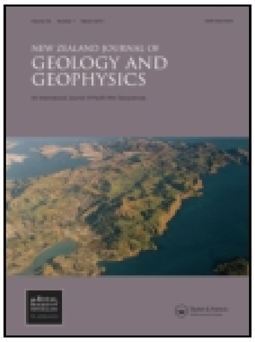

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ENVIRONMENTALLY SIGNIFICANT SEDIMENTOLOGIC CHARACTERISTICS OF BEACH SANDS

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ABSTRACT

Comparative study of five South Island beaches and a beach on the central Texas coast suggests a short list of features that are diagnostic of the coastal beach. Beach sediments are clean (no mud matrix) and are very well to moderately well sorted. Foreshore strata occur as even, internally laminated, thin beds that dip seaward at low angles. The angle of dip is directly related to the slope of the foreshore surface (especially the beach face), which in turn is largely dependent upon the mean size of the beach sediment, that is, the coarser the grain size the steeper the foreshore. Backshore strata occur as lens- and slightly wedge-shaped, internally laminated thin beds. Scour surfaces and cross-stratified lenses are characteristic. Dip of strata varies from 0° to 15°, and strata dip directly or obliquely landward. A transition zone (foreshore or above high tide level plus outer backshore) is characterised by mixed foreshore and backshore stratification, and some strata dip landward, others dip seaward.

Contrary to the widely held view that grain size distributions of beach sediments are negatively skewed, many beaches furnish positively skewed distributions. We conclude that skewness is not necessarily an environment-sensitive measure, and that skewness values commonly reflect grain size characteristics inherited from the source rocks.

INTRODUCTION

In the interpretation of the origin, especially of the environment of deposition, of ancient sedimentary rocks, sedimentologists are making increasing use of clues provided by studies of modern depositional environments. As studies of modern environments multiply, the list of criteria diagnostic of any one environment is repeatedly reviewed, and is refined as necessary. This report describes features that are common to five New Zealand examples of one modern depositional environment, the coastal beach. Observations from these examples are compared with data obtained by Andrews from a beach on St Joseph Island, central Texas coast, Gulf of Mexico, and with published data from Mustang Island, south of St Joseph Island (Mason and Folk, 1958; Milling and Behrens, 1966).

Five South Island beaches were sampled, three on the west coast, and two on the east coast (Fig. 1). There is considerable variation among them in physiographic setting, beach morphology, sediment size, nature of the source rocks, and hydrological setting.

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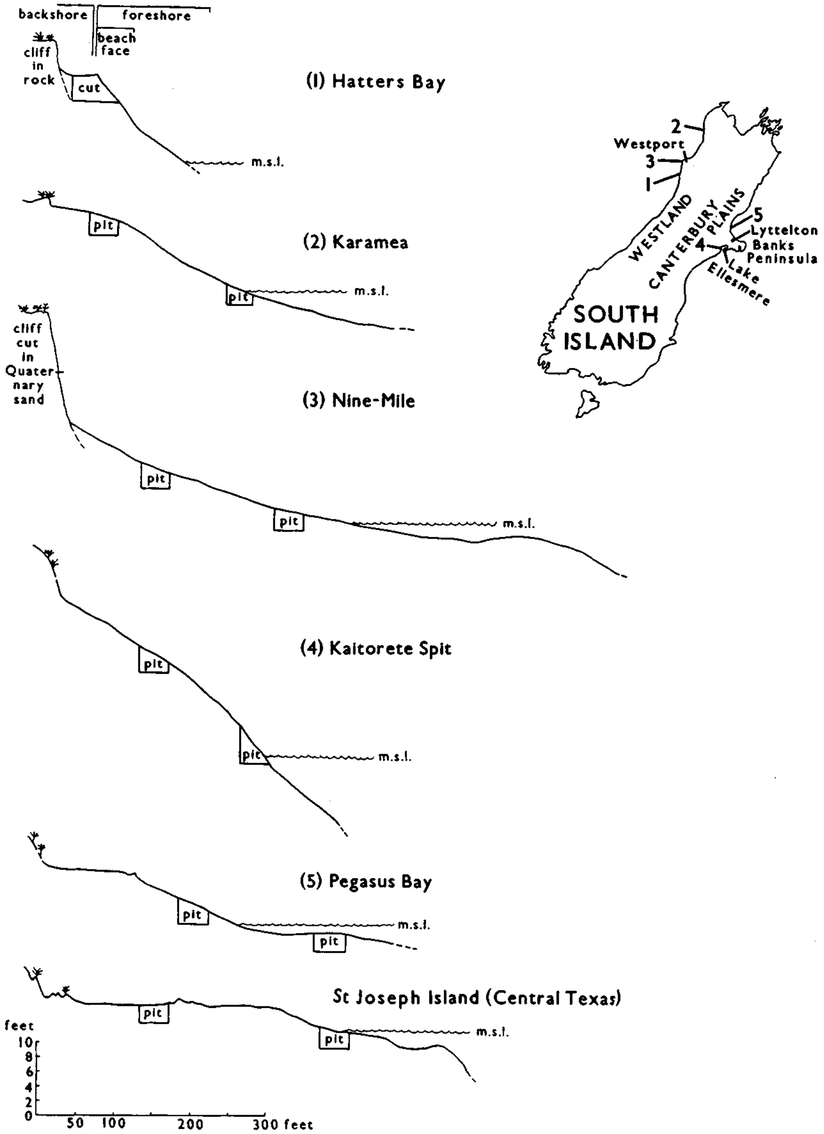

FIG. 1—Beach profile for each locality. The basic beach terminology is given as it applies to the Hatters Bay profile. The geographical location of each South Island beach studied, and the place names cited in the text are shown on the outline map. The Kaitorete Spit profile was supplied by Mr R. Kirk, University of Canterbury. The "pits" and "cut" were made to observe underlying strata, e.g., as in Fig. 2.

WEST COAST BEACHES

Hatters Bay is a small bay beach backed by a rock cliff 2 m high, and defended by rock promontories at each end. The beach is narrow and clearly divisible into a flat or landward-sloping backshore and very steep foreshore*. Beach sediment is a mixture of coarse to very coarse sand and granules.

Karamea and Nine-Mile Beaches both border narrow coastal plains that consist of unconsolidated Quaternary sand and gravel. Karamea Beach is divisible into a moderately steep foreshore (gradient of 1 in 13) and a narrow backshore, which is covered with low dunes and which grades into the coastal plain. Large beach cusps are characteristic. The distance from horn to horn was 70 m in May 1967, and 40 m in October 1967. Beach sediment is coarse to fine sand, with medium sand predominant.

Nine-Mile Beach, south of Westport, is a straight, wide beach composed of fine to very fine sand. It is backed by a 5 m cliff cut in sand. The beach cross-profile (Fig. 1) is not divisible into foreshore and backshore. Instead, the beach surface is smooth and slopes regularly seaward, at an ever-decreasing gradient.

