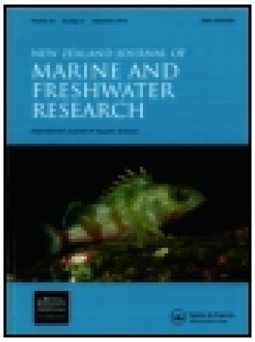

New Zealand Journal of Marine and Freshwater Research

ISSN: 0028-8330 (Print) 1175-8805 (Online) Journal homepage: https://www.tandfonline.com/loi/tnzm20

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To cite this article: Graeme P. Marks & Campbell S. Nelson (1979) Sedimentology and evolution of Omaro Spit, Coromandel Peninsula, New Zealand Journal of Marine and Freshwater Research, 13:3, 347-371, DOI: 10.1080/00288330.1979.9515811

To link to this article: https://doi.org/10.1080/00288330.1979.9515811

New Zealand Journal of Marine & Freshwater Research, 1979, 13 (3): 347–372

Sedimentology and evolution of Omaro Spit, Coromandel Peninsula

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The sedimentary structures, composition, and texture of sediments from the barrier coast complex (Matarangi Beach–Omaro Spit–Whangapoua Harbour) at Whangapoua, Coromandel Peninsula, are described. Sediments are mainly fine sands, rarely muddy or silty, and most are plagioclase feldsarenites, reflecting derivation from a predominantly Tertiary volcanic hinterland. Sediments from each of the modern environments, namely nearshore, foreshore, backshore, frontal dunes, tidal flats, and tidal channels, are characterised by a particular combination of sedimentary structures and subtle textural parameters. Dune ridge and barrier flat paleoenvironments on Omaro Spit were successfully identified by comparing their lithologic properties with the modern sediments. 'Surficial' sediments of the well-preserved dune ridge system developed immediately inland from Matarangi Beach closely resemble those in the modern frontal dunes, and the 'in depth' dune ridge sediments are more analogous to the present foreshore sands. The barrier flat deposits separating the dune ridge system from Whangapoua Harbour have similar characteristics to the modern tidal flat sediments in the harbour.

Omaro Spit probably began as an offshore bar across the mouth of Whangapoua Harbour, an embayment formed by the post-glacial drowning of a Late Tertiary dislocated fault-block. Tidal flat sedimentation within the harbour formed the ancient barrier flat deposits which rise to at least 2 m above the modern harbour flats, suggesting local sea level at the time was higher than at present. During a subsequent cyclic fall in sea level, supratidal aeolian deposition led to a succession of 15 to 18 parallel dune ridges developed on high-tide berms. Linear regression analyses of dune ridge and swale heights and the height distribution of positive (aeolian) and negative (beach foreshore) skewness values and of contrasting sedimentary structures in dune ridge paleosediments, together with the stages in dune soil development across the barrier, suggest initial sedimentation occurred from 4000–5000 years ago when local sea level was 2–3 m above present mean high water level. Barrier progradation was interrupted by an important period of coastal erosion during a temporary rise in sea level immediately before deposition in the dune ridge system of a layer of 2000-year-old sea-rafted Leigh Pumice. Sea level probably reached its modern position at Whangapoua about 1000 years ago, since when some evidence suggests the barrier spit may have experienced minor uplift.

INTRODUCTION

Omaro Spit, on the east coast of Coromandel Peninsula (Fig. 1), separates Matarangi Beach on the Pacific Ocean side from the tidal flats of Whangapoua Harbour, has an area of about 400 ha and extends 4 km in a west-northwest direction. It consists of a series of dune ridges on the ocean side and a low-lying barrier flat on the harbour side (Fig. 2).

Mean spring tidal range in the harbour is 1.6 m (Admiralty Chart N.Z.531 1971). Prevailing winds are from the southwest and northeast (Fig. 1), the northeasterlies, in particular, generate high seas.

The gross physiography of the Whangapoua region results from the dissection and later drowning of a lithologically varied fault-block (Skinner 1967). Structure controls both the drainage pattern, which is characterised by short, steep streams, and the very crenulate coastline. The hinterland consists mainly of Jurassic sedimentary rocks derived from an andesitic provenance, and Middle–Late Cenozoic andesites, ignimbrites, rhyolites, and dacites (Thompson 1966, Schofield 1967). A thin (<1 m) sequence of Late Quaternary tephras, dominated by 41 700 ± 3500 years BP Rotoehu Ash, discontinuously mantles the Whangapoua region (A. Hogg, pers. comm.). Around the periphery of the harbour, Holocene (Aranuian) fluvial gravels and sands underlie coastal terraces and valley flats in the vicinity of stream mouths entering the harbour. The open coastline is fringed by long stretches of sandy beach while rocky headlands, steep cliffs, shore platforms, and offshore reefs are locally prominent coastal features.

The main purposes of this study are:

(a) to document the sedimentary structures, texture, and composition of the surficial sediments on and adjacent to Omaro Spit;

Received 14 August 1978; revision received 8 May 1979

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(b) to use this data to distinguish between the various environments of deposition;

(c) to determine the provenance and mechanisms of transport and deposition of sediments; and

(d) to elucidate Holocene development of the barrier.

ANALYTICAL METHODS

Eighty-eight samples were collected from several, separately recognised, geomorphic units; stratified sampling (Krumbein & Slack 1956) was used within each geomorphic unit. Statistically, each unit can be considered as a natural stratum. Sampling was partly from transects across the spit (Figs 1 & 2), extending from about 200 m off Matarangi Beach inland to the *tidal flats of Whangapoua Harbour. Bottom samples* from tidal channel and offshore areas were collected with a 500 ml capacity Marukawa grab sampler; the offshore samples were collected in about 10 m of water. Foreshore samples were collected midway between mean low water level (MLWL) and the berm crest; backshore samples came from about midway between the berm crest and frontal dune. Frontal dunes were sampled on the seaward face, about halfway up the ridge. Inland from the frontal dunes, pits were dug to the water table at regular intervals along each transect and samples were collected from the major stratigraphic units present (see Fig. 6). All surface samples were taken below 5 cm but above 50 cm depth in what was visually a uniform body of sediment.

Continuous topographic profiles across the beach–dune–dune ridge system were recorded with an Elliot Profile Recorder N.X.12 which traces the transect on gridded wax paper. Insignificant variation was measured between duplicate runs in opposite directions. This instrument has a vertical accuracy of less than 0.2 m in 10 m and a horizontal accuracy of less than 1 m in 100 m. The surveys were conducted during January–February 1975 when wind and wave conditions were extremely calm and mean high water level (MHWL) was clearly defined on the seaward side of a distinctive berm crest along the full length of Matarangi Beach. This high water strandline was surveyed using staff and level and formed a local datum for relating profiles.

Sedimentary structures in the modern beach were observed in trenches dug to the water table and oriented both parallel and perpendicular to the strike of the beach. Sedimentary structures in the dune ridges were best exposed in a cutting through and normal to a ridge crest about 200 m inland from MHWL near Transect 1. Elsewhere, structures were observed in pits dug to the water table.

All samples were washed, dried at 60°c, and split. Subsamples were treated with 4.4 M acetic acid and with 25 vol. hydrogen peroxide to remove calcium carbonate and organic matter respectively, and the weight percent of these components in samples was calculated by weight loss. Skeletal carbonate was removed from all samples to enable a more meaningful textural comparison to be made between the various environments (*cf.* Nelson 1977). Carbonate grains are rarely hydraulically equivalent to similar-sized terrigenous grains (Maiklem 1968) and dissolution of carbonate material effectively eliminates the coarse tail of textural distribution curves. Samples with greater than about 5% insoluble mud were wet sieved through a 4 ϕ (63 μm) sieve to separate the terrigenous sand and mud fractions. The mud was dispersed using sodium hexametaphosphate and silt and clay percentages were determined by pipette *analysis. The sand fraction was sieved for 10 min in* a mechanical sieve shaker using $\frac{1}{4}$ ϕ interval sieves over the range 0–4 ϕ. A cumulative frequency curve was plotted on linear probability paper for each sample and the Folk & Ward (1957) statistical parameters of mean size ($M_z\phi$), sorting ($\sigma_1\phi$), skewness (Sk_I), and kurtosis (K_G), were calculated by computer. Tabulated results of all carbonate, organic matter, and textural analyses are available on request.

The compositional characteristics of sediments are based on detailed analyses of 22 samples. Bulk mineralogy was determined by X-ray diffraction analysis using the semi-quantitative method of Nelson & Cochrane (1970). The clay mineralogy of the less than 2 μm fraction of oriented particle mounts was determined for samples containing greater than 5% by weight mud by standard X-ray diffraction procedures (Carroll 1970) and semi-quantified using the method of Weaver (1967). Heavy minerals in the very fine sand grade (3–4 ϕ) were separated using bromoform (s.g., 2.87) by centrifuging for 3 min at 2000 r.p.m. Heavy mineral concentrations in the centrifuge tubes were frozen using liquid nitrogen and light minerals were decanted off and examined microscopically. After thawing and washing, the heavy minerals were mounted on slides for petrographic examination and point-counting (av. 200 grains).

DEPOSITIONAL ENVIRONMENTS

Omaro Spit and Whangapoua Harbour can be subdivided into several, well-defined sedimentary environments, namely the modern beach, foredune, and harbour environments, and the dune ridge and barrier flat paleoenvironments (Figs 1 & 2).

MATARANGI BEACH/FOREDUNE ENVIRONMENT

The beach zone can be subdivided into four littoral subzones, namely, nearshore bottom, foreshore, backshore, and frontal dunes (*cf.* Krumbein & Slack 1956). Profiles from Transects 1–3 across Matarangi

