoreline - common in association with ebb-tidal deltas such as that off the Katikati entrance - may have enhanced this process. This contradicts the findings of Munro (1994), who suggested that deflation was a significant contributor to lake formation on this part of the barrier.

2.1.2.5 Backbarrier washover slope

A gently harbourward-sloping surface occurs along the inner margin of the Matakana Island barrier between approximately Cottage and Pipeline Roads to the northwest and varies between approximately 180 and 360 metres in width (see Figure 2.18). A small remnant slope of similar width is present approximately 400 metres southwest of the intersection of Hume Highway North and Waiherere Road. Shoreline recession along Hunter's Creek has removed the rest of this slope (if it was present) from the inner part of the barrier between this remnant

and Duck Bay.

This feature is interpreted as a backbarrier washover slope. 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. 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 occurs where numerous washover lobes coalesce into a regular slope on the inner margin of the barrier. Washover ridges, as described from the Americas by Tanner (1988), are wider and flatter than simple wave-built beach ridges, tend to have a "whale back" profile and have very gentle side slopes in the order of 1°-4° (Tanner 1988).

Washover is a common feature of the barrier islands of the eastern United States, where relative sea level has risen slightly more than 30 centimetres in the past century (Dolan *et al.* 1980). The eastern part of the barrier island of Perdido Key, in Florida, USA, exhibits extensive and abundant washover features, associated with the landward migration of the barrier by up to 200 metres since the mid 1860s (Psuty 1993). In southeastern Australia, washover is inferred to have occurred on inner parts of Holocene barriers of the Myall Lakes area, as indicated by backbarrier sands overlying estuarine and lagoonal sediments (Thom *et al.* 1992).

Following a stabilisation of sea level, onshore sediment movement may lead to the accumulation of a berm and ultimately aeolian sand on the seaward side of the washover ridge and a cessation of overtopping of the ridge by storms. A foredune may eventually develop on the washover ridge, although the trapping of available sand by foredune vegetation on the seaward side would tend to leave the backbarrier washover slope relatively unmodified. Continued onshore sediment movement results in shoreline progradation and the formation of a succession of relict foredunes as discussed in Section 2.1.2.2. Therefore backbarrier washover slopes are associated only with the innermost margin of a relict foredune sequence.

Washover appears to have also occurred on a recurved spit extending to the northwest of the central part of the pre-barrier Holocene shoreline. This is suggested by the presence of a

regular, landward-dipping inner slope with numerous small lobes along its landward margin, which suggest overtopping of the spit by waves when it was exposed to the open ocean. An active washover lobe occurs on the contemporary ocean shoreline approximately 2.5 kilometres northwest of Boundary Road (Figure 2.16), where the shoreline is presently receding. The landward-sloping surface dips at an angle of approximately 1°.

2.1.2.6 Relict estuarine flats

Flats associated with the Holocene barrier are common at the heads of Hunter's Creek, Blue Gum Bay and further northwest, where they range up to 700-750 metres in width. Former estuarine channels can be detected on aerial photographs of these flats in the vicinity of Cottage Road (Figure 2.18). The flats are occupied by a mature swamp forest, although no studies or surveys of its species composition are known to the author. The boundary between these flats and the backbarrier washover slope described above is indistinct and has been inferred from changes in vegetation indicated by aerial photographs.

A wedge-shaped area of relict estuarine flats extends obliquely towards the ocean coast immediately northwest of Culvert Road, and represents a former tidal entrance to Tauranga Harbour which extended through Blue Gum Bay. This feature was significant to the early development of the barrier (see Chapter 5). A small zone of relict estuarine flats also occurs at the head of Duck Bay, fringed by active flats colonised by abundant *Avicennia resinifera.* A small hooked spit extends across the mouth of this bay from the northwest.

Estuarine flats become inactive (relict) following cessation of inundation by tidal water. This may be a result of a fall in relative sea level (as has occurred in parts of eastern North Island (Ota *et al.* 1990)), a contraction of the tidal range of an estuary through the narrowing of its entrance to the sea, or by sedimentation sufficient to raise the estuarine surface above the level of the highest spring tide. The spread of salt marsh vegetation over an estuarine flat gives it greater protection from harbour waves, lowering its energy regime and leading to higher rates of deposition, representing an early stage of the transition of an estuarine flat from active to relict (Salmon 1986). Sedimentation rates on estuarine flats tend to decrease with time as the surface elevation approaches that of the highest spring tide (Pethick 1981). Sediment

deposition above this level is enhanced by the presence of salt marsh vegetation such as that described by Beadel (1989a), where organic sedimentation becomes significant (White 1979).

Contemporary estuarine flats occupy a large proportion of Tauranga Harbour and over 90 percent of the area of the harbour covered at high tide is exposed at low tide (Hume and Herendorf 1992). A full investigation into the characteristics of these flats was beyond the scope of this study.

2.2 SUMMARY

The oldest parts of Matakana Island are the highest terraces on the southwestern part of the island. They are probably at least *c.*210 000 years old and the highest terrace may possibly be *c.*300 000 years old. The lowest terrace, to the northeast of the two highest terraces, probably dated from the Last Interglacial maximum *c.*125 000 years ago.

The lowest terrace originated as a relict foredune plain, similar to the present Holocene barrier. Parabolic dunes which moved across the old relict foredunes are orientated in a similar direction to parabolic dunes on the Holocene barrier, suggesting that the wind climate during the Last Interglacial was similar to that of the Holocene.

This plain is buried to a depth of approximately thirteen metres by Pleistocene tephra deposits. The relict foredune ridges are now at or below present sea level and, after allowance is made for sea level height during the Last Interglacial, an average local subsidence rate of between 104 and 120mm/1 000 years is indicated for the last 125 000 years.

The northeastern boundary of the Pleistocene part of Matakana Island is delineated by a wave-cut cliff, marking the limit of shoreline recession following the Postglacial Marine Transgression which ended *c.*6 500 ^{14}C years BP.

The Holocene barrier also contains a wide range of landforms which testify to a complex evolutionary history. The majority of the barrier comprises relict foredunes which indicate

the pattern of barrier progradation throughout its development. A washover ridge comprises the inner part of the barrier northwest of Blue Gum Bay. A washover ridge may also have existed along parts of the southeastern part of the barrier, but subsequent shoreline recession has removed any evidence for this with the exception of a remnant near the head of Hunter's Creek.

Near the Katikati Entrance, the relict foredunes curve westward towards the harbour. The increasingly irregular pattern of these dunes, often separated by lakes or wetlands, clearly demonstrates a relationship between the beach-foredune system and the complex dynamics of the Katikati Entrance. Recurved ridges also occur near Blue Gum Bay along the inner barrier and indicate the former existence of a third tidal entrance to Tauranga Harbour. The closure of this entrance coincides with an abrupt increase in relict foredune size and a link between the two phenomena is suggested.

Relict foredunes are truncated in places at each end of the barrier, indicating that the barrier ends were eroded substantially at times during barrier development. In particular, the truncation of the relict foredunes by a scarp aligned obliquely across the southeastern end of the barrier near the Tauranga Entrance represents a significant development in the evolution of the barrier.

Transgressive dunes are common on parts of the barrier, particularly near the ocean coast. Dune alignment is consistent with calculated geomorphically significant wind resultants and is similar to that of the Pleistocene dunes described above.

The harbour shoreline has also prograded in places during mid- to late Holocene time. Relict estuarine flats bearing a successional vegetation pattern clearly indicate this progradation, particularly in Blue Gum Bay and northwest of Pipeline Road. Many of the estuarine spits and islands occurring in association with Matakana and Rangiwaea Islands appear to be very recent features as suggested by their often sparse vegetation cover and in some cases are still evolving rapidly.

Chapter Three: Sediment Characteristics

Introduction

Sediment sampling was carried out on the Matakana Island barrier to enable the identification, description and explanation of spatial variations in sediment characteristics. Sampling of all sedimentary environments was not possible, but samples were selected in order to identify general trends within some landform categories, and to assist with the interpretation of landform evolution in specific areas.

This chapter is in two main parts. Section 3.1 describes sediment textural parameters, with an emphasis on shore-parallel and shore-normal variations. Section 3.2 investigates the mineralogy of the barrier sediments.

3.1 SEDIMENT SIZE PARAMETERS

Sediment size is a reflection of the size characteristics of available source materials and the processes of transportation and deposition (Folk 1974). Textural parameters of sediments are expressed in phi-units (denoted ϕ), where grain diameter (ϕ) = $-\log_2$(grain diameter(mm)) (Krumbein 1934: cited in Lindholm 1987). Descriptions of Folk-Ward grain size parameters (Folk 1974) are listed in Appendix 4.

Sediment samples were collected for textural analysis from several parts of the Matakana Island barrier and its shoreline. Beach samples were taken from the Katikati Harbour and Tauranga Harbour shorelines and two series of samples were collected from the ocean beach.

Corresponding samples from the contemporary foredune were collected and shore-parallel sampling was also carried out along the "Long Ridge" described in Section 2.1.2.2.

Shore-normal changes in sediment texture were determined along five short beach-foredune transects and four longer transects across the barrier. Relict beach sediments from below relict foredunes were sampled from the southeastern part of the barrier and also the recurved ridges near Pipeline Road (Section 2.1.2.2). Folk-Ward grain size parameters were calculated for the samples using the PC-GRAN grain size analysis program. The raw data from the following analyses are located in Appendix 5.

3.1.1 Shore-parallel variations in sediment textural parameters

Beach and dune sediments for the entire Bay of Plenty sandy shoreline are reported to be within the range of *medium* to *fine sand* (1ϕ-3ϕ) (Healy *et al.* 1977, Harray and Healy 1978). Variation in mean size increases in a seaward direction. Swash platform and nearshore sediments range from *coarse sand* to *fine sand* (0ϕ-3ϕ), and offshore sediments vary from *very coarse sand* to *very fine sand* (-1ϕ-4ϕ) (Healy *et al.* 1977).

Sediments within Tauranga Harbour are widely variable in grain size, ranging from *coarse sand*, *granules* and *pebbles* in the main tidal channels (Davies-Colley and Healy 1978a) to *very fine sand* and *silt* in the upper parts of estuaries and in salt marshes (White 1979). Dune sands of the Bay of Plenty littoral system are reported to be generally *moderately well sorted* to *well sorted*: sorting becomes more variable in a seaward direction with berm, swash platform and nearshore sediments varying between *well sorted* and *poorly sorted* (Healy *et al.* 1977).

3.1.1.1 Ocean Beach

Two series of beach samples were collected (Figure 3.1): one in January 1993 during a period of beach accretion accompanying offshore winds and swell wave conditions, another in August 1994 following an onshore storm event which had caused beach erosion. A sample from Waihi Beach is included with the 1993 samples.

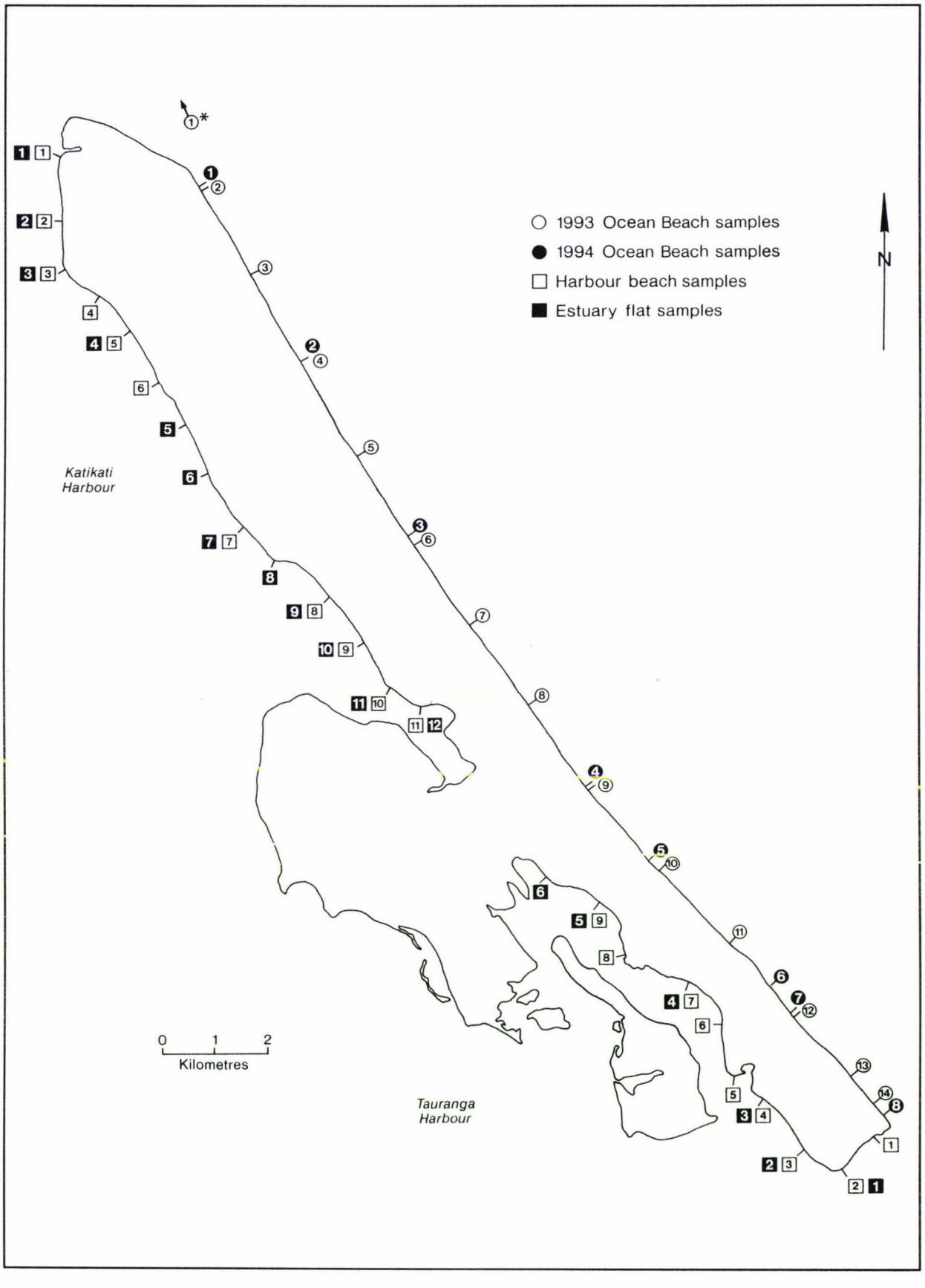


Figure 3.1: Locations of 1993 and 1994 Ocean Beach samples and Katikati/Tauranga Harbour shoreline samples (Section 3.1.1.4). 1993 Ocean Beach sample 1 (marked with *) was collected from the mid-foreshore of Waihi Beach, approximate grid reference NZMS 260 U13 724144.

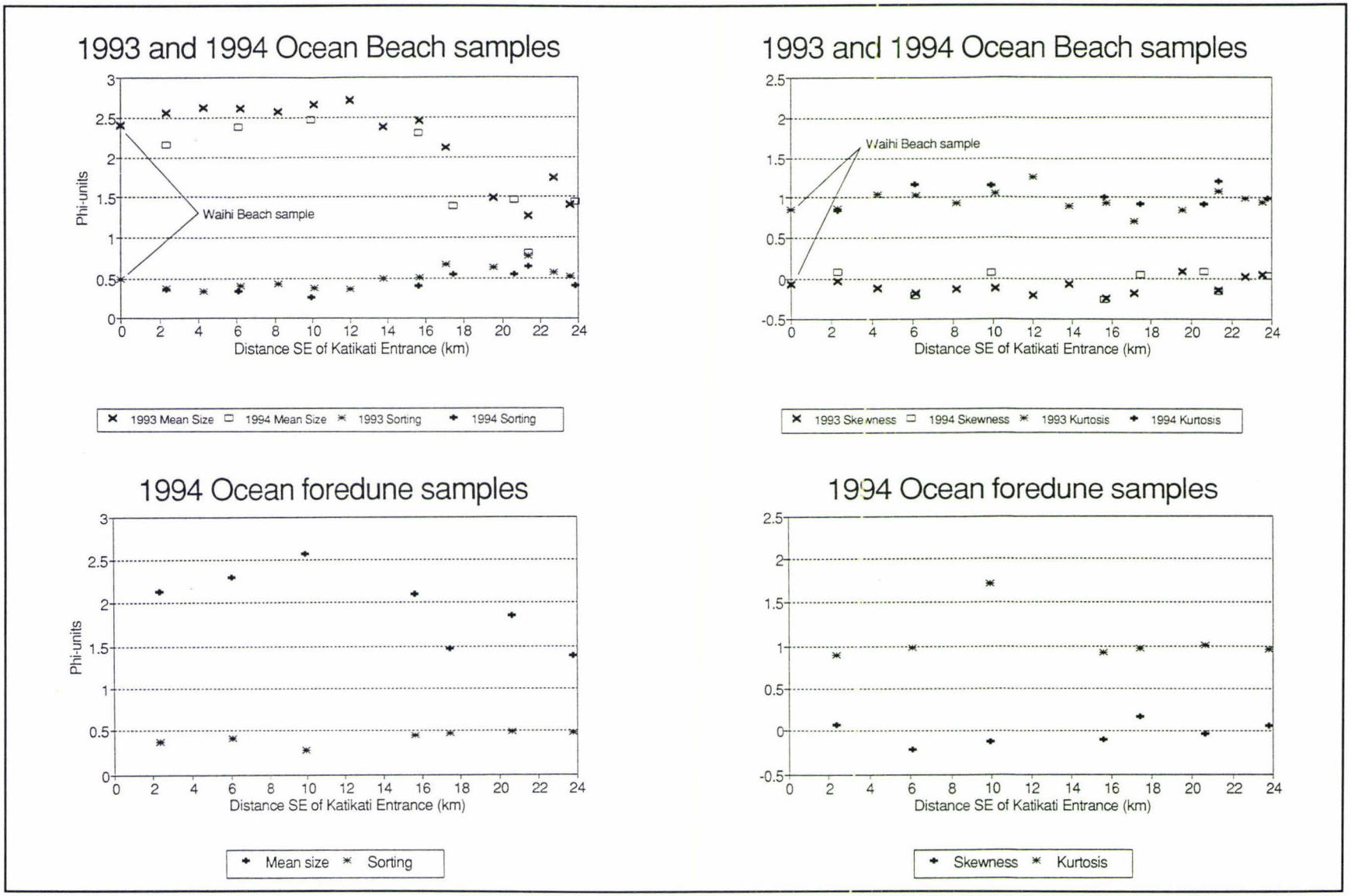


Figure 3.2: Textural properties, 1993/1994 Ocean Beach and 1994 Ocean Foredune samples.

The textural properties of each set of samples are plotted in Figure 3.2. *Fine sand* characterises the ocean beach from the Katikati Entrance to a point about 16 kilometres southeastward of the entrance. Mean grain size increases markedly further southeastward towards Panepane Point in both sets of samples, consistent with similar trends reported by Healy *et al.* (1977). The Waihi Beach sample in the 1993 samples is slightly coarser than the most northerly barrier beach samples. Overall sediment size overall is marginally coarser in the 1994 samples.

Ocean beach sediments are *well sorted* northwest of a point about 16 kilometres southeast of the Katikati Entrance. Sorting becomes generally poorer further to the southeast in both sets of samples. The coarsest sediments sampled, approximately 21.5 kilometres southeast of the Katikati Entrance, are the least well sorted, particularly in the 1993 samples in which the sands are *moderately well sorted.* Sorting increases slightly in the vicinity of Panepane Point in both sets of samples, corresponding with a decrease in sediment size.

Skewness and kurtosis show little trend in either set of samples.

3.1.1.2 Ocean Foredune

Contemporary foredune samples were collected concurrently with the 1994 Ocean Beach series (Figure 3.1). Sample locations (Figure 3.3 below) correspond to those of the 1994 Ocean Beach series described above. A contemporary foredune was absent from the location of 1994 Ocean Beach sample 7, where beach erosion was occurring.

Mean grain size of foredune sediments is closely related to that of the beach sediments along the length of the barrier (Figure 3.2). Foredune sediments are slightly finer than the adjacent beach sediments in some places, reflecting selective aeolian transport of fine sand from the beach, but elsewhere foredune sediments are either comparable to or coarser than the corresponding beach sediments. The contemporary foredune sediments were generally *well sorted* with little variation. No systematic trends in skewness or kurtosis were apparent.

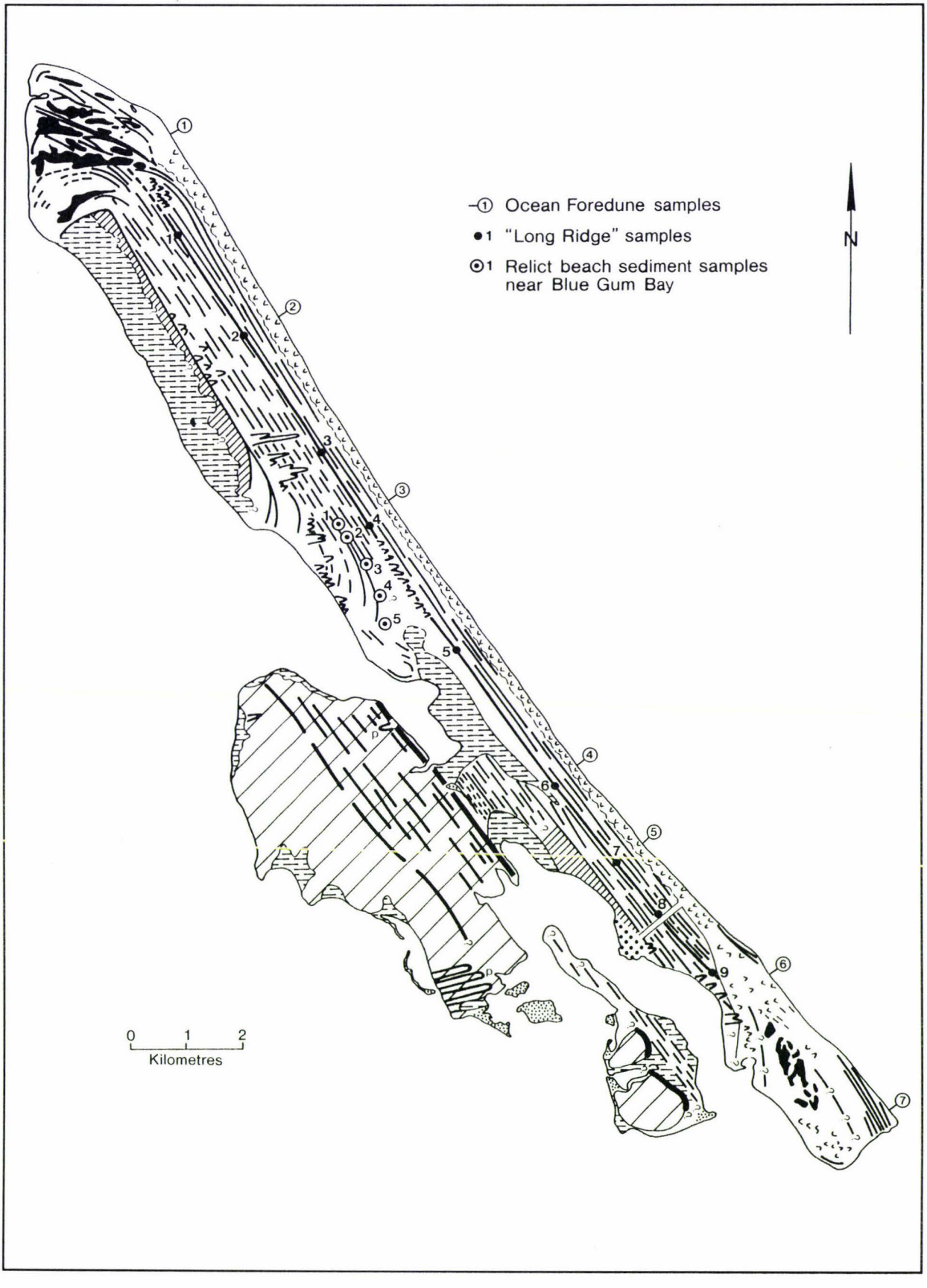


Figure 3.3: Locations of 1994 Ocean Foredune, "Long Ridge" (Section 3.1.1.3) and relict beach sediment samples from the vicinity of Blue Gum Bay (Section 3.1.1.6).

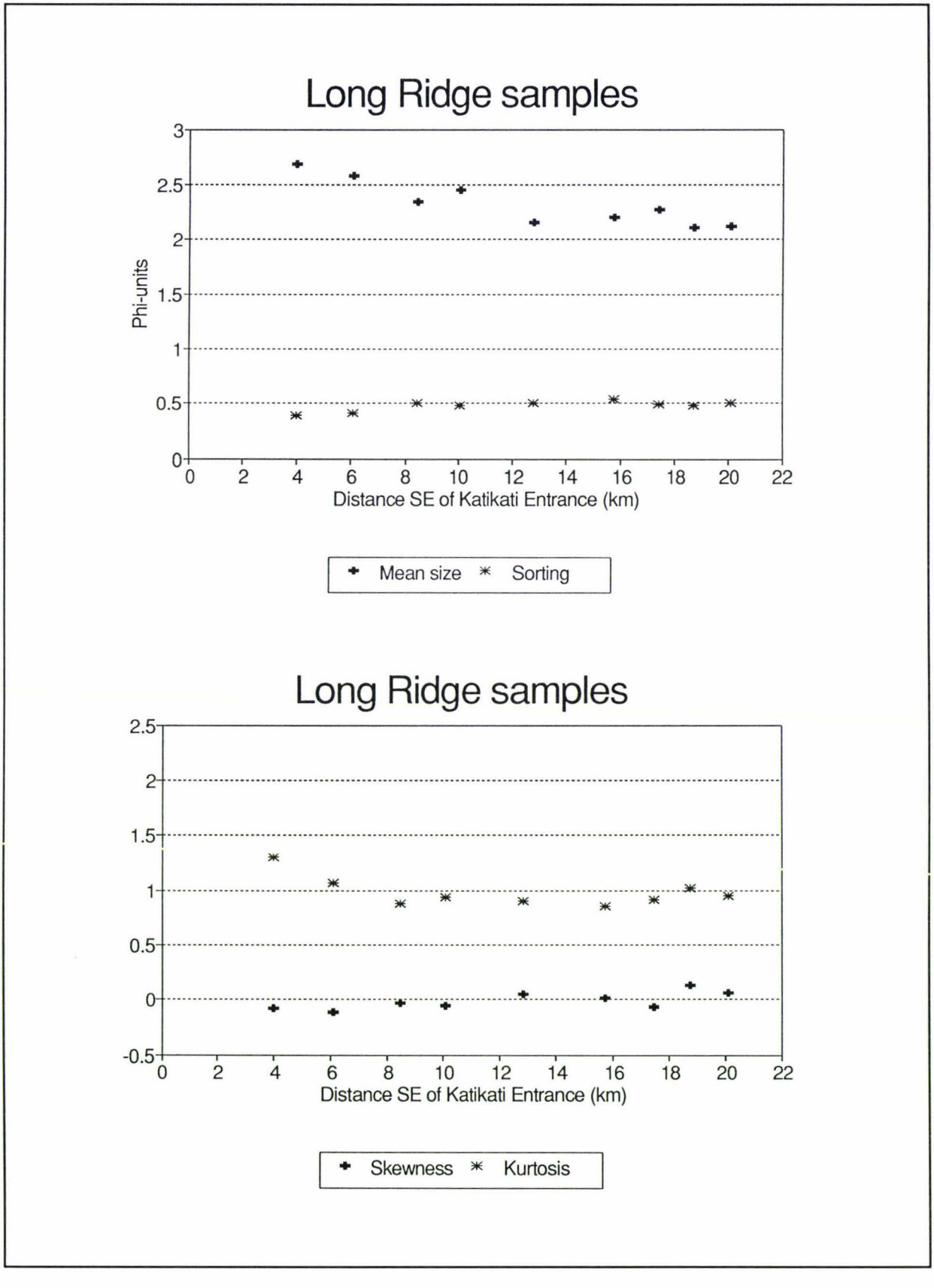


Figure 3.4: Textural parameters, "Long Ridge" samples.

3.1.1.3 "Long Ridge"

The "Long Ridge" is a prominent relict foredune which occurs on the landward boundary of the large relict foredunes of the third morphological unit discussed in Section 2.1.2.2 (Figure 2.15). This ridge was traced and sampled for approximately 18 kilometres southeastward of Cottage Road. Sample locations are given in Figure 3.3 and the data are plotted in Figure 3.4.

Fine sand occurs along the entire transect, with a slight coarsening towards the southeast. Sorting is very uniform for all samples. A weak trend in sediment size distributions from slightly *coarse-skewed* near Cottage Road to slightly *fine-skewed* at the southeastern end is apparent but there is no trend in kurtosis.

3.1.1.4 Katikati and Tauranga Harbour shorelines

Two sets of samples were collected from each harbour shoreline. Beach samples were collected from the high water mark as indicated by stranded debris and estuary flat samples were taken from tidal flats approximately 30-100 metres away from the beach. The latter were analysed for their silt/clay contents. Sample locations are shown in Figure 3.1.

Textural parameters are plotted in Figure 3.5. Uniform *medium sand* dominates the entire Katikati harbour beach, with the exception of *fine sand* occurring near the Katikati Entrance. Beach sands are slightly finer along the Tauranga Harbour shoreline, coarsening at the Tauranga Entrance. At each entrance, mean grain size is comparable to that of the adjacent 1993 Ocean Beach samples (Figure 3.2), suggesting that sediment transport is occurring from the Ocean Beach into the harbour entrances. Sorting deteriorates away from each entrance, reflecting the lower energy environments of Blue Gum Bay and upper Hunter's Creek. Sediment size distributions tend to be *fine-skewed* at the entrances, becoming generally *near-symmetrical* towards the upper estuarine locations.

The silt/clay content of the estuarine flat sediments (Figure 3.6) along the Katikati Harbour shoreline increases strongly towards Blue Gum Bay, although overall percentages are still very low compared to those of many other estuaries (e.g., MacPherson and Lewis 1978).

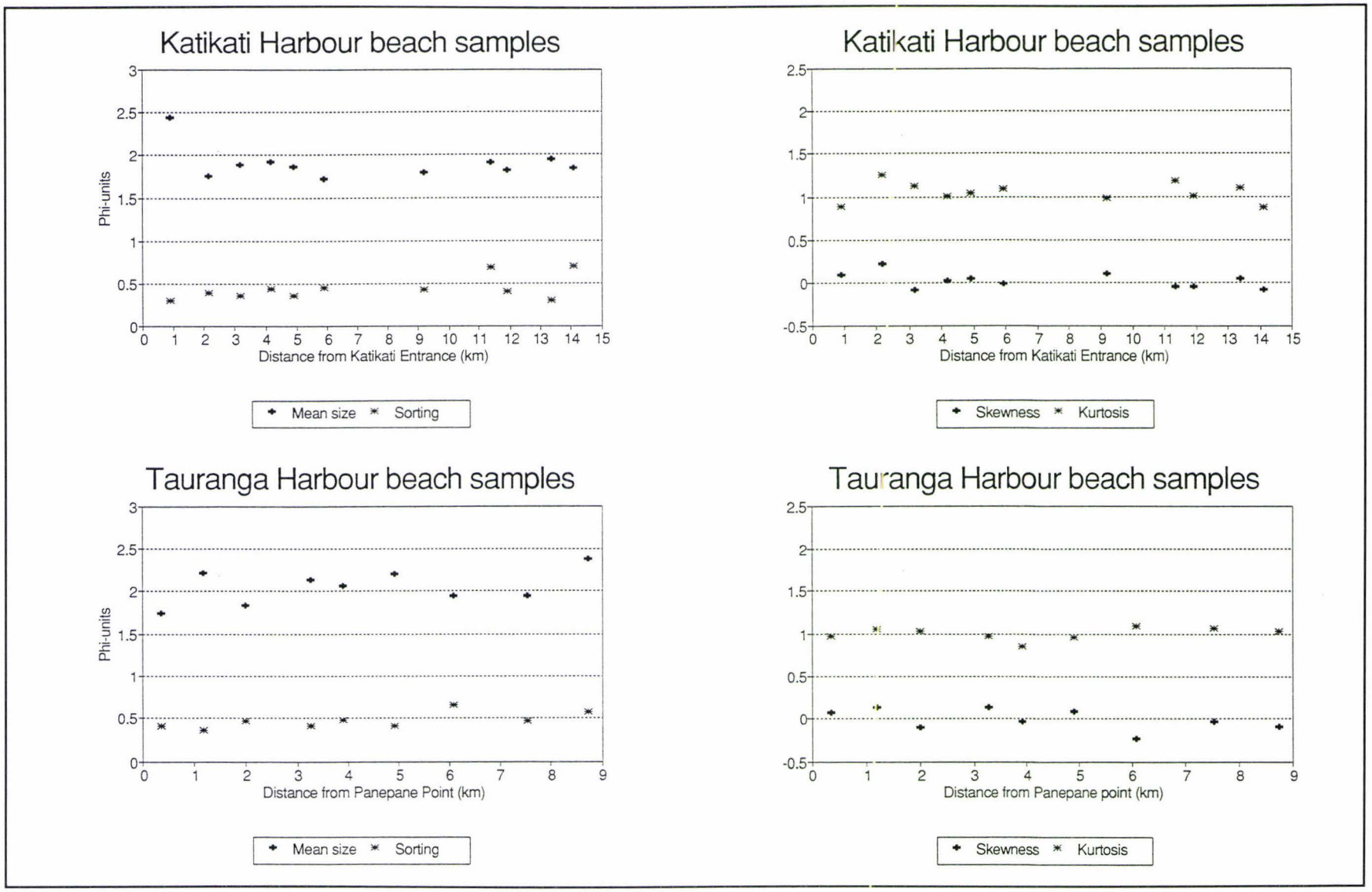


Figure 3.5: Textural properties, Katikati and Tauranga Harbour shorelines.

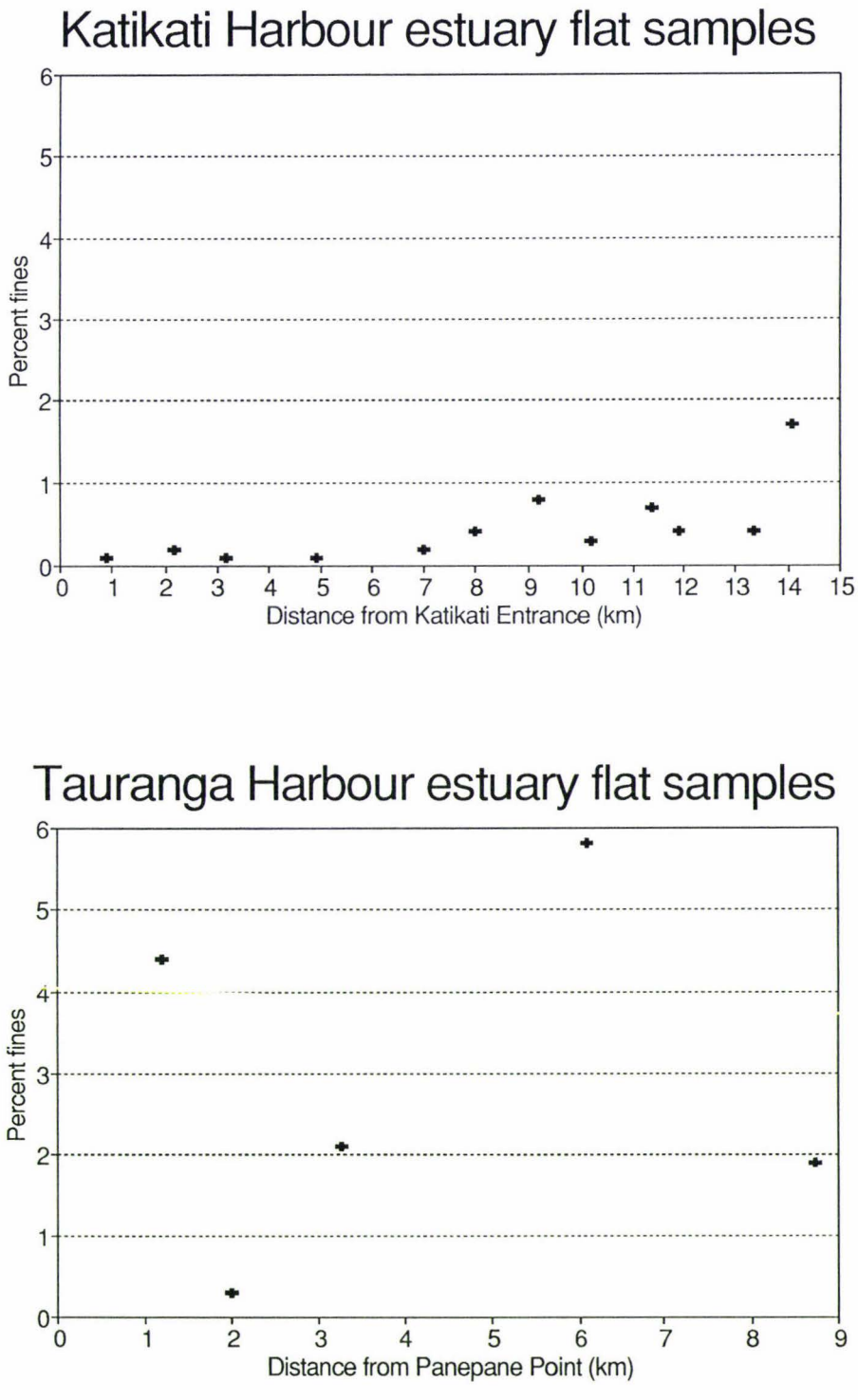


Figure 3.6: Silt/clay percentages, Katikati and Tauranga Harbour shorelines.

Silt/clay percentages are higher along the Tauranga Harbour shoreline, although no directional trend is evident. There is no apparent association with harbour wave fetch or tidal channel proximity and other factors, such as tidal flat vegetation, must play a role. For example, the trapping of fines by abundant *Zostera capricorni* (Eel grass), as demonstrated by White (1979), may be responsible for the higher silt/clay proportion of Sample 4. Although the low energy environment of Sample 6 is likely to be responsible for the relatively high silt/clay percentage there, a comparable proportion in Sample 1 is from a higher energy environment.

3.1.1.5 Relict beach sediments of the southeastern part of the barrier

Thirty-two samples were recovered from the water table level, assumed to approximate the upper level of the contemporary beach, from various parts of the barrier and its ocean shoreline at and southeast of Culvert Road. Mean size and sorting are plotted in Figure 3.7 below.

A trend of coarsening and poorer sorting of beach sand towards the southeast is observed on the contemporary beach and under the older shoreline ridges. This trend begins *c.*7 kilometres northwest of Panepane Point, slightly northwest of the bulge on the present coast which is located adjacent to the terminal lobe of the Tauranga ebb-tidal delta. The coarsening and poorer sorting under the older ridges suggests the close proximity of an ebb-tidal delta while these ridges were forming.

A shore-normal coarsening trend is also apparent from the ocean beach towards the inner part of the barrier, particularly for the northwestern half of the sampling region. A shore-normal trend in sorting is less obvious. Skewness and kurtosis (not plotted) showed no directional trends.

3.1.1.6 Relict beach sediments in the vicinity of Blue Gum Bay

Six samples were collected from the water table level along the seaward side of a recurved relict foredune in the vicinity of Blue Gum Bay (Figure 3.3). The data are plotted in Figure 3.8.

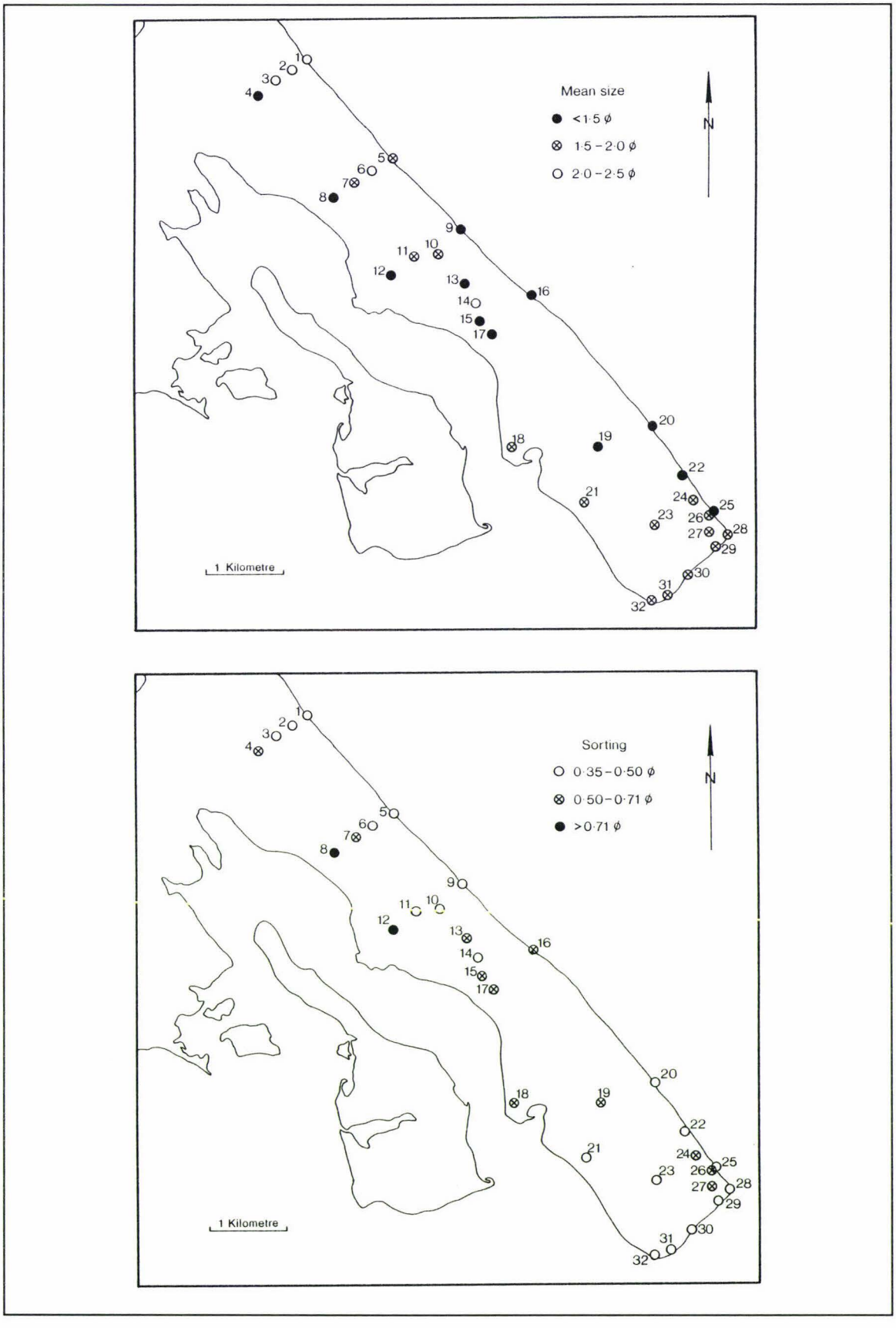
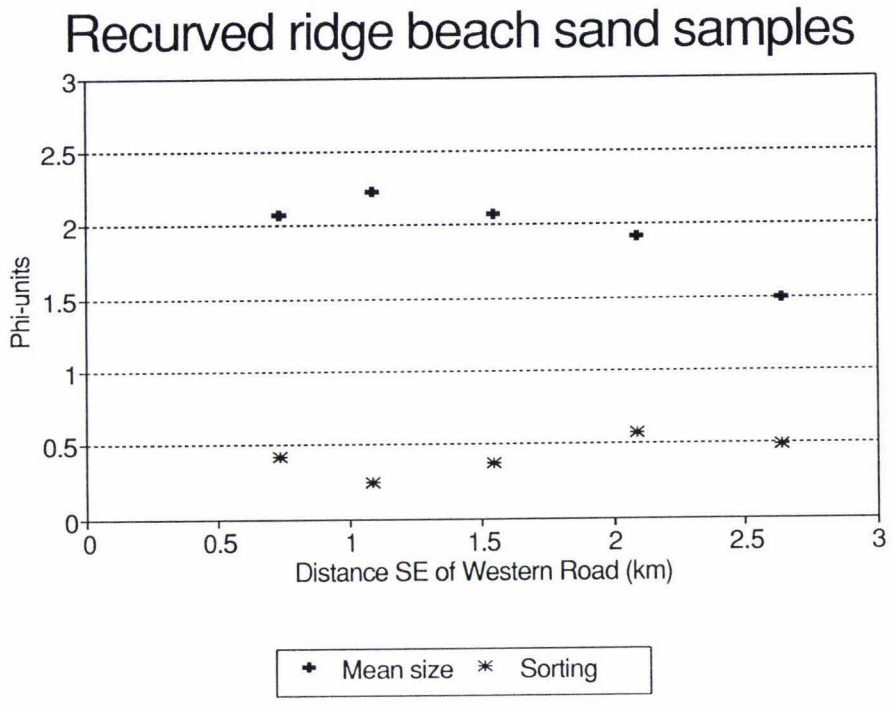


Figure 3.7: Mean size and sorting of relict and contemporary beach sediments from the southeastern end of the barrier. Sample numbers correspond to textural data provided in Appendix 5.



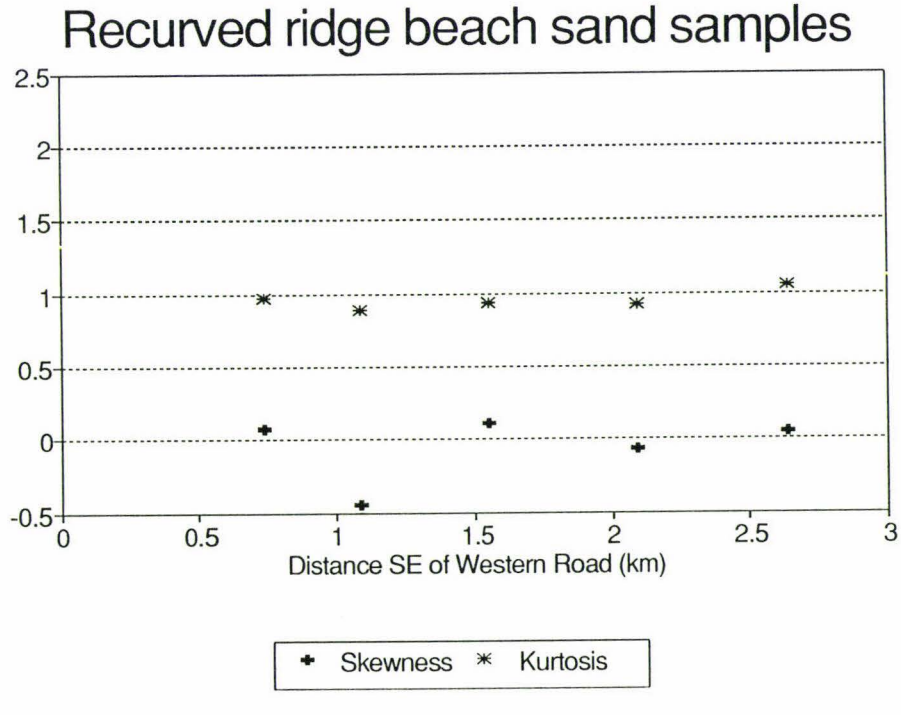


Figure 3.8: Textural parameters of relict beach sediments near Blue Gum Bay.

Mean grain size increases in a southeastward direction, the rate of coarsening increasing towards the end of the recurved ridge. This occurs concurrently with a weak trend to less well sorted sediments.

Little trend in either skewness or kurtosis is evident. *Strongly coarse-skewed* sediments occurring in the sample *c.*1.1 kilometres southeast of Western Road (Figure 3.8) may indicate the sample contained more than one population of sediments.

3.1.2 Shore-normal variations in sediment textural parameters

Relict foredune sands were sampled in a shore-normal direction in order to determine variations in sediment characteristics as the barrier prograded seaward. Sampling was carried out along four of the levelled profiles (Profiles 2-5) indicated on Figure 2.6. Two additional samples (Samples S1 and S2) were taken from the inner part of the barrier adjacent to the pre-barrier Holocene shoreline: one from the recurved spit described in Section 2.1.2.2 and the second *c.*400 metres seaward. These samples were analysed to determine whether or not the sediments of the recurved spit were derived from erosion of the Pleistocene part of the island. Textural and mineralogical details of these two samples are provided in Appendices 5 and 6.

In an effort to identify short-term variations in sediment texture, a series of short beach-foredune transects (see Section 3.1.2.2) were also sampled. The transects and associated samples are located in Figure 3.9 below.

3.1.2.1 Transects across the barrier

Sediment textural parameters are plotted for the transects in Figures 3.10 and 3.11. Overall, there is very little systematic variation in size parameters along or between any of the transects, demonstrating that the dune sands of the barrier are essentially uniform. However, a marked coarsening in the underlying beach sediments was observed at the innermost ridge in places, including the sample sites described in Section 3.1.1.6.

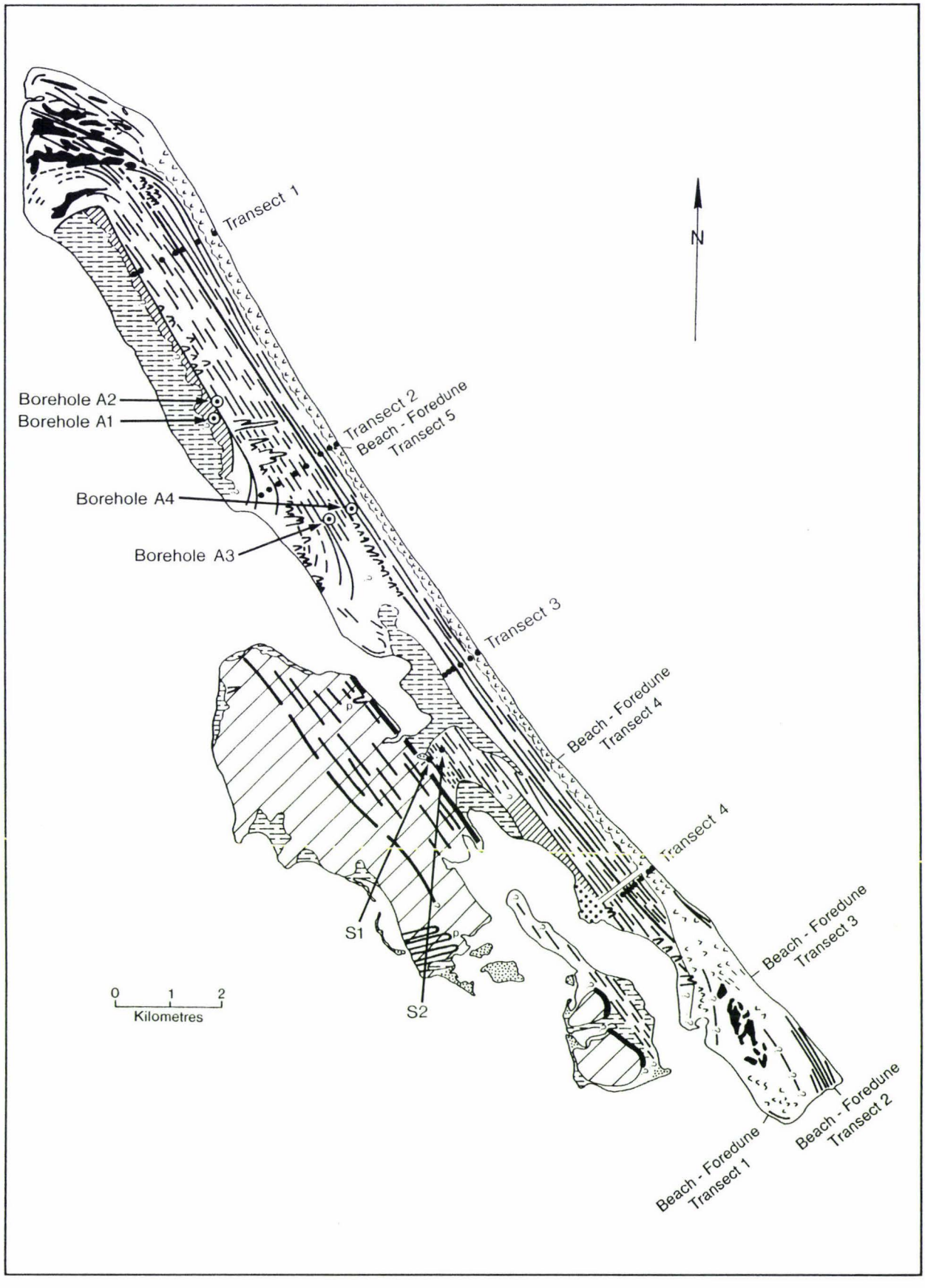


Figure 3.9: Locations of shore-normal transects, sample S1, S2 and Boreholes A1-A4 (Section 3.1.3; Appendix 6).