All three west coast beaches are oriented north–south, and appear to be exposed to the same hydrological conditions. They are exposed both to the strong and persistent south-west swell that originates in the Southern Storm Belt (Davies, 1964), and to the predominant south-west wind. Strong north-moving longshore drift affects the whole coastline (Furkert, 1947). Records from the Westport tide gauge station show that tides are semi-diurnal with a mean spring tidal range of 3 m (Marine Department, 1966).

A diverse range of rock types probably contributes detritus to all three beaches. Granite gneiss, granite, and Mesozoic and Tertiary–Quaternary sedimentary rocks crop out near and south of both Hatters Bay and Nine-Mile. Gill (*in* McPherson, in press) suggests that some detritus that reaches Nine-Mile Beach is derived via northerly longshore drift from garnetiferous amphibolite schist that crops out in inland South Westland. If that deduction is correct, then the same detritus reaches Hatters Bay. Similarly, rivers near and not far to the south of Karamea must supply detritus from granite, granodiorite, extrusive volcanic rock of Paleozoic age, and sedimentary rocks of probable Precambrian, Paleozoic, and Tertiary age.

EAST COAST BEACHES

Immediately south-west of Banks Peninsula a 25 km-long spit, Kaitorete Spit, separates Lake Ellesmere from the Pacific Ocean. This spit points west-south-west. The beach on Kaitorete is largely composed of gravel, but at the point sampled, midway along its length, the beach sediment is a mixture of very coarse sand, granules, and small pebbles. The beach is divisible into backshore and foreshore, the foreshore being steep (gradient of 1 in 8), and the very narrow backshore being almost buried by a belt of coastal dunes.

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*The nomenclature of beach features used is that of Shepard (1963) and Ingle (1966).

North of Banks Peninsula a continuous sandy beach, 40 km long, borders Pegasus Bay. The beach was sampled midway along its length, at Spencer Park. Beach sediment is fine sand. At the sampling locality the beach is clearly divisible into a foreshore and a wide backshore that is sparsely veneered by small, low dunes. Landward, the backshore is bounded by a wide zone of high coastal dunes. The foreshore is divisible into a moderately steep beach face (gradient of 1 in 20) which merges with a shallow runnel about mid-tide level and then grades into the offshore profile. According to Kirk (1967) and Blake (1964), the source rock for both east coast beaches is indurated sandstone and mudstone (Torlesse Group of Mesozoic age), with minor amounts of Cretaceous and Tertiary sedimentary rocks.

Records from the Lyttelton tide gauge station show that tides are semidiurnal with a mean spring range of 2 m (Marine Department, 1966). Onshore winds predominate at both localities. South of Banks Peninsula, north-easterly and southerly winds are predominant, the latter being stronger, more frequent, and potentially significant in producing north-moving longshore drift, according to Kirk (1967).

North of Banks Peninsula, north-easterly and southerly winds prevail according to Blake (1964). Swell induced by north-easterly winds is refracted to produce a strong south-moving longshore drift in Pegasus Bay (Blake). Davies' (1964) qualitative observations suggest that east coast swell is less continuous and lower than west coast swell.

CENTRAL TEXAS BEACH – ST JOSEPH ISLAND

The St Joseph Island beach (Fig. 1) has a well defined, wide, near-flat backshore that is commonly covered with low wind-shadow dunes. At its inner edge it is bordered by a near-continuous, high foredune ridge. Transition to the narrow foreshore is commonly marked by a low ridge at the berm crest. Beach sediments are fine to very fine sand. Tides in the western Gulf of Mexico are diurnal, with a mean spring range of 0·5 m (Fairbridge, 1966, p. 921). The predominant wind is onshore south-easterly during spring and summer, and obliquely offshore northerly during winter. Onshore swell is comparatively low and not persistent.

STRATIFICATION AND SEDIMENTARY STRUCTURES

At five localities observations were obtained from hand-dug pits. One pit was dug at approximately the mid-tide position, and a second either above high tide level or nearer low tide level (Fig. 1). At Hatters Bay observations were obtained from a titivated natural cut 1·0–1·5 m deep that a small stream had eroded through the beach (Fig. 2).

Foreshore (with particular reference to the inter-tidal zone)

Despite considerable variation in beach morphology and in mean grain size of sediments, all beaches have similar stratification. Foreshore strata consist of beds 1–15 cm thick. Each bed is internally laminated, the laminae being plane and parallel (Fig. 3). Each bed is either uniform in thickness

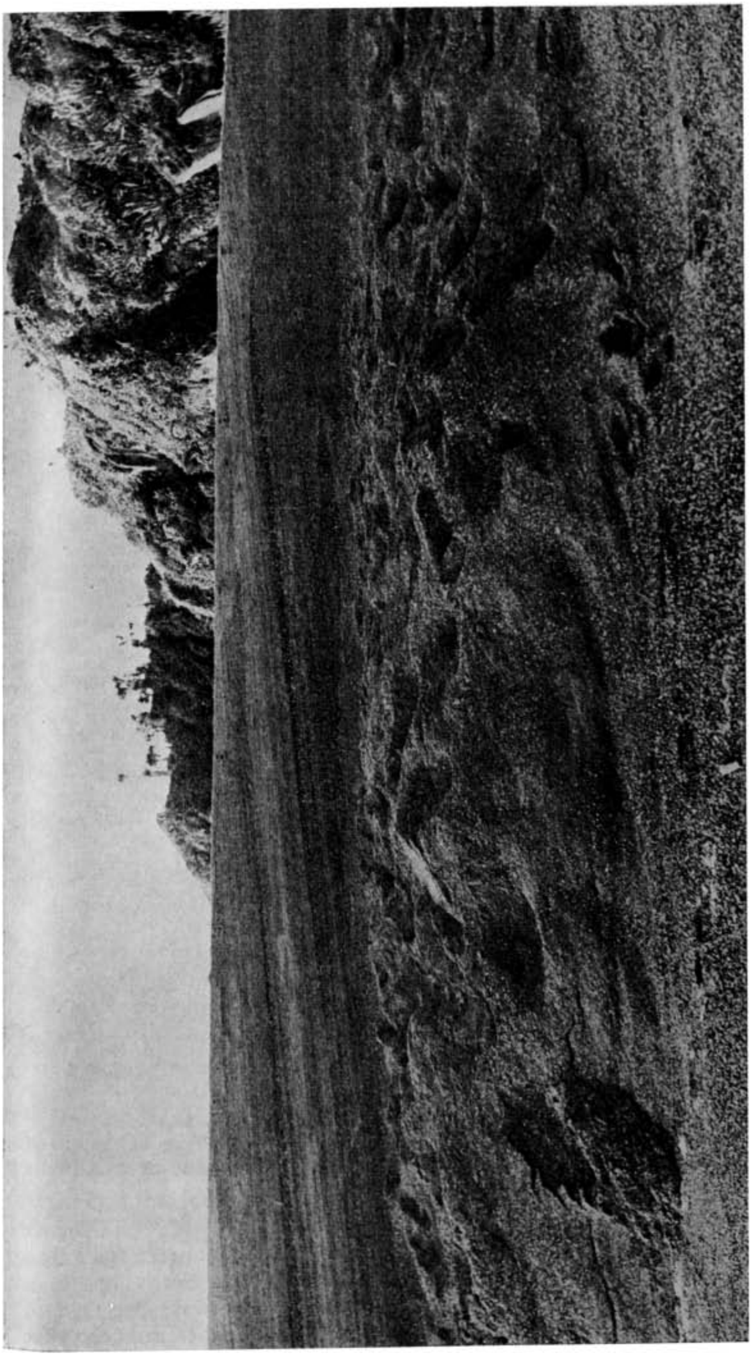

FIG. 2—Natural cross section cut by stream across Hatters Bay beach. Beach face strata occupy most of the view, but gently landward-dipping backshore strata are visible at the extreme right. The trodden ground in the foreground is the sediment scraped off in cleaning the cross section. The cross section width shown is approximately 7 m (the numbers along the top of the section are 90 cm apart).

