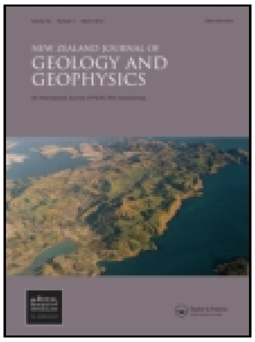

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SEDIMENT VARIATION ON FAREWELL SPIT, NEW ZEALAND

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ABSTRACT

Grain-size parameters and mineralogy of 30 sand samples from Farewell Spit have been studied. The foreshore, backshore, and dune environments have distinctive means, sorting, skewness, percentages of heavy minerals, and distribution of selected mineral species. Grain-size parameters and mineralogy indicate that sand is eroded from the north side of the spit and carried southwards by the wind. Mineral distribution may reflect the importance of grain shape during the erosion of sand by wind.

INTRODUCTION

Farewell Spit extends eastward from Cape Farewell, north-east Nelson, for approximately 20 miles (inset, Fig. 1). The spit varies in width from about 1 mile at its junction with the mainland to nil about 2 miles east of the Farewell Spit lighthouse. Most of the spit is covered with dunes of varying height (up to 70 ft), with small freshwater ponds in some of the depressions between them. Vegetation exists throughout the length of the spit and many of the dunes have been stabilised by marram grass, lupins, and manuka scrub. Most of the dunes on the north side appear to be unstable and are probably being continually changed by the addition and subtraction of sand. Some wind-eroded dunes display excellent cross bedding, emphasised by alternating layers of light- and dark-coloured mineral grains (Fig. 2). The north side of the spit is composed of a wide (up to 100 yd) gently sloping foreshore and a backshore of variable width. The upper limit of the foreshore is marked by a distinct change in slope, which represents the extreme limit of high tides. The term "backshore" as used here refers to the land lying between the foreshore and the coastline (Shepard, 1963). The coastline in this case is the first dunes. Presumably this backshore area is affected by wave action during severe storms, as is suggested by occasional large pieces of driftwood, shell beds, and small local gravel accumulations, but it is primarily a relatively flat wind-swept area. The south side of the spit is a tidal flat up to several miles wide. At the sample localities on the tidal flat, the upper 1–2 in. of sand was clean and light-coloured whereas the sand below this was blackish and had a fetid smell typical of a reducing environment.

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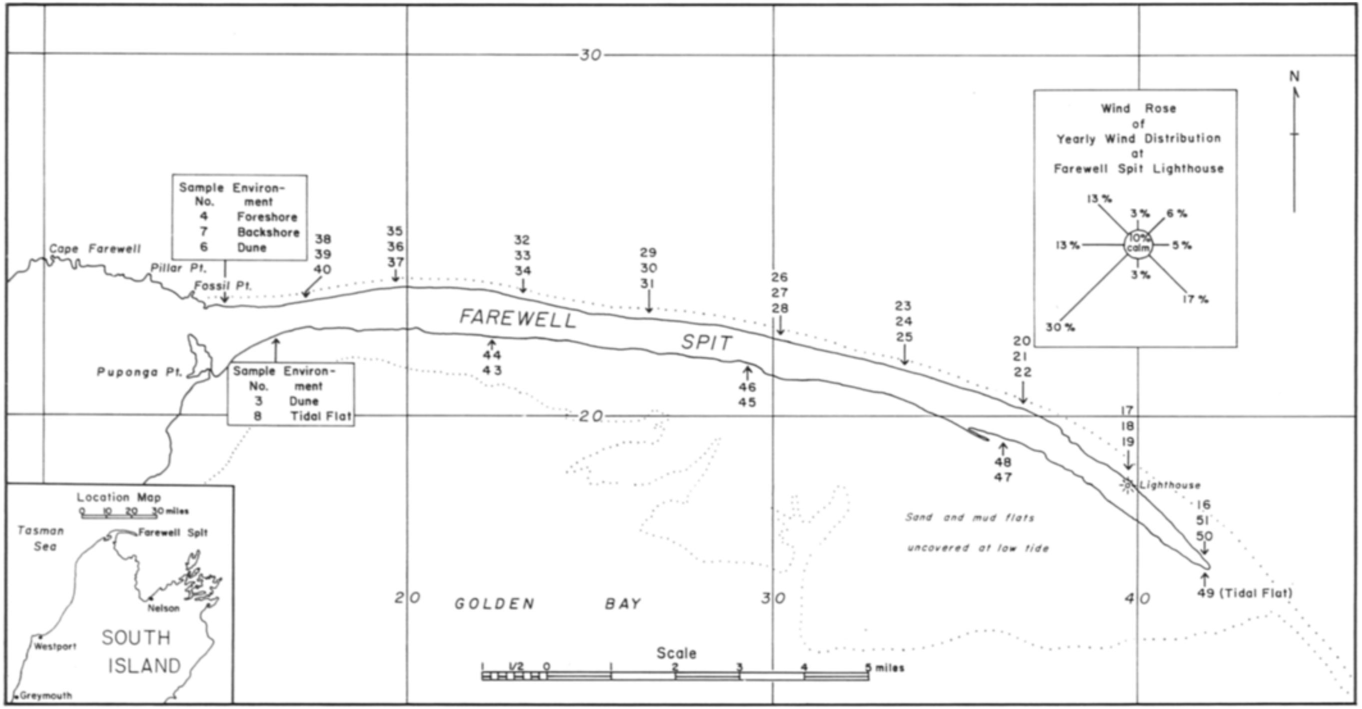

