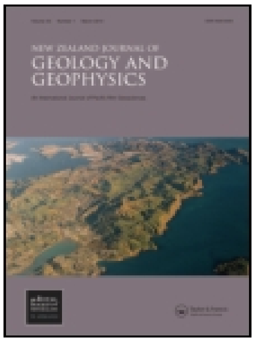

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Abstract New Zealand's largest barrier island, Matakana Island, consists of an elongate coastal sand barrier of Holocene age that encloses Tauranga Harbour and adjoins an area of Pleistocene terraces and terrace remnants. The lowest Pleistocene terrace is well preserved, with a degraded marine cliff, vestiges of shore-parallel relict foredunes, and a parabolic dune. These hitherto unrecognised coastal landforms are analogous to those of the Holocene barrier and indicate that a prograded coastal plain underlies the terrace. The original landforms of the coastal plain are now mainly below sea level but survived the postglacial marine transgression because at least 12 m of tephra accumulated on the surface, preserving the topography, albeit in a subdued form. In a separate area of the island, the present morphology may reflect the former presence of large parabolic dunes of Pleistocene age. Morphological evidence indicates that coastal processes shaped the island during both Pleistocene and Holocene times, and that the Holocene barrier is welded to a Pleistocene "proto-barrier".

Keywords Matakana Island; Pleistocene; terraces; relict foredunes; parabolic dunes; dunes; sea level; Tauranga Basin; barrier island

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INTRODUCTION

Matakana Island forms a barrier between the Bay of Plenty and Tauranga Harbour, which it encloses (Fig. 1). Barrier islands are rare in New Zealand, but Matakana Island is of particular interest because it is not only the largest but also the only one with a history extending back into Pleistocene time, comparable with some of the barrier islands in the eastern United States (e.g., Hayes 1994). The island consists of two distinct parts. The larger, seaward part, comprises a Holocene sand barrier, which extends parallel to the oceanic shoreline for a distance of 24 km. Its landforms consist primarily of shore-parallel relict foredunes, together with some transgressive dunes and extensive backbarrier deposits. The harbourward part, which adjoins the centre of the Holocene barrier, consists of Pleistocene terraces overlain by a mantle of tephra and other cover deposits. Detailed geomorphological and paleoenvironmental studies have been restricted to the Holocene part of the island (Munro 1994; Betts 1996; Shepherd et al. 1997; Giles et al. 1999). This paper aims to identify and describe some previously unrecognised coastal landforms on the Pleistocene part of the island, and to demonstrate that the Holocene barrier is welded on to a Pleistocene barrier remnant.

GEOLOGICAL SETTING

Matakana Island and Tauranga Harbour lie within the Tauranga Basin, which is a downwarped depression of Pliocene–Pleistocene (Whitbread-Edwards 1994) or Pleistocene (Shaw & Healy 1962; Houghton & Cuthbertson 1989) age. The Tauranga Basin is considered to be either tectonically stable (Selby et al. 1971; Wigley 1990) or subsiding (Schofield 1968; Cole 1978).

Up to 500 m of Pleistocene deposits accumulated within the Tauranga Basin. These were originally grouped as the Tauranga Beds by Henderson & Bartrum (1913). Subsequent studies, summarised by Briggs et al. (1996), refined the stratigraphic relationships and age of these deposits. The upper beds consist of mid–late Quaternary tephra and nonwelded ignimbrite (Selby et al. 1971; Pullar & Birrell 1973; Harmsworth 1983; Hogg & McCraw 1983; Briggs et al. 1996), overlying and interbedded with fluviatile (Healy et al. 1964), fluviatile-estuarine (Davies-Colley 1976), lacustrine (Hollis 1995), loessic (Macky 1997), and postulated marine/eolian deposits (see below).

