# 4. Rates of barrier progradation

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

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

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

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

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

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

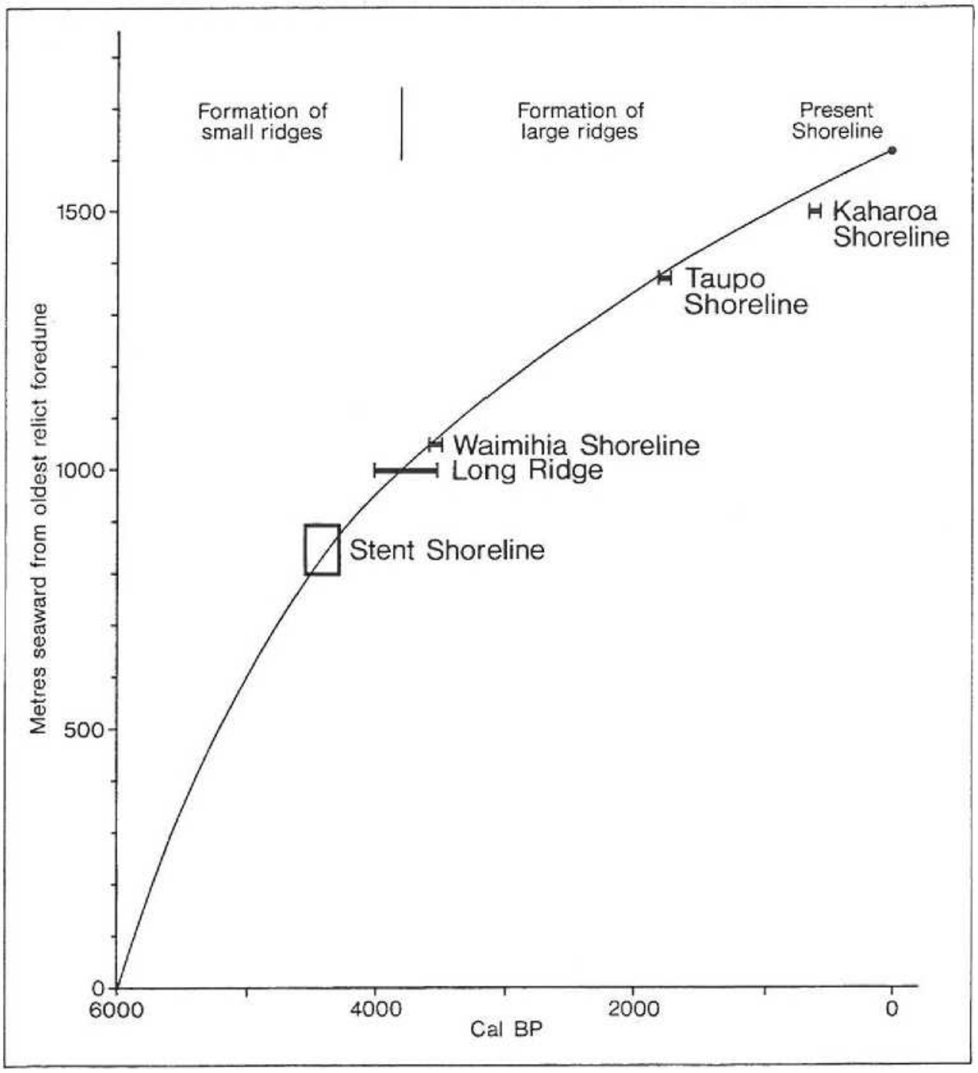


FIGURE 29. RATES OF PROGRADATION FOR MATAKANA BARRIER BASED ON DATED SHORELINE POSITIONS. UNCERTAINTY OF AGES AND POSITIONS SHOWN BY ERROR BARS.