Fig. 1—Farewell Spit showing location of sand samples collected (map from N.Z. Topographical Series: 1 : 63360, sheets S. 1, S. 3, and S. 4), and wind rose of wind distribution at Farewell Spit lighthouse (data from Mr N. G. Robinson, New Zealand Meteorological Service).

The main purpose of this study was to determine whether or not the distinct foreshore, backshore, and dune environments of Farewell Spit could be distinguished by means of grain-size parameters and mineralogy. A secondary purpose was to ascertain whether or not the same factors showed any trends that could be used in interpreting the nature of sediment movement in the area.

FIG. 2—Aeolian cross bedding in a Farewell Spit sand dune accentuated by layers of heavy mineral concentration.

PROCEDURES

Bulk sand samples of about 1,500 kg were collected during August 1961 from the sites shown in Fig. 1. All samples were taken below 1 in. and above 4 in. in depth, in what was visually a uniform layer of sediment. (Some foreshore sampling sites showed alternating layers of coarse and fine sand, in which case the finer sediments were collected, since these were characteristic of the whole foreshore at the time of collection.) Foreshore samples were taken from about half way between high- and low-water marks; backshore samples from about 100 ft inland from high-tide mark; dune samples on the north side of the spit from near the top of the north side of the first dune (no differentiation was made regarding the height of the dune); dune samples on the south side of the spit from near the top of the south side of the first dune; and tidal flat samples on the south side of the spit from about 100 yd below high-tide mark.

All samples were treated by standard techniques of washing and splitting. Samples, 35–50 g, were shaken for half an hour in an "Endrock" sieve shaker through A.S.T.M. sieves using $\frac{1}{2}$ ϕ sieve intervals. Size parameters of mean, sorting, skewness, and kurtosis were calculated on the IBM 1620 Digital Computer in the Mobil Computer Laboratory, University of Canterbury. Heavy mineral separations of the 0·062–0·125 mm size fraction were made with bromoform by centrifuging for 10 minutes. The grains were mounted in Canada balsam, and were identified with a petrographic microscope. Three hundred grains were counted on each slide by traversing the slide until the required number of grains had been counted.

VARIATIONS OF GRAIN-SIZE PARAMETERS

The size parameters of mean, sorting, skewness, and kurtosis were calculated for all samples by the method of moments (Friedman, 1961). To simplify visual presentation, the data are plotted as a simple grid. The use of this grid distorts the scale, which in turn overemphasises the continuity of the data across the centre of the spit and lessens the sharpness of the environmental boundaries, but in no way affects the reality of the data. The data were contoured at suitable contour intervals and are presented in Fig. 3. Student's *t* test was applied to the data for foreshore, backshore, and dune environments on the north side of the spit to show the statistical significance of the apparent visual trends. These results are presented in Table 1.

