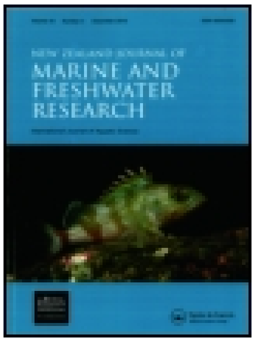

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Beach erosion at Waihi Beach Bay of Plenty, New Zealand

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ABSTRACT

Since the 1940s, severe dune erosion has threatened property at Waihi Beach. This paper investigates beach erosion and dune recession in relation to wave climate, sedimentology and mineralogy of the beach sediments, cyclical beach changes and sediment budget, and the littoral drift.

Average dune recession along the entire beach between 1948 and 1977 was 27 m, although maximum recession recorded to 1977 was 83 m. Sand loss rates 1948-1977 average 3.4 m^3 per metre of beach per year.

The sediment budget of the entire beach is about 850 $\times$ 10^3 m^3 and up to 74% of this was recorded as being 'cut' from the beach in one erosive episode. The cut and fill cycles are dominantly controlled by wave steepness, which has a critical value of 2.1 $\times$ 10^{-3} for breaking waves on Waihi Beach.

Net littoral drift is towards the south-east, and the basic reason for beach erosion at Waihi Beach is the lack of sediment to supply the littoral drift.

INTRODUCTION

THE PROBLEM

Waihi Beach township developed as a resort for the Waihi goldminers late last century. Initial development was haphazard, and buildings were constructed directly on the frontal dunes. Since the 1950s, with the advent of coastal subdivision, dwellings have been constructed close to the frontal dune.

Severe erosion was noticed in the 1950s, and by the early 1960s some houses were moved back from the crest of the frontal dune. At present about 25 houses are at risk. Protection from continuing erosion is expensive, and since 1968 $110 000 has been spent on the construction of a vertical semi-permeable sea wall, rock back-filling, and gabion baskets (S. W. Didsbury, Ohinemuri County Council Engineer, pers. comm.).

The present research was done to:

(i) gain basic information on the beach sediments and the behaviour of the beach under the influence of waves and storms,

(ii) attempt to ascertain the sediment budget of the beach, i.e., the volume of sediment involved in the "cut and fill" cycles,

(iii) obtain indications of the magnitude and direction of the long-term littoral drift, which is presently unknown for the Bay of Plenty–Coromandel coast, and

(iv) determine the magnitude of past erosion from analysis of historical aerial photographs.

LOCATION AND PHYSIOGRAPHY

Waihi Beach is located 35 km northwest of Tauranga in the Bay of Plenty. The beach forms the northernmost section of the long, sandy, littoral system of the Bay of Plenty. The coast to the north is rocky with occasional pocket sandy beaches such as at Orokawa and Whiritoa.

Waihi Beach is a 9 km long, straight barrier beach, attached as a tombolo to Bowentown Head at the southern end (Fig. 1). In plan the beach contains a number of minor embayments of 0.5–2.0 km length. The cross-sectional profile changes along the beach with the embayments. Towards the centre of an embayment the beach cross-section is typically short and steep, however at the horn of an embayment the profile exhibits a more gentle slope. Most of the beach is backed by a frontal dune, except in the extreme north where the dune has been destroyed. The frontal dune increases in size from 1.5 m at Site I to up to 10 m towards the south. The continuity of the frontal dune is interrupted by public access paths, dune blowouts, and trail-bike tracks. Within dune blowouts and in some of the swales, pumice deposits occur as a fossil beach berm. The pumice is tentatively identified as Taupo Pumice from the 130 A.D. eruption (Healy 1976).

Although Waihi Beach is a long, straight barrier beach it does not exhibit good sets of parallel dune

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ridges evident on nearby Matakana Island, and on the barrier spits formed further north on the Coromandel Peninsula. However, an inner set of higher paleo-frontal dunes (still Holocene in age) can be discerned some 50–100 m behind the present frontal dunes. Towards the centre and southern end of Waihi Beach these paleo-frontal dunes are transected by older, stabilised, parabolic and transgressive dunes. Pleistocene paleodunes are evident on the Tauranga Harbour side of the tombolo, identified by their mantle of Rotoehu Ash. This forms the "Bowentown surface" of Selby *et al.* (1971).

PREVIOUS WORK

The general physiography of the Tauranga Harbour and northern Bay of Plenty lowlands was first outlined by Bell & Fraser (1912) and Henderson & Bartrum (1913) in their geological surveys of the Aroha and Waihi-Tairua subdivisions. Morgan (1924) and Thompson (1966) subsequently reported on the geology of the Waihi area.