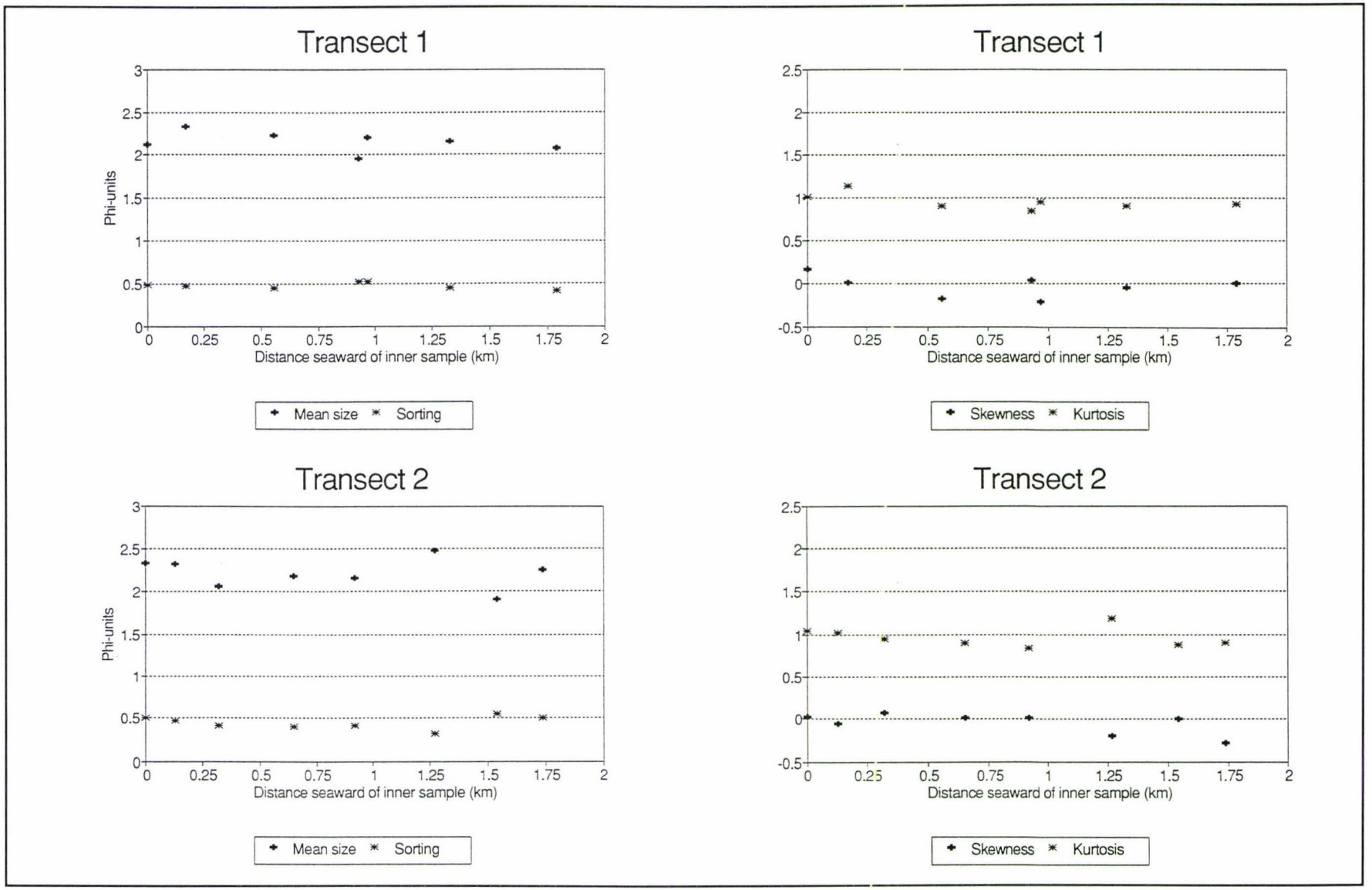


Figure 3.10: Sediment size parameters, Transects 1 and 2.

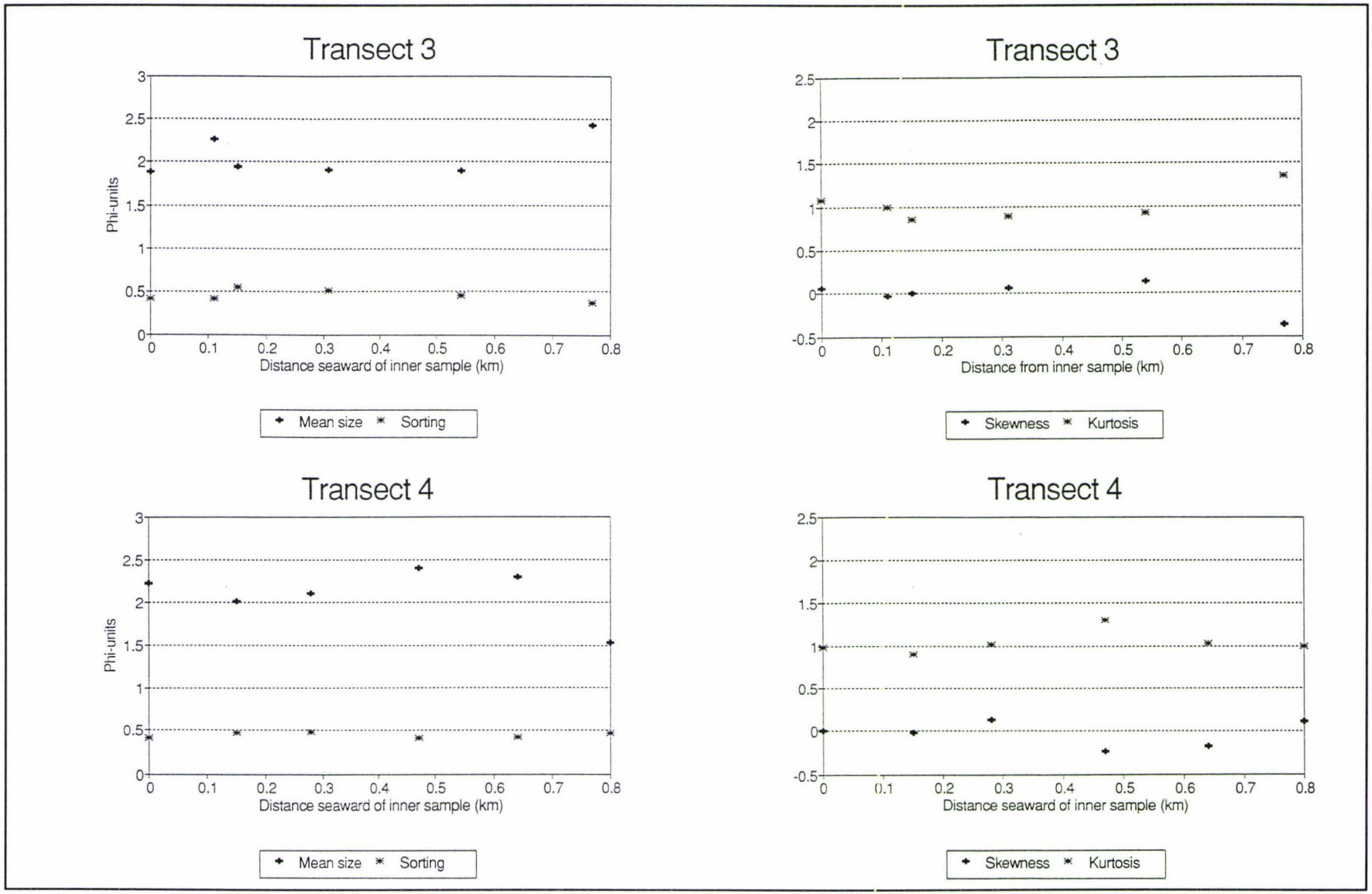


Figure 3.11: Sediment size parameters, Transects 3 and 4.

The sample *c*.1.25 kilometres seaward of the innermost sample in Transect 2 differs from the rest of the samples from the transect in terms of all textural properties. The sample also has a distinctive mineralogical composition and relates to the Taupo eruption (discussed in Chapter 4).

With the exception of Sample 6 from Transect 4, which is considerably coarser than any other transect samples, there is very little systematic variation in size parameters along or between any of the transects, demonstrating that the barrier sediments are essentially uniform. This is significant for the interpretation of barrier evolution and is discussed further below.

3.1.2.2 Beach-foredune transects

Five short transects across the beach and contemporary foredune were sampled to examine the relationship between beach and foredune sediments. The transects are located in Figure 3.9. In Beach-Foredune Transects 1 and 2 (Figure 3.12 below), the beach sample was coarser than the dune samples, consistent with selective aeolian sediment transport mentioned in Section 3.1.1.2. For Beach-Foredune Transects 3 to 5 (Figures 3.13 and 3.14 below), the beach sample was finer than the dune samples, indicating a possible recent change in the nature of the beach sediments. This probably reflects the accretion of fine beach sand associated with swell wave conditions at the time the samples were collected. Skewness and kurtosis values varied irregularly with no consistent trends.

3.1.3 Borehole information

Four boreholes were drilled with a trailer-mounted drilling rig (Figure 3.15) in order to investigate the deeper stratigraphy of the barrier. Their locations are shown in Figure 3.9.

It was originally intended to drill to the base of the Holocene sand wedge, but this proved to be beyond the capacity of the rig. A maximum depth of 12 metres was achieved at Borehole A2. Full details of the barrier stratigraphy at each borehole are provided in Appendix 6.

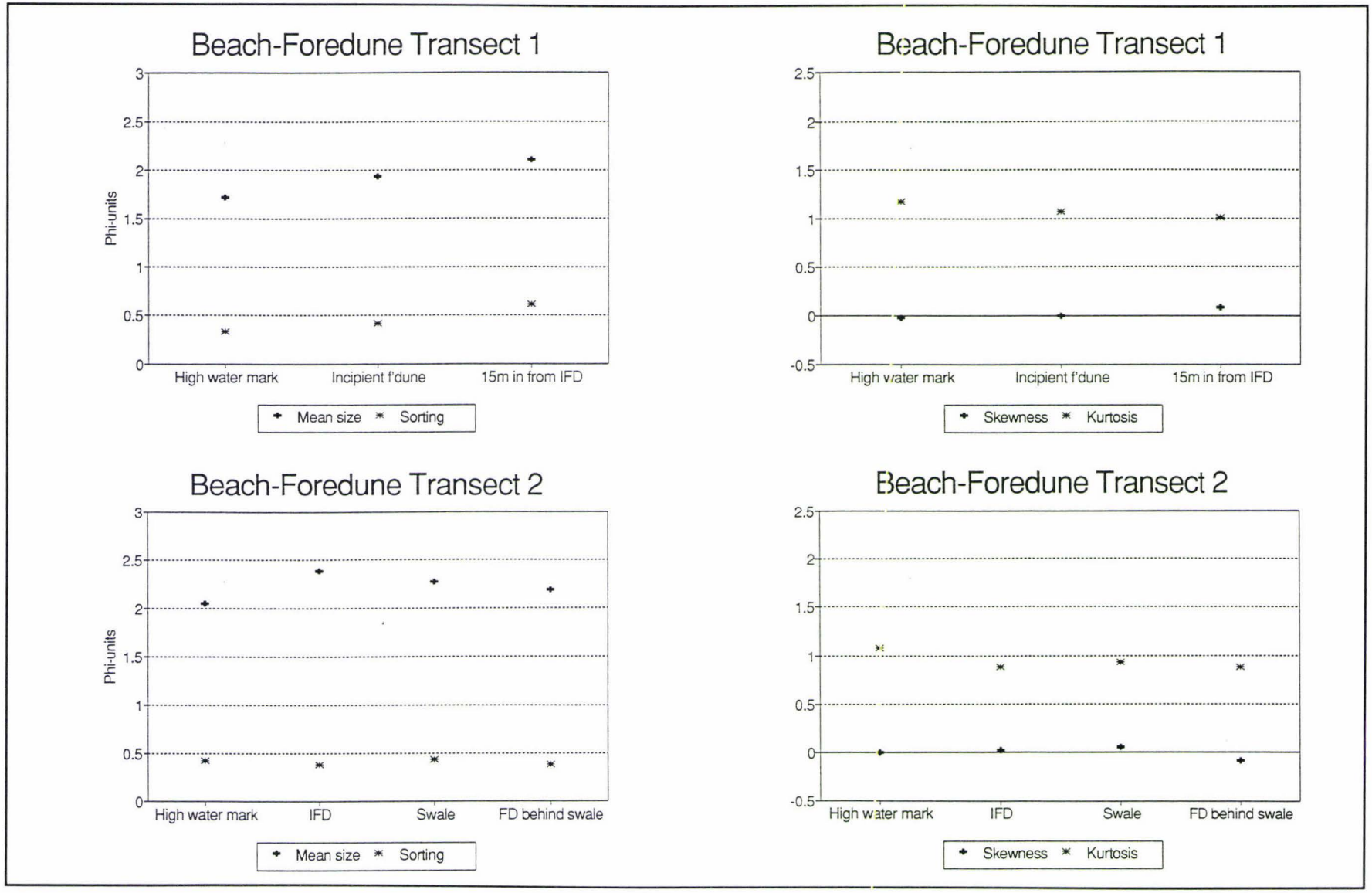


Figure 3.12: Sediment size parameters, Beach-Foredune Transects 1 and 2.

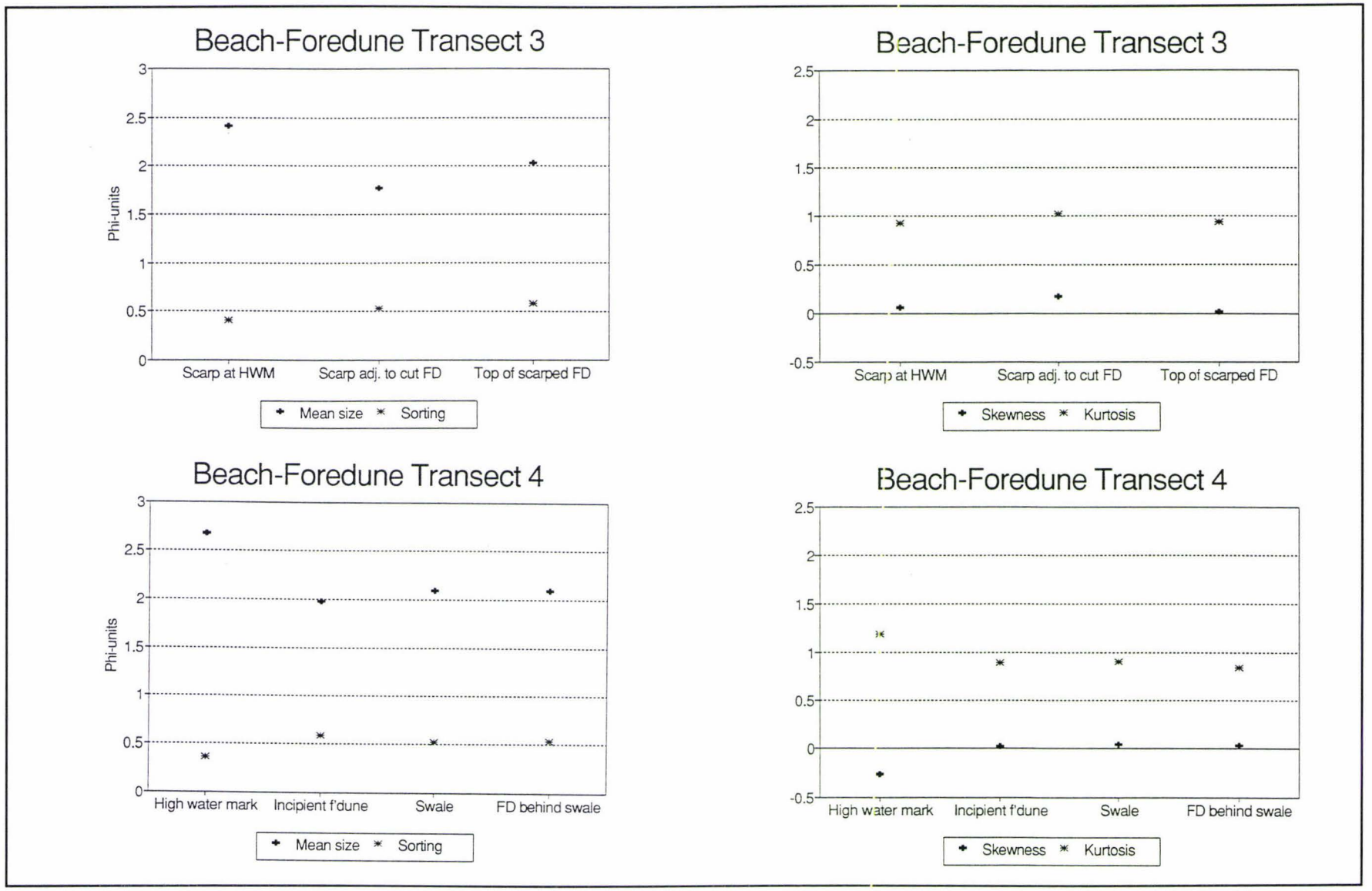


Figure 3.13: Sediment size parameters, Beach-Foredune Transects 3 and 4.

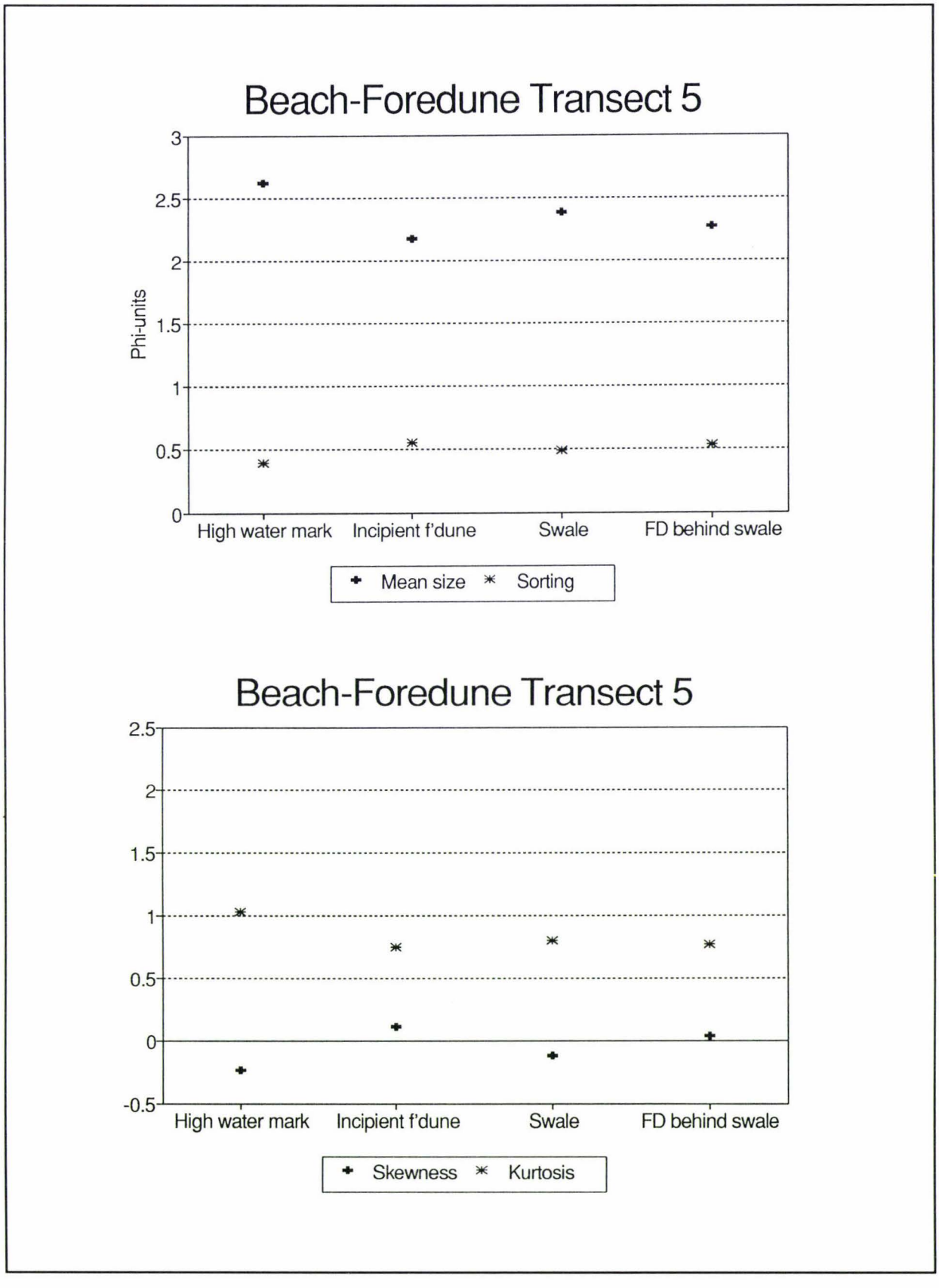


Figure 3.14: Sediment size parameters, Beach-Foredune Transect 5.

Figure 3.15: Drilling of Borehole A4, August 1993.

3.1.3.1 Stratigraphic section

Figure 3.16 below is a schematic diagram showing generalised stratigraphy for a cross section of the upper facies of the barrier, in terms of the borehole stratigraphy described in Appendix 6. All four boreholes show fine dune sand overlying coarser sand. At the innermost borehole (Borehole A1) the coarse sand overlies estuarine deposits of silty sand and clay which are absent from the seaward boreholes. The coarsest sand occurred in Borehole A2 which was drilled on the immediate seaward side of the innermost ridge. The sand was strongly bedded and contained shells and shell fragments, granules and small pebbles, and heavy mineral seams. At Borehole A1 the coarse sand was slightly bedded and occurred in a thinner layer. It was not as coarse as that in Borehole A2, and lacked the whole shells, granules and small pebbles.

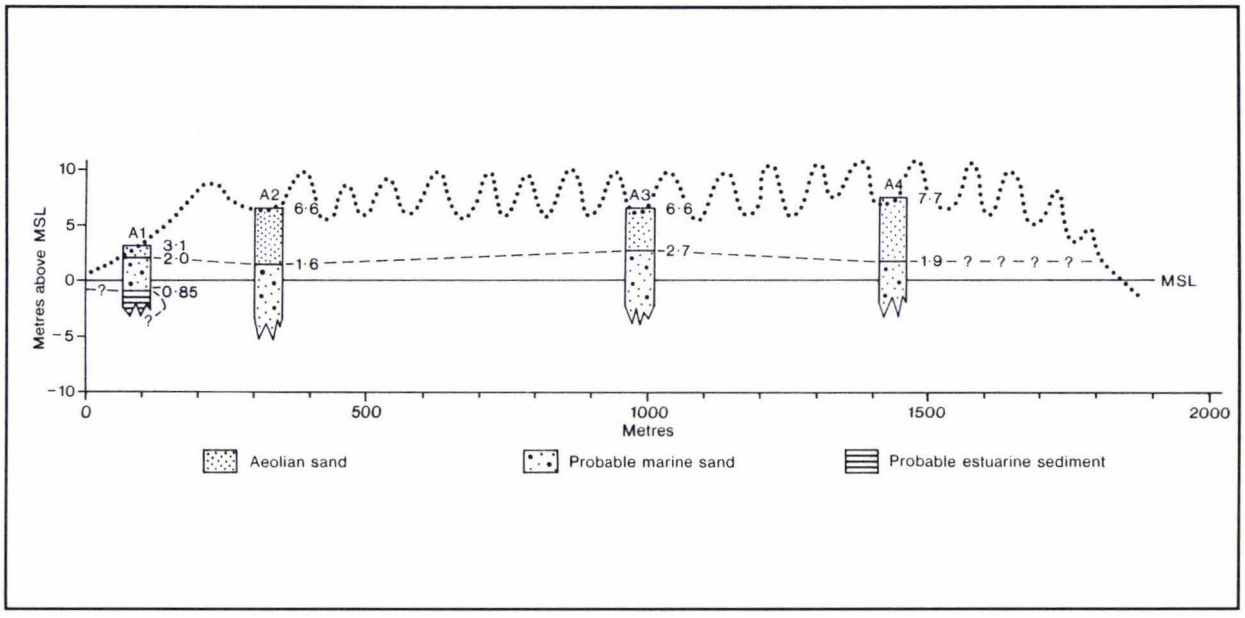


Figure 3.16: Schematic diagram showing hypothesised barrier stratigraphy as determined from Boreholes A1-A4 (ridges and swales not to scale).

The "coarser" sand in Boreholes A3 and A4 was much finer and better sorted than that in Boreholes A1 and A2 (Appendix 6), and lacked the shells, shell fragments, granules and pebbles. It was almost as fine as the overlying dune sand, but was distinguishable in Borehole A3 by the presence of heavy mineral seams which probably indicate the upper level of a former beach.

Marine sand in each borehole, indicated by heavy mineral seams and abraded shell fragments, has an upper limit within 1.3 metres of the contemporary high water swash mark (*c*.2.9 metres above mean sea level: see Section 2.1.2.1.1). The burial of estuarine sediments by marine and aeolian sand is typical of a backbarrier washover slope, as described in Section 2.1.2.5. This has been described from other Holocene barrier systems around the world (e.g., Roy *et al.* 1980), and is hypothesised by the dashed boundary between marine and estuarine sediments shown in Figure 3.16.

3.1.4 Discussion

The above analyses of sediment texture of the barrier have identified several important spatial patterns:

(1) Ocean beach sediments are fairly uniform in the northern and central parts of the barrier, but coarsen and become less well sorted southeastward of a point about 16 kilometres southeast of the Katikati Entrance (within about eight kilometres of the Tauranga Entrance). This pattern is directly reflected in the contemporary foredune sediments. Such a trend is consistent with the recirculation of coarse sediments onto the southeastern part of the barrier from the Tauranga ebb-tidal delta described by Davies-Colley (1976), Davies-Colley and Healy (1978b) and Dahm (1983), where coarse sand from within the Tauranga Entrance is transported to the ebb-tidal delta by the ebb jet and moved landward to the southeastern barrier shoreline by wave action (Barnett 1985). Consequently, the incorporation of coarse material into the barrier beach sediments is a function of the morphology and dynamics of the offshore ebb-tidal delta. The presence of this coarsening trend in the older beach sediments suggests that the Tauranga ebb-tidal delta has influenced the sediment characteristics of the southeastern barrier shoreline for a considerable part of the barrier's history. the barrier. This is discussed further in Chapter 5. A similar coarsening trend is evident in relict beach sediments towards the former harbour entrance at Blue Gum Bay suggesting a similar process operated on this part of the barrier during the early stages of barrier formation.

The lack of a similar trend adjacent to the Katikati Entrance may relate to the smaller size of the entrance or a lack of coarse material. However, a direct comparison between the southeastern end of the barrier (updrift of the Tauranga Entrance) and the northwestern end of the barrier (downdrift of the Katikati Entrance) may not be valid and further investigation would be required in order to explain the apparent lack of coarse sand on this latter part of the shoreline. A sample from the contemporary foreshore of Waihi Beach had similar textural properties to those of the northwestern barrier samples, suggesting that any interaction between the Katikati ebb-tidal delta and the shoreline had little influence on sediment texture at the time of sampling. However, coarse shelly sand is common inland from the shoreline near the Katikati Entrance, suggesting that coarser sediment from the ebb-tidal delta has been transported onshore in the past.

Sediment movement into the Katikati Entrance from the ocean beach had occurred prior to sampling, indicated by the fining of the Katikati Harbour beach sediments at the Katikati Entrance. The reverse appears to have occurred at the Tauranga Entrance, where coarse

sediments from the entrance and associated delta have been transported onto the ocean beach as described above.

(2) The sediments of the "Long Ridge" show a similar coarsening trend towards the southeast. Beach sediments below this and other relict foredune ridges also coarsen towards the Tauranga Entrance in a similar fashion to the contemporary beach sediments, suggesting an ebb-tidal delta was present off the Tauranga Entrance during earlier stages of barrier formation and had an influence on the adjacent beach sediments similar to that of the present delta.

(3) Beach sand underlying the innermost ridge was found to be substantially coarser than equivalent sediments further seaward as indicated by analysis of beach sediments near Blue Gum Bay (Section 3.1.1.6) and Boreholes A1-A4 (Section 3.1.3). Marine sands in Borehole A4 (see Appendix 6) are generally finer than corresponding sediments further landward, a change which may have resulted from a depletion of the offshore source for barrier sands, a process suggested by Tanner (1988). This trend was apparent in the marine sand samples described in Section 3.1.1.5 but not in the dune sand samples described in the transects, suggesting that although barrier sediments appear uniform from analyses of relict foredune sands, selective aeolian transport of fine sand may have disguised a landward-coarsening trend as suggested in Section 3.1.1.5 and by the boreholes.

The stratigraphy of the innermost ridge at Borehole A1 (Appendix 6), consisting of probable estuarine sediments overlain by marine and aeolian sands, supports a washover ridge origin for the ridge as suggested in Section 2.1.2.5. The coarsest sand at Borehole A2 has the characteristics of a basal transgressive layer of strongly reworked sediment which accumulated during and shortly after the Postglacial Marine Transgression (Thom 1984). The coarse sand at Borehole A1 represents a backbarrier washover deposit (Figure 3.16) 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 Boreholes A3 and A4 is relatively uniform, similar in grain 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 barrier sands deposited during progradation (Thom 1984).

(4) Away from the entrances the barrier dune sands are very uniform in texture. This suggests a shelf origin for the barrier sediments and demonstrates that throughout the history of the barrier the dominant direction of sediment movement has been shoreward. The southeastward extension of recurved spits in the vicinity of Blue Gum Bay suggests that longshore transport of sediment from the Coromandel coast to the north may also have contributed to progradation of the barrier, but the uniformity of the barrier sand suggests that reworked shelf sand was probably the ultimate source material in either case. A sample (Sample S1) from the recurved spit adjacent to the pre-barrier Holocene shoreline previously described is similar in texture and mineralogy to a sample (S2) from the barrier further seaward. This suggests that the innermost part of this part of the barrier was also constructed from sediments derived from the shelf, rather than sediments eroded from the Pleistocene part of the island.

A texturally distinctive sample from Transect 2 (Section 3.1.2.1) illustrates the temporary influx of sediments derived from the Taupo eruption. This is further supported by mineralogical evidence described below.

(5) Short-term variability in beach sediment texture is illustrated by the series of short beach-foredune transects in Section 3.1.2.2. Further sampling under a range of conditions would be required, but the available data and ancillary observations suggest these variations probably relate to wind and wave conditions prior to sampling.

(6) Sorting of sediments, a function of sediment transport and deposition mechanisms, is also related to mean grain size, finer sediments tending to be better sorted. This is illustrated by a size-sorting plot for all samples analysed, shown in Figure 3.17. Having originated largely from the continental shelf (Davies-Colley 1976, Davies-Colley and Healy 1978a, Dahm 1983, Abrahamson 1987, Healy and de Lange 1988, Hume and Herendorf 1992, Hume and Hicks 1993, Munro 1994), the barrier sediments probably underwent considerable sorting during reworking on the shelf prior to their incorporation into modern deposits. This would have limited the size range and imposed a degree of "pre-determined" sorting on the available sediments (Davies-Colley 1976), evident from the relative uniformity of sediment textural characteristics described here.

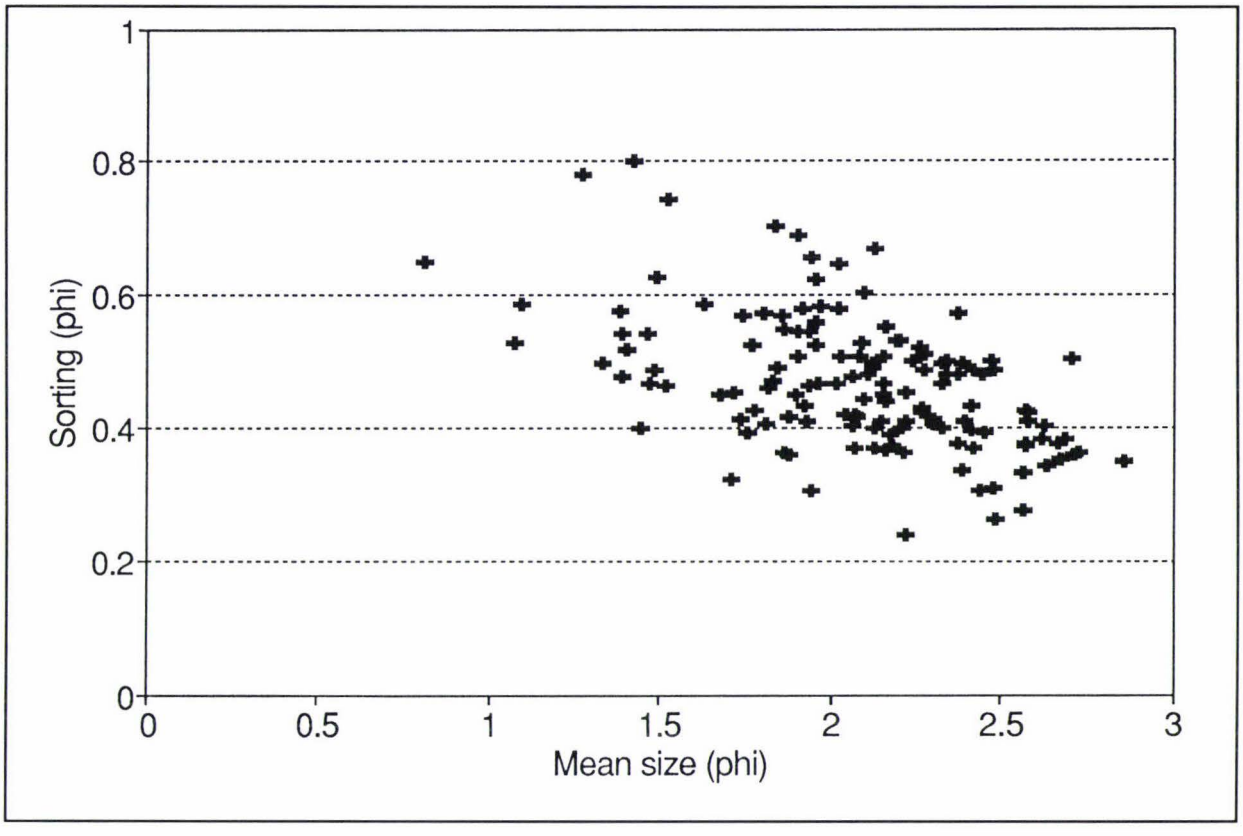


Figure 3.17: Mean size versus sorting for all samples, demonstrating a tendency for finer sediments to be better sorted.

(7) In all analyses carried out, skewness and kurtosis have contributed little to the identification of sedimentological trends. Skewness is a measure of the symmetry of a size distribution: negative skewness indicates an accentuated "tail" of coarse sediment (*coarse* skewness), while positive skewness indicates an excess of fines (*fine* skewness). Therefore, skewness reflects the degree of mixing of multiple sediment populations. In this study major departures from a symmetrical distribution are uncommon, suggesting a generally uniform sediment source. Baker (1968) considered kurtosis to be of little use as a grain size parameter and it has been of minimal value to this study. Similarly, Healy *et al.* (1977) did not consider kurtosis in their investigations into the sedimentology of the Bay of Plenty coast.

(8) The apparent lack of substantial variation in the elevation of the boundary between beach sand and dune sand across the barrier (Figure 3.16) suggests there has been no significant change in relative mean sea level throughout the evolution of the barrier, consistent with a stable sea level since the Holocene stillstand as postulated by Gibb (1986). If Gibb's sea level curve is correct, this would also suggest minimal vertical tectonic movements have occurred since barrier formation began. The proposed maximum subsidence rate of 120mm/1 000 years

in Section 2.1.1.2 is not inconsistent with the hypothesised barrier stratigraphy in Figure 3.16: this rate would translate to a total subsidence of about 0.72 metres over the last *c*.6 000 years, within the variability of the upper limit of marine sand between the boreholes.

3.2 MINERALOGY

Mineralogical analyses were carried out on sediment samples described above to further investigate sediment sources and transport patterns. The analyses comprised a determination of the total heavy mineral content of the sediments, followed by the identification of the mineralogy of the heavy and light fractions. In the following mineralogical plots, lines drawn between points on the plots serve only to distinguish between multiple series of points when more than two series are shown on the same graph. The raw data are provided in Appendix 7.

3.2.1 Total heavy mineral percentages

Heavy mineral separations were performed on samples from the four shore-normal transects described in Section 3.1.2.1 plus samples from the ocean beach and the Katikati and Tauranga Harbour shorelines.

3.2.1.1 Shore-normal variations

Sample locations for the transects are shown in Figure 3.9 and the data are plotted in Figure 3.18 below. High heavy mineral concentrations are clearly associated with the innermost ridge on the barrier (Transects 1 and 2), although peak concentrations in the innermost ridge are considerably lower for Transect 3 (Figure 3.18) where the innermost ridge at this location is of a younger age. Analysis of sediments from Transect 4 revealed considerably lower heavy mineral percentages in the innermost ridge, comparable to outer barrier sediment samples in the preceding three transects.

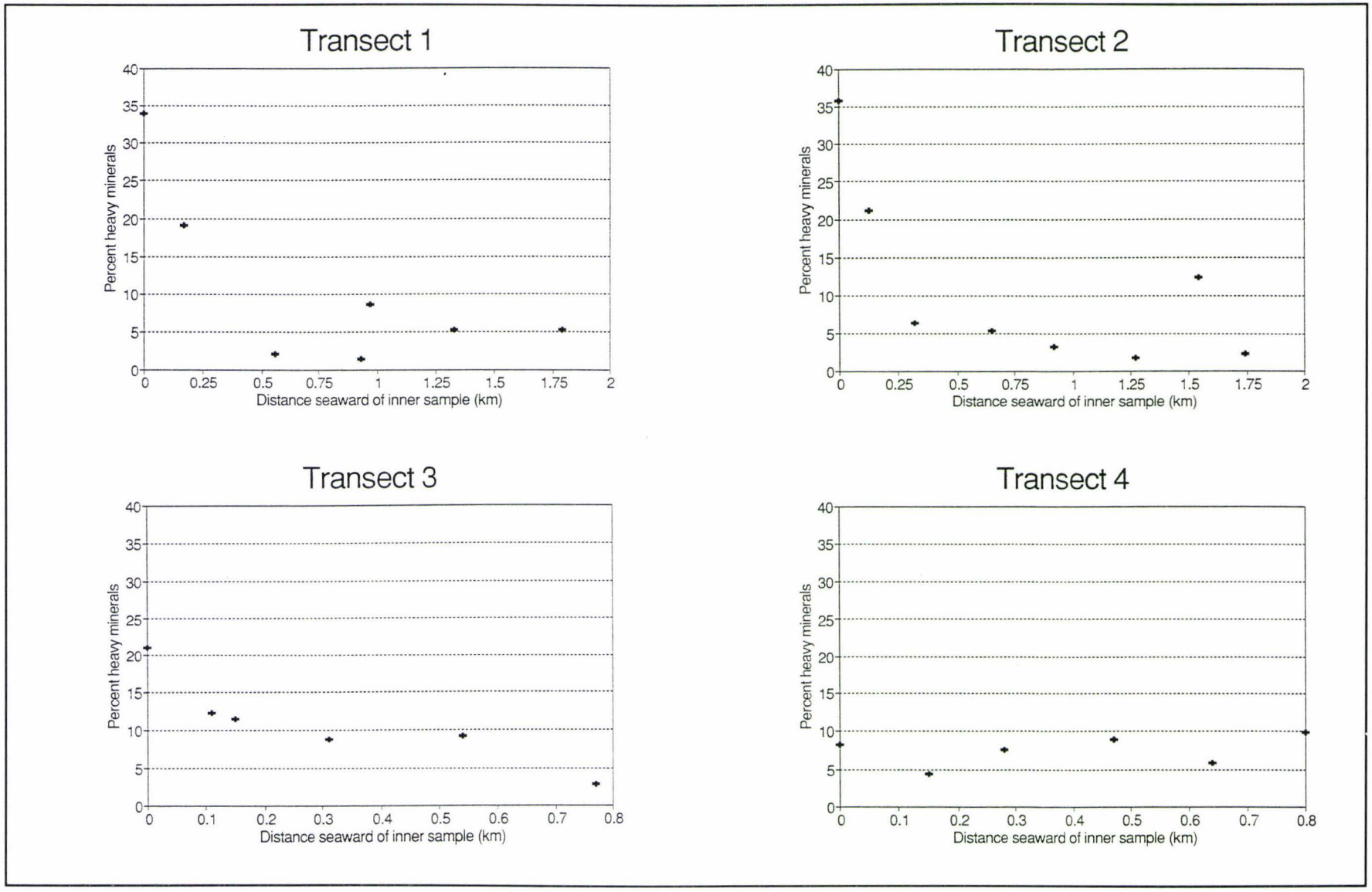


Figure 3.18: Heavy mineral percentage trends across the barrier.

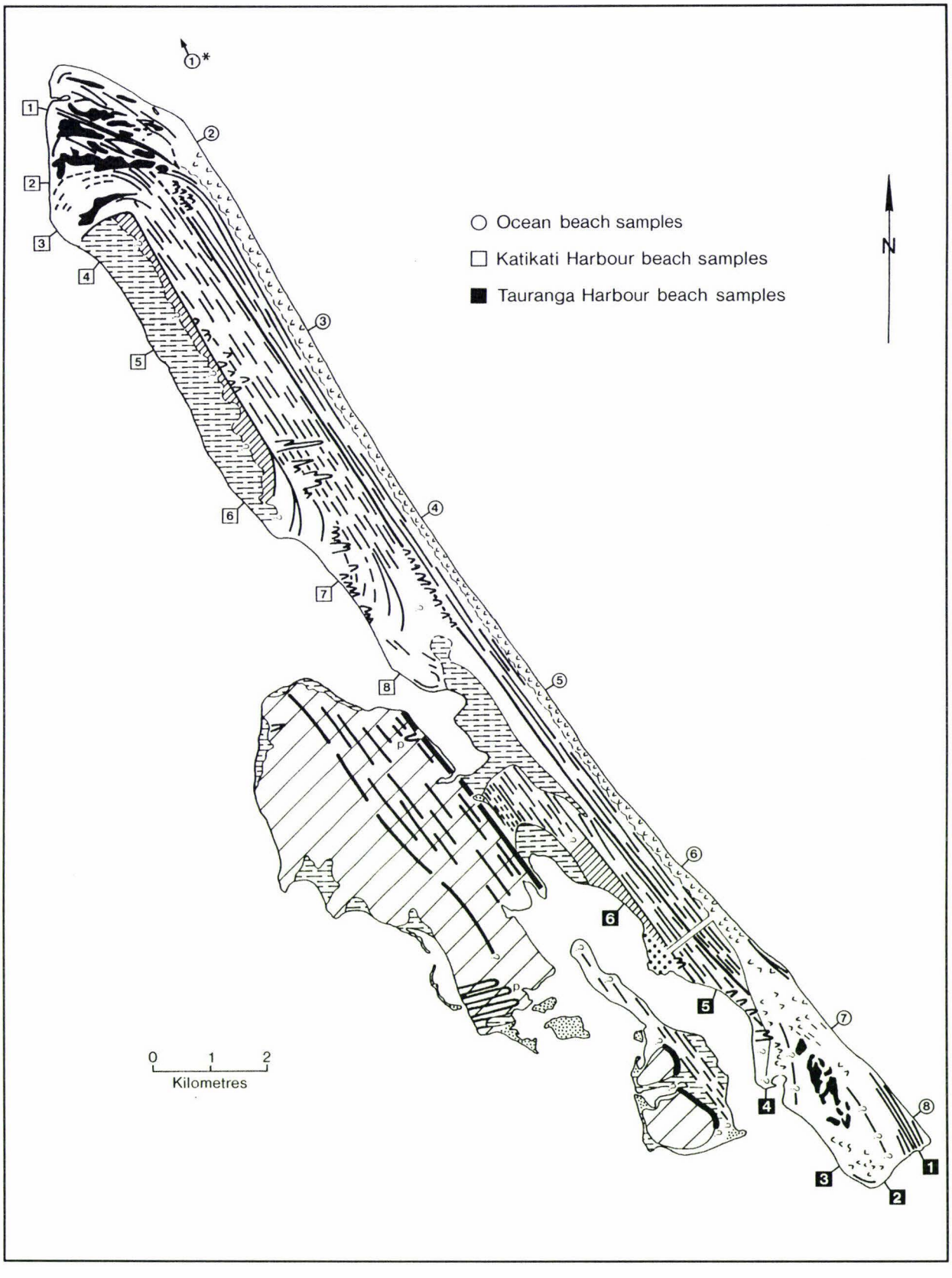


Figure 3.19: Locations of Ocean Beach, Katikati Harbour and Tauranga Harbour beach samples (Section 3.2.1.2). Ocean Beach sample 1 from Waihi Beach as for Figure 3.1.

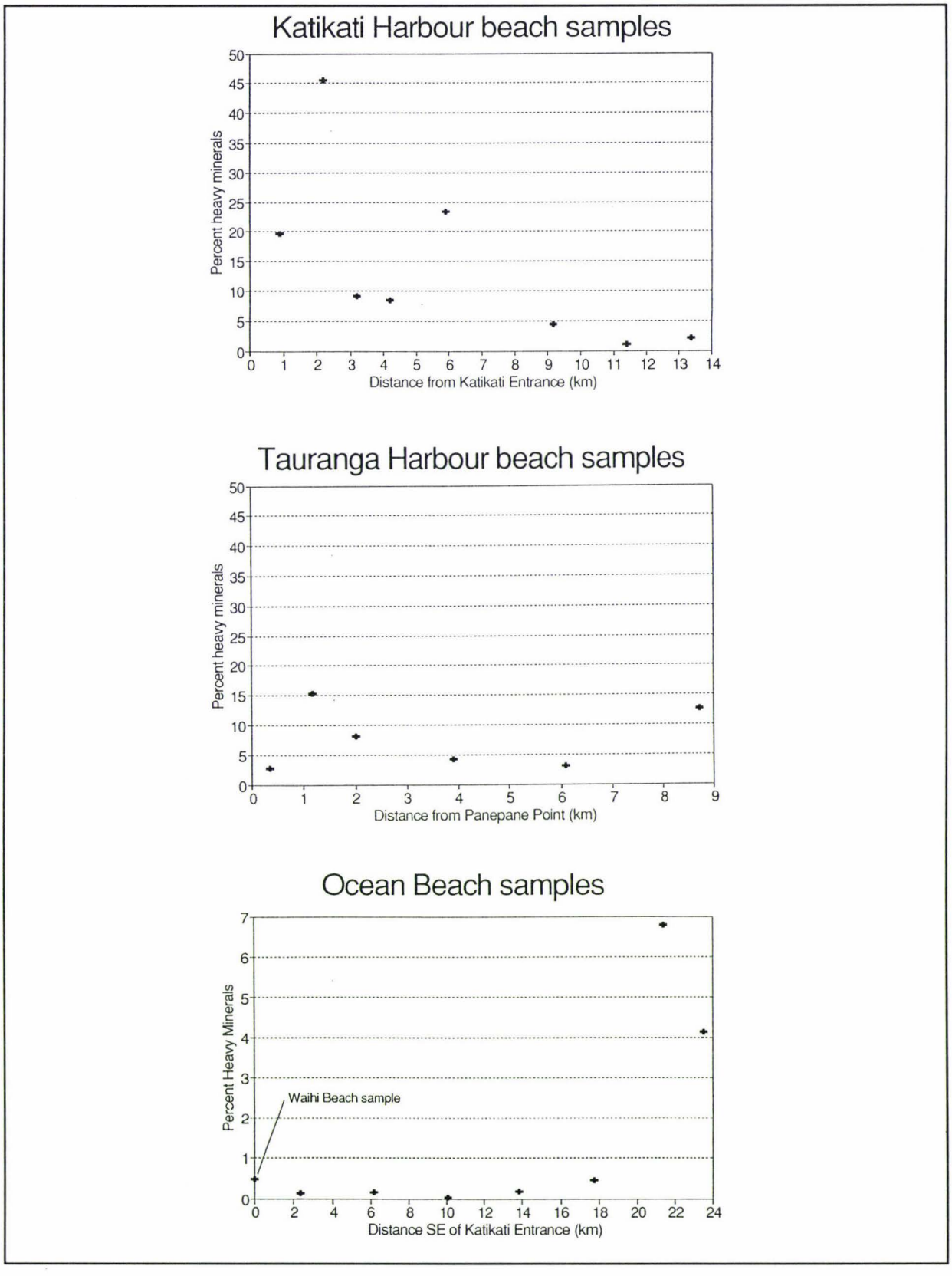


Figure 3.20: Heavy mineral concentrations along the Katikati Harbour, Tauranga Harbour and ocean shorelines (Section 3.2.1.2).

3.2.1.2 Variations along the shoreline

Samples collected from the ocean beach and the Katikati and Tauranga Harbour shorelines (Figure 3.19 above) vary considerably in heavy mineral concentration (Figure 3.20 above). Heavy mineral percentages decrease along the Katikati Harbour shoreline towards the central part of the barrier, but no trend is apparent along the Tauranga Harbour shoreline. Overall heavy mineral percentages are extremely low along much of the ocean beach, including the Waihi Beach sample, but increase sharply near the Tauranga Entrance apparently in association with the increase in mean grain size. This is discussed in Section 3.2.4.

3.2.2 Heavy mineral composition

This section describes and discusses the results of point-counting of the heavy mineral fractions, shown in Figures 3.21 and 3.22 below.

3.2.2.1 Shore-normal variations

Hypersthene is the dominant heavy mineral, typically accounting for between 50 and 70 percent of the heavy minerals. Hornblende is usually the next most abundant mineral, making up between 20 and 50 percent of the heavy minerals. With the exception of magnetite, the other heavy minerals vary irregularly up to approximately ten percent of the total heavy mineral content.

Magnetite percentages are often highly variable (e.g., Transect 4). No systematic variation is involved and the inclusion of magnetite-dominated heavy mineral seams in some of the samples may be responsible. Augite, rock fragments and other minerals have consistently low frequencies and typically show no spatial trends.

A marked change in between Samples 4 and 5 in Transect 1, where magnetite and hypersthene increase while hornblende decreases. This is discussed in Section 3.2.4.

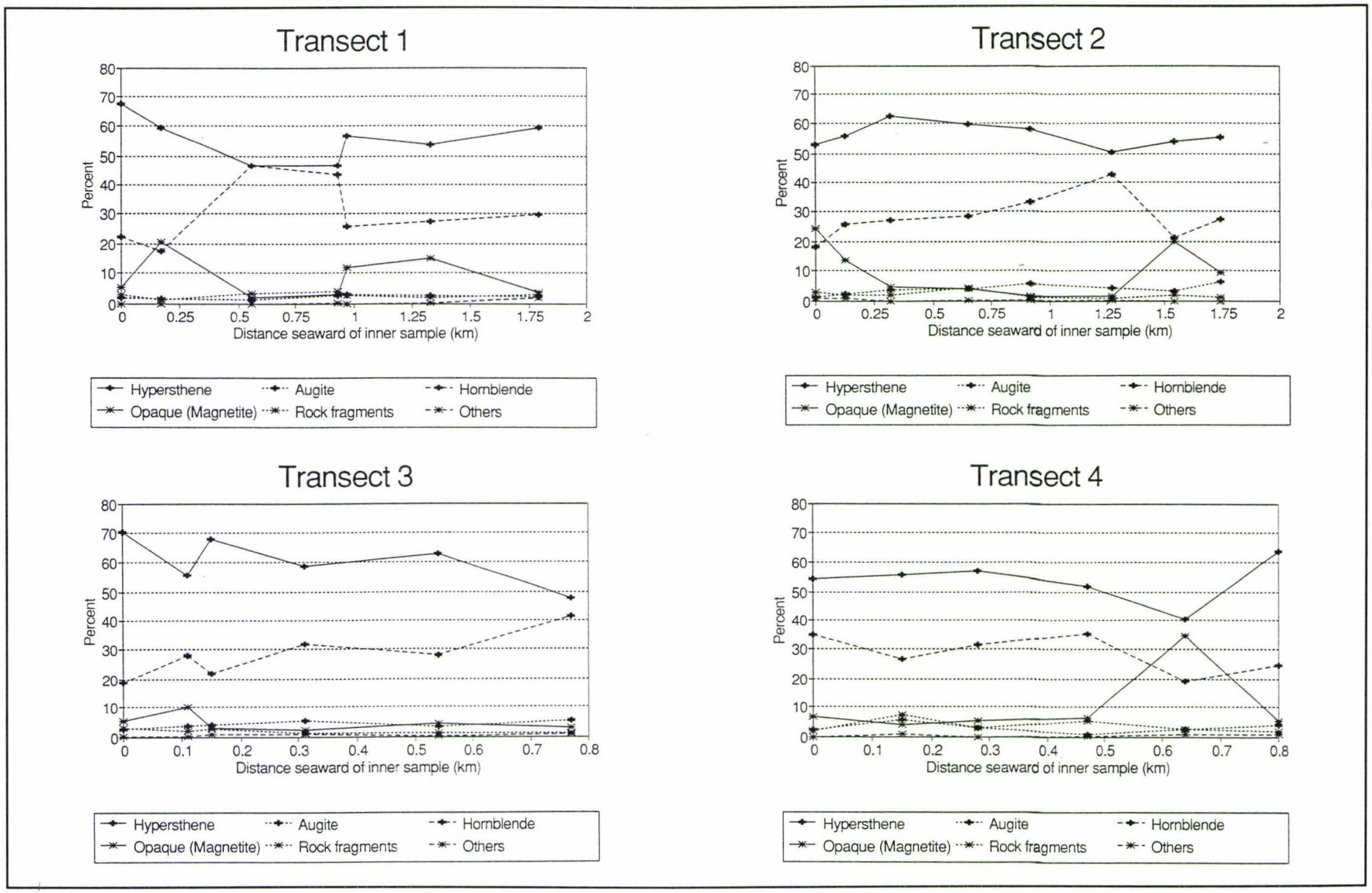


Figure 3.21: Heavy mineral composition, Transects 1-4.