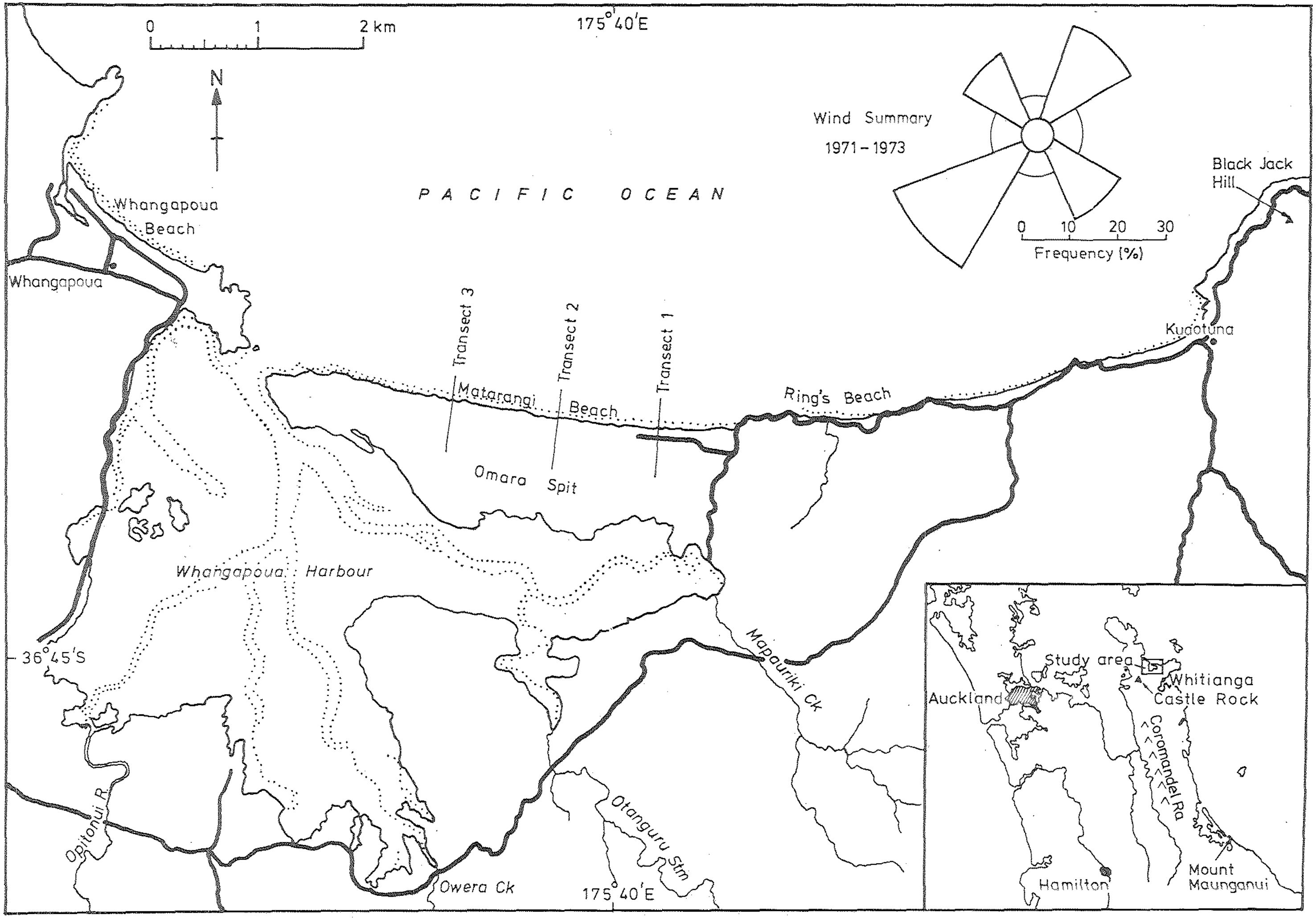

Fig. 1. Locality map, wind summary diagram (after Mander 1974), and position of transects across Omaro Spit.

Fig. 2. Composite aerial photograph of Omaro Spit showing sample locations. Note well developed series of dune ridges on ocean side of spit. (Photograph prepared from Lands and Survey Department (1973) N.Z. Mosaic Map Series 3, Sheets N40/7–Whangapoua and N40/8–Kuaotunu.)

Beach are very gentle (3°–5°) reflecting the relatively fine nature of the beach deposits (Fig. 3). The width of the foreshore ranges from 40 to 60 m with berm crest elevations of 20–50 cm (Fig. 4). Changes occur constantly as wave conditions vary, with fill during quiet periods and cut during storms. The width of the backshore ranges from 20 to 40 m (Fig. 4) but is greatly reduced during periods of intense storms. The backshore continues around to the harbour side of the barrier as a sandy fringe 2–4 m wide and ends as a microspit enclosing a small lagoon (Fig. 2). The plan curvature of the beach zone at the distal terminus of the spit is recurved convexly towards the oceanside, or is a distal recurve (Fig. 2), a feature typical of many barrier spits (Evans 1942). At Whangapoua the distal recurve results from wave refraction through as much as 270° around the terminus of Omaro Spit, so that wave trains on the harbour side of the barrier travel in an opposite direction to those on the seaward side. The beach zone surrounding the distal recurve is subject to frequent variation, being influenced both by the flood and ebb tides and by refracted wave action.

Macrofaunal remains on the ocean beach are completely dominated by molluscs. The most abundant bivalves are *Amphidesma australe* (pipi), *A. subtriangulatum* (tuatua), and *Dosinia* spp. (biscuit shells). Other common bivalves include *Spisula aequilateralis* (triangle trough shell), *Mytilus canaliculus* (green-edged mussel), *Notovola novaezelandica* (queen

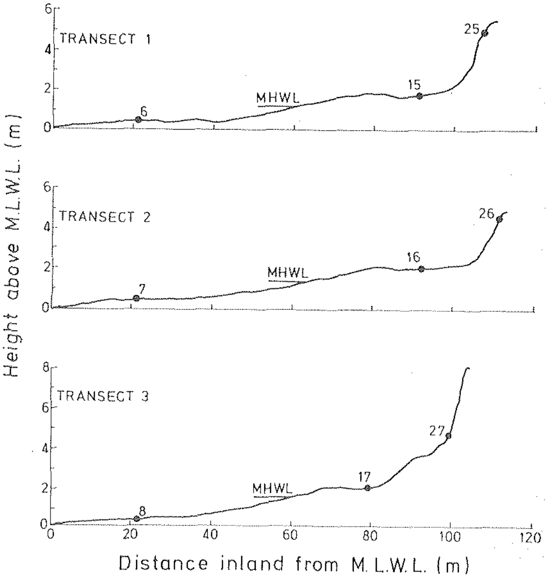

Fig. 3. Beach profiles and sample sites across Matarangi Beach. Transects located in Fig. 1. MLWL & MHWL, mean low and mean high water levels respectively.

Fig. 4. View west from about the position of Transect 3 (see Fig. 1) along Matarangi Beach towards entrance of Whangapoua Harbour showing part of dune ridge system on left (here partly forested), frontal dune belt, incipient foredunes, and backshore zone. Seaward face of frontal dune belt, here interrupted by a large blowout, is colonised mainly by marram grass (*Ammophila arenaria*) and the incipient foredunes support the strongly creeping *Spinifex hirsutus*.

scallop), *Chione* (*Austrovenus*) *stutchburyi* (common cockle), *Tawera spissa* (morning star), and *Resania lanceolata* (lanceolate trough shell). Gastropods are less abundant and include *Zethalia zelandica* (wheel shell), *Struthiolaria papulosa* (ostrich foot), and *Zeacumantus lutulentus* (horn shell).

The frontal dune belt includes both the incipient foredunes being accreted by sand blown up the beach and the frontal dunes which extend the length of the barrier (Fig. 4). The height of the frontal dunes varies from 2 to 4 m, with a steep (35°–45°) seaward slope and a long, more gentle inland-facing slope. The incipient foredunes are being colonised by the strongly creeping plant *Spinifex hirsutus* which tends to promote relatively uniform accumulation of sand (Fig. 4). Marram grass (*Ammophila arenaria*), pingao (*Desmoschoenus spiralis*), and cottonwood (*Cassinia* sp.) have colonised the existing frontal dune belt and, together with *Spinifex,* promote a rather undulating ridge-like topography. The frontal dune belt is frequently interrupted by blowouts, especially where vegetation is noticeably sparse. Towards the eastern end of the barrier the frontal dunes have been removed through real estate development and a serious threat of excessive coastal erosion exists.

A restricted belt of relatively small frontal dunes (0.5–1.0 m high) occurs on the harbour side. Their limited development reflects a lower rate of sediment supply and increased protection from onshore winds.

WHANGAPOUA HARBOUR ENVIRONMENT

The lower reaches of the harbour consist mainly of broad intertidal flats of silty sand, with a green sward of *Zostera* (sea-grass) at low water mark, flanking the main channel(s). The protected flats experience only small, subdued waves and support a prolific benthic fauna, including the bivalves *Macomona liliana* (tulip shell), *Chione stutchburyi* (common cockle), and *Amphidesma australe* (pipi), and the gastropods *Alcithoe arabica* (arabic volute), *Struthiolaria papulosa* (ostrich foot), *Baryspira australis* (southern olive), and *Pervicacia tristis.* A narrow backshore fringes the shoreline and disappears towards the upper harbour zone.

The upper harbour consists mainly of broad tidal mudflats drained by tidal gullies and channels up to 6 m deep. Wave action and water movement are normally incapable of winnowing mud from the sediment. A distinct beach front no longer exists, but instead broad flats of sandy mud extend above high water mark. A fringe of maritime plants replaces the high, tidal beach characteristic of the lower harbour. Mangrove, *Avicennia resinifera,* is common both in this zone and along meander courses of tidal streams, particularly Owera and Mapauriki creeks (Fig. 1).

OMARO DUNE RIDGE SYSTEM

The dune ridge system forms a pronounced ridge and swale topography (Fig. 5). Its width is 360 m at the proximal terminus of the spit and about 200 m near the distal terminus (Fig. 2). Between 15 and 18 ridges lie generally parallel to Matarangi Beach, although they are not necessarily continuous or entirely regular in form. Towards the modern distal terminus they become convex to the general plan of the barrier, perhaps because of wave refraction at former harbour inlets.

The innermost ridges show an overall decrease in height towards the distal end of the barrier, possibly due to a decrease in wave height in the same direction as a consequence of refraction of the prevailing swell around the former distal termini (Davies 1959).

Fig. 5. View southwest over ridge and swale topography of dune ridge system on Omaro Spit (Castle Rock in left background).

The outermost ridges, especially the frontal dune, appear to have an opposite height trend only because of modification by real estate development towards the eastern end of the spit.

More significant is the progressive increase in height of the dune ridges away from Matarangi Beach (Fig. 6). Linear regressions (as obtained by least squares) of ridge heights and swale heights on distance inland from MHWL show that a significant regression factor exists for each transect (Table 1); the regression trends for ridge elevations appear statistically stronger than those for corresponding swale elevations (*cf.* Davies 1961, Pullar & Warren 1968). The oscillation about the trend lines (Fig. 6) may be related to the variable amounts of wind-blown sand deposited on the ridge system, promoting

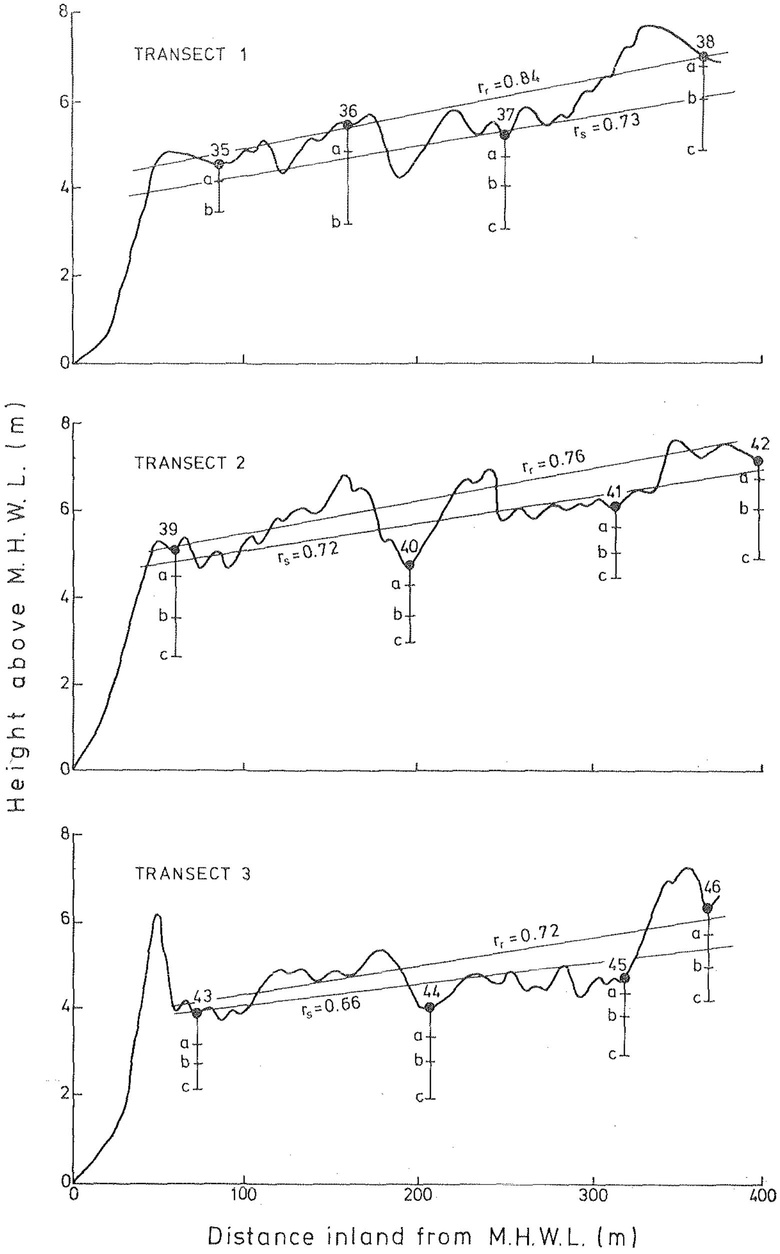

Fig. 6. Profiles and sample and pit locations across dune ridge system on Omaro Spit. Overall linear regressions for elevations of ridges and swales superimposed on profiles. Transect locations in Fig. 1. (r_r and r_s refer to product moment correlation factors for regression lines for heights of ridges and swales, respectively, along each transect).

