New Zealand Journal of Geology and Geophysics

ISSN: 0028-8306 (Print) 1175-8791 (Online) Journal homepage: http://www.tandfonline.com/loi/tnzg20

Wave disturbance and texture of beaches in Palliser Bay, southern North Island, New Zealand

Eric R. Matthews

To cite this article: Eric R. Matthews (1983) Wave disturbance and texture of beaches in Palliser Bay, southern North Island, New Zealand, New Zealand Journal of Geology and Geophysics, 26:2, 197-212, DOI: 10.1080/00288306.1983.10422517

To link to this article: http://dx.doi.org/10.1080/00288306.1983.10422517

New Zealand Journal of Geology and Geophysics, 1983, Vol. 26 : 197–212.

0028–8306/83/2602–0197$2.50/0

Wave disturbance and texture of beaches in Palliser Bay, southern North Island, New Zealand

ERIC R. MATTHEWS
Department of Geology
Victoria University of Wellington
Private Bag
Wellington, New Zealand*

Abstract A method using marker stakes and rings has been developed to measure the disturbance of beach sediments. Results of a study using this method in Palliser Bay reveal marked differences between the head of the bay, which is fully exposed to the prevailing southerly waves, and the eastern side of the bay, which is in a more sheltered position. At the head of the bay, wave conditions dominantly control diurnal variations in beach disturbance, but on the eastern side of the bay, the effect of rhythmic tidal translation of the breakpoint is more important. This is because of the wave-energy filtering effect of wave refraction and a subtidal rock and boulder reef.

At the head of the bay, diurnal fluctuations in the height of water tables within the beach are also dominantly controlled by the prevailing wave conditions. Water table levels were not studied on the eastern side of the bay, but it is expected that tidal fluctuations are dominant here.

At all 3 sites studied, disturbed sediment is predominantly of granule size, and disturbance on the lower part of the beach averages around 0.2 m. The maximum disturbance observed was 1.65 m.

Keywords waves; swash; beaches; disturbance; water tables; sand; gravel; Palliser Bay

INTRODUCTION

Detailed process-response studies have been carried out by Zeigler et al. (1959), Dolan & Ferm (1966), Strahler (1966), Harrison (1969, 1972), Kirk (1970, 1975), and others. Even though some of these studies used sophisticated measurement techniques, the relationships between process and response variables have been difficult to identify because of the great complexity of the littoral environment. In studies by the writer at Palliser Bay, the intention has been first to describe changes in beach morphology and texture quantitatively and then to develop a general understanding of the processes responsible for these changes.

Description of beaches in Palliser Bay

Palliser Bay is situated at the southern end of a 20 km wide block-faulted depression (Fig. 1). The downfaulted block is of Neogene mudstone which has been eroded by waves at the head of Palliser Bay to form sea cliffs, in front of which beaches of mixed sand and gravel have accumulated. The elevated blocks to east and west are of Mesozoic indurated greywacke and argillite and control the configuration of the sides of the bay. All the beaches, including those at the head of the bay, are composed of greywacke and argillite clasts.

At the head of the bay, the shoreline is gently curving, and beach sediments rest on a surface of relatively easily eroded mudstone. The submarine mudstone surface has been cut down to the level where it is no longer directly eroded by breaking waves, and there is a large volume of gravel in the subtidal break-point step. In contrast, beaches along the sides of the bay rest on resistant rock, and the shoreline is more irregular. Where the configuration of the bedrock allows, as at the mouths of streams and rivers, crescentic beaches have formed and are connected by narrow beaches, irregular in plan, and resting on a rock and boulder platform which may extend 100–200 m offshore. Waves often break on the offshore platform, and beach sediment is largely restricted to the intertidal zone, with very little moving across the subtidal platform.

Waves in Palliser Bay arrive predominantly from due south and are mostly about 0.5 m high with a period of about 9 s. Storm waves are often 2.0 m high and occasionally exceed 5.0 m (Matthews 1980, 1982). At the head of the bay, waves arrive relatively unmodified by refraction, and Ocean Beach and Whangaimoana (Fig. 1) are fully exposed to storm waves. The rocky eastern side of the bay trends north–south, and the beach at the mouth of Washpool Creek (Fig. 1) is partly protected by refraction.

The beaches tend to reflect rather than dissipate wave energy (see Wright et al. 1979) and have subtidal gravel steps beneath the breakpoint.

*Present address: New Zealand Oil and Gas, P.O. Box 3149, Wellington, New Zealand.

Received 25 August 1982, accepted 28 February 1983

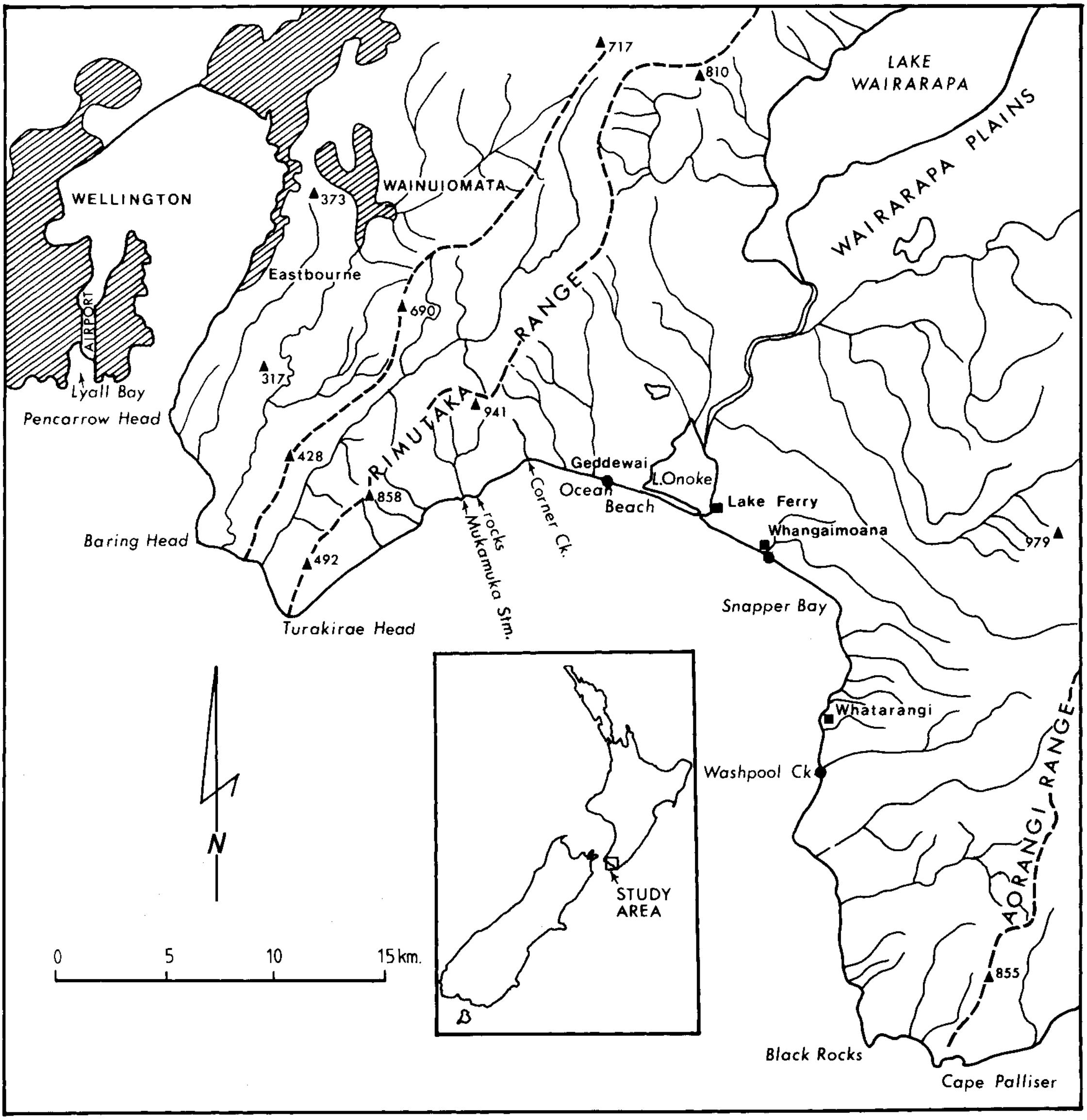


Fig. 1 Palliser Bay showing position (inset) and localities mentioned in the text. Dots mark locations of experimental sites.