During Pleistocene interglacials, the Tauranga Basin formed a sink for fluvial, estuarine, and marine sediments, but during the glacials these beds were dissected by streams that flowed in valleys that extended below present sea level. The rising seas of the postglacial marine transgression drowned the lower parts of the valleys to form Tauranga/Katikati Harbour (Healy et al. 1964; Davies-Colley 1976; Dahm 1983). Some of the higher interfluves remained above

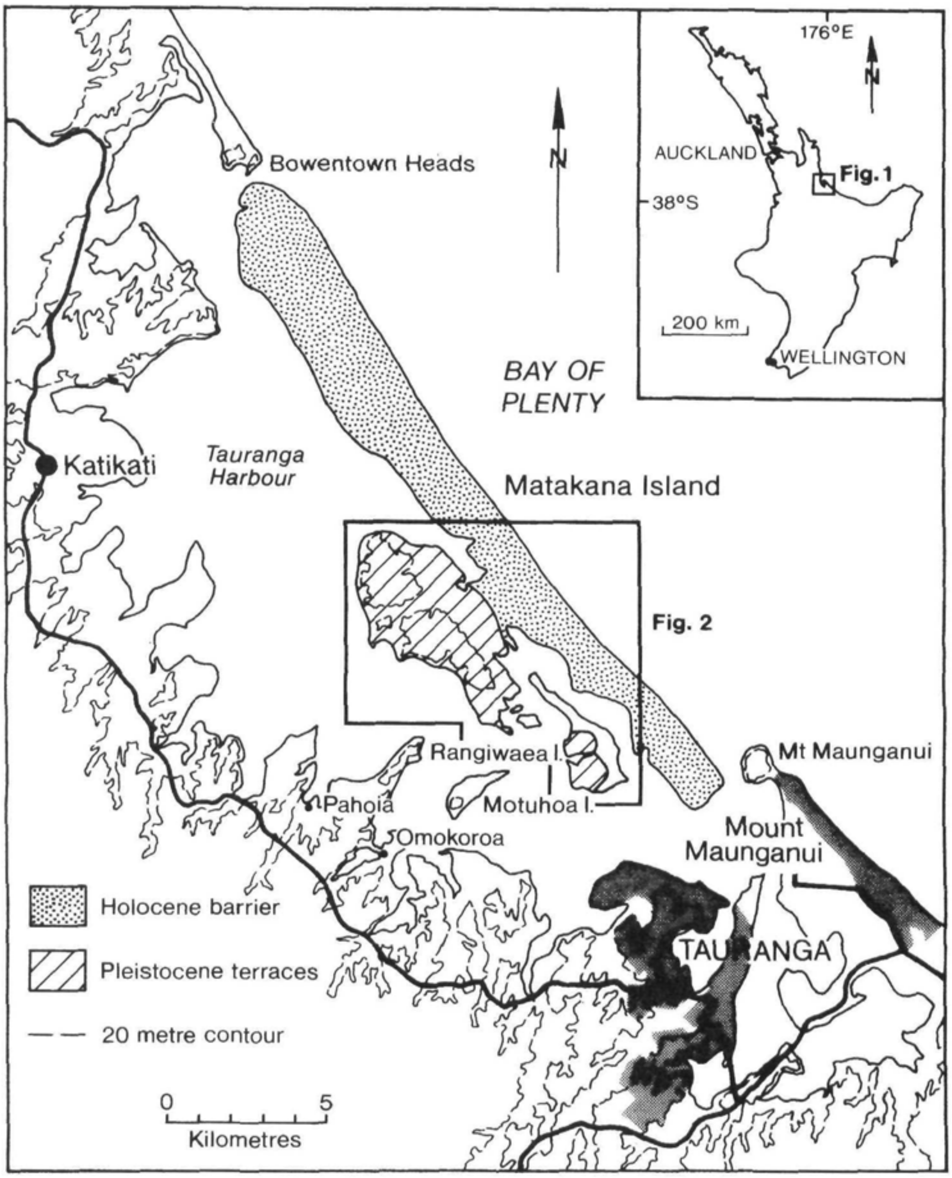

Fig. 1 The location of Matakana Island and its subdivision into a Holocene barrier and an area of Pleistocene terraces.

sea level, forming the Pleistocene parts of present-day Matakana and Rangiwaea Islands, together with the headlands which project into the harbour from the mainland (Healy & de Lange 1988).