Coastal sand dunes and terraces at Waihi Beach were investigated by Kear & Waterhouse (1961), who related the terraces to the classical Mediterranean sequence of supposed higher sea levels. Their interpretation was disputed by Selby *et al.* (1971). Chappell (1975) examined tectonic warping of the region by tracing the terraces south-eastwards around the Bay of Plenty.

PROCEDURES

Five sites, selected as representative of the various sectors of the beach (Fig. 1) were profiled with an Elliott Profile Recorder from the top of the dune to the low tide mark each week for 56 weeks from April 1974 to May 1975. The sites were also profiled daily for 2 weeks (17–29 April 1975). From analysis of the profiles the volume of sand lost and gained on the beach was calculated.

Records of wind speed and direction, and of wave height, period, and direction were also taken daily from April 1974 to May 1975 at Site II (Fig. 1) by a local resident.

Sediment samples were collected from the foredune, berm (or middle reaches of the beach when no berm was evident), and the low tide swash platform on three occasions (20 April 1974, 14 July 1974, 29 April 1975). The shell was removed by acid and the samples were sieved according to standard procedures outlined in Folk (1968). Mean grain size and sorting were calculated to ascertain possible sediment variation along the beach. Samples at Sites I, III, and V were analysed for mineralogical variation along the beach to determine the origin of the sand. The samples were split into magnetic and non-magnetic fractions using a Franz magnetic separator. The magnetic fraction was examined under the petrological microscope and the non-magnetic fraction analysed on a Phillips X-ray diffractometer (XRD) according to the procedures outlined in Nelson & Hume (unpublished 1974).

During the detailed profile monitoring 200 kg of beach sand, dyed with Sancol fluorescent sand tracer, was placed at Site V. Sand samples were traced up to 3 km to the north and around to Cave Bay in the Katikati Entrance (Fig. 1).

Historical aerial photographs and cadastral maps were used to gain information on the changes in the high water mark (HWM) and base of the frontal dune. Measurements of the dune erosion and accretion were made from the aerial photographs following Stafford's method (1971).

WIND AND WAVES

Waihi Beach faces the Pacific Ocean and experiences a mild to moderate swell-wave energy environment, and has a moderate tidal range (2–4 m) (Davies 1972).

Winds for Tauranga show a strong southwesterly component (de Lisle 1962). Winds for Tauranga are also given in the Wallingford Report on Tauranga Harbour (Unpublished 1963). Waihi Beach lies 35 km north of Tauranga but because of topographic channelling the wind data is probably not directly applicable to Waihi Beach.

For this study, daily wind records were taken from Site II (Fig. 1). The resultant wind was north-westerly, while the resultant of the onshore winds was north-easterly (Fig. 2).

The wave direction resultant at Tauranga, constructed from data collected by the Bay of Plenty Harbour Board pilot boat, plots near normal to the shoreline. The wave data collected during this project also produced a resultant near normal to the shoreline but directed 4° towards the south.

The wave heights and wave steepnesses recorded during the study are shown in Fig. 3. Wave steepness (H_b/L_o) was calculated from the daily wave height and period estimates taken at Site II. The significant wave height ($H_{1/3b}$) for a breaking wave at Waihi Beach was 0.6 m; by comparison, Davies-Colley & Healy (1978) recorded a significant wave height of 1.5 m approximately 2.5 km north-east of Mount Maunganui. The mean wave period was 11 s, which corresponds to a deep-water wave length of 188 m. However, wave period ranged from 5 s during locally generated "chop" conditions, to 15 s at times of long swell waves. Low waves ($H_b < 0.3$ m) occur 55% of the time (Fig. 3, *upper*).

There were 42 erosive events (wave steepness $> 2.1 \times 10^{-3}$) during the period of investigation. However, 10 of these were 1-d events. Examination of daily wind records led to the compilation of Table 1 on storms generated locally and those generated at some distance from Waihi Beach.