Because of the mesotidal nature of the area (tidal range 0.9–1.2 m) and the relatively steep beach face slope (4–12°), the breakpoint is essentially stationary at the head of the bay. Major changes to the beaches are effected only by storm waves that sometimes produce swashes powerful enough to reach the berm crest, which is 5–6 m above and 60–70 m horizontally distant from the low water line. Along the sides of the bay, the berm crest is 3–4 m above and 20–40 m horizontally away from the low water line, increasing southwards with exposure to wave action.

Cusps are common features. They are particularly well developed at Whangaimoana where they generally have wavelengths of 50–70 m and amplitudes of about 1 m. Elsewhere, cusps are often present, but are smaller, rarely more than 20 m between crests and 0.5 m high.

METHODS

Initiation of the experiments

As part of a wider study of beaches in Palliser Bay (Matthews 1982), 3 sites were chosen for detailed study. At each site, pebble tracer experiments were conducted and daily observations of beach changes were made. The sites were therefore selected to be: (1) widely spaced; (2) representative of the range of beach types in the bay and; (3) accessible to trucks and heavy equipment. Sites selected (see Fig. 1) were at Ocean Beach (NZMS 260, metric grid reference R28/836787), Whangaimoana (NZMS 260, S28/914753), and Washpool (NZMS 260, S28/943655). Although it would have been desirable, it was not possible to conduct an experiment on the western side of the bay because of poor access.

At each site, a series of vertical steel pipes was set across the beach face to provide reference points for measurement of the beach profile and the depth of sediment disturbance. A tractor-mounted post driver was used to fix the pipes at 10 m intervals along a profile across the beach face between low water level and a point some distance landwards of the berm crest. This was done without significant disturbance of the beach. Each pipe was between 2.5 and 3.0 m long, with an outside diameter of 90 mm, and was driven into the beach leaving 1 m exposed. The vertical and horizontal position of the top of each pipe was then surveyed to an accuracy of ±5 mm.

Measurement of profiles and depth of disturbance

Changes in the beach profiles were determined by measuring the exposed lengths of the pipes each day. Depths of sediment disturbance were measured by using steel rings placed over each pipe. As the beach surface was lowered by wave action, the rings were able to move freely down the pipe, to be subsequently covered. The lowest position of the beach surface during the intersurvey period was determined by digging down to each ring and measuring its elevation. The difference between this and the height of the active beach was the depth of sediment disturbed since the previous visit.

Localised scouring occurred around the bases of the pipes, the zone of worst scour being within 50 mm of the pipes. Rings of 300 mm diameter, made from 8 mm rod, gave an average clearance of 100 mm around the pipes, so that most of each ring lay beyond the zone of worst scour.

After excavation, the height of the uppermost surface of the ring was measured, if the ring was lying parallel to the beach surface. If the ring was found to be tilted, the height of the horizontal midline of the plane of the tilted ring was measured. In fact, it was rare to find rings tilted at significant angles to the beach surface, and repeated measurements indicate an accuracy of better than ±30 mm.

At points low on the beach (and even high on the beach during storms) it was impossible to dig down to the rings because of the swash and backwash. In those cases, a hooked probe 1.3 m long, made of 15 mm galvanised pipe, was used. Once the ring was caught on the hook, the length of shaft exposed above the beach surface was measured and the depth of disturbance determined directly. Because the orientation of the ring was unknown, an accuracy of ±60 mm is claimed for these measurements. The height of the beach surface was measured to an accuracy of ±10 mm.

At Washpool, it was necessary to use 2.5 mm lengths of railway iron instead of the steel pipe in order to overcome the greater resistance to penetration caused by cobbles and boulders in the beach. Some of the pipes low on the beach at each site were lost in storms and were replaced as required with 2.0 m lengths of 23 mm O.D. galvanised steel water pipe which were driven into the beach by hand, leaving about 0.7 m exposed. These generally lasted only a few weeks, but this was long enough to be useful. Hand-driven pipes were also installed higher up on the beach to provide supplementary information.

From the profile data at each site a level was established above which reliable estimates of the cross-sectional area of disturbance of the beach could be consistently made. The height of this level was determined by the accessibility of stakes low on the profile during storm events and was 0.5 m above the position of Chart Datum estimated by reference to ocean water level at Washpool, 1.5 m at Whangaimoana, and 1.0 m at Ocean Beach. After plotting the data, the cross-sectional areas of disturbance were determined by cutting tracing paper to the shape of the disturbed area and weighing on a precision balance. The gradient of the active part of the beach was also calculated.

Sediment texture

During March and August 1980, representative samples of the sediment disturbed during 24 h since the previous day were collected by sampling sediment deposited above the level of the buried rings, at 5 m intervals across the beach face. As in a core, the volume of each sample was proportional to the depth of disturbance, so that all samples from the profile could be combined to produce a composite representative of the disturbed sediment. Each sample was washed, dried, and sieved at 0.5 ϕ intervals, according to the methods described in Folk (1968). Moment measures were computed using the programm GRAINSIZE described by Adams (1977).

Beach water tables

To permit measurement of water levels, the ends of the beach marker pipes were squeezed and welded shut to exclude sediment during installation. Holes of 10 mm diameter were drilled at 0.5 m intervals over the lowest 1.5 m of pipe to allow free flow of water, and on the exposed end of each pipe a steel cap was fitted to reduce sediment infill by swash action. Water levels were measured to an accuracy of ±30 mm using a lightweight graduated aluminium rod with a float attached to its lower end. Measurement was possible in most pipes for about 4 months, but some pipes low on the beach were filled with sediment sooner than this.

Swash parameters

The limit of swash action between consecutive visits was determined by inspection of the beach surface and by the disposition of the rings. Lengths of individual swashes were measured to an accuracy of ±1 m using the pipes as a scale. **Swash period** including both runup and backwash, is defined here as the time between formation of the runup and the development of a water film after the backwash, and was measured with a stopwatch. During and after August 1980, the **runup period**, defined as the time between development of the runup and the point of zero velocity between runup and backwash, was also measured. Measurements of swash length and period were repeated at least 20 times and average values calculated.

Some subjectivity was involved in the measurement of swash and runup periods, especially when there was interference between a returning backwash and the next wave, or when well-developed cusps influenced the circulation of water. A brief test indicated that observation by 1 observer could be repeated to an accuracy of ±0.1 s, and that those by different observers could be repeated to ±0.5 s. Overall, the error involved in measurement of swash and runup periods was probably less than ±5%.

Wave parameters

To determine wave period, the average time between breaking of 11 waves was measured with a stopwatch. Occasionally it was difficult to pick out individual wave crests, and sometimes 2 wave trains were present. The former situation was rare, but the latter often occured at Washpool when strong northwesterly winds created local waves large enough to interfere with refracted southerly swell waves. Under these conditions, repeated observations were made in an attempt to determine the period of each wave train.

Daily estimates of wave height were made at a point 1.3 km offshore from Lake Ferry, in 10 m of water, by measuring the rise and fall of a moored buoy, using a telescope with a graduated eyepiece. During storm conditions it was sometimes impossible to see the buoy, so hindcast estimates of deep-water wave height, made by the New Zealand Meteorological Service for a point 65 km due south of Turakirae Head, were used.