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

# 5. Structure and origin of Matakana Barrier

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

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

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

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

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

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

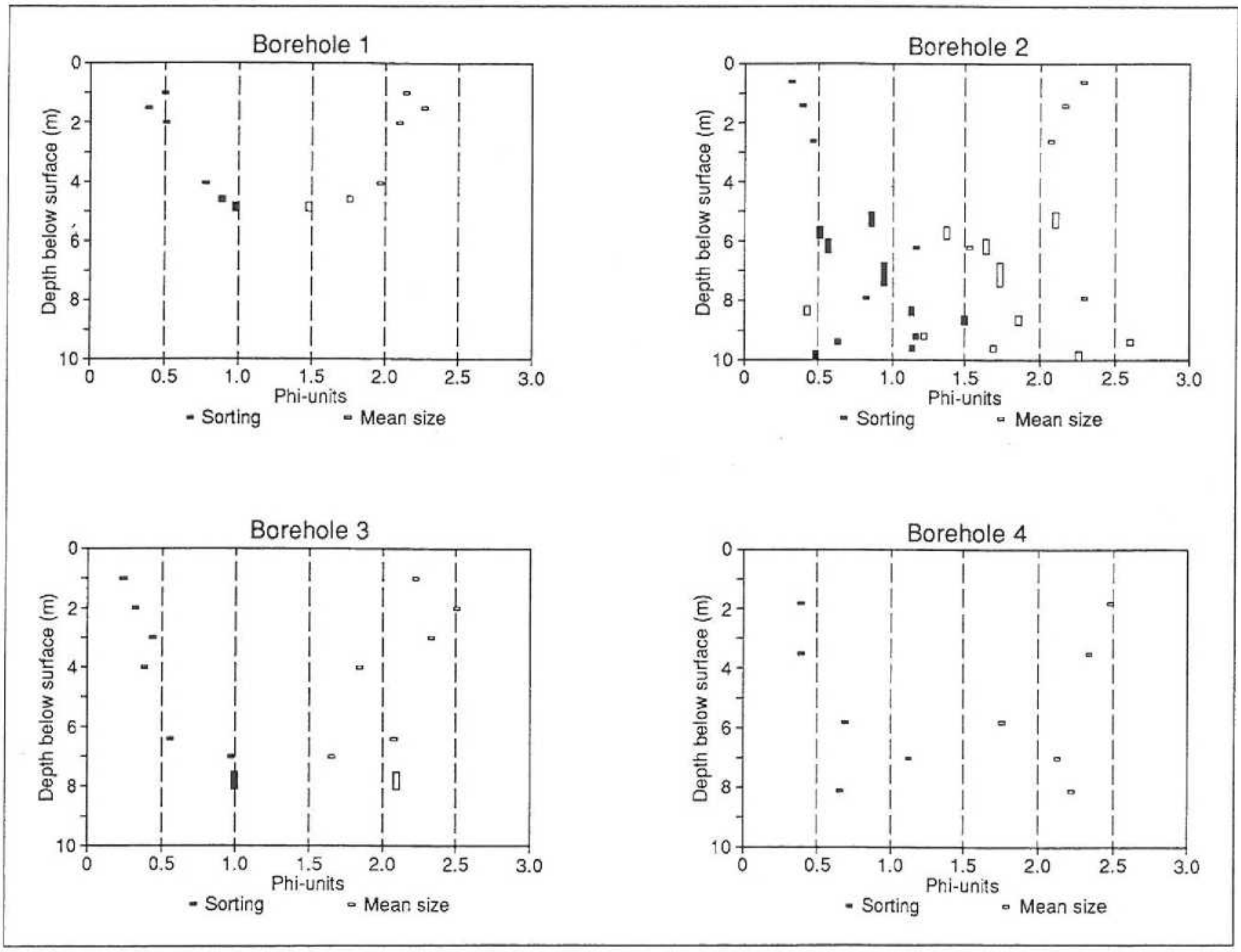


FIGURE 30. MEAN SIZE AND SOR'T'ING OF SAND SAMPLES FROM BOREHOLES I-IV (FIG. 8). VERTICAL BAR LENGTHS INDICATE DEPTHS OVER WHICH SAMPLES WERE COLLECTED.