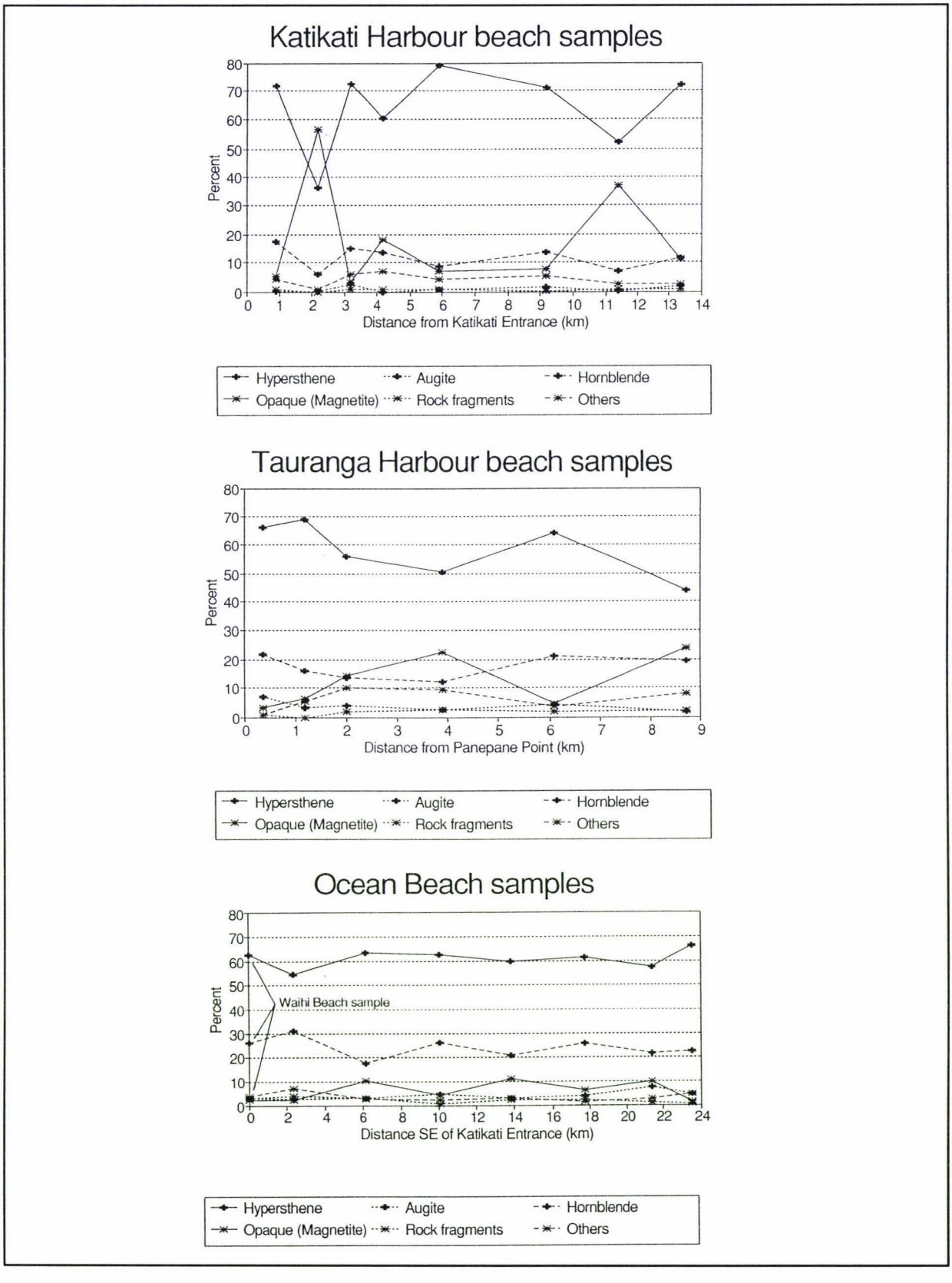


Figure 3.22: Heavy mineral composition along the Katikati Harbour, Tauranga Harbour and ocean shorelines.

3.2.2.2 Variations along the shoreline

These are plotted in Figure 3.22 above. The heavy minerals of the Ocean Beach samples are similar to those of the transects, consisting mainly of hypersthene, hornblende and magnetite in decreasing order of abundance. The harbour shorelines have a more variable mineralogy: hypersthene values range from approximately 40 to 80 percent and hornblende is generally less abundant than on the barrier or the ocean beach. Similarly to the transects, magnetite percentages are quite variable: a sharp peak occurs at the second sample from the Katikati Harbour shoreline.

3.2.3 Light mineral composition

3.2.3.1 Shore-normal variations

These are plotted in Figure 3.23 below, with quartz:glass and feldspar:glass ratios shown in Figure 3.24. A very uniform light mineral assemblage across the barrier is evident from Figure 3.23. Mineral proportions are generally 50-70 percent quartz, 20-30 percent feldspar, 5-15 percent rock fragments, 0-5 percent glass and a small shell fraction of up to about 1.3 percent which is restricted to the contemporary foredune.

The marked change between Samples 4 and 5 of Transect 1 described from heavy mineral analyses above is much less apparent from Figure 3.23. A considerable change in the light mineral assemblage occurs at Sample 6 of Transect 2, where glass and rock fragment percentages peak sharply while quartz and feldspar percentages decrease. Quartz:glass and feldspar:glass ratios are generally highest at the innermost part of the barrier, except at Transect 4.

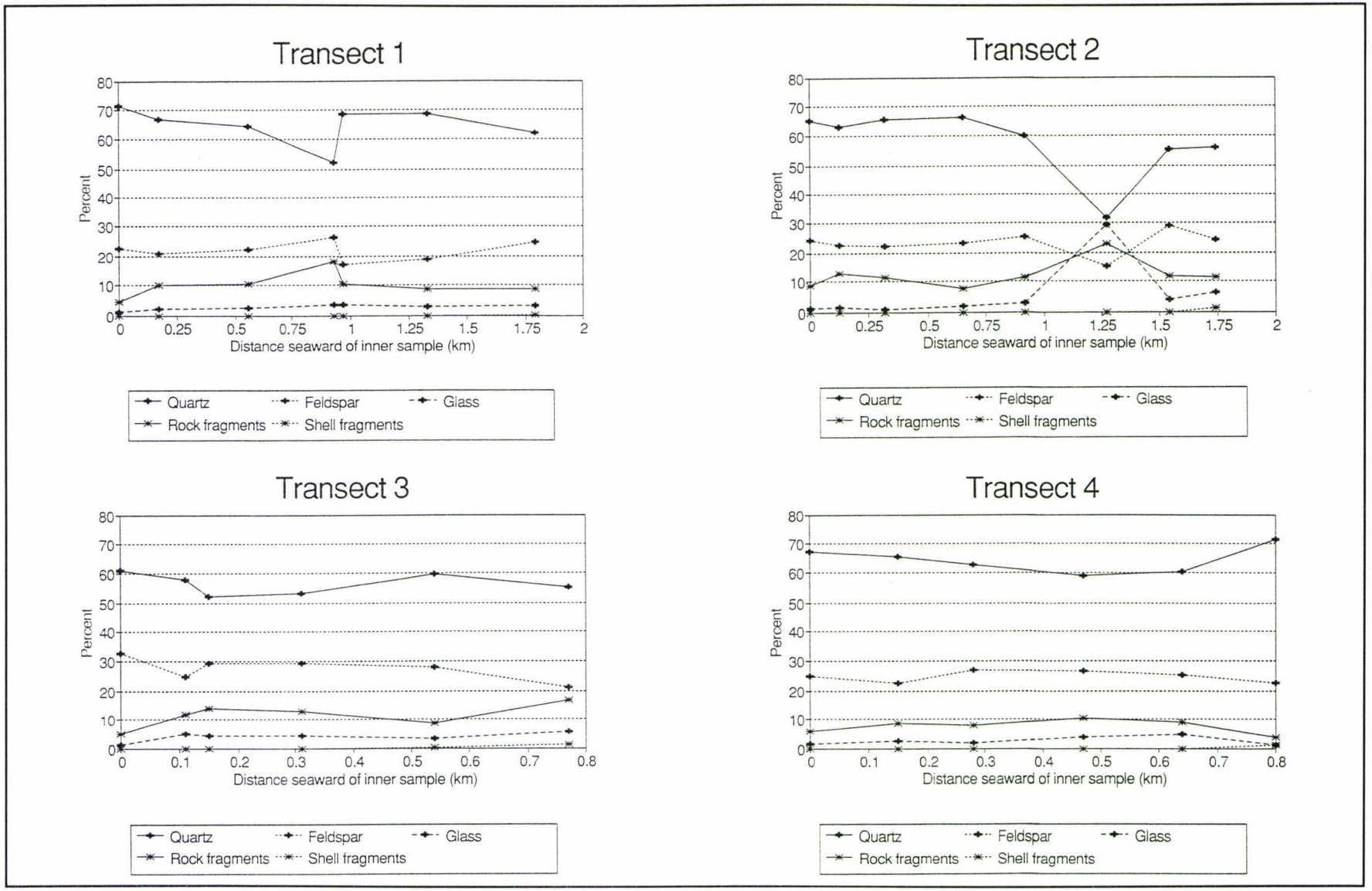


Figure 3.23: Light mineral composition, Transects 1-4.

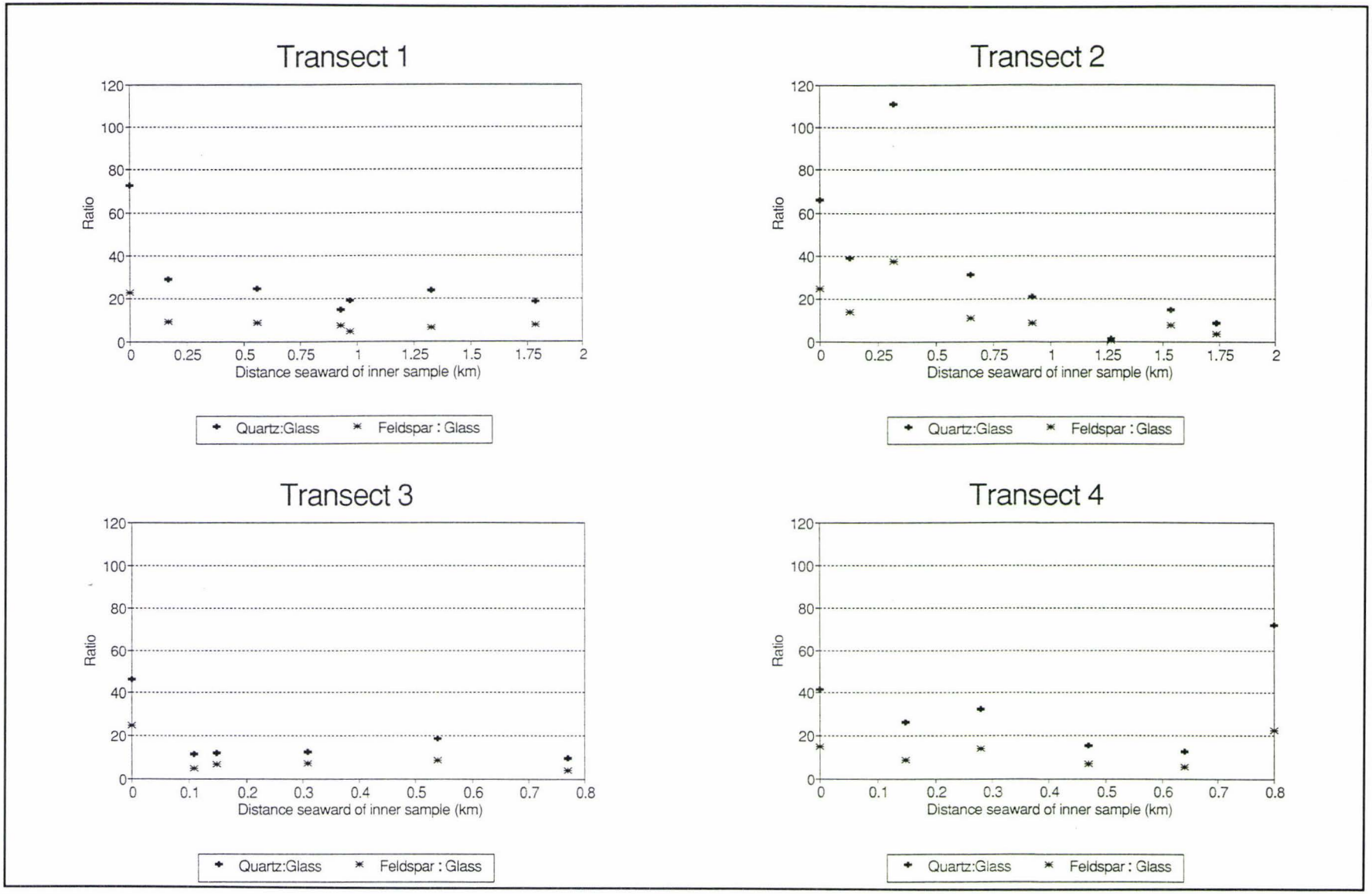


Figure 3.24: Quartz:glass and feldspar:glass ratios, Transects 1-4.

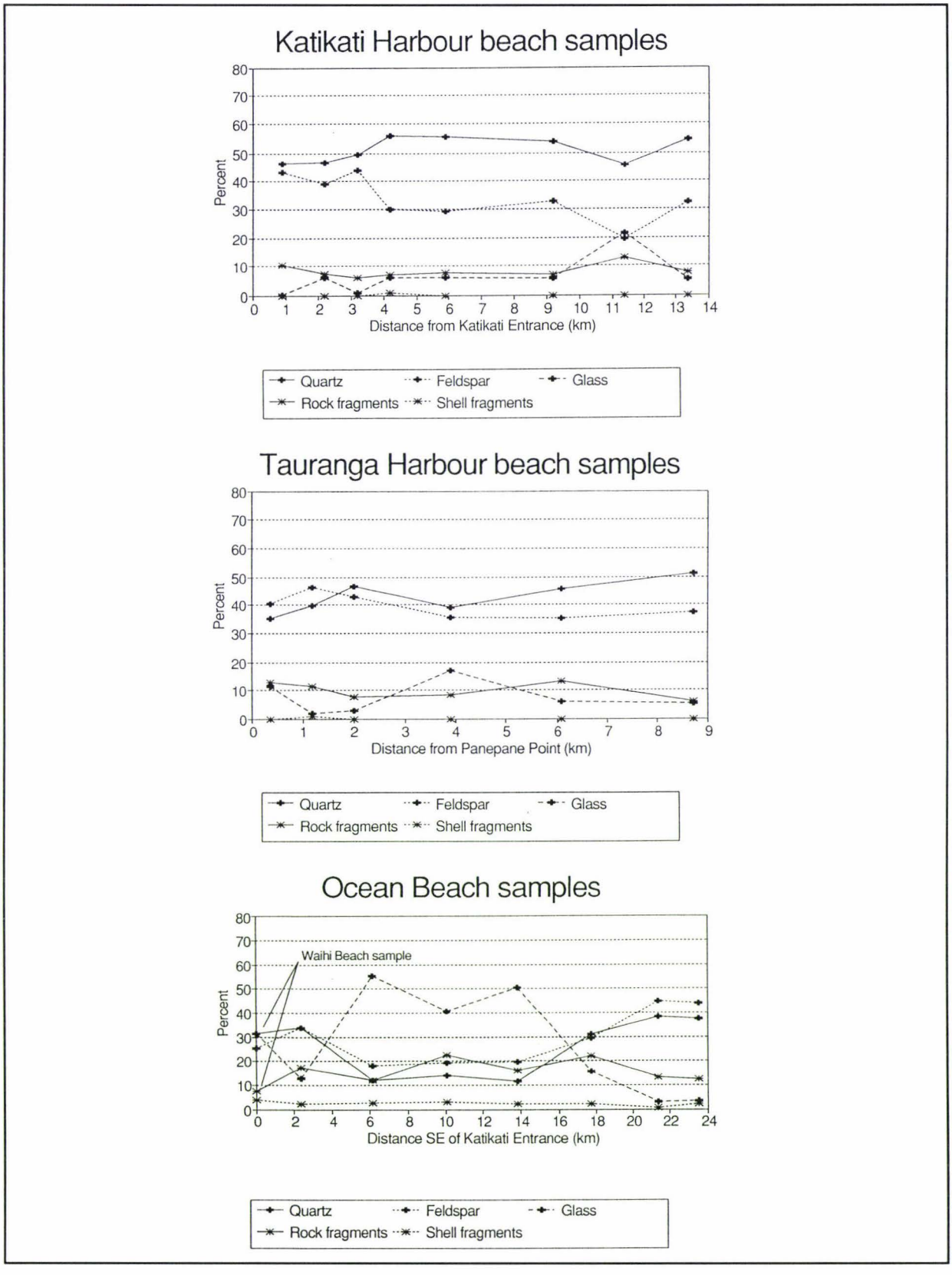


Figure 3.25: Light mineral composition along the Katikati Harbour, Tauranga Harbour and ocean shorelines.

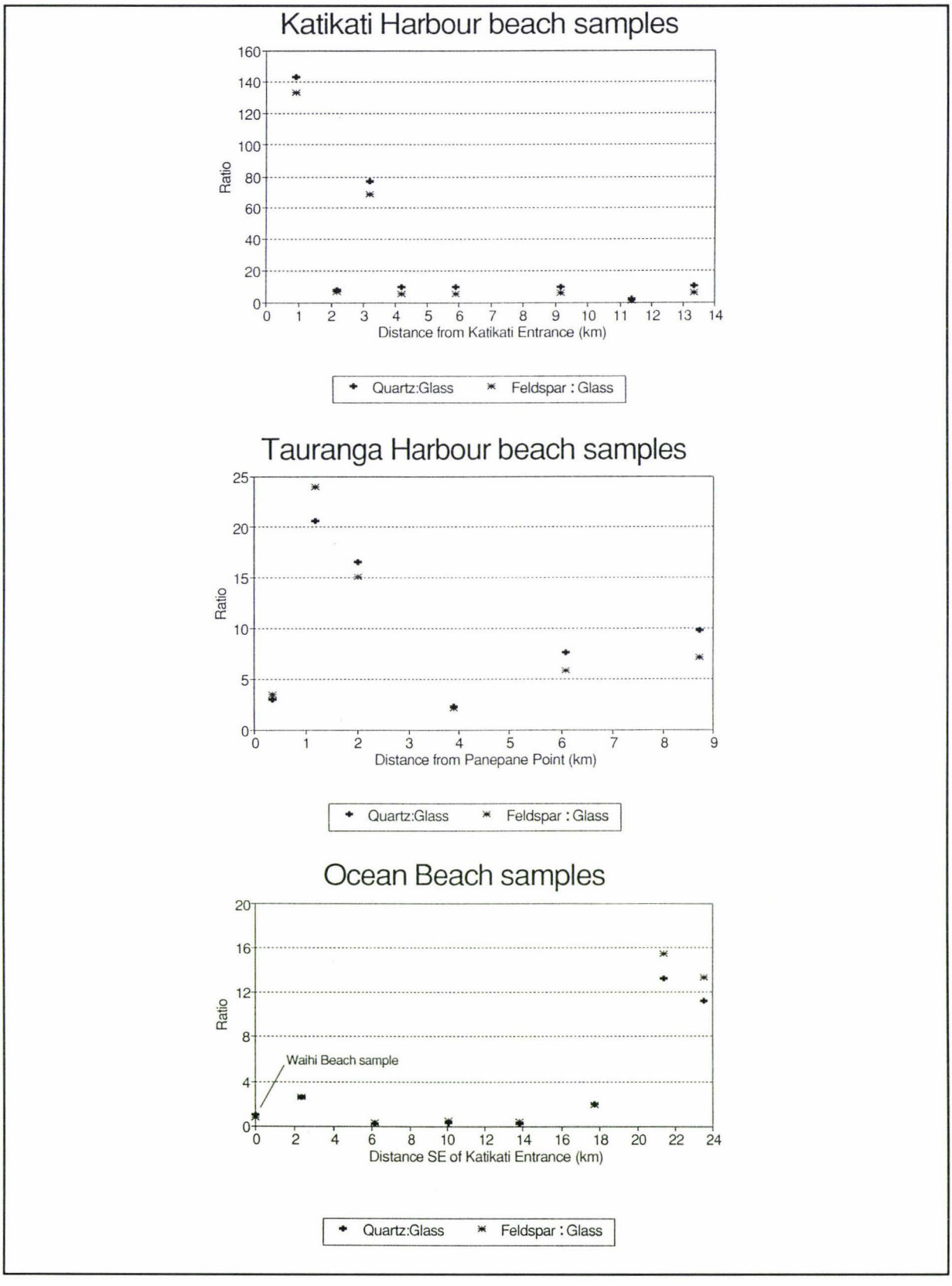


Figure 3.26: Quartz:glass and feldspar:glass ratios along the Katikati Harbour, Tauranga Harbour and ocean shorelines.

3.2.3.2 Variations along the shoreline

Ocean beach sediments (Figure 3.25 above) tend to contain less quartz and more glass and feldspar, and show considerable variability in composition. Glass and rock fragment percentages are highest along the central barrier and decrease near the harbour entrances. Glass percentages are particularly low near the larger Tauranga Entrance and consequently quartz:glass and feldspar:glass ratios are highest there (Figure 3.26 above).

Along the harbour shoreline, quartz and feldspar have similar abundances at the ends of the barrier, with quartz becoming dominant over feldspar towards the central part of the barrier. Quartz:glass and feldspar:glass ratios are highest at the ends of the barrier, decreasing towards the central part of the barrier.

3.2.4 Discussion

Existing studies indicate the beach sands of the Bay of Plenty littoral system consist mainly of plagioclase feldspar, quartz and volcanic glass in the light fraction (Healy *et al.* 1977). Plagioclase feldspar dominates the sediments of the Mount Maunganui tombolo, with an apparent lack of quartz (Cole 1967), although Healy and de Lange (1988) state that quartz, pumice, volcanic glass and rock fragments are all represented on both Matakana Island and the Maunganui tombolo. Heavy minerals present on the Mount Maunganui tombolo are predominantly hypersthene, hornblende and magnetite (Cole 1967).

Davies-Colley (1976) reported carbonate contents as high as 89.6 percent in sediment samples recovered from major tidal channels in Tauranga Harbour, where channel armouring by shell lag deposits is common (Davies-Colley and Healy 1978a). Quartz, feldspar and volcanic glass with a small fraction of heavy minerals (up to 11 percent) constitute the remainder of Tauranga Harbour sediments. The heavy fraction is dominated by hornblende, hypersthene and magnetite (Davies-Colley 1976, Davies-Colley and Healy 1978), with augite common in the sediments of Waikaraeo Estuary (White 1979).

At Waihi Beach, the light fraction of beach sands comprises predominantly feldspar, quartz,

volcanic glass and a small proportion of shell fragments, with a heavy fraction (up to 23 percent) dominated by hypersthene, hornblende and calcic amphibole (Harray and Healy 1978).

The investigations into the mineralogy of the Matakana Island barrier in this study indicate the sands have a similar composition to those described from the literature above, although quartz appears to be more dominant. Several samples were stained following the procedure of Lewis and McConchie (1994) to verify the results of point counting and confirmed the general dominance of quartz over feldspar.

The generally uniform barrier mineralogy suggests a uniform sediment source for barrier progradation throughout the mid- to late Holocene. Beach, harbour and shelf sediment mineralogy described in the literature indicates that the active Taupo Volcanic Zone is probably the original source of coastal sediments (Davies-Colley 1976, Healy 1977, Davies-Colley and Healy 1978a, White 1979, Dahm 1983). During the last period of glacially-lowered sea level, these materials (as constituents of the Pleistocene "Tauranga Beds" described in Section 1.2.1) underwent fluvial incision and were redeposited on the continental shelf as alluvial and deltaic sediments (Dahm 1983). During and after the Postglacial Marine Transgression, these sediments were moved landward by wave action and became available for coastal progradation following the stillstand (Dahm 1983), as described above. The principal constituents of the beach and harbour sediments in the vicinity of Tauranga Harbour are well represented on the continental shelf (Dahm 1983), suggesting the shelf was the major sediment source for barrier progradation. Onshore sediment from the continental shelf has also been reported from the South Kaipara barrier (Schofield 1975), coastal barrier systems of southeastern Australia (Roy *et al.* 1980, Roy and Thom 1981, Thom *et al.* 1981, Chapman *et al.* 1982, Thom *et al.* 1992), Western Australia (Shepherd 1981) and the Americas (Tanner 1988).

A *temporary change* in sediment supply is indicated by Sample 6 from Transect 2 which is also distinctive in texture (Section 3.1.2.1). As described above, this indicates that material from the Taupo eruption was temporarily a major source of sediment to the ocean shoreline. An abrupt change in the heavy mineral assemblage between Samples 4 and 5 along Transect

1 (Figure 3.21) coincides with the marked change in relict foredune morphology described in Chapter 2 (Figure 2.15). It appears likely that the two phenomena are related, as suggested in Section 5.1.9.

Relatively high heavy mineral and low glass and rock fragment contents characterise the innermost ridge. High heavy mineral concentrations within the innermost part of the barrier at Transects 1 and 2 parallel the findings of Baxter (1977) and Thom (1984), who documented similar patterns in the mineralogy of coastal barrier systems in parts of Australia. Preferential seaward transport of light sedimentary particles by asymmetrical wave-induced bottom currents (Zenkovich 1967) is often reflected in a relatively high content of heavy minerals in transgressive sand facies at the innermost part of a prograded barrier system. In addition, washover ridges commonly have a high heavy mineral content as a result of the winnowing out of lighter minerals by washover processes.

The inner ridges occurring on Transects 1 and 2 are absent from Transect 3, where the innermost ridge of this part of the barrier corresponds to approximately the central part of the barrier further northwest. The innermost ridge at Transect 3 shows limited evidence of washover processes, which may account for its lower heavy mineral concentration.

Reworking of the sediments tends to preferentially remove and/or destroy the softer, lighter glass fraction (Healy 1978c) and disaggregate rock fragments into their constituent mineral grains. The lower rock fragment and glass contents (and consequently high quartz:glass and feldspar:glass ratios) of the innermost ridge (Figures 3.23 and 3.24) reflect a probable greater degree of reworking of the inner barrier sediments, consistent with the suggested transgressive and washover origin of the innermost ridge. This probably involved a long period of reworking of the sediments as sea level rose towards the present level. The original innermost ridge on the part of the barrier crossed by Transect 4 has been removed by harbour shoreline recession, accounting for the absence of evidence for sediment reworking on the present inner part of this part of the barrier.

With all other factors equal, heavy mineral percentages tend to be higher in reworked sediment than in first-cycle sediment (M.J. Shepherd, pers. comm. 1995), a phenomenon also

apparent from plots of quartz:glass and feldspar:glass ratios against percent heavy minerals. Therefore, high heavy mineral contents together with relatively high quartz:glass and feldspar:glass ratios can be interpreted as good indicators of reworked sediments. For example, heavy mineral percentages increase along the ocean beach near the Tauranga Entrance in association with high quartz:glass and feldspar:glass ratios. This, in addition to the interpretations of sediment texture described in Section 3.1, confirms the recirculation of reworked sediments from the Tauranga Entrance onto the southeastern end of Matakana Island documented by Davies-Colley (1976), Davies-Colley and Healy (1978b) and Dahm (1983). The relatively high glass percentages away from the entrances may have been related to the calm conditions at the time of sampling, possibly leading to the preferential onshore movement of fine sediments (see Section 3.1.2.2) and those of lower specific gravity (such as glass).

Sediment exchange between the harbour and the ocean shoreline is also indicated at the Katikati Entrance by the mineralogical similarity of the Waihi beach sample to that of the samples from the nearby ocean beach and harbour shoreline of the barrier. A common sediment source and/or sediment transport between these locations appears likely. This is supported by Harray and Healy (1978), who suggest that littoral drift towards the southeast probably leads to the transport of sediment from Waihi Beach onto the Katikati delta, where it either moves into the harbour or bypasses the entrance and moves onto the Matakana barrier.

The harbour beach sediments show considerable spatial variation in heavy mineral content. Much of the variation in these sequences is probably related to localised concentrations of heavy minerals by harbour waves (Figure 3.27), rather than an overall change in the shoreline sediments *per se*. One sample from the Katikati Harbour shorelines in particular had a heavy mineral concentration of over 45 percent, which Figure 3.22 shows to consist primarily of magnetite. It is possible that composite samples of a greater depth range (say several tens of centimetres) than those collected in this study would help avoid the spurious results which may arise from the presence of heavy mineral seams in the harbour beach sediments. Such deposits were observed to be up to 30 centimetres thick in places.

Figure 3.27: An active swash bar along the southern margin of Rangiwaea Island. Note the wave-concentrated heavy minerals in the foreground. View to the northeast.

Variability in light mineral assemblages along the harbour shorelines may relate to variability in the source of harbour beach sediments, which may originate from longshore transport by harbour currents and waves or erosion of the inner barrier as is occurring at Hunter's Creek. Wave energy variability may also play a role. Quartz:glass and feldspar:glass ratios increase at the ends of the barrier, a pattern which may be related to the more intense reworking of harbour sediments and consequent destruction of glass at the ends of the barrier, where the major tidal channels of the harbour occur. It may also relate to the lower specific gravity of glass, which would tend to be preferentially removed from sites of high current energy and deposited where energy is lower, such as near the central barrier harbour shoreline in the vicinity of Blue Gum Bay and the head of Hunter's Creek.

3.3 CONCLUSIONS

The textural and mineralogical investigations carried out in this study have identified significant trends in the sediment characteristics of the Matakana Island barrier:

(1) Barrier sediments are generally both texturally and mineralogically uniform, except within a few kilometres of the Tauranga Entrance where there is significant variation. The uniformity suggests a uniform sediment source throughout the evolution of the barrier. The source is thought to have been primarily the continental shelf as has also been suggested in the literature regarding the Bay of Plenty and other sandy coasts, both within New Zealand and overseas. Contributions of sediment from the Coromandel coast by longshore transport are also likely. A temporary disruption to the uniformity of sediments in the later stages of barrier formation, a result of the Taupo eruption, is apparent from Transect 2. The entire barrier southeast of the escarpment near the Mill (see Section 2.1.2.2) consists of sediments which are considerably coarser than those elsewhere on the barrier. The significance of the coarse sediments of this part of the barrier is discussed in Chapter 5.

(2) Textural and mineralogical evidence from the innermost part of the barrier suggests that the sediments of the innermost ridge underwent considerable reworking prior to deposition. This is consistent with a washover origin for this ridge, a hypothesis supported by morphological evidence (Section 2.1.2.5) and also by the presence of probable estuarine sediments overlain by marine sands on the harbourward margin of this ridge (Section 3.1.3).

(3) Interaction between the Tauranga Entrance and the adjacent southeastern barrier is clearly demonstrated by sediment textural and mineralogical variations near the Tauranga Entrance. The variation is consistent with the findings of Davies-Colley (1976), Davies-Colley and Healy (1978b) and Dahm (1983) regarding the recirculation of ebb-tidal delta sediments to the southeastern end of the barrier by currents and wave action. Relatively high heavy mineral contents and high quartz:glass and feldspar:glass ratios at this end of the barrier also suggest sediment reworking in association with the Tauranga Entrance.

(4) Textural and mineralogical variations are not a feature of the shoreline sediment at the Katikati Entrance. Interaction between the Katikati ebb-tidal delta and the adjacent barrier shoreline is evident from the morphology of relict foredunes and the present shoreline, but this does not appear to have influenced sediment characteristics, at least at the time of sampling. Harbourward transport of ocean beach sand at the Katikati Entrance previously suggested by Harray and Healy (1978) is confirmed, but there is no evidence for sediment reworking and recirculation of entrance and delta sediments as at the Tauranga Entrance. Observations of coarse shelly sediments at the surface inland of the present shoreline at this end of the barrier suggest that the apparent lack of such sediment at this entrance may be a temporary phenomenon, although further investigation is required.

Chapter Four: *Chronology of the Matakana Island Barrier*

4.1 DATING TECHNIQUES

This study uses both *numerical-age* and *relative-age* methods (Colman *et al.* 1987). Numerical ages have been derived primarily by radiocarbon dating, with historical changes determined from published records and cadastral maps. Relative ages are gained from tephrochronology, a soil chronosequence developed on the barrier and archaeological investigations.

This chapter presents the results of the use of these techniques to determine the chronology of the Matakana Island barrier. Details of the locations of dated samples and their radiocarbon ages are listed and mapped and the spatial distributions of Holocene tephra deposits are also mapped. Historical shorelines were obtained from cadastral maps. A soil chronosequence occurring on the barrier is described and the abundant prehistoric Maori occupation sites (with characteristic large shell middens, some of which have been radiocarbon dated) on the barrier are also used as chronological markers.

This information is then used to determine the chronological development of the barrier. Palaeoshorelines are established for various stages during the mid- to late Holocene and the ages of relict transgressive dunes on the barrier are also determined.

4.1.1 Radiocarbon dating

Thirteen samples for radiocarbon dating were collected from the barrier (Table 4.1). Sample locations are shown on the landform map (Map 1) in the folder at the rear of this thesis.

Table 4.1: Details of ^{14}C dates

Field Reference	Laboratory No.	$\delta^{13}C$ ‰	Conventional Radiocarbon Age Years BP (1950)	Calibrated Age, Years BP (95% Confidence Interval	Material Dated	NZMS 260 Grid Reference	Depth Below Ground Surface (m)
AK2[1] (5.9-6.4)	NZA-3878	+1.91	5 635 ± 69	6 205-5 905	Marine shells (*Zethalia zelandica*)	U13 775037	5.90-6.40
AK2[1] (9.5-10.1)	NZA-3879	+1.74	7 697 ± 70	8 295-7 975	Marine shells (*Zethalia zelandica*)	U13 775037	9.50-10.10
AK4[1] (8.0-8.2)	NZA-3880	+1.39	8 703 ± 72	9 490-9 195	Marine shells (*Zethalia zelandica*)	U13 796016	8.00-8.20
CS 190	NZA-4654	-38.85	10 991 ± 94	13 070-12 665	Estuarine sediment	U14 807973	1.90
CS 293	NZA-4833	-31.23	8 243 ± 88	9 425-8 950	Plant material	U14 807973	2.93
E11	NZ-7997	+1.60	2 114 ± 46	1 830-1 590	Marine shells (*Paphies ventricosa/subtriangulata, Maurea tigris, Spisula aequilateralis, Paphies australis, Tawera spissa, Chione stutchburyi, Myadora boltina*)	U14 879917	0.45-1.40
E3	NZ-8021	+1.70	701 ± 31	435-295	Marine shells (*Struthiolaria papulosa, Paphies australis*)	U14 884920	0.70-1.20
M2	NZ-8125	+1.50	667 ± 36	415-270	Midden shells (*Paphies subtriangulata*)	U14 862935	1.30
U14/-	NZ-8187	+0.10	677 ± 29	415-280	Midden shells (*Paphies subtriangulata*)	U14 863933	0.30
CR1	NZ-8235	+1.30	4 914 ± 65	5 435-5 050	Marine shells (*Zethalia zelandica, Spisula aequilateralis, Paphies subtriangulata*)	U13 800006	0.90-1.10
DT1	NZ-8236	+1.50	5 462 ± 68	6 015-5 695	Marine shells (*Zethalia zelandica*)	U14 820988	4.35-4.45
KG1	NZ-8294	-25.50	1 449 ± 51	1 400-1 195	Kauri gum	U13 753071	0.10
M1 (1995)	NZ-8311	-0.10	751 ± 37	480-315	Midden shells (*Paphies australis*)	U14 882905	2.15

Footnote: [1] AK2 renumbered to A2; AK4 renumbered to A3.

Two samples from the swamp core described in Appendix 1 were submitted for AMS dating (NZA-4654 and NZA-4833), as were three shell samples (NZA-3878, NZA-3879 and NZA-3880) recovered from boreholes. All other samples were submitted for conventional dating by gas counting. To the knowledge of the author, a sample of kauri gum recovered from the northwestern end of the barrier (NZ-8294) is the first such sample dated in New Zealand. Reworking of shell material used for dating (see Section 5.1.14.2) has meant the radiocarbon ages reported here are regarded as maximum ages only. Where radiocarbon ages and tephrochronological evidence conflict, the former have been disregarded.

4.1.2 Tephrochronology

Tephrochronology involves the identification, dating and correlation of airfall volcanic deposits. While strictly referring to primary airfall deposits, the term "tephrochronology" is also applied here to water-borne pumice deposits, which are reworked airfall tephric material.

Identifiable and correlable tephra and pumice deposits are useful markers for the dating of palaeoshorelines from which former rates of shoreline progradation can be derived. Pullar and Selby (1971) and Wigley (1990) used this technique to establish rates of progradation for the Rangitaiki Plains and Te Puke lowlands respectively. Pumice shorelines have been used as chronological markers in coastal studies by Wellman (1962), Pullar and Selby (1971) and McFadgen (1982, 1989, 1994).

Airfall tephra deposits are best preserved in topographic lows, such as swales (Munro 1994), as preservation is often reduced or prevented on topographic highs by aeolian erosion and slope wash processes. Similarly, tephra deposited on an incipient foredune may be completely removed together with the dune by storm waves, reducing the spatial distribution of the tephra following deposition. Therefore, the seaward limit of a tephra deposit does not necessarily represent the exact position of the shoreline at the time of deposition and should thus be regarded as providing a *maximum age* for the palaeoshoreline.

Identifiable airfall tephras and sea-rafted pumices occurring on the Matakana Island barrier (Figure 1.5) are described in Section 1.2.2. As mentioned in that section, tephra deposits older

than the Taupo Tephra were probably deposited on the barrier, but their poor or non-preservation has prevented any study of their distributions. However, a tephra deposit of approximately one centimetre in thickness has been observed in two sections on the inner barrier: one at Hunter's Creek (grid reference NZMS 260 U14 858936) and the second near the Matakana Mill (grid reference NZMS 260 U14 846944). Glass chemistry suggests this tephra was derived from the Taupo Volcanic Centre (Mr A. Hammond, pers. comm. 1995). At Hunter's Creek it is preserved within unweathered relict foredune sand, suggesting deposition on an actively accreting foredune. On the basis of this and the locations of this section *c*.300 metres landward of the Waimihia Pumice shoreline (see Figure 4.1), the deposit is tentatively correlated with the Stent tephra described by Alloway *et al* (1994). This tephra has not been identified elsewhere on the barrier.

The use of water-borne pumice for dating coastal deposits is not always reliable, because pumice may be reworked at any time after the time the primary deposit was formed. For this reason, some workers regard pumice shorelines as being too unreliable to be of any practical use as chronological markers and recommend they not be used (e.g., Pullar *et al.* 1977, Osborne *et al.* 1991). However, any identifiable pumice deposit, primary or secondary, is still useful for dating and correlation because it provides a maximum age for subsequent deposits (McFadgen 1994).

Pumice can be a useful chronological marker even when derived from a distant source. For example, pumice erupted from the South Sandwich Islands during March 1962 was deposited on beaches of southern New Zealand during 1964. The pumice had travelled a nett distance of some 13 000 kilometres, illustrating the potential for some pyroclastic materials to be transported for great distances (Coombs and Landis 1966).

Investigations into the spatial distributions of tephra and pumice deposits has facilitated the dating of six palaeoshorelines, mapped in relation to barrier geomorphology in Figure 4.1.

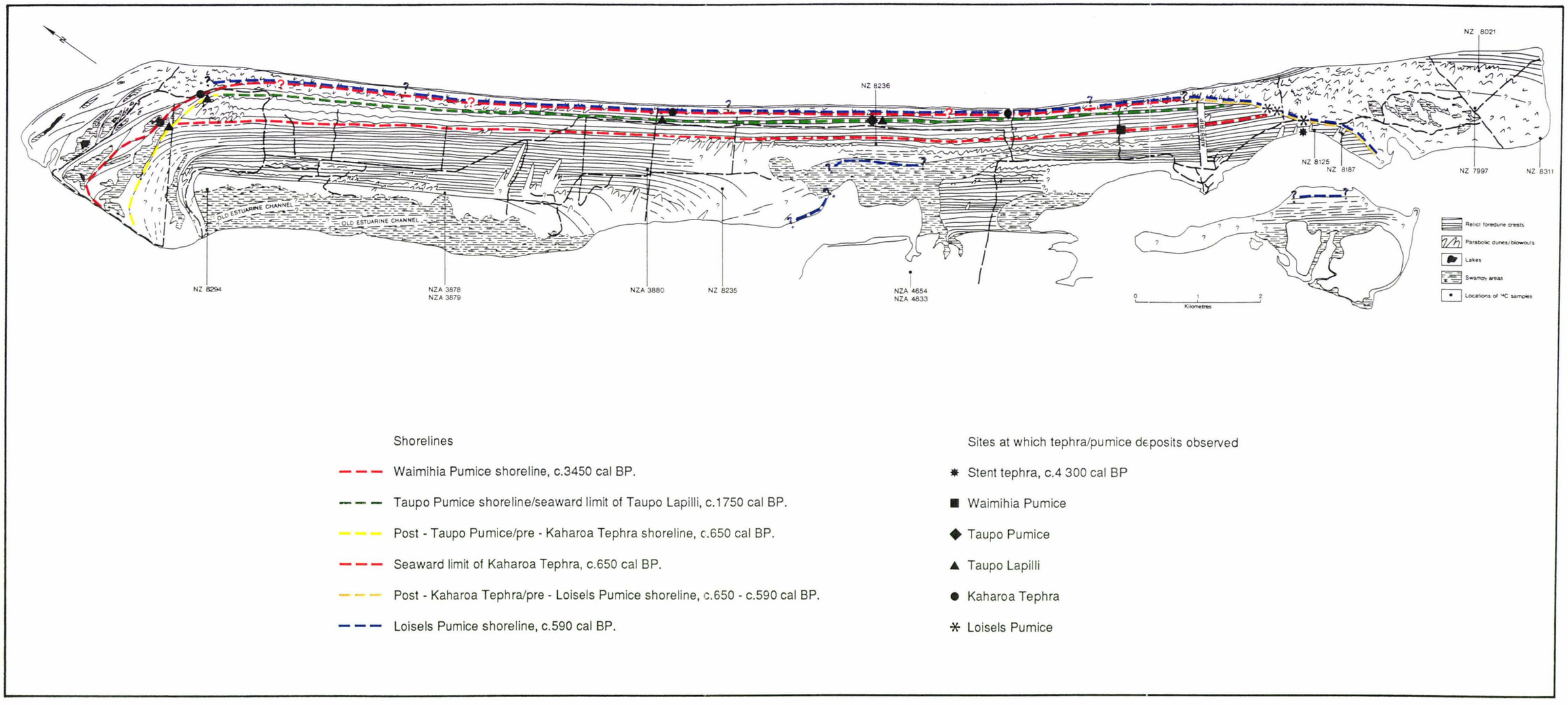


Figure 4.1: Matakana Island barrier palaeoshorelines identified by tephrochronology.

The Waimihia shoreline, identified from the distribution of sea-rafted Waimihia Pumice, is located below a swale seaward of the "Long Ridge" (Figure 2.1) at Hutt Road. The deposit consists of abundant rounded pumice clasts up to approximately five centimetres in diameter which were identified by Dr. P.C. Froggatt (Geology Department, Victoria University of Wellington). The Taupo shoreline is located by the distributions of Taupo Lapilli and sea-rafted Taupo Pumice. Taupo Pumice also occurs along the inner barrier at Blue Gum Bay (Marshall 1994, Y.M. Marshall, pers. comm. 1994, personal observations) and indicates the harbour shoreline has prograded since *c.*1 750 cal BP. A deposit of Taupo Pumice of limited spatial extent occurs near the seaward margin of Rangiwaea Island, where it has been deposited in an estuarine environment.

Relict foredunes at the northwestern end of the barrier are truncated by an erosional shoreline which is post-Taupo but pre-Kaharoa in age (Taupo Lapilli is absent seaward of here but Kaharoa Tephra is present). The Kaharoa shoreline (*c.*650 cal BP) is established from the distribution of Kaharoa Tephra. This shoreline is truncated at the southeastern end of the barrier by a second erosional shoreline, of post-Kaharoa but pre-Loisels Pumice age (Loisels Pumice occurs seaward of here). The Loisels Pumice shoreline (*c.*590 cal BP) is identified from the distribution of Loisels Pumice.

The shorelines shown in Figure 4.1 rely to varying extents on extrapolations between locations (indicated by symbols) where airfall tephras and sea-rafted pumice deposits have been found. The Waimihia and Taupo shorelines can be traced confidently along the barrier in association with the laterally continuous relict foredunes adjacent to the sites where the relevant pumices and/or tephra deposits were located. Similarly, the post-Taupo/pre-Kaharoa and post-Kaharoa/pre-Loisels Pumice shorelines are traced along well-defined escarpments.

The Kaharoa and Loisels Pumice shorelines are largely extrapolated from the sites where Loisels Pumice and the seawardmost occurrences of Kaharoa Tephra were located on the barrier. The Loisels Pumice shoreline can be followed parallel to the post-Kaharoa, pre-Loisels Pumice shoreline, but is extrapolated between the seaward limit of this to another deposit of the pumice near Waikoura Point (Figure 4.1). Further northwest, the location of the Loisels Pumice shoreline was not established. However, the historical shorelines described

below (see Figure 4.2 below) suggest that it is unlikely to be within 1000 metres of the coast at this end of the barrier. The Kaharoa shoreline is obscured by relict parabolic dunes along much of the barrier, but Kaharoa Tephra has been located to within 120 metres of the contemporary shoreline both at Culvert Road and approximately 300 metres southeast of Pipeline Road. At the northwestern end of the barrier, the Kaharoa shoreline coincides with a well-defined relict foredune.

4.1.3 Historical records

Cadastral, topographic and bathymetric maps dating from the late 1800s and the earlier part of this century provide useful information with respect to very recent geomorphological changes on the barrier. Healy (1977) used such information in combination with early aerial photographs to identify the position of the southeastern Matakana Island barrier shoreline for the years 1852, 1901, 1954 and 1972. His results are incorporated into Figure 4.3 below.

4.1.3.1 Shoreline changes

This section focusses on the ends of the barrier adjacent to the harbour entrances, the shorelines of which have changed significantly in historical times. Corresponding shoreline changes away from the entrances have apparently been limited, particularly as Kaharoa Tephra has been found within 120 metres of the incipient foredune at Pipeline and Culvert Roads.

A search of the Tauranga Public Library archives revealed several useful historical maps. Exact matching of the older maps in particular was not possible owing to a lack of reliable control points, hence the overlays in Figures 4.2 and 4.3 represent a "best possible fit".

Historical shorelines thus identified are shown for the Katikati Entrance in Figure 4.2 and the Tauranga Entrance in Figure 4.3.

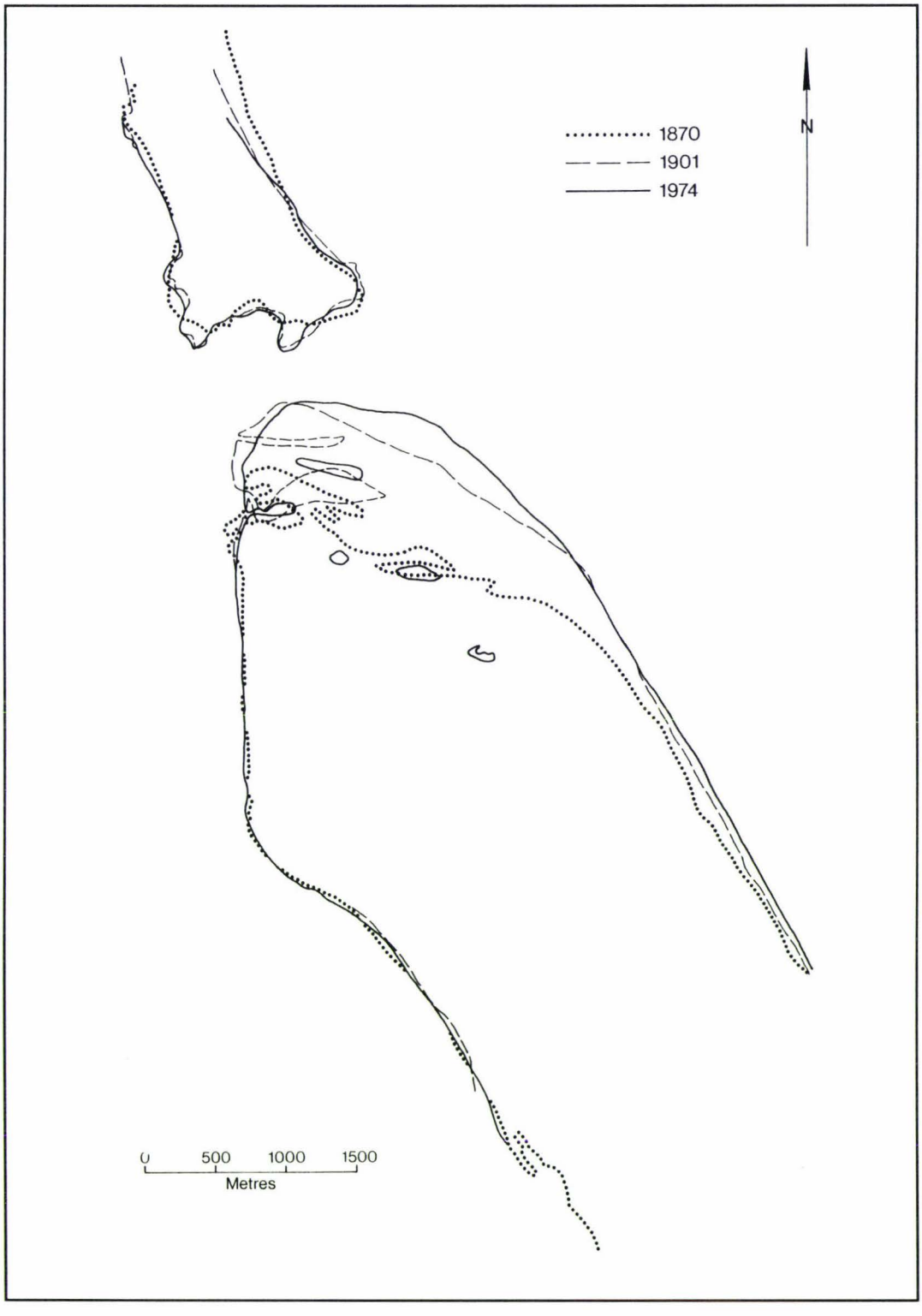


Figure 4.2: Shoreline change, Katikati Entrance, 1870-1974.

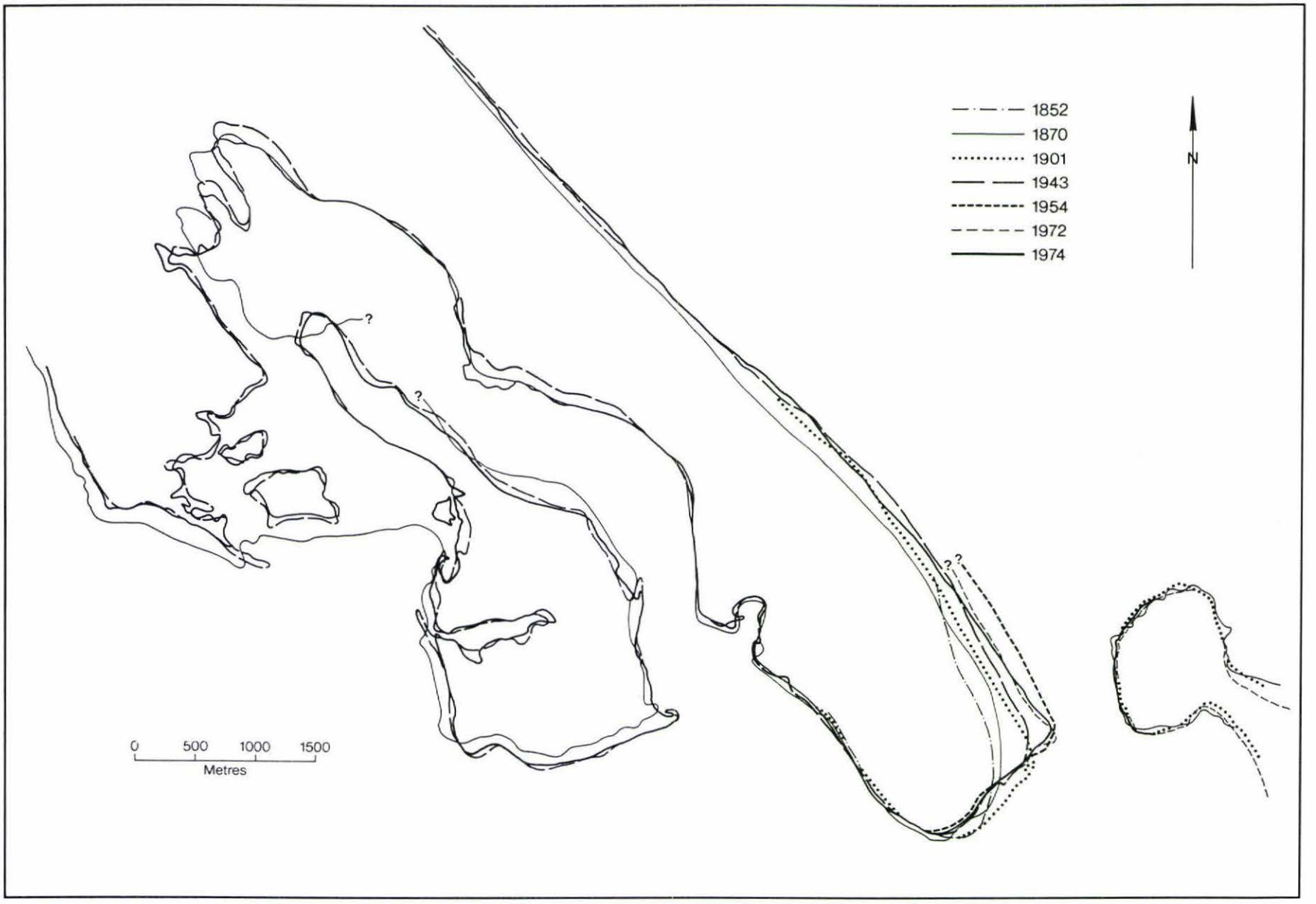


Figure 4.3: Shoreline change, Tauranga Entrance, 1852-1974.