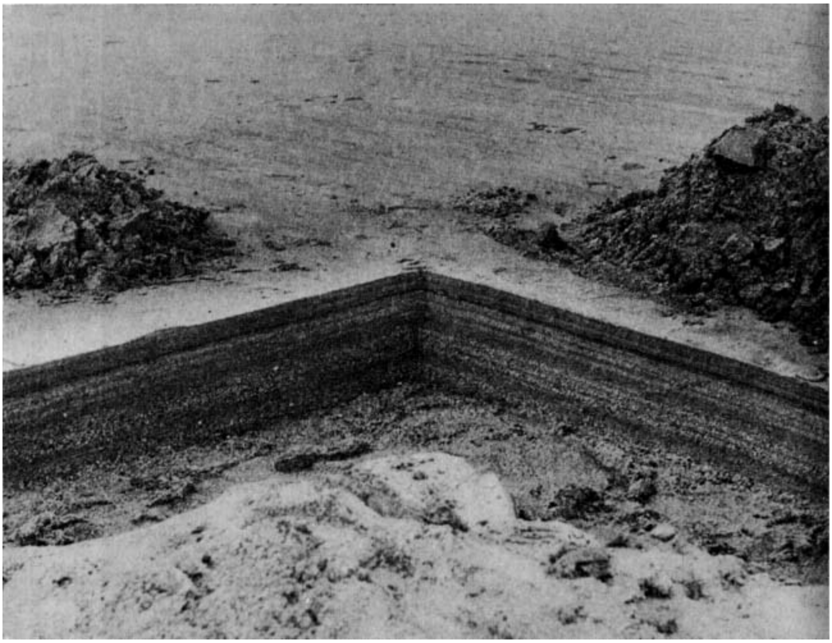

FIG. 3—Foreshore strata at Karamea. Note the regular, thin bedding and well-developed internal lamination. Lamination is a product of segregation both of different grain sizes, and of heavy and light minerals into alternating layers. The three numbers (extreme left; centre; extreme right) are 90 cm apart.

or slightly wedge-shaped in cross section. Internal lamination is a product of segregation of grains of contrasting composition or slightly contrasting size. Where grains of different colour (composition) are segregated, the successive laminae are clearly visible. At Nine-Mile and to some extent at Karamea, dark minerals are abundant in some laminae but sparse in the alternating laminae. On St Joseph Island, whitish shell fragments are abundant in some laminae but terrigenous clastic grains, especially quartz, are abundant in the alternating laminae. At Hatters Bay and Kaitorete Spit, lamination is largely a result of size segregation. At Pegasus Bay, segregation by colour (composition) or size is not obvious, and laminae are not distinguishable in the field, although thin beds show up very faintly. Nevertheless, beach sands at Pegasus Bay are laminated as perfectly as at Nine-Mile. Undisturbed samples were impregnated with a solution of cellulose acetate glue, and differential penetration by the glue revealed fine parallel lamination throughout the sample (Fig. 4).

Beach strata are deposited parallel to the beach surface and hence inclination of strata is dependent upon the slope of the beach face and lower foreshore. Although experiments suggest that foreshore slope is a function of several factors, including sediment grain size, wave length, and wave steepness (King, 1959), studies of modern beaches suggest that

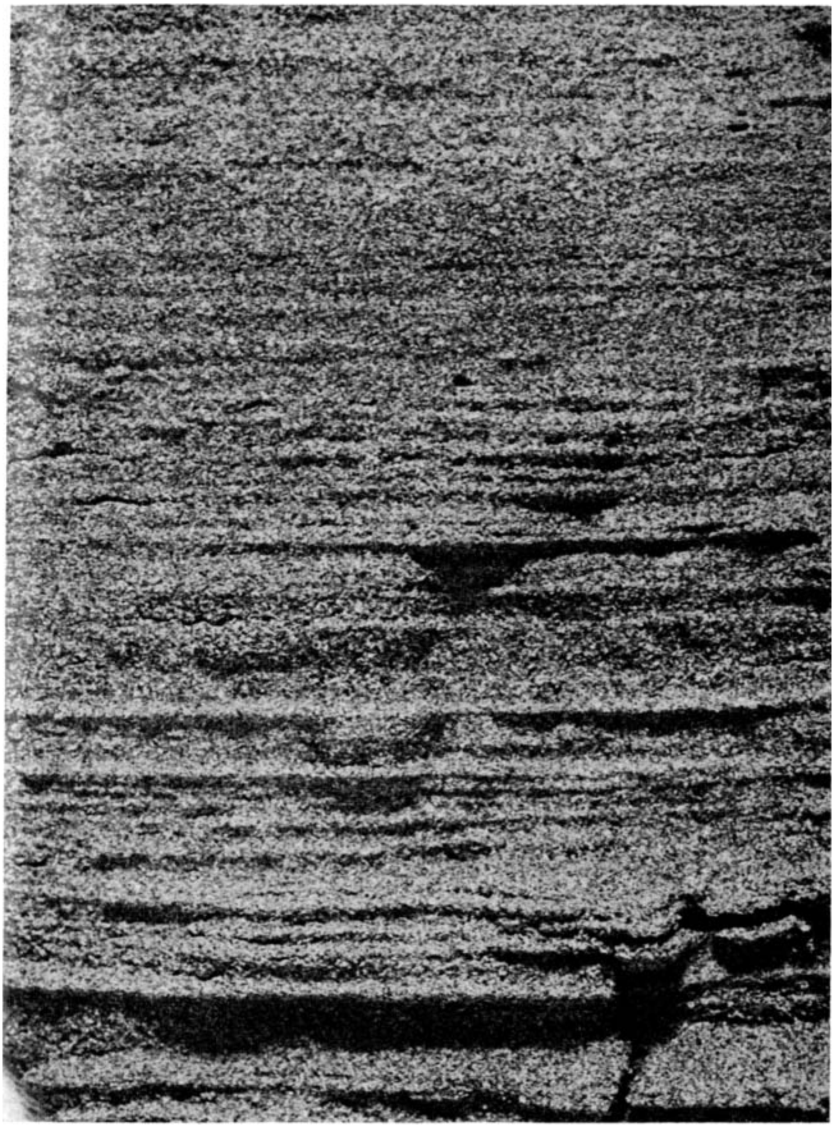

FIG. 4—Relief peel of Pegasus Bay beach face sand, formed by impregnating an undisturbed sample with cellulose acetate glue. Regular lamination not visible in the pit wall is clearly revealed by this technique. The peel is 16 × 11 cm.