Breaker height was estimated for each site by correcting the wave height for local refraction effects (see Matthews 1982) and then using the method described in the Shore Protection Manual (Coastal Engineering Research Centre 1977) to estimate the modification due to shoaling. Breaker celerity and energy were then computed by the solitary wave theory (Munk 1949) using the equations:

$$C_b = \sqrt{[g\ (H_b \times h_b)]}$$

and $$E_b = {}^8\!/\!_3 \rho g h_b^{\,3}\ \gamma\sqrt{(\gamma/3)}$$

where C_b = breaker celerity, g = acceleration of gravity (9.81 m/s), H_b = breaker height, h_b = water depth at breakpoint, E_b = energy of breaking wave, ρ = water density − 1.024×10^3 kg/m^3, $\gamma = H_b/h_b$ = 0.78.

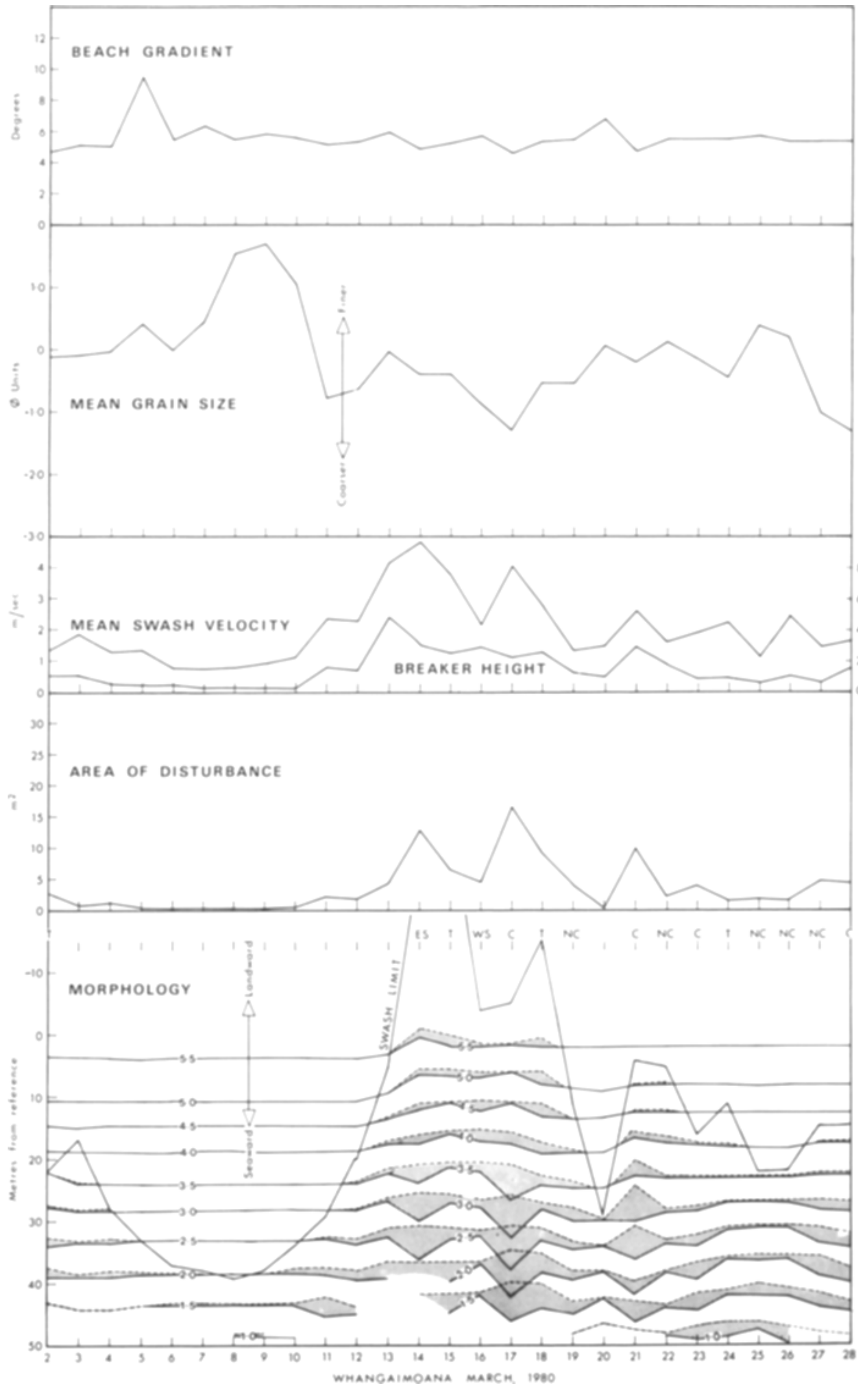
RESULTS AND DISCUSSION

Daily variation in beach form

The observations described in the previous section were made daily for 4 weeks at Whangaimoana and Ocean Beach in March 1980 and at Whangaimoana and Washpool in August 1980 and are summarised in Fig. 2–5.

At the 2 sites at the head of the bay, the disturbance of beach sediment varied from day to day in a fashion clearly related to the wave and

Fig. 2 *(opposite)* Daily variation in morphology, depth, and area of disturbance, breaker height, swash velocity, grain size, and gradient of the active beach at Whangaimoana, March 1980. Beach morphology and depth of disturbance data are presented in the form of time-space contour diagrams. Contours are in metres above the reference level for each site. The space between the contours that represent the active beach surface and those that represent the lowest intersurvey level of the beach has been hachured, and is proportional to the depth of disturbance. The horizontal reference is the position of the most landward pipe driven into the beach. Cusp positions are noted as follows: C = line of pipes on cusp horn; T = line of pipes on cusp trough; NS, SS, ES or WS = line of pipes are north, south, east or west of cusp horn; NC = no cusps.


BEACH GRADIENT
Degrees
MEAN GRAIN SIZE
Ø Units
Finer
Coarser
MEAN SWASH VELOCITY
m/sec
BREAKER HEIGHT
Breaker height (m)
AREA OF DISTURBANCE
m2
MORPHOLOGY
Metres from reference
Landward
Seaward
SWASH LIMIT
ES T WS C T NC C NC C T NC NC NC C
WHANGAIMOANA MARCH, 1980