Substantial shoreline changes have clearly occurred in historical times at both entrances. Panepane Point prograded by approximately 500 metres from 1852 to 1974 (Figure 4.3), at a rapid average rate of 4.10 metres per year. Progradation at Waikoura Point was even greater: up to 1000 metres of progradation occurred between 1870 and 1974 (Figure 4.2), at an average rate of almost *ten* metres per year.

Figure 4.3 suggests considerable shoreline changes have also occurred between Rangiwaea and Matakana Islands since 1870. However, the inexact nature of the 1870 survey is a reason for caution: the area between the island is presently exposed at times of low tide and may have been interpreted as being above the limit of high water if surveyed at such times. This is a very low energy environment: it is therefore difficult to hypothesise any form of shoreline recession to the extent suggested by the 1870 and subsequent shorelines if the 1870 map is correct. Other shorelines in Figure 4.3 are thought to have been little changed through historical times, even though differences are apparent (e.g., at the head of Hunter's Creek). As noted above, a lack of reliable control points, particularly for the older survey maps, is the likely cause of such discrepancies.

Figure 4.2 shows the lake which is presently located about 300 metres landward of the contemporary beach at the Katikati Entrance (Figure 2.26; referred to as "L1" by Munro 1994) had clearly formed some time after 1870, in contrast to suggestions that lake formation occurred over 300 ^{14}C years BP (Munro 1994: Figure 4.3c). Furthermore, Lake Waikoura was also open to the sea in 1870, even though Munro similarly assigns a minimum age of about 300 ^{14}C years BP.

Munro suggests that the wetland areas have not changed significantly in the last *c.*300 ^{14}C years. However, the 1870 shoreline shown in Figure 4.2 shows that significant changes in the shoreline (and therefore many of the wetland areas) *have* occurred. Radiocarbon dating of shell carried out by Munro has been considerably influenced by the presence of reworked shell in the sediments of this part of the barrier, as indicated by older radiocarbon ages stratigraphically above or seaward of younger dates (Munro 1994: Figure 3.6b). Consequently, misinterpretation of these dates has led to a misunderstanding of the development of this part of the barrier. Shell dates are discussed further below and in Chapter 5.

4.1.3.2 Relict transgressive dunes

Historical evidence of transgressive dune activity on the barrier is limited. A bathymetric chart of the Tauranga Entrance sounded in 1901-1902 describes "low sand hills", 25 to 35 feet high, throughout the southeastern part of the barrier, although it is not stated whether these dunes were active or vegetated. An equivalent chart of the Katikati Entrance describes "low sand hills, 10 to 15 feet high... good grazing ground... covered with bushes and coarse grass". No mention is made of active sand dunes.

A 1943 topographic map also indicates extensive sand dunes on the barrier to the northwest of Boundary Road, but again no indication is made as to whether or not the dunes were mobile. The land use history of the barrier since the turn of the century has been summarised by Faulkner (1955), but mobile sand dunes were not noted. Cockayne (1909) describes:

> " ...a long strip [of dunes] on the shore of the Bay of Plenty, from Tauranga Harbour to the Waiaua River beyond Opotiki, 92 miles in length, with an average breadth of 37 chains." (Cockayne 1909: p.5).

These are not explicitly described as active, although a preceding general description of New Zealand sand dunes by Cockayne appears to refer specifically to active dunes. The "strip" described by Cockayne may be the mainland equivalent of the strip of coastal dunes described from the Matakana Island barrier in Section 2.1.2.3, which, according to his descriptions and preceding discussion, may have been active around the turn of the century.

Information on historical dune activity on Matakana Island is limited and vague, but Cockayne's descriptions suggest that dunes may have been mobile, at least on the coastal part of the barrier, during the early stages of European settlement.

4.1.4 Pedological development

Prehistoric Maori occupation (see Section 4.1.5) and, more recently, forestry operations, have caused widespread destruction of the soils developed on the barrier. Widespread garden soils

(Marshall *et al.* 1994) attest to extensive cultivation of the soils in prehistoric times. The advent of forestry operations in 1925 (Section 1.2.5) led to widespread destruction of the already damaged soils. In particular, the practice of V-blading, designed to uproot stumps in the preparation of felled blocks for replanting (Marshall *et al.* 1994), has completely removed the soil profile from many relict foredunes and transgressive dunes. Soils in swales tend to be buried by sand removed from the dune crests by these operations, but are not necessarily intact. Only about 1000 hectares out of about 4000 hectares of forestry land on the barrier remains unbladed. The practice was discontinued following the discovery of the disastrous effect it had on archaeological sites on the barrier (Marshall *et al.* 1994).

Intact soil profiles are therefore uncommon on the barrier. Exploratory excavations revealed soils in swales to be relatively well preserved in the vicinity of Blue Gum Bay, which then became the focus for a more detailed study (Appendix 2). It was not possible to include a soil transect across the wider, older part of the barrier to the northwest, owing to the lack of undisturbed soils in that location.

Soils on the Matakana Island barrier are categorised as *central yellow brown sands* by Gibbs *et al.* (1968). Within this soil type, a *soil chronosequence* occurs on the barrier. A soil chronosequence is defined as geographic arrangement of related soils that differ from each other principally in terms of the soil forming factor of time (Jenny 1941). The relationship between soil profile development and duration of pedogenesis (Birkeland 1984) is a useful indicator of the relative age of the surface on which the soil has formed. Soil chronosequences have been previously described from the South Island high country (Birkeland 1984), Holocene relict foredune systems along the Coromandel Peninsula (Abrahamson 1987) and from many other parts of the world (see review by Bockheim 1980). The soil chronosequence occurring on the northwestern part of the Matakana Island barrier near Waikoura Point has been described by Munro (1994).

The locations of the transect and full details of soil profiles and chemistry are given in Appendix 2. Soil profiles become progressively older in a landward direction from the ocean coast, similarly to the findings of Munro (1994) from his soil transect southeastward of Waikoura Point. However, progressive changes are not as well developed here as from other

chronosequences reported in the literature. It is possible that tephra accumulations and slope wash deposits in swales have affected (decreased) soil development. Soil profiles also shallow rapidly harbourward of the innermost ridge, which, in addition to the distribution of Taupo Lapilli and sea-rafted Taupo Pumice, suggests recent progradation of the harbour shoreline. This is discussed further in Section 5.1.9.

Black, organic-rich soils commonly overlie Kaharoa Tephra. These probably relate either to the post-occupation spread of *Pteridium esculentum* (with which such soils are associated), or an increase in soil moisture, perhaps due to the impedance of soil water percolation by Kaharoa Tephra, resulting in increased organic accumulation.

The trends in soil chemistry (excluding cultural effects) are only weak overall (see Table A2.1 in Appendix 2), suggesting the differences in the time elapsed since commencement of soil development are not great between test pits 5 and 9. This implies the shoreline prograded relatively rapidly between these test pits, although a lack of any direct comparable information from any other part of the barrier makes this conclusion tentative. As cautioned in Appendix 2, the absence of strong trends may also relate to the fact that the soils described here have been buried, possibly with subsequent alteration of their chemical properties.

4.1.5 Archaeology

Prehistoric occupation of the barrier by Maori was extensive, as indicated by the hundreds of shell midden present (Figure 4.4). Some of these are up to 100 metres in diameter and attest to substantial, structured and sustained occupation of the barrier environment. Associated gardening was extensive and occurred repeatedly prior to European arrival (Marshall *et al.* 1994). Vegetation changes on the barrier resulting from Maori occupation are discussed in Section 5.1.11.

Figure 4.4: A large shell midden overlying a relict transgressive dune near Blue Gum Bay, typical of the hundreds of middens present on the barrier.

Marshall *et al.* (1994) suggest initial Maori occupation of the island is likely to have begun at least 600 years ago. No conclusive evidence for human activity has been found stratigraphically below Kaharoa Tephra in this study, nor by Marshall *et al.* (1994), although the possibility remains. However, on the basis of available evidence and the current age for the Kaharoa Tephra, the first human occupation of the barrier occurred after 650 cal BP which is in agreement with recent analyses of radiocarbon dates for New Zealand prehistory (Anderson 1991, McFadgen *et al.* 1994).

The abundant shell middens on the barrier have been radiocarbon dated in some instances (Table 4.1). In order to avoid misinterpretation, suspected midden shell deposits require close examination to differentiate them from natural deposits, which may have formed outside the period of occupation. Shell deposits are often extensive on the contemporary beach (Figure 4.5) and often persist at or near the ground surface inland of the beach where rapid

progradation and/or subsequent deflation has occurred (Figure 4.6). Such deposits may be mistaken for midden, but differ fundamentally in terms of the presence of abraded shell fragments and shell species which are not normally collected for food and are therefore rare or absent in middens, but may be common in natural deposits. Very small shells which would not be viable as a food source may also be abundant.

Figure 4.5: Abundant shells on the contemporary beach at Panepane Point. A wide variety of shell species occur and abraded fragments are common.

These deposits may consist of shells with a wide variety of ages due to reworking, have no connection with occupation and should not be regarded as cultural deposits. Shell middens, on the other hand, tend to be characterised by whole, unabraded shells, sometimes in position of articulation. Food species, such as *Paphies australis* (pipi), *Paphies subtriangulata* (tuatua), *Struthiolaria papulosa* (large ostrich foot) and *Chione stutchburyi* (common cockle) tend to predominate and small shells unsuitable as a food source are less common. The occasional presence of fire-cracked stones, fish scales and/or bones also indicate cultural deposits.

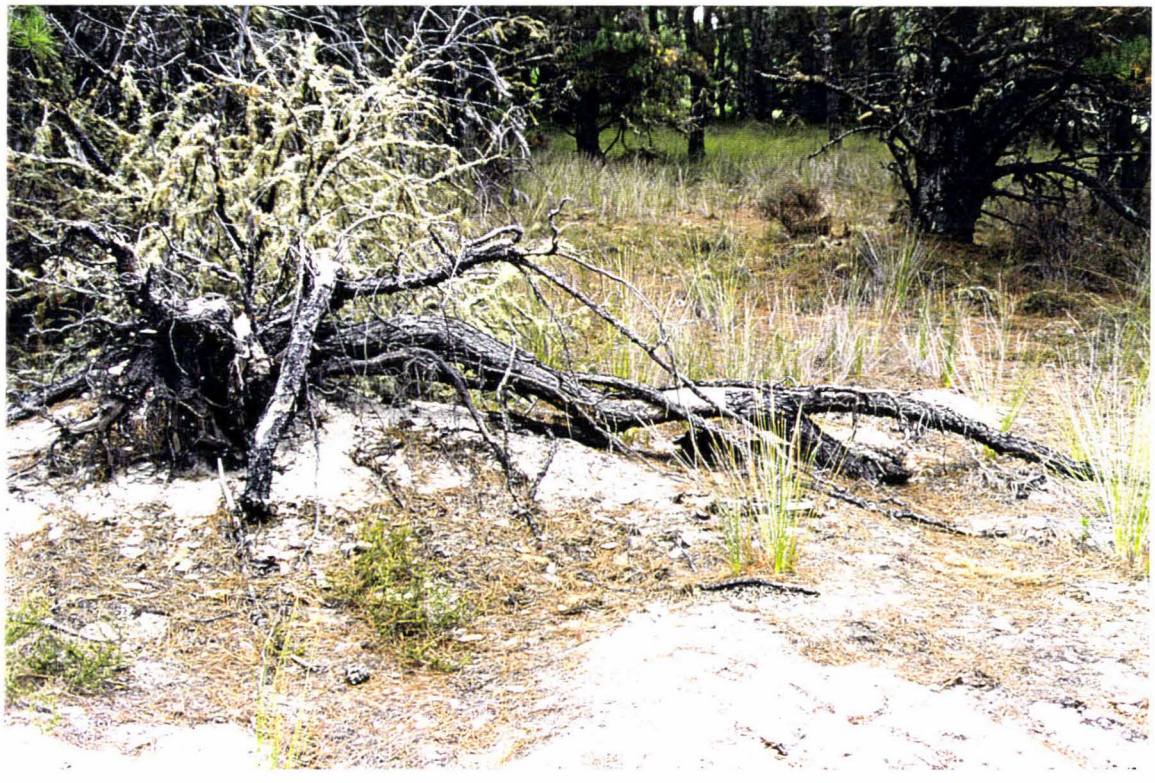


Figure 4.6(a): A natural shell deposit at the surface *c.*100 metres inland of the beach at Waikoura Point.

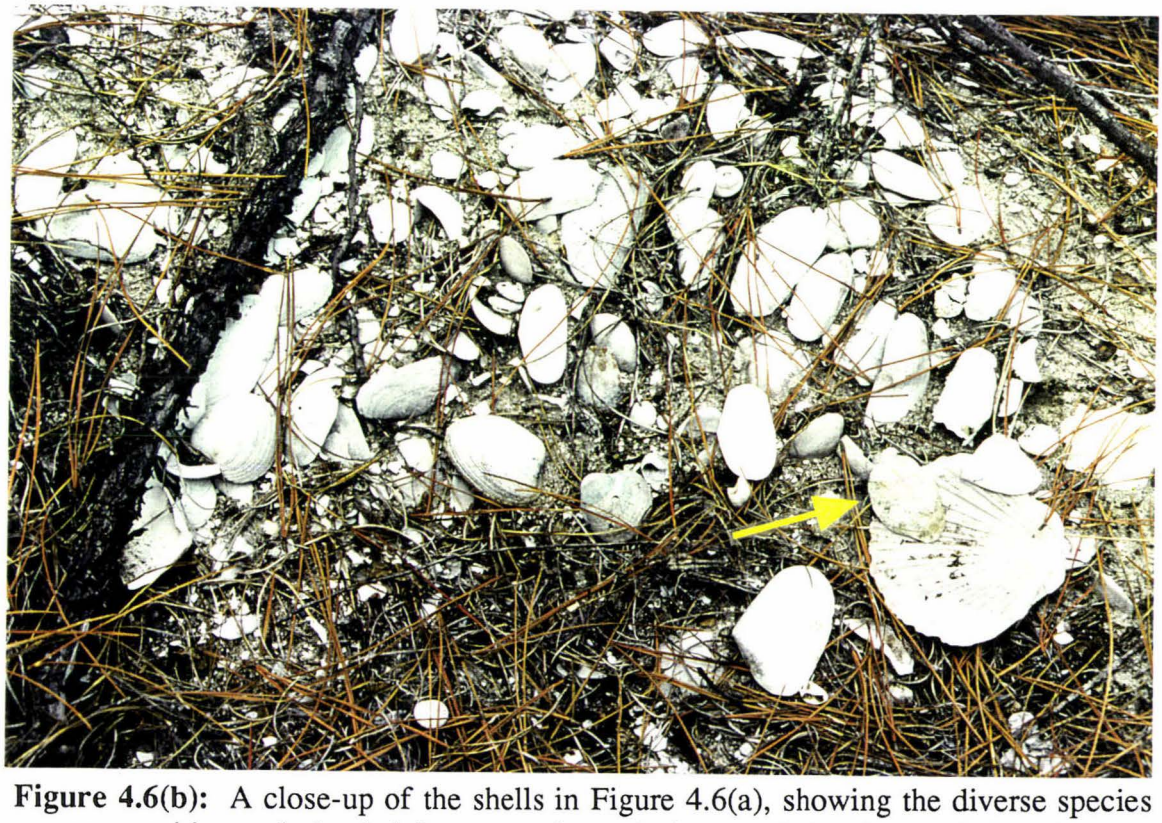


Figure 4.6(b): A close-up of the shells in Figure 4.6(a), showing the diverse species composition and abraded fragments (arrow) characteristic of natural deposits.

The abundant cultural layers present on the barrier are useful indicators of relative chronology, particularly when applied to relict transgressive dunes. The presence of occupation layers below such dunes, for example, indicates the timing of dune movement relative to occupation and may have some bearing upon the cause of dune mobilisation. This is discussed in Section 4.2.2.

4.2 CHRONOLOGY OF THE BARRIER

This section integrates the chronological data described above to provide an outline of overall barrier chronology. Palaeoshorelines are dated by means of the information presented in Sections 4.1.1 to 4.1.3, supplemented by information on soil development in Section 4.1.4. The age of relict transgressive dunes is assessed by reference to associated to tephra deposits and occupation layers, together with radiocarbon dating.

4.2.1 Age of palaeoshorelines

Historical changes in the barrier shoreline have been described above (Figures 4.2 and 4.3). Figure 4.7 below shows the prehistoric shorelines identified by tephrochronology in Figure 4.1 together with the radiocarbon ages from Table 4.1. Five ages from Munro (1994) are included for the northwestern barrier.

Reworking of shell fragments is apparent from the anomalous ages (NZ-7997, NZ-8021, NZ-8236, Wk-3204-3207 inclusive and possibly Wk-3208) in Figure 4.7. All these ages are somewhat older (NZ-7997 and Wk-3207 in particular) than the palaeoshorelines dated by tephrochronology, indicating the incorporation of older, reworked shell into the deposits sampled for dating. Shell dates are therefore interpreted as giving *maximum ages* only, owing to possible reworking. For this reason, the interpretations and inferences made by Munro (1994) from shell dates from northwestern Matakana Island may need to be revised.

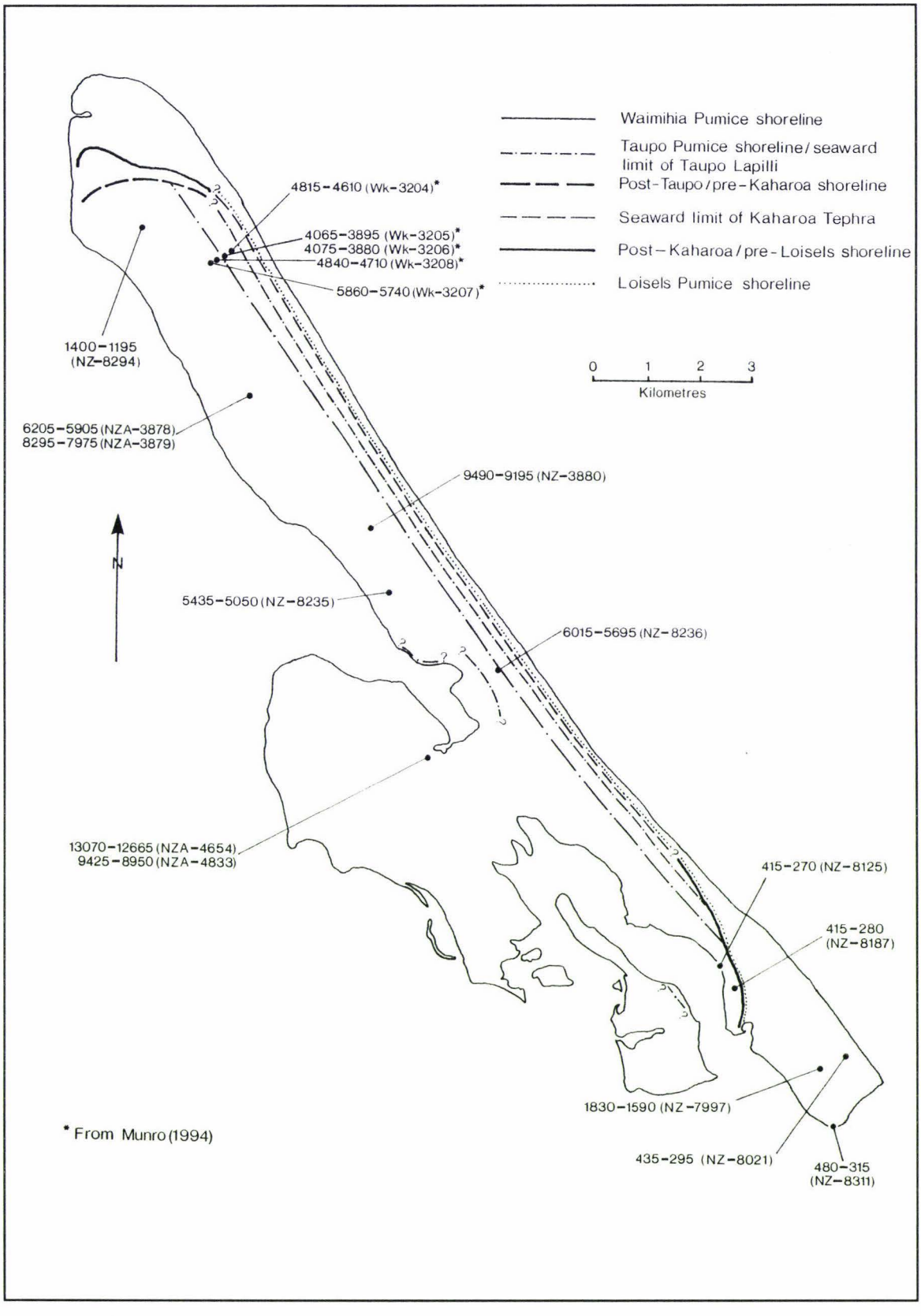


Figure 4.7: Dated palaeoshorelines and radiocarbon dates for the barrier. Ages in calibrated years BP.

Radiocarbon ages in Figure 4.7 suggest the barrier had begun to form *c.*6 000 cal BP. Initially it was in at least two sections, separated by a former tidal entrance to Tauranga Harbour adjacent to present-day Blue Gum Bay.

These two sections were joined by the formation of the "Long Ridge". This is dated by radiocarbon samples of shells from both harbourward and seaward of the ridge. Samples from the harbour side provide a maximum age for its formation and include NZ-8235, NZ-8236 (Table 4.1) and Wk-3207 (Munro 1994). The youngest maximum age (NZ 8235) is from the recurved ridges near Blue Gum Bay (Figure 4.7; Map 1) and provides a maximum age for the beginning of formation of the "Long Ridge" of *c.*5 200 cal BP. However, the sample site is separated from the "Long Ridge" by more than six relict foredunes over 400 metres and the "Long Ridge" will therefore be considerably younger than the sample. Stent tephra is provisionally identified harbourward of the "Long Ridge" at Hunter's Creek and near the Matakana Mill, providing a maximum possible age of *c.*4 300 cal BP. The Waimihia Pumice shoreline shown in Figure 4.1 gives a minimum age for the "Long Ridge" provided the pumice is a primary deposit. If this is the case, then the "Long Ridge" would have stopped accreting prior to *c.*3 450 cal BP. Considering the above ages, a provisional age range for the "Long Ridge" of 4 000-3 500 cal BP is suggested, and the midpoint of this range of *c.*3 750 cal BP is adopted for further discussions regarding the closure of the Blue Gum Bay entrance.

Subsequent shorelines dated by tephrochronology indicate that progradation rates have generally decreased considerably toward the present. However, the entire southeastern end of the barrier post-dates the Kaharoa eruption, indicating that extremely high rates of progradation occurred here during the last few centuries. This is discussed further in Section 5.1.14.2, where an association between this and the occurrence of reworked shell is hypothesised.

4.2.2 Age of relict transgressive dunes

The morphology and distribution of relict transgressive dunes on the barrier have been discussed in Section 2.1.2.3. The tephrochronological and archaeological evidence provided

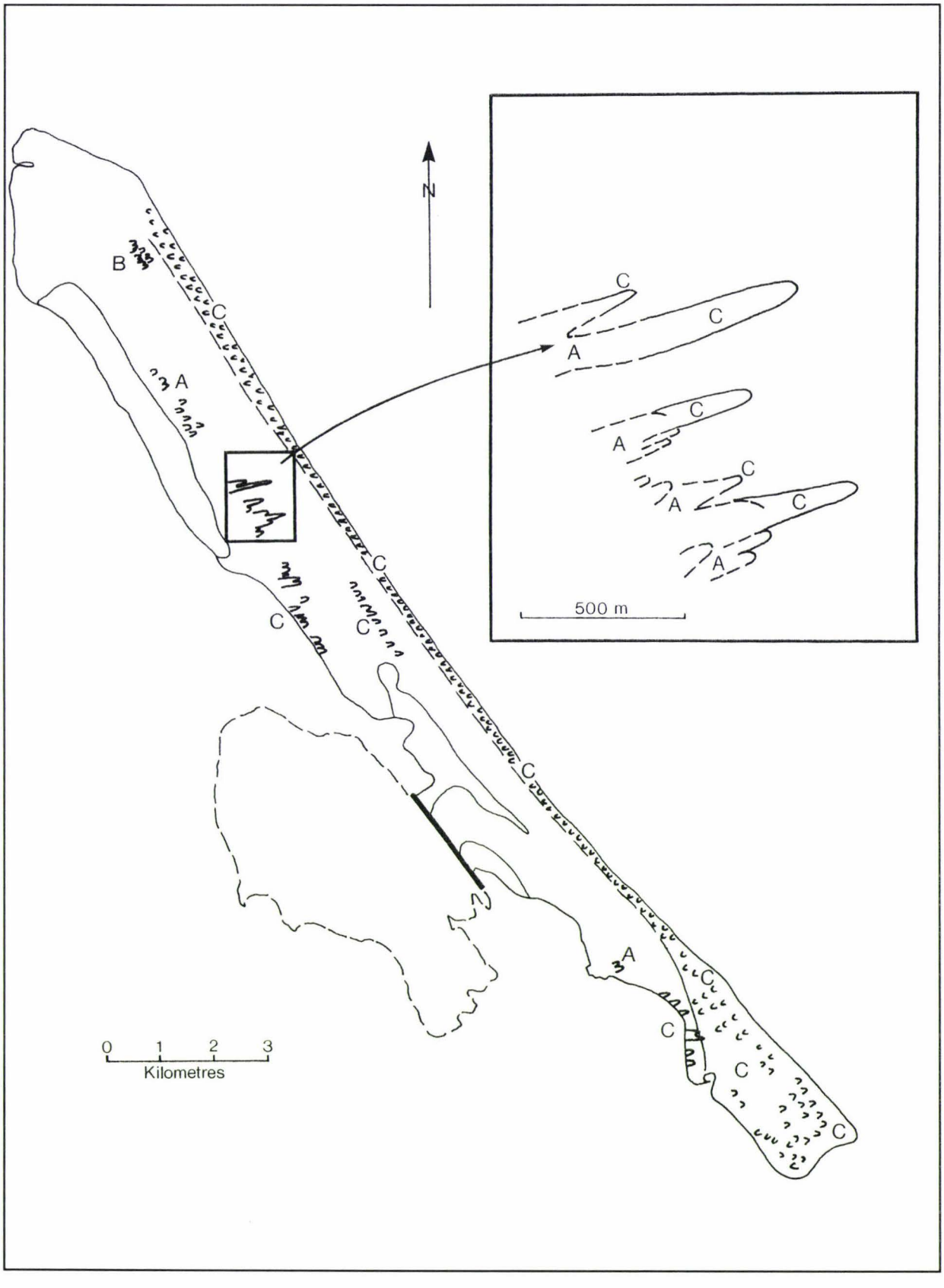


Figure 4.8: Age classification of relict transgressive dunes on the barrier into: (A) pre-Taupo; (B) post-Taupo/pre-Kaharoa; and (C) post-Kaharoa.

below indicates that these dunes were mobile at various times in the past and in some cases went through more than one period of activity.

Transgressive dune movement on the barrier can be classified into three major time periods (Figure 4.8), according to the following criteria:

(1) Dunes which formed prior to the Taupo eruption (*c.*1 750 cal BP) are covered by Taupo Lapilli.

(2) Dunes which formed subsequent to the Taupo eruption, but prior to the Kaharoa eruption (*c.*650 cal BP). They contain a lag of Taupo Lapilli in their basins and are overlain by Kaharoa Tephra.

(3) Dunes which formed after the Kaharoa eruption, which show very little or no soil development and lack a mantle of airfall tephra.

4.2.2.1 Transgressive dunes of pre-Taupo age

Relict transgressive dunes mantled by Taupo Lapilli and Kaharoa Tephra occur along the inner part of the barrier, predominantly in the vicinity of Blue Gum Bay and northwest of Pipeline Road (Figure 4.8). The southwestern portions of the large parabolic dunes northwest of Western Road and numerous small blowouts on the inner part of the barrier northwest of Blue Gum Bay are also of pre-Taupo age, as indicated by a mantling of Taupo Lapilli. The oldest parabolic dunes occur near the inner margin of the barrier. A Taupo-sourced rhyolitic tephra tentatively correlated with the Stent tephra (Alloway *et al.* 1994) is interbedded with dune sand near the Matakana Mill (approximate grid reference given in Section 4.1.2), indicating dune migration was occurring at about 4 300 cal BP at that site.

Clearly these dunes were initiated by natural causes. These may include blowout formation contemporaneously with or soon after foredune formation, before the surface is stabilised by vegetation and soil development. Natural fires may also lead to dune transgression through the destruction of dune vegetation. Transgressive dune activity can also be initiated by wave

erosion of the contemporary foredune, where unconsolidated sands are exposed to sand-moving winds. This process has been observed by the author above the eroding shoreline at Hunter's Creek (see Figure 2.10(b)) during strong westerly winds, where sand from the escarpment face was being entrained and driven across the barrier. After several days of persistent strong westerlies, a small shadow dune (Hesp and Thom (1990)) about three metres long by one metre high at its apex was observed to have formed across a nearby forestry track, in the lee of a cutting through a relict parabolic dune.

Small relict and active shoreline scarps occur along parts of the inner barrier northwest of Blue Gum Bay, attesting to former temporary periods of harbour shoreline recession occurring through to the present which may have initiated some of the pre-Taupo transgressive dunes in this area.

4.2.2.2 Post-Taupo/pre-Kaharoa dune activity

Evidence for dune movement during this period is limited to the northwestern barrier inland of Waikoura Point (grid reference NZMS 260 U13 762081). Taupo Lapilli occurs in the basin of at least one of these parabolic dunes as a lag deposit indicating that deflation occurred subsequent to the Taupo eruption. Kaharoa Tephra occurs directly above the lapilli and the lack of soil development below the Kaharoa Tephra suggests dune movement occurred close to the time of the Kaharoa eruption, providing an age for the dune of little more than 650 years (see Figure 4.9 below). Adjacent dunes are likely to be of similar age.

Similarly to the pre-Taupo dunes discussed above, the initiation of these dunes is likely to have resulted from natural causes. Shoreline recession is not thought to be a likely factor, as indicated by the location of the Taupo Pumice shoreline seaward of the dunes and their seaward orientation. Natural disturbance of the vegetation cover, perhaps by natural fires or storm events, may have contributed to the dune mobilisation.

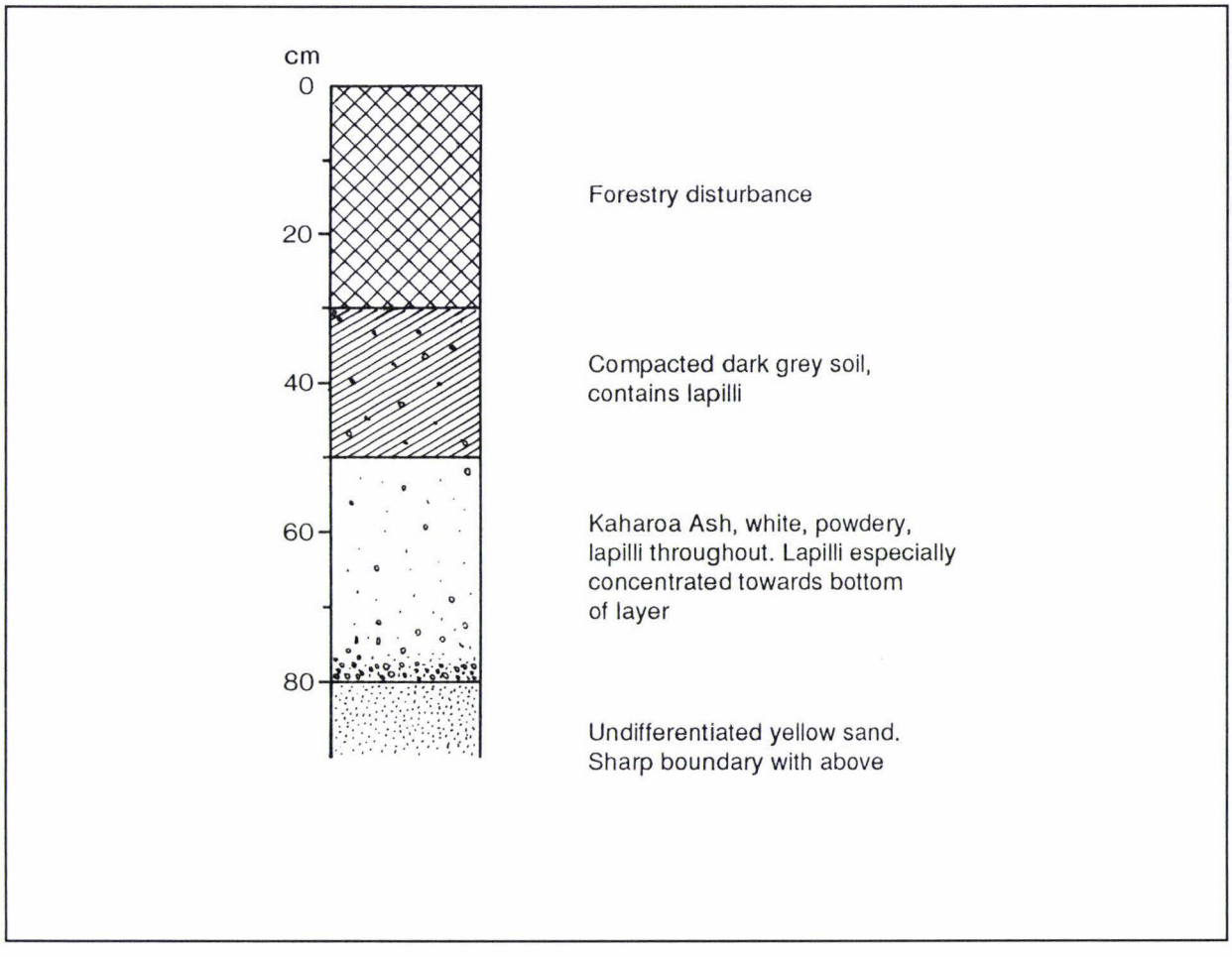


Figure 4.9: Stratigraphy of a test pit dug in the basin of a post-Taupo/pre-Kaharoa parabolic dune near Waikoura Point.

4.2.2.3 Dune movement subsequent to the Kaharoa eruption

Considerable transgressive dune activity occurred on the barrier between the time of the Kaharoa eruption and the present, most of which appears to have ceased before historical times (see Section 4.1.1.3.2). The largest area of such dunes forms a strip some 100-230 metres wide, aligned parallel to the coast along most of the barrier, with its seaward limit about 20-60 metres landward of the incipient foredune. Two phases of post-Kaharoa movement of these dunes is suggested by the stratigraphy of test pits described in Appendix 2. Kaharoa Tephra was also found buried beneath these dunes *c.*120 metres landward of the contemporary foredune at both Culvert Road and *c.*300 metres southeast of Pipeline Road. These dunes represent a period of considerable dune instability along the ocean shoreline, a

phenomenon which has been described from other parts of the Bay of Plenty. Possible causes are discussed below.

Relict transgressive dunes of post-Kaharoa age are common in places along the inner barrier northwest of Blue Gum Bay. These younger dunes tend to be sharper in outline, have steeper slopes, show little or no profile development and lack surface tephra deposits. The northeastern parts of very large parabolic dunes to the northwest of Western Road, the southwestern parts of which are pre-Taupo in age, show no profile development and have no mantling of tephra, indicating they are post-Kaharoa in age. Hand augering revealed that Kaharoa Tephra occurs beneath these parts of the dunes. This is evidence for these dunes being reactivated subsequent to the Kaharoa eruption, as discussed further below.

Large relict parabolic dunes occur along and harbourward of the "Long Ridge" southeast of Pipeline Road (Map 1). Their steep slip faces and the absence of soil profile development and tephra on their surfaces indicate they are also post-Kaharoa in age. The length of these dunes is uncertain, owing to a lack of suitable aerial photographs of this area and difficult terrain. The possibility that they are reactivated dunes originally of pre-Taupo age, similar to those northwest of Western Road, cannot be eliminated.

Post-Kaharoa dune mobility may be attributed to a variety of possible initiating factors. The natural causes discussed above cannot be excluded. However, Maori occupation also began following the Kaharoa eruption, and, as already described, led to widespread destruction of barrier vegetation and disturbance to soils. Transgressive dune initiation and/or reactivation due to human activity is therefore highly likely, particularly as this phase of dune transgression is also the most extensive. A section at Hunter's Creek (grid reference NZMS 260 862935), showing cultural layers separated vertically by aeolian sand, clearly indicates that dune movement occurred during occupation of the site.

Midden shell from a cultural layer occurring on another parabolic dune, about 650 metres to the southeast (grid reference NZMS 260 U14 863933), yielded a minimum age of 412-282 cal BP for the dune, which is clearly post-Kaharoa in age as it breaches the post-Kaharoa/pre-Loisels Pumice shoreline shown in Figure 2.21(b).

As noted above the large parabolic dunes northwest of Western Road have undergone at least two distinct phases of activity. Reactivation of these dunes following the Kaharoa eruption resulted in considerable dune movement, the largest dune terminating adjacent to Hume Highway North about one kilometre northwest of Western Road (Map 1). The remains of previously stable parabolic dune noses extending into the basins of some of these extended dunes (Figure 4.10) provides additional evidence for their reactivation.

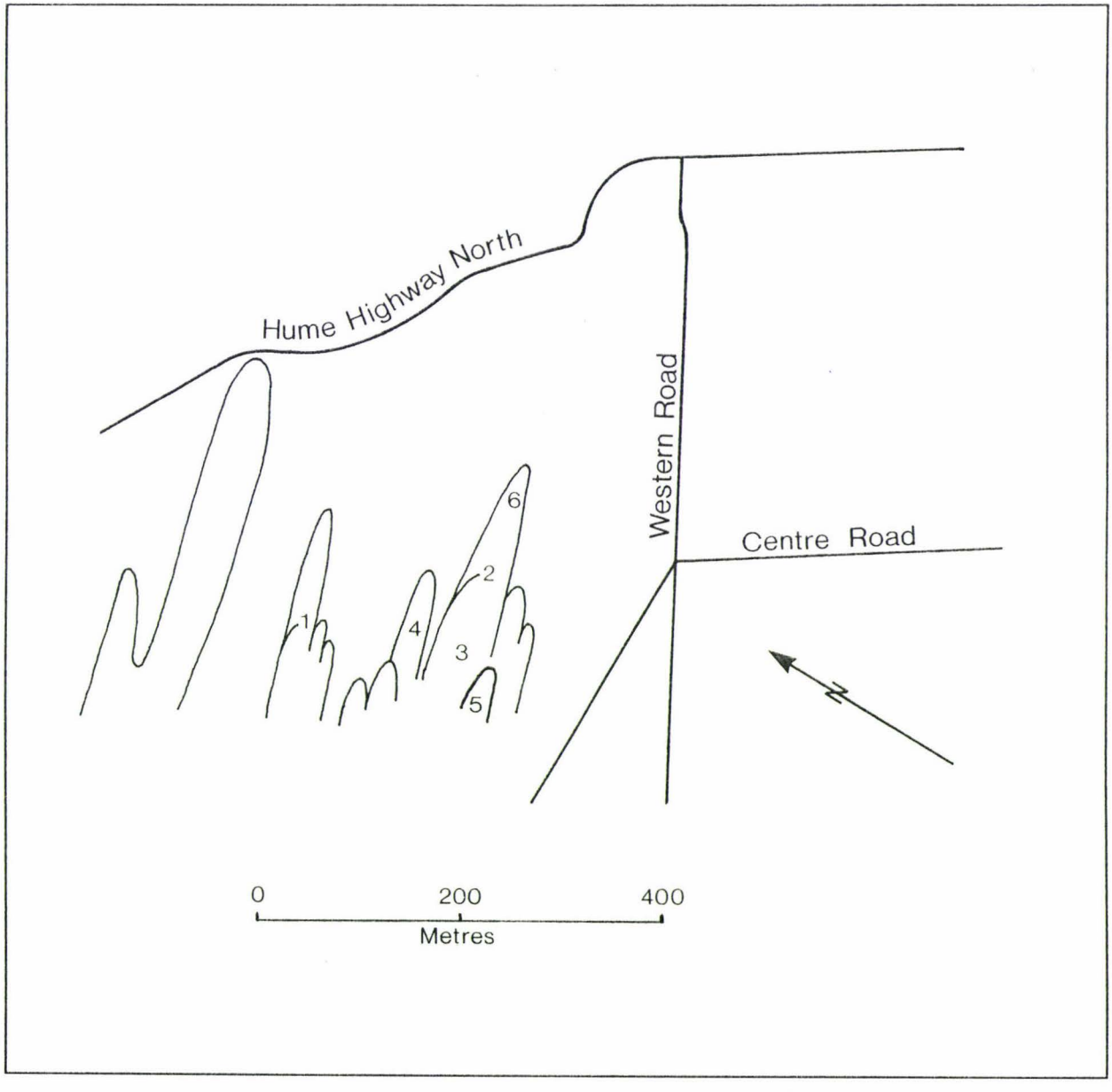


Figure 4.10: Sites investigated on relict parabolic dunes northwest of Western Road. The remains of formerly stabilised parabolic dune noses mantled with Taupo Lapilli and Kaharoa Tephra, blown out during post-Kaharoa destabilisation, occur at Sites 1 and 2.

A test pit dug at Site 3 revealed clean, undifferentiated sand, with no tephra present. A garden soil, containing Kaharoa Tephra and Taupo Lapilli, occurs at the surface at Site 4, on intact relict foredunes between two parabolics. A cross section between these two sites illustrates the post-occupation movement of the dune containing Site 3 (Figure 4.11).

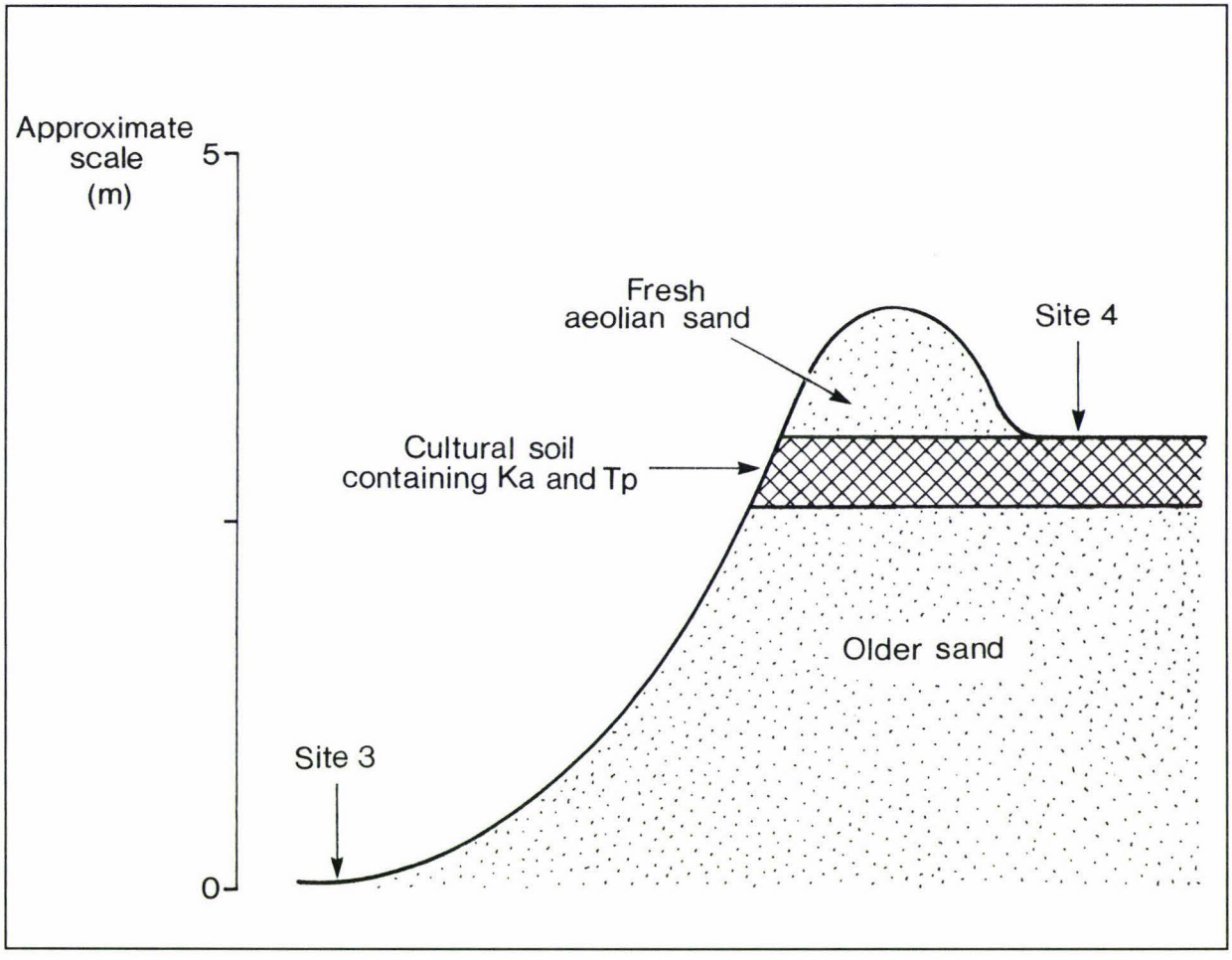


Figure 4.11: Cross section between Sites 3 and 4 of Figure 4.10. Post-occupation dune movement has deflated the surface at Site 3 and buried a cultural soil between this and Site 4 under aeolian sand.

An auger hole drilled through a parabolic dune at Site 6 revealed a dark peaty soil developed in a former swale, buried by *c*.4.25 metres of undifferentiated aeolian sand. Analysis of pollen preserved in this soil by W.L. McLea (Geology Department, Victoria University) indicated a podocarp-broadleaf vegetation composition, with abundant charcoal attributed to local burning. The absence of *Pinus* pollen suggests that the soil was buried prior to European arrival (W.L. McLea, pers. comm. 1994).

Clearly the dunes on this part of the barrier went through considerable change after the Kaharoa eruption. Similarly to Hunter's Creek, occupation layers have been buried by aeolian sand (Site 4 described above), indicating dune movement contemporaneous with prehistoric occupation.

Human occupation as a cause of dune initiation is not proven, but the widespread vegetation and soil destruction which resulted from Maori activities are likely contributors.

4.3 SUMMARY

Palaeoshorelines have been established from the distributions of Waimihia Pumice, Taupo Pumice/Taupo Lapilli, Kaharoa Tephra and Loisels Pumice, together with radiocarbon ages.

Evidence presented in this chapter illustrates a pattern of considerable and sustained barrier progradation throughout the mid- to late Holocene. During this time the ends of the barrier have been eroded periodically, a process which historical records show to have continued through to the present.

A transect of soil pits excavated across the barrier at Blue Gum Bay revealed substantial shore-normal changes in soil profile development, increasing harbourward to a maximum immediately seaward of the innermost relict foredune of this part of the barrier. Substantial progradation of the harbour shoreline towards Blue Gum Bay in recent times is indicated by considerably reduced profile development further harbourward of the innermost ridge. Results of investigations into soil chemistry showed only weak overall trends (excluding possible cultural effects), suggesting the shoreline prograded relatively rapidly between the sites investigated. However, the absence of absolute dates and the burial of these soils by Kaharoa Tephra makes this conclusion tentative.

Transgressive dune activity on the barrier is classified into three broad time periods, based on tephrochronology. Dunes which formed prior to the Taupo eruption occur along the inner part of the barrier at Blue Gum Bay and northwest of Pipeline Road. Numerous small pre-Taupo

blowouts also occur on relict foredunes of the inner part of the barrier and morphological and stratigraphic continuity with their parent foredunes suggests they are likely to have been active during or immediately following foredune formation. Dune transgression between the Taupo and Kaharoa eruptions appears to have been limited to the northwestern barrier inland of Waikoura Point. The apparent absence of archaeological remains stratigraphically below Kaharoa Tephra indicates that transgressive dunes of pre-Kaharoa age were initiated by natural processes.

Abundant post-Kaharoa dunes on the barrier indicate that considerable dune transgression occurred after the Kaharoa eruption. Dunes of this period are most extensive along a shore-parallel zone extending along much of the barrier near the ocean shoreline and along the inner barrier northwest of Blue Gum Bay. Large parabolic dunes of pre-Taupo age in the vicinity of Blue Gum Bay and Western Road were reactivated during this period. It is possible that these dunes also had a natural origin, but it is considered more likely that the arrival of the Maori and the subsequent destruction of barrier vegetation was a major contributing factor to dune movement during this period.

Chapter Five:
Late Quaternary Evolution of Matakana Island

Introduction

This chapter uses the geomorphological and other evidence described in Chapters 2-4 to reconstruct the late Quaternary evolutionary history of Matakana Island. A discussion of the environment at and following the time of human occupation is included. Contemporary morphological changes are also described and possible future shoreline changes discussed. The development of the barrier is then related to models of barrier development proposed or discussed in other studies, with particular reference to the coastal barrier systems of southeastern Australia which have a similar sea level history to that of Matakana Island.

5.1 THE EVOLUTION OF MATAKANA ISLAND

The ages referred to in the following discussions are approximations, particularly for Period 5 for which radiocarbon evidence is sparse. Owing to the problem of reworking, shell dates are regarded as providing maximum ages only. Where radiocarbon ages are clearly anomalous, they are disregarded in favour of tephrochronological evidence.

The reconstruction of barrier evolution described below incorporates a number of assumptions. Firstly, the behaviour of tidal deltas associated with the barrier is inferred. Secondly, it is assumed that nett littoral drift has been predominantly southeastward since barrier formation began. Northwestward littoral drift is suggested to have occurred during periods in the Holocene (e.g., Dahm 1983), but firm evidence for this is lacking. Evidence from recurved

spits during the evolution of the Matakana Island barrier indicates a southeastward drift throughout the barrier's history. Littoral drift is assumed to have been of less importance than onshore sediment movement during early barrier formation. As the barrier prograded and onshore sediment movement declined, the *relative* significance of littoral drift is assumed to have increased, indicated in particular by the migration and closure of an old entrance at Blue Gum Bay (see Sections 5.1.7 and 5.1.8) and the extension of the southeastern end of the barrier (see Section 5.1.11).

Thirdly, progradation of the central barrier is assumed to have been continuous compared to the irregular behaviour of both ends. No consideration is given to the possible effects of sea level fluctuations since the stillstand. Eustatic sea level is suggested to have been *c.*0.6 metres above present *c.*3 600 ^{14}C years BP (J.G. Gibb, pers. comm. 1995) (*c.*3 800 cal BP), with a subsequent gradual fall to present levels. A slight sea level fall may possibly have contributed to the closure of the Blue Gum Bay entrance by shallowing the offshore profile and promoting increased onshore sediment movement. This requires further investigation. Fourthly, a lack of dating control between the maximum date provided by NZ-8236 (Figure 4.7) and the position of the Waimihia Pumice shoreline (Figure 4.1) requires the ages assigned to the scenarios in Figures 5.4 to 5.6 below to be inferred.

5.1.1 Period 1: Prior to the Last Interglacial

The highest parts of Pleistocene Matakana Island contain remnants of at least two late Pleistocene terraces, deeply buried by tephra. A sandy, shell-bearing, probably marine, deposit exposed in a cliff section at Flax Point suggests the underlying surfaces are likely to be of marine origin. However, the present elevation of these surfaces relates to the thickness of the overlying tephra deposits, which are probably several tens of metres thick. The original terrace surfaces were probably formed during interglacial periods which occurred during oxygen isotope stages 7 (*c.*210 000 years ago) and 9 (*c.*300 000 years ago) (Pillans *et al.* 1992).

As the original surface was not observed higher than *c.*3-4 metres above present mean sea level and late Pleistocene sea levels are not considered to have risen more than a few metres

above the present, the area appears to have experienced relatively minor tectonic movement during the formation of Matakana Island in comparison to many other parts on the North Island. In spite of this relative stability there appears to have been a variable pattern of tectonic movement. Extrapolation of the maximum mean post-Last Interglacial subsidence rate of 120mm/1 000 years (Section 2.1.1.2) back into the late Pleistocene implies the shell-bearing deposit at Flax Point (assuming it was formed at intertidal depths) was formed at a sea level stand of *c.*26 metres above present for an age of *c.*210 000 years, or *c.*37 metres above present for an age of *c.*300 000 years. These heights are considerably more than the suggested Last Interglacial sea level of four to six metres above present mean sea level (Roy and Thom 1981, Gibb 1986). Therefore it appears that the subsidence of the last *c.*125 000 years may have been preceded by a period of uplift.

5.1.2 Period 2: The Last Interglacial maximum

The Last Interglacial peaked *c.*125 000 years ago (Pillans *et al.* 1992), and the lowermost Pleistocene terrace of Matakana Island formed during this time. Evidence from aerial photographs (Figure 2.2(b)) and well logs (Table 2.1) clearly shows this to consist of a coastal relict foredune plain. Although well-preserved in comparison to the older Pleistocene terraces this plain was also more extensive at the time of its formation and has subsequently been truncated at its margins by fluvial erosion during the Last Glacial followed by marine and estuarine erosion after the Postglacial Marine Transgression. Pleistocene barriers of this age are also described from the eastern Coromandel Peninsula by Abrahamson (1987) and are well preserved in southeastern Australia (e.g., Thom *et al.* 1992).

Remnants of five large parabolic dunes (labelled "p" in Figure 2.1) are visible on parts of this lower terrace (Figure 2.4(a)) and, in common with the relict foredunes of this plain, their morphology has been preserved by airfall tephra deposits. Their almost identical alignment to that of large transgressive dunes on the Holocene barrier (Section 2.1.2.3) indicates a similar wind climate during the Last Interglacial to that of the region during the Holocene. Despite the subsidence of the area since the Last Interglacial maximum, the surface topography of this plain has been preserved above sea level by the deposition of several metres of tephra (Table 2.1). A consequent rectangular drainage pattern, controlled by the old

swales, has begun to develop on this surface (Figure 2.2(b)).