sediment grain size is the predominant factor (Bascom, 1951). Our observations support Bascom's conclusion. Despite the fact that beaches exposed to contrasting hydrological conditions were included in the survey, our observations show that the coarser the grain size, the steeper the foreshore (particularly the beach face), and hence the greater the dip of foreshore strata. In Table 1 the modal dip of foreshore strata at each locality is presented. Measurements from Hatters Bay, Pegasus Bay, St Joseph Island, and Kaitorete Spit represent the beach face. Measurements from Nine-Mile and Karamea were taken from lower on the foreshore, or its equivalent, where the beach surface gradient is less than that at the beach face proper.

TABLE 1—Modal Dip of Foreshore Strata in Relation to Beach Face Gradient and Grain Size. Further explanation in the text

Location	Predominant Sediment Sizes	Beach Face Gradient	Modal Dip of Foreshore Strata
Kaitorete	Very coarse sand, granules, and small pebbles	8°	6° true*
Hatters Bay	Very coarse sand and granules	8°	7° apparent
Karamea	Coarse to fine sand	4·5°	5° true
Pegasus Bay	Fine sand	3°	4° apparent
St Joseph I.	Fine and very fine sand	3°	4° apparent
Nine-Mile	Fine and very fine sand	1–2°	3° true

*Median reading not modal reading.

Where possible, a true dip of strata was obtained by measuring apparent dip of each stratum on two intersecting walls of a pit, then converting to true dip on a Schmidt stereonet. Fig. 5 summarises the range in dip of foreshore strata encountered at each locality. The unifying feature is that foreshore strata dip at very low angles to the horizontal, a feature emphasised by McKee (1957). Also, for any one locality, the range in dip values is low. True dip ranges over 2°–5° at Nine-Mile, 1°–6° at Karamea, and 3°–8° at Kaitorete, while the few visible strata at Pegasus Bay all dipped 4° (apparent), and at Hatters Bay foreshore strata ranged over 0°–15° (apparent).

Plots of true dip azimuths of inclined foreshore strata give a distinctive pattern (Fig. 6). Plots are unimodal with a low standard deviation. The strata dip directly seaward, although where a beach is cusped, the spread of readings is greater. Very similar results have been obtained by McKee (1957), Klein (1967), and Milling and Behrens (1966)*.

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*One exception to this observation exists. On a few beaches, ridge and runnel systems are well developed within the tide zone. Sediment accumulates both on the steep landward-facing slip face and on the gently-sloping seaward flank of the ridge. Foreshore strata thus provide a bimodal plot of cross-strata azimuths (Reineck, 1963), with steeply inclined strata dipping landward and gently inclined strata dipping seaward.

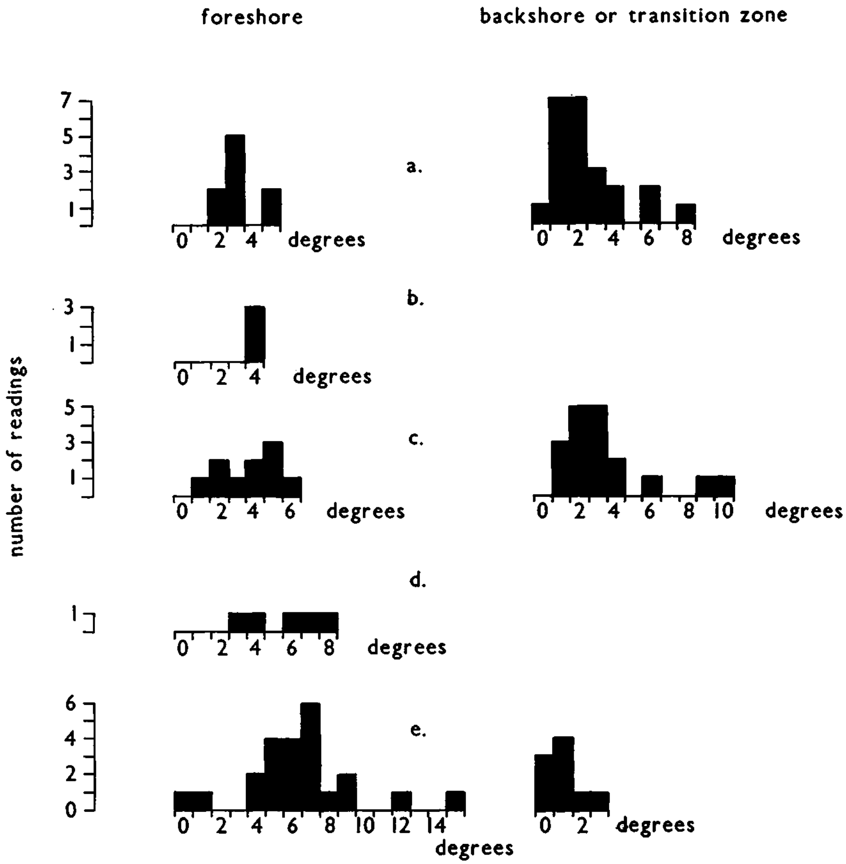
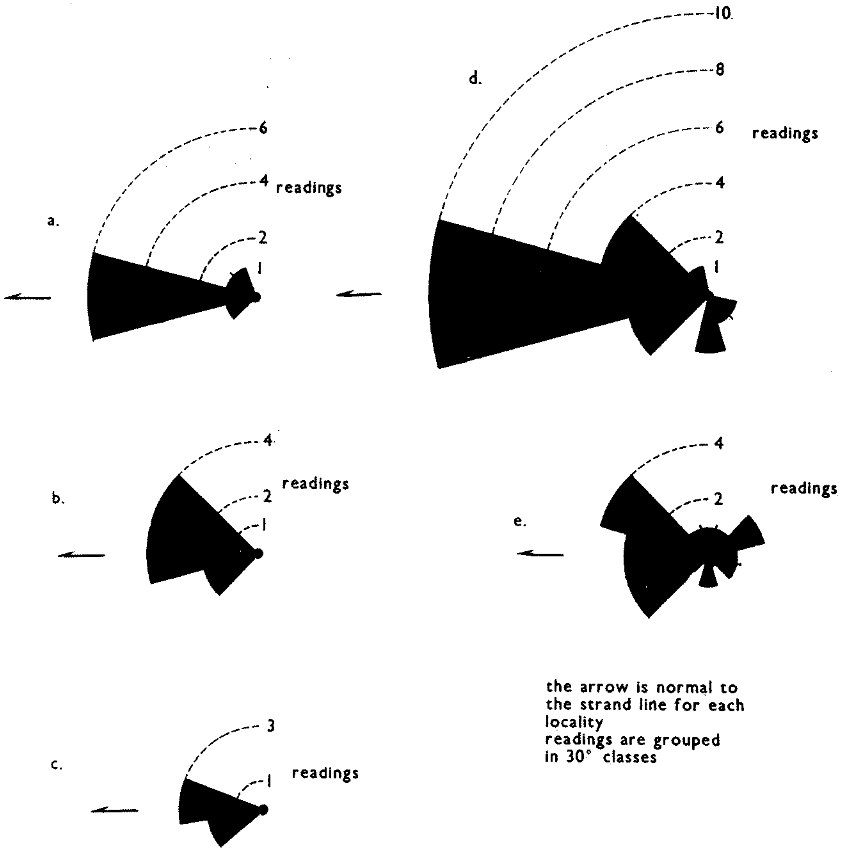