No full description of Matakana Island's Pleistocene stratigraphy has been published, but Hollis (1995) and Briggs et al. (1996) described some sections which included lacustrine and lignite deposits of the Matua Subgroup (<2.18–>0.35 Ma), Te Puna Ignimbrite (>0.78 Ma), and Pahoia Tephra (<2.18–>0.35 Ma). A small, isolated outcrop of basalt that occurs near Flax Point (Fig. 2), known locally as Ratahi Rock, is the only known outcrop of older volcanic rock on the island (Henderson & Bartrum 1913; Briggs et al. 1996).

The origin and age of Pleistocene terraces in the Tauranga Basin are far from clear. Harmsworth (1983) suggested four possible modes of origin, only one of which was marine, whereas Hall (1994) highlighted the uncertainty surrounding much of the evidence. Chappell (1975) referred to terraces of coastal origin in the Waihi area near Matakana Island and attempted to correlate them with the New Guinea sea-level curve to obtain their approximate ages.

PLEISTOCENE LANDFORMS

Terraces

The Pleistocene part of Matakana Island consists mainly of tephra-covered terraces which are dissected to various degrees. The lowest terrace, which is largely undissected, is 1.0–1.5 km wide and extends for 6.5 km along the seaward side (Fig. 2). Its inner margin is delineated by a riser separating it from a more elevated area of older, more dissected Pleistocene terraces to the southwest (Fig. 2, 3). Its seaward margin was eroded at or near the end of the postglacial marine transgression to form a linear sea cliff (Fig. 2) from which part of the Holocene barrier subsequently developed.

The older terraces, with undissected remnants at c. 40 and c. 70 m above sea level, comprise the remainder of the

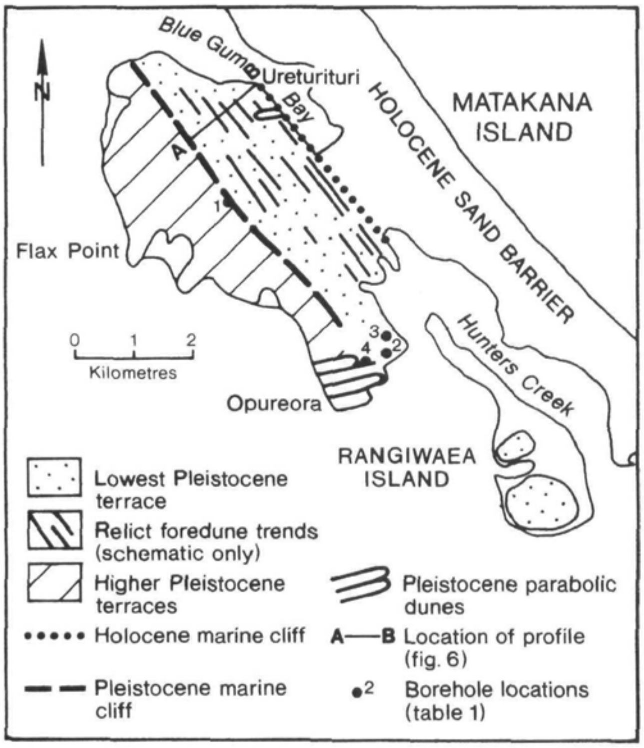

Fig. 2 The main geomorphological features of the Pleistocene part of Matakana Island and location of boreholes.

Pleistocene part of the island. Many terraces in the Tauranga district developed upon pyroclastic flow deposits or fluvial surfaces (Harmsworth 1983), so their height is unrelated to sea level. If the older terraces on Matakana Island overlie coastal deposits, their higher altitude may be attributed primarily to the thickness of their coverbeds, which increases with age, rather than to tectonic uplift as in many other parts of New Zealand. Coastal cliff exposures and well logs indicate that the older Matakana Island terraces are mantled with coverbeds at least 35 m in thickness (Fig. 4), which consist mainly of tephra fall deposits and pyroclastic flow deposits, commonly overlying a bed of fine lacustrine sediment.