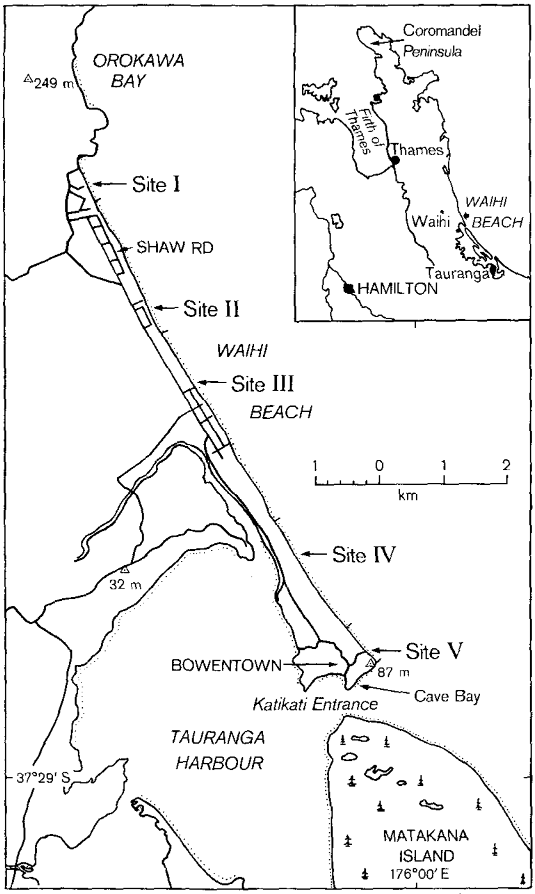

FIG. 1—Waihi Beach showing locations of sites profiled April 1974–May 1975.

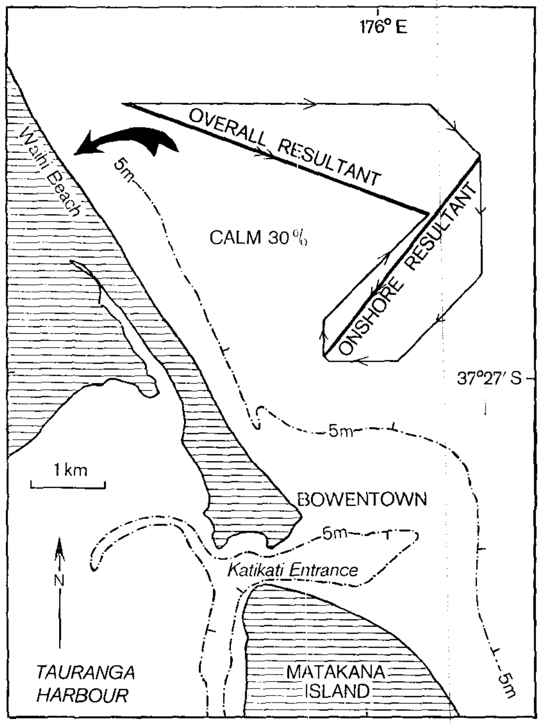

FIG. 2—Wind resultants and bathymetry at Waihi Beach; resultants from daily observations at Site II, April 1974–May 1975.

TABLE 1—Analysis of local versus external generation of erosive waves, Waihi Beach 1974-75

	Locally generated "sea"	Steep swell generated from external storms	Uncertain
Storm episodes longer than 1 d	17	10	5
All storm episodes	21	13	7

Kirk (1975) notes that south-easterly storm waves, occurring 12–15 times per year, form the dominant component of wave action on the Kaikoura coast. They also maintain the dominant component of longshore drift. For Waihi Beach and presumably the Bay of Plenty the dominant storm waves are from the northeast and are locally generated (Table 1). However, storm waves generated from tropical cyclones, and from depressions to the south of New Zealand also produce erosive swell waves in the Bay of Plenty (Harray unpublished 1977).

SEDIMENTOLOGY AND MINERALOGY

The dune and beach sands at Waihi Beach have similar mean grain sizes (Fig. 4). For the 45 samples analysed, mean grain sizes range from medium sand (1.56ϕ) to fine sand (2.7ϕ). There is a general trend of increase in grain size towards the southern (Bowentown) end of the beach (Fig. 4) where higher energy conditions and a steeper beach slope prevail. These observations are in accordance with the now well-known wave energy, grain size, beach slope relationship established by Bascom (1951). Irregularities in the general grain-size trend are caused by minor embayments along this long straight barrier beach, as well as the complex wave refraction patterns and tidal currents where the Bowentown ebb tidal delta joins the beach bar.

Sorting of the dune and berm sands is similar and tends to deteriorate towards the southern end of the beach. For individual samples the sorting values range from 0.30ϕ (very well sorted) at the northern end of the beach to 0.55ϕ (moderately well sorted) at the southern end (Fig. 4). Sorting within the swash platform zone is poorer (0.36–0.64ϕ) as might be expected in such a turbulent and rapidly changing sedimentary environment.

Mineralogically the beach sands are relatively homogeneous in composition along the beach (Fig. 5).