FIG. 5—Range in dip of beach strata for each South Island locality: a. Nine-Mile (foreshore and transition zone); b. Pegasus Bay (beach face); c. Karamea (foreshore and berm crest); d. Kaitorete Spit (beach face); e. Hatters Bay (beach face and backshore). Readings for a, c, and d are true dips; for b and e, apparent dips.



the arrow is normal to the strand line for each locality
readings are grouped in 30° classes

FIG. 6—Distribution of true dip azimuths. a. Nine-mile (foreshore); b. Karamea (foreshore); c. Kaitorete Spit (beach face); d. Nine-Mile (transition zone); e. Karamea (berm crest).

Transition Zone and Backshore

On the transition zone (arbitrarily defined to include the foreshore above high tide level plus the outer backshore) and on the backshore, strata are deposited and eroded by storm waves and by winds blowing both onshore and offshore. As a result, stratification and sedimentary structures are much more diverse than on the foreshore (McKee, 1957; Milling and Behrens, 1966). Stratification consists of internally laminated thin beds up to 25 cm thick. Lamination is generally parallel, but low-angle cross-lamination is commonly produced by back-filling of scour-troughs, and occurs in lens- or wedge-shaped units (Figs. 7 and 8). In some places the latter have the appearance of ripple stratification.

On sandy beaches dip of strata is more variable than on the adjoining foreshore (Fig. 5). Cross-laminated strata, either in aeolian ripples and low dunes or in scour-trough fillings, may furnish much higher dip readings than any obtained from the foreshore (Milling and Behrens, 1966; and this investigation).

FIG. 7—Transition zone strata at Nine-Mile. Note the variable nature of the stratification in comparison with foreshore strata (Fig. 3). Both bedding and lamination are clearly expressed as a result of segregation of light and dark minerals. The rectangular structure at the surface to the upper left is one of a series of horse hoof-print structures that are described in Van der Lingen and Andrews (in press). The numbers are 90 cm apart.

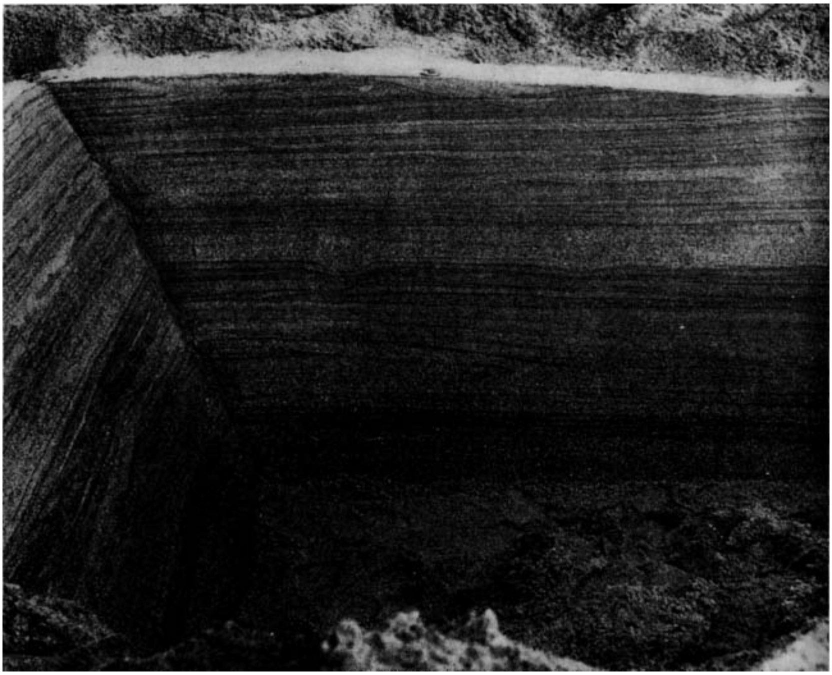


FIG. 8—Transition zone strata (berm crest) at Karamea. Again stratification is more variable than on the foreshore (Fig. 3). Especially note the broad scour-surfaces that bound wedge-shaped beds, and the smaller scour-troughs. The width shown across the top of the cross section is about 1·8 m.

Plots of the true dip of azimuths of transition zone strata give a distinctly different pattern from that for lower foreshore strata (Fig. 6). At Nine-Mile, dip of inclined strata was obtained from a pit dug in the upper foreshore above high tide level. Similarly, at Karamea measurements were made in a pit dug on the berm crest. At both localities the plot of inclined strata azimuths consists of a primary mode directed seaward and a secondary mode oriented either directly landward or obliquely landward. This bimodal pattern contrasts further with the pattern common to the backshore proper. Observations by Andrews on St Joseph Island, and observations reported by Klein (1967) and Milling and Behrens (1966), all show that backshore patterns are unimodal, with strata dipping directly and obliquely landward.

Patterns of true-dip azimuths clearly distinguish the three major divisions of most beaches. The foreshore furnishes a unimodal pattern directed seaward, the backshore furnishes a unimodal pattern directed landward, and a transition zone furnishes a bimodal pattern, the two modes commonly being 180° apart. Fig. 2 illustrates the sharp separation of foreshore and backshore strata on a granular beach.

GRAIN SIZE CHARACTERISTICS

Fifty-two samples were collected for analysis of grain size characteristics. Forty samples were collected from pits in the form of 5-cm cubes scraped from discrete thin beds. Individual laminae were not sampled. Twelve of the 14 samples from St Joseph Island are scrapings from the beach surface.

The samples were sieved through calibrated sieves into half-phi grades for the $-4\ \phi$ to $2\ \phi$ range, and into quarter-phi grades for the $2\ \phi$ to $4\ \phi$ range. Each fraction was examined under the stereo microscope and corrections made for the rare shell fragment or aggregate particle. The corrected grain size distributions were plotted as cumulative frequency curves on arithmetic probability paper and the Folk and Ward (1957) grain size parameters calculated (Table 2).

All sediment samples can be described as clean. Twenty samples contain no silt or clay size particles. The remainder all contain less than 0·6%, most containing less than 0·1% silt or clay size particles.