variation in dune ridge and swale elevation, or to second-order sea-level fluctuations. Although ridge and swale heights are related to factors other than sea-level height, the regression coefficients appear to be sufficiently high to suggest there may have been a general lowering of sea level during barrier development, assuming wind and wave characteristics were generally similar throughout this period. The relatively consistent fall of 2–3 m for each transect suggests a sea-level drop of about the same magnitude; such a lowering might promote sea-floor erosion (Schofield 1968), and sand would be returned to the coast causing strong berm formation and coastal progradation.

The anomalously high frontal dune may be the result of a combination of little-understood and uncertain factors. Because of this uncertainty, and because of modification by man at its eastern end, the frontal dune belt was not included in the overall regression trend analysis. A period of coastline revision may be going on at present, as the older ridges cut out against the present shore; this is particularly noticeable near Locality 27 and between Localities 27 and 26 (Fig. 2), where blowouts also occur. The erosion is possibly associated with a contemporary rise in sea level (Schofield 1975).

OMARO BARRIER FLAT ENVIRONMENT

The 600-m-wide, roughly level, coastal barrier flat covers about two-thirds of the total area of the spit on its landward side (Fig. 2). The innermost dune ridge bordering the flat consists of blowout dunes (Fig. 2), and the adjacent margin of the flat was surveyed as lying about 2 m above MHWL in Whangapoua Harbour. The harbour side is fringed by tidal swamps which pass out into the tidal flat area proper. Although drains have enabled parts to be farmed, a large portion is covered by manuka (*Leptospermum scoparium*). Original vegetation still covers the tidal swamp areas and includes salt meadow plants and rush beds of *Juncus* and *Leptocarpus similis*.

PRIMARY SEDIMENTARY STRUCTURES

MATARANGI BEACH

FORESHORE. Sedimentary structures in the foreshore are characterised by planar strata dipping seawards at angles of 2°–5° parallel to the beach slope (Fig. 7), which in turn is largely a function of mean grain size (*cf.* Komar 1976). Strata consist of laminae, from 0.2 to 2.0 cm thick. Sets of laminae are either uniform in thickness or slightly wedge-shaped in cross-section. Stratification near the water table is less apparent because of the well sorted nature of the sediment and the general compositional uniformity. The laminae presumably result from the swash-backwash action of waves, which is capable of selectively sorting and uniformly spreading sediment into individual layers (McKee 1957, Clifton 1969).

BACKSHORE. In contrast to the foreshore zone, backshore deposits are characterised by more irregularities in their stratification (Fig. 8). Laminae are generally parallel, but low-angle (6°–8°) tabular and trough cross-laminae occur. Stratification typically occurs as internally laminated very thin beds, up to 5 cm thick, which appear consistently thicker than those of the foreshore zone. At and below the water table, at about 80 cm depth, the sands are stained dark greyish-black by hydrogen sulphide-bearing compounds. Backshore stratification is the result of both wave and aeolian processes with deposition on an irregular surface (Milling & Behrens 1966).

FRONTAL DUNES. Stratification is characterised by high-angle, wedge-shaped cross-beds with dips of 2°–45° in directions approximately at right angles to the strike of the ridges (Fig. 9). The thickness of internal laminae ranges from 0.1 to 2.0 cm. Asymmetric ripples (ripple index = 18) occur on the windward side of dunes, generally with their crests parallel to the frontal dune ridge. Ripple laminations are seldom preserved internally in strata. Dune stratification is the result of aeolian action modified by post-depositional processes induced by vegetation and organic activity (Fig. 9).

OMARO SPIT DUNE RIDGE SYSTEM

The dune ridges are characterised by numerous, large-scale sets (0.5–1.5 m thick) of tabular cross-strata with steeply dipping laminae (20°–35°); the steepest dips occur on the upper parts of the slip face (Fig. 10). Downslope, on either side of the dune ridge crests, the angle of dip generally decreases. These structures are typical of aeolian deposition. In depth, the cross-strata are consistently underlain by rather structureless sands which grade below into sub-parallel sets of thin, approximately horizontal laminae, distinguished by segregation of light and heavy

Table 1. Linear regression functions, overall elevation difference, and coefficient of correlation values (r) of heights of ridges (h_r) and swales (h_s) above, and distance (d), from, mean high water level along Transects 1, 2, & 3 (Fig. 1) across Omaro Spit.

Transect	Linear regression function	Difference in elevation (m)	r
1	$h_r = 0.012d + 4.908$	3.0	0.84
	$h_s = 0.155d + 2.650$	2.0	0.73
2	$h_r = 0.006d + 5.197$	1.9	0.76
	$h_s = 0.006d + 4.542$	1.9	0.72
3	$h_r = 0.007d + 2.622$	2.2	0.72
	$h_s = 0.006d + 2.307$	1.9	0.66

minerals (Fig. 11). These latter structures are more consistent with a foreshore origin.

WHANGAPOUA TIDAL FLATS

The tidal flat deposits are characterised by a surficial, grey-brown oxidised layer, up to 2 cm thick, above grey to black "reduced" sediments with a pungent hydrogen sulphide odour. Much of the surface of the tidal flats is covered by straight and sinuous asymmetric ripples (ripple index = 8) resulting from sheet flood movement. The essentially structureless appearance of subsurface tidal flat deposits results from considerable sediment reworking by benthic organisms, chiefly burrowing worms, bivalves—especially the pipi (*Amphidesma australe*) and cockle (*Chione stuchburyi*)—gastropods, and echinoderms.

SEDIMENT COMPOSITION

The bulk composition of samples is dominated by plagioclase (50–70%) and quartz (25–40%), with lesser amounts of ferromagnesian minerals (0–10%) and aragonite (0–15%), occasional sedimentary and volcanic rock-fragments (<5%), and rare potash feldspar, calcite, glass shards, clay minerals, and organic matter. No significant variations appear to exist in the kinds or relative abundances of minerals between samples from different environments. The dominant feature is the high content of plagioclase feldspar in samples, as noted also by Schofield (1970); the ratio of plagioclase to quartz is typically about 1.5 to 2.5. The sands consistently classify as plagioclase feldsarenites (Fold *et al.* 1970).

The plagioclase consists mainly of subhedral to euhedral crystals and less abundant, rounded sericitised gains. Quartz varieties include euhedral, pyramidal, watery clear crystals, subangular to subrounded clear grains, and less common subrounded to rounded grains with pitted or frosted surfaces; the latter are especially evident in dune sands.

Most offshore, beach, and channel samples at Whangapoua contain between about 10–20% by weight of heavy minerals in the very fine sand grade.

Fig. 7. Trench in foreshore fine sands, Matarangi Beach, showing parallel laminae dipping gently seawards at angle of slope of beach face. Camera lens cover (5 cm across) lies perpendicular to beach front.

In contrast, adjacent dune and surficial dune ridge samples contain from 40 to 80% of heavy minerals in the same size fraction. Shephard & Young (1961) have explained similar relationships as being due to the highly effective winnowing of light minerals by wind in the dune environment. There appear to be no significant differences in the proportions or types of individual heavy mineral species with environment and the following values averaged over all samples are typical: opaques, dominated by titanomagnetite and ilmenite, with rare pyrite, 37%; hypersthene, 20%; enstatite, 11%; green-brown hornblende, 11%; epidote, 9%; augite, 6%; red-brown hornblende, 2%; zircon, 2%; others, 2%.

The clay mineralogy of the less than 2 μm fraction of mud-bearing samples is dominated by illite (30–35%) and chlorite (30–35%), with common kaolinite (20–30%) and montmorillonite (10–15%), and small amounts of mixed-layered clays (5–10%). The broad and generally diffuse nature of most *d*001 reflections suggest that the clays are relatively poorly crystalline.

The detrital mineralogy is consistent with ultimate derivation from sandstones and siltstones of the Jurassic Manaia Hill Group and from Upper Tertiary volcanics of the Beesons Island Volcanics, Castle Rock Dacite, and Whitianga Group (Skinner 1967, Rabone 1975). The dominance of plagioclase feldspar over quartz, the common subhedral to euhedral crystal form of feldspar and quartz grains, and the preponderance of titanomagnetite, pyroxenes, and hornblende in heavy mineral fractions emphasise the importance of a volcanic provenance at Whangapoua. More refined provenance determinations are hindered by the general lack of detailed mineralogic data for all hinterland rocks.

The calcium carbonate content of samples ranges from 0 to 15% and consists mainly of aragonite with subordinate calcite. It is almost exclusively skeletal, of which molluscs are the major contributors in both ocean beach and harbour environments. Offshore and foreshore sediments contain somewhat more shell material than backshore and dune sediments (Fig. 12). This may reflect the reduced ability of wind to transport shell fragments as compared with terrigenous grains, the susceptibility of shell material to mechanical breakdown, and/or the potential for greater solution of carbonate with increasing distance from MHWL.

Organic matter is essentially absent except in the barrier flat and tidal flat environments where sediments contain from 0.5 to 15% by weight (av. 3% by weight) organic matter.