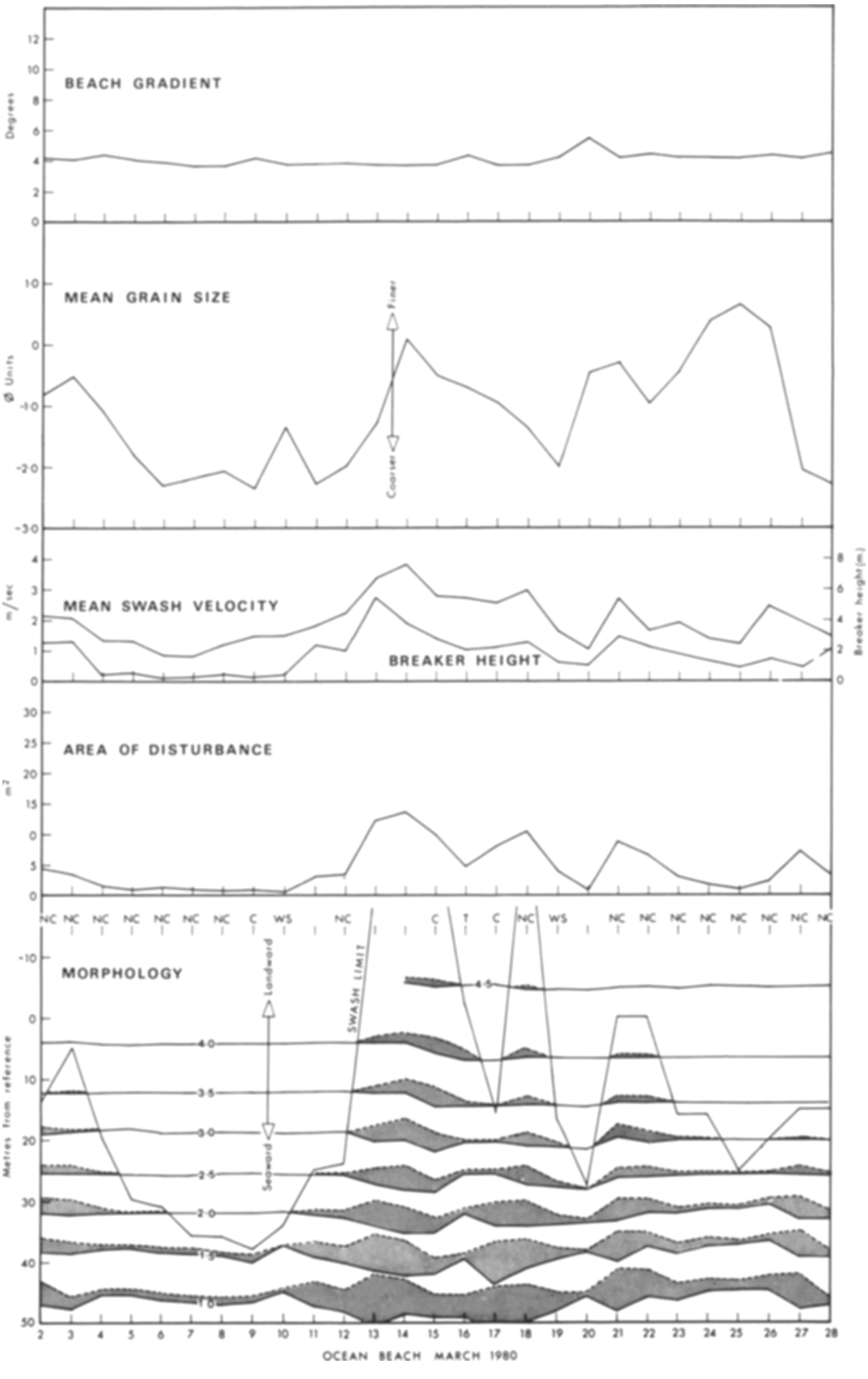


Fig. 3 Daily variation of the active beach at Ocean Beach, March 1980. (See caption of Fig. 2 for details.)

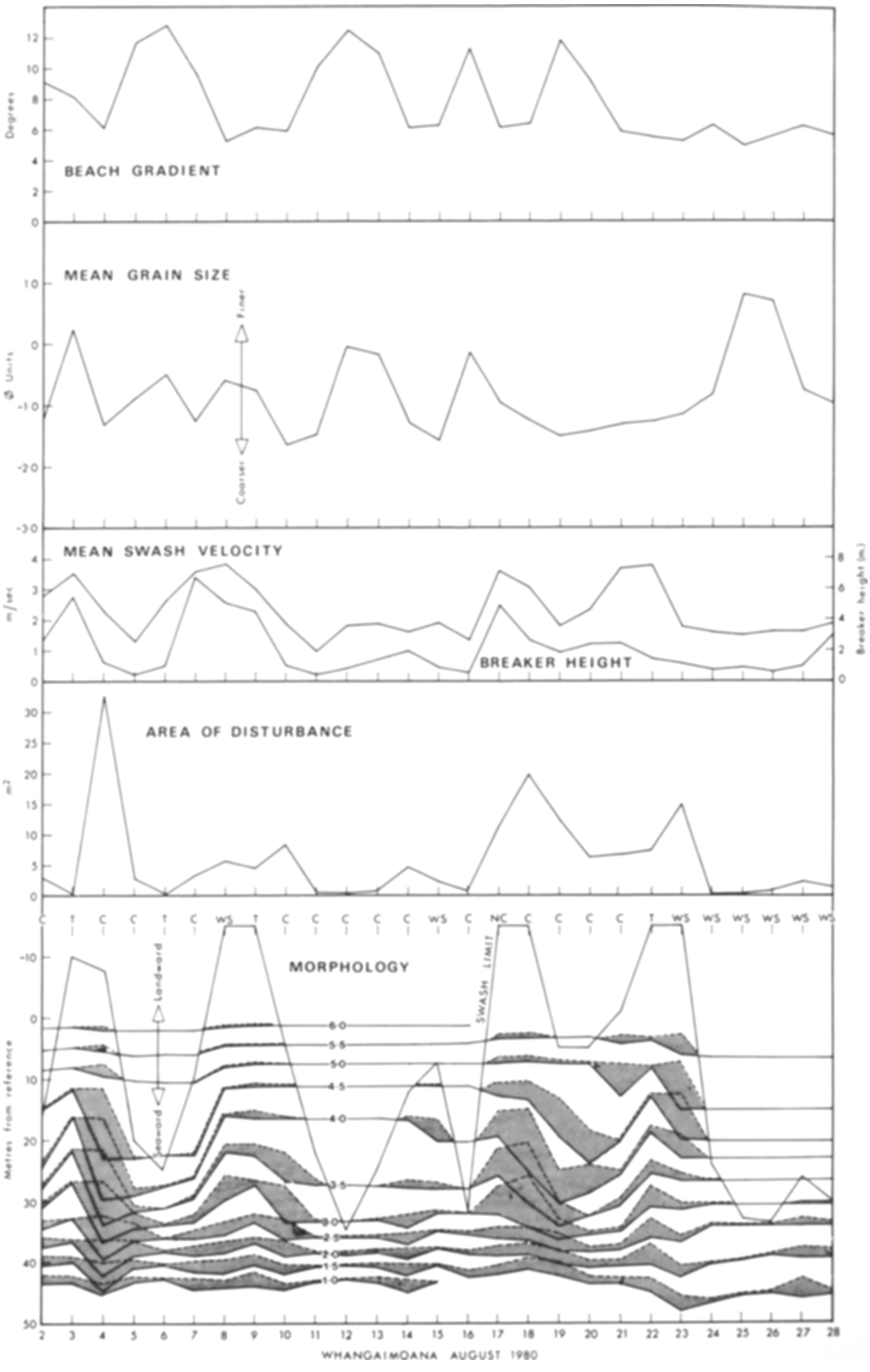


Fig. 4 Daily variation of the active beach at Whangaimoana, August 1980. (See caption of Fig. 2 for details.)