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

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

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

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

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

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

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

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

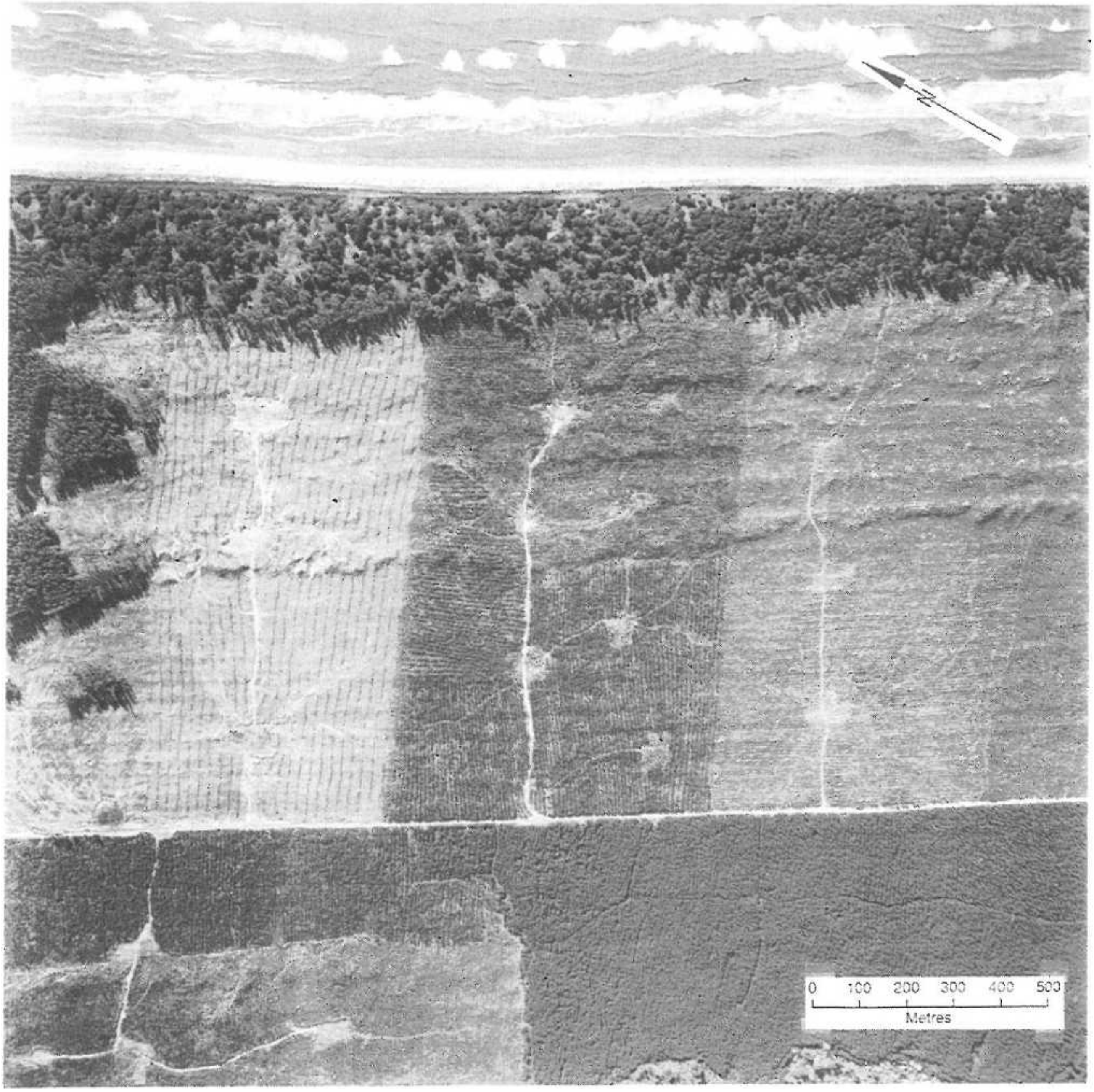


FIGURE 31. VERTICAL AERIAL PHOTOGRAPH OF THE BARRIER *c.* 3km SOUTH-SOUTHEAST OF WAIKOURA POINT, SHOWING THE ABRUPT CHANGE SEAWARD TO LARGER, LESS REGULAR RELICT FOREDUNES. PHOTOGRAPH COURTESY OF P.F. OLSEN AND CO. LTD.