TABLE 2—Bulk mineralogy of Waihi Beach sands: all samples collected from the berm and analysed in a Phillips X-ray diffractometer after removal of the magnetic and shell fractions

DATE OF COLLECTION	PERCENTAGE OF TOTAL SAMPLE					
	Quartz	Feldspar	Glass	Magnetic	Shell	Felds/Qtz
20 April 1974 (after erosion)						
Site I	20.64	46.0	27.2	4.2	2.0	2.23
Site III	19.1	50.0	24.3	4.6	2.0	2.62
Site V	11.9	45.8	33.8	3.3	5.2	3.85
14 July 1974 (after minor accretion)						
Site I	15.3	38.9	33.2	6.7	5.9	2.54
Site III	15.5	42.3	31.2	5.1	5.9	2.73
Site V	16.2	47.2	29.1	3.3	4.2	2.91
29 April 1975 (after accretion)						
Site I	13.2	43.9	30.7	8.7	3.5	3.33
Site III	17.5	43.3	31.3	2.0	5.8	2.47
Site V	18.5	47.1	14.9	15.1	4.4	2.55

The magnetic separation isolated magnetic mineral fractions of 1–23%. The X.R.D. analysis of the remaining 77–99% non-magnetic fraction showed the beach sediments to consist of quartz (12–21%), feldspar (35–56%) and a residue of volcanic glass (15–34%). The magnetic mineral fraction comprises the following minerals: hypersthene (44–66%), hornblende (21–43%), calcic amphibole (cummingtonite? 4–14%) and opaque minerals (1–11%).

The feldspar/quartz ratio of the sands collected in this study ranged from 2.1–4.7 (Table 2). On two occasions, one immediately following a storm event, the ratio increased towards the southern end of the beach. On a third sample collection the ratio decreased towards Bowentown following the trend noted by Schofield (1970). Schofield's analyses may not be directly comparable in that he analysed sand over a wide size range, whereas we used only the 2–3ϕ range in an effort to avoid the influence of varying size ranges on the feldspar/quartz ratio.

The textural and mineralogical homogeneity evident in Figs 4 and 5 is indicative of intense mixing along the beach. A fluorescent sand-tracing experiment also showed that rapid sand movement and intense mixing occur parallel to the shoreline. Sampling 12 h after the tracer was released showed significant quantities of sand 3 km north of the dump site (Site V) under waves of 0.3 m with a 10.1 s period. In 36 h the tracer sand had moved around a rocky headland and into Cave Bay in significant quantities while the concentrations at sampling sites to the north of the dump increased, indicating that sand was being moved rapidly in both directions. From Cave Bay the sediments are probably moved into Tauranga Harbour as tidal currents exceeding 2 $m.s^{-1}$ run through the tidal gorge in close proximity to Cave Bay. As with the textural and mineralogical analysis, the sediment tracing did not clearly show a net direction of littoral drift.

However, the magnetic mineral assemblages do give clues as to the ultimate origin of the beach sediment (Table 3). The magnetic mineral assemblages of Waihi Beach do not show affinity with any of the nearby source rocks of Minden Rhyolites or Beesons Island Volcanics (Hayward 1974), or with the Quaternary tephra deposits on the Coromandel (A. G. Hogg, Earth Sciences, Waikato University, 1976, pers. comm.). The magnetic mineral percentages are consistent with an ultimate origin from erosion of the Quaternary pyroclastics of the Taupo Volcanic Zone (Ewart 1966). The Tarawera, Rangitaiki, and Kaituna Rivers which drain that area have probably transported the sediment to the Bay of Plenty littoral zone.

Waihi Beach sediments appear distinctly different from those at Orokawa Bay to the north. From Schofield's (1970, p. 813) mineralogical data, a *t*-test was made to test the difference between the mean percentages of quartz, potassium feldspar, sodium feldspar, and mafic minerals of Orokawa and Waihi Beaches. The results show that the null hypothesis (no difference between the individual mineral means) can be rejected at the 5% level ($t > 2.1$, 10 d.f., $P < 0.05$) that is, there is a 95% probability that the means are drawn from separate populations. Waihi Beach is evidently the northern limit of the Bay of Plenty sandy littoral system.

PROFILE CHANGES AND SEDIMENT BUDGET

The weekly profiles from the five sites were planimetered, and volumes of sand moving on and off the beach each week were calculated. Figure 6 depicts the weekly volumetric fluctuation of sediment for the whole of Waihi Beach. Notably, both erosion and accretion fluctuations were irregularly cyclical and large, at times up to 448 $\times$ 10^3 m^3 (i.e. 50 m^3 per metre of beach). During the period of monitoring the beach showed a net loss of 219 $\times$ 10^3 m^3 of sand, although the final profiles were taken after a storm event and much of this sand could be expected to be in offshore bars. The major erosive events were in autumn, as noted also at Whiritoa Beach (M. J. Christophersen, Earth Sciences Department, University of Waikato, pers. comm.) and Wainui Beach (R. K. Smith, hydrologist, MOWD, Napier, pers. comm.).