Ten samples are either bimodal or polymodal, as determined by inspection of either the cumulative frequency curves (Fig. 9), or frequency curves derived from the cumulative frequency curves according to the graphic method described by Folk (1965). The remainder are unimodal. A scatter plot (Fig. 10) of standard deviation (sorting) versus mean size shows that all but two unimodal samples have sorting values in the range $0{\cdot}18\ \phi$–$0{\cdot}67\ \phi$ (very well sorted to moderately well sorted according to the verbal classification of Folk, 1965). The scatter plot is sinusoidal, with best sorting occurring at $-1{\cdot}5\ \phi$ (granule) and at $2{\cdot}8\ \phi$ (fine sand), while poorest sorting occurs at $1{\cdot}5\ \phi$ (medium sand) and at coarser than $-3\ \phi$ (pebble). Numerous workers have recognised similar sinusoidal trends in many suites of samples (*see* Folk, 1966). Such trends are commonly believed to reflect mixing of natural grain size populations. Rock weathers in three distinct ways to give three separate natural grain size populations, two of which are represented in the suite of samples discussed herein. Rock breakage, which is controlled by joint and bedding plane patterns, releases pebble-sized fragments; rock disintegration releases sand-sized, especially fine sand-sized, crystals or grains; and thirdly, chemical decay produces clay-sized mineral grains. Sediments consisting of one or other of these three natural grain size populations are best sorted, while those that contain mixtures of two or more of the populations are less well sorted. The suite of samples discussed herein includes two of these populations, small pebbles and granules on the one hand, and fine sand on the other. Sediments that consist dominantly of one or other of the two populations are best sorted (Fig. 10).

The bimodality-polymodality of some samples results from a probable combination of two factors. Firstly, such samples may include more than one sedimentation unit, since beds of laminated sand were sampled and not individual laminae. Some of the discrete beds sampled certainly contain laminae of disparate grain size distribution (*see also* Walger, 1962). Secondly, within each of the natural grain size populations there may exist secondary populations that are not distinguishable in the sinusoidal plot, for example, pebbles derived from thin-bedded limestone would be smaller

TABLE 2—Grain Size Parameters—Beaches from the South Island, New Zealand, and St Joseph Island, Texas.

Sample	Mean M_z ϕ	Standard Deviation $\sigma\phi$	Skewness Sk_I	Kurtosis K_G	Transformed Kurtosis K_G'	Position on Beach Profile
Hatters Bay						
HB–10	−0·28	0·59	+0·15	1·03	0·51	backshore
HB–11	−1·16	0·33	+0·20	1·08	0·52	backshore
HB–12	−1·55	0·31	+0·26	1·02	0·50	backshore
HB–13	−0·28	0·48	+0·26	1·13	0·53	backshore
HB–14	−0·80	0·40	+0·17	1·01	0·50	backshore
HB–15	−0·39	0·55	+0·14	1·05	0·51	backshore
HB–16	0·50	0·62	+0·11	1·28	0·56	backshore
HB–17	−1·39	0·65	+0·34	1·14	0·53	beach face
HB–18*	0·95	1·00	+0·09	0·86	0·46	beach face
HB–19*	−0·30	1·21	+0·15	1·15	0·53	beach face
HB–20*	1·07	1·33	−0·21	0·70	0·41	beach face
Karamea						
KB–1	2·18	0·40	−0·15	0·98	0·49	foreshore
KB–2	1·35	0·67	+0·15	0·95	0·49	foreshore
KB–3*	0·89	0·98	+0·28	0·86	0·46	foreshore
KB–4	1·30	0·86	+0·13	1·10	0·52	berm crest
KB–5	1·94	0·63	+0·08	0·97	0·49	berm crest
KB–6	1·11	0·64	+0·13	1·10	0·52	berm crest
KB–7	1·53	0·66	+0·14	0·98	0·49	berm crest
KB–8*	0·09	0·96	+0·12	0·97	0·49	berm crest
Nine-Mile						
NB–11	2·78	0·29	+0·01	0·99	0·50	upper foreshore
NB–12	3·07	0·23	+0·12	1·05	0·51	upper foreshore
NB–13	2·63	0·25	+0·10	1·19	0·54	upper foreshore
NB–14*	2·69	0·53	−0·37	1·54	0·61	upper foreshore
NB–15	3·01	0·22	+0·12	1·16	0·54	upper foreshore
NB–16*	2·01	0·85	−0·37	0·69	0·41	upper foreshore
Pegasus Bay at Spencer Park						
SP–10	2·47	0·37	−0·23	0·95	0·49	beach face
SP–11	2·47	0·37	−0·26	0·98	0·49	beach face
SP–12	2·43	0·29	−0·14	1·01	0·50	beach face
SP–13	2·45	0·35	−0·02	0·93	0·48	intertidal ridge
Kaitorete Spit						
KS–1	−0·81	0·55	+0·18	1·08	0·52	beach face
KS–2	0·74	0·55	+0·14	1·24	0·55	beach face
KS–3	−0·12	0·49	+0·13	1·06	0·51	beach face
KS–4*	−1·04	1·22	+0·34	2·18	0·69	beach face
KS–5	−1·36	0·64	+0·07	1·10	0·52	beach face
KS–6	−2·69	0·98	−0·07	1·04	0·51	beach face
KS–7*	−0·83	1·01	+0·68	1·34	0·57	backshore
KS–8	−2·81	0·59	+0·29	1·20	0·55	backshore
KS–9*	−1·00	1·21	−0·03	1·28	0·56	backshore

TABLE 2—*continued*

Sample	Mean M_z ϕ	Standard Deviation $\sigma\phi$	Skewness Sk_I	Kurtosis K_G	Transformed Kurtosis K_G'	Position on Beach Profile
St Joseph Island, Central Texas Coast						
B–2c†	2·84	0·23	−0·02	1·10	0·52	foreshore
B–5c†	2·93	0·27	−0·09	1·07	0·52	foreshore
B–6c†	2·88	0·25	−0·03	1·10	0·52	foreshore
B–8c†	2·94	0·24	−0·02	1·05	0·51	foreshore
B–10b	2·83	0·22	+0·02	0·99	0·50	foreshore
B–2b†	2·88	0·20	+0·03	1·03	0·51	berm crest
B–5b†	2·96	0·21	+0·07	1·04	0·51	berm crest
B–6b†	2·85	0·19	+0·04	1·08	0·52	berm crest
B–8b†	2·93	0·20	+0·06	1·08	0·52	berm crest
B–2a†	2·82	0·19	−0·02	1·14	0·53	backshore
B–5a†	2·88	0·19	+0·01	1·01	0·50	backshore
B–6a†	2·81	0·18	−0·04	1·07	0·52	backshore
B–8a†	2·79	0·19	+0·03	1·08	0·52	backshore
B–9b	2·83	0·20	+0·03	1·03	0·51	backshore

*Bimodal or polymodal sample. †Surface scraping.

than pebbles derived from sparsely-jointed granite. Certainly with respect to west coast samples, the diversity of probable source rocks is such that one would expect a range of secondary grain size populations to be released during weathering. Although not fully tested, there appears to be some supporting evidence for this factor. In bimodal sands from Karamea, K-feldspar is predominant in one grain size mode (coarse sand) and igneous rock fragments, microcline, plagioclase, and quartz are predominant in a second grain size mode (granules - very coarse sand). In addition, sedimentary rock fragments separate into the same two grain size modes. We can conclude that source rock lithology may strongly affect the grain size characteristics of derived sediments.