Relict foredune plain

Although the beds underlying the tephra cover of the lowest Pleistocene terrace have not previously been identified as marine/eolian in origin, and are mapped by Hollis (1995) as lacustrine sediments, the area occupied by the lowest terrace appears to have originated primarily as a prograded coastal plain with relict foredune topography (Hesp 1984), analogous to the Holocene plain which comprises the greater part of the barrier to seaward.

Evidence for a Pleistocene relict foredune plain

1. The riser at the rear of the terrace is a linear feature (Fig. 2, 3) aligned parallel to the Holocene marine cliff, to the relict foredunes of the Holocene barrier, and to the present ocean shoreline. Its morphology and orientation suggest that it originated as a marine cliff.
2. Although the surface of the terrace is relatively flat, oblique aerial photographs clearly indicate the presence of subdued ridges also trending parallel to the present coastline (Fig. 2, 5). A profile (Fig. 6) levelled across the terrace, from the shoreline at Blue Gum Bay to the riser to the southwest, indicates that only the two innermost ridges exceed 1 m in amplitude (cf. amplitudes of c. 1–9 m for the Holocene relict foredunes). The surface is generally 9–11 m above mean sea level but rises to c. 16 m near its inner margin. Colluvium from the adjacent riser covers the innermost margin of the plain.

The ridges on the lowest Pleistocene terrace have an average spacing of c. 80 m. On the adjacent Holocene barrier, the spacing is mainly c. 30–40 m, with the largest relict foredunes c. 100 m apart. However, the observed spacing of the Pleistocene ridges may not reflect their initial spacing. In Australia and eastern United States,

Fig. 3 Oblique aerial photograph showing the lowest Pleistocene terrace and riser. View to the northwest with older Pleistocene terraces to the left.

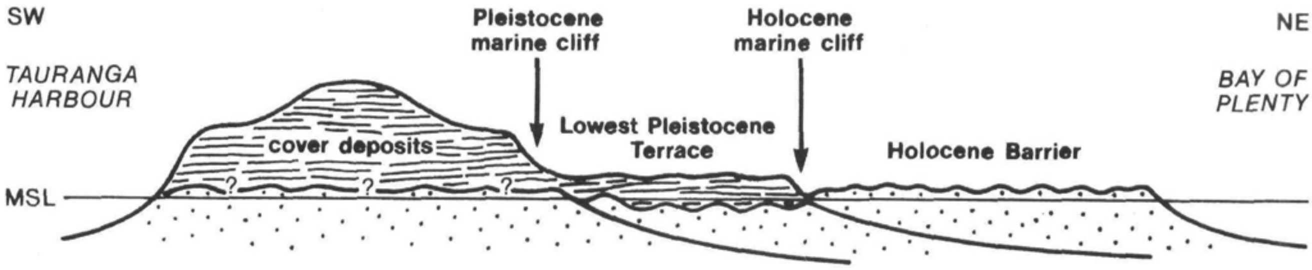

Fig. 4 Schematic stratigraphic section across Matakana Island showing the relationship between the thickness of the coverbeds and terrace elevation.

Fig. 5 Oblique aerial photograph showing the presence of low, shore-parallel, relict foredune ridges on the lowest Pleistocene terrace. View eastwards towards Blue Gum Bay and the Holocene barrier (top left). Note the developing rectangular drainage pattern. The levelled section in Fig. 6 extends from Blue Gum Bay (centre of left boundary) to Tirohanga Road and relict marine cliff (centre of lower boundary).

degradational processes caused many Pleistocene relict foredune ridges to coalesce, resulting in ridge spacing which has increased through time (Thom 1965, 1970, 1975; Thom et al. 1992). However, at Matakana Island, any smaller Pleistocene foredunes present may have been obscured by the overlying tephra (see below).

It may seem surprising that any vestiges of the original relict foredune topography survived the accumulation of coverbeds, but the largest relict foredunes on the adjacent Holocene barrier are prominent topographic features with amplitudes of up to c. 9 m.