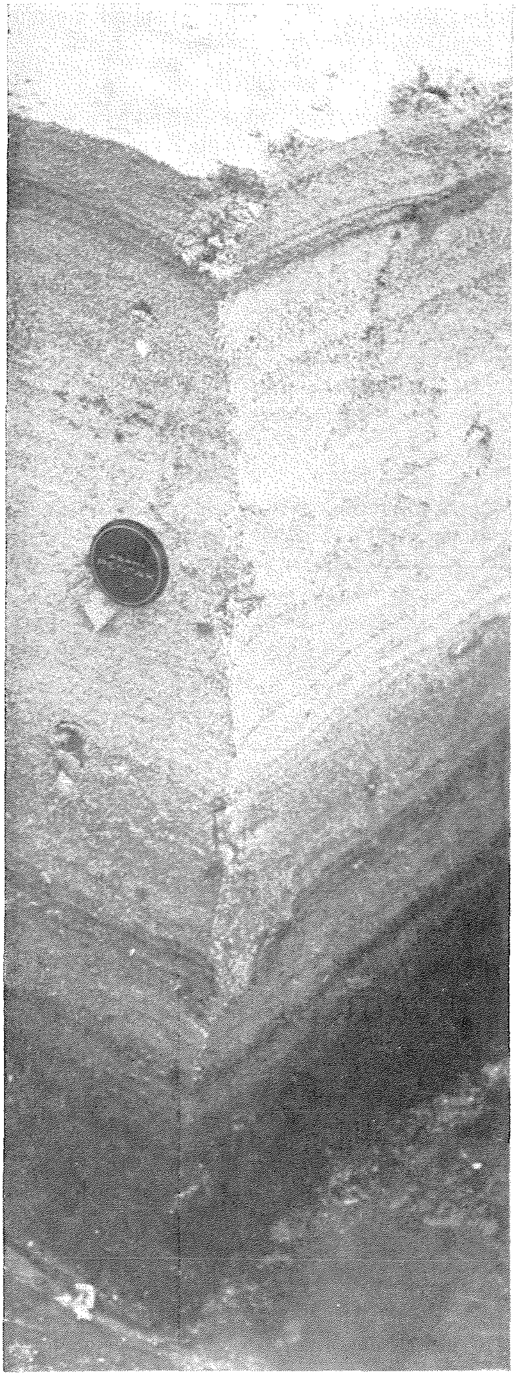

Fig. 8. Trench in backshore fine sands at Omaro Spit showing sets of low angle subparallel laminae, local micro-undulations, and dark staining by hydrogen sulphide-bearing compounds in vicinity of water table. Camera lens cover (5 cm across) lies perpendicular to beach front.

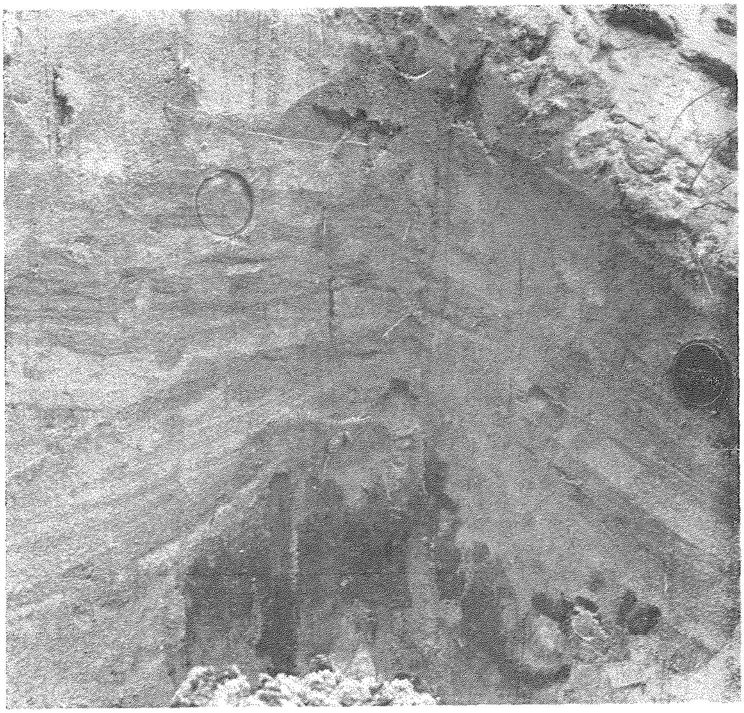

Fig. 9. High angle (25–30°) wedge-shaped sets of cross-strata dipping towards observer within pit dug in frontal dune fine sands, Omaro Spit. Stratification partly modified by growth of grass roots and by burrowing insects, giving mottled appearance. Camera lens cover (5 cm across) is perpendicular to strike of frontal dune ridge.

SEDIMENT TEXTURE

TEXTURAL PLOT

The texture of sediments is summarised on Folk's (1968) triangular sand-silt-clay diagram (Fig. 13). Analysis of the data reveals the following textural characteristics.

(a) Offshore sediments contain between 95% and 99% sand.

(b) Foreshore sediments are 100% sand indicating that offshore sediments are effectively flushed of mud during shoreward transport.

(c) Backshore and frontal dune sediments are also 100% sand as their source of supply is from the foreshore.

(d) The 'surficial' dune ridge sediments are sands with up to 4% mud (predominantly silt) derived, very probably, from post-depositional processes.

(e) The mud content of sediments on barrier and tidal flats ranges from about 2% to 23%, increasing towards the upper harbour as current velocities decline. Tidal flat sediments range from sands in the more unprotected areas of the harbour mouth to silty sands in upper harbour reaches.

(f) The mud content of tidal channel sediments ranges from 0% to 27% and, as for tidal flat deposits, increases up harbour. The sediments range from sands to muddy sands.

(g) In general the mud content of harbour samples increases both from the channel to the adjacent shoreline and on passing up harbour. However, channel sediments in the upper harbour are muddier than sediments on the adjacent tidal flats, suggesting that current speeds here are higher on tidal flats (*cf.* Sherwood & Nelson, in press).

GRAIN SIZE DISTRIBUTION CURVES

Visher (1969) described a technique for analysing grain size distributions in terms of sediment transport mechanisms as reflected in cumulative frequency plots on arithmetic probability paper. The method has subsequently found wide application for discriminating between different sedimentary processes and between various sedimentary environments (e.g., Visher 1972, Hume *et al.* 1975, Siemers 1976, Amaral & Pryor 1977, Nelson 1977, Sherwood & Nelson, in press). Essentially, Visher's method describes the total grain size distribution of a sample in terms of one or more log-normal grain size (sub)-populations, each of which is recognised as a separate straight line segment in the plot. In general, each truncated grain size population may be related to a specific transport process, such as traction (bedload), saltation (mixed load), or suspension. The number, size range, and sorting of the populations, and the amount of mixing between them, reflect variations in the sedimentary dynamics of different depositional environments. The hydrodynamic interpretation is discussed fully by Visher (1969).

Typical grain size curves from the various depositional environments at Whangapoua are shown in Fig. 14 and their characteristics are summarised in Table 2. Despite apparent overall textural uniformity, features of the distribution curves appear sufficiently diagnostic to enable characterisation of the different environments. The shapes and properties of curves from each of the offshore, beach, and dune environments agree in detail with those established by Visher (1969) for sands from similar modern environments. Offshore wave rippled sands (Fig. 14A) typically display three separate populations as current energy is insufficiently strong or persistent to remove all suspension material and to sort or remove the coarser bedload population. Consequently, the saltation–traction break point occurs at a finer size than in sediments from most other environments and significant mixing of populations is evident. Foreshore sands (Fig. 14B) are characterised by two well sorted saltation populations related to swash and backwash. As aeolian processes become dominant the two saltation populations are resolved into a single, excellently sorted saltation population in the backshore and dune deposits (Fig. 14C & D). Tidal flat sediments (Fig. 14E) are characterised by the return of three, variably mixed populations, which include only a moderately sorted saltation population and a conspicuously developed, poorly sorted suspension population. In comparison with the beach–dune curves these features are consistent with lower and more variable energy conditions, less selective sediment reworking, and a more varied provenance. Tidal channel deposits (Fig. 14F) are highly variable and mainly reflect the gradual decrease in current competency on passing up harbour. Thus with increasing distance from the harbour mouth, channel sediments show an increase in the amount of suspension material, a fining from about 1.25 ϕ to 2.0 ϕ of the saltation–traction truncation point, and a deterioration of the sorting value for all populations.

Fig. 10. Cutting through and normal to a dune ridge along Transect 1 on Omaro Spit showing large-scale, high angle tabular cross-stratification of aeolian origin preserved in pedogenetically iron-stained fine sands.

Distribution curves of 'surficial' dune ridge sediments (Fig. 14G) exhibit a single, excellently sorted saltation population and are identical to those for the wind-transported modern frontal dune sands, suggesting that 'surficial' dune ridge and frontal dune sands have a similar (aeolian) origin. However, curves for dune ridge sediments 'at depth' (Fig. 14H) clearly exhibit two saltation populations with entirely similar properties to those characterisinig the modern foreshore sands. Significantly, Visher (1969, p. 1083) found that "In the hundreds of analyzed samples this particular curve shape is always associated with the foreshore of a beach". Thus the 'at depth' dune ridge sediments possibly represent paleoforeshore deposits formed by swash-backwash action on a beach.

Barrier flat sediments (Fig. 14I) show three, well-developed, moderately mixed populations suggesting similar depositional processes to those now operating on tidal flats.

Grain Size Parameters

Grain size parameters are summarised in Fig. 15 and their interrelationships between different environments are analysed using Student's *t*-test (Table 3).

Mean grain size is mostly fine sand with a progressive decrease from the beach to the tidal flat environment. Student's *t*-test results indicate no significant difference in the mean grain size of sediments from any of the environments.

Sorting in all environments is good. It ranges from moderately well sorted in the sheltered tidal flat sediments, through well sorted in the more exposed beach and channel deposits, to very well sorted in wind-transported dune sands. The well sorted nature

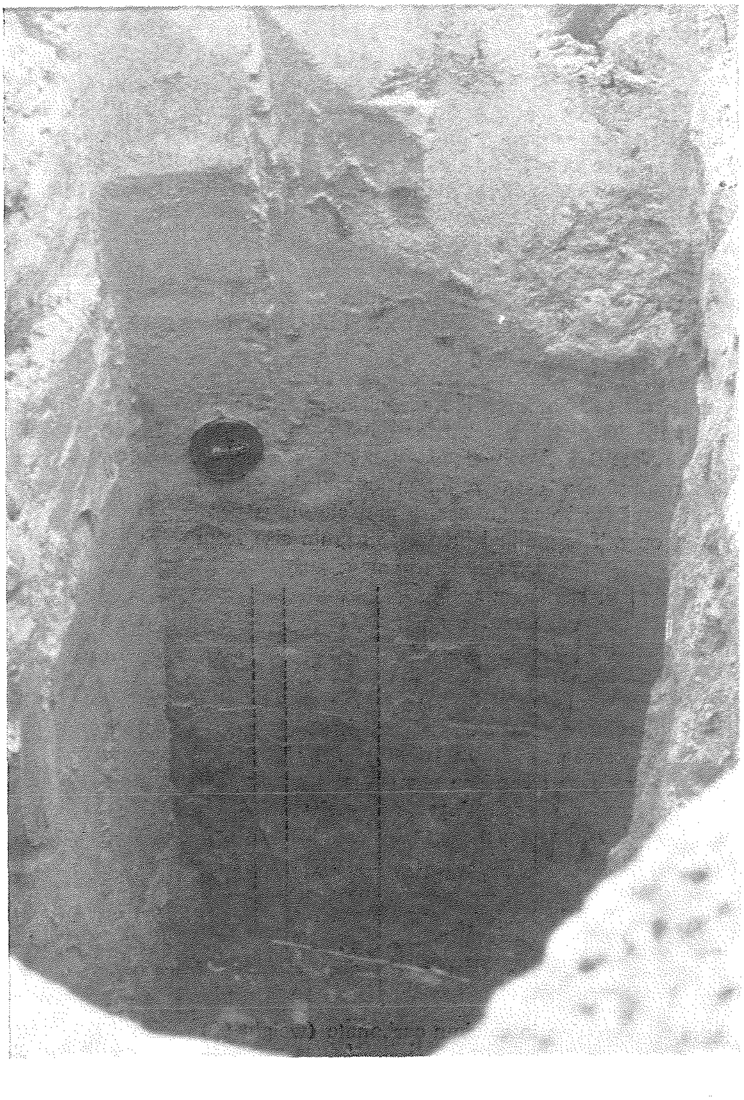

Fig. 11. Pit dug at base of dune ridge of Fig. 10, Omaro Spit, showing the transition below into subparallel sets of thin horizontal laminae, defined by segregation of light and heavy minerals, which are typical foreshore beach structures.

of beach sands probably also reflects partly a provenance control. Student's *t*-test shows a significant difference in sorting between foreshore and dune sands and between 'surficial' and 'at depth' dune ridge sediments, but no significant sorting difference occurs between tidal flat and barrier flat sediments.