## 5.1 TRANSGRESSIVE DUNES

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

## 5.2 GROWTH OF THE BARRIER ENDS

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

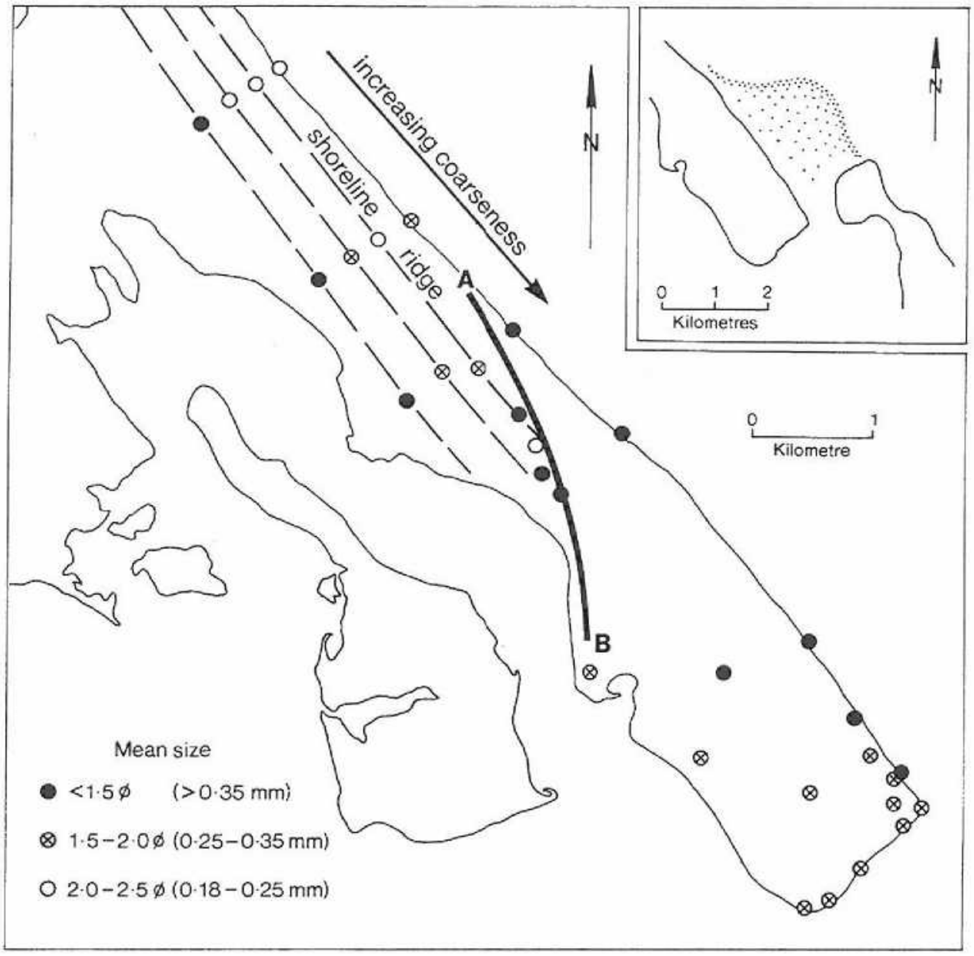


FIGURE 32. MAP OF SOUTHEASTERN MATAKANA BARRIER SHOWING THE COARSENING OF BEACH SEDIMENT TOWARDS THE TAURANGA HARBOUR ENTRANCE. THE INSET SHOWS THE LOCATION OF THE PRESENT EBB-TIDAL DELTA ADJACENT TO THE TAURANGA ENTRANCE.

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

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

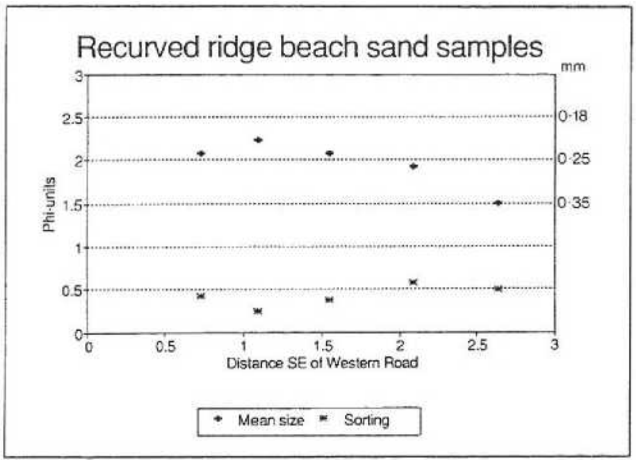


FIGURE 33. MEAN SIZE AND SORTING OF BEACH SAND BENEATH A RECURVED RIDGE ADJACENT TO BLUE GUM BAY. MEAN SIZE SHOWN IN PHI UNITS AND MILLIMETRES. SORTING SHOWN IN PHI UNITS ONLY. SAMPLED POINTS SHOWN IN APPENDIX 2. FOR LOCATION OF WESTERN ROAD SEE APPENDIX 7.

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

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

## 5.3 BLUE GUM BAY HARBOUR ENTRANCE

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

# 6. Palaeoenvironment and human settlement

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

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

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

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

TABLE G. IDENTIFICATIONS* OF CHARCOAL FROM SOILS.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

# 7. Conclusions

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

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

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

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

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

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

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

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

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

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

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

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

# 8. Acknowledgements

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

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

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

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

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

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

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

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

# 9. References


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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

**Maps consulted**

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

NZMS 260 Sheet U13 1st Edition 1979.

NZMS 260 Sheet U14 1st Edition 1980.

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

# Appendix 1

## VEGETATION OF MATAKANA ISLAND

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

### Dunes

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

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

### The harbour shoreline

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

## Wetlands

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

## References


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

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

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

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

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

# Appendix 2

## SEDIMENTARY TECHNIQUES

### Sampling

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

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

### Size analysis

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

Sediment size is expessed as phi units (ø), where ø = -log2 (grain diameter in mm).

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

1. *GRAPHIC MEAN*

$$M_Z = \frac{\text{Ø}_{16} + \text{Ø}_{50} + \text{Ø}_{84}}{3}$$

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