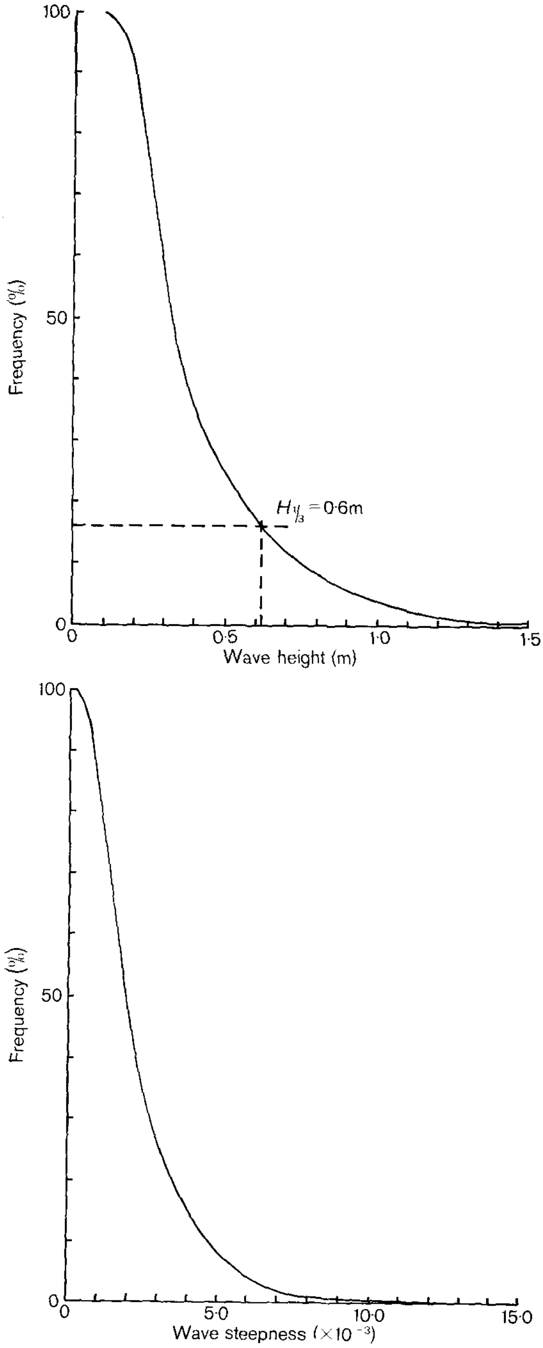

FIG. 3—(*Upper*) Cumulative frequency of breaking wave heights (H_b) from daily records, April 1974–May 1975. The significant wave height ($H_{1/3}$) is the average of the largest one-third of all waves recorded. (*Lower*) Cumulative frequency of wave steepness (H_b/L_o) calculated from daily records of wave height and wave period. L_o is the deep-water wavelength.

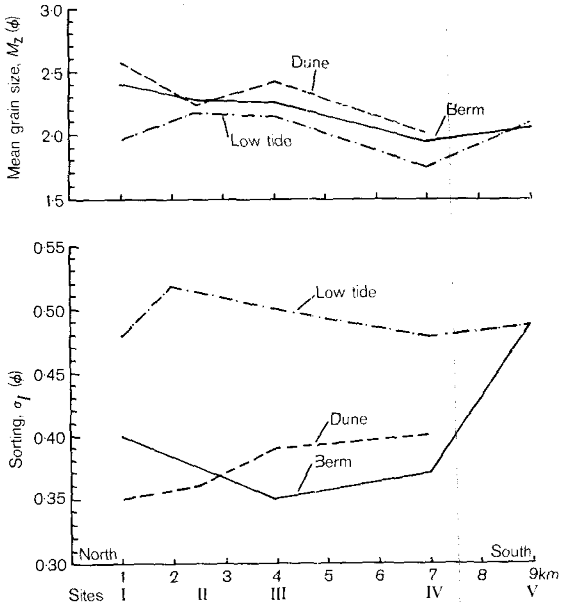

FIG. 4—Mean grain size (*upper*) and sorting (*lower*) averaged over three set sof samples (20 April 1974, 14 July 1974, and 29 April 1975) at each site, Waihi Beach.

From analysis of the weekly variation in beach profiles at the five representative sites along Waihi Beach, attempts were made to obtain an "order of magnitude" estimate of the total sediment budget, or *mobile sediment volumes being transferred within* the nearshore-beach-dune system. Table 4 summarises the sediment budget for Waihi Beach during the period of observation. The total sediment budget for Waihi Beach was measured as 846 × 10^3 m^3 or 94 m^3 per metre of beach. The largest weekly erosive event for the whole beach was 448 × 10^3 m^3 or 53% of the sediment budget. The largest weekly accretionary event was 357 × 10^3 m^3 or 42% of the sediment budget.

During a 13-d period of daily beach profiling rapid changes were recorded as listed below:

17–20/4/75 accretion: 306 × 10^3 m^3: 36% of sediment budget

21–26/4/75 erosion: 628 × 10^3 m^3: 74% of sediment budget

27–29/4/75 accretion: 273 × 10^3 m^3: 32% of sediment budget.