Most offshore, beach, and channel sediments are negatively skewed as a result of washing out of fines by wave action (*cf.* Friedman 1961, 1967, Duane 1964). Positive skewness characterises dune sands, where aeolian processes promote infiltration of fines (*cf.* Friedman 1961, 1967), and tidal flat deposits, where fine clastics are able to periodically settle from suspension (*cf.* Duane 1964). Whereas *t*-test results demonstrate a significant difference between beach and dune deposits and between 'surficial' and 'at depth' dune ridge sediments, there is none between foreshore sands and dune ridge sediments 'at depth'.

Where the suspension population exceeds about 5% of the sediment by weight the extreme addition of a fine tail produces high kurtosis values. Thus tidal and barrier flat sediments are very leptokurtic whereas sands from beach and dune environments, which show little textural differentiation, are mainly mesokurtic or only slightly leptokurtic. Student's *t*-test results show that no significant differences exist in kurtosis values between dune ridge sediments 'at depth' and foreshore sands, but that real differences occur between 'surficial' and 'at depth' dune ridge deposits.

Variations in grain size parameters in similar environments (offshore, foreshore, backshore, and dune) along the length of the barrier have been analysed by least-squares linear trend functions (Table 4). Significantly consistent variation occurs in all environments for mean grain size and skewness parameters only. The gradual increase in grain size from east to west suggests that there exists a parallel longshore increase in wave energy level, which is perhaps related to degree of exposure. The increasingly negative skewness of sands towards the west probably reflects the above mean size variation along the barrier.

SCATTER PLOTS

Several combinations of textural parameters have been suggested to differentiate sediments from different depositional environments (e.g. Friedman 1961, 1967, Moiola & Weiser 1968, Passega 1972), but the world-wide applicability and reliability of these plots remains questionable (e.g., Solohub & Klovan 1970, Nelson 1977). Locally, several scatter plots appear to effectively separate the bulk of the beach and dune sands (Fig. 16). Moreover, although the 'surficial' dune ridge sediments cluster with the frontal dune plots, the 'at depth' dune ridge samples cluster mainly with the beach sands, suggesting a marine origin for the subsurface dune ridge sands. Close inspection indicates that the marine-nonmarine environmental distinction is primarily a function of skewness (Fig. 16B, C & D) and, to a lesser extent, sorting (Fig. 16A). The bulk of the sediment entering the Whangapoua barrier system is already reasonably well sorted and predominantly of fine sand grade. Small differences in transport mode and environmental energy level affect only the tails of the grain size distributions and this in turn is manifested mainly by the skewness value (*cf.* Mason & Folk 1958). Accordingly at Whangapoua, as many investigators have found elsewhere (e.g. Folk & Ward 1957, Mason & Folk 1958, Friedman 1961, 1967, Duane 1964, Sevon 1966, Chappell 1967, Hails 1967, Awasthi 1970, Cronan 1972, Valia & Cameron 1977), skewness is the most environmentally sensitive textural parameter.

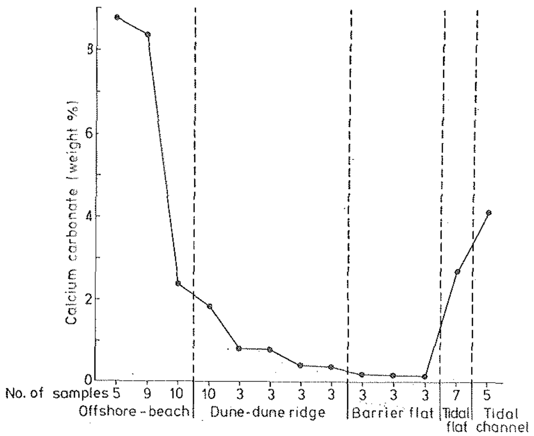

Fig. 12. Variation in calcium carbonate (weight %) in samples across Omaro Spit. Values averaged from samples in Transects 1, 2, & 3 (Figs 1 & 2).

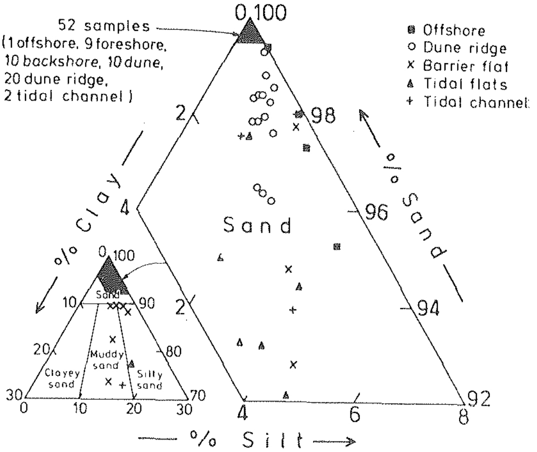

Fig. 13. Textural plots of sediments from Omaro Spit and Whangapoua Harbour. (Textural classification scheme after Folk (1968).)

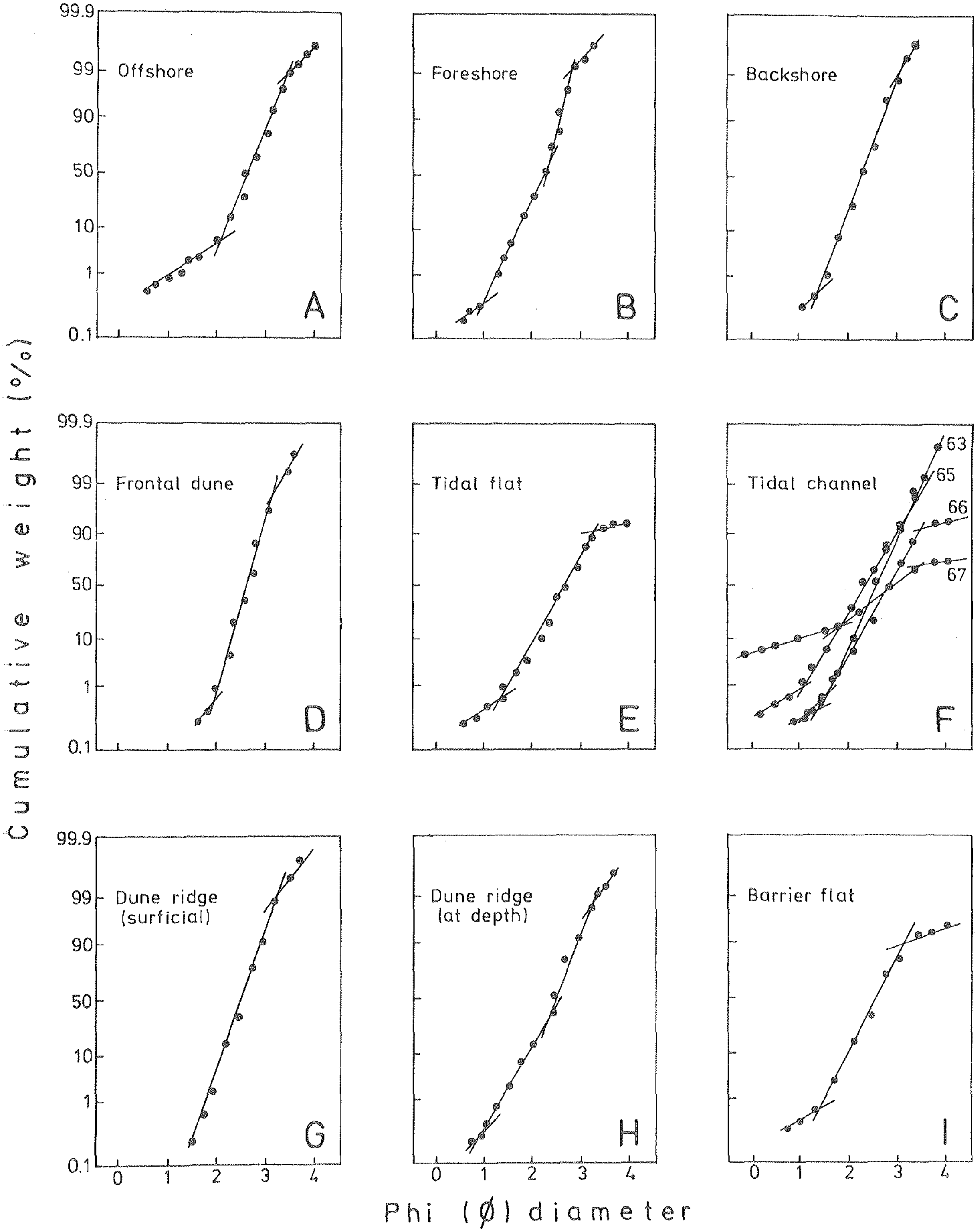

Fig. 14. Representative grain size distribution curves for sediments from various depositional environments at Whangapoua.

SIGNIFICANCE OF SKEWNESS IN THE DUNE RIDGE SYSTEM

A plot of skewness values against height above MHWL for all dune ridge sediments indicates that most negatively skewed samples lie about 2–4 m (maximum 6 m) above MHWL and that most positively skewed ones occur from 3.5 to 6.0 m (maximum 7 m) above the same level (Fig. 17). In the light of the environmental sensitivity of skewness in distinguishing marine and nonmarine sediments demonstrated above, the data could be interpreted as indicating that the maximum beach height during barrier formation was at least up to 4 m higher than at present. Moreover, the null skewness isoline separating inferred 'surficial' aeolian deposits from 'in depth' beach foreshore sediments for each of the three transects across the barrier (Fig. 18) dips gently seawards from an inland height of 4–6 m above MHWL to a shoreward height immediately inland of the frontal dune belt of 2–3 m above MHWL. The isoline defines a similar slope to the linear regression lines for the elevations of dune ridges and swales (Fig. 6). However, maximum beach height is a function of other variables besides sea level, such as changing wave and wind conditions, differences in the type of beach material and, perhaps most importantly, storm events (e.g., Zenkovich 1967; Shepherd 1970). The excellent state of preservation and the consistency in orientation of the dune ridges, together with their general textural and compositional uniformity, suggest a relative constancy in wind–wave climate and provenance throughout the Holocene at Whangapoua. However, the suggested beach height values can probably be reduced to offset the effect of sediments deposited during severe storms (Shepherd 1970), even though storm deposits have not beeen recognised in the few pits dug in the dune ridges. It is thus possible that a maximum beach height of up to about 4 m above MHWL existed at Whangapoua during the construction of Omaro Spit. The conclusion is entirely consistent with earlier data concerning the morphology (Fig. 6), internal sedimentary structures (Figs 10 & 11; Table 5), grain size distribution curves (*cf.* Fig. 14D & B with G & H, respectively), and grain size parameters (Fig. 16 & 18) of dune ridge sediments.