Mean

The regular pattern shown in Fig. 3A and the Student's *t* test results (Table 1) allow the following conclusions about mean grain size: (1) The mean grain size of the foreshore sand varies along the length of the spit, but shows a tendency to increase from west to east. (2) The mean grain size of the foreshore sand is significantly larger than the mean grain size

TABLE 1—Values for Student *t* Test Applied to the Mean, Sorting, Skewness, and Kurtosis Measures of Sands from the Foreshore, Backshore, and Dune Environments of the north side of Farewell Spit. (F = foreshore; B = backshore; D = dune; F × D = test applied to samples from these two environments; NS = not significant; ** = highly significant)

Size Parameter	Inter-relationship	*t*	Significance Level
Mean	F × B	7·39	0·001 **
	F × D	6·44	0·001 **
	B × D	1·39	0·20 NS
Sorting	F × B	4·92	0·001 **
	F × D	6·08	0·001 **
	B × D	0·75	0·50 NS
Skewness	F × B	5·49	0·001 **
	F × D	3·93	0·001 **
	B × D	0·47	0·70 NS
Kurtosis	F × B	1·00	0·40 NS
	F × D	1·29	0·25 NS
	B × D	2·50	0·025

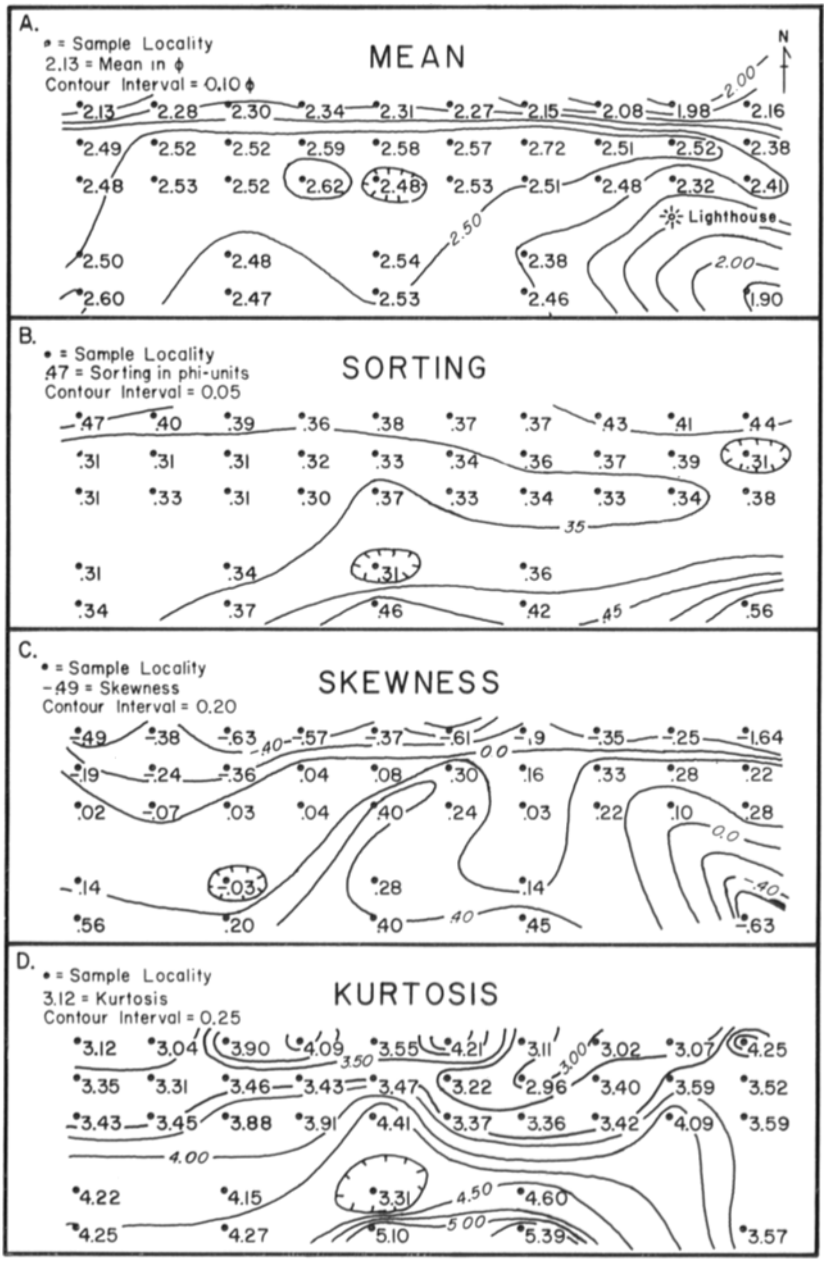

FIG. 3—Variations in size parameters of mean (A), sorting (B), skewness (C), and kurtosis (D) in Farewell Spit sand samples.

of the backshore and dune sands. (3) The mean grain size of the backshore sand does not differ significantly from the mean grain size of the dune sand. (4) The mean grain size of the dune and tidal flat sands from the south side of the spit does not differ appreciably from that of the backshore and dune sands of the north side of the spit.