Distinguishing Beach Sands from Other Sizes on the Basis of Grain-size Characteristics

Grain-size characteristics of beach sediments fall within limits that have encouraged investigators to believe that beach sands are commonly distinguishable from dune and river sands, for example, on the basis of grain size characteristics alone. For example, Folk (1962) notes that sorting values of beach sediments (expressed as σ_I) commonly fall in the range 0·30–0·60 ϕ regardless of the size, shape, or composition of the detrital particles. However, while sorting values of many river sands fall outside this range according to Folk (1965) and Friedman (1961 and 1967), dune sands furnish sorting values very similar to those for beach sands (Folk, 1965; Friedman, 1961; Hayes, 1965).

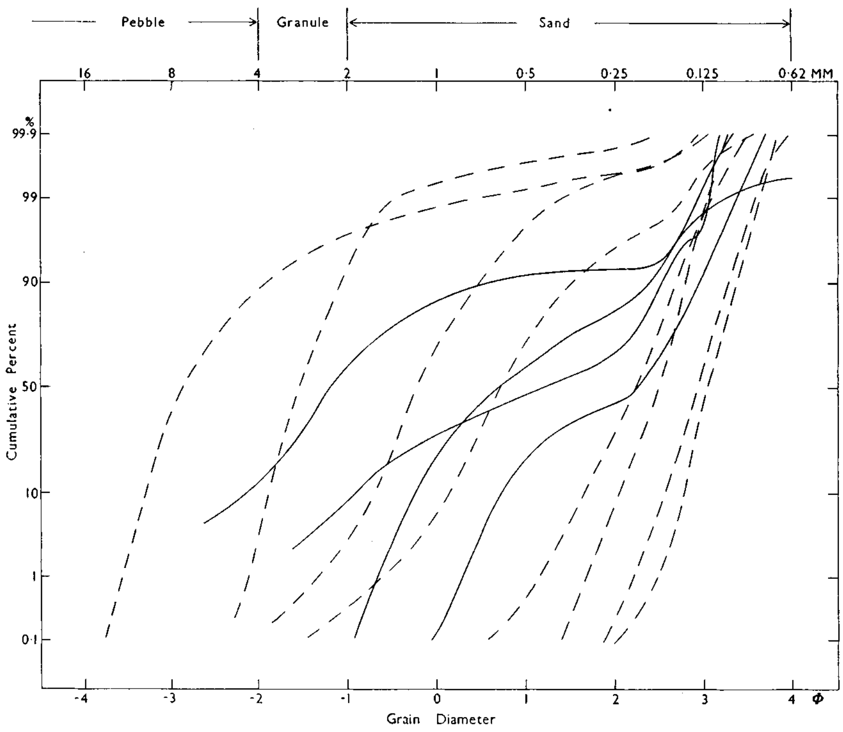


FIG. 9—Cumulative frequency curves for selected samples of beach sediment. Unimodal distributions are shown as a continuous line; polymodal distributions are shown as a dashed line.

Several workers have concluded that beach and dune sands are distinguishable on the basis of skewness, with beach sands being negatively skewed and dune sands being positively skewed (Keller, 1945; Mason and Folk, 1958; Friedman, 1961 and 1967; Duane, 1964; Chappell, 1967; Hails, 1967). The results reported here do not substantiate this conclusion. A plot of skewness versus standard deviation (sorting) (Fig. 11) shows that only 29% of the unimodal samples are negatively skewed. Only the St Joseph Island samples, which have near-symmetrical distributions, can be segregated on the basis of skewness into sands that were probably deposited from swash/backwash and sands that were deposited by wind. The majority of the St Joseph Island foreshore samples are negatively skewed, while the majority of samples from the berm crest and backshore, features at least veneered by aeolian sand, are positively skewed. In fact, Fig. 11 shows that with few exceptions, samples from the same locality fall in a discrete small cluster. All Pegasus Bay samples are well sorted and negatively skewed; all Nine-Mile samples are very well sorted and positively skewed;

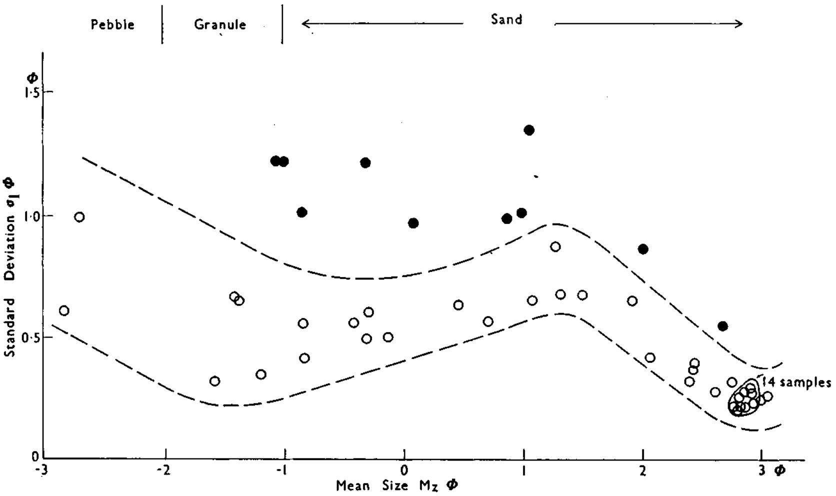


FIG. 10—Scatter plot of standard deviation (sorting) against mean size. All samples are plotted, unimodal samples as open circles, and polymodal samples as solid spots. Note that the unimodal samples occupy a zone that is sinusoidal in outline, a phenomenon widely commented on in the literature.