5.1.3 Period 3: The Last Glacial period (*c.*73 000 years ago to *c.*14 000 ^{14}C years BP)

The Last Glacial period extends from *c.*73 000 years ago (Suggate 1974) to the beginning of the Aranuian Interglacial (Mansergh 1973). The glacial maximum occurred between about 20 000 and 18 000 ^{14}C years BP, when eustatic sea level was probably *c.*120 metres below present (Pillans *et al.* 1992).

During this period the shoreline lay approximately 20-30 kilometres seaward of the present shoreline in the western Bay of Plenty (Wright 1989). Fluvial incision into earlier Pleistocene materials, including those of the terraces described above, resulted in large accumulations of alluvial and deltaic sediments on the continental shelf (Dahm 1983, Abrahamson 1987). The Pleistocene parts of present-day Matakana and Rangiwaea Islands probably represent remnants of interfluves occurring within the Tauranga Basin which were dissected by fluvial processes during this time. These remnants were topographically isolated from the mainland to become islands during the Postglacial Marine Transgression (Figure 5.1).

5.1.4 Period 4: The Postglacial Marine Transgression (*c.*18 000 ^{14}C years BP to *c.*7 000 cal BP)

This period marked the onset and culmination of a rapid rise in sea level in response to a warming climate following the peak of the Last Glacial. This rise was interrupted by two stillstands during the late Holocene, followed by rapid transgressions. Both stillstands were of sufficient duration to form shoreline features which have since been submerged on the shelf (Gibb 1986), although there is no evidence from bathymetric charts (e.g., Pantin *et al.* 1973) for such features on the shelf off Matakana Island.

River valleys incised into Pleistocene sediments were also submerged, forming the highly irregular mainland shoreline of Tauranga Harbour. The dissected interfluve or interfluves

postulated above were isolated from the mainland to form the Pleistocene parts of Matakana and Rangiwaea Islands, the latter occurring in two sections (Figure 5.1). The rhyolitic Bowentown Heads and Mount Maunganui were also islands at the end of this period (Dahm 1983).

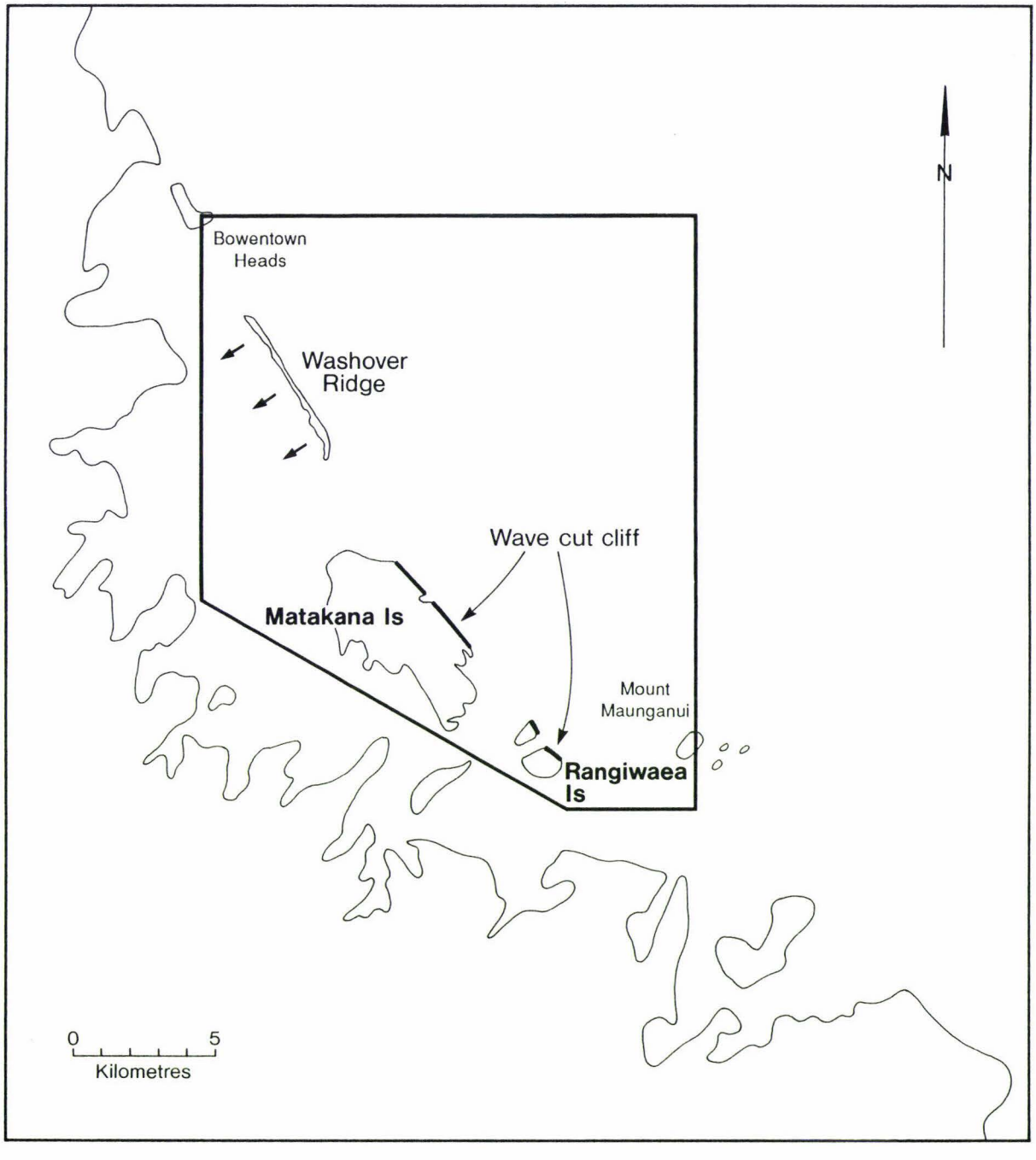


Figure 5.1: Tauranga Harbour and associated islands at the end of the Postglacial Marine Transgression, *c.*7 000 cal BP. Mount Maunganui and Bowentown Heads were isolated from the mainland at this stage (after Dahm 1983). A washover ridge was probably migrating landward across the inner continental shelf southeastward of Bowentown Heads at this time. Further discussions below focus on the highlighted area.

In the absence of the Holocene barrier and tombolo system which presently shelters Tauranga Harbour from the open ocean, a true estuarine environment would not have existed. The infilling of the basin with Holocene marine and estuarine sediments began only after submergence, hence the extensive intertidal flats presently occurring in the harbour would have been absent at the end of this period. Shoreline recession on the seaward part of proto-Matakana Island in response to the sea level rise led to the formation of the linear wave-cut pre-barrier Holocene shoreline described in Section 2.1.1.5 (Figure 2.5). A similar process probably occurred on Rangiwaea "Islands", although a linear escarpment was not formed owing to the small size of the islands. The washover ridge which forms the inner part of the barrier northwest of Blue Gum Bay may have already existed by this stage, migrating landward across the inner shelf towards its present position (Figure 5.1).

The following discussions focus on the development of Matakana Island subsequent to the Postglacial Marine Transgression. Tidal deltas are shown schematically: the position of the main ebb channel, channel margin linear bars, terminal lobe and swash bars is inferred for ebb-tidal deltas, while the main body of inferred flood-tidal deltas, the ebb shield, is represented (terminology after Hayes 1980: cited in Boothroyd 1985). The infilling of embayments of the Pleistocene part of the island is shown proportional to time since *c.*7 000 cal BP.

5.1.5 Period 5: Early barrier formation (*c.*7 000 cal BP to *c.*5 200 cal BP)

Following the end of the Postglacial Marine Transgression, onshore sediment movement from the shelf began to form the Matakana Island barrier (Figure 5.2). The migrating washover ridge mentioned above stabilised to form the innermost ridge of the northwestern part of the barrier *c.*6 000 cal BP as indicated by the maximum age from NZA-3878 (Figure 4.7; Table 4.1). The extensive backbarrier washover slope (Section 2.1.2.5) on the washover ridge now underlying the innermost ridge described here indicates considerable reworking by washover processes had occurred, a process also supported by sedimentological evidence described in Chapter 3.

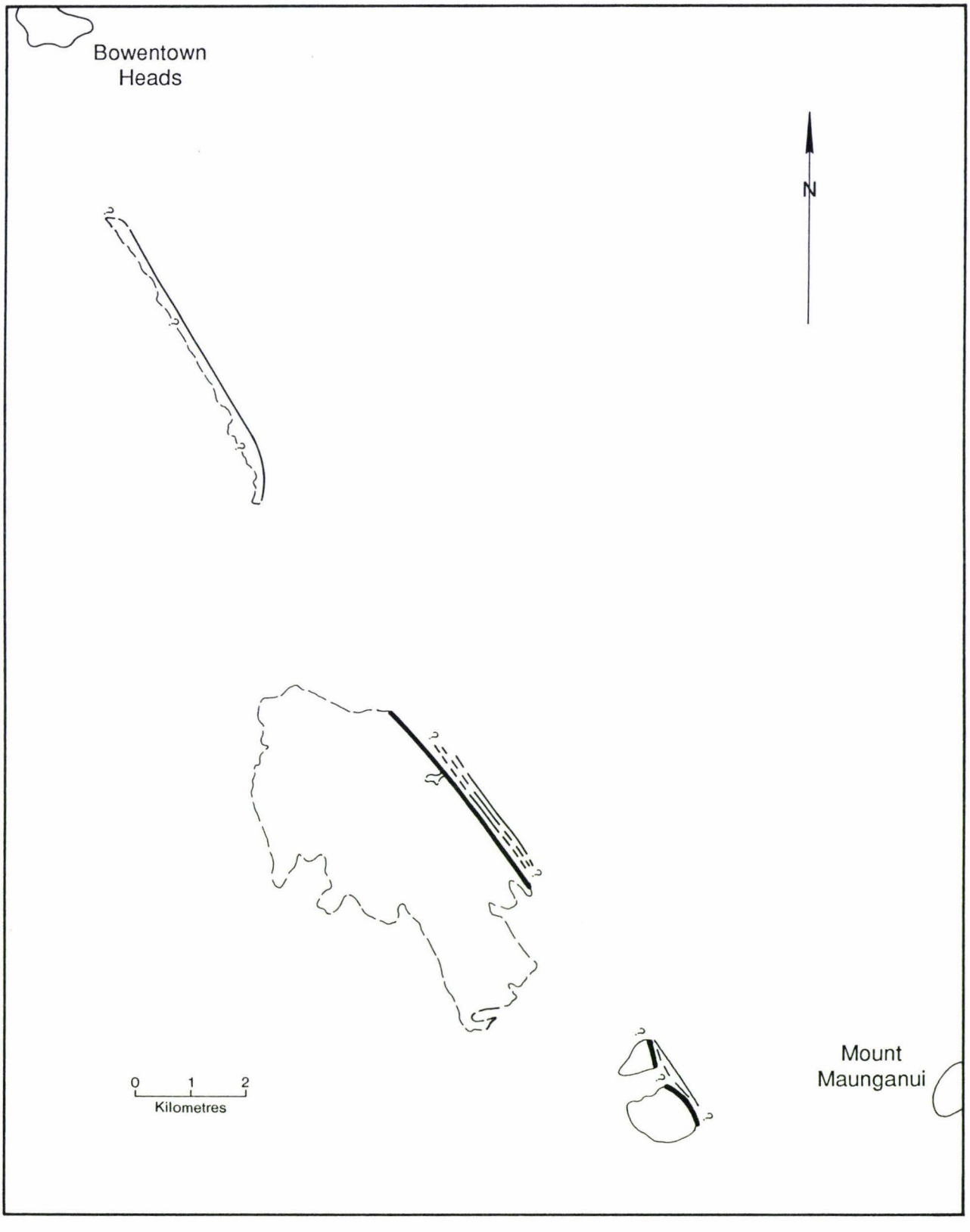


Figure 5.2: Initial formation of the Matakana Island barrier, *c.*6 000 cal BP.

This stage marked the beginnings of present-day Tauranga Harbour and the development of a backbarrier estuarine environment, and formed morphological unit 1 described in Section 2.1.2.2.

The initial pattern of barrier formation is complex. The barrier probably initially developed adjacent to the Pleistocene islands of Matakana and Rangiwaea. Early barrier development also occurred to the northwest in association with the abovementioned washover ridge, independent of any land mass, where the sea floor may have been shallow. Recurved ridges in the vicinity of Blue Gum Bay (Section 2.1.2.2; Map 1), together with a wedge-shaped area of relict estuarine flats (Section 2.1.2.6; Map 1) show that the barrier initially formed in at least two sections. These were separated by an entrance to Tauranga Harbour located at present-day Blue Gum Bay. Additional entrances to the developing Tauranga Harbour at this stage included the proto-Katikati Entrance (and possibly another entrance northwest of Bowentown Heads), the proto-Tauranga Entrance, an entrance southeast of Mount Maunganui and another between Matakana and Rangiwaea Islands (Figure 5.2). The early separation of these proto-barrier features by tidal entrances probably reflects control by former fluvial channels occurring at the northwestern and southeastern margins of the remnant interfluve which comprises the Pleistocene part of Matakana Island.

Low relict foredunes described from Profile 7 in Section 2.1.2.2 suggest that progradation adjacent to Pleistocene Matakana Island in the earliest stages of barrier development was rapid. This would have been favoured by a shallow offshore profile. The large recurved spit adjacent to the pre-barrier Holocene shoreline (Figure 2.1) suggests progradation was initially slow in the earliest stages of onshore sediment movement (perhaps during the final stage of the Postglacial Marine Transgression), rapidly increasing as sea level stabilised and sediment supply increased.

Figure 5.3 below shows Matakana Island *c.*5 200 cal BP (maximum age for this stage from NZ-8235). The onset of initially rapid onshore sediment movement, as is widely reported to have occurred with many Holocene barrier systems, is not thought to have immediately resulted in rapid progradation of the entire barrier. Instead, the author proposes that a considerable proportion of this available sand was absorbed by flood- and ebb-tidal deltas

Figure 5.3: The Matakana Island barrier *c.*5 200 cal BP, showing the development of ebb-tidal deltas as the barrier prograded seaward.

developing in association with the harbour entrances (Figure 5.3), reducing the amount available for barrier progradation. It is suggested that a consequently slow progradation rate resulted in the formation of the large ridges of the inner part of the barrier (the inner part of morphological unit 2 illustrated by Profiles 2 and 3 in Figure 2.17), and also began to form larger foredunes seaward of the low relict foredunes described from Profile 7. Seaward progradation is also likely to have been reduced by the southeastward extension of the barrier towards Blue Gum Bay during this time (Figure 5.3).

The Mount Maunganui tombolo is not thought to have become attached to Mount Maunganui until *c.*3 000 ^{14}C years BP (J.G. Gibb, pers. comm. 1995), or about 3 150 cal BP. Prior to this, tidal currents would have passed both sides of the Mount, as well as between Matakana and Rangiwaea Islands. The open nature of the "harbour" southeast of Pleistocene Matakana Island probably resulted in significantly lower tidal current velocities through the "entrances" than those occurring through the present single narrow Tauranga Entrance. Tidal deltas are generally poorly developed in the absence of strong tidal currents (Boothroyd 1985) and it is therefore suggested that delta formation was limited to shoals or had not occurred southeastward of Pleistocene Matakana Island by this stage. In contrast, the larger tidal prism of the northwestern part of the harbour was serviced by only two major harbour entrances at this time, probably resulting in relatively stronger tidal current velocities and greater delta development. Evidence for the time of attachment of the Waihi Beach tombolo is unknown to the author, but with southeastward littoral drift it is tentatively suggested to have linked up to Bowentown Heads during the early part of this period.

Small transgressive dunes along the inner barrier northwest of Western Road probably formed at this stage from blowouts prior to soil and vegetation development on the relict foredunes.

5.1.6 Period 6: *c.*5 200 cal BP to *c.*4 500 cal BP

Rapid onshore sediment movement is suggested to have enabled the tidal deltas to "mature" relatively quickly. As the deltas approached this stage, progressively more sand would have become available for shoreline progradation, increasing the progradation rate and consequently forming smaller relict foredunes (Figure 5.4) as described from Section 2.1.2.2.

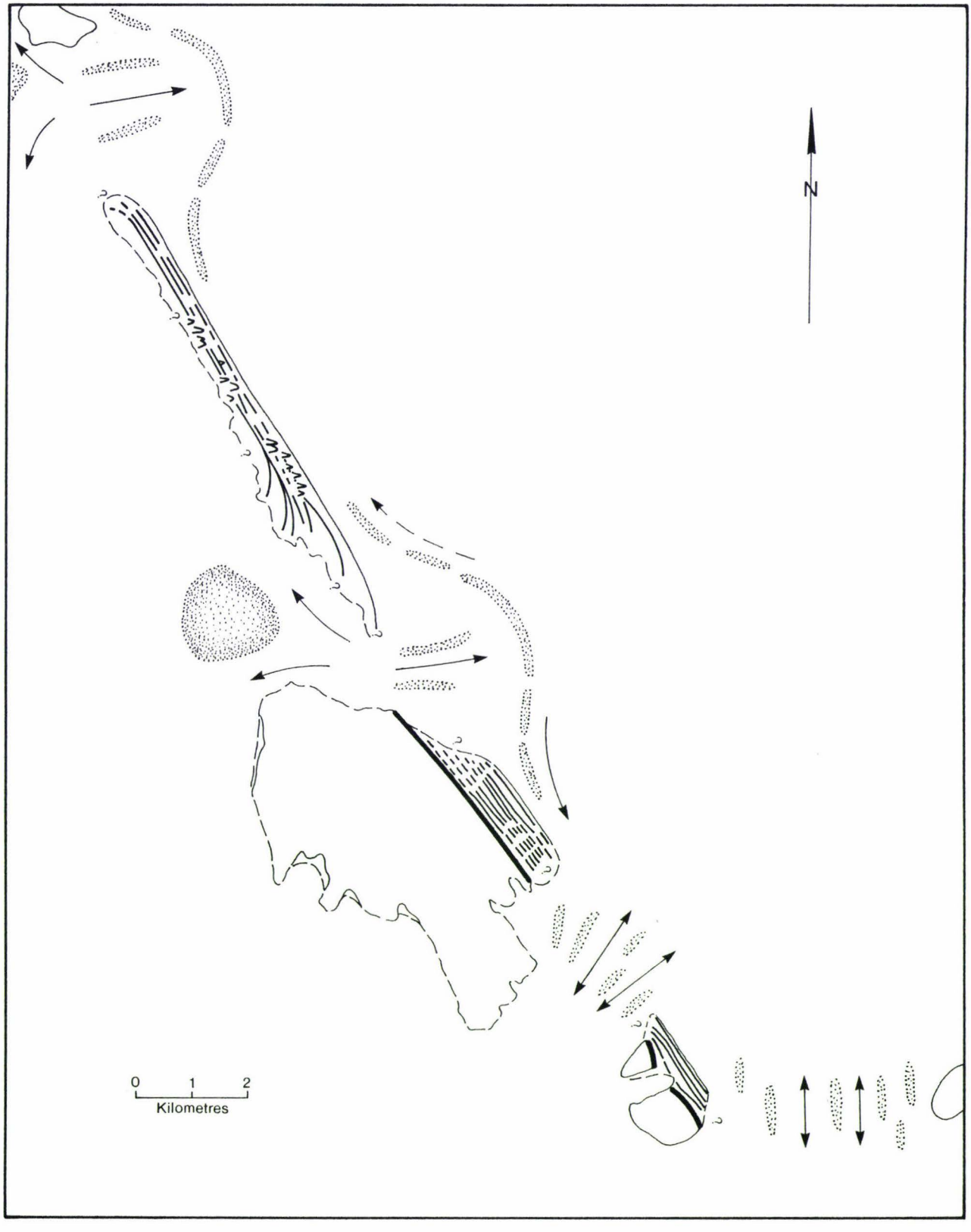


Figure 5.4: *c.*4 500 cal BP. The ebb-tidal deltas reached maturity by this stage, resulting in increased barrier progradation via an increased sediment supply.

The progressive narrowing of the entrance at Blue Gum Bay by the southeastward extension of recurved spits (Figure 2.1; Map 1) acted to reduce its size. With the gradual reduction of currents through the Blue Gum Bay entrance, the associated ebb-tidal delta would have become a relict feature. Consequently, the "excess" deltaic sediments would have been progressively reworked by waves and incorporated into the barrier as the entrance narrowed, contributing further to barrier progradation (Figure 5.4). This is inferred to have occurred from *c.*4 500 cal BP. Shell material dated at 8 703 ± 72 ^{14}C years BP (NZA-3880) from the approximate position of the shoreline at this stage was certainly reworked.

5.1.7 Period 7: *c.*4 500 cal BP to *c.*4 100 cal BP

As the Blue Gum Bay entrance narrowed it migrated southeastward in the direction of littoral drift, truncating older relict foredunes on its southeastern margin (Figure 5.5). The entrance became increasingly offset as this occurred, enabling waves to further redistribute ebb-tidal delta sediments along the beaches of the barrier. This is thought to have enabled a spit from the southeastern part of the barrier to develop and extend across the harbour entrance which existed between Rangiwaea and Matakana Islands, deflecting this entrance southeastward (Figure 5.5). A possible recurved ridge adjoining this spit is preserved at the northwestern end of the Mill settlement. This spit was initially subject to washover processes, forming a second backbarrier washover slope southeastward of the Mill (Figure 2.1). The southeastward growth of this spit led to the development of present-day Hunter's Creek and sheltered Rangiwaea Island from ocean waves, ending foredune plain development on Rangiwaea Island.

The low relict foredunes adjacent to the pre-barrier Holocene shoreline of Matakana Island were probably eroded from the southeast at around this time (*c.*4 100 cal BP), forming a semicircular escarpment. It is tentatively suggested that flood tidal currents associated with the developing Hunter's Creek caused this erosion. Further to the north, discontinuous relict foredunes formed along and parallel to the northwestern margin of the Blue Gum Bay entrance as it began to narrow, indicating a higher-energy harbour entrance environment rather than an estuarine environment for this part of the barrier at the time (Figure 5.5).

Figure 5.5: Matakana Island *c.*4 100 cal BP.

A relict Holocene parabolic dune occurring on the Pleistocene part of Matakana Island has been described in Section 2.1.1.4. Sediment availability along this shoreline is presently insufficient to form transgressive dunes and this dune is therefore thought to have formed while the Blue Gum Bay entrance was active, when sediments associated with a flood-tidal delta may have been available for dune building. Transgressive dune activity probably continued northwest of Western Road to form the older portions of the large transgressive dunes shown in Figure 4.11. The inner ridge near the Mill was also modified by the development of isolated parabolic dunes.

Instability of the Katikati Entrance during this period is evident from the truncation of relict foredunes by a scarp which occurs about 600 metres north of the northwestern limit of the backbarrier washover slope shown in Figure 2.1. Subsequent progradation led to the formation of a wetland area seaward of this scarp, probably initially as a spit-enclosed lagoon. At the southeastern end of the barrier, the probable early stages of development of the spit which eventually became the Mount Maunganui tombolo, combined with the southeastward diversion of Hunter's Creek, would have concentrated tidal currents through the present-day Tauranga Entrance. Accordingly, tidal delta formation at this entrance probably commenced about this time (Figure 5.5).

5.1.8 Period 8: *c.*4 100 cal BP to *c.*3 750 cal BP

By between *c.*4 100 and *c.*3 750 cal BP the Blue Gum Bay entrance had begun to close off, resulting in the rapid redistribution of associated ebb-tidal delta sediments onto the barrier as it extended southeastward. The abundant available sediment led to rapid progradation of this part of the barrier, forming the small ridges (the seaward part of morphological unit 2) described from Profile 5 in Section 2.1.2.2. Interaction between the shoreline of this time and the entrance is illustrated by the seaward-concave plan form of relict foredunes on the southeastern margin of the entrance. At the same time, the northwestern part of the barrier continued to prograde and extended towards Blue Gum Bay as the tidal entrance narrowed (Figure 5.6) and tidal delta growth continued at the Tauranga Entrance.

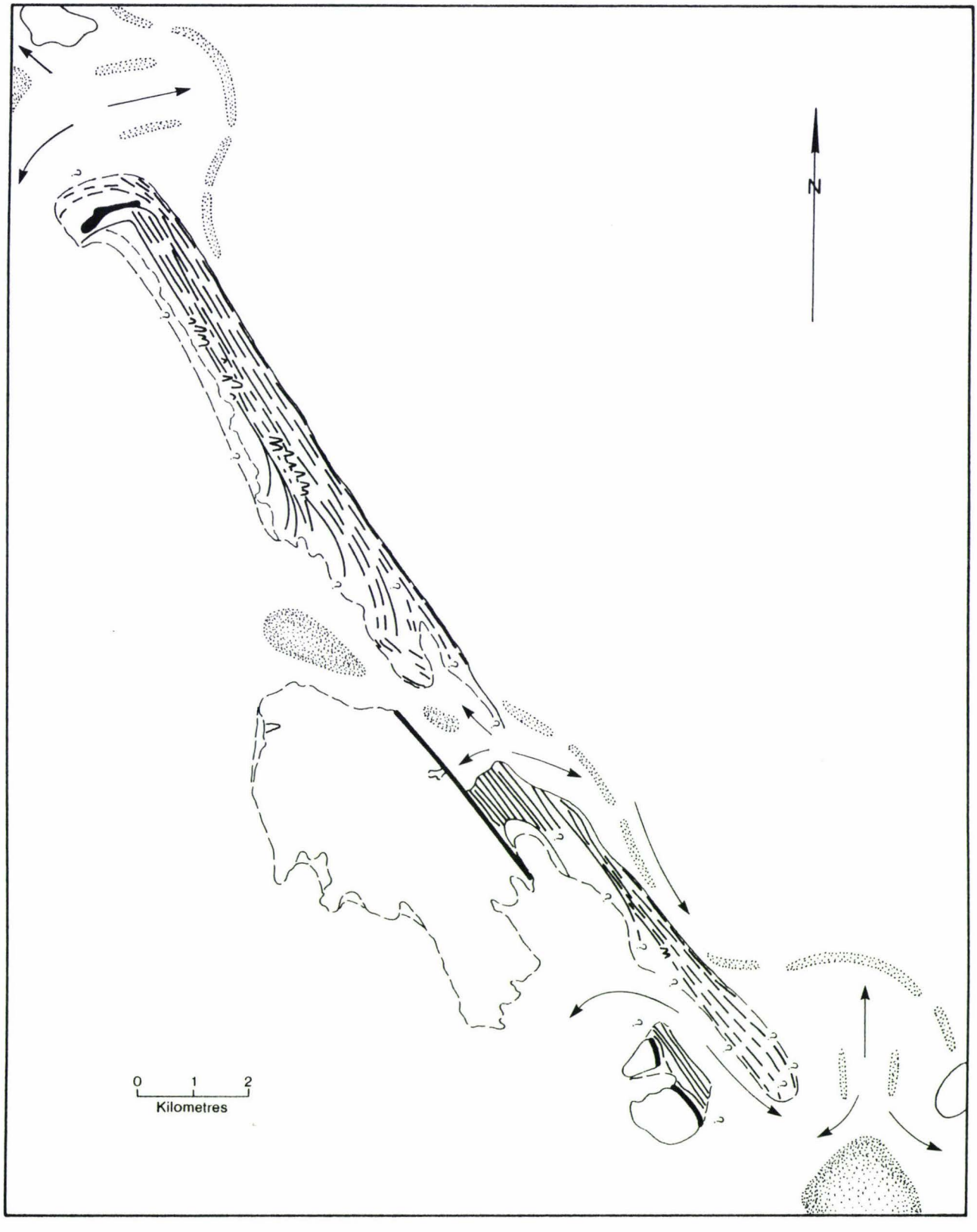


Figure 5.6: Matakana Island immediately prior to *c.*3 750 cal BP, with the Blue Gum Bay entrance almost closed.

Textural and mineralogical analyses in Chapter 3 showed the barrier sediments to be uniform in a shore-normal direction, suggesting an offshore origin for the sediments forming the barrier during this period. Longshore transport of sediments from the northwest is assumed to be relatively less significant in terms of the probable large volumes of sediment being derived from offshore at the time. Size analysis of relict beach sediments in the vicinity of Blue Gum Bay illustrates sediment coarsening with proximity to the Blue Gum Bay entrance, in a pattern analogous to that of the contemporary beach sediments near the Tauranga Entrance.

An average progradation rate of about 0.46 metres/year (see Table 5.1(a) below) is suggested for the northwestern part of the barrier, derived from the position of the innermost ridge at *c.*6 000 cal BP and the shoreline at *c.*3 750 cal BP (the "Long Ridge"). This may have varied considerably within this period, probably being lower in the early stage of barrier formation.

5.1.9 Period 9: *c.*3 750 cal BP to *c.*1 750 cal BP

The beginning of this period is particularly significant for the development of the barrier. The Blue Gum Bay entrance closed off completely *c.*3 750 cal BP as indicated by the Waimihia Pumice shoreline (*c.*3 450 cal BP), which occurs about 200 metres to seaward (Figure 4.1) and radiocarbon dating of the "Long Ridge" (see Section 4.2.1). This event marks the transition to a single Matakana Island barrier (Figure 5.7).

An abrupt change to considerably larger relict foredunes (morphological unit 3 described in Section 2.1.2.2) accompanied the closure of this entrance, beginning with the "Long Ridge". Section 2.1.2.2 related relict foredune size to progradation rates, whereby slower progradation generally resulted in larger foredunes (after Shepherd 1987). This appears to have occurred on the barrier following the closure of the Blue Gum Bay entrance. The mean progradation rate during this period was approximately 0.16 metres/year in the vicinity of Western Road, less than 35 percent of that for Period 5 (see Table 5.1(a)). As discussed below in Section 5.2, relict foredune systems in New Zealand and Australia have widely experienced decreasing progradation rates towards the present, independently of events such as the closure of tidal inlets. However, the abrupt change apparent here, immediately following the closure of the entrance described above, suggests that the closure also influenced the local sediment budget.

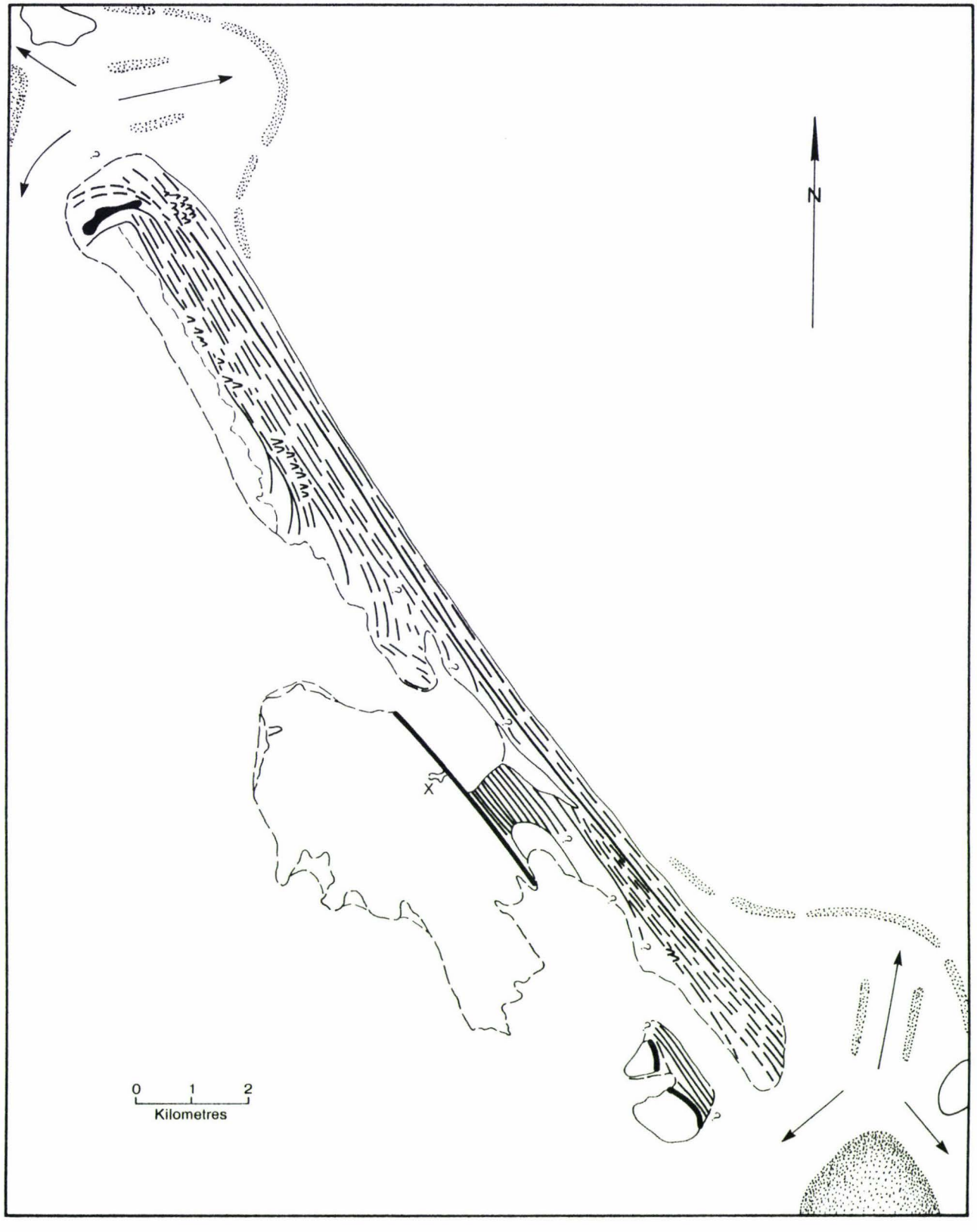


Figure 5.7: Matakana Island *c.*1 750 cal BP. The Blue Gum Bay closed off *c.*3 750 cal BP, forming a single barrier. The swamp core site mentioned on page 165 and described in full in Appendix 1 is located with an "x".

Submarine deltas associated with tidal inlets are effective sediment traps (Oertel 1972) which interrupt the longshore transport of sediment (Healy *et al.* 1977), particularly if they are in disequilibrium and accumulating large amounts of sediment. The closure of the Blue Gum Bay entrance probably resulted in an increase in tidal current energy through the Katikati Entrance, leading to probable enlargement of the Katikati Entrance and sand accumulation on its associated delta. Consequently, less sand would have been available for shoreline progradation, slowing progradation rates and leading to the formation of successive large foredunes.

Following this event, the reduced progradation rate resulted in the formation of seven major relict foredunes (decreasing to five towards the northwestern end of the barrier) prior to the Taupo eruption. These irregular dunes were modified by numerous blowouts during their formation. Increased aeolian modification of these dunes may have related to their greater height, causing greater wind stresses across their crests which were consequently partially deflated.

The development of the barrier across the Blue Gum Bay entrance led to the sheltering of the adjacent Pleistocene part of Matakana Island from salt-laden onshore winds. This is suggested to have resulted in the displacement, from the swamp site investigated in Appendix 1 (labelled "X" in Figure 5.7), of previously dominant shrubs and ferns by podocarp-dominated forest. The closure of the Blue Gum Bay entrance probably also led to increased tidal flows through the Katikati Entrance, causing erosion of the adjacent Matakana barrier as indicated by truncated ridges (including the innermost ridge) on the inner part of the northwestern end of the barrier.

With the Blue Gum Bay entrance closed and the barrier extending southeastward beyond Rangiwaea Island, the reduced energy regime of the harbour facilitated the increased development of estuarine flats as the harbour shorelines accumulated sediment. Reworking of the relict flood tidal delta in Blue Gum Bay by harbour waves is thought to have led to substantial infilling of Blue Gum Bay and the relict inlet gorge, a process which continued beyond the Taupo eruption as mentioned below. A small spit (approximate grid reference NZMS 260 U14 802987, not shown in Figure 2.1) aligned with its distal end towards Blue

Gum Bay confirms the transport of sediment into the bay.

The Mount Maunganui tombolo probably became attached to Mount Maunganui during this period, and, as with the Katikati Entrance following closure of the Blue Gum Bay Entrance, tidal flows were consequently increased at the Tauranga Entrance causing the adjacent barrier to erode (Figure 5.7). The attachment of the Mount Maunganui tombolo may have been similarly responsible for erosion of the northwestern end of the barrier which continued beyond the end of this period, as indicated by the post-Taupo/pre-Kaharoa shoreline shown in Figure 4.1. This suggests that the tidal flats of the present-day Katikati Bar between Matakana Island and the mainland were considerably lower in elevation or not present at this time, in order to allow for substantial interaction between present-day Katikati and Tauranga Harbours which are presently almost hydraulically independent (Davies-Colley 1976). Erosion of the ends of the barrier continued beyond the time of the Taupo eruption, particularly at the Tauranga Entrance.

5.1.10 Period 10: *c.*1 750 cal BP to *c.*650 cal BP

The Taupo eruption occurred at the beginning of this period, depositing abundant Taupo Lapilli on the barrier. Large amounts of sea-rafted Taupo Pumice are likely to have been stranded on both the ocean and harbour shorelines of the barrier, although subsequent erosion probably removed it from many parts of the harbour shoreline of the island, particularly at Hunter's Creek and near the Katikati Entrance. The location of the Taupo Pumice shoreline is further confirmed on the ocean side of the barrier by the results of mineralogical analyses described in Section 3.2.3.1, where an influx of volcanic glass and rock fragments (Figure 3.23) is attributed to tephric material from the Taupo eruption being washed up on the region's beaches shortly after the event. This also explains the distinctive texture of the sediments of this relict foredune (Section 3.1.2.1). Local vegetation appears not to have been significantly disturbed by this event, although a sharp rise in charcoal influxes (see Appendix 1) suggests burning may have occurred elsewhere in the region.

Progradation rates continued to slow following the Taupo eruption, indicating the contribution of tephric material to barrier progradation from the Taupo eruption was minimal. This was

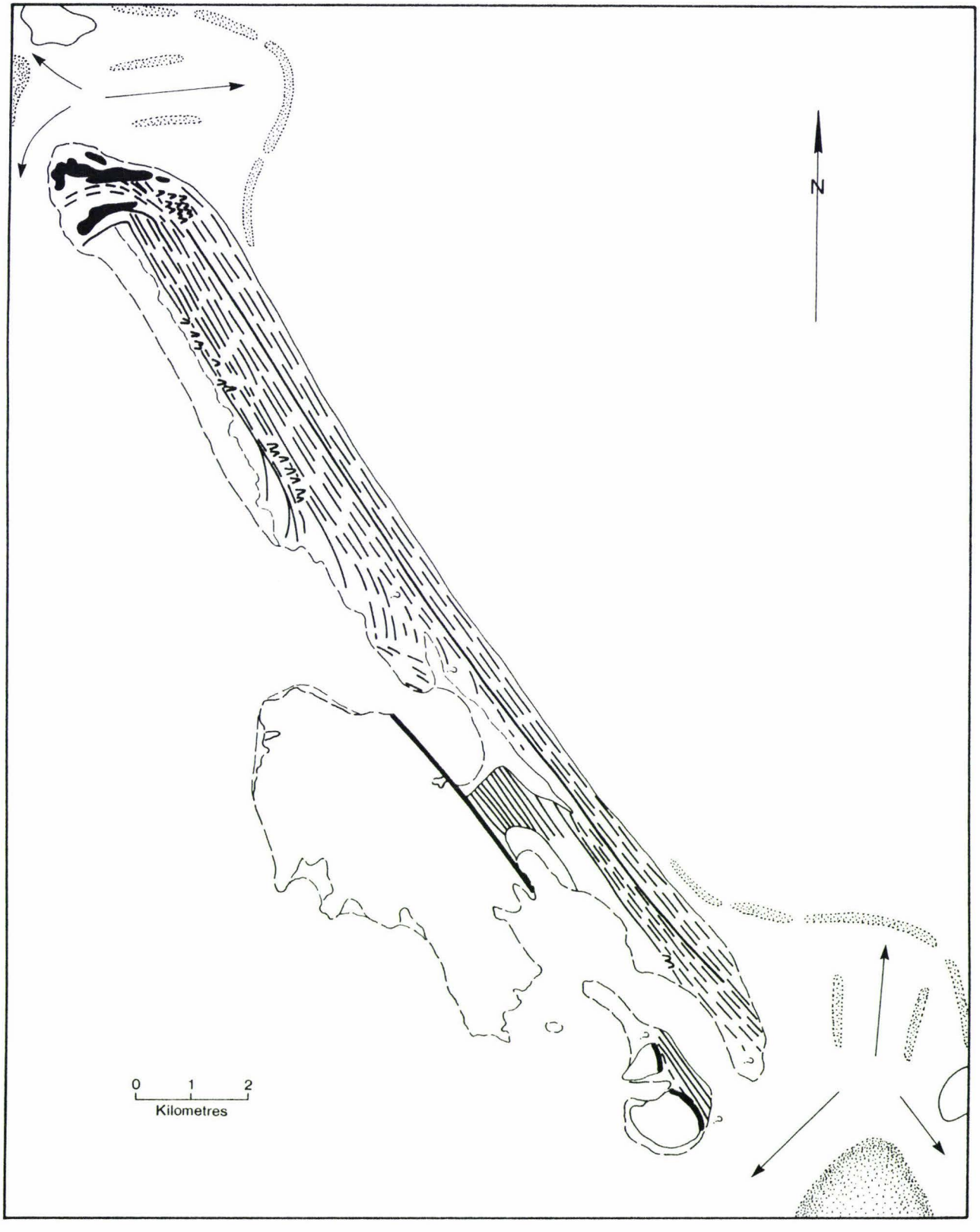


Figure 5.8: Matakana Island *c.*650 cal BP.

confirmed by Figure 3.23 which showed the influx of eruptives described above to be a temporary phenomenon. A mean progradation rate of 0.11 metres/year is derived for the barrier (Table 5.1(a)), based on the distance between the Taupo and Kaharoa shorelines in Figure 4.1 measured near Western Road. Infilling of Blue Gum Bay is likely to have continued, to form extensive relict estuarine flats. Much of this infilling occurred after the Taupo eruption as indicated by the position of the Taupo Pumice shoreline in Figure 4.1. Other estuarine flats had probably formed by this stage (Figure 5.8), although their exact chronology is not known.

A continuation of the shoreline recession at the northwestern end of the barrier, which began prior to this period, formed the post-Taupo/pre-Kaharoa shoreline discussed in Section 4.1.2. Similarly, the erosion of the southeastern part of the barrier precludes any reconstruction of its history for this period although it is likely to have been eroding. Prior to the Kaharoa eruption the northwestern part of the barrier again prograded, forming several new wetland areas (Figure 5.8). Meandering tidal channels began to widen the narrow inlet occupied by Hunter's Creek, removing the inner part of the barrier seaward of Rangiwaea Island. This may account for the lack of a harbourward-coarsening sediment size trend for this part of the barrier (Section 3.1.2.1; Transect 4). The northwestward extension of Rangiwaea Island to form the "panhandle" spit possibly began at around this time in response to the low energy regime or infilling which prevailed in upper Hunter's Creek. However, the exact origin of the "panhandle" requires further investigation.

Transgressive dunes near Waikoura Point (Section 4.2.2.2) were active during this period. Dune initiation may have been related to the erosion of large relict foredunes, or to vegetation disturbances suggested above.

5.1.11 Period 11: *c.*650 cal BP to the present

Rapid and substantial change occurred in the barrier environment during this period. Major shoreline changes occurred at the ends of the barrier and the arrival of the Maori led to rapid and widespread vegetation clearance and soil disturbance. Present barrier geomorphology is shown in Figure 2.1.

Barrier geomorphology at the time of human arrival is assumed to have been similar to that shown in Figure 5.8 above. A podocarp-dominated forest probably existed on the inner and central barrier, grading seaward to scrubland and then pioneering dune vegetation as detailed by Beadel (1989b) (Section 1.2.6) as soil fertility decreased.

The arrival of the Maori led to the widespread destruction of the vegetation on the barrier. Charcoal fragments sampled from the buried soils below Kaharoa Tephra along the soil pit transect described in Appendix 2 were identified by R. Wallace (Department of Anthropology, University of Auckland) and indicate a mature forest existed on the barrier prior to the Kaharoa eruption. Charcoal of *Podocarpus totara* (totara), *Prumnopitys taxifolia* (matai) and other conifers were present, along with *Nestegis* spp. (maire). *Pteridium esculentum* (bracken) was also common in places. A garden soil sampled adjacent to test pit 5 (located in Figure A2.1 in Appendix 2) showed a dominance of *Pteridium esculentum*, indicating forest disturbance in association with cultivation.

Charcoal identification was also carried out by R. Wallace as part of the archaeological study of Marshall *et al.* (1994). All samples were from cultural layers and therefore representative of the vegetation present around the sites during prehistoric occupation.

Charcoal described from sites in the vicinity of Profile 2 (Figure 2.17) by Marshall *et al.* (1994) indicate an open scrubland vegetation dominated by *Leptospermum scoparium* (manuka) and *Pteridium esculentum*, with only a limited range of other shrubs present (Wallace 1994). A similar vegetation type in association with occupation was determined by charcoal identification adjacent to Blue Gum Bay southeast of Pipeline Road.

A different pattern emerged from Duck Bay. Charcoal fragments from cultural sites immediately northwest of the bay indicated a mixed broadleaf forest/shrubland vegetation (Wallace 1994), perhaps indicating the early stages of occupation before widespread clearance occurred. The absence of this vegetation further northwest and the dominance of the pioneers *Pteridium esculentum* and *Leptospermum scoparium* is a strong indicator of widespread forest disturbance by human occupation. Forest clearance is also clearly demonstrated by the virtual disappearance of podocarps and strong increases in *Pteridium* indicated by pollen analyses

described in Appendix 1. Radiocarbon ages from the swamp core studied were anomalous and failed to identify the time at which forest clearance occurred around the site. Appendix 1 suggests that the Pleistocene part of Matakana Island in the vicinity of Blue Gum Bay and possibly the wider Tauranga Basin, was originally forested by podocarps (particularly *Dacrydium cupressinum* (rimu)) prior to clearance. A piece of kauri (*Agathis australis*) gum recovered from the inner part of the northwestern part of the barrier was dated at 1 449 ± 51 ^{14}C years BP (NZ-8294), indicating the past presence of this species on the barrier.

Shoreline change during this period was extremely variable with substantial extension of the ends of the barrier. Some erosion of the southeastern margin of the barrier continued after the Kaharoa eruption, with the post-Kaharoa wave-cut scarp marking the limit of shoreline retreat (Figure 4.1). This limit was probably reached *c*.600 cal BP, indicated by the position of the Loisels Pumice shoreline. Subsequent progradation was rapid and sustained, causing the Tauranga Entrance to narrow by *c*.83 percent from about 3.2 kilometres to the present 540 metres, at an average rate of 4.43 metres/year. A rate of 4.00 metres/year is derived for the last 140 years from the position of the 1852 shoreline (Figure 4.3), indicating that a high rate of progradation continued well into historical times. Similarly, the Katikati Entrance narrowed by about 1250 metres (*c*.75 percent) following the Kaharoa eruption, at an average rate of 1.92 metres/year. However, as mentioned above, Figure 4.2 indicates that most of this progradation occurred in historical times, with up to 1000 metres of progradation occurring between 1870 and 1974 at an average rate of almost ten metres per year. In contrast, much of the barrier shoreline northwest of Western Road prograded much more slowly at about 0.18 metres/year (see Table 5.1(a)). Reasons for this apparently late progradation at the Katikati Entrance are unclear but the entrance, being unstable (Munro 1994), may have oscillated in width rather than having simply narrowed over recent centuries.

Progradation of the southeastern end of the barrier proceeded at higher rates at the distal end, resulting in an anticlockwise rotation of the ocean shoreline from the post-Kaharoa shoreline to the present configuration (Figure 5.9). Southward spit extension is suggested to have occurred in the early stages of progradation, partially enclosing an embayment to form present-day Duck Bay. The high rate of progradation prevented the formation of large foredunes, instead forming a series of very low ridges illustrated by Profile 6 in Figure 2.17.

These were considerably modified by wind, probably as a result of large areas of unconsolidated sand being exposed to the effects of wind as the shoreline rapidly prograded (similarly to present-day Panepane Point), to form the present low, irregular topography of the area. Topographic lows and wetland areas have a distinctive north-south orientation, supporting the pattern of shoreline progradation suggested here (Figure 5.9).

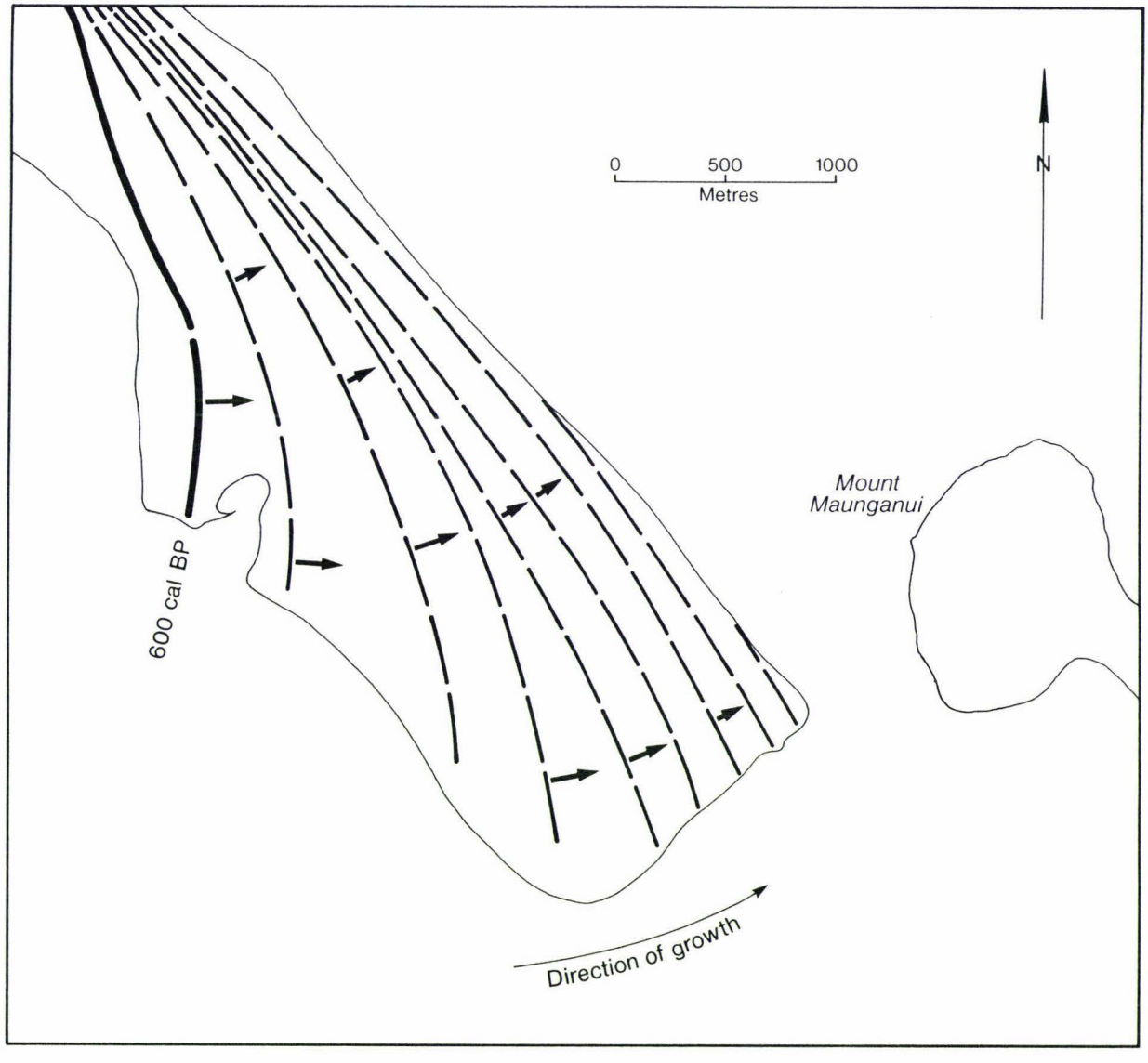


Figure 5.9: Progradation of the southeastern part of the barrier between *c.*600 cal BP and the present, resulting in an anticlockwise rotation of the ocean shoreline.

The recent substantial narrowing of both entrances to Tauranga Harbour, particularly the Tauranga Entrance, implies considerable change has occurred within the harbour itself since the Kaharoa eruption. One possibility is the effect of the eruption on the amount of sediment

supplied to the harbour. A large influx of volcanic material into the harbour, both directly and by fluvial transport from the hinterland, could have greatly reduced the tidal prism of the harbour, particularly if antecedent sedimentation had infilled the harbour to about the level of mean low tide.

A second possibility is the impact of human activities in the region. The widespread deforestation and soil disturbance accompanying occupation almost certainly led to sharply increased erosion of the catchments draining into the harbour, raising their sediment yields and accelerating the rate of harbour sedimentation. Similar processes occurring in response to deforestation have been reported from other locations in New Zealand, e.g., Striewski *et al.* (1994).

To test these hypotheses it would be necessary to investigate the stratigraphy of the harbour sediments. This was beyond the scope of this thesis. However, a 30 centimetre thick deposit of Kaharoa Tephra has been reported from a quiet restricted part of Ohiwa Harbour by Richmond (1977), indicating the deposition of substantial volumes of ash in the harbour by this event.

Thirdly, rapid progradation may result from a change in tidal inlet dynamics, perhaps triggered by slight changes within the harbour. A wide, shallow, wave-dominated inlet type, suggested by Munro (1994) to have characterised the Katikati Entrance about 900 ^{14}C years BP, could have narrowed rapidly without a significant change in the tidal prism if tidal currents scoured a deeper tidally-dominated inlet gorge. Such a scenario would be possible in a transition from wave-dominated to tidally-dominated inlet types, but implies a significant decrease in incident wave energy which cannot be supported by available evidence.