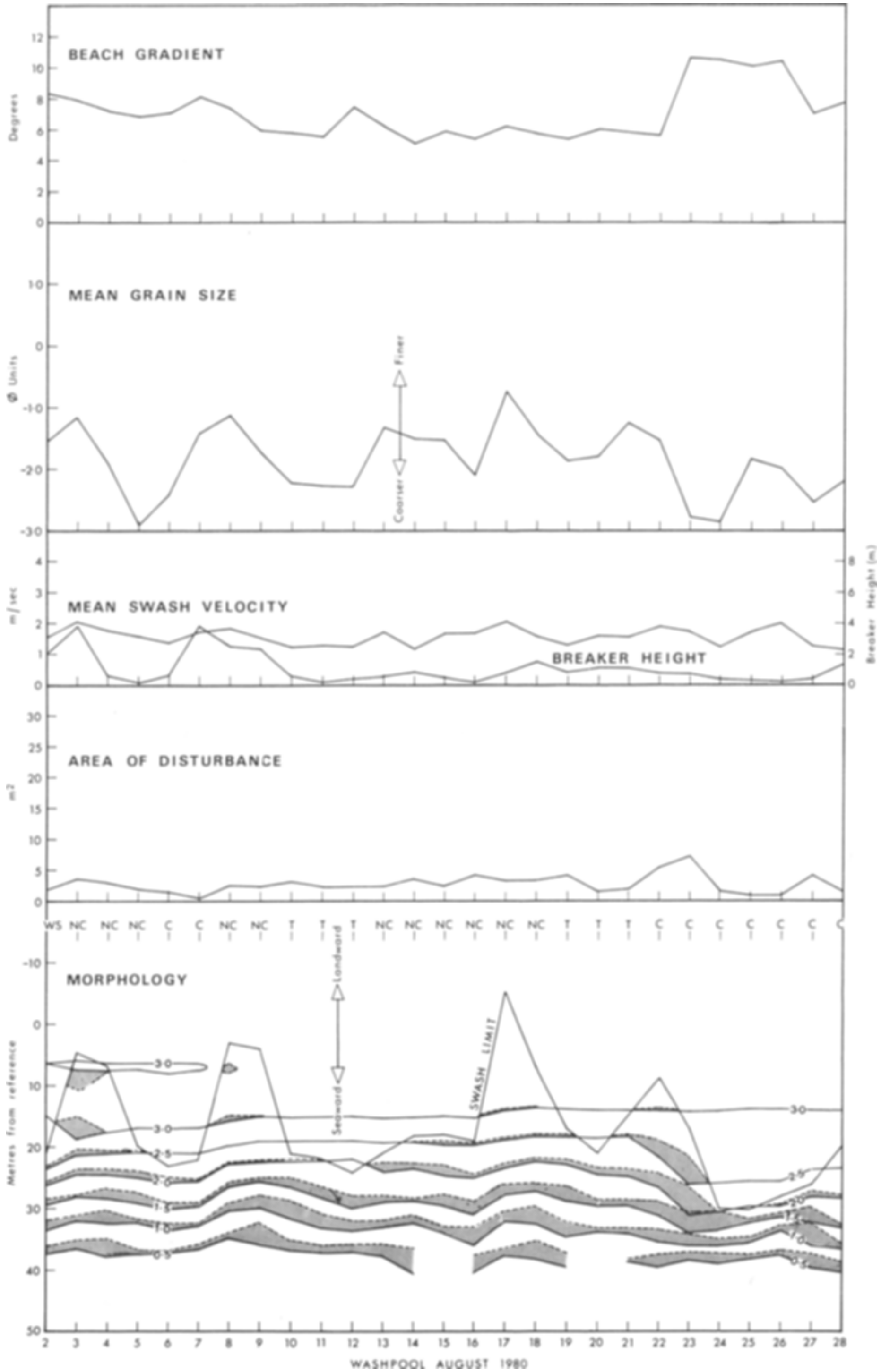


Fig. 5 Daily variation of the active beach at Washpool, August 1980. (See caption of Fig. 2 for details.)

swash conditions (Table 1). Such behaviour is typical of mixed sand and shingle beaches (see Kirk 1980, p. 194). It is best seen in the data collected during March at Ocean Beach and Whangaimoana. During August at Whangaimoana, the wave conditions were more strongly correlated with the area of disturbance measured the following day than with the disturbance measured at the same time as the wave conditions. This was caused by sequential changes of the beach. After the beach had been eroded by storm waves, the rings were left near the surface of the beach and a small cross-sectional area of disturbance would be measured. Subsequently, landwards transfer of sediment or cusp migration would cover the rings with a considerable thickness of sediment, and a large amount of disturbance would be recorded.

In March there was 1 6-day period of storm conditions during the middle of the month, whereas in August, there were 2 short events of 2 days each at the beginning of the month and a 6-day period towards the end (Fig. 2 and 4). The greater frequency of storm periods interrupting sequential changes is probably the reason for the poor correlation of the August data from Whangaimoana.

Table 1 Correlation coefficients and probabilities of no correlation for linear relationships between daily measurements of breaker height, swash velocity, and area of disturbance at the 3 sites during March and August 1980.

	Swash velocity	Area of disturbance in the preceding 24 h	Area of disturbance in the following 24 h
Ocean Beach (March 1980)			
Breaker height	$r=0.84$ $p \ll 0.001$	$r=0.83$ $p \ll 0.001$	$r=0.68$ $p \ll 0.001$
Swash velocity	—	$r=0.88$ $p \ll 0.001$	$r=0.69$ $p \ll 0.001$
Washpool (August 1980)			
Breaker height	$r=0.33$ NS	$r=0.17$ NS	$r=0.09$ NS
Swash velocity	—	$r=0.09$ NS	$r=0.17$ NS
Whangaimoana (March 1980)			
Breaker height	$r=0.83$ $p \ll 0.001$	$r=0.63$ $p<0.001$	$r=0.70$ $p \ll 0.001$
Swash velocity	—	$r=0.77$ $p \ll 0.001$	$r=0.70$ $0.01>p>0.001$
Whangaimoana (August 1980)			
Breaker height	$r=0.78$ $p \ll 0.001$	$r=0.03$ NS	$r=0.57$ $0.01>p>0.001$
Swash velocity	—	$r=0.18$ NS	$r=0.61$ $p<0.001$

The poor correlation observed at Washpool can not be explained in the same way. The rock and boulder platform at Washpool causes significant tidal translation of the breakpoint. The translation effect is greater on large waves than on small waves and so acts as a wave energy filter. This process reduced day-to-day variation, so that the swash velocity and area of disturbance remained nearly constant and were not simply related to the wave conditions.

Depth of disturbance

The amount of disturbance increased seawards down the beach face towards the breakpoint (Fig. 6). The maximum daily depth of disturbance recorded was 1.25 m on 4 August at Whangaimoana. The average daily depth of disturbance rarely exceeded 0.20 m, even on the lowest part of the beach. At Whangaimoana on 17 March, 20 m seawards of the reference, 0.5 m thickness of sediment accumulated in 1 h. This gives some indication of the potential speed of the processes that cause beach profile changes.

At the head of the bay (Ocean Beach and Whangaimoana) the average depth of disturbance increases more or less evenly seaward. At Washpool, on the eastern side of the bay, the average depth of disturbance increases greatly at a position 39 m seaward of the reference. This irregularity was caused by the periodic movement of sediment in response to rhythmic tidal fluctuations.

At Whangiamoana there was more disturbance during August than during March, a result of the greater frequency of storm events during August.

From the observations presented in Fig. 2–5, it is apparent that cusps are highly mobile features that can be formed or destroyed within 24 h. Particular changes are hard to explain, but it is generally true that the major changes occurred during and immediately after storms.

Swash conditions

Mean swash velocities calculated daily for the combined runup–backwash flow ranged from 0.76 m/s to 4.84 m/s. Average values calculated for each month of observations were about 2.0 m/s at the head of the bay and 1.6 m/s at Washpool (Table 2). Kirk (1975) measured swash and backwash velocities with a flow meter at the midswash position on 2 Kaikoura beaches. He found that the runup velocities ranged from 0.5 to 2.5 m/s and averaged 1.68 m/s, while backwash velocities averaged 1.4 m/s. However, these measurements did not include the high-velocity flows below the midpoint of the swash, which may explain the slightly higher values recorded from Palliser Bay.