It should be pointed out that the backshore and dune samples from the easternmost end of Farewell Spit were taken from areas in which neither environment was well developed at the time of sample collection and may have been subject to flooding during high spring tides. The tidal flat sample from the easternmost end of the spit came from a shell bank.

Sorting

The pattern shown in Fig. 3B and the Student's *t* test results in Table 1 allow the following conclusions about the sorting of the Farewell Spit sands: (1) The sorting of the backshore and dune sands is significantly better than the sorting of the foreshore sands. (2) No significant difference exists between the sorting of the backshore and dune sands. (3) The tidal flat sands from the south side of the spit show a slight decrease in sorting from the dune sands.

Skewness

The Student's *t* test values in Table 1 and the pattern of Fig 3C allow the following conclusions about skewnness: (1) All the foreshore sands are negatively (toward the coarser sizes) skewed. (2) Almost all of the backshore and dune sands are positively skewed. (3) The tidal flat sands are even more positively skewed than the dune sands.

Kurtosis

Fig. 3D shows the contoured data for kurtosis. This parameter shows considerable variation and a tendency for higher values in the dune and tidal flat sands. The Student's *t* test (Table 1) was applied to transformed values of kurtosis using the transformation suggested by Folk and Ward (1957). Although not significant, there does appear to be a regular difference in kurtosis between the backshore and dune sands and between the foreshore and dune sands. This is in agreement with the findings of Mason and Folk (1958), although the reason for the difference is not clear.

Discussion of Size Parameter Variations

The mean grain size of the foreshore sands is the only size parameter that shows consistent variation along the length of Farewell Spit. The increase in mean grain size from west to east probably results from differential transport and the tendency for the fine sand to be removed either by wave or wind erosion. Implicit in this conclusion is the assumption that the sediment comprising Farewell Spit comes wholly from a single source at the west end of the spit. This assumption is supported by the grain size and heavy mineral data. The grain-size data presented in Table 2 show almost no variation in maximum grain size throughout the length of

TABLE 2—Variation of Maximum Grain Size in Farewell Spit Foreshore Sand Samples

Sample number	4	38	35	32	29	26	23	20	17	16
Maximum size in ϕ	0·5	1·0	0·5	0·5	1·0	0·5	1·0	0·5	0·5	0·5
Percentage (by weight) in maximum grade	0·01	0·13	0·02	T	0·23	0·02	0·14	T	0·03	0·12

T = Trace (not measurable at 0·00 g)

the spit and a relatively consistent variation in quantity within the maximum grade size. Because of the lack of variation of the maximum grain size in the foreshore sands, it may be assumed that no coarser sediments are added to the spit from a second source area (such as offshore Quaternary deposits). The heavy minerals present in the foreshore sand samples show sufficient similarity in mineral suite and quantities of individual species to further support the assumption of a single sediment source.

There are a number of size-parameter variations across the width of the spit indicating that significant differences exist among some of the depositional environments. With the exception of kurtosis, all of the grain-size parameters show significant differences between the foreshore sands on the one hand and the backshore and dune sands on the other. There appears to be relatively no difference in grain-size parameters between the backshore and dune sands. Such a pattern of variation suggests that the backshore and dune sands are closely related and derive their grain-size characteristics from the wind, whereas the foreshore sands owe their different characteristics to wave action. The difference in mean grain size reflects the greater power of the waves to transport and concentrate the coarser sizes, while the slightly better sorting of the backshore and dune sands reflects the limited range of sizes that the wind can move. The negative skewness of the foreshore sands results from the concentration of coarse sand during wash and removal of fine sand during backwash, while the positive skewness of the backshore and dune sands results from the tendency of the wind to transport a greater proportion of fine material.