The rapid narrowing of the harbour entrances and associated extension of the ends of the barrier was probably caused by harbour sedimentation, accelerated either by tephra deposition or indirect cultural influences, or perhaps a combination of the two. Substantial fluctuations in the position of the shoreline have continued through to the present day at each entrance, as shown in Figures 4.2 and 4.3. In April 1976, an area of approximately twenty hectares was eroded from Waikoura Point (Healy *et al.* 1977) and the shoreline continued to retreat up until

at least 1992 (Figure 4.2). Figure 5.10 illustrates the severity of this erosion, where a dead radiata pine tree had been left stranded on the mid-foreshore, still in growth position, by shoreline recession. Within two months of the photograph being taken, subsequent progradation had raised the beach surface by over 1.7 metres.

Figure 5.10: A radiata pine tree remaining in growth position after severe shoreline recession, Waikoura Point, December 1994. Note the erosion of the forest area in the background. By February 1995 a return to progradation had buried the trunk to above the author's head.

Transgressive dune activity on the barrier was most extensive during this period and continued through to early historical times (Section 4.1.3.2). Dunes of this period occur along the harbour shoreline between Blue Gum Bay and Western Road, at Hunter's Creek and as an extensive strip near the contemporary shoreline along much of the barrier (morphological unit 4 of Section 2.1.2.2). This strip widens southeastward of the Mill (Figure 2.1) where rapid progradation was followed by widespread dune mobility. The large parabolic dunes northwest of Western Road described in Section 4.2.2.3 were remobilised during this period and other

parabolics further southeast along the "Long Ridge" were clearly active at a similar stage, but it is not known whether they also developed in two stages.

The extensive relict transgressive dunes near the contemporary ocean shoreline represent a recent period of considerable instability, an apparently regional phenomenon (Cockayne 1909) which has also been described from the Te Puke lowlands by Lowe *et al.* (1992) and the eastern Bay of Plenty by Pullar and Selby (1971). At least two phases of activity are suggested from test pit 13 (Appendix 2; Section 4.1.4), although this may not necessarily represent the entire coastal strip discussed here. Causes of this instability are uncertain but may possibly be cultural, suggested by the coincidence of this most extensive period of dune transgression in the history of the barrier with the arrival of humans. For example, post-Kaharoa dunes on the coastal Rangitaiki plains are suggested to have been initiated by human activity (Pullar 1977), and the Motuiti and Waiterere phases of dune activity in the Manawatu district have also been attributed to the arrival of the Maori and Europeans by Cowie (1963).

Conclusive evidence for cultural causes of dune initiation is unavailable on Matakana Island, but a causal link is likely in view of the widespread environmental disturbance associated with human activity. Harbour shoreline recession in the vicinity of Pipeline Road may account for the initiation of very young dunes here, but dune activity may have been exacerbated by cultural influences (such as burning, gardening and trampling of dune vegetation). Similarly, transgressive dunes at Hunter's Creek may have been mobilised by shoreline recession, cultural disturbance, or a combination of the two. A search of historical records of early settlement on the island (such as early editions of the Tauranga Herald) and of literature on dune erosion problems in New Zealand early this century (e.g., Cockayne 1909), revealed no evidence for the initiation of dune instability by Europeans on Matakana Island, in spite of severe disturbance to the vegetation. As mentioned in Chapter 4, early maps of the island did not clearly distinguish between unvegetated and vegetated dunes. However, Cockayne (1909) suggests dunes were active around the turn of the century.

Slowing barrier progradation, allowing progressively larger foredunes to form, may have contributed to dune transgression through extensive aeolian modification of large relict foredunes. The formation of small, intact relict foredunes (morphological unit 5 in Section

2.1.2.2) to seaward implies a subsequent increase in progradation rates in this scenario. However, it is the author's opinion, although unproven, that the arrival of the Maori on Matakana was largely responsible for subsequent transgressive dune activity.

5.1.12 Matakana Island at present

The present-day geomorphology of Matakana Island is shown in Figure 2.1 and Map 1. The history of the island has been characterised by often rapid change and the present is of no exception.

Figures 4.2, 4.3 and 5.10 show the barrier shoreline near the harbour entrances to have been unstable through to the present. Positional stability but morphological instability is common for northeastern North Island inlets (Hume and Herendorf 1992) and the ends of the barrier are subject to periodic erosion and accretion in response to changes in harbour entrance and ebb-tidal delta dynamics. The Katikati Entrance is morphologically unstable, as indicated by spatial and temporal variations in the morphology of the adjacent shoreline. Morphological instability is also a characteristic of the Tauranga Entrance and associated ebb-tidal delta (Dahm 1983). Progradation of the central part of the barrier is presently very slow or negligible. Sedimentological evidence from offshore samples collected by Healy, *et al.* (1977) suggests that the shelf is presently not contributing large quantities of sediment to the nearshore-beach-dune system (Healy, *et al.* 1977: p.37). Erosion is continuing at Hunter's Creek (Figure 2.10(b)) as a meander of the main channel continues to impinge against the inner part of the barrier.

Estuarine spits and islands associated with Matakana and Rangiwaea Islands are also highly dynamic. Small hooked spits present around the margins of Rangiwaea Island are generally sparsely vegetated, suggesting continuing sand accumulation. On the other hand, Tahunamanu Island, adjacent to Opureora, has been eroded significantly in recent years.

Almost the entire barrier is now devoted to commercial forestry operations, apart from relict estuarine flats, lakes and wetlands which were generally left in their natural state (Section 1.2.5).

5.1.13 Possible future geomorphological changes

The inherently unstable nature of both the Katikati and Tauranga Entrances means that irregular and often rapid changes in the position of the shoreline are likely to continue into the future as entrance and tidal delta conditions fluctuate. Similarly, the erosion of the Hunter's Creek shoreline will continue for as long as the main tidal channel continues to meander seaward. A progressive reduction in the hydraulic gradient of the channel as the meander lengthens will probably eventually limit further seaward migration, although the timing of this and the likely position of the channel by this stage are uncertain.

Continued infilling of the harbour by marine, fluvial and organic sedimentation, with possible additions of tephra, is expected to further reduce the volume of its tidal prism. The harbour entrances would probably narrow in response, with further reduction of the size of the present ebb-tidal deltas and continued redistribution of ebb-tidal delta sediment along the coast. This may be insufficient to offset a continued reduction in barrier progradation or a change to recession as offshore sediment sources become depleted, as may have occurred in Australia (Roy *et al.* 1980). Initially, progressively larger foredunes may develop, followed by dune instability and transgression as shoreline progradation diminishes and foredunes become very large and unstable. With a cessation of onshore sediment movement, losses of littoral sediment to longshore transport or landward aeolian transport (Roy *et al.* 1980, Hesp and Thom 1990) may lead to shoreline recession and further dune mobility as has already occurred on some southeastern Australian barriers (Chapman *et al.*

Ultimately, assuming no further changes in sea level, the harbour will become completely infilled. A coastal plain similar to the present-day Papamoa lowlands (Wigley 1990) may result, dissected by fluvial courses draining the mainland and following similar courses to the present tidal channels. Infilling of backbarrier lagoons or estuaries may lead to renewed progradation as fluvial sediments are transported directly to the coast, provided fluvial inputs exceed marine erosion of the barrier (e.g., Roy *et al.* 1980). However, present fluvial sediment inputs into Tauranga Harbour are low (Davies-Colley 1976) and may not be sufficient to cause coastal progradation upon harbour infilling.

5.1.14 Discussion

5.1.14.1 Progradation rates

Progradation of the Matakana Island barrier has declined overall towards the present. Progradation rates considered here (Table 5.1(a)) have been calculated from the barrier adjacent to Western Road, away from the Tauranga and Katikati Entrances where progradation rates are likely to have been more erratic. The rates have been determined from the *c.*6 000 cal BP shoreline, the "Long Ridge", the *c.*1 750 cal BP Taupo shoreline and the *c.*650 cal BP Kaharoa shoreline. Because the Kaharoa shoreline is obscured by the parabolic dunes along the ocean coast, the distance between this shoreline and the sea is assumed to be *c.*120 metres based on the distance inland of two sites to the southeast where Kaharoa Tephra was observed.

Table 5.1(a): Rates of progradation of the Matakana Island barrier.

Period	Calibrated Years BP (approx.)	Distance of Progradation (m)	Progradation Rate (m/yr)
5-8	6 000 - 3 750	1050	0.46
9	3 750 - 1 750	325	0.16
10	1 750 - 650	125	0.11
11	650 - present	120	0.18

Table 5.1(b): Comparison of post-Taupo progradation rates between this study and other studies in the region.

	Matakana Island (this study)	Matakana Island (Munro 1994)	Rangitaiki Plains (Pullar and Selby 1971)	Gisborne Plains (Pullar and Penhale 1970)
Distance of Progradation (m)	225	464	484 - 1 627	360 - 1 470
Progradation Rate (m/yr)[1]	0.13	0.27	0.28 - 0.93	0.21 - 0.84

Footnote: [1] Progradation rates calculated from reported distance of progradation and the calibrated age of the Taupo eruption (*c.*1 750 cal BP).

Table 5.1(a) indicates that *c.*65 percent of the progradation occurred during the first *c.*2 250 years of barrier formation, consistent with the findings of Lowe and Wigley (1992) for the Papamoa-Te Puke coastal plain to the southeast. The change in progradation rate with time is graphed in Figure 5.11, which contains the points indicated by Table 5.1(a) plus two additional points. These are the "Long Ridge" and the inferred Stent tephra shoreline. The "Long Ridge" has an adopted age of *c.*3 750 cal BP (Section 4.2.1), which is less precise than the ages derived from tephrochronology. The Stent tephra is found only near the southeastern end of the barrier, where it is interbedded with relict foredune sand along Hunter's Creek. Its position in the sequence of relict foredunes on the northwestern part of the barrier has been inferred in two ways. The first is based on the number of ridges harbourward from the "Long Ridge"; the second on the distance harbourward of the "Long Ridge". Figure 5.11 shows a general trend, which may disguise short-term fluctuations, of an initially rapid rate of progradation which diminishes exponentially with time.

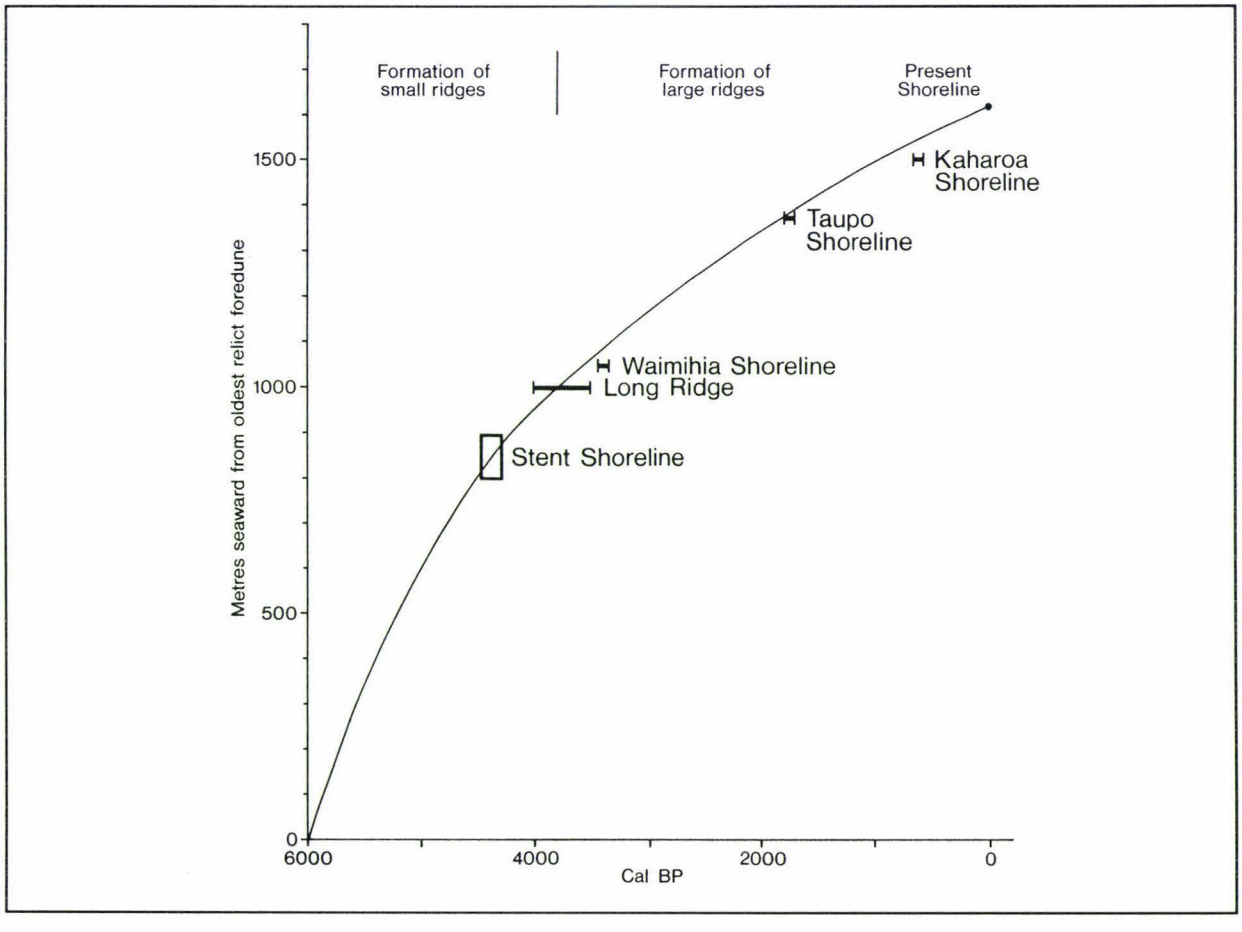


Figure 5.11: The pattern of progradation for the Matakana Island barrier based on dated shoreline positions. Uncertainty of shoreline position and age represented by error bars.

The seaward decreasing rates occur for two different but complementary reasons:

(1) As the barrier progrades into progressively deeper waters progradation rates decrease seaward as a greater volume of sediment is required per metre of progradation, assuming a constant sediment supply. This phenomenon has been well documented from Holocene barrier systems of southeastern Australia (e.g., Chapman *et al.* 1982).

(2) Onshore sediment transport gradually declines as the offshore profile approaches equilibrium with present sea level (Thom 1984, Abrahamson 1987).

These factors are further discussed in Section 5.2. The very rapid progradation of the ends of the barrier described above has been attributed to onshore movement of ebb-tidal delta sediments, which may also have contributed to the recent marginal increase in progradation rates shown in Table 5.1(a).

An average progradation rate of *c.*0.13 metres/year following the Taupo eruption is considerably lower than rates reported from elsewhere in the region (Table 5.1(b)). Progradation of 0.27 metres/year for this period at Waikoura Point (after Munro 1994) may have been influenced by proximity to the Katikati Entrance, which has been shown above to have changed considerably during historical times. Progradation rates of 0.21 to 0.84 metres/year for the Gisborne Plains (after Pullar and Penhale 1970) and 0.28 to 0.93 metres/year for the Rangitaiki Plains (after Pullar and Selby 1971) have apparently been raised by fluvial sediment inputs, particularly during historical times near the Rangitaiki River mouth (Pullar and Selby 1971).

5.1.14.2 Shell dates as evidence for reworking of tidal delta sediments

In this study, the value of radiocarbon dating of shell to the determination of barrier chronology has been affected by extensive reworking of shell-bearing sediments. Similarly, Chapman *et al.* (1982) attributed spurious radiocarbon ages from a barrier system at Tuncurry, New South Wales, to reworked shell in modern deposits. Radiocarbon ages presented in this study were consequently regarded as maximum ages. Shell dates have been similarly

interpreted by Bernard *et al.* (1962: cited in Thom *et al.* 1981), who drew time lines based on the youngest available dates and rejected the remainder as anomalously old. The "noisy" nature of shell dates is suggested by Thom *et al.* (1981) to be inversely related to progradation rates: shells on a stable coast would tend to be reworked for longer periods of time before incorporation into the barrier, whereas those on a rapidly prograding shoreline are likely to be less reworked.

The likelihood of anomalous shell dates appears to increase near both harbour entrances on Matakana Island. An anomalous radiocarbon age of 2 114 ± 46 ^{14}C years BP was obtained from a sample (NZ-7997) collected approximately 1.5 kilometres seaward of the post-Kaharoa/pre-Loisels Pumice shoreline discussed above. In addition, NZ-8021, collected seaward of the position of the 1852 shoreline shown in Figure 4.3, gave a radiocarbon age of 701 ± 31 ^{14}C years BP. Numerous anomalous shell dates were also reported from Waikoura Point by Munro (1994).

Sediment recirculation from ebb-tidal deltas is likely to have been responsible for this phenomenon. Interaction between ebb-tidal deltas and adjacent sandy shorelines, including those at the Tauranga Entrance, is well documented (e.g., Davies-Colley 1976, Healy *et al.* 1977, Oertel 1977, Dahm 1983, Fitzgerald 1984, Hayes 1991 and Healy and Kirk 1992). Shoreline configuration near tidal entrances is commonly influenced by entrance and delta processes (Fitzgerald 1984), demonstrating considerable sediment exchange between the shoreline and offshore ebb deltas. This is illustrated on Matakana Island by the presence of rounded bulges in the ocean shoreline at Waikoura Point (Healy and Kirk 1992) and about 3.4 kilometres northwest of Panepane Point. Rapid shoreline changes in association with tidal entrance dynamics are also documented by Wright (1969) at the North and South Kaipara Heads, and similar changes have occurred at the ends of the Matakana Island barrier (Figures 4.2 and 4.3).

The development of tidal deltas in association with the Tauranga and Katikati Entrances involved the accumulation and storage of large quantities of sand, incorporating shells from the harbour and adjacent beaches in the process. Present residence times of sediments in these deltas have been calculated at 675 and 430 years for the Tauranga and Katikati Entrances

respectively (Hicks and Hume 1991). Assuming these deltas are presently nearer equilibrium with their respective entrances than at any stage in the past, residence times could be expected to have been much longer in earlier times when the deltas were actively accumulating sediments. Residence times of other North Island ebb-tidal deltas, estimated from the ratio of total annual littoral drift to ebb-tidal delta volume, can be as much as several thousand years (Hicks and Hume 1991: Table 1). Ebb-tidal deltas, therefore, comprise a large reservoir of sediments and incorporated shells which may have been in storage for hundreds or perhaps thousands of years. Anomalously old dates result when these shells are reworked and incorporated into barrier sediments.

The recent and rapid progradation of both ends of the barrier described above involved a considerable narrowing of both entrances and a probable consequent reduction in the size of the respective ebb-tidal deltas. It is suggested that "surplus" delta sediments were transported onshore by wave action (similarly to the Blue Gum Bay delta described above), where they were incorporated into regressive barrier sediments. This is supported by size analysis of sediments of the southeastern barrier. Sediments coarsen seaward of the post-Kaharoa shoreline (Section 3.1.1.5), suggesting material from the Tauranga ebb-tidal delta was moved onshore and incorporated into the growing barrier as the entrance narrowed. Reworked shells from this source probably account for the anomalous shell dates discussed above.

A similar process probably occurred at the Katikati Entrance, indicated by the abundance of anomalous shell dates reported from Waikoura Point (Munro 1994: Figure 3.6b). Reworked shells at Waikoura Point are attributed to storm overwash processes by Munro (1994), although evidence for this (e.g., washover fans or lobes such as in Figure 2.16) has not been observed by the author at Waikoura Point. Storm overwash need not be invoked to explain the deposition of reworked shells stratigraphically above contemporary shells if the shoreline is prograding and incorporating older shell material derived from offshore.

The incorporation of reworked shell into barrier sediments near tidal entrances is therefore a normal process. Despite the care taken in this study to select only unabraded, preferably whole shells for radiocarbon dating, it appears that shells can be stored within ebb-tidal deltas for long periods of time without being abraded. It is therefore recommended that

interpretations of shell dates from near tidal inlets be made with extreme caution, particularly in investigations into very recent events.

5.1.14.3 Inheritance

The possibility of control of present morphology by inheritance has been considered by Dahm (1983) and substantiated by shallow seismic profiling carried out by Healy *et al.* (1985: cited in Healy and de Lange 1988). The profiling indicated the presence of deep palaeochannels (= Pleistocene valleys?) extending to the northwest of the present Tauranga Entrance but not to the southeast of Mount Maunganui. Dahm (1983) suggests these channels restricted the tidal flow to the northwest of Mount Maunganui throughout the barrier's history and contributed to the development of the Mount Maunganui tombolo in an apparently updrift direction. Palaeochannels are also suggested in this study to have initially controlled the positions of the Blue Gum Bay and Matakana-Rangiwaea entrances during early barrier development.

The overall pattern of barrier development is controlled primarily by pre-existing topography, sea level history, sediment supply and sediment transport mechanisms. The following section attempts to relate this pattern to published models of barrier evolution.

5.2 EVOLUTION OF THE MATAKANA ISLAND BARRIER IN COMPARISON WITH EXISTING MODELS

Barrier systems occur on thirteen percent of the world's coastlines (King 1972), but only in recent decades have they been studied in detail and their depositional histories understood. Receding barrier systems of the eastern United States have recently received considerable attention (e.g., Dolan *et al.* 1980, Nummedal 1983) as shoreline recession and washover threatens urban development on these features. New Zealand and Australian barrier systems, by comparison, are presently generally stable or prograding. Sea level here has been considered stable since *c.*6 500 ^{14}C years BP (Gibb 1986) or *c.*7 000 cal BP, whereas it is presently rising at 30 cm per century along the eastern United States coast (Dolan *et al.* 1980).

Morphological variation within and between barrier systems relates to spatial and temporal variation in the factors and processes responsible for their development. Thom (1984) identified two primary controls on the distribution and character of coastal barrier complexes as energy conditions (wind, wave and occasionally tidal) and the way in which sediment accumulated in response to variations in sea level and sediment supply. Variations in the interactions between these in time and space are ultimately responsible for variations in barrier morphology.

Detailed studies of barrier morphology and stratigraphy in southeastern Australia led to a conceptual classification of different barrier types by Chapman *et al.* (1982) and Thom (1984), who classified barrier complexes on the basis of morphology and hypothesised patterns of evolution. Under this classification (Figure 5.12), Matakana Island is clearly a *prograded barrier.*

Barrier progradation in both regions generally commenced between *c.*6 500 and *c.*5 000 cal BP (Roy *et al.* 1980, Thom *et al.* 1981, Dahm 1983, Thom 1984, Abrahamson 1987), in response to the onshore sediment movement which resulted from a disequilibrium between wave power, sediment supply and gradient on the inner continental shelf (Thom 1984). Simulation modelling reported by Roy *et al.* (1994) indicates that an onshore movement of sediment should occur when sea level rises across a coast with an initial substrate gradient of less than 0.8°; the gradient offshore from Matakana Island would have been less than half this figure (Pantin *et al.* 1973).

A washover ridge origin is suggested for the northwestern part of the Matakana Island barrier, indicated by morphological and sedimentological evidence from the innermost part of the barrier, and consistent with the origins of the innermost parts of some Holocene barrier systems in southeastern Australia (e.g., Thom *et al.* 1992).

Progradation rates of Holocene barrier systems are widely reported to have decreased towards the present since barrier formation began (e.g., Davies-Colley 1976, Roy *et al.* 1980, Abrahamson 1987), with minimal progradation or in some cases erosion occurring at present (Roy *et al.* 1980). The mechanisms behind this change are illustrated in Figure 5.13 below.

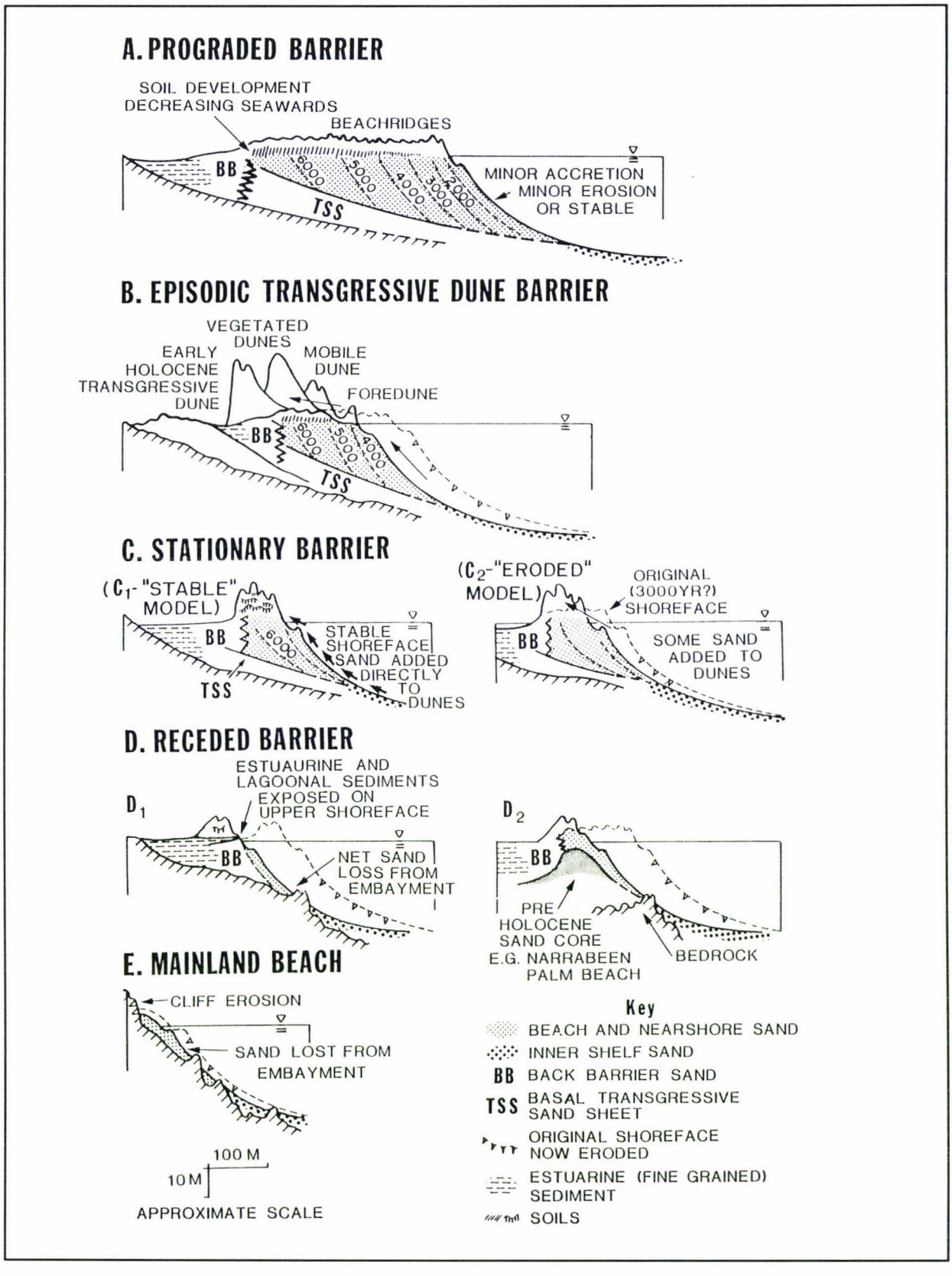


Figure 5.12: Classification of coastal barrier systems on the basis of morphology and evolutionary history (from Chapman *et al.* 1982).

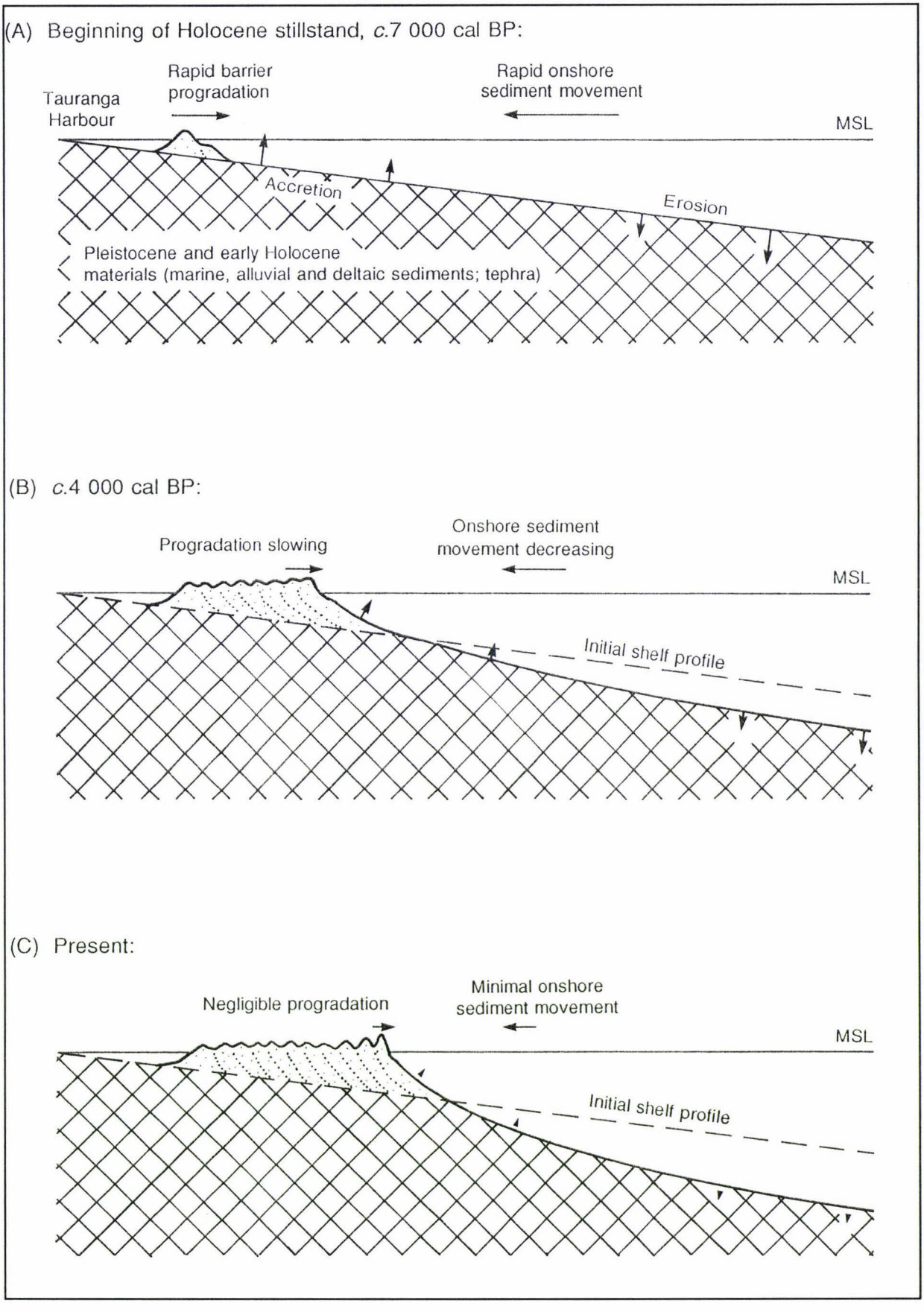


Figure 5.13: Schematic illustration of the readjustment of a disequilibrium shelf profile following the stillstand, with consequent barrier progradation. Dotted lines indicate the seaward-thickening sediment wedges described by Chapman *et al.* 1982).

Progradation rates followed a similar trend on Matakana Island. The formation, evolution and reworking of sand bodies related to harbour entrances complicated the pattern, particularly during early barrier formation and following the Kaharoa eruption. However, averaged progradation rates shown in Table 5.1(a) and Figure 5.11 clearly illustrate an overall decreasing trend. Similar patterns are reported from eastern Coromandel barrier systems by Abrahamson (1987) and from the Mount Maunganui tombolo by Pullar and Cowie (1967).

As previously discussed, tidal inlets such as the Katikati and Tauranga Entrances exert a strong influence on the morphology and dynamics of adjacent sandy shorelines. These interactions suggest that changes in the adjacent barrier shorelines are a function of the stability of the respective entrances and their deltas. Tidal inlet stability can be represented by the ratio of the tidal prism (Ω) to total annual littoral drift (M_{tot}) (Bruun and Gerritsen 1960). In general, a Ω/M_{tot} ratio of more than 300 represents high stability, with poor stability prevailing for ratios below 100 (Table 5.2).

Table 5.2: Classification of tidal inlets based on tidal prism to total annual littoral drift (Ω/M_{tot}) ratios (from Hume and Herendorf 1992: Table 2).

Ω/M_{tot} Ratio	Entrance Condition
$\Omega/M_{tot} > 300$	Little or no ocean bar outside gorge (ocean shoal may occur further out), good entrance conditions and flushing
$150 < \Omega/M_{tot} < 300$	Little ocean bar
$100 < \Omega/M_{tot} < 150$	Low ocean bar, navigation problems usually minor
$50 < \Omega/M_{tot} < 100$	Wider and higher ocean bar, increasing navigation problems
$20 < \Omega/M_{tot} < 50$	Wide and shallow ocean bar, navigation difficult
$\Omega/M_{tot} < 20$	Very shallow ocean bar, navigation very difficult, entrance unstable

Hume and Herendorf (1992) found these ratios to exceed 300 for both the Katikati and Tauranga Entrances. However, they also acknowledged that the value calculated for the Katikati Entrance may be anomalous, in view of the shallow and changeable nature of bars associated with the entrance, and questioned the reliability of drift values used in the calculation.

Figure 5.14: Vertical aerial photograph of the northwestern end of the barrier, showing the irregular pattern of relict foredunes adjacent to the unstable Katikati Entrance. Note the ebb-tidal delta clearly visible offshore. Scale = *c.*1:20 000. Photograph courtesy of Air Maps NZ Limited.

The greater instability of the Katikati Entrance in comparison to the Tauranga Entrance is reflected in the surface morphology of the adjacent Matakana Island barrier. Former shorelines as indicated by the pattern of relict foredunes are very irregular, especially when viewed from the air (Figure 5.14 above), attesting to considerable shoreline instability during the formation of this part of the barrier. The more stable Tauranga Entrance, while clearly having had a significant influence on the development of the southeastern part of the barrier, appears to have been considerably less variable than the Katikati Entrance.

In general, the evolution of the Matakana Island barrier is broadly similar to that of prograded barrier systems in New South Wales (Chapman *et al.* 1982) where the local Holocene sea level curve (Thom and Chappell 1975) is comparable to the New Zealand curve (Gibb 1986). At both places modern sea level was attained *c.*7 000 cal BP, and barrier progradation rates were initially rapid prior to *c.*3 000 cal BP. Following the Postglacial Marine Transgression, the continental shelf in both regions underwent considerable readjustment to the new sea level, involving the onshore movement of large quantities of shelf sediment to form the extensive Australian Holocene barrier systems and the Matakana Island barrier.

In New South Wales most barrier sand was derived from offshore (Chapman *et al.* 1982). The same may be true for the Matakana barrier, except that the southeastward extension of recurved spits which deflected the Blue Gum Bay entrance about eight kilometres to the southeast, and also the southeastward diversion of Hunter's Creek, suggests an additional alongshore sediment source from the northwest in addition to an offshore source. This would be consistent with the suggestion by Healy *et al.* (1977) of nett littoral drift towards the southeast based on the wave approach resultant. The continuing but decreasing progradation of the Matakana barrier may thus relate to a diminishing offshore sediment supply superimposed upon a relatively constant alongshore supply, and Figure 5.11 may illustrate a change from a dominant offshore to a dominant alongshore sediment supply. The sediments of the Matakana barrier are mineralogically very uniform and did not enable the two sources to be distinguished.

The patterns of progradation of Matakana Island barrier were probably also complicated by the development and evolution of associated tidal inlets, although progradation rates clearly

decrease towards the present. Some southeastern Australian barrier systems have already begun to recede as onshore sediment movement becomes insufficient to counteract losses to littoral drift and inland aeolian transport and Matakana Island may eventually undergo a similar process as onshore sediment transport continues to diminish.

Chapter Six: Summary

6.1: SUMMARY OF MAIN FINDINGS

The research carried out in this thesis has facilitated both a detailed description of the geomorphology of Matakana Island and an interpretation of its dynamics and evolution. Matakana Island comprises two broad geological units - an area of mainly Pleistocene materials to the southwest and the larger Holocene barrier to the northwest. This study has focussed primarily on the geomorphology of the Holocene barrier.

The highest parts of Pleistocene Matakana Island contain remnants of at least two late Pleistocene terraces, mantled with Pleistocene tephra. The underlying terrace surfaces are probably marine in origin and were probably formed during late Pleistocene interglacials. During the Last Interglacial *c.*125 000 years ago, the lowest Pleistocene terrace formed to seaward as a relict foredune plain.

The Holocene barrier began forming *c.*6 000 cal BP as a result of similar processes to those which caused the older part of the island to prograde during the Last Interglacial. The barrier began forming in at least two parts. The southeastern part abutted the Pleistocene part of the island, forming against a Holocene wave-cut cliff. The northwestern part began as a landward-migrating washover ridge, partially enclosing Katikati Harbour. The two parts were separated by an early entrance to Tauranga Harbour located near Blue Gum Bay.

Subsequent development of both parts occurred by the formation of successive foredunes as the shoreline prograded seawards in response to the shoreward movement of sediments reworked from the continental shelf. The Blue Gum Bay entrance was closed *c.*3 750 cal BP. This was followed by an abrupt change in the morphology of the foredunes which became larger and less regular. As the barrier developed the rate of shoreline progradation slowed as

the offshore sediment supply became depleted.

The ends of the barrier have a more complex history and underwent periods of erosion. The most recent erosion of the northwestern end occurred after *c.*1 750 cal BP and was followed by erosion of the southeastern end which ceased *c.*600 cal BP. Both the Katikati and Tauranga Entrances have narrowed rapidly during the last *c.*650 years.

Transgressive dunes occur on many parts of the barrier and have formed throughout the history of the barrier. The largest began forming prior to human settlement, migrating as parabolic dunes in an easterly direction and some were reactivated following human settlement. Significant transgressive dune formation during the past *c.*650 years occurred adjacent to the present ocean beach, Hunter's Creek and at the southeastern end of the barrier.

No evidence of human settlement prior to the Kaharoa eruption *c.*650 cal BP was observed on the island. Following human arrival, the existing forest on the barrier was progressively cleared and replaced by scrub and *Pteridium esculentum* (bracken fern). Transgressive dune activity following human settlement buried cultural sites in places, which, owing to extensive disturbance by recent forestry operations, are likely to be the only intact sites remaining on the barrier.

An offshore sediment source for the formation of the Matakana Island barrier was confirmed by sediment texture and mineralogy, which is generally very uniform. However, reworked sediments have different sedimentological characteristics and are common along the innermost part of the barrier and at the barrier ends.

The sequence of events which led to the development of the Matakana Island barrier can be related directly to evolutionary models proposed elsewhere in the literature. Matakana Island appears to have developed in a similar fashion to many Holocene barrier systems in southeastern Australia in terms of a shelf sediment source, onshore sediment transport following the end of the Postglacial Marine Transgression and decreasing overall progradation rates towards the present as onshore sediment movement diminished.

6.2 RECOMMENDATIONS FOR FURTHER RESEARCH

This study has identified a number of opportunities for further research into the evolution of Matakana Island and its relationship to developments in Tauranga Harbour:

(1) The remnants of terraces on the Pleistocene part of the island, particularly the terrace or terraces older than the Last Interglacial, have not been examined in detail in this study and correlations with earlier interglacials are tentative. The stratigraphy and tephra cover of these terraces also require further investigation.

(2) The resolution of dating of palaeoshorelines on the Holocene barrier may be further improved by a detailed investigation into the possible presence and distribution of tephra deposits older than the Waimihia Pumice. Further investigations into the distribution of the Stent tephra may locate the Stent shoreline on the northwestern part of the barrier, which was inferred in this study. Such work would require an exploratory phase to locate suitable undisturbed profiles where the tephras could be identified. Similarly, the soil chronosequence across the widest part of the barrier northwest of about Western Road could be studied in full to either supplement or supersede the work reported in this study and by Munro (1994).

(3) The behaviour of the Blue Gum Bay entrance prior to and during closure may be further determined by studying the underlying stratigraphy and sediment characteristics. Sediment textural properties as palaeoenvironmental indicators have been used by Moslow and Heron (1978), who consider inlet-fill sediment bodies preserved within the barrier island systems of southern Core Banks, North Carolina, USA, to be clearly related to relict tidal inlets. Similar sedimentary bodies associated with the former Blue Gum Bay entrance are likely to have been preserved within the Matakana Island barrier facies and could be studied by means of deep coring in the vicinity of the apex of the old inlet near the intersection of Hume Highway and Waiherere Road.

(4) Further sampling is required both onshore and offshore at the Katikati Entrance to determine the nature of sediment circulation at this end of the barrier and to explain the apparent lack of the sharp changes in sediment characteristics which presently occur at the

Tauranga Entrance. Although it is clear that ocean beach sediment is being transported into the harbour via the Katikati Entrance as indicated by the large flood-tidal delta and results described in this study, the full nature of sediment transport at and around this entrance is still incompletely understood. Conclusions based on the single sample collected from Waihi Beach in this study also require strengthening by the collection and analysis of a greater number of samples.

(5) Future investigations into the dynamics of ebb-tidal deltas, both in this setting and elsewhere, may be assisted by radiocarbon dating of reworked shell material from the deltas and adjacent sandy shorelines as an indication of residence times of sediment within the delta systems.

(6) This study has dated parabolic dunes on the barrier primarily by means of tephrochronology, which has facilitated the grouping of the dunes into three broad chronological periods. Other methods may enable the age of various dunes to be estimated to greater accuracy, particularly those which appear to have been related to human activity.

(7) Finally, there is presently an apparent lack of detailed information on the stratigraphy of the sediments within Tauranga Harbour. This problem could be addressed by the coring of the sediments to study possible accretion rates, changes in these, sediment sources and possible relationships between these and the formation of the Matakana Island barrier. This would probably be most successful if carried out in quiet, restricted parts of the harbour, where sediment mixing by waves and currents would be minimised. One such place worthy of attention would be the head of Hunter's Creek (T.M. Hume, pers. comm. 1995), where a very low energy environment exists. Such investigations may contribute to an explanation for the rapid changes in the harbour entrances in the last *c.*650 years, which may relate to factors such as the influx of Kaharoa Tephra into the harbour or increased sedimentation due to human activities in the wider Tauranga Basin.

6.3 CONCLUSION

Matakana Island has clearly had a complex evolutionary history which has involved a number of major stages of development, controlled primarily by glacio-eustatic changes in sea level since the late Pleistocene. The most recent of these stages led to the formation of the Holocene barrier, which itself has developed in a complex fashion.

Research into the dynamics and history of the Bay of Plenty coastal plain as a whole has, to date, largely ignored the significance of Matakana Island as an important component of the coastal system. This is especially apparent from studies of Tauranga Harbour to date, which generally include little information on Matakana Island and its significance to harbour evolution.

This study provides a foundation for future studies aimed at addressing this gap in the understanding of the Bay of Plenty coastal system. It is hoped, in view of the growing pressure for urbanisation on Matakana Island, that these studies will be carried out without delay.

References

Abrahamson, L. (1987): Aspects of late Quaternary stratigraphy and evolution of some coastal embayments on the east Coromandel Peninsula, New Zealand. *Unpublished M.Sc. Thesis, University of Waikato, Hamilton.*

Alloway, B., Lowe, D.J., Chan, R.P.K., Eden, D. and Froggatt, 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.

Baker, R.A. (1968): Kurtosis and peakedness. *Journal of Sedimentary Petrology 38:* 279-681.

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

Baxter, J.L. (1977): Heavy mineral sand deposits of Western Australia. *Geological Survey of Western Australia, Mineral Resources Bulletin 10.*

Beadel, S.M. (1989a): Notes on the vegetation and flora of Tauranga Harbour and Little Waihi Estuary, Bay of Plenty. *Report prepared 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 for the Department of Conservation, Rotorua.*

Bird, E.C.F. (1968): *Coasts* (1st edition). Australian National University Press, Canberra, Australia. 246pp.

Bird, E.C.F. (1972): *Coasts* (2nd edition). Australian National University Press, Canberra, Australia. 246pp.

Birkeland, P.W. (1984): Holocene soil chronofunctions, Southern Alps, New Zealand. *Geoderma 34:* 115-134.

Birrell, K.S., Pullar, W.A. and Searle, P.L. (1977): Weathering of Rotoehu Ash in the Bay of Plenty district. *New Zealand Journal of Science 20:* 303-310.

Bockheim, J.G. (1980): Solution and use of chronofunctions in studying soil development. *Geoderma 24:* 71-85.

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

Bruun, P. and Gerritsen, F. (1960): *Stability of coastal inlets*. North-Holland Publishing Company, Amsterdam.

Callahan, J. (1987): A nontoxic heavy liquid and inexpensive filters for separation of mineral grains. *Journal of Sedimentary Petrology 57, 4:* 765-766.

Carter, R.W.G. (1988): *Coastal environments*. Academic Press, London, 174-182.

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, 341pp.

Chappell, J. (1974): Upper Quaternary warping and uplift rates in the Bay of Plenty and West Coast, North Island, New Zealand. *N.Z. Journal of Geology and Geophysics 18, 1:* 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. (1967): Mineralogy of dune sands at Mount Maunganui. Appendix in: Pullar, W.A. and Cowie, J.D. (1967): Morphology of subfulvic and related soils on dunelands at Mt. Maunganui, Bay of Plenty. *N.Z. Journal of Science 10:* 180-189.

Cole, J.W. (1978): Tectonic setting of Mayor Island volcano (Note). *N.Z. Journal of Geology and Geophysics 21, 5:* 645-647.

Cole, J.W. (1979): Structure, petrology and genesis of Cenozoic volcanism, Taupo Volcanic Zone, New Zealand - a review. *N.Z. Journal of Geology and Geophysics 22, 6:* 631-657.

Colman, S.M., Pierce, K.L. and Birkeland, P.W. (1987): Suggested terminology for Quaternary dating methods. *Journal of Quaternary Research 28:* 314-319.

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

Cowie, J.D. (1963): Dune-building Phases in the Manawatu district, New Zealand. *New Zealand Journal of Geology and Geophysics 6:* 268-280.

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

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

Dahm, J., Lowe, D.J., Wigley, G.N.A. and Nagatomo, Y. (1994): A tephra-based model of Holocene coastal evolution, Bay of Plenty-Coromandel, and implications for management. *Proceedings of the Inter-INQUA Conference, University of Waikato, 1994:* 28.

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. (1964): A morphogenetic approach to world shorelines. *Zeitschrift fur Geomorphologie 8:* 127-142.

Davies, J.L. (1972): *Geographical variation in coastal development.* Oliver and Boyd, Edinburgh, 204pp.

Davies, J.L. (1980): *Geographical variation in coastal development* (2nd ed.). Longman, London; New York; 212pp.

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. *N.Z. Journal of Marine and Freshwater Research 12, 3:* 225-236.

Davies-Colley, R.J. and Healy, T.R. (1978b): Sediment transport near the Tauranga Entrance to Tauranga Harbour. *N.Z. Journal of Marine and Freshwater Research 12, 3:* 237-243.

de Lange, W.P. (1988): Wave climate and sediment transport within Tauranga Harbour, in the vicinity of Pilot Bay. *Unpublished Ph.D. Thesis, University of Waikato, Hamilton.*

de Lange, W.P. and Healy, T.R. (1991): Hydrodynamics and sediment transport in a mesotidal estuarine lagoon: a comparison of analytical approaches. *Proceedings of the 10th Australasian Conference on Coastal and Ocean Engineering, Auckland, 2-6 December, 1991:* 97-102.

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

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

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

Faulkner, R. (1955): From Kauri to pine on Matakana Island. *N.Z. Timber Journal 2, 2:* 39.

Felgate, M.W. (1992): Preliminary archaeological research on Matakana Island, Tauranga: Holocene tephras and landscape changes. *Unpublished Research Practicum, University of Auckland, Auckland.*

Fitzgerald, D.M. (1984): Interactions between the ebb-tidal delta and landward shoreline: Price Inlet, South Carolina. *Journal of Sedimentary Petrology 54, 4:* 1303-1318.

Folk, R.L. (1974): *Petrology of Sedimentary rocks.* Hemphills, Austin, Texas, 170pp.

Foster, D.M., Healy, T.R. and Warren, S.K. (1991): Environmental impacts of a recent dredge spoil dumping operation off Tauranga, New Zealand. *Proceedings of the 10th Australasian Conference on Coastal and Ocean Engineering, Auckland, 2-6 December, 1991:* 141-145.

Froggatt, P.C. (1981): Stratigraphy and nature of Taupo Pumice Formation. *New Zealand Journal of Geology and Geophysics 24:* 231-248.

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.

Gale, S.G. and Hoare, P.G (1991): *Quaternary sediments: petrographic methods for the study of unlithified rocks.* Belhaven Press; Halstead Press.

Gibb, J.G. (1978): Rates of coastal erosion and accretion in New Zealand. *New Zealand*

Journal of Marine and Freshwater Research 12, 4: 429-456.

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.

Gibbs, H.S., Cowie, J.G. and Pullar, W.A. (1968): Soils of North Island. *In: New Zealand Soil Bureau Bulletin 26(1):* 48-67.

Godfriaux, B.L. (1973): Sediment variability in offshore sampling areas. *New Zealand Journal of Marine and Freshwater Research 7, 4:* 323-329.

Hall, G.J. (1994): Volcanic geology of the southeastern Tauranga Basin, New Zealand. *Unpublished M.Sc. Thesis, University of Waikato, Hamilton.*

Harms, C. (1989): Dredge spoil dispersion from an inner shelf dump-mound. *Unpublished M.Sc. Thesis, University of Waikato, Hamilton.*

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. *N.Z. Journal of Marine and Freshwater Research 12, 2:* 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:* 1343-1355.

Healy, J. (1964): Dating of the younger volcanic eruptions of the Taupo region: Part 1. *New Zealand Geological Survey Bulletin 73:* 7-39.

Healy, T.R. (1977): Progradation at the entrance, Tauranga Harbour, Bay of Plenty. *N.Z. Geographer 33, 2:* 90-92.

Healy, T.R. (1978a): *Bay of Plenty coastal erosion survey report 78/2.* Department of Earth Sciences, University of Waikato, Hamilton.

Healy, T.R. (1978b): *Bay of Plenty coastal erosion survey report 78/3.* Department of Earth Sciences, University of Waikato, Hamilton.

Healy, T.R. (1978c): *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, 74pp.

Healy, T.R. (1980): Erosion and sediment drift on the Bay of Plenty coast. *Soil and Water, August 1980:* 12-14.

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:* 65-74.

Healy, T.R., Harms, C. and de Lange, W.P. (1991): Dredge spoil and inner shelf investigations off Tauranga Harbour, Bay of Plenty, New Zealand. *Coastal Sediments '91: Proceedings of a specialty conference on quantitative approaches to coastal sediment processes, Seattle, Washington, June 25-27, 1991:* 2037-2051.

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

Healy, T.R. and Kirk, R.M. (1992): Coasts. *pp.161-186 in*: Soons, J.M. and Selby, M.J.

(eds.) (1992): *Landforms of New Zealand* (Second Edition). Longman Paul.

Heath, R.A. (1975): Stability of Some New Zealand coastal inlets. *New Zealand Journal of Marine and Freshwater Research 9, 4:* 449-457.

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, 9-10:* 289-291.

Hesp, P.A. and Thom, B.G. (1990): Geomorphology and evolution of active transgressive dunefields. *Ch. 12 in*: Nordstrom, K.F., Psuty, N.P. and Carter, R.W.G. (1990): *Coastal dunes: form and process.* John Wiley and Sons.

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:* 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.*

Hogg, A.G. and McCraw, J.D. (1983): Late Quaternary tephras of Coromandel Peninsula, North Island, New Zealand: a mixed peralkaline and calcalkaline tephra sequence. *New Zealand Journal of Geology and Geophysics 26:* 163-187.

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, 4:* 1073-1092.

Hughes, G.R. (1993): Volcanic geology of the eastern Tauranga Basin and Papamoa Range. *Unpublished M.Sc. Thesis, University of Waikato, Hamilton.*

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, 23-27 August, 1993.*

Hume, T.M. and Herendorf, C.E. (1992): Factors controlling tidal inlet characteristics on low drift coasts. *Journal of Coastal Research 8, 2:* 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.

Jenny, H. (1941): *Factors of soil formation: a system of quantitative pedology.* McGraw-Hill, New York, London, 281pp.

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

King, C.A.M. (1972): *Beaches and coasts* (second edition). Edward Arnold, 570pp.

Kuchler, A.J. (1972): The mangrove in New Zealand. *New Zealand Geographer 28:* 113-129.

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

Lewis, D.W. and McConchie, D. (1994): *Analytical sedimentology*. Chapman and Hall, New York, 197pp.

Lindholm, R. (1987): *A practical approach to sedimentology*. Allen and Unwin, London.

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 (Rotorua)*: 36-41.

MacPherson, J.M. and Lewis, D.W. (1978): What are you sampling? *Journal of Sedimentary Petrology 48, 4:* 1341-1344.

Mansergh, G.D. (ed.) (1973): The New Zealand Quaternary: an introduction. *Proceedings of the 9th INQUA Conference, Christchurch, 1973.*

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. *N.Z. Journal of Science 25:* 379-392.

McFadgen, B.G. (1989): Late Holocene depositional episodes in coastal New Zealand. *New Zealand Journal of Ecology 12 (supplement):* 145-149.

McFadgen, B.G. (1994): Archaeology and Holocene sand dune stratigraphy on Chatham Island. *Journal of the Royal Society of New Zealand 24, 1:* 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, 2: 221-236.