Kirk (1975) also made measurements of the

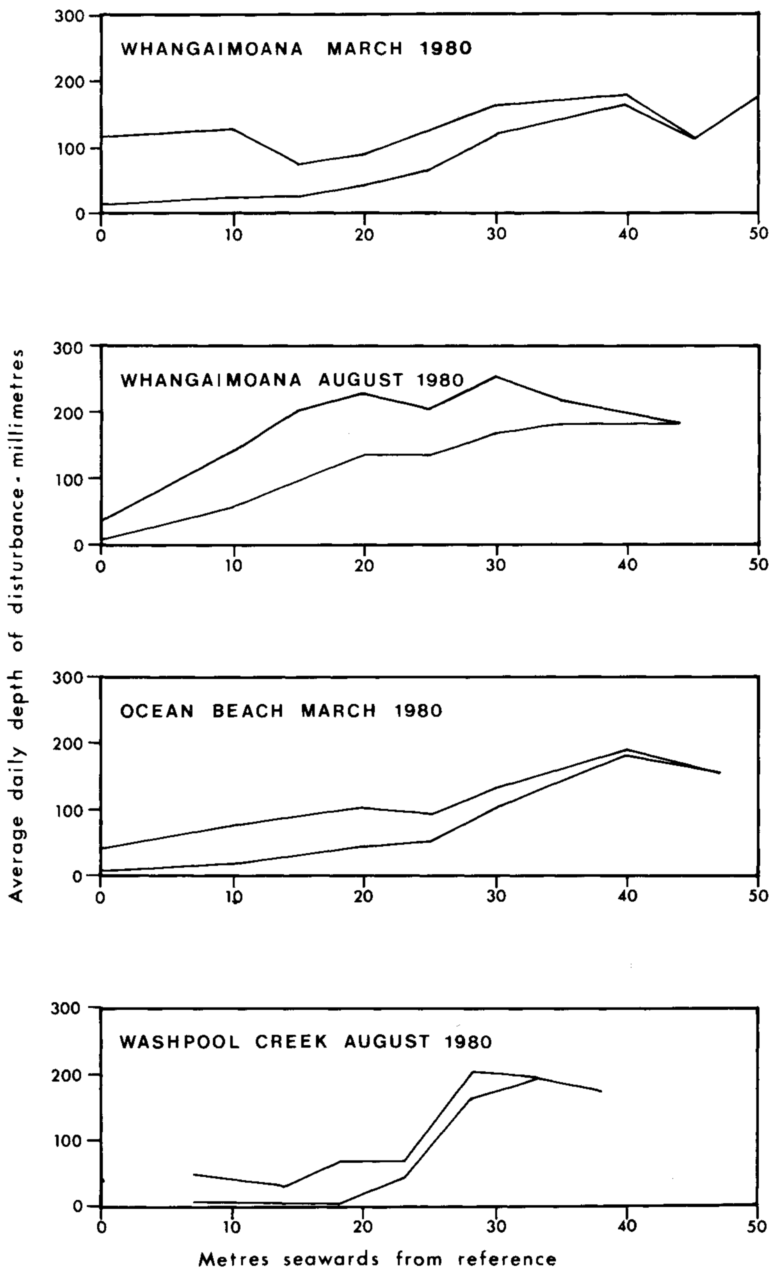


Fig. 6 Average daily depth of disturbance at each of the 3 sites. The lower line is the average for all days in the month and the upper line is the average for only those days on which some disturbance was recorded. The width between the lines is inversely related to the frequency of disturbance.

breakers and found that the efficiency of transmission of breaker velocity to swash velocity decreased as the breaker energy increased.

A similar negative relationship was determined by the writer at Palliser Bay (Fig. 7), and was found to be strongest at Washpool. As breaker energy increases, an increasing loss of energy through vertical water movement and turbulence is thought to decrease the efficiency of velocity transmission. The strong relationship at Washpool results because the rock and boulder platform causes the larger more energetic waves to break far from the shore, greatly decreasing the efficiency of velocity transmission.

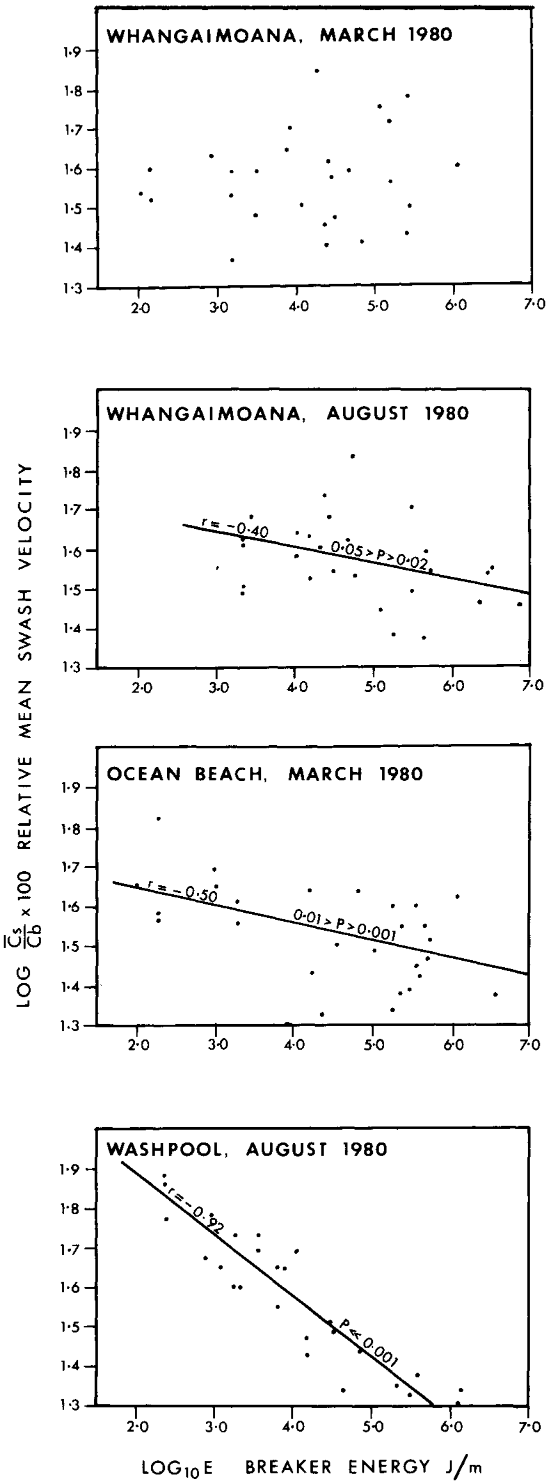


Fig. 7 Relationship between relative mean swash velocity and breaker energy.

Table 2 Overall means of daily mean swash velocities determined during March and August 1980 (m/s). n = number of observations; x̄ = mean; s = standard deviation.

	n	x̄	s
Whangaimoana March 1980	28	2.02	1.07
Whangaimoana August 1980	28	2.28	0.87
Ocean Beach March 1980	28	1.95	0.75
Washpool August 1980	28	1.58	0.27

Beach water tables

It was possible to measure changes in the level of water saturation in the beach only during March 1980, before the pipes were filled with sediment. Water levels were found to oscillate with a lag of 2–3 h behind the tides (cf. Emergy & Foster (1948) and Ericksen (1970)), but more important changes were caused by varying wave conditions (Fig. 8 and 9). During the storm in the middle of March, the water tables were elevated by the long swashes reaching far up the beach face.

Texture of the disturbed sediment

To determine the "average" texture of sediment regularly moved by waves at each site, each daily composite sample was weighted according to the cross-sectional area of disturbance measured along the profile on that day. The weighted values in each size fraction were then summed for the month of daily observation at each site, yielding grain-size distributions of the disturbed sediment (Fig. 10). These show that granules form the modal size fractions of mobile beach sediments in Palliser Bay. Pebbles comprise between 10 and 37%, granules between 27 and 35%, and medium–coarse sand between 17 and 64% by weight (Table 3).

At Whangaimoana, the mobile sediment was coarser and better sorted in August than in March. The change resulted from the removal of medium and coarse sand, rather than from the introduction of coarser sediment, and was probably caused by the greater frequency of storm events in August than in March. The average slope of the active beach face was steeper in August (7.7°) than in March (5.6°). A corresponding increase in size and sorting associated with an increase in beach slope has been reported by many workers including Bascom (1951) and McLean & Kirk (1969).