Clearly there are large volumes of sand being moved within the nearshore-beach-dune system under the rapidly changing wave conditions.

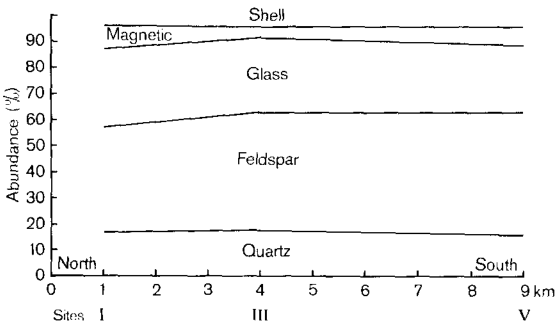

FIG. 5—Mineralogical trends along Waihi Beach, from means from three samples (20 April 1974, 14 July 1974, and 29 April 1975).

The critical parameter determining such sediment fluxes and the cut and fill process is wave steepness. That is, above a critical steepness, waves will erode the beach and below this critical steepness waves will bring sand on to the beach. Based on weekly averaged values for wave steepness and morphological characteristics of the beach profiles, Harray (unpublished 1977) deduced that the critical wave steepness lay in the range 1.6–3.0 $\times$ 10^{-3}. Using daily beach profiles and wave records, he concluded that the critical wave steepness was about 2.1 $\times$ 10^{-3}. Subsequently the wave steepness values were regressed against the volume of sediment eroded or accreted during the daily profile monitoring (Fig. 7). The regression line intercepts the abcissa at 2.1 $\times$ 10^{-3} and thus this is the critical wave steepness for Waihi Beach.

HISTORICAL TRENDS OF EROSION

The first cadastral map of the area included the southern third of Waihi Beach and was surveyed in 1870. Unfortunately this map does not portray any permanent locations that can be identified on later surveys. The Shaw Road area (Fig. 1) was surveyed between 1948 and 1951 and redrawn in 1968 when a semipermeable sea wall was constructed to halt dune erosion. The mean retreat of MHWM at Shaw Road between 1951 and 1968 was 49.2 m. Reconstructing the 1951 dune profile we obtain an 'order of magnitude' estimate of 244 $\times$ 10^3 m^3 of sand eroded from this area. This is equivalent to a loss of 13 m^3 per metre of beach per year.

A comparison of the position of the frontal dune as portrayed in the 1942–48, 1969, and 1977 air photographs shows considerable net erosion over this period (Healy *et al.* 1977). The mean retreat of the frontal dunes between 1948 and 1969 was 20 m, which involved 636 $\times$ 10^3 m˙ of sand or 30 $\times$ 10^3 m^3 per year (3.4 m^3 per metre of beach per year). During this period the dunes at Site V accreted approximately 21 metres. During the interval 1948–1977 the air photographs show that the dunes retreated a mean distance of 27 m which involved 856 $\times$ 10^3 m^3 of sand or 29.5 $\times$ 10^3 m^3 per year (3.3 m^3 per metre of beach per year). The sections of the beach which did not show erosion from 1969 to 1977 were sections of the beach protected by sea walls and on the horns of the embayments. The most dramatic erosion has been at the centres of the large embayments which interrupt the generally straight character of the beach. This is marked at Sites II and IV where 42 m and 83 m of dune retreat were measured respectively. Despite the sea wall protecting large sections of the dunes, a similar volume of sand is still being removed from the unprotected dunes since the emplacement of the structures.

DISCUSSION

The preceding aerial photograph and cadastral map analysis indicated that Waihi Beach has experienced overall net erosion since 1942. There is a considerable body of further evidence to show that in the longer term the beach has been eroding, especially at the northern end. Moreover, the direction of the littoral drift is clearly south-eastwards towards the Bowentown end of the beach. These conclusions are based on the following evidence:

TABLE 3—Petrological determination of magnetic ($\simeq$ heavy) mineral assemblages of Waihi Beach sands based on 150 counts per slide

SAMPLE	HYPERSTHENE	HORNBLENDE	CALCIC AMPHIBOLE	OPAQUES	OTHERS
Sample collected 20 April 1974					
Site I	44.8	44.3	8.5	2.5	1.0
Site III	43.9	43.4	9.3	1.7	1.7
Site V	56.4	35.9	4.5	2.6	0.7
Sample collected 14 July 1974					
Site I	57.1	29.3	7.1	3.5	3.0
Site III	48.6	37.0	8.9	2.1	3.4
Site V	51.5	36.0	9.6	0.7	1.2
Sample collected 29 April 1975					
Site I	53.8	26.5	10.6	6.1	3.0
Site III	46.3	35.3	13.3	4.4	0.7
Site V	66.1	21.2	4.2	5.9	2.6