The tidal flat sands, although not tested statistically because of the small number of samples, appear to be closely related to the dune sands, even though slight differences in sorting and skewness are present. These differences are probably a reflection of a greater amount of fine-grained material added to the tidal flat from the dunes and the foreshore on the north side of the spit (bypassing the dunes). This fine-grained material, once deposited, would not be removed by wind erosion or the inefficient wave action on the tidal flat. Presumably there is sufficient variation in the grain-size distribution of the tidal flat sands to allow the mean to remain similar to that of the dunes while sorting and skewness show differences.

Size Parameter Variations for Environmental Differentiation

Comparison with recent papers on somewhat similar studies using size parameters to distinguish environments (Mason and Folk, 1958; Shepard and Young, 1961) shows that the present work supports that of Mason and Folk and is in direct contrast to that of Shepard and Young. Folk (1962) has pointed out that Shepard and Young's conclusions regarding the significance of size parameters are probably not comparable, since they used a settling tube for their size analysis. The present writer agrees with Folk that the settling tube does not give results comparable to those obtained by sieving, particularly in view of the work of Hulsey (1961), which demonstrates that the settling tube gives variable results depending on the size and sorting of the sand and the degree of turbulence in the system (which would vary with the size of the sample).

Some other workers who have attempted to differentiate foreshore and dune sands by means of size parmeters (Friedman, 1961; Keller, 1945) have found only skewness to be of any value in distinguishing the environments. The reason for this may lie in the nature of their samples: both Friedman and Keller used a large number of samples, but these came from widespread localities and were not necessarily from adjacent environments, and so it is to be expected that the data would show considerable variation and overlap. The writer feels that, with the exception of skewness, the use of size parameters for differentiation of environments composed almost entirely of sand is a satisfactory method only when the samples are all from the same sphere of influence or, in the case of a coastal area, the same physiographic unit (as defined by Mason, 1950, p. 282). This conclusion is supported by the literature (Friedman, 1961; Keller, 1945; Mason and Folk, 1958) and unpublished work of the present writer involving over 180 samples.

Use of size parameters to indicate trends in environments and transitions from one environment to another seems feasible. The present study shows this most clearly in the similarity of the tidal flat and dune sands.

HEAVY MINERALS

Because of the large number of weathered unidentifiable heavy minerals present in the Farewell Spit sands and the limited number of mineral species that occur in sufficient quantity to allow statistical evaluation, only the four most common mineral groupings were studied with a petrographic microscope. These groupings are: all garnets, magnetite–ilmenite, amphibole–pyroxene, and the rest. The garnet suite includes clear garnets, pink garnets, and clear garnets with black inclusions. With the exception of a few well rounded grains all the garnets are angular and nearly equidimensional. The undifferentiated black magnetite–ilmenite grains are all relatively unweathered, rounded, and equidimensional. The undifferentited amphibole–pyroxene grains vary from dark green to light greenish brown and are all angular and tabular flake-shaped. The remainder of the heavy mineral suite consists of weathered angular to rounded grains for which no optical properties are obtainable, rare extremely well rounded grains of apatite and epidote, rare euhedral or rounded rod-shaped grains of tourmaline (some with inclusions), occasional angular grains of andalusite, and very rare rounded rod-shaped grains of zircon. Other rare constituents may be present, but were not noticed.

Fig. 4A shows the distribution of heavy mineral percentages in the 0·062 to 0·125 mm size range. This figure suggests that there is a significantly higher percentage of heavy minerals in the backshore and dune sands than in the foreshore sands, and that there is no significant difference between the percentage of heavy minerals of the backshore and dune sands. The suggestion is supported by the results of the Student's *t* test presented in Table 3. The original heavy mineral percentages (by weight) were transformed by the arc sine square root transformation before the *t* test was applied. The occurrence of a higher percentage of heavy minerals in the fine fraction of dune sands has been noted by a number of writers (Carroll, 1939; Bradley, 1957; Shepard, 1960; Shepard and Young, 1961). Barrett (1940) noted that the percentage of heavy minerals in the sands he studied decreased away from the foreshore and attained the lowest pecrentage at the top of the adjacent dunes. He used the percentage of heavy minerals in the whole sample rather than a particular size and thus his work is not comparable. It would be possible for the total percentage to decrease as a result of lag concentration of the coarse heavy minerals on the foreshore while the percentage of the finer grades increased in the wind-deposited sediments.