3. Elements of a rectangular drainage pattern, with the course of some stream sections apparently controlled by the orientation of former swales, are developing on parts of the terrace (Fig. 5). Similar drainage patterns are evolving on Pleistocene coastal plains in Australia and eastern United States (Thom 1970, 1975).
4. Borehole data (see below) from the margins of the plain indicate that sandy deposits and marine clay containing shells underlie the coverbeds.
5. Since the postglacial marine transgression, the coast in the vicinity of Matakana Island was a major sink for

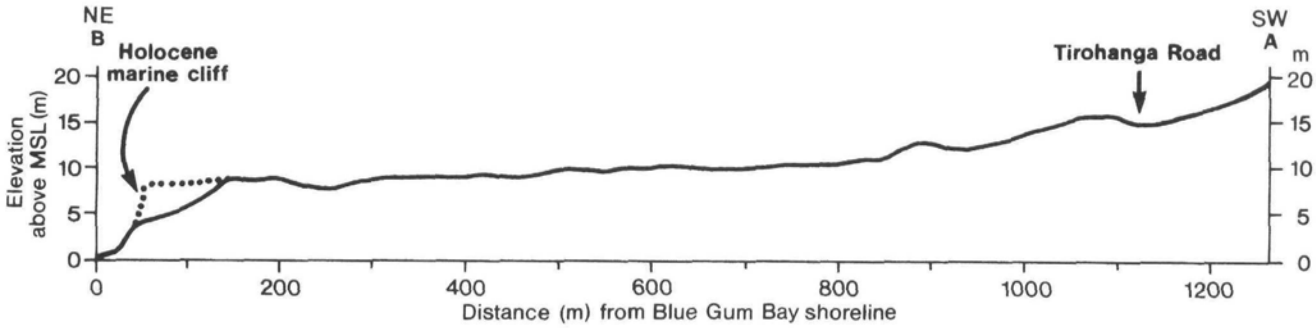

Fig. 6 Levelled section across the lowest Pleistocene terrace. For location of profile refer to A–B on Fig. 2.

sediment transported onshore and alongshore (Shepherd et al. 1997). Wave approach direction, sediment supply, and boundary conditions were likely to have been similar during late Pleistocene interglacials.

6. Pleistocene coastal barrier systems are present elsewhere in New Zealand, although they have been little studied. Healy & Kirk (1992) mentioned Pleistocene barriers along the east coast of the Coromandel Peninsula to the northwest of Matakana Island, while others are present in Northland (Hicks 1975, 1983) and south of Westport.

A relict foredune plain preserved by its coverbeds

Although the surface of the lowest Pleistocene terrace is above sea level, the surface of the underlying relict foredunes is likely to be mainly below present sea level. In cliff sections at the northwestern end of the plain (grid ref. U14/802987*), only tephra fall and possibly lacustrine deposits are exposed above sea level, and the original surface of the coastal plain, if present, is not visible. Auger holes immediately offshore from the eroded southeastern end of the plain (U14/828747) indicated that the coverbeds extend to at least 1 m below mean sea level. Logs from several water wells (wells 1, 2 and 3; Table 1) located near the margins of the lowest Pleistocene terrace were insufficiently detailed to be of major stratigraphic value, but indicated a thickness of 12–20 m of coverbed material overlying sandy strata which may represent the original surface of the coastal plain. However, no well or exposure was located where foredune ridge topography is clearly evident at the surface.

As the elevation of the lowest Pleistocene terrace is mainly 9–11 m above mean sea level (Fig. 6), the surface of the underlying relict foredune plain is likely to be at least 1–4 m below sea level, possibly owing to slow tectonic downwarping. It can be concluded that, apart from its innermost margin, the plain would now be below sea level, and probably destroyed by wave action, were it not for the coverbeds which accumulated on the original surface.

Age of the Pleistocene relict foredune plain

The age of the Pleistocene relict foredune plain is uncertain. Its maximum age is c. 780 000 yr because, in contrast to the higher terraces on the island, Te Puna Ignimbrite is absent from the coverbeds. The maps of Hollis (1995) and Briggs et al. (1996) show the lowest Pleistocene terrace surface to be overlain by lacustrine beds of the Matua Subgroup, with a minimum age of c. 220 000 yr, but no descriptions of the coverbeds in the vicinity of the lowest Pleistocene terrace have been published. It is difficult to envisage how the ridge/swale morphology of the plain could have survived the deposition of several metres of lacustrine deposits as mapped by Hollis (1995). A tephra fallout origin for the coverbeds overlying the relict foredune plain would seem necessary in order for the ridge/swale pattern to have been preserved at the surface.