McFadgen, B.G. and Manning, M.R. (1990): Calibrating New Zealand radiocarbon dates of marine shells. *Radiocarbon 32, 2:* 229-232.

McKenzie, P. (1958): The development of sand beach ridges. *Australian Journal of Science 20:* 213-214.

Moslow, T.F and Heron, S.D. Jr. (1978): Relict inlets: preservation and occurrence in the Holocene stratigraphy of southern Core Banks, North Carolina. *Journal of Sedimentary Petrology 48, 4:* 1275-1286.

Muckersie, C.A. (1989): The location and orientation of coastal parabolic sand dunes in New Zealand. *Unpublished M.Sc. Thesis, Massey University, Palmerston North.*

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

Munro, A.J., Lowe, D.J. and Green, J.D. (1994): Application of tephrochronology and (paleo)pedology to the Holocene evolution of northwestern Matakana Island, Bay of Plenty, New Zealand. *Proceedings of the international inter-INQUA field conference and workshop on tephrochronology, loess, and palaeopedology, Hamilton, 7-12 February 1994:* 44.

Nummedal, D. (1983): Barrier islands. *Ch. 5 in*: Komar, P.D. (ed.): *CRC handbook of coastal processes and erosion.* Boca Raton, Florida: CRC Press, 1983.

Oertel, G.F. (1972): Sediment transport of estuary entrance shoals and the formation of swash platforms. *Journal of Sedimentary Petrology 42, 4:* 857-863.

Oertel, G.F. (1977): Geomorphic cycles in ebb deltas and related patterns of shore erosion and accretion. *Journal of Sedimentary Petrology 47, 3:* 1121-1131.

Osborne, N.M., Enright, N.J. and Parnell, K.E. (1991): The age and stratigraphic significance of sea-rafted Loisels Pumice in northern New Zealand. *Journal of the Royal Society of New Zealand 21, 4:* 357-371.

Ota, Y., Hull, A.G., Iso, N., Ikeda, Y., Moriya, I. and Yoshikawa, T. (1992): Holocene marine terraces on the northeast coast of North Island, New Zealand, and their tectonic significance. *New Zealand Journal of Geology and Geophysics, 35, 3:* 273-288.

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, 2:* 571-577.

Pickrill, R.A. and Mitchell, J.S. (1979): Ocean wave characteristics around New Zealand. *New Zealand Journal of Marine and Freshwater Research, 13, 4:* 501-520.

Pillans, B. (1987): Quaternary sea-level changes: Southern Hemisphere data. *In*: Devoy, R.J.N. (ed.) (1987): *Sea surface studies: a global view.* Croom Helm, London.

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

Pillans, B. (1990): Pleistocene marine terraces in New Zealand: a review. *New Zealand Journal of Geology and Geophysics 33:* 219-231.

Pillans, B., Pullar, W.A., Selby, M.J. and Soons, J.M. (1992): The age and development of the New Zealand landscape. *Ch. 2 in*: Soons, J.M. and Selby, M.J. (eds.) (1992): *Landforms of New Zealand (2nd edition).* Longman Paul.

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

Psuty, N.P. (1993): Foredune morphology and sediment budget, Perdido Key, Florida, USA. *pp.145-157 in:* Pye, K. (ed.) (1993): *The dynamics and environmental context of aeolian sedimentary systems.* Geological Society Special Publication No. 72.

Pullar, W.A. (1977): Bay of Plenty district. *pp.53-64 in:* Neall, V.E. (ed.) (1977): *Soil groups of New Zealand. Part 2: Yellow-brown sands.* New Zealand Society of Soil Science.

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 1*, 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. *N.Z. 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. *N.Z. Journal of Geology and Geophysics 20, 4:* 697-717.

Pullar, W.A. and Selby, M.J. (1971): Coastal progradation of Rangitaiki Plains, New Zealand. *N.Z. Journal of Science 14:* 419-434.

Pullar, W.A. and Penhale, H.R. (1970): Periods of recent infilling of the Gisborne Plains basin - associated marker beds and changes in shoreline. *New Zealand Journal of Science 13:* 410-434.

Quayle, A.M. (1984): The climate and weather of the Bay of Plenty region. *New Zealand Meteorological Service, Miscellaneous Publication 115, 1 (2nd edition):* 56pp.

Richmond, B. (1977): Geomorphology and modern sediments of Ohiwa Harbour, Bay of Plenty, New Zealand. *Unpublished M.Sc. Thesis, University of Waikato, Hamilton.*

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., Thom, B.G. and Wright, L.D. (1980): Holocene sequences on an embayed high-energy coast: an evolutionary model. *Sedimentary Geology 26:* 1-19.

Roy, P.S., Cowell, P.J., Ferland, M.A. and Thom, B.G. (1994): Wave-dominated coasts. *pp.121-186 in:* Carter, R.W.G. and Woodroffe, C.D. (eds.) (1994): *Coastal evolution: late Quaternary shoreline morphodynamics.* Cambridge University Press, 517pp.

Salmon, J.T. (1986): *The native trees of New Zealand.* Reed, 384pp.

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

Schofield, J.C. (1975): Sea-level fluctuations cause periodic, post-glacial progradation, south Kaipara barrier, North Island, New Zealand. *New Zealand Journal of Geology and Geophysics 18, 2:* 295-316.

Schwartz, M.L. (1971): The multiple causality of barrier islands. *Journal of Geology 79:* 91-94.

Selby, M.J. (1985): *Earth's changing surface - an introduction to geomorphology.* Clarendon Press, Oxford, 607pp.

Selby, M.J., Pullar, W.A. and McCraw, J.D. (1971): The age of Quaternary surfaces at Waihi Beach. *Earth Science Journal 5, 2:* 106-113.

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

Shepherd, M.J. (1970): Coastal geomorphology of the Myall lakes area, New South Wales. *Unpublished Ph.D. Thesis, University of Sydney, Sydney, Australia.*

Shepherd, M.J. (1981): The Rockingham coastal barrier system of Western Australia. *Western Geographer 5, 1-2:* 67-81.

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

Striewski, B., Elliott, M.B., Flenley, J.R. and Sutton, D.G. (1994): *Date of colonisation of Northland, Part 1, Year 2: Report on work done in 1993.* Unpublished report to the Foundation for Research Science and Technology, 98pp.

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, 1:* 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, 1:* 215-229.

Suggate, R.P. (1974): When did the Last Interglacial end? *Quaternary Research 4:* 246-252.

Tanner, W.F (1988): Beach ridge data and sea level history from the Americas. *Journal of Coastal Research 4, 1:* 81-91.

Taylor, N.H. and Pohlen, I.J. (1970): *Soil survey method.* New Zealand Soil Bureau Bulletin 25.

Thom, B.G. (1970): Carolina bays in Horry and Marion counties, South Carolina. *Geological Society of America Bulletin 81:* 783-814.

Thom, B.G. (1975): Modification of coastal and deltaic terrain subsequent to deposition.

Zeitschrift Fur Geomorphologie Supplement 22: 145-170

Thom, B.G. (1984): Sand barriers of eastern Australia: Gippsland - a case study. *pp.233-259 in*: Thom, B.G. (ed.) (1994): *Coastal geomorphology in Australia.* Academic Press, Australia.

Thom, B.G., Bowman, G.M, Gillespie, R., Temple, R. and Barbetti, M. (1981): *Radiocarbon dating of Holocene beach-ridge sequences in South-East Australia.* Monograph No.11, Department of Geography, University of New South Wales, at Royal Military College, Duntroon, Australia.

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

Thom, B.G., Shepherd, M.J., Ly, C.K., Roy, P.R., Bowman, G.M. and Hesp. P.A. (1992): *Coastal geomorphology and Quaternary geology of the Port Stephens-Myall Lakes area.* Monograph No.6, Department of Biogeography and Geomorphology, Australian National University, Canberra, Australia, 407pp.

Turner, I. (1993): Beachface permeability, the groundwater effluent zone and intertidal profiles of macro-tidal beaches - a conceptual model. *Ch. 8 in*: Thoms, M.C. (ed.) (1993): *Catchments and coasts in eastern Australia.* Research Monograph no.5, Department of Geography, University of Sydney, Australia.

Vogel, J.C., Fuls, A. and Visser, E. (1993): Pretoria calibration curve for short-lived samples, 1930-3350 BC. *Radiocarbon 35, 1:* 73-85.

Vucetich, C.G. and Pullar, W.A. (1964): Stratigraphy of Holocene ash in the Rotorua and Gisborne districts: Part 2. *New Zealand Geological Survey Bulletin 73:* 43-63.

Vucetich, C.G. and Pullar, W.A. (1969): Stratigraphy and chronology of late Pleistocene volcanic ash beds in central North Island, New Zealand. *New Zealand Journal of Geology and Geophysics 12:* 784-837.

Wallace, R. (1994): Charcoal identifications. *Appendix 4 in*: 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.

Wallingford Hydraulics Research Station (1963): *Tauranga Harbour investigation.* Wallingford Hydraulics Research Station, Berkshire, England. Unpublished report on the first stage, Report No. Ex 201, 69pp.

Warren, S.K., Healy, T.R., Moon, V.G. and Foster, D.M. (1991): Aspects of the geomechanics of dredge spoil disposed of on the inner shelf, Tauranga, New Zealand. *Proceedings of the 10th Australasian Conference on Coastal and Ocean Engineering, Auckland, 2-6 December, 1991:* 135-140.

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, 5:* 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.*

Wright, I.C. (1989): Bay of Plenty bathymetry (2nd edition). *New Zealand Oceanographic Institute chart, Coastal Series, 1:200 000.*

Wright, L.W. (1969): Coastal changes at the entrance to the Kaipara Harbour 1836-1966. *New Zealand Geographer 25, 1:* 58-61.

Zenkovich, V.P. (1967): *Processes of coastal development.* Oliver and Boyd, Edinburgh; London.

MAPS CONSULTED

Sheet SO 9385 (1870): Plan of Opuhi Island, Tauranga. *Held by Department of Survey and Land Information, Hamilton.*

Tauranga County Almanac (1884): Tauranga Harbour Bathymetric Chart. *General Assembly Library.*

New Zealand East Coast - Bay of Plenty: Tauranga Harbour 1903: Surveyed by *H.M.S. Penguin* 1901/2.

New Zealand East Coast - Bay of Plenty: Tauranga Harbour 1907: Surveyed by *H.M.S. Penguin* 1901/2.

Sheet N58, Tauranga Provisional 1 Mile Series (1943), scale 1:63 360. *Copy held by Tauranga Public Library, Tauranga.*

NZMS 260 Sheets U11, U12, U13 - Waihi Beach (1979), Scale 1:50 000.

NZMS 260 Sheet U14 - Tauranga (1980), Scale 1:50 000.

Hydrographic Office (1993): Bathymetric chart, Tauranga Harbour: Katikati Entrance to Mount Maunganui. *Hydrographic Office of the Royal New Zealand Navy, Auckland.*

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Appendix One: Palynology of a Swamp Core from the Pleistocene Part of Matakana Island

A1.1 INTRODUCTION

In order to further investigate vegetation changes which may have occurred on Matakana Island and its environment, a swamp on the Pleistocene part of the island was cored for palynological analysis (NZMS 260 grid reference U14 807973, Figure A1.1).

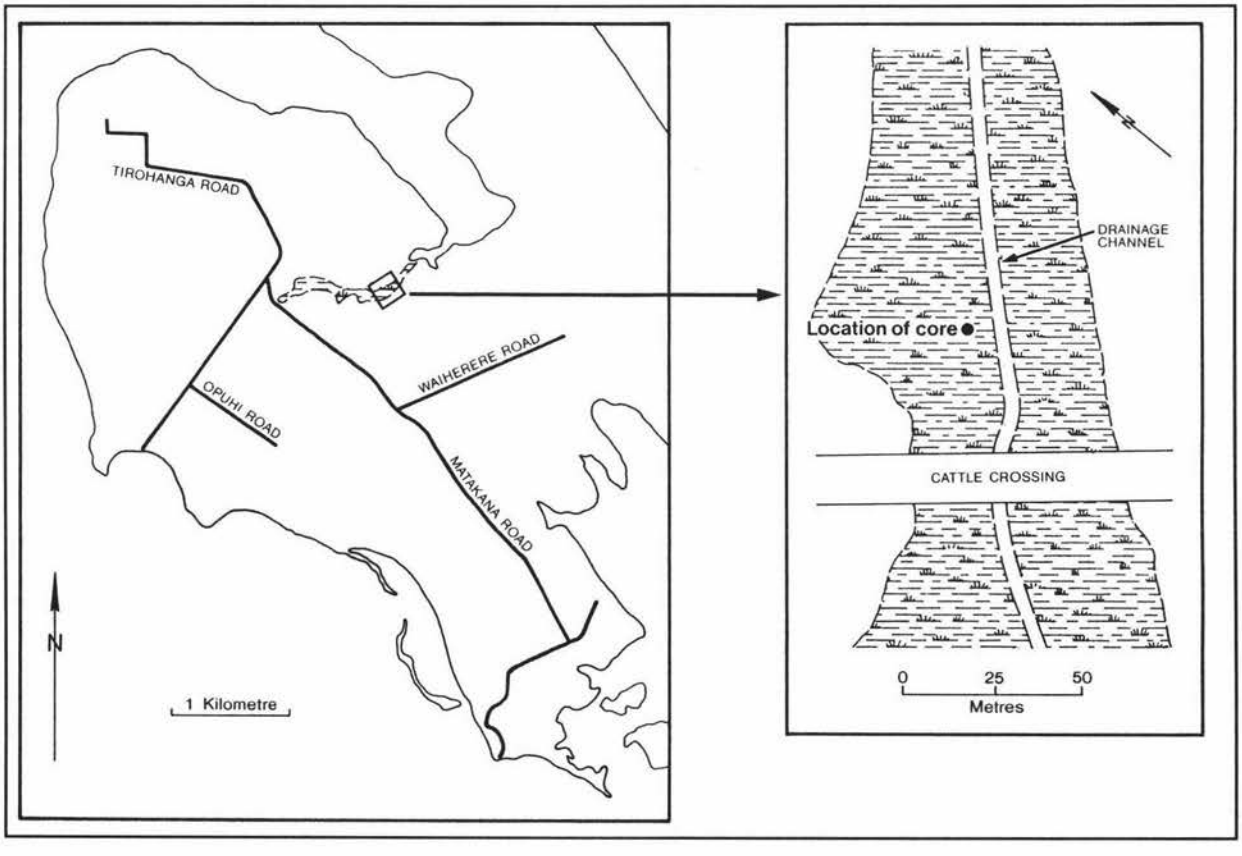

Figure A1.1: Site and core location.

The swamp occupies a late Pleistocene-early Holocene fluvial course, drowned by the Postglacial Marine Transgression which terminated about 6 500 ^{14}C years BP (Gibb 1986), or *c.*7 000 cal BP.

Sampling was carried out with a D-Section (or Russian) peat corer and the core was recovered in 33cm sections from two holes, spaced about one metre apart, in an alternating fashion. Following extraction the core was stored and transported in one-metre PVC core boxes, three sections of core to a box. The three-metre core consisted of eight broad stratigraphic units:

1. (0 - 0.62m): Fresh peat.

2. (0.62 - 0.76m): A layer of sandy material.

3. (0.76 - 1.30m): Clay-rich sediment, containing detritus and charcoal fragments with a small sand fraction.

4. (1.30 - 1.50m): Predominantly sandy material.

5. (1.50 - 2.00m): Grey clay, containing finely disseminated charcoal and charcoal fragments.

6. (2.00 - 2.75m): Sandy clay.

7. (2.75 - 2.95m): Peaty material.

8. (Below 2.95m): Muddy sand.

Ten 1 cm^3 samples were extracted from the core. During preparation, Stockmarr Tablets (Stockmarr 1971) containing known amounts of *Lycopodium* spores, were added at the rate of one tablet per sample to facilitate the estimation of absolute pollen counts. The samples were prepared using standard palynological preparation procedures, mounted on slides in silicone oil and sealed with paraffin wax. The finished slides were examined under a Zeiss Axiophot photomicroscope and pollen identification carried out by comparison to reference slides and photographs.

Two slides were mounted from each sample and approximately 100 pollen grains (excluding the *Lycopodium* spores) were counted from each of the 20 slides prepared. Charcoal fragments larger than 5μm in diameter were counted per 10 *Lycopodium* spores for each of the ten samples in order to estimate the absolute charcoal content of the samples. The absolute pollen diagram in Figure A1.2 was constructed using the TILIA and TILIAGRAPH software packages (Grimm 1987).

Three major zones were identified on the pollen diagram using a combination of visual interpretation of the diagram and cluster analysis using CONISS (Grimm 1987). Zone 1 consists of the two lowest samples from the core, below 2.40 metres. Zone 2 encloses the five samples between 0.60 and 2.40 metres, while Zone 3 makes up the three shallowest samples above 0.60 metres. It is possible that the broad Zone 2 contains sub-zones, but any further subdivision was not feasible without a greater density of sampling.

Radiocarbon ages derived from the core (NZA-4654 and NZA-4833; Figure A1.2) are reversed and both clearly anomalous, given that the swamp probably formed after the end of the Postglacial Marine Transgression. The swamp was sampled approximately 200 metres "upstream" of an active salt marsh and is itself a relict estuarine flat. Consequently, the pollen spectrum for much of the core described in Figure A1.2 probably represents not only changes in vegetation at and around the coring site, but also changes occurring around the wider Tauranga Basin due to the likelihood of pollen being transported to the site via the harbour. With the transition from an active to a relict estuarine flat, the swamp site, at around 100 metres in diameter, would probably contain a pollen spectrum reflecting the local and extra-local vegetation within several hundred metres of the site (Jacobsen and Bradshaw 1981).

A small component of the pollen spectrum is likely to have been transported from the mainland by the prevailing westerly winds. For example, *Nothofagus fusca* pollen is well represented in this lowland coastal site (Figure A1.2), even though *Nothofagus* is a cooler-climate or upland species and is probably limited to the Kaimai Ranges in the west.

A1.2 RESULTS

Absolute pollen counts (grains per cm^3 of sediment) are provided in Figure A1.2 in the pocket at the rear of this thesis.

A1.2.1 Vegetation changes

Relatively low frequencies of podocarp pollen and high levels of *Cyathea* and monolete fern spores occur in Zone 1, suggesting the vegetation at this time was dominated by ferns and scrub. The pollen of *Metrosideros*, a species common in regenerating forest (M.B. Elliott, pers. comm. 1993) began to increase in this zone, possibly indicating the early stages of forest development. However, the lack of a similar increase in *Kunzea/Leptospermum* pollen, also good indicators of forest regeneration, requires further investigation. Aquatic pollen counts are also very low in this zone for possible reasons discussed below.

Zone 2 shows a considerable increase in tree pollen, particularly in podocarps and *Knightia excelsa*. 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 show an increase at this time. This may be an early successional change as a result of continuing development or recovery of the local vegetation. This probably accounts for the decrease in small tree/shrub pollen and fern spores upward in this zone, with a corresponding rise in tree pollen. A small increase in *Nothofagus* also occurs. This is likely to reflect an increase in *Nothofagus* populations in regional upland areas, such as the Kaimai Ranges, because it is a cooler-climate species and the rise in *Nothofagus* coincides with an increase in *Ascarina*, an indicator of warm, moist climates. This contention is tentative, owing to the difficulty of separating the pollen from a large population of producers at a long distance from a smaller producing population much closer to the study site (Oldfield 1970). However, Newnham *et al.* (1995) also associate *Nothofagus* pollen occurring in pollen records from Papamoa and Waihi Beach with adjacent upland populations of the species.

Charcoal counts rise sharply in this zone, indicating that vegetation burning occurred at the site and/or elsewhere within the Tauranga Basin. The latter is supported by the persistence of the dominant podocarps in parallel with the sharp charcoal peak, suggesting that the

charcoal and pollen were derived from different sources. *Dacrydium cupressinum* can withstand most ground fires and can persist over long periods (Bray 1989), which may also explain its co-existence with high charcoal influxes. However, this does not explain why other podocarps also persist through the charcoal peak. A possible cause of this peak is discussed in Section A1.2.2.4.

The decline of *Ascarina* pollen in this zone implies a cooler, drier climate (McGlone 1983, McGlone *et al.* 1984, McGlone 1988, Newnham *et al.* 1989); this is discussed below.

Zone 3 contrasts sharply with Zone 2. The pollen counts for podocarps and *Nothofagus fusca* drop substantially and *Pteridium* increases sharply in response. In the upper part of this zone, the modern adventive *Pinus radiata* shows a sudden large increase. An abrupt drop in podocarp pollen for a similar time (post-Kaharoa) has also been noted by McGlone (1983) at Lake Rotorua. The drop in total tree pollen is further highlighted if the exotic *Pinus* pollen is excluded from this total. Increased amounts of *Dacrydium dacrydioides* pollen in this zone, against the trend shown by other indigenous trees, may have been derived from isolated individuals occurring on the site particularly as the species is commonly associated with swampy flats.

Small trees and shrubs increase in this zone, especially *Kunzea/Leptospermum* and to a lesser extent *Metrosideros*. These are colonisers which generally increase following 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 outside of the study area. The appearance of the exotic coloniser *Ulex* (gorse) in Zone 3 also contributes to the increase in the small trees/shrubs total.

The aquatics *Cyperaceae*, *Haloragaceae* and *Restionaceae* increase strongly to dominate the pollen spectrum in Zone 3. A probable cause for this is discussed below. Herb species also show a marked increase in this zone, including the adventive *Taraxacum*.

A1.2.2 Interpretation of vegetation changes

The vegetation changes described above have resulted from a number of factors:

A1.2.2.1 Development of the Matakana Island barrier

The lack of reliable dating control on the results found here means that any inferences made can only be tentative.

Prior to the development of the Matakana Island barrier, the swamp site would have been exposed to the open sea with considerably higher energy and exposure to salt-laden onshore winds than at present. Such environments do not favour well-developed forest vegetation and scrubland would probably have been more dominant. It is suggested that Zone 1 and the lower part of Zone 2 described above represent this situation.

The formation of the barrier would have caused a significant change to this situation: exposure to wind-borne salt would have decreased substantially and the overall strength of onshore winds at the site would probably also have decreased. Given this change to a more sheltered, less saline environment, a transition from scrubland vegetation to lowland forest may have occurred in response, suggested by the successional change described from Zone 2 above. The brief peak in *Leguminosae* possibly represents an early successional stage.

The location of the site directly opposite the old Blue Gum Bay entrance described in this thesis suggests that shelter by the developing barrier from onshore winds would probably not have been very significant until the entrance was almost closed, *c*.3 750 cal BP. Assuming this and that vegetation responded quickly to the change in environment, it is therefore tentatively suggested that the lower boundary of Zone 2 has an age of about 3 750-3 000 cal BP.

The lowered energy regime of the site following barrier development may have been ultimately responsible 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, although this requires further investigation.

A1.2.2.2 Climate

Vegetation changes related primarily to climatic fluctuations are well documented from throughout New Zealand and the world (e.g., McGlone *et al.* (1984) and McGlone (1988)). Although climatic variations are certain to have influenced the vegetation the Tauranga Basin in the past, the significance of climate change relative to the formation of the Matakana Island barrier is less clear. However, two possible climatic changes are suggested from Figure A1.2:

Firstly, a temporary increase in *Ascarina* pollen followed by a virtual disappearance occurs in Zone 2. *Ascarina*, being drought- and frost-sensitive, is favoured by warm, moist climates (McGlone 1983, McGlone *et al.* 1984, McGlone 1988, Newnham *et al.* 1989). This species was abundant in North Island forests in the early to mid Holocene with a major decline setting in at about 5 000 ^{14}C years BP (*c.*5 700 cal BP) and virtual extinction after about 2 000 ^{14}C years BP (*c.*1 950 cal BP) (McGlone and Moar 1977). It is suggested here that *Ascarina* became established around the study site towards the late Holocene, when barrier formation gave rise to a more favourable environment for forest growth. The decline in *Ascarina* reported in the literature suggests a predominance of a cooler, drier climate in the mid to late Holocene than previously. The virtual extinction of *Ascarina* described from Zone 2 is tentatively correlated to the similar extinctions reported from the mainland, suggesting an age for the core, at a depth of one metre, of about 1 950 cal BP. This is consistent with evidence from cores from Waihi Beach and the Papamoa lowlands for a drier climate between about 1 850 and 700 ^{14}C years BP (Newnham *et al.* 1995) (*c.*1 750 and *c.*650 cal BP).

Secondly, the substantial increase in aquatic species in Zone 3 implies a considerably wetter environment, which could possible be climatically related. However, the author suggests that a transition of the site from an active to a relict estuarine flat at around the upper part of Zone 2, with consequent colonisation of the site by aquatic species, is more likely.

A1.2.2.3 Human impact

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. The timing of this change is not clear in the absence of dating control, although archaeological evidence from the Holocene barrier (see Chapter 4) supports a post-Kaharoa age for the beginning of Maori occupation. However, the possibility of earlier occupation cannot be disregarded: significant human influences on vegetation are suggested to have begun immediately prior to the Kaharoa eruption in the western Bay of Plenty by Newnham *et al.* (1995).

The pollen spectra of the two shallowest samples clearly relate to European influences as indicated by the presence of exotic pollen. Pre-European disturbance by Maori is suggested by the sample at 0.53 metres, where podocarps begin to decline and *Pteridium* peaks strongly but modern adventive species are absent.

Decreasing charcoal counts in the upper part of Zone 2 to low values in Zone 3 reflect the removal of flammable material (ie. vegetation) from the site and its surrounds, consistent with forest clearance.

A1.2.2.4 Possible volcanic influences

Again, a lack of dating control precludes the correlation of any part of the core to specific past events. However, the rise in charcoal fragments in Zone 2 appears to have occurred prior to human influences on vegetation (notwithstanding possible changes in sedimentation rates). This suggests burning by natural causes, such as lightning strikes or volcanic activity. Bog vegetation is highly inflammable when dry (McGlone, *et al.* 1984) and the prolonged dry spells which occur in this region (de Lisle, 1962) would encourage natural fires.

Newnham *et al.* (1995) report evidence from the Bay of Plenty coastal plain for forest disturbance following the Taupo eruption. This included influxes of charcoal suggesting burning, a phenomenon possibly responsible for the apparently early rise in charcoal seen here. As suggested above, burning does not appear to have occurred at the site itself, and it appears instead that the burning may have occurred elsewhere in the Tauranga Basin with the charcoal transported to the site via the harbour.

A1.3 CONCLUSIONS

A major limitation to the interpretation of vegetation changes from the core collected in this study has been the lack of reliable dating control. However, significant changes have clearly occurred and can be tentatively attributed to a variety of causes. The site represents a Pleistocene fluvial course which was drowned and infilled during and after the Postglacial Marine Transgression, which terminated *c.*7 000 cal BP. A salt marsh environment probably prevailed at the site until relatively recently when it became relict and a freshwater swamp environment developed, as indicated by the spread of aquatics in Zone 1. Prior to this, sediment transport and deposition in the harbour probably renders the pollen record more representative of regional vegetation changes rather than local, although the proportions of which cannot be ascertained.

The development of the Matakana Island barrier and consequent sheltering of the site from strong salt-laden onshore winds is suggested to have led to the development of a podocarp forest where coastal scrub and ferns previously dominated. This is thought to have occurred at around 3 750-3 000 cal BP. The timing of formation of a freshwater swamp on the site is not clear, but appears to be within the period of human occupation as indicated by the late spread of aquatic vegetation. The virtual extinction of *Ascarina* in Zone 2 suggests a change to cooler, drier conditions and is tentatively attributed to a drier regional climate between about 1 850 and 700 ^{14}C years BP (*c.*1 750 and *c.*650 cal BP) suggested by Newnham *et al.* (1995).

Forest disturbance by humans is clearly indicated in Zone 1. The lower sample in this zone probably represents Maori occupation where podocarps begin to decline and *Pteridium* peaks sharply but modern adventive species are absent. European influences are characteristic of the upper two samples which contain exotic pollen including the abundant *Pinus*, probably derived largely from the commercial forests on the barrier which were first planted early this century (Faulkner 1955). Early forest disturbance prior to human occupation is suggested by the rise in charcoal in Zone 2 and may be related to natural causes such as burning following the Taupo eruption. However, burning does not appear to have occurred at the site itself and charcoal transport to the site via the harbour is suggested.

A1.4 REFERENCES

Bray, J.R. (1989): The use of historical vegetation dynamics in interpreting prehistorical vegetation change. *Journal of the Royal Society of New Zealand 19, 2:* 151-160.

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

Faulkner, R. (1955): From Kauri to Pine on Matakana Island. *N.Z. Timber Journal 2, 2:* 39.

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. *N.Z. 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.

Grimm, E.C. (1987): CONISS: a FORTRAN 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares. *Computers and Geosciences 13:* 13-35.

Jacobsen, G.L. and Bradshaw, R.H.W. (1981): The selection of sites for Palaeovegetation studies. *Quaternary Research 16:* 80-96.

McGlone, M.S. (1983): Holocene Pollen diagrams, Lake Rotorua, North Island, New Zealand. *Journal of the Royal Society of New Zealand 13, 1/2:* 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, 3:* 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.*18 000 years ago. *Journal of the Royal Society of New Zealand 19, 2:* 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, 2:* 283-300.

Oldfield, F. (1970): Some aspects of scale and complexity in pollen analytically-based Palaeoecology. *Pollen et Spores 12, 2:* 163-172.

Stockmarr, J. (1971): Tablets with spores used in absolute pollen analysis. *Pollen et spores 13:* 615-621.

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Appendix Two: Pedological Development on the Barrier

Introduction

The results of an investigation into pedological changes across the barrier adjacent to Blue Gum Bay are presented here and summarised in Section 4.1.4. The transect of test pits is located in Figure A2.1.

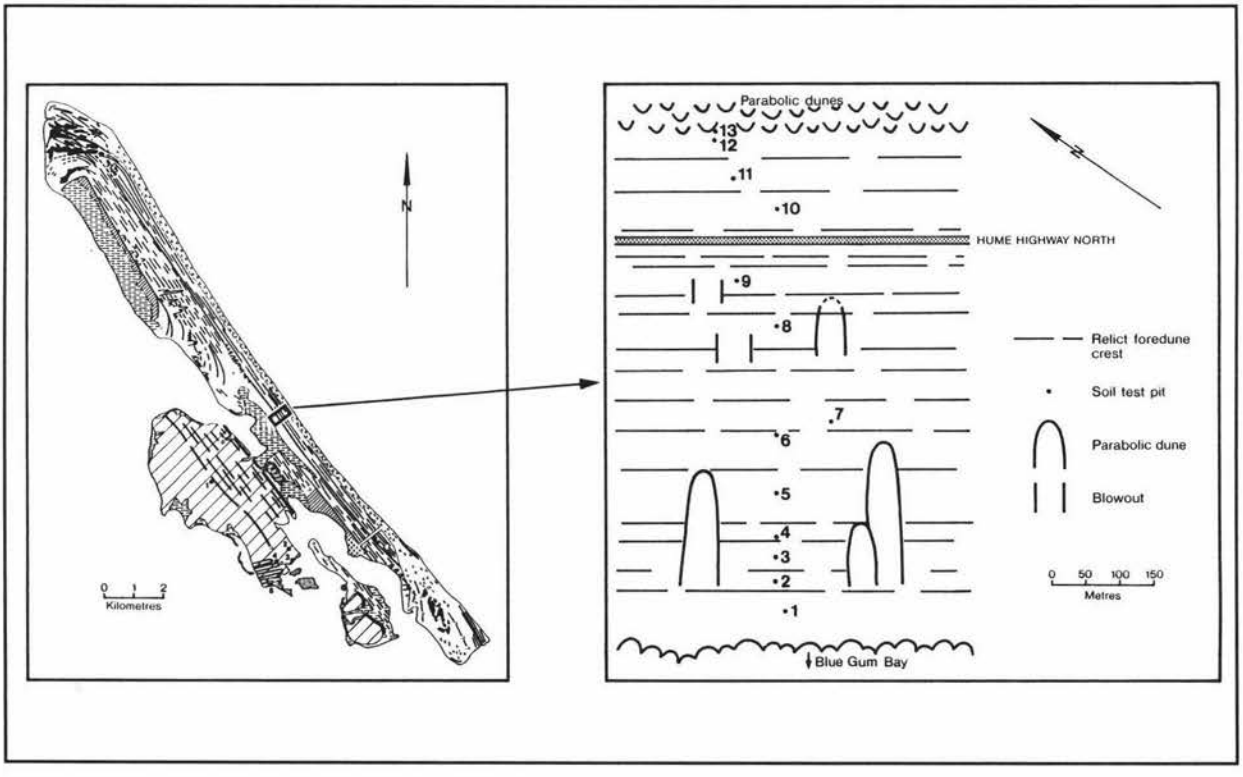


Figure A2.1: Location of Blue Gum Bay Transect and test pits.

A2.1 PROFILE CHANGES ACROSS THE BARRIER

It is stressed that soil profiles on the Matakana Island barrier are extremely variable, even within a single swale. For example, a test pit dug within a few metres of test pit 5, which contained *c.*1.2 metres of identifiable soil horizons and deposits, showed little or no profile development. Forestry operations may be responsible, but they tend to bury rather than destroy soils within swales. Wind throw of trees may significantly alter the profile in restricted areas (Figure A2.2), a process which may have been widespread on the unconsolidated sandy soils of the barrier prior to forest clearance.

Figure A2.2: The base of a large wind-felled tree on the inner margin of the barrier adjacent to Blue Gum Bay, showing large amounts of Kaharoa Tephra retained by the root system.

Figure A2.3 below attempts to correlate the major pedological and stratigraphic units across the barrier. The soil profiles have been superimposed on Profile 4 (from Figure 2.18 in Chapter 2) along which the soil test pits were excavated. In some test pits the original profile has been modified or destroyed by prehistoric Maori activities, particularly gardening. This includes the eight innermost test pits. A shell midden containing oven stones was penetrated by test pit 6. Forestry operations have also destroyed the upper part of the profile in many test pits.

The profiles change significantly across the barrier. The greatest depth of pedogenesis below the Kaharoa Tephra occurs immediately seaward of the innermost ridge of this part of the barrier, at test pit 5. From here the profiles shallow both landward and seaward, suggesting a decreasing relative age in both directions. The seaward trend relates to the progradation of the barrier, where dunes further seaward are progressively younger and therefore have less well-developed soil profiles.

The separation of buried soils by layers of clean sand in test pits 12 and 13 is evidence for two distinct influxes of sand from the adjacent seaward strip of parabolic dunes in recent times. The first encroachment led to the burial of a peaty soil at both sites which had formed over Kaharoa Tephra. This was followed by a period of stability and development of an A horizon on the new surface before the second encroachment buried this horizon in test pit 13.

The rapid harbourward shallowing of the profiles from the inner ridge indicates the harbour shoreline has also prograded, although Maori and forestry activities have destroyed much of the record. Muddy, probably estuarine sands containing abundant small shell fragments underlie a thin peaty soil in test pit 1, confirming the history of harbour shoreline progradation.

The lack of a deeply-developed soil in test pit 4 on the landward side of the inner ridge may relate to the absence of a well-developed swale which would have promoted the accumulation of organic matter, sand and tephric material from which the soil has formed. Any soil which had developed at this site is likely to have been destroyed by Maori gardening and forestry operations.

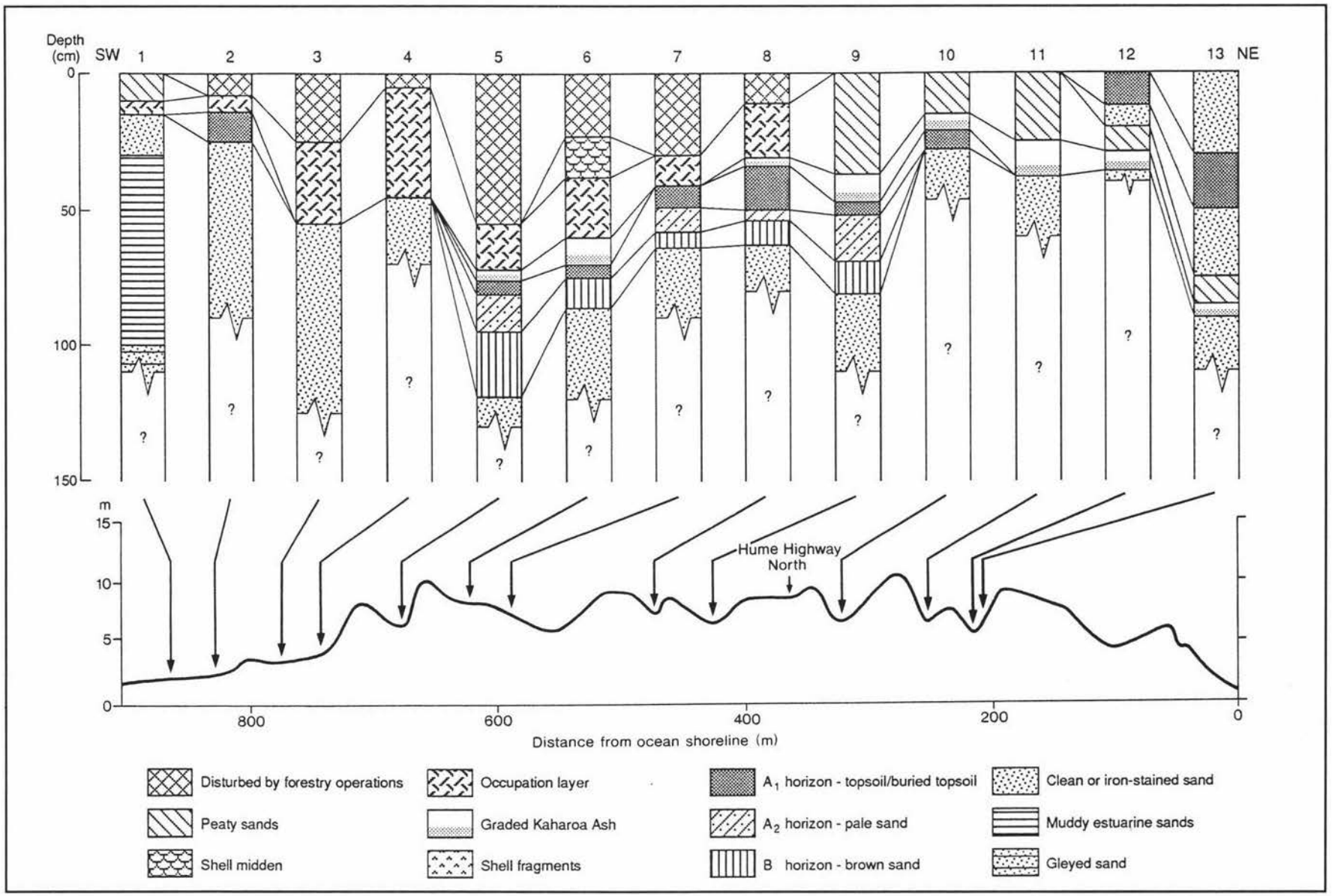


Figure A2.3: Summarised and correlated soil profiles, Blue Gum Bay Transect.

Disturbance of the soil by Maori activity ceases abruptly seaward of test pit 8. This probably reflects soil fertility - the younger soils further seaward are less well-developed and therefore less fertile, rendering them unsuitable for gardening. This is discussed further in Section A2.2.

Taupo Lapilli occurs in test pits 2-10 where it is mixed into occupation layers or occurs directly below Kaharoa Tephra in undisturbed sections. The apparent absence of accumulated material separating them, despite *c.*1 100 years between eruptive events, indicates that swale-filling processes must have been slow or negligible in the absence of human disturbance. The absence of Taupo Lapilli from test pit 1 suggests the harbour shoreline lay between test pits 1 and 2 at the time of the Taupo eruption. Similarly, the ocean shoreline is inferred to have occurred between test pits 10 and 11 at the time of the Taupo eruption, based on the disappearance of Taupo Lapilli seaward of test pit 10. These conclusions are supported by the distribution of sea-rafted Taupo Pumice described in Section 4.1.2. Although Kaharoa Tephra was not observed in test pit 1 it was observed on relict estuarine flats further harbourward. However, the Kaharoa shoreline was not located accurately on this part of the barrier.

Where soils are buried by Kaharoa Tephra (test pits 2-10; Kaharoa Tephra is mixed into the occupation layers in test pits 2, 3, 4 and 7), subsequent accumulation on the surface has exceeded the total depth of soil development prior to the deposition of Kaharoa Tephra. This implies a rapid post-Kaharoa increase in the rate of surface accumulation, possibly in response to the clearing of vegetation by Maori and consequently more intense slope wash processes depositing materials into swales. The post-Kaharoa development of black organic-rich topsoils is common, best observed in undisturbed sections in test pits 9-13. These may be bracken (*Pteridium esculentum*) soils, which, when formed in direct association with tephra deposits, tend to develop very high organic contents and become very intensely black in colour (Birrell *et al.* 1971: cited in Marshall *et al.* 1994). Being a pioneer species, *Pteridium esculentum* quickly spreads in areas where vegetation is disturbed and the extent of vegetation disturbance by and following the Kaharoa eruption would have been conducive to the formation of a bracken soil (Marshall *et al.* 1994). Increased organic accumulation following the Kaharoa eruption may also have been favoured by an increase in soil moisture content, which may have occurred as a result of Kaharoa Tephra impeding percolation of soil water and creating a moister surface environment (B.G. McFadgen, pers. comm., 1995).

A2.2 FORMAL DESCRIPTIONS AND SOIL CHEMICAL ANALYSES

As part of an associated project on Matakana Island, formal descriptions and analyses of soil chemistry were carried out for test pits 5-9, the oldest and best-developed profiles from the transect above (Figure A2.3). Chemical analyses of palaeosols occurring below Kaharoa Tephra were carried out by the Department of Soil Science, Massey University. The main findings from this work are summarised below.

A2.2.1 Soil profile descriptions

Descriptions after Taylor and Pohlen (1970) are as follows:

Test pit 5

0-25cm Brown (10YR 4/4) sand. Weakly developed medium granular structure, single grain, few roots. Sharp, irregular boundary.

25-56cm Brownish black (10YR 3/2) sand, with many faint fine mottles in upper part of horizon and abundant distinct fine and medium mottles in lower part. Very friable. Weakly developed fine and medium nut structure. Few roots, few fine charcoal fragments, rare lapilli. Sharp, irregular boundary.

56-72cm Black (10YR 1.7/1) sandy loam, with many distinct fine and medium pockets of dull yellow (2.5Y 6/3) Kaharoa Tephra. Very friable to friable, moderately well developed fine to medium nut and medium to coarse granular structure. Few roots, occasional lapilli up to about 5mm in diameter, occasional fine charcoal fragments with rare charcoal fragments up to 10mm in diameter. Sharp, irregular boundary.

72-76cm Graded Kaharoa Tephra - fine fraction between 72cm and 74cm; coarse fraction between 74cm and 76cm. Overall thickness variable between 2 and 10 centimetres. Upper part disturbed. Sharp, irregular boundary.

76-80cm Brownish-black (10YR 3/2) sandy loam, with many faint medium dark brown (10YR 3/3) mottles. Very friable, moderately developed very fine to medium granular structure. Few roots, many lapilli up to 5mm in diameter, rare charcoal up to 10mm in diameter. Indistinct, smooth boundary.

80-92cm Dull yellow-brown (10YR 4/3) sandy loam, with few medium and coarse dull yellowish brown (10YR 5/3) mottles. Very friable, moderately developed very fine to medium nut structure. Few roots. Distinct, wavy boundary.

92-94cm Coarse ash - possibly Waimihia Tephra? Thickness variable up to 3cm. Distinct, irregular boundary.

>94cm Dull yellowish (10YR 5/4) sand, with many medium and coarse dull yellow (2.5YR 6/4) mottles. Loose to very friable, single grain structure. Few roots.

Test pit 6

0-23cm Disturbed by forestry operations.

23-60cm Cultural soil.

60-69cm Graded Kaharoa Tephra.

69-75cm Black (10YR 1.7/1) sandy loam. Very friable, moderately developed very fine to fine nut and some fine to very fine blocky structure. Few roots, few fine and medium charcoal fragments, many and few medium lapilli. Indistinct, wavy boundary.

75-86cm Brownish-black (10YR 3/2) sandy loam, with many faint medium to coarse mottles ranging in colour from dull yellow brown (10YR 5/4) to greyish yellow brown (10YR 4/2). Friable, moderately developed very fine to fine nut with some very fine to fine blocky structure. Few roots, few lapilli. Distinct to

diffuse wavy boundary.

>86cm Dull yellow orange (10YR 6/5) sand, with many fine to coarse distinct brown (10YR 6/3) mottles. Loose, single grain structure. Few roots.

Test pit 7

0-30cm Disturbed by forestry operations - well defined layers and lenses of dark and light coloured sand. Sharp, irregular boundary.

30-41cm Brownish black (10YR 2/3) sandy loam, with many faint fine brownish black (10YR 3/2) and few distinct medium yellow brown (2.5Y 5/3) mottles. Friable to firm, massive in position breaking to moderately developed very fine to fine nut structure. Few roots, few fine and medium charcoal fragments, few fine lapilli. Indistinct smooth boundary.

41-49cm Dull yellowish brown (10YR 4/3) sandy loam, with many faint medium dull yellowish brown (10YR 4/3-5/3) mottles. Friable, massive breaking to very fine to fine nut. Few roots, few fine charcoal fragments, many fine lapilli. Indistinct wavy boundary.

49-58cm Dull yellow-brown (10YR 5/3) sandy loam (silty sand), with many faint fine to medium dull yellow orange (10YR 6/3) mottles. Friable, massive breaking to moderately developed very fine to fine blocky and nut structure. Few roots. Distinct, wavy boundary.

58-64cm Yellowish brown (10YR 5/6) silty sand grading downwards to sand, with many faint medium bright yellowish brown (10YR 6/6) mottles. Friable to loose; silty sand component breaks to moderately developed very fine to fine blocky and nut structure, sandy component breaks to weakly developed very fine to fine blocky and nut with single grain. Few roots. Indistinct, wavy boundary.

>64cm Bright yellowish brown (10YR 6/6) sand, with many faint medium to coarse brown (10YR 4/6) mottles. Loose, single grain structure. Few roots.

Test pit 8

0-11cm Brownish black (10YR 2/3) loamy sand, with many faint coarse dark brown (10YR 3/3) mottles. Very friable, weakly developed medium granular and fine nut structure with single grain. Few roots. Sharp, wavy boundary.

11-31cm Black (10YR 2/1) sandy loam, with few faint medium to coarse brownish black (10YR 3/2) mottles and many distinct fine to coarse dull yellow (2.5Y 6/3) mottles. Friable, moderately developed fine to medium blocky and very fine nut structure. Few roots, few fine and medium charcoal fragments, few fine and medium lapilli. Sharp irregular boundary.

31-37cm Graded Kaharoa Tephra. Distinct, smooth boundary.

37-50cm Brownish black (10YR 3/2) sandy loam, paling downwards to greyish yellow brown (10YR 4/2), with many faint fine to medium brownish black (10YR 3/2) mottles. Friable, moderately developed very fine to medium blocky and very fine nut structure. Few roots, many fine lapilli, few fine charcoal fragments. Indistinct, wavy boundary.

50-54cm Dull yellowish brown (10YR 5/3) sandy loam, with many faint fine to medium dull yellow brown (10YR 4/3) mottles. Very friable, moderately developed very fine blocky and fine nut structure. Few roots. Indistinct, smooth boundary.

54-63cm Yellowish brown (10YR 5/6) sandy loam, with many distinct fine and medium dull yellow orange (10YR 6/4) to dark brown (10YR 3/4) mottles. Friable, moderately developed very fine blocky and fine nut structure, with weakly developed nut and single grain structure in sandy part. Few roots. Indistinct,

smooth boundary.

>63cm Dull yellowish brown (10YR 3/4) sand, with many medium to coarse dull yellow orange (10YR 6/4) mottles. Loose, single grain structure. Few roots.

Test pit 9

0-37cm Brownish black (10YR 2/2) sandy loam, with few faint medium to coarse dark brown (10YR 3/3) mottles, becoming abundant towards bottom of layer. Firm, weakly developed fine to very fine nut structure. Few roots, few fine lapilli, few fine charcoal fragments. Sharp to distinct irregular boundary.

37-47cm Dull yellow (2.5Y 6/3) Kaharoa Tephra. Graded, with *c.*2cm of fines overlying coarse base. Distinct, wavy boundary.

47-52cm Dull yellowish brown (10YR 5/3) sand. Friable, weakly developed fine to very fine nut structure. Few roots, many fine to very fine angular lapilli and few coarse rounded pumice fragments up to 10mm in diameter; few fine charcoal fragments. Indistinct, wavy boundary.

52-69cm Dull yellow orange (10YR 7/3) sand, with few faint medium dull yellow orange (10YR 6/3) mottles. Very friable, single grain structure. Few roots. Distinct, smooth boundary.

69-81cm Dull yellow brown (10YR 5/3) loamy sand, with many faint fine and medium brown (10YR 4/4) mottles. Firm, weakly developed very fine to coarse nut and blocky structure. Few roots. Indistinct, smooth boundary.

81-100cm Dull yellowish brown (10YR 5/4) sand, with many distinct medium and coarse brown (7.5YR 4/4) mottles. Very friable, single grain structure. Few roots. Distinct, irregular boundary.

>100cm Dark reddish brown (5YR 3/3) sand, with profuse faint medium brown (7.5YR 4/4) mottles. Firm, weakly developed very fine to fine nut and fine blocky structure with single grain.

A2.2.2 Soil profile changes along the transect

Several changes occur in the soil profile from test pits 9 to 5 (youngest to oldest):

(1) The B horizon thickens.

(2) The percentage of silt and clay (ie., material finer than 4ϕ) increases sharply landward between test pits 9 and 8 (Figure A2.4 below), then remains fairly uniform through to test pit 5. A section in a sand quarry adjacent to the Matakana Mill (grid reference NZMS 260 U14 848945), landward of the "Long Ridge" adjacent to which test pit 5 is located, is taken to be older than any of the profiles analysed in Figure A2.3 on the basis of its location on the barrier and is included for comparison. Silt/clay percentages are similar at the Mill section to those of the inner part of the transect adjacent to Blue Gum Bay. The high contents of fines landward of test pit 9 (Figure A2.4 below) probably reflect the incorporation of airfall tephra into the soil.

(3) The A1 horizon darkens from dull yellow-brown (10YR 5/3) to brownish-black (10YR 3/2) and the A2 horizon from dull yellow-orange (10YR 7/3) to dull yellow-brown 10YR 5/3). Little systematic change in colour is evident in the B horizon which is yellowish-brown (10YR 5/6) to brownish-black (10YR 3/2).

(4) Structural development of the A1 and B horizons increases from weakly developed to moderately developed and the A2 horizon from single grain to moderately developed.

(5) Cementation of sand by iron oxides occurs in an iron pan at the Mill section mentioned above. Older sands of the inner barrier northwest of Western Road, and also adjacent to Waiherere Road, are extensively cemented (the "coffee rock" described by Munro (1994)). The increased concentrations of heavy minerals in the inner barrier sands (Section 3.2.1) are likely to have contributed to cementation due to increased iron contents.

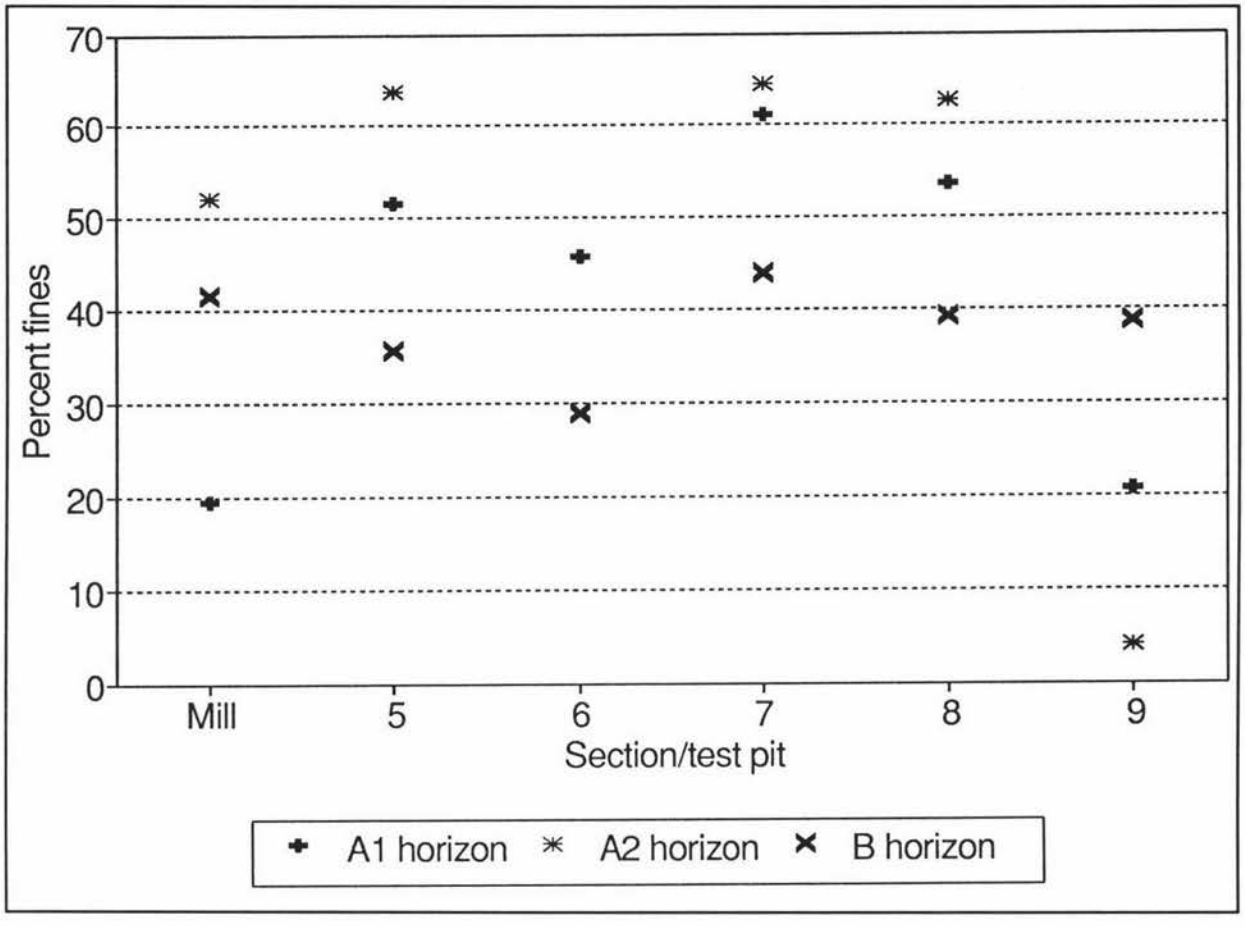


Figure A2.4: Silt/clay contents of soil horizons in test pits 5-9.