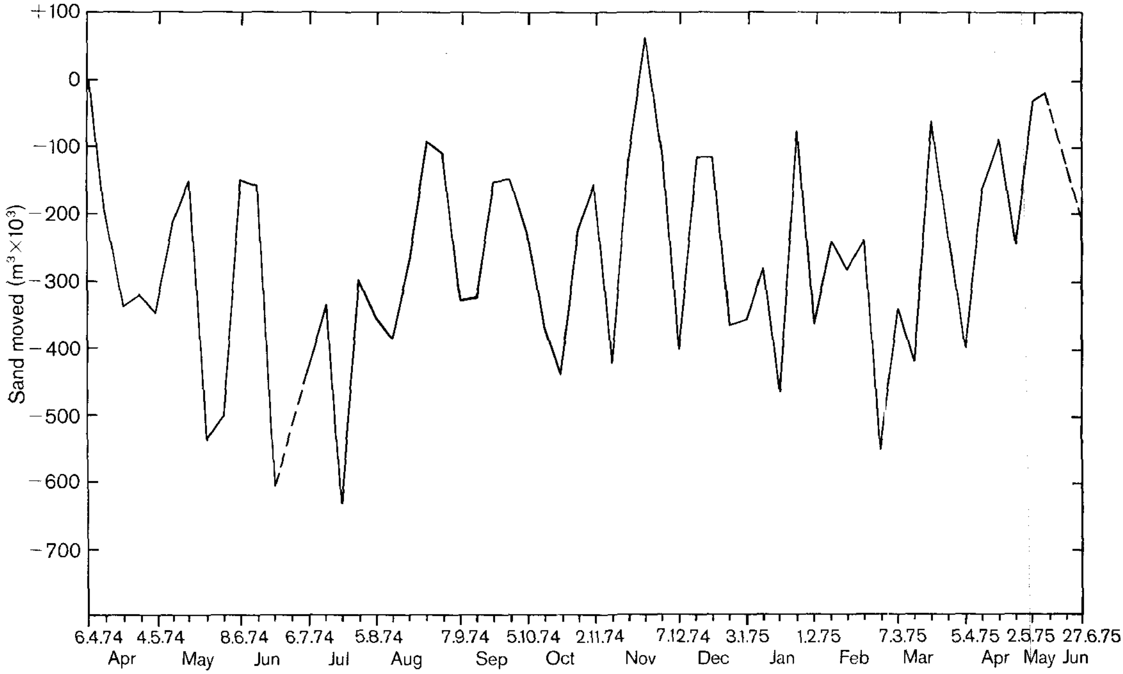

FIG. 6—Weekly variation in volume of beach sand moved, relative to 6 April 1974 (- - - - = break in record).

DUNE MORPHOLOGY

There is an increase in dune size towards the Bowentown end of the beach, indicating greater sediment accumulation and availability on this section of the beach. Dunes here also show instability, with some recent blowouts and some older stabilised transgressive and parabolic dune fields a short distance inland.

BEACH MORPHOLOGY

A persistent lack of a berm and a characteristic "eroded" profile typifies the northern end of the beach at Sites I and II. Regular berms appear in the central and southern sectors of the beach in association with cyclical "cut and fill" in the nearshore-beach-dune system.

ORIENTATION OF THE BOWENTOWN BAR

The Bowentown bar is morphologically a sub-tidal delta at the Bowentown entrance to Tauranga Harbour. The normal beach nearshore bar merges obliquely seawards to the Bowentown bar (Fig. 2). The main channel on the sub-tidal delta is located on its southern side, indicative of major sediment flux from the north.

HISTORICAL EVIDENCE OF FORMER HIGHER DUNES

Pipe (1967) refers to dunes "100 ft" high at Waihi Beach near the present surf club in the 1920s. These dunes no longer exist.

WIND RESULTANTS

In the mild swell environment of the Bay of Plenty, local wind generated waves are of considerable importance for generating longshore currents. Based on the wind data collected at Site II during the period of observation, both the overall and onshore wind resultants (Fig. 2) generate southerly components of wave-generated littoral drift in the breaking wave zone. The onshore wind resultant is particularly significant as it lies at an agle of 72° to the shoreline.

WAVE RESULTANTS

The wave resultant from records of wave height and direction data observed at Site II is inclined only 4° from normal to the beach towards the south. Although this resultant refers to refracted breaking waves it nevertheless indicates a tendency for southerly directed littoral drift.

The present mineralogical analyses did not conclusively show the direction of littoral drift. Further, although the sediments in the nearshore-beach-dune system apparently originated from the central Volcanic Plateau, yet the present net littoral drift is clearly south-eastwards.