HOLOCENE HISTORY

BARRIER DEVELOPMENT

Initial barrier formation has been the subject of much discussion. De Beaumont (1845, cited in Zenkovich 1967) considered that sediment was transported landward across the shelf by wave action and that it was piled up into a ridge shoreward of the breaker zone. His theory was modified by Davis (1912, cited in Zenkovich 1967) and Johnson (1919), and generally accepted by Davies (1957), Bird (1960), Shepard (1963), Zenkovich (1967), Hoyt (1967), Hails (1968), and Otvos (1970). Differences of opinion exist as to whether the initial barrier ridge grows from a submerged longshore bar, or from accumulation of wind- and/or water-deposited sediments immediately landward of the shoreline followed by subsequent submergence to produce a barrier island or spit. In all probability, barrier inception is polygenetic (Komar 1976). In general, an initial offshore bar may be built up above high water into a barrier beach where there is a high sediment supply rate and a sufficiently flat gradient on the offshore shelf to promote sediment deposition.

Table 2. Typical characteristics of grain size distribution curves of sediments from the major depositional environments and paleoenvironments at Whangapoua (C.T. and F.T., coarse and fine truncation points respectively).

	Saltation population A				Suspension population B				Traction population C			
Depositional Environment	%	Sorting	C.T. φ	F.T. φ	%	Sorting	Mixing A & B	F.T. φ	%	Sorting	C.T. φ	Mixing A & C
Offshore	90	Very good	2.10	3.35	2	Good	Average	3.75	8	Poor	0.50	Average
Foreshore	99	2 populations (2.25φ break) Very good	1.00	2.75	<0.5	Good	Little	3.50	<1	Good	0.25	Little
Backshore	98	Very good	1.25	3.00	<1	Very good	Little	3.25	<1	Good	1.00	Little
Frontal dune	99	Excellent	1.95	3.25	<1	Very good	Little	3.75	<0.5	Good	1.75	Little
Dune ridge 'surficial'	99	Excellent	1.50	3.45	1	Very good	Little	4.00	—	—	—	—
Dune ridge 'at depth'	98	2 populations (2.25–2.5φ break) Very good	1.00	3.25	<1	Good	Little	3.50	<0.5	Good	0.50	Little
Barrier flat	89	Good	1.75	3.20	9	Poor	Average	7.50	2	Good	0.50	Average
Tidal flat	90	Good	1.60	3.25	8	Poor	Average	7.50	2	Poor	0.75	Average
Channel	60–99	Poor–very good	1.25–1.75	3.00–3.75	0–20	Poor	Average	—	<1–20	Poor–good	–1.00–0.75	Little–much

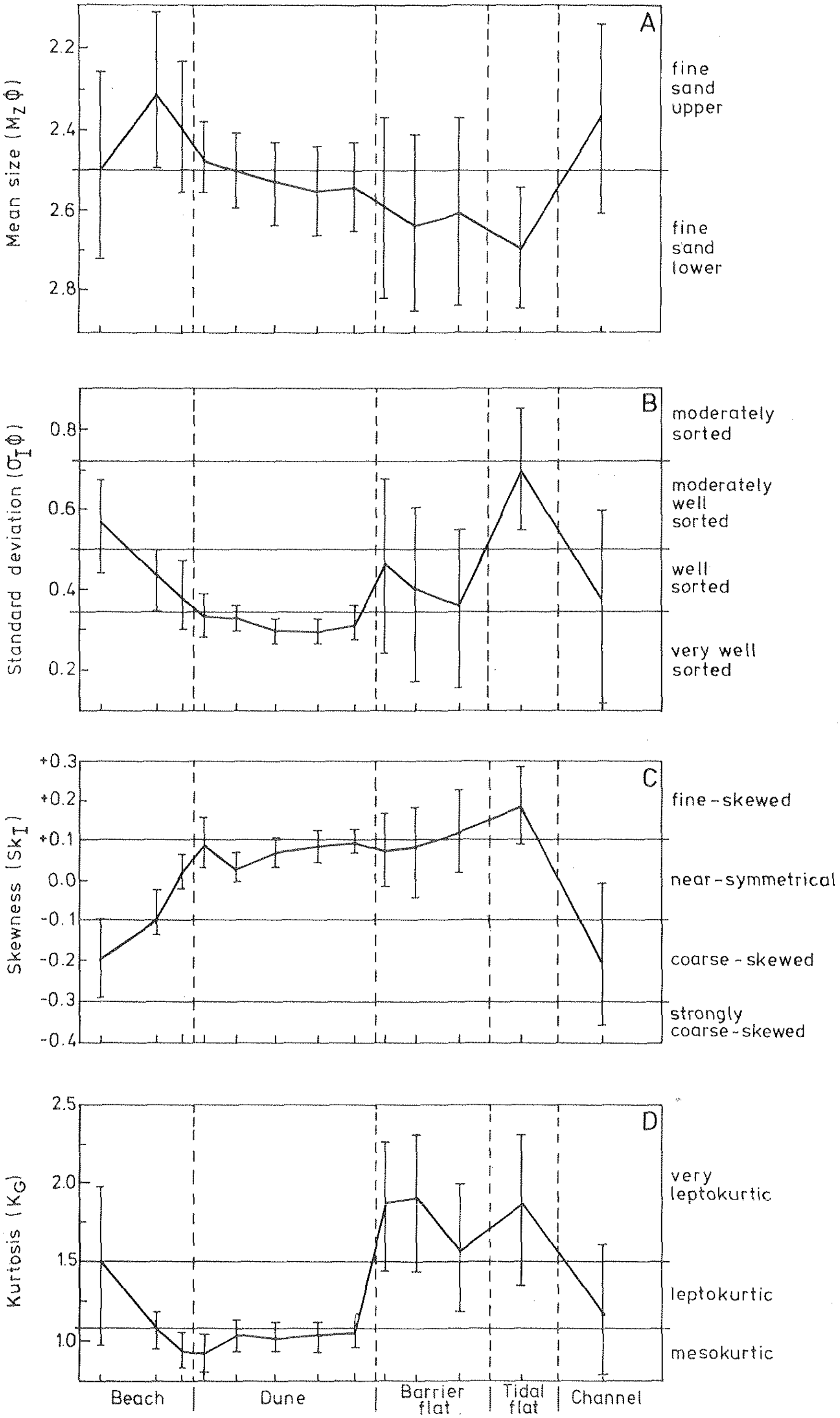

Fig. 15. Mean variations in grain size parameters of samples across Omaro Spit. Values averaged from samples in Transects 1, 2, & 3 (Figs 1 & 2). Vertical lines indicate 95% confidence level range for each mean value.

Omaro Spit probably began as a submerged offshore bar enclosing Whangapoua Harbour, with sediment deposition being influenced by both the low angle offshore shelf and the orientation of the hinterland shoreline. The relatively high energy regime of the barrier ocean beach environment effectively eliminated any argillaceous sediment and soft rock fragments, and resulted in widespread deposition of clean, well sorted, quartzofeldspathic sands. The mud fraction may have ultimately settled from suspension in the more protected harbour environment. After enclosure of the harbour, the rate of harbour sedimentation has probably increased significantly because of restriction of wave activity and colonisation by various sediment-trapping tidal plants (such as *Zostera* and *Avicennia*) contributing to barrier flat formation.

Seaward progradation of the barrier has occurred by addition of successive dune ridges. Dune ridge formation depends on the amount of wind and wave energy, tidal range, sedimentary supply, sediment size, and vegetation character (Shepherd 1970). Davies (1957) believed that parallel ridges originated as high-tide berms and were accreted with aeolian sands blown up from the adjacent foreshore. After a period of erosion a new ridge may form against the previous one where there is a sufficient supply of sand. Davies's 'cut-and-fill' theory has been elaborated upon by McKenzie (1958) and Thom (1964) who suggested that vegetation is the initial factor responsible in ridge formation. On Matarangi Beach the pioneer grass *Spinifex hirsutus* colonies the incipient foredunes which appear to have grown from the sites of former berm terraces; the berm crests were flat before aeolian accretion commenced (Fig. 4). Sediments in the dune ridges and the upper part of the swales have been shown to be wind-deposited and probably had a similar origin.

The progressive seaward decrease in ridge height probably reflects a first-order lowering of sea level during barrier progradation, as discussed above and below. At present, however, there appears to be a phase of more active coastal erosion, as evidenced by the common, cliffed seaward margin and large-scale blowout features in the frontal dune belt. This probable dominance of cut over fill is a result of either increased storm wave activity (Davies 1957) or, more likely, a contemporary lower-order rise in sea level (Bird 1968, Schofield 1975). The height and spacing of dune ridges is a function of several factors, including rate of sand supply to the shore, history of cut-and-fill, effectiveness of vegetation, and sea-level fluctuations. The dune ridges across Omaro Spit are large and well spaced indicating that cut has been moderate, reflecting either infrequent storms or infrequent lower-order rises in sea level.

AGE OF DUNE RIDGES

Inland the normally light brownish grey sands become increasingly weathered to yellow-brown, variably mottled sands, the upper layers of which are leached of shell material and iron oxides by humic acids from root vegetation (Fig. 19). Illuvium in the lower horizons is not uncommonly in the form of an iron-rich, slighly cemented, reddish brown pan. The sequence, thickness, and classification of the types of soil across the spit (Fig. 19) are remarkably similar to the dune soils developed under generally similar climatic and vegetation conditions across the Mount Maunganui tombolo to the south where radiometric ages are available for the soils (Pullar & Cowie 1967). If direct correlation is valid, then the strongly illuvial subfulvic soils with a variably developed, weakly cemented, moderately thick (up to 40 cm) iron pan beneath the innermost dune ridges are over

Table 3. Student t-test values (t) and verbal significance (P = 0.05) for interrelation of similar grain size parameters between major sedimentary environments at Whangapoua. Number of samples and abbreviations as follows: F, foreshore (9); B, backshore (8); D, dune (9); DR(s), dune ridge 'surficial' (12); DR(d), dune ridge 'at depth' (22); BF, barrier flat (9); TF, tidal flat (10); NS, not significant; S, significant.

Inter-relationship	*t*	Significance
Mean ($M_z\phi$)		
F×B	1.54	NS
F×D	1.97	NS
B×D	1.05	NS
DR(d)×F	1.17	NS
DR(d)×D	1.94	NS
DR(d)×DR(s)	2.01	NS
TF×BF	1.38	NS
BF×DR(s)	1.60	NS
Sorting ($\sigma_I\phi$)		
F×B	1.52	NS
F×D	3.11	S
B×D	1.32	NS
DR(d)×F	0.99	NS
DR(d)×DR(s)	2.80	S
TF×BF	0.20	NS
BF×DR(s)	4.03	S
Skewness (Sk_I)		
F×B	3.76	S
F×D	3.50	S
B×D	1.98	NS
DR(d)×F	0.35	NS
DR(d)×D	2.80	S
DR(d)×DR(s)	2.62	S
TF×BF	0.25	NS
BF×DR(s)	1.95	NS
Kurtosis (K_G)		
F×B	1.97	NS
F×D	2.00	NS
B×D	0.98	NS
DR(d)×F	0.36	NS
DR(d)×D	2.37	S
DR(d)×DR(s)	2.50	S
TF×BF	0.88	NS
BF×DR(s)	4.84	S

4000 years old (Fig. 19). Progressively younger soil ages are indicated for the dune ridges as Matarangi Beach is approached (Fig. 19).