As there is no significant uplift in the area (Pillans 1986, 1990), the coastal plain beneath the terrace surface is likely to have developed during an interglacial period. A relatively young age for the terrace is supported by: (1) its lack of dissection by streams; (2) its position as the seawardmost Pleistocene terrace, located adjacent to the Holocene barrier; and (3) the preservation of vestiges of its original topography. In South Taranaki, which has similar annual rainfall, <60% of the Penultimate Interglacial terrace surface remains undissected while <40% of the 400 000 yr old terrace surface has survived (Pillans 1988, fig. 2A). This contrasts sharply with the surface of the lowest Pleistocene terrace at Matakana Island which is >90% intact.

These characteristics suggest that the terrace may be analogous to the prograded late Pleistocene barriers of eastern Australia. Limited thermoluminescence dating indicates that most of those barriers, which lack coverbeds, are of Last Interglacial age (oxygen isotope stage 5e), with some of Penultimate Interglacial age (stage 7) and one which formed during stages 5a–c with sea level 3–5 m below present (Bryant et al. 1997; Roy et al. 1997). In spite of degradational processes, the relict foredunes, even on the older barriers, retain some subdued surface topography, which is most clearly seen on aerial photographs as a shore-parallel ridge/swale pattern (Melville 1984; Thom et al. 1992; Bryant et al. 1997).

Pleistocene parabolic dunes

The landforms of the Holocene barrier on Matakana Island consist not only of relict foredunes but also of parabolic dunes, the largest of which were initiated at the harbour shoreline and, under the influence of the dominant westerly winds, migrated eastwards towards the ocean shore (Shepherd et al. 1997). The morphology of some landforms on the Pleistocene part of the island suggests that similar dunes may have been active during Pleistocene time.

A series of parallel ridges and valleys, partially truncated at the harbour shoreline, occur to the south of the Pleistocene relict foredune plain near the settlement of Opureora (Fig. 7). Several of the ridges converge to form features resembling

*Grid references refer to the 1:50 000 topographic map series NZMS 260.

Table 1 Well head elevations, approximate thicknesses of cover deposits, and approximate elevation of underlying sand surfaces for the wells located in Fig. 2. Source: S. Halliday, Bay of Plenty Regional Council and M. Carlyle, well driller, pers. comms. (1995).

Well ID No. on Fig 2 (Environment BOP No.)	NZMS 260 grid reference	Elevation above mean sea level (m)*	Thickness of cover deposits (m)	Elevation (m.s.l.) of underlying sand surface (m)
1 (1053)	U14/798968	15.1	12.2	2.9
2	U14/824942	11.0	12.0	c. −1.0
3	U14/824946	8.5	20.0	c. −11.5
4 (2407)	U14/819940	12.4	13.0	−0.6

*Elevations for the well heads were obtained with a Trimble Pro-XL GPS system.

Fig. 7 Oblique aerial photograph of ridges near Opureora, which probably originated as Pleistocene parabolic dunes aligned parallel to the dominant sand-moving wind direction.