TABLE 3—Values for Student *t* Test Applied to Heavy Mineral Percentages (by weight) in the 0·062–0·125 mm fraction of sands from the foreshore, backshore, and dune environments of the north side of Farewell Spit. (F = foreshore; B = backshore; D = dune; F × D = test applied to samples from these two environments; ** = highly significant; NS = not significant)

Inter-relationship	*t*	Significance Level
F × B	4·59	0·001 **
F × D	3·95	0·001 **
B × D	1·30	0·25 NS

Carroll (1939) and Shepard and Young (1961) have suggested that the greater percentage of heavy minerals in the fine sizes of the dune sands may be the result of lag concentrations. This idea deserves further elaboration. In an initial dune (or backshore) surface layer, a few grains thick, in which the grains have been eroded from an adjacent foreshore by the wind, the amount of heavy minerals in the dune sediment would probably be very similar to the amount in the source sediment, since the wind velocity necessary to erode the slightly moist grains from the foreshore area would be sufficient to carry a wide range of grain sizes regardless of specific gravity. Once deposited in the dune area, however, these grains will be subjected to considerable reworking by winds not capable of disturbing the foreshore sands. These winds will vary considerably in velocity and some may be capable of removing grains of equivalent diameter but of less specific gravity than the heavy mineral grains under consideration. In this