A2.2.3 Soil chemistry

Results of analyses of soil chemistry are provided in Table A2.1 below. Comparisons to modern active soils should be made with caution on account of the soils described having been buried by Kaharoa Tephra and subsequent accumulation.

The main findings are:

(1) Organic accumulation decreases only slightly seaward. The Maori garden soil sampled from test pit 5 has a higher organic content suggesting composting of the soil occurred during prehistoric occupation of the site.

Table A2.1: Results of soil chemical analyses, test pits 5-9.

Sample ID	pH	Olsen P	SO4	Exch K	Exch Ca	Exch Mg	Exch Na	CEC	P retn (%)	Org Matter (%)
Test pit 5 (A1 horizon)	6.2	2	3.0	0.04	3.4	0.74	0.2	10	25	4.2
Test pit 5 (A2 horizon)	6.3	9	1.5	0.05	1.8	0.35	0.1	7	13	3.2
Test pit 5 (B horizon)	6.8	3	33.5	0.03	5.3	1.12	0.1	11	67	3.2
Test pit 5 (Garden soil)	5.8	5	4.0	0.04	3.2	1.18	0.3	16	35	5.3
Test pit 6 (A Horizon)	8.1	6	2.0	0.14	13.3	0.14	0.2	16	27	3.9
Test pit 6 (B horizon)	8.1	8	<1.0	0.05	8.1	0.09	<0.1	10	16	1.9
Test pit 7 (A1 horizon)	6.1	5	2.5	0.38	1.2	0.28	0.2	13	36	3.7
Test pit 7 (A2 horizon)	6.2	6	2.5	0.33	0.5	0.22	<0.1	7	29	3.1
Test pit 7 (B horizon)	5.1	9	62.0	0.07	0.5	0.03	<0.1	7	30	2.4
Test pit 8 (A1 horizon)	5.8	23	1.5	0,10	0.9	0.24	0.3	9	22	2.9
Test pit 8 (A2 horizon)	5.7	17	2.5	0.09	1.2	0.14	0.2	10	35	3.4
Test pit 8 (B horizon)	5.9	19	1.0	0.06	0.9	0.64	0.3	9	19	2.4
Test pit 9 (A1 horizon)	5.3	10	6.0	0.02	1.0	0.15	0.6	10	12	1.8
Test pit 9 (A2 horizon)	5.4	8	2.5	0.01	0.6	0.21	0.2	8	6	0.5
Test pit 9 (B horizon)	5.1	20	35.0	0.03	0.2	0.06	0.3	10	22	2.4

(2) The shell midden layer present in test pit 6 has considerably raised the pH and exchangeable calcium levels of the palaeosol. No podzolisation is evident. The pH level in test pit 5 is outside the range suitable for podzolisation, suggesting that the addition of sewerage nutrients and shells to the soil took place in association with prehistoric gardening (A.S. Palmer, pers. comm. 1995).

(3) Exchangeable potassium, a limiting factor for plant growth, is very low for all profiles. Minimal levels of exchangeable K occur in test pit 9, which may explain the absence of cultivation at and seaward of this test pit. The soils, including the garden soil at test pit 5, are not very fertile overall (A.S. Palmer, pers. comm. 1995).

Appendix Three: Aerial Photographs Consulted in This Study

Flown by	Job/*negative* number	Date
Carter Holt Harvey	90/65-2 (3 photos)	19-09-90
Carter Holt Harvey	90/21-1 (2 photos)	18-03-90
Carter Holt Harvey	89/56-5 (3 photos)	20-07-89
Carter Holt Harvey	81/87 (8 photos)	04-08-81
Carter Holt Harvey	88/40-6 (4 photos)	26-03-88
Carter Holt Harvey	93/30-1 (2 photos)	23-03-92
Carter Holt Harvey	81/88 (6 photos)	04-08-81
Carter Holt Harvey	89/13-4 (2 photos)	05-03-89
Carter Holt Harvey	85/14 (2 photos)	24-02-85
Carter Holt Harvey	87/47-2 (5 photos)	07-04-87
Carter Holt Harvey	91/58-1 (7 photos)	31-10-91
Carter Holt Harvey	83/34 (2 photos)	28-04-83
Carter Holt Harvey	84/23 (2 photos)	25-03-84
Carter Holt Harvey	83/104 (2 photos)	15-12-83
Carter Holt Harvey	92/30-1 (2 photos)	23-03-92
Carter Holt Harvey	86/7 (2 photos)	04-02-86
Carter Holt Harvey	83/67 (2 photos)	29-07-83
Carter Holt Harvey	89/13-2 (2 photos)	05-03-89
Carter Holt Harvey	87/47-1 (3 photos)	07-04-87
Carter Holt Harvey	87/47-3 (1 photo)	07-04-87
Air Maps N.Z. Ltd.	*154049-154058 inclusive*	10-06-82
Air Maps N.Z. Ltd.	*163062*	06-02-90
Air Maps N.Z. Ltd.	*163812*	24-02-91
Air Maps N.Z. Ltd.	*163823-163824*	24-02-91
Air Maps N.Z. Ltd.	*163826-163827*	24-02-91
Air Maps N.Z. Ltd.	*163840*	24-02-91
Air Maps N.Z. Ltd.	*166684*	22-06-92
Air Maps N.Z. Ltd.	*166837-166843 inclusive*	12-09-92
Air Maps N.Z. Ltd.	*177907-177908*	28-01-94
N.Z. Aerial Mapping Ltd.	*167-168*	19-03-86
N.Z. Aerial Mapping Ltd.	*171-172*	19-03-86
N.Z. Aerial Mapping Ltd.	*185-186*	19-03-86
N.Z. Aerial Mapping Ltd.	*292-293*	19-03-86
N.Z. Aerial Mapping Ltd.	*304-305*	19-03-86

Appendix Four:
Sediment Size Parameters and Verbal Classifications (Folk 1974)

1. GRAPHIC MEAN

$$M_z = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3}$$

M_z (ϕ)	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

2. INCLUSIVE GRAPHIC STANDARD DEVIATION (SORTING)

$$\sigma_I = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6}$$

σ_I (ϕ)	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

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

Sk_I (ϕ)	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

$$K_G = \frac{\phi_{95} - \phi_5}{2.44(\phi_{75} - \phi_{25})}$$

K_G (ϕ)	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

Appendix Five:
Textural Parameters of Sediment Samples

Table A5.1: Sediment size parameters

Sample ID	Mean Size	Sorting	Skew-ness	Kurtosis	Sample Weight (g)	Sieve Error (%)
1993 Ocean Beach (1)	2.422	0.487	-0.065	0.848	100.0	0.3
1993 Ocean Beach (2)	2.575	0.375	-0.036	0.874	100.0	0.2
1993 Ocean Beach (3)	2.635	0.343	-0.115	1.052	100.0	0.1
1993 Ocean Beach (4)	2.623	0.405	-0.192	1.032	100.0	0.5
1993 Ocean Beach (5)	2.583	0.424	-0.131	0.932	100.0	0.2
1993 Ocean Beach (6)	2.664	0.376	-0.124	1.054	100.0	0.1
1993 Ocean Beach (7)	2.727	0.364	-0.214	1.265	100.0	0.3
1993 Ocean Beach (8)	2.391	0.499	-0.073	0.884	100.0	0.2
1993 Ocean Beach (9)	2.474	0.502	-0.248	0.933	100.0	0.5
1993 Ocean Beach (10)	2.131	0.669	-0.178	0.701	100.0	0.4
1993 Ocean Beach (11)	1.495	0.626	0.073	0.842	100.0	0.7
1993 Ocean Beach (12)	1.274	0.779	-0.153	1.089	100.0	0.1
1993 Ocean Beach (13)	1.741	0.570	0.010	0.991	100.0	0.3
1993 Ocean Beach (14)	1.408	0.518	0.038	0.944	100.0	0.3
1994 Ocean Beach (1)	2.166	0.369	0.073	0.844	100.0	0.1
1994 Ocean Beach (2)	2.386	0.337	-0.209	1.174	100.0	0.5
1994 Ocean Beach (3)	2.489	0.262	0.063	1.158	100.0	0.2
1994 Ocean Beach (4)	2.324	0.403	-0.265	1.002	100.0	0.7
1994 Ocean Beach (5)	1.396	0.542	0.047	0.918	100.0	0.1
1994 Ocean Beach (6)	1.467	0.542	0.087	0.924	100.0	0.3
1994 Ocean Beach (7)	0.810	0.650	-0.157	1.210	100.0	0.1
1994 Ocean Beach (8)	1.445	0.400	0.023	0.996	100.0	0.2
1994 Ocean Foredune (1)	2.129	0.370	0.072	0.899	100.0	0.1
1994 Ocean Foredune (2)	2.300	0.407	-0.222	0.979	100.0	0.0
1994 Ocean Foredune (3)	2.569	0.277	-0.128	1.707	100.0	0.1
1994 Ocean Foredune (4)	2.097	0.444	-0.106	0.923	100.0	0.1
1994 Ocean Foredune (5)	1.470	0.469	0.168	0.972	100.0	0.3
1994 Ocean Foredune (6)	1.849	0.491	-0.035	1.002	100.0	0.1
1994 Ocean Foredune (7)	1.390	0.477	0.054	0.957	100.0	0.3

Table A5.1 (continued)

Sample ID	Mean Size	Sorting	Skew-ness	Kurtosis	Sample Weight (g)	Sieve Error (%)
Long Ridge (1)	2.684	0.384	-0.081	1.300	100.0	0.0
Long Ridge (2)	2.579	0.410	-0.116	1.062	100.0	0.5
Long Ridge (3)	2.341	0.501	-0.028	0.874	100.0	0.2
Long Ridge (4)	2.448	0.480	-0.064	0.935	100.0	0.2
Long Ridge (5)	2.158	0.506	0.050	0.906	100.0	0.3
Long Ridge (6)	2.203	0.534	0.014	0.858	100.0	0.8
Long Ridge (7)	2.273	0.489	-0.073	0.911	100.0	0.2
Long Ridge (8)	2.109	0.482	0.132	1.018	100.0	0.2
Long Ridge (9)	2.121	0.498	0.061	0.941	100.0	0.0
Katikati Harbour Beach (1)	2.438	0.306	0.091	0.893	100.0	0.0
Katikati Harbour Beach (2)	1.756	0.393	0.223	1.251	100.0	0.3
Katikati Harbour Beach (3)	1.878	0.359	-0.080	1.122	100.0	0.4
Katikati Harbour Beach (4)	1.921	0.435	0.031	1.012	100.0	0.2
Katikati Harbour Beach (5)	1.864	0.364	0.053	1.044	100.0	0.1
Katikati Harbour Beach (6)	1.715	0.453	-0.013	1.091	100.0	0.2
Katikati Harbour Beach (7)	1.782	0.427	0.110	0.979	100.0	0.5
Katikati Harbour Beach (8)	1.902	0.690	-0.052	1.180	100.0	0.9
Katikati Harbour Beach (9)	1.812	0.408	-0.044	1.004	100.0	0.4
Katikati Harbour Beach (10)	1.942	0.306	0.047	1.106	100.0	0.5
Katikati Harbour Beach (11)	1.839	0.701	-0.075	0.872	100.0	0.0
Tauranga Harbour Beach (1)	1.738	0.413	0.073	0.968	100.0	0.1
Tauranga Harbour Beach (2)	2.214	0.363	0.137	1.055	100.0	0.5
Tauranga Harbour Beach (3)	1.830	0.470	-0.100	1.033	100.0	0.2
Tauranga Harbour Beach (4)	2.133	0.401	0.129	0.971	100.0	0.6
Tauranga Harbour Beach (5)	2.065	0.477	-0.029	0.855	100.0	0.7
Tauranga Harbour Beach (6)	2.206	0.402	0.083	0.954	100.0	0.6
Tauranga Harbour Beach (7)	1.940	0.654	-0.233	1.085	100.0	0.7
Tauranga Harbour Beach (8)	1.938	0.464	-0.033	1.061	100.0	0.7
Tauranga Harbour Beach (9)	2.379	0.571	-0.095	1.022	100.0	0.4
SE Barrier Relict Beach (1)	2.043	0.497	0.104	0.929	139.7	0.1
SE Barrier Relict Beach (2)	2.354	0.385	-0.079	1.102	62.5	0.5
SE Barrier Relict Beach (3)	2.048	0.484	-0.093	0.904	101.2	0.1
SE Barrier Relict Beach (4)	1.259	0.751	-0.047	0.997	137.6	0.6
SE Barrier Relict Beach (5)	1.885	0.455	0.057	0.957	93.2	0.4
SE Barrier Relict Beach (6)	2.190	0.447	-0.105	0.937	91.3	0.1
SE Barrier Relict Beach (7)	1.757	0.612	0.016	0.852	129.0	0.6
SE Barrier Relict Beach (8)	1.193	1.123	-0.118	0.754	125.9	0.5
SE Barrier Relict Beach (9)	1.400	0.428	0.085	0.982	117.4	0.5
SE Barrier Relict Beach (10)	2.168	0.455	-0.046	0.969	112.7	0.1

Table A5.1 (continued)

Sample ID	Mean Size	Sorting	Skew-ness	Kurtosis	Sample Weight (g)	Sieve Error (%)
SE Barrier Relict Beach (11)	1.588	0.497	0.083	1.130	94.2	0.4
SE Barrier Relict Beach (12)	1.465	0.863	-0.048	0.857	93.0	0.3
SE Barrier Relict Beach (13)	0.828	0.675	0.266	1.278	121.2	0.2
SE Barrier Relict Beach (14)	2.059	0.441	-0.040	0.885	93.8	0.2
SE Barrier Relict Beach (15)	1.434	0.564	0.019	1.030	121.3	0.6
SE Barrier Relict Beach (16)	1.368	0.572	0.185	0.999	117.9	0.1
SE Barrier Relict Beach (17)	1.590	0.521	0.173	1.014	77.8	0.4
SE Barrier Relict Beach (18)	1.836	0.617	-0.228	0.908	79.5	0.2
SE Barrier Relict Beach (19)	1.259	0.690	0.031	0.906	71.4	0.1
SE Barrier Relict Beach (20)	1.394	0.479	0.086	1.096	110.3	0.1
SE Barrier Relict Beach (21)	1.993	0.415	0.094	1.018	115.1	0.1
SE Barrier Relict Beach (22)	1.241	0.410	0.084	1.070	129.7	0.1
SE Barrier Relict Beach (23)	1.829	0.484	0.010	1.089	91.4	0.0
SE Barrier Relict Beach (24)	1.570	0.574	0.046	1.036	79.3	0.5
SE Barrier Relict Beach (25)	1.066	0.374	0.117	0.986	101.6	0.0
SE Barrier Relict Beach (26)	1.865	0.519	-0.005	1.021	107.7	0.1
SE Barrier Relict Beach (27)	1.619	0.587	-0.004	1.182	113.2	0.1
SE Barrier Relict Beach (28)	1.919	0.371	0.029	1.019	76.7	0.1
SE Barrier Relict Beach (29)	1.794	0.412	0.035	1.033	110.2	0.0
SE Barrier Relict Beach (30)	1.999	0.348	0.091	0.982	88.2	0.4
SE Barrier Relict Beach (31)	2.045	0.366	0.054	0.949	126.0	0.1
SE Barrier Relict Beach (32)	1.838	0.390	0.162	1.054	76.7	0.0
Blue Gum Bay Relict Beach (1)	2.077	0.417	0.072	0.964	96.5	0.2
Blue Gum Bay Relict Beach (2)	2.220	0.241	-0.441	0.888	95.7	0.3
Blue Gum Bay Relict Beach (3)	2.069	0.370	0.104	0.930	101.4	0.1
Blue Gum Bay Relict Beach (4)	1.916	0.578	-0.069	0.918	93.1	1.1
Blue Gum Bay Relict Beach (5)	1.487	0.487	0.051	1.050	100.3	0.3
S1	2.576	0.376	0.079	1.479	98.3	0.2
S2	2.162	0.443	0.071	0.993	97.1	0.8
Transect 1 (1)	2.120	0.491	0.165	1.010	100.0	0.3
Transect 1 (2)	2.340	0.480	0.014	1.134	100.0	0.5
Transect 1 (3)	2.222	0.455	-0.176	0.902	100.0	0.4
Transect 1 (4)	1.955	0.526	0.040	0.836	100.0	0.3
Transect 1 (5)	2.199	0.533	-0.207	0.948	100.0	0.3
Transect 1 (6)	2.159	0.451	-0.040	0.898	100.0	0.2
Transect 1 (7)	2.068	0.421	-0.003	0.921	100.0	0.2
Transect 2 (1)	2.327	0.499	0.032	1.040	100.0	0.2
Transect 2 (2)	2.326	0.466	-0.056	1.018	100.0	0.1

Table A5.1 (continued)

Sample ID	Mean Size	Sorting	Skew-ness	Kurtosis	Sample Weight (g)	Sieve Error (%)
Transect 2 (3)	2.062	0.405	0.080	0.948	100.0	0.2
Transect 2 (4)	2.178	0.392	0.008	0.906	100.0	0.2
Transect 2 (5)	2.149	0.412	0.010	0.836	100.0	0.2
Transect 2 (6)	2.480	0.309	-0.196	1.180	100.0	0.2
Transect 2 (7)	1.907	0.547	0.006	0.868	100.0	0.3
Transect 2 (8)	2.242	0.501	-0.282	0.905	100.0	0.2
Transect 3 (1)	1.876	0.417	0.066	1.069	100.0	0.3
Transect 3 (2)	2.266	0.425	-0.036	0.988	100.0	0.4
Transect 3 (3)	1.937	0.545	-0.006	0.852	100.0	0.1
Transect 3 (4)	1.908	0.507	0.059	0.881	100.0	0.3
Transect 3 (5)	1.897	0.450	0.136	0.918	100.0	0.2
Transect 3 (6)	2.421	0.373	-0.365	1.346	100.0	0.1
Transect 4 (1)	2.224	0.411	-0.001	0.981	100.0	0.3
Transect 4 (2)	2.017	0.467	-0.020	0.899	100.0	0.3
Transect 4 (3)	2.109	0.482	0.132	1.018	100.0	0.2
Transect 4 (4)	2.398	0.410	-0.232	1.305	100.0	0.6
Transect 4 (5)	2.298	0.416	-0.179	1.030	100.0	0.1
Transect 4 (6)	1.522	0.463	0.107	0.987	100.0	0.0
Beach-Foredune Transect 1 (1)	1.714	0.325	-0.031	1.175	100.0	0.8
Beach-Foredune Transect 1 (2)	1.931	0.410	-0.005	1.063	100.0	0.6
Beach-Foredune Transect 1 (3)	2.095	0.604	0.076	1.005	100.0	0.7
Beach-Foredune Transect 2 (1)	2.045	0.420	-0.008	1.073	100.0	0.7
Beach-Foredune Transect 2 (2)	2.378	0.378	0.010	0.876	100.0	0.6
Beach-Foredune Transect 2 (3)	2.269	0.431	0.043	0.933	100.0	0.3
Beach-Foredune Transect 2 (4)	2.181	0.374	-0.094	0.877	100.0	0.5
Beach-Foredune Transect 3 (1)	2.410	0.397	0.055	0.922	100.0	0.4
Beach-Foredune Transect 3 (2)	1.770	0.526	0.170	1.007	100.0	0.5
Beach-Foredune Transect 3 (3)	2.023	0.579	0.017	0.933	100.0	0.5
Beach-Foredune Transect 4 (1)	2.674	0.356	-0.268	1.179	100.0	0.2
Beach-Foredune Transect 4 (2)	1.970	0.582	0.012	0.889	100.0	0.8
Beach-Foredune Transect 4 (3)	2.084	0.506	0.035	0.904	100.0	0.3
Beach-Foredune Transect 4 (4)	2.092	0.528	0.024	0.835	100.0	0.6
Beach-Foredune Transect 5 (1)	2.617	0.385	-0.232	1.028	100.0	0.8
Beach-Foredune Transect 5 (2)	2.166	0.551	0.106	0.746	100.0	0.2
Beach-Foredune Transect 5 (3)	2.378	0.480	-0.126	0.798	100.0	0.1

Table A5.1 (continued)

Sample ID	Mean Size	Sorting	Skew-ness	Kurtosis	Sample Weight (g)	Sieve Error (%)
Beach-Foredune Transect 5 (4)	2.262	0.520	0.034	0.764	100.0	0.2
Borehole A1 (depth = 1.0m)	2.138	0.501	0.066	1.003	73.4	0.1
Borehole A1 (1.5m)	2.264	0.389	-0.020	0.955	71.4	0.7
Borehole A1 (2.0m)	2.094	0.509	0.089	0.955	76.5	0.7
Borehole A1 (4.0-4.1m)	1.966	0.778	0.050	1.107	71.4	0.9
Borehole A1 (4.5-4.7m)	1.758	0.885	0.080	1.430	66.5	0.2
Borehole A1 (4.7-5.0m)	1.480	0.985	-0.003	1.205	76.6	0.9
Borehole A2 (0.6m)	2.228	0.317	0.013	0.892	81.6	0.5
Borehole A2 (1.4m)	2.166	0.390	0.037	0.953	94.6	0.4
Borehole A2 (2.6m)	2.070	0.463	0.089	1.050	81.5	1.3
Borehole A2 (5.0-5.5m)	2.105	0.852	0.128	1.411	81.6	2.0
Borehole A2 (5.5-5.9m)	1.376	0.509	2.139	0.325	71.1	0.6
Borehole A2 (5.9-6.4m)	1.641	0.563	1.082	0.313	90.5	1.1
Borehole A2 (6.7-7.5m)	1.734	0.939	-0.089	0.992	71.5	1.6
Borehole A2 (7.9m)	2.296	0.818	-0.036	1.537	60.9	1.8
Borehole A2 (8.2-8.5m)	0.425	1.131	0.518	0.605	92.4	0.9
Borehole A2 (8.5-8.8m)	1.857	1.499	-0.321	0.705	80.7	1.5
Borehole A2 (9.1-9.3m)	1.220	1.162	0.078	0.475	80.6	0.2
Borehole A2 (9.3-9.5m)	2.600	0.632	0.115	1.734	66.4	1.6
Borehole A2 (9.5-9.7m)	1.692	1.138	-0.391	1.070	61.4	0.4
Borehole A2 (9.7-10.0m)	2.261	0.484	-0.197	1.243	63.1	0.7
Borehole A3 (1.0m)	2.220	0.241	-0.441	0.888	93.1	1.1
Borehole A3 (2.0m)	2.509	0.320	-0.091	1.200	69.6	0.1
Borehole A3 (3.0m)	2.330	0.436	-0.019	1.085	69.2	0.8
Borehole A3 (4.0m)	1.841	0.381	0.099	1.028	87.0	0.2
Borehole A3 (6.4m)	2.076	0.559	-0.039	0.997	95.2	1.0
Borehole A3 (7.0m)	1.656	0.971	0.148	1.250	86.7	1.2
Borehole A3 (7.5-8.1m)	2.093	0.995	-0.057	1.135	91.7	1.8
Borehole A4 (1.8m)	2.481	0.390	-0.288	1.137	62.3	0.4
Borehole A4 (3.5m)	2.340	0.395	-0.182	0.993	83.0	0.4
Borehole A4 (5.8m)	1.758	0.689	0.115	0.823	91.2	1.4
Borehole A4 (7.0m)	2.130	1.124	-0.166	1.035	77.9	0.6
Borehole A4 (8.1m)	2.223	0.656	-0.318	1.027	72.0	0.8

Table A5.2: Estuary flat samples

Sample ID	Percent Silt/Clay	Sample Weight (g)	Percent Error
Katikati Harbour Estuary Flat (1)	0.1	286.5	1.4
Katikati Harbour Estuary Flat (2)	0.2	299.7	1.2
Katikati Harbour Estuary Flat (3)	0.1	346.5	2.1
Katikati Harbour Estuary Flat (4)	0.1	349.4	1.8
Katikati Harbour Estuary Flat (5)	0.2	190.0	0.4
Katikati Harbour Estuary Flat (6)	0.4	227.0	0.8
Katikati Harbour Estuary Flat (7)	0.8	283.0	0.4
Katikati Harbour Estuary Flat (8)	0.3	231.2	1.9
Katikati Harbour Estuary Flat (9)	0.7	267.0	1.0
Katikati Harbour Estuary Flat (10)	0.4	205.1	1.1
Katikati Harbour Estuary Flat (11)	0.4	261.5	1.5
Katikati Harbour Estuary Flat (12)	1.7	244.7	0.9
Tauranga Harbour Estuary Flat (1)	4.4	344.5	0.6
Tauranga Harbour Estuary Flat (2)	0.3	274.3	1.2
Tauranga Harbour Estuary Flat (3)	2.1	300.5	1.4
Tauranga Harbour Estuary Flat (4)	5.8	237.0	0.9
Tauranga Harbour Estuary Flat (5)	1.9	294.4	0.8
Tauranga Harbour Estuary Flat (6)	3.8	797.5	0.4

Appendix Six:
Stratigraphy and Sediment Texture, Boreholes A1-A4

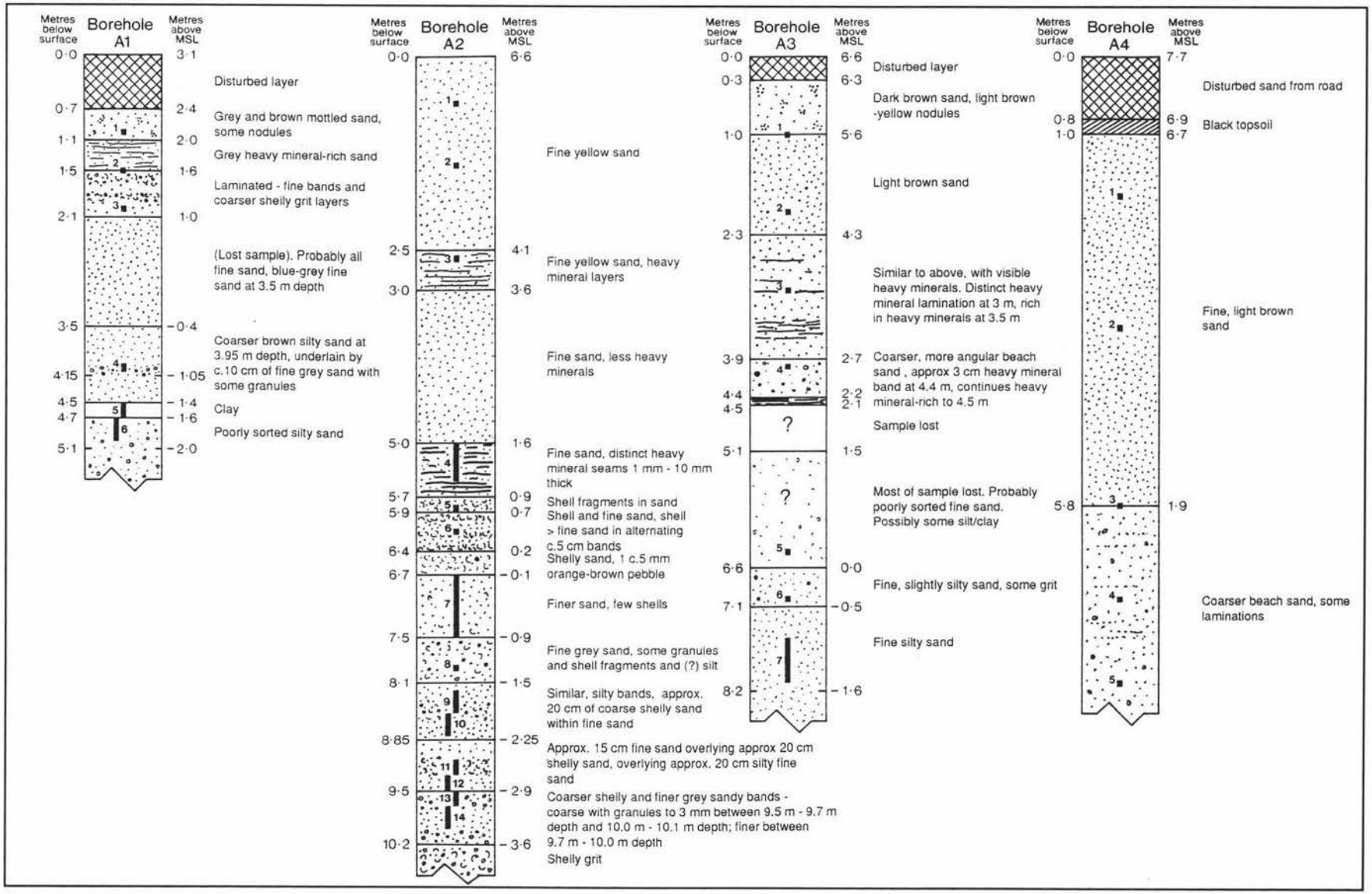


Figure A6.1: Stratigraphy and sample positions, Boreholes A1-A4.

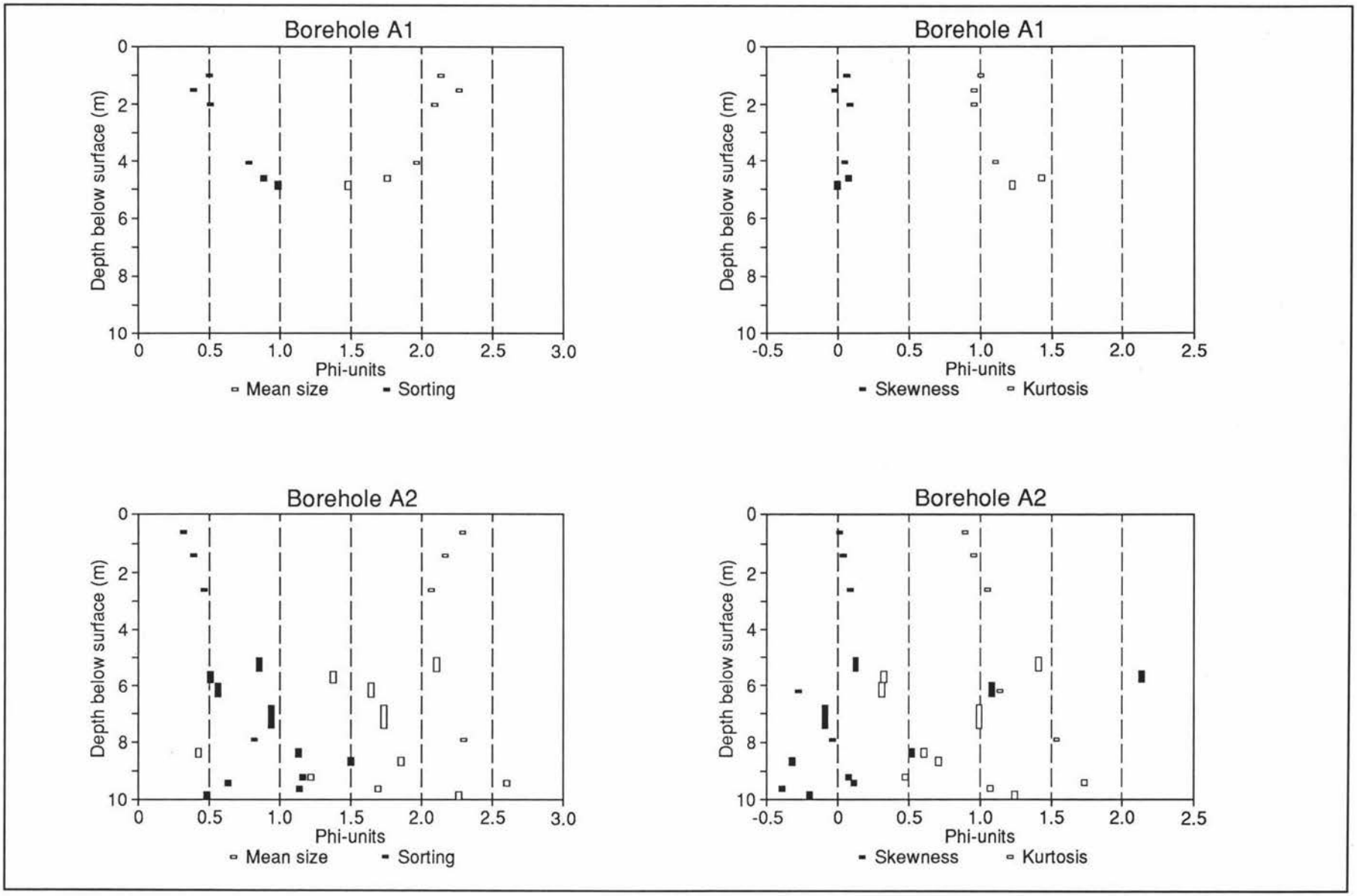


Figure A6.2: Textural parameters, Boreholes A1 and A2.

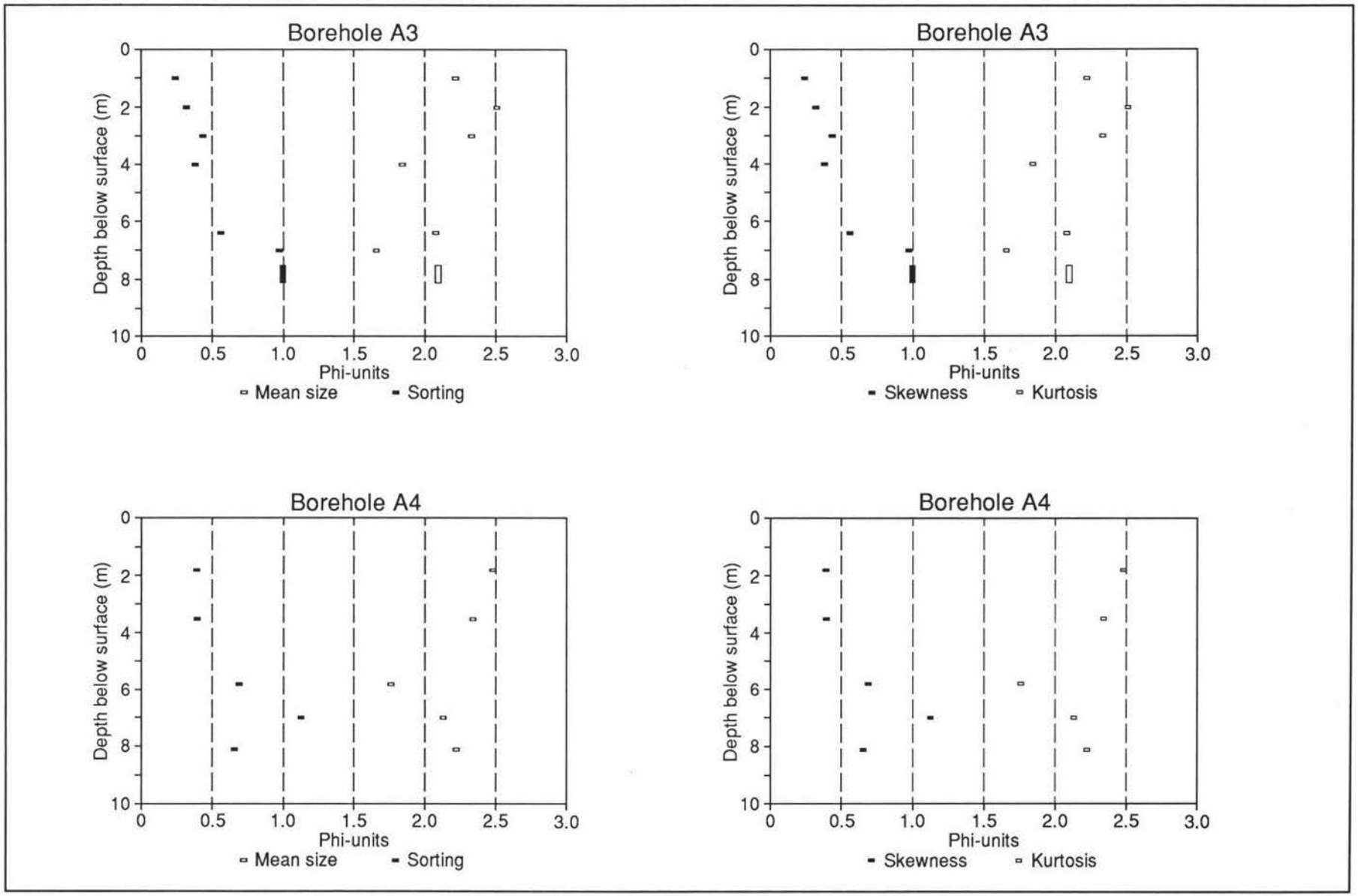


Figure A6.3: Textural parameters, Boreholes A3 and A4.

Appendix Seven: Mineralogical Data

Table A7.1: Total heavy mineral percentages

Sample ID	% Heavy Minerals	Sample Weight (g)	% Error
Transect 1 (1)	33.81	9.3813	0.03
Transect 1 (2)	19.09	9.9688	0.09
Transect 1 (3)	2.09	9.8091	0.13
Transect 1 (4)	1.43	9.8635	0.05
Transect 1 (5)	8.64	9.3310	0.03
Transect 1 (6)	5.12	9.4098	0.45
Transect 1 (7)	5.19	9.9555	0.07
Transect 2 (1)	35.79	9.5361	0.34
Transect 2 (2)	21.07	10.2067	0.06
Transect 2 (3)	6.38	10.2291	1.26
Transect 2 (4)	5.23	9.9275	0.02
Transect 2 (5)	3.24	10.9750	0.44
Transect 2 (6)	1.65	9.8860	0.14
Transect 2 (7)	12.37	9.5245	0.61
Transect 2 (8)	2.22	9.6084	0.77
Transect 3 (1)	21.02	9.9447	0.66
Transect 3 (2)	12.26	10.4729	0.76
Transect 3 (3)	11.51	8.0595	1.38
Transect 3 (4)	8.83	5.3985	0.13
Transect 3 (5)	9.10	6.1135	0.22
Transect 3 (6)	2.66	10.5362	0.19
Transect 4 (1)	8.30	9.2069	0.12
Transect 4 (2)	4.34	9.8198	0.01
Transect 4 (3)	7.53	9.5667	0.07
Transect 4 (4)	8.97	9.3982	0.14
Transect 4 (5)	5.84	9.3587	0.05
Transect 4 (6)	9.86	9.8108	0.04
S1	14.01	9.2182	0.03
S2	21.78	9.2767	0.00

Table A7.1 (continued)

Sample ID	% Heavy Minerals	Sample Weight (g)	% Error
1993 Ocean Beach (1)	0.49	9.7677	0.04
1993 Ocean Beach (2)	0.13	8.9754	0.31
1993 Ocean Beach (3)	0.16	11.8929	0.36
1993 Ocean Beach (4)	0.04	10.6201	0.37
1993 Ocean Beach (5)	0.20	9.8642	0.08
1993 Ocean Beach (6)	0.46	9.1861	0.37
1993 Ocean Beach (7)	6.82	8.5007	0.91
1993 Ocean Beach (8)	4.15	5.4423	1.06
Katikati Harbour Beach (1)	19.63	9.4594	0.28
Katikati Harbour Beach (2)	45.46	9.9076	0.21
Katikati Harbour Beach (3)	9.12	7.2460	0.48
Katikati Harbour Beach (4)	8.46	10.1682	0.32
Katikati Harbour Beach (5)	23.47	8.8908	0.18
Katikati Harbour Beach (6)	4.46	10.2674	0.32
Katikati Harbour Beach (7)	1.09	10.2326	0.22
Katikati Harbour Beach (8)	2.01	9.5127	0.72
Tauranga Harbour Beach (1)	2.77	8.4586	0.28
Tauranga Harbour Beach (2)	15.40	8.8888	0.35
Tauranga Harbour Beach (3)	8.17	8.6204	0.29
Tauranga Harbour Beach (4)	4.19	10.2491	0.34
Tauranga Harbour Beach (5)	3.06	8.8833	0.16
Tauranga Harbour Beach (6)	12.75	10.1276	0.18

Table A7.2: Heavy mineral composition

Sample ID	Grains Counted	% Hypersthene	% Augite	% Hornblende	% Opaques	% Rock Fragments	% Others
Transect 1 (1)	329	67.78	2.13	22.19	5.17	2.74	0.00
Transect 1 (2)	303	59.41	1.65	17.16	20.46	1.32	0.00
Transect 1 (3)	306	46.73	1.31	46.73	1.96	3.27	0.00
Transect 1 (4)	322	46.89	2.48	43.79	2.80	3.73	0.31
Transect 1 (5)	317	56.78	2.84	25.87	11.99	2.52	0.00
Transect 1 (6)	341	53.37	2.35	27.27	14.96	1.76	0.29
Transect 1 (7)	306	59.48	2.29	29.74	3.59	2.94	1.96
Transect 2 (1)	309	52.75	1.29	18.12	24.27	2.91	0.65
Transect 2 (2)	312	55.77	2.24	25.64	13.46	1.92	0.96
Transect 2 (3)	305	62.62	3.61	27.21	4.59	1.97	0.00
Transect 2 (4)	317	59.62	3.79	28.39	3.79	4.10	0.32
Transect 2 (5)	311	57.88	5.47	33.44	1.61	1.29	0.32
Transect 2 (6)	309	50.49	4.21	42.72	1.62	0.65	0.32
Transect 2 (7)	307	53.75	3.26	21.17	19.87	1.95	0.00
Transect 2 (8)	316	55.38	6.33	27.53	9.49	1.27	0.00
Transect 3 (1)	314	70.38	2.55	18.79	5.10	2.87	0.32
Transect 3 (2)	334	55.69	3.59	28.14	10.18	2.10	0.30
Transect 3 (3)	323	68.11	4.02	21.98	2.79	2.48	0.62
Transect 3 (4)	307	58.96	5.21	31.92	2.28	0.98	0.65
Transect 3 (5)	318	62.89	3.46	27.99	4.09	1.26	0.31
Transect 3 (6)	322	47.83	5.28	41.61	3.11	1.24	0.93

Table A7.2 (continued)

Sample ID	Grains Counted	% Hypersthene	% Augite	% Hornblende	% Opaques	% Rock Fragments	% Others
Transect 4 (1)	314	54.14	2.23	35.03	6.69	1.91	0.00
Transect 4 (2)	317	55.52	5.68	26.50	3.79	7.57	0.95
Transect 4 (3)	303	57.10	2.97	31.68	5.28	2.97	0.00
Transect 4 (4)	312	51.60	0.96	35.26	6.41	5.45	0.32
Transect 4 (5)	312	40.38	2.56	18.91	34.62	2.56	0.96
Transect 4 (6)	313	63.90	3.83	24.60	5.11	1.92	0.64
S1	328	53.05	0.91	26.83	13.41	5.49	0.30
S2	318	65.41	0.94	23.58	7.23	2.52	0.31
1993 Ocean Beach (1)	311	62.38	2.89	26.05	1.93	2.89	3.86
1993 Ocean Beach (2)	259	54.44	2.32	30.89	1.93	3.47	6.95
1993 Ocean Beach (3)	319	63.64	3.13	17.55	10.34	2.82	2.51
1993 Ocean Beach (4)	300	62.67	4.67	26.00	4.00	0.67	2.00
1993 Ocean Beach (5)	321	59.81	3.12	20.87	11.21	1.87	3.12
1993 Ocean Beach (6)	310	61.29	3.87	25.48	6.13	1.94	1.29
1993 Ocean Beach (7)	332	57.53	7.23	21.69	9.94	0.90	2.71
1993 Ocean Beach (8)	322	66.46	4.66	22.36	1.24	0.62	4.66
Katikati Harbour Beach (1)	314	71.66	0.32	17.52	5.10	0.96	4.46
Katikati Harbour Beach (2)	321	36.45	0.31	5.92	56.70	0.00	0.62
Katikati Harbour Beach (3)	319	72.41	2.51	15.05	3.45	0.63	5.96
Katikati Harbour Beach (4)	302	60.60	0.00	13.58	18.21	0.66	6.95
Katikati Harbour Beach (5)	312	78.85	0.64	8.65	7.05	0.64	4.17

Table A7.2 (continued)

Sample ID	Grains Counted	% Hypersthene	% Augite	% Hornblende	% Opaques	% Rock Fragments	% Others
Katikati Harbour Beach (6)	316	71.20	1.58	13.61	7.91	0.32	5.38
Katikati Harbour Beach (7)	307	52.12	0.33	7.17	37.13	0.65	2.61
Katikati Harbour Beach (8)	305	72.13	1.97	11.48	11.15	0.66	2.62
Tauranga Harbour Beach (1)	311	66.56	7.07	21.86	3.22	0.64	0.64
Tauranga Harbour Beach (2)	313	69.01	3.19	15.97	6.39	0.00	5.43
Tauranga Harbour Beach (3)	328	56.10	3.96	13.72	14.33	1.83	10.06
Tauranga Harbour Beach (4)	339	50.44	2.65	12.39	22.42	2.65	9.44
Tauranga Harbour Beach (5)	310	64.19	4.19	21.29	4.84	1.94	3.55
Tauranga Harbour Beach (6)	306	44.12	1.96	19.61	23.86	2.29	8.17

Table A7.3: Light mineral composition

Sample ID	Grains Counted	% Quartz	% Feldspar	% Glass	% Rock Fragments	% Shell Fragments	% Others	Quartz: Glass	Feldspar: Glass
Transect 1 (1)	303	71.62	22.77	0.99	4.62	0.00	0.00	72.33	23.00
Transect 1 (2)	307	66.78	20.85	2.28	10.10	0.00	0.00	29.29	9.14
Transect 1 (3)	309	64.72	22.33	2.59	10.36	0.00	0.00	25.00	8.63
Transect 1 (4)	312	52.24	26.28	3.53	17.95	0.00	0.00	14.82	7.45
Transect 1 (5)	306	68.63	16.99	3.59	10.46	0.00	0.33	19.09	4.73
Transect 1 (6)	314	68.79	18.79	2.87	8.92	0.00	0.64	24.00	6.56
Transect 1 (7)	304	62.17	24.67	3.29	8.88	0.33	0.66	18.90	7.50
Transect 2 (1)	302	65.23	24.50	0.99	8.94	0.00	0.33	65.67	24.67
Transect 2 (2)	308	63.31	22.40	1.62	12.66	0.00	0.00	39.00	13.80
Transect 2 (3)	337	65.58	22.26	0.59	11.57	0.00	0.00	110.50	37.50
Transect 2 (4)	332	66.27	23.19	2.11	7.83	0.00	0.60	31.43	11.00
Transect 2 (5)	318	60.06	25.47	2.83	11.32	0.00	0.31	21.22	9.00
Transect 2 (6)	318	32.08	15.41	29.56	22.96	0.00	0.00	1.09	0.52
Transect 2 (7)	322	55.28	29.19	3.73	11.80	0.00	0.00	14.83	7.83
Transect 2 (8)	304	56.25	24.34	6.58	11.51	1.32	0.00	8.55	3.70
Transect 3 (1)	302	60.93	32.78	1.32	4.97	0.00	0.00	46.00	24.75
Transect 3 (2)	303	58.09	25.08	4.95	11.88	0.00	0.00	11.73	5.07
Transect 3 (3)	300	52.33	29.33	4.33	14.00	0.00	0.00	12.08	6.77
Transect 3 (4)	308	53.25	29.55	4.22	12.99	0.00	0.00	12.62	7.00
Transect 3 (5)	315	59.68	27.94	3.17	8.89	0.32	0.00	18.80	8.80
Transect 3 (6)	320	55.31	21.25	5.63	16.56	1.25	0.00	9.83	3.78

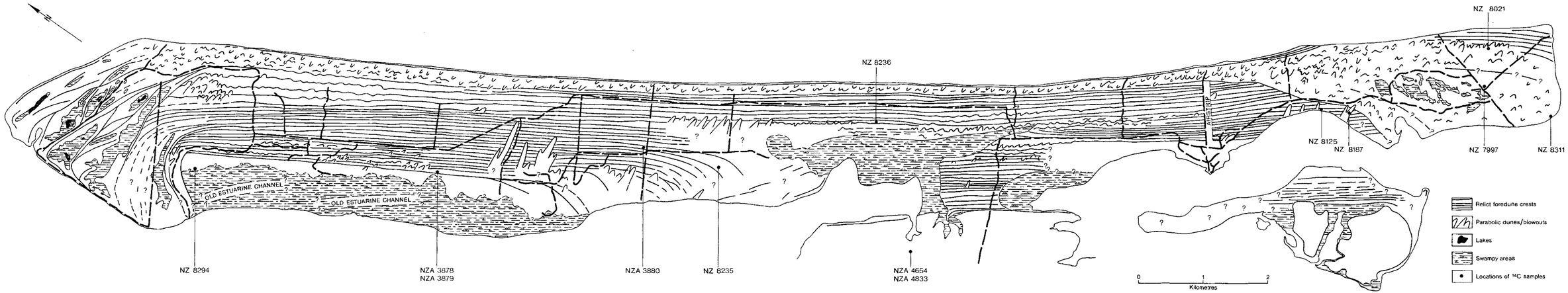
Table A7.3 (continued)

Sample ID	Grains Counted	% Quartz	% Feldspar	% Glass	% Rock Fragments	% Shell Fragments	% Others	Quartz: Glass	Feldspar: Glass
Transect 4 (1)	306	67.32	24.84	1.63	6.21	0.00	0.00	41.20	15.20
Transect 4 (2)	315	65.71	22.54	2.54	8.89	0.00	0.32	25.88	8.88
Transect 4 (3)	308	62.99	26.95	1.95	8.12	0.00	0.00	32.33	13.83
Transect 4 (4)	310	59.03	26.77	3.87	10.32	0.00	0.00	15.25	6.92
Transect 4 (5)	325	60.62	25.23	4.92	9.23	0.00	0.00	12.31	5.12
Transect 4 (6)	303	71.29	22.44	0.99	3.96	1.32	0.00	72.00	22.67
S1	308	57.47	25.65	3.25	13.64	0.00	0.00	17.70	7.90
S2	311	64.31	25.40	1.29	9.00	0.00	0.00	50.00	19.75
1993 Ocean Beach (1)	301	31.23	25.25	31.56	7.31	3.65	1.00	0.99	0.80
1993 Ocean Beach (2)	314	33.76	33.76	12.74	17.20	2.23	0.32	2.65	2.65
1993 Ocean Beach (3)	305	12.13	18.03	55.41	11.80	2.30	0.33	0.22	0.33
1993 Ocean Beach (4)	319	13.79	19.12	40.75	22.57	3.13	0.63	0.34	0.47
1993 Ocean Beach (5)	313	11.50	19.49	50.48	15.97	2.24	0.32	0.23	0.39
1993 Ocean Beach (6)	322	30.75	29.19	15.53	22.05	1.86	0.62	1.98	1.88
1993 Ocean Beach (7)	347	38.33	44.67	2.88	13.26	0.29	0.58	13.30	15.50
1993 Ocean Beach (8)	333	37.24	44.14	3.30	12.31	2.10	0.90	11.27	13.36
Katikati Harbour Beach (1)	309	46.28	43.04	0.32	10.36	0.00	0.00	143.00	133.00
Katikati Harbour Beach (2)	303	46.86	39.27	5.94	7.26	0.00	0.66	7.89	6.61
Katikati Harbour Beach (3)	314	49.36	43.95	0.64	6.05	0.00	0.00	77.50	69.00
Katikati Harbour Beach (4)	307	56.03	30.29	5.86	7.17	0.65	0.00	9.56	5.17
Katikati Harbour Beach (5)	305	55.74	29.51	5.90	7.87	0.00	0.98	9.44	5.00

Table A7.3 (continued)

Sample ID	Grains Counted	% Quartz	% Feldspar	% Glass	% Rock Fragments	% Shell Fragments	% Others	Quartz: Glass	Feldspar: Glass
Katikati Harbour Beach (6)	312	53.85	33.01	5.77	7.05	0.00	0.32	9.33	5.72
Katikati Harbour Beach (7)	326	45.71	19.63	21.47	12.88	0.00	0.31	2.13	0.91
Katikati Harbour Beach (8)	309	54.69	32.36	5.18	7.77	0.00	0.00	10.56	6.25
Tauranga Harbour Beach (1)	300	35.33	40.33	11.67	12.67	0.00	0.00	3.03	3.46
Tauranga Harbour Beach (2)	312	39.74	46.15	1.92	11.54	0.64	0.00	20.67	24.00
Tauranga Harbour Beach (3)	319	46.71	42.63	2.82	7.84	0.00	0.00	16.56	15.11
Tauranga Harbour Beach (4)	317	39.12	35.65	17.03	8.20	0.00	0.00	2.30	2.09
Tauranga Harbour Beach (5)	302	45.70	35.10	5.96	13.25	0.00	0.00	7.67	5.89
Tauranga Harbour Beach (6)	305	51.15	37.38	5.25	5.90	0.00	0.33	9.75	7.13

Map 1: Geomorphology of the Matakana Island barrier



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