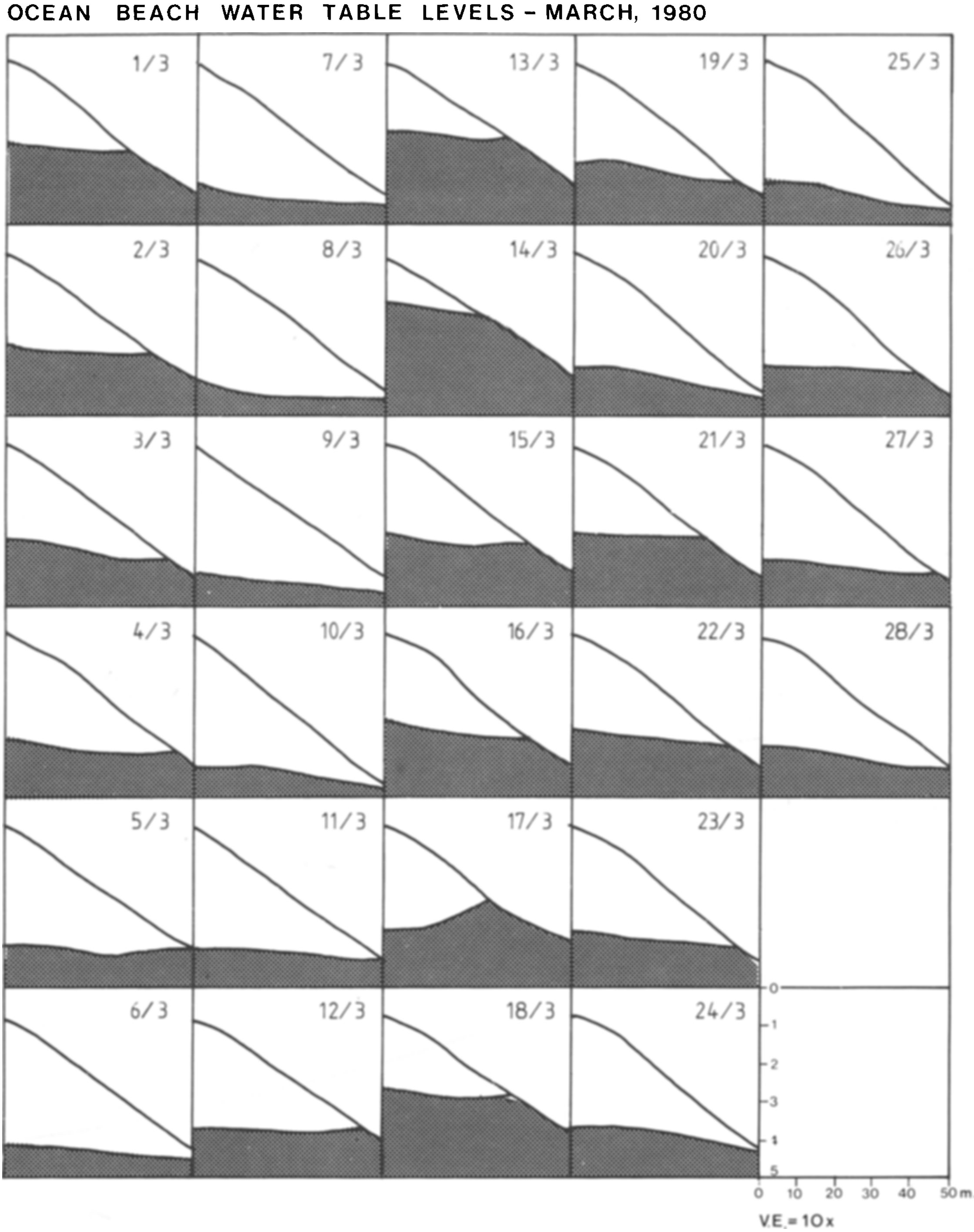


Fig. 8 Daily variation in beach water table levels at Ocean Beach during March 1980. The hachured area represents that part of the beach cross-section saturated by water.

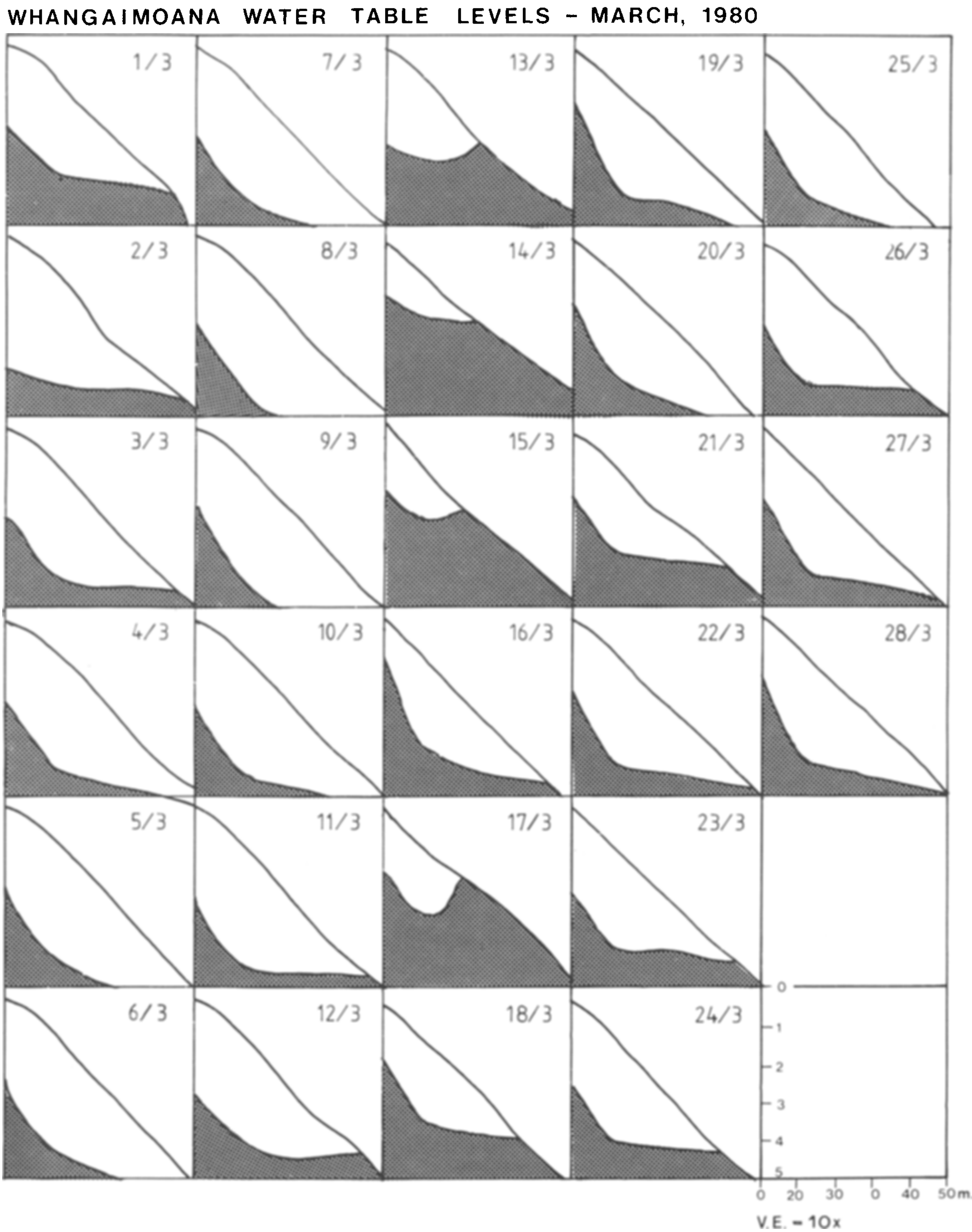


Fig. 9 Daily variation in beach water table levels at Whangaimoana during March 1980.