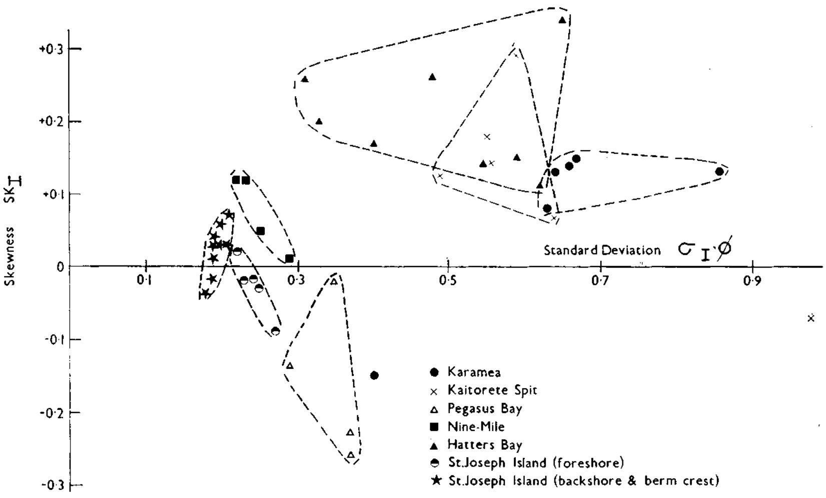


FIG. 11—Scatter plot of skewness versus standard deviation. Samples from the same locality show strong tendency to group together. Only unimodal samples plotted.

all Hatters Bay samples are very well to moderately well sorted and positively skewed; all Kaitorete samples but one are well to moderately sorted and positively skewed; and similarly all Karamea samples but one are moderately well to moderately sorted and positively skewed. Our conclusion is that the grain size distribution of the sediment supplied to the depositional site more commonly reflects the grain size characteristics inherited from the local source rocks. It is likely that an extraordinarily long time must be spent exposed to swash hydrodynamics before the fine tail of the grain size distribution becomes truncated to produce negative skewness values. Hayes (1965) came to the same conclusion in investigating changes in the grain size characteristics of beach and aeolian sands along a 100-mile stretch of the south-east Texas coast. Similarly, Folk (1966) emphasised "the important role of *source material* in controlling the statistics of grain size distribution" (p. 82).

SUMMARY

The observations described, when examined in the light of published descriptions of beach sediments, make it possible to enumerate the characteristics of most modern beaches. The following features can be used in detecting ancient beach deposits in the rock record.

Beach sediments are clean (mud-free). They are very well to moderately well sorted in the descriptive terminology of Folk (1965). Though sediments from many beaches are negatively skewed, probably just as many beaches consist of positively skewed sediments.

The most diagnostic characteristic of a beach deposit is stratification. Tabular or slightly wedge-shaped thin beds, internally well laminated, occur on the foreshore. The strata dip seaward and give a unimodal plot of cross-strata azimuths. A transition zone contains equally thin-bedded, internally laminated strata, but with some small lens- and wedge-shaped cross-stratified units. Plots of cross-strata azimuths give a bimodal plot, one directed seaward and the second mode directed landward. Backshore strata are still internally laminated but bed geometry is more variable with trough-shaped scours back-filled with steep-dipping strata. Plots of cross-strata azimuths are again unimodal, with the strata dipping landward.

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REFERENCES

BASCOM, W. N. 1951: The relationship between sand-size and beach-face slope. *Trans. Am. geophys. Un. 32 (6)*: 866–74.

BLAKE, G. J. 1964: Coastal progradation in Pegasus Bay. (M.Sc. thesis lodged in University of Canterbury library.) 188 pp.

CHAPPELL, J. 1967. Recognising fossil strand lines from grain-size analysis. *J. sedim. Petrol. 37 (1)*: 157–65.

DAVIES, J. L. 1964: A morphogenic approach to world shorelines. *Z. wiss, Geomorph. n.s. 8 (spec. no.)*: 127–42.

DUANE, D. B. 1964: Significance of skewness in Recent sediments, Western Pimlico Sound, North Carolina. *J. sedim. Petrol. 34 (4)*: 864–74.

FAIRBRIDGE, R. W (Ed.) 1966: The Encyclopedia of Oceanography". Reinhold, New York. 1021 pp.

FOLK, R. L. 1962: Sorting in some carbonate beaches of Mexico. *Trans. N.Y. Acad. Sci. ser. 2, 25*: 222–44.

——— 1965: "Petrology of Sedimentary Rocks". Hemphill's, Austin, Texas. 159 pp.

——— 1966: A review of grain-size parameters. *Sedimentology 6 (2)*: 73–93.

FOLK, R. L.; WARD, W. C. 1957: Brazos River bar: a study in the significance of grain size parameters. *J. sedim. Petrol. 27 (1)*: 3–27.

FRIEDMAN, G. M. 1961: Distinction between dune, beach and river sands from their textural characteristics. *J. sedim Petrol. 31 (4)*: 514–29.

——— 1967: Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands. *J. sedim Petrol. 37 (2)*: 327–54.

FURKERT, F. W. 1947: Westport Harbour. *Trans. R. Soc. N.Z. 76 (3)*: 373–402.

HAILS, J. R. 1967: Significance of statistical parameters for distinguishing sedimentary environments in New South Wales, Australia. *J. sedim. Petrol. 37 (4)*: 1059–69.

HAYES, M. O. 1965: Sedimentation on a semiarid, wave-dominated coast (South Texas) with emphasis on hurricane effects. (Ph.D. dissertation lodged in the University of Texas library.) 350 pp.

INGLE, J. C. 1966: "The Movement of Beach Sand". Developments in Sedimentology 5. Elsevier, Amsterdam. 221 pp.

KELLER, W. D. 1945: Size distribution of sand in some dunes, beaches, and sandstones. *Bull. Am. Ass. Petrol. Geol. 29 (2)*: 215–21.

KING, C. A. M. 1959: "Beaches and Coasts". Edward Arnold, London. 403 pp.

KIRK, R. 1967: Beach morphology and sediments of the Canterbury Bight. (M.A. thesis lodged in University of Canterbury library.) 173 pp.

KLEIN, G. DE VRIES 1967: Paleocurrent analysis in relation to modern marine sediment dispersal patterns. *Bull. Am. Ass. Petrol. Geol. 51 (3), Pt. 1:* 366–82.

MCKEE, E. D. 1957: Primary structures in some recent sediments. *Bull. Am. Ass. Petrol. Geol. 41 (8)*: 1704–47.

MCPHERSON, R. I. (in press): Geology of Quaternary ilmenite-bearing coastal deposits at Westport. *Bull. N.Z. geol. Surv. 87.*

MARINE DEPARTMENT, 1966: "New Zealand Tide Tables for the Year 1967". Government Printer, Wellington. 67 pp.

MASON, C. C.; FOLK, R. L. 1958: Differentiation of beach, dune, and aeolian flat environments by size analysis, Mustang Island, Texas. *J. sedim. Petrol. 28 (2)*: 211–26.

MILLING, M. E.; BEHRENS, E. W. 1966: Sedimentary structures of beach and dune deposits: Mustang Island, Texas. *Publs Inst. mar. Sci. Univ. Tex. 11*: 135–48.

SHEPARD, F. P. 1963: "Submarine Geology". 2nd ed. Harper & Row, New York. 557 pp.

REINECK, H. E. 1963: Sedimentgefüge im Bereich der südlichen Nordsee. *Abh. senckenb. naturforsch. Ges. 505.* 137 pp.

VAN DER LINGEN, G J.; ANDREWS, PETER B. (in press): Beach structures related to horse hoof impressions. *J. sedim. Petrol.*

WALGER, E. 1962: Die Korngrössenverteilung von Einzellagen sandiger Sedimente und ihre genetische Bedeutung. *Geol. Rdsch. 51 (2)*: 494–507.