The change from a thick to a thin iron pan in the subfulvic soils about 180 m inland from MHWL appears to coincide with a period of more intensive coastal erosion which may have been associated with a sharp, temporary 1.5 m rise in sea level from 2500 to 2000 years ago (Schofield 1975). The erosion is evident in Fig. 2, where the low between Pits 4 and 5 in Fig. 19 corresponds to the vegetated swale connecting Localities 36, 40, and 44. The swales north of this vegetated low lie parallel to it and are narrower than those lying to the south. Between Localities 40 and 36 the southern ridges cut out against the vegetated swale showing costal erosion before deposition of the narrower ridges to the north. Furthermore, Fig. 2 shows there are apparent fixed blowouts associated with this coastal erosion. This is particularly true in the vicinity of Locality 40 where Transect 2 shows a well developed ridge immediately inland of the low when compared with the other two transects (Fig. 6). This discontinuity is neither morphologically or pedogenetically expressed at Mount Maunganui where the coast was apparently prograding at this time, probably because of the abundant supply of rhyolitic eruptive material from the nearby Central Volcanic Region of the North Island.

Table 4. Least squares linear trend functions, coefficients of correlation (*r*), and significance levels of grain size parameters from similar sedimentary environments along the length of Omaro Spit. Gradients of trend functions indicate rate of variation within each grain size parameter, which is similar except for kurtosis and sorting. *Y*, value of grain size statistic; *X*, distance (km) from east to west along the spit.

Population	Trend function	r	Significance level of r
Mean ($M_z\phi$) trends			
Offshore	$Y = 2.80 - 0.10X$	–0.76	0.05
Foreshore	$Y = 2.79 - 0.19X$	–0.88	0.01
Backshore	$Y = 2.59 - 0.06X$	–0.77	0.02
Dune	$Y = 2.82 - 0.15X$	–0.96	0.001
Sorting ($\sigma_I\phi$) trends			
Offshore	$Y = 0.50 + 0.02X$	+0.21	0.1
Foreshore	$Y = 0.52 - 0.01X$	–0.42	0.1
Backshore	$Y = 0.52 - 0.52X$	–0.74	0.02
Dune	$Y = 0.24 + 0.03X$	+0.88	0.05
Skewness (Sk_I) trends			
Offshore	$Y = 0.01 - 0.04X$	–0.73	0.1
Foreshore	$Y = 0.02 - 0.05X$	–0.86	0.01
Backshore	$Y = 0.01 - 0.05X$	–0.96	0.001
Dune	$Y = 0.23 - 0.05X$	–0.92	0.01
Kurtosis (K_G) trends			
Offshore	$Y = 1.81 - 0.28X$	–0.53	0.1
Foreshore	$Y = 1.20 - 0.07X$	–0.52	0.1
Backshore	$Y = 0.77 + 0.10X$	+0.63	0.1
Dune	$Y = 0.79 + 0.10X$	+0.51	0.1

Unfortunately, no *in situ* tephra deposits have been found on or within the dune ridges, although very fine pumice fragments occur locally in organic-rich top soils in swale sites of some of the innermost dunes and may represent airfall Taupo Lapilli erupted about 1750 years ago (Grant-Taylor 1976). However, additional evidence for the age of the barrier is provided by a distinctive pumice layer within a dune ridge about 170 m inland from MHWL (Fig. 19). The finely vesicular pumice fragments are typically medium grey with a slightly weathered rusty surface, range in size from 2 to 5 cm, have well worn but irregular blocky shapes, and are associated with high-angle tabular cross-stratification of aeolian origin. It is likely that the pumice represents sea-rafted material carried on to a paleobarrier beach and subsequently redeposited by wind on the paleofrontal dune. It seems probable that the time interval between eruption and deposition in the dune was short as the pumice is restricted to the one dune ridge. The medium grey colour, the high refractive index of the glass of 1.517, the dominance of opaques over ferromagnesian minerals in the heavy mineral fraction, and the ferromagnesian mineral assemblage of augite $\geqslant$cummingtonite$>$ hypersthene identify the pumice as probably reworked Leigh Pumice (Wellman 1962) erupted about 2000 years ago, fragments of which characteristically have a 'subangular' shape in sea-rafted deposits in Northland (J. E. Cox, Soil Bureau, DSIR, Auckland, pers. comm.). An apparent anomaly exists between the Leigh Pumice age of 2000 years and Pullar & Cowie's (1967) suggested age of 3000–4000 years for the associated subfulvic soils with a thin pan (Fig. 19) indicating, perhaps, the inherent limitations of applying too rigidly the Mount Maunganui soil ages at Whangapoua.

SEA-LEVEL FLUCTUATIONS

Although there is general agreement that sea level has risen some 130 m over the past 15 000–17 000 years (Flandrian Transgression), there has been considerable uncertainty as to the shape of the eustatic sea-level curve for the Holocene (Newman 1968, Curray *et al.* 1970, Mörner 1971, Vita-Finzi 1973). Most controversy has concerned whether or not sea level has ever been higher than at present during the last 7000 years. Two schools of opinion exist; one that sea level was some 2–3 m above present at some time between 3500 and 5000 years ago (e.g., Fairbridge 1961, Fujii & Fuji 1967, Schofield 1973, 1977, Gupta & Amin 1974, Buddemeier *et al.* 1975, Lovell 1975), and the other that sea level has been at or near, but not above, its present level since about 4000 years ago (e.g., Curray 1961, Jelgersma 1966, Redfield 1967, Curray *et al.* 1970, Cook & Polach 1973). However Mörner (1976) has shown that these differences are probably more apparent than real

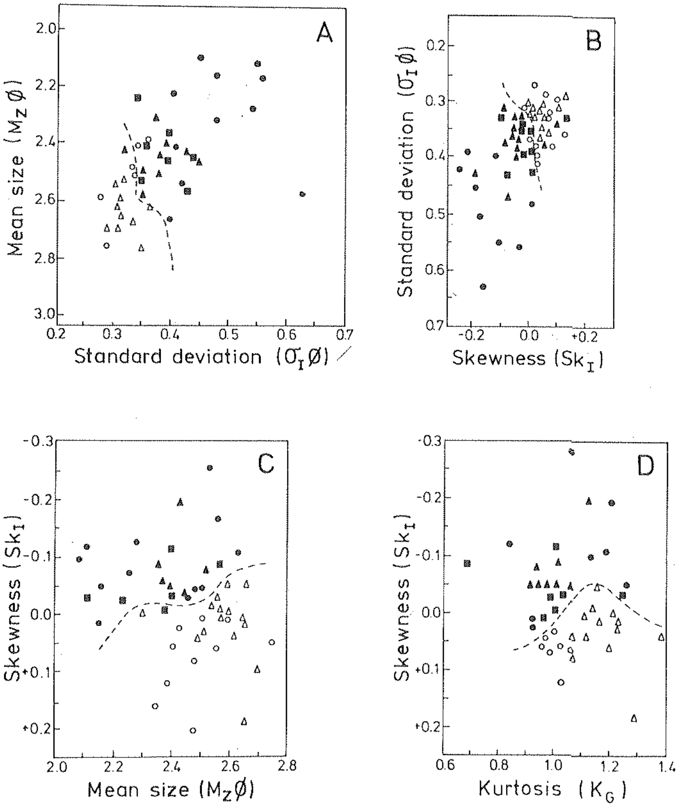

Fig. 16. Scatter plots showing interrelationships of grain size parameters for samples from Omaro Spit: solid circles, foreshore; solid squares, backshore; open circles, dunes; open trianges, dune ridge (surface); solid triangles, dune ridge (at depth). Note that dune ridge (surface) samples group with dune sands and dune ridge (at depth) samples cluster with beach sands. Dashed line in each plot roughly separates samples of (inferred) foreshore beach (solid symbols) and aeolian (open symbols) origin.

because cyclic changes in the configuration of the ocean geoid probably invalidate the simple concept of global eustasy. Pirazzoli (1977) emphasises further the necessity for establishing local rather than global sea-level curves because of the variable effects of isostasy and tectonism from region to region.

Evidence from Omaro Spit indicates that local sea level was at least 2 m higher than present some 4000–5000 years ago and that it reached its modern level about 1000 years ago. This conclusion is based on the following evidence.

1. The overall seaward decrease in height by 2–3 m of successive dune ridges and swales across the barrier (Fig. 6).
2. The generally similar seaward dip of the probable boundary between aeolian and beach foreshore sediments in pits across the dune ridge system (Fig. 18) as defined by consistent variations in sedimentary structures (Table 5) and textural characteristics (Figs 14 & 16).
3. The extension to the Whangapoua area of the general relationship between stages of dune soil development and age as established at the nearby Mount Maunganui area. Independent evidence of age is provided by a layer of sea-rafted pumice in a dune

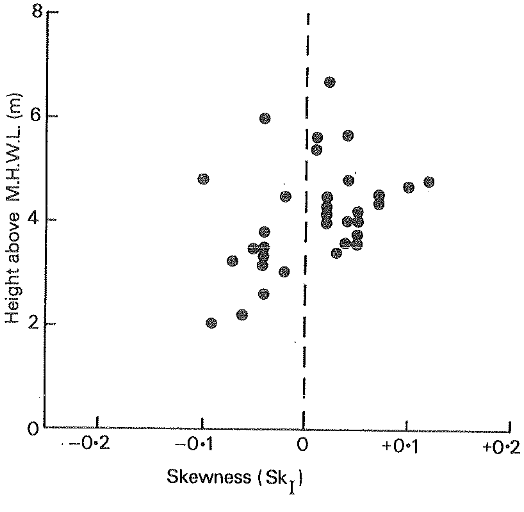

Fig. 17. Relation between skewness and height above mean high water level (MHWL) of sediments from within dune ridge system on Omaro Spit. The zero skewness line possibly separates samples of predominantly beach (negative skewness) and predominantly aeolian (positive skewness) origin.

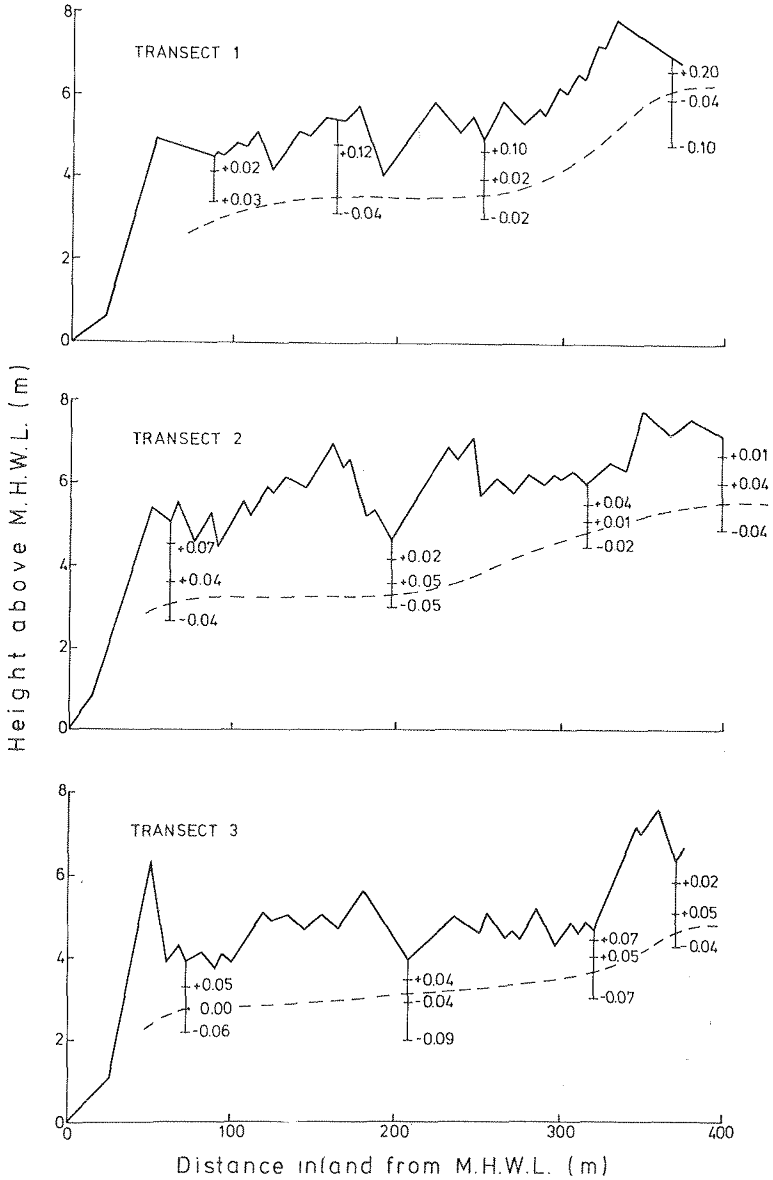

Fig. 18. Cross-sections through dune ridge system at Omaro Spit showing skewness values of subsurface sands and inferred boundary (dashed line) between sediments of aeolian origin (above line) and marine (beach) origin (below line). Transect locations in Fig. 1.

ridge nearly halfway back through the ridge sequence and derived from the 2000-year-old Leigh Pumice.