We propose to account for this thus: Schofield (1965) argued for an increase in erosion during cold periods to account for the Hinuera sedimentation. While the finer points of his hypothesis can be debated (Hume *et al.* 1975), the very swift sedimentation during the Hinuera deposition would also have

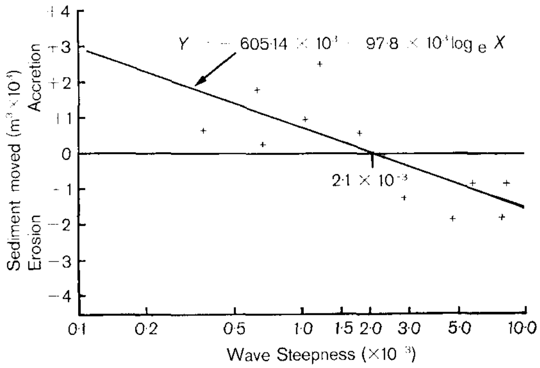

FIG. 7—Relationship between wave steepness (H_b/L_o) and the volume of beach sand eroded or accreted. The data were obtained from monitoring Waihi Beach daily for 11 d, April 1975.

occurred along the main rivers draining to the Bay of Plenty. Probably much of the sediment at present in the Holocene sandy barrier systems and deposits was injected into the littoral system at this time, when sea level was up to 100 m lower.

The CLIMAP Project (1976) reconstructions show that a very sharp thermal gradient existed across the central North Island during glacial conditions. As a result the "driving force" of the general circulation would have increased (Riehl 1962), and more cyclonic storms and cold air surges originating in the Southern Ocean, would have affected central New Zealand; there would have been more and stronger southerly winds. In the Late Pleistocene cooler climate, the net littoral drift would have been towards the northwest in the Bay of Plenty. Upon the post-glacial rise in sea level, the rapid onshore movement of this sediment resulted in the present extensive sand barrier formations along the Bay of Plenty coast, including Waihi Beach.

CONCLUSIONS

1. Beach erosion has been an expensive problem at Waihi, and with continued encroachment at Shaw Road, it will continue to be so. About 25 dwellings are presently at risk.

2. Erosion is not uniform along the 9 km of the straight barrier beach, but tends to be emphasised especially in the north and within localised minor embayments.

3. Average annual loss rates from Waihi Beach are about 3.4 m^3 per metre of beach per year, but rates of erosion in the localised most severely eroded areas seem to be about 13 $m^3.m^{-1}\,y^{-1}$.

4. The critical wave steepness for Waihi Beach is 2.1×10^{-3}. Waves steeper than this cause beach erosion.

5. Within the nearshore-beach-dune system, sediment fluxes may be extraordinarily large and rapid. From one closely monitored erosion episode, 628×10^3 m^3 or 70 m^3 per metre of beach were recorded as being removed from the beach in 6 d.

6. Littoral drift is clearly towards the southern end of the beach. Sediment probably moves southwards along the offshore bar onto the Bowentown subtidal delta, and either bypasses the entrance or moves into Tauranga Harbour. The drift rates along Waihi Beach are unknown.

7. Sediment on Waihi Beach is probably derived from the central North Island volcanic region. Littoral drift from the north is clearly not supplying much sediment to Waihi Beach as the sands of Orokawa Beach are distinctly different.

8. The ultimate cause of long term erosion at Waihi Beach is the excess of littoral drift potential over available sediment supply, and thus erosion and dune recession will continue.

TABLE 4—Summary of beach profile changes and sediment budget for Waihi Beach: sediment budget was determined by comparing the "most badly eroded" and the maximum accreted profiles at each site

Site and representative length	Sediment budget ($m^3.m^{-1}$ of beach)	Largest weekly erosive event ($m^3.m^{-1}$ of beach)	Largest weekly accretionary event ($m^3.m^{-1}$ of beach)	Net change 6.4.74–27.6.75 ($m^3.m^{-1}$ of beach)	Net beach volume change 6.4.74–27.6.75 (m^3)
Site I (900 m)	111.5	77.1 (22.6.74)	77.5 (8.6.74)	+ 6.1	+ 5 490
Site II (2 300 m)	93.0	56.2 (24.5.74)	36.9 (30.5.74)	− 2.7	− 6 210
Site III (3 400 m)	127.5	61.9 (20.7.74)	52.6 (22.3.75)	− 33.5	−113 900
Site IV (1 500 m)	161.7	70.8 (22.6.74)	53.5 (25.1.75)	+ 0.2	+ 300
Site V (900 m)	116.1	57.4 (24.5.74)	56.1 (28.7.74)	−116.1	−104 490
Total Beach (9 000 m)	93.98	49.75 (22.6.74)	39.64 (22.3.75)	− 24.31	−218 810

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