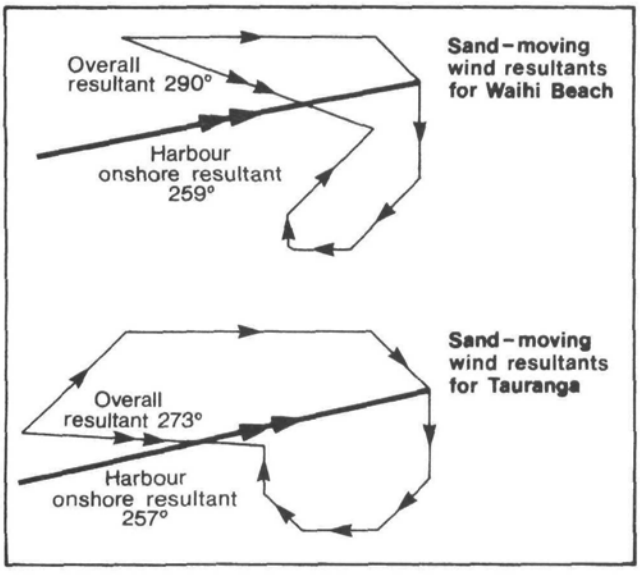

Fig. 8 Diagram showing sand-moving wind vectors and resultants for Tauranga and Waihi Beach (after Healy et al. 1977). Added to the diagrams are resultants (accentuated) for onshore winds affecting harbour shorelines of Matakana Island (from Shepherd et al. 1997).

eastward-migrating parabolic dunes, with a depositional lobe, trailing arms, and central deflation basin. Other ridges have a less-distinct parabolic dune form but have the same alignment. The ridges are up to 1 km in length and similar in size and orientation to the largest Holocene parabolic dunes. Depressions between the ridges were partially drowned during the postglacial transgression to form salt marshes and tidal inlets. The embayment which bisects the Pleistocene part of Rangiwaea Island (Fig. 2) has a similar orientation.

The orientation of the postulated dune ridges at Opureora and the elongate inlet at Rangiwaea Island is 261°, which is almost identical to the orientation (av. 259°) of the large parabolic dunes on the Holocene barrier and to the sand-moving wind resultants of 259° and 257° at Opureora calculated from Waihi Beach and Tauranga wind data, respectively (Healy et al. 1977), using onshore wind vectors only (Jennings 1957) (Fig. 8). Whereas the orientation of the ridges is consistent with a dune origin, indicating that wind directions were similar to present during late Pleistocene time, it contrasts with the northeast–southwest orientation of the peninsulas and stream valleys of the adjacent mainland, which may be related to faulting in the underlying basement (Briggs et al. 1996).

Because of the thickness of the coverbeds, Pleistocene dune sand was not observed in any exposure, and, if present, may be below sea level. However, log data from a water well (No. 4 in Table 1) located on one of the ridges indicates that fine sand underlies c. 13 m of "clay" (presumably fine or weathered tephra). If the ridges and valleys originated as dunes, the drainage pattern would have been determined by the initial topography, which in turn would have been modified by subsequent fluvial and slope processes and by coverbed accumulation.

A smaller postulated relict parabolic dune, with an alignment of 72°, occurs near Urituritur (Fig. 2) at the outer margin of the postulated Pleistocene relict foredune plain. It is mantled with Pleistocene tephra and truncated by the Holocene marine cliff at the outer margin of the terrace (Fig. 9). The dune appears to have migrated inland from a former ocean beach, in the same manner as the small parabolic dunes, with an average orientation of 82°, adjacent to the present ocean beach of the Holocene barrier.

CONCLUSION

Only the Holocene part of Matakana Island has previously been recognised as coastal in origin. The morphological evidence presented above indicates that a relict foredune plain, now mainly below sea level, underlies the lowest

Fig. 9 Pleistocene parabolic dune (centre of photo) which migrated inland from a former ocean shoreline. The trailing arms are now truncated by the Holocene marine cliff, adjacent to Blue Gum Bay south of Uretuituri (see Fig. 2). View to the northwest.

Pleistocene terrace on Matakana Island. Coverbeds elevated the surface of the plain and enabled the original coastal landforms to be preserved as a palimpsest (Bloom 1967). The vestiges of shore-parallel relict foredunes and a parabolic dune indicate that the processes operating during coastal plain development were similar to those prevailing during the construction of the adjacent Holocene barrier. A separate, probably older, phase of Pleistocene transgressive dune development is suggested by landforms near Opureora. Although Holocene coastal deposits form the main barrier which encloses Tauranga Harbour, morphological evidence suggests that coastal processes played a significant role in the development of the island in Pleistocene time and that the Holocene barrier was welded to a late Pleistocene proto-barrier.

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