4. The level of the barrier flat, a paleotidal flat (Figs 14 & 15; Table 5), rises to at least 2 m above the modern tidal flats of Whangapoua Harbour.

The suggestion of a Holocene high sea level at Whangapoua accords well with the evidence from several nearby coastal localities described by Wellman (1962) and Schofield (1960, 1973, 1975). Schofield (1973, 1975) demonstrated that the highest Holocene beach ridge at several of these sites records at +2 m sea level about 4400 years ago, since when the sea has fallen to its present level in a fluctuating manner. Because evidence for a similar +2 m Holocene sea level occurs over about 300 km in the Northland and Auckland regions of northern New Zealand, Schofield (1973) favoured a purely eustatic origin for the stranded beach ridges. We accept Schofield's post-glacial high sea level and suggest that the bulk of the dune ridge system at Omaro Spit developed in response to a 2–3 m eustatic lowering of sea level since 4000–5000 years ago. However, the evidence at Whangapoua could be interpreted as indicating a Holocene sea level up to 4–5 m above present (Figs

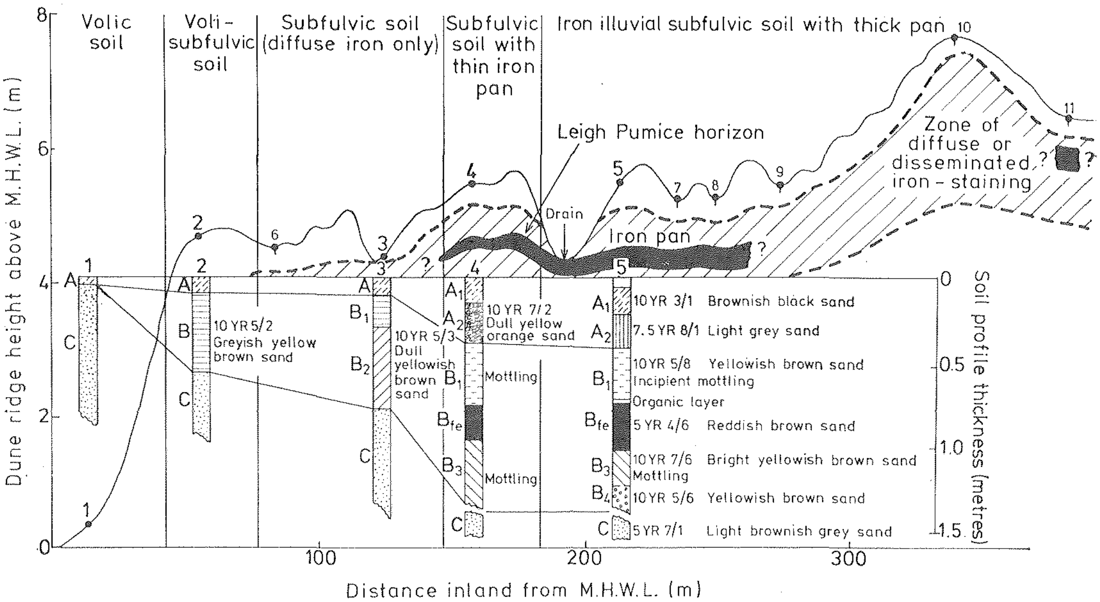

Fig. 19. Cross-section of dune ridge system at Omaro Spit along Transect 1 (Fig. 1) showing progressive dune soil profile development inland, and soil classification types (following Taylor & Pohlen 1962). *Standard Munsell symbols used for soil colour and similar soil types are identified by similar hatching.* Note location of horizon of sea-rafted Leigh Pumice. Sites 1–5, soil pits; Sites 6–11 augered holes only.

Table 5. Summary of compositional, textural, and sedimentary structural characteristics of sediments from major depositional environments in barrier coast complex at Whangapoua. Compositional types listed in decreasing order of abundance; bracketed species of minor abundance. R.I., ripple index; ?, unknown; —, not applicable.

	Sedimentary structures			Mean textural properties						
Environment	External	Internal	Composition	Sand (%)	Silt (%)	Clay (%)	$M_z\phi$	$\sigma_I\phi$	Sk_I	K_G
Offshore	Symmetric ripples	?	Plagioclase-quartz-shell (-heavies)	97.9	1.9	0.2	2.53	0.49	−0.07	1.38
Foreshore	Plane bed	(Sub) horizontal strata	Plagioclase-quartz-shell (-heavies)	100	—	—	2.33	0.47	−0.10	1.06
Backshore	Plane bed, asymmetric ripples	Irregular strata, low angle (2–8°) cross-strata	Plagioclase-quartz (-shell -heavies)	100	—	—	2.15	0.39	−0.07	0.95
Frontal dune	Asymmetric ripples (R.I. = 18)	High angle (25–30°) tabular cross-strata	Plagioclase-quartz-heavies	100	—	—	2.43	0.39	+0.10	1.01
Tidal flat	Asymmetric ripples (R.I. = 8), organic traces	Massive and horizontal or lenticular strata	Plagioclase-quartz-shell-clay-organic matter	91.7	4.9	3.4	2.71	0.56	+0.21	1.67
Tidal channel	Asymmetric ripples	?	Plagioclase-quartz-shell	92.9	4.4	2.7	2.38	0.84	−0.03	1.38
Dune ridge ('surficial')	Vegetated	High angle (20–35°) tabular cross-strata	Plagioclase-quartz-heavies	98.7	0.8	0.5	2.54	0.34	+0.05	1.10
Dune ridge ('at depth')	—	Massive or subhorizontal strata	Plagioclase-quartz (-heavies)	99.6	0.3	0.1	2.31	0.36	−0.05	1.04
Barrier flat	Vegetated	Massive	Plagioclase-quartz-clay-organic matter	88.8	7.3	3.9	2.63	0.62	+0.05	1.98

6 & 18), so that either storm deposits have contributed significantly to the construction of the barrier spit or as much as 2–3 m of this height may be due to tectonic uplift. If the latter, then movement probably occurred mainly after the eustatic drop in sea level. This could then account for the abnormally high frontal dune ridge on Omaro Spit (Figs 4 & 6), built up because of sudden uplift of the offshore sea floor, and also explain the apparent rapid steepening of the aeolian–marine boundary at the seaward edge of the dune ridge system (Fig. 18).

SUMMARY AND CONCLUSIONS

The sedimentary structures and compositional and textural characteristics of sediments from major depositional environments in the barrier coast complex at Whangapoua, Coromandel Peninsula are summarised in Tables 2 and 5. Despite the general uniformity in composition and texture of all sediments—which are mainly fine plagioclase feldsarentes—combinations of these properties (especially of sedimentary structures and subtle textural differences) are sufficient to define uniquely each of the modern environments. The response reflects mainly the dominant transport mechanism operating in each environment, namely wave and longshore current action immediately offshore, wave swash and backwash on the beach face, aeolian processes in the frontal dunes, and tidal current flows in the harbour flats and channels. The character of tidal flat deposits is additionally influenced by the browsing and burrowing activity of a benthic, dominantly molluscan fauna, and by the current-baffling and sediment-trapping functions of localised stands of mangrove (*Avicennia resinifera*) and sea-grass (*Zostera* sp.); several species of pioneer grasses (especially *Spnifex hirsutus* and *Ammophilia arenaria*) significantly influence the development of the frontal dunes. Saltation is the dominant sediment transport process in all environments, although suspension transport becomes increasingly important within the more protected confines of the harbour.

Sediment mineralogy is dominated by plagioclase feldspar and quartz, with smaller quantities of ferromagnesian minerals (chiefly titanomagnetite, ilmenite, hypersthene, enstatite, and hornblende) and skeletal aragonite. The detrital mineralogy is consistent with an essentially local derivation from Mesozoic sedimentary and Tertiary volcanic rocks, the latter provenance dominating. Sediment is supplied to the beach zone by erosion of coastal rocks followed by longshore drift and/or by net landward movement of offshore sands from the shallow continental shelf. Sediment is also supplied to the harbour as fluvial load.

Paleoenvironments within the barrier system are successfully identified by comparing their lithologic properties with modern sediments. Thus the 'surficial' sediments of the dune ridge system closely resemble those in the modern frontal dunes, and the 'in depth' dune ridge sediments are more analogous to the modern foreshore sands. The barrier flat deposits adjacent to the dune ridge system have similar characteristics to the tidal flat sediments now forming in the harbour.

Sedimentation at Omaro barrier spit may have started as an offshore bar from shoreward and longshore movement of sand derived from offshore sandbelts and coastal erosion during culmination of the post-glacial rise in sea level. The bar/barrier developed in an east–west direction across Whangapoua Harbour, an embayment formed by drowning of a dislocated fault-block. Tidal flat sedimentation within the harbour was consequently greatly accelerated and formed the ancient barrier flat deposits which occur up to a level of at least 2 m above the modern harbour flats. During a subsequent fluctuating fall in sea level, supratidal aeolian deposition led to a succession of 15 to 18 parallel dune ridges developed on high-tide berms, their accretion being promoted by sea-level fall and supported by colonisation by pioneer grasses (Fig. 4). Linear regression analyses of dune ridge and swale heights (Fig. 6) and the height distribution of positive (aeolian) and negative (beach foreshore) skewness values (Fig. 18) and of contrasting sedimentary structures (Table 5) in dune ridge paleosediments, together with the stages in dune soil development across the barrier (Fig. 19), suggest initial sedimentation occurred from 4000 to 5000 years ago when local sea level was 2–3 m above present MHWL. Barrier progradation was interrupted by a pronounced period of coastal erosion immediately before deposition in the dune ridge system of a layer of 2000-year-old Leigh Pumice. The erosion probably coincides with a prominent submergence event resulting from a temporary rise in sea level from 2000 to 2500 years ago (Schofield 1975). Sea level probably reached its modern position about 1000 years ago since when mild tectonic uplift of the spit may have occurred.

ACKNOWLEDGMENTS

We thank Kenwood Properties Ltd. for permission to undertake this study at Omaro Spit and Dr M. J. Selby (Department of Earth Sciences, University of Waikato) and Mr J. C. Schofield (N.Z. Geological Survey, DSIR, Otara) for reading, and suggesting material improvements to, the manuscript.

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