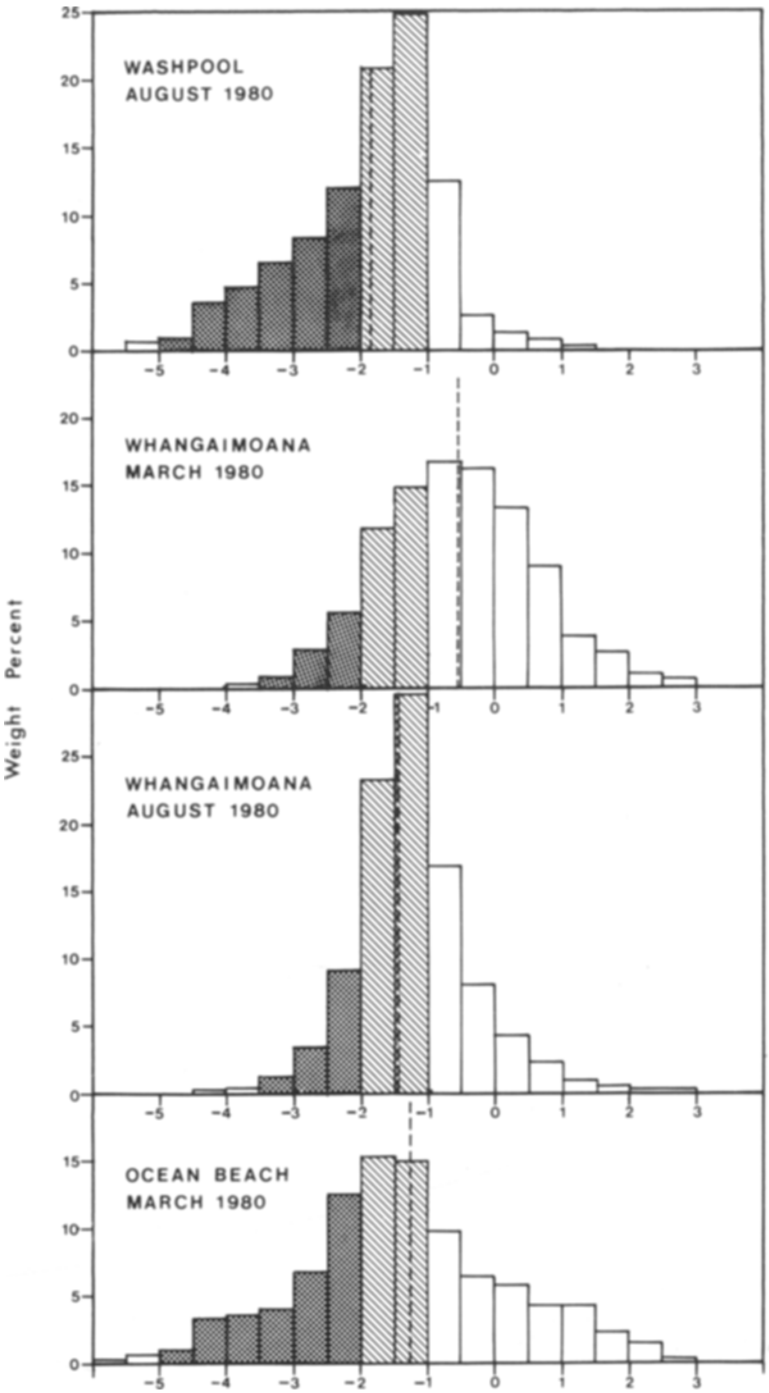


Fig. 10 Grain-size distributions of sediment disturbed by waves during the month of observation at each site. Pebble and granule size fractions have been hachured. Mean grain size is indicated by the dashed lines.

Table 3 Texture of the mobile beach at each site.

		Mean grain size (ϕ)	Sorting	Percentage of pebbles	Percentage of granules	Percentage of sand
Whangaimoana	March	−0.55	1.17	9.6	26.6	63.8
Whangaimoana	August	−1.22	0.84	14.0	52.8	33.1
Ocean Beach	March	−0.98	1.62	22.5	27.7	49.5
Washpool	August	−1.88	1.09	36.7	45.8	17.3

CONCLUSIONS

There are significant differences between the reflective beaches at the head of Palliser Bay and the occasionally reflective beaches on the sides of the bay. During storms and at low tide, waves break on a rock and boulder platform along the sides of the bay so that the gravelly beach and nearshore reef together function like a dissipative beach. Because of the wave-energy filtering effect, the offshore wave conditions are not closely related to disturbance of the beaches here, in contrast to the situation at the head of the bay.

The beaches are most frequently disturbed nearest to the breakpoint, where, at all sites, the average depth of disturbance is around 0.2 m. The maximum depth of disturbance recorded was 1.25 m and was the result of cusp development near the middle of the beach face. These values are rather greater than the 50 mm maximum recorded by King (1951).

The disturbed sediment is a mixture of sand and gravel and is predominantly of granule size. It is best sorted at Whangaimoana where the beach-face slope is generally steeper than at the other 2 sites. The sorting of sediment at Whangaimoana improved during August when less sand was present on the beach because of the greater frequency of storm events.

ACKNOWLEDGMENTS

The paper reports part of a Ph.D. project carried out at the Department of Geology, Victoria University of Wellington. It was funded by the National Water and Soil Conservation Organisation of the Ministry of Works and Development and a University Grants Committee postgraduate scholarship.

I thank Dr P. J. Barrett for his interest, advice and constructive criticism of the manuscript, and Dr R. A. Pickrill for help during the formative stages of the project. Professor P. Vella also made useful comments on the manuscript. Val Hibbert did the typing and Dale Rudman drew the figures.

REFERENCES

Adams, J. 1977: Computer processing of grainsize data *Geology Department, Victoria University of Wellington publication No. 6.* 21 p.

Bascom, W. H. 1951: The relationship between sand size and beach face slope. *Transactions of the American Geophysical Union 32* : 866–874.

Coastal Engineering Research Centre 1977: Shore protection manual. 3rd ed. Washington D.C., U.S. Army Corps of Engineers, 3 vols.

Dolan, R.; Ferm, J. 1966: Swash processes and beach characteristics. *Professional geographer 18* : 210–213.

Emery, K. O.; Foster, J. F. 1948: Water tables in marine beaches. *Journal of marine research 7* : 644–653.

Ericksen, N. J. 1970: Measurement of tide induced changes to water table profiles along Pegasus Bay, Canterbury. *Earth science journal 4* : 24–31.

Folk, R. L. 1968: Petrology of sedimentary rocks. Austin, Texas, Hemphill's, 170 p.

Harrison, W. 1969: Empirical equations for foreshore changes over a tidal cycle. *Marine geology 7* : 529–551.

——— 1972: Changes in foreshore sand volume on a tidal beach; role of fluctuations in water table and ocean still-water level. *Proceedings 24th International Geological Congress, Canada* : 159–166.

King, C. A. M. 1951: Depth of disturbance of sand on sea beaches by waves. *Journal of sedimentary petrology 21(1)* : 131–140.

Kirk, R. M. 1970: Swash zone processes: an examination of water motion and the relations between water motion and foreshore response on some mixed sand-shingle beaches, Kaikoura, New Zealand. Unpublished Ph.D. thesis lodged in the Library, Canterbury University, Christchurch, 378 p.

——— 1975: Aspects of surf and runup processes on mixed sand and gravel beaches. *Geografiska Annaler series A57(1)* : 117–133.

——— 1980: Mixed sand and gravel beaches morphology, processes and sediments. *Progress in physical geography (London) 4(2)* : 189–210.

McLean, R. F.; Kirk, R. M. 1969: Relationships between grain size, size-sorting and foreshore slope on mixed sand-shingle beaches. *New Zealand journal of geology and geophysics 12* : 138–155.

Matthews, E. R. 1980: Observations of beach gravel transport, Wellington Harbour entrance, New Zealand. *New Zealand journal of geology and geophysics 23* : 209 – 222.

——— 1982: Dynamics of mixed sand and gravel beaches between Cape Palliser and Wellington, New Zealand. Unpublished Ph.D. thesis lodged in the Library, Victoria University of Wellington, Wellington, 324 p.

Munk, W. H. 1949: The solitary wave theory and its application to surf problems. *Annals of the New York Academy of Science 51(3)* : 376 – 424.

Strahler, A. N. 1966: Tidal cycle of changes on an equilibrium beach. *Journal of geology 74* : 247 – 268.

Wright, L. D.; Chappell, J.; Thom, B. G.; Bradshaw, M. P.; Cowell, P. 1979: Morphodynamics of reflective and dissipative beach and inshore systems: southeastern Australia. *Marine geology 32* : 105 – 140.

Zeigler, J. M.; Hayes, H. R.; Tuttle, S. D. 1959: Beach changes on outer Cape Cod, Massachussetts. *Journal of geology 67(3)* : 318 – 335.