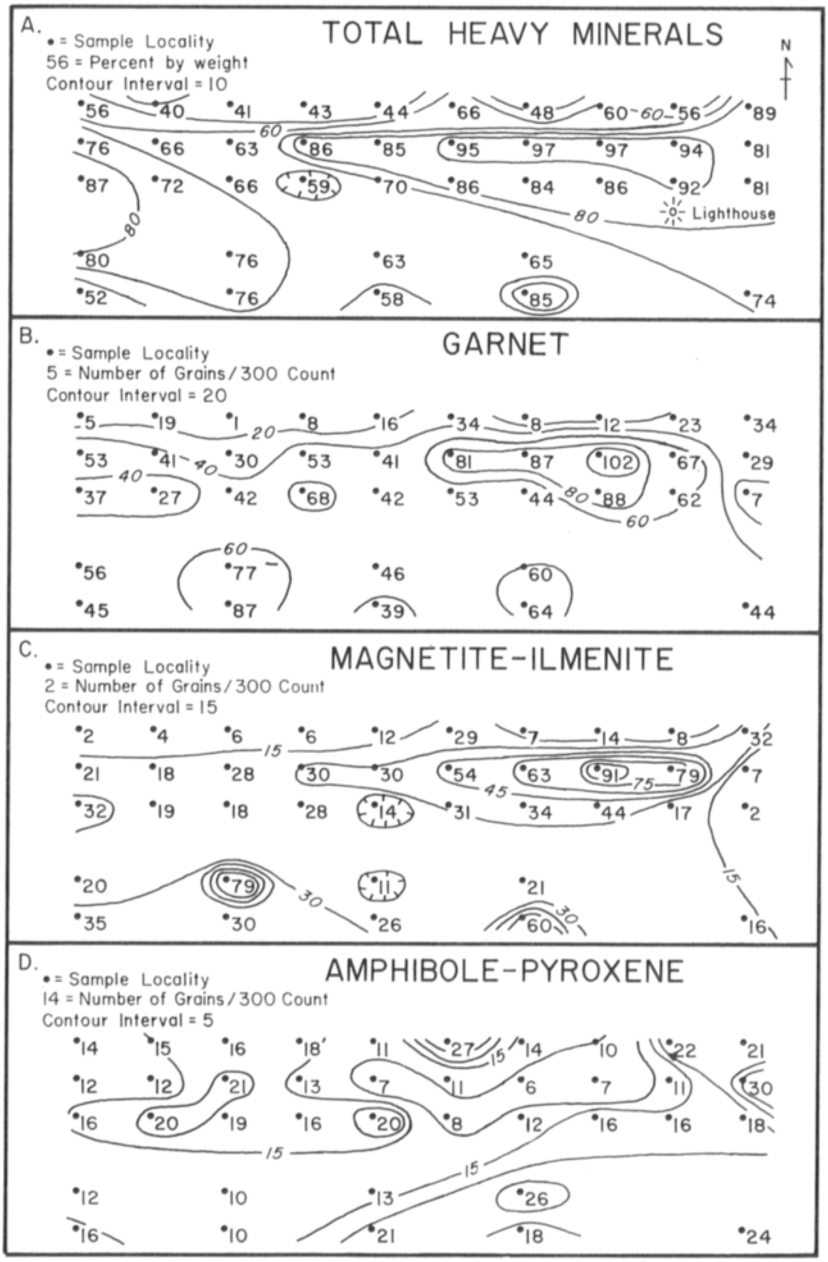

FIG. 4—Variations in percentage (by weight) of heavy minerals (A), number of occurrences of garnet (B), magnetite–ilmenite (C), and amphibole–pyroxene (D) in the 0·062–0·125 mm size fraction of Farewell Spit sand samples.

manner a concentration of heavy mineral grains may occur. If this lag concentrate is then covered with more sand, it retains its identity as a thin layer of heavy mineral grains. This concentration into individual layers occurs on Farewell Spit, as is shown by the alternating light and dark layers which accentuate the cross bedding of the dune sands (Fig. 2).

Figs. 4B, 4C, and 4D show contoured diagrams of the number distribution of garnet, magnetite–ilmenite, and amphibole–pyroxene in the sands of Farewell Spit. Table 4 presents the χ^2 values and their significance levels for the chi-square tests performed on the relationships between environments. There is a very significant difference in the distribution of garnets and magnetite–ilmenites, taken as individual species, between all environments. The amphibole–pyroxene distribution shows a significant difference between the foreshore and backshore and much less difference in the other two relationships.

TABLE 4—Values for χ^2 Test Applied to Heavy Minerals in samples from the foreshore, backshore, and dune environments of the north side of Farewell Spit. (F = foreshore; B = backshore; D = dune; F × D = test applied to sample from these two environments; ** = highly significant; NS = not significant)

Mineral Species	Inter-relationship	χ^2	Significance Level
Garnet	F × B	79·18	0·001 **
	F × D	124·24	0·001 **
	B × D	32·00	0·001 **
Magnetite–Ilmenite	F × B	110·00	0·001 **
	F × D	92·20	0·001 **
	B × D	39·28	0·001 **
Amphibole–pyroxene	F × B	28·54	0·001 **
	F × D	15·66	0·10 NS
	B × D	20·16	0·02 NS

To check the variations of the mineral suite as a whole, an analysis of variance was made following the format of Krumbein and Tukey (1956). An arc sine square root transformation was applied to the mineral percentage (by count) values. The variables in each analysis are: 2 environments, 2 halves of each environment, and 5 samples in each half, with 4 mineral groupings in each sample. The results of this analysis are presented in Table 5. The analysis of variance shows that there is a significant difference between the mineral distribution of the foreshore and backshore and the foreshore and dune environments, but no significant difference in mineral distribution between the backshore and dune environments.

The dune and tidal flat sands from the south side of the spit suggest that

TABLE 5—Analysis of Variance of Heavy Mineral Composition (0·062–0·125 mm size fraction) of foreshore, backshore, and dune sands from Farewell Spit. (d.f. = degrees of freedom; F = variance ratio)

(NS = not significant; L = significant at 0·25 level; * = significant at 0·01 level; ** = highly significant at 0·001 level)

Foreshore × Backshore

Source	Sums of Squares	d.f.	Mean Square	F
Between environments	5,239	1	(5,239)	
Between halves within environments	218	2	(109)	
Between counts within halves	5,122	16	(320)	
Between types	29,882	3	(9,961)	
Environments × types	7,854	3	2,618	20·45 *
Halves × types	769	6	128	1·78 NS
Counts × types	3,476	48	72	26·37 **
Total	52,560	79		

Foreshore × Dune

Source	Sums of Squares	d.f.	Mean Square	F
Between environments	33	1	(33)	
Between halves within environments	20	2	(10)	
Between counts within halves	49	16	(3)	
Between types	34,880	3	(11,627)	
Environments × types	1,143	3	381	7·47 L
Halves × types	307	6	51	1·55 NS
Counts × types	1,601	48	33	12·09 **
Total	38,033	79		

Backshore × Dune

Source	Sums of Squares	d.f.	Mean Square	F
Between environments	5,284	1	(5,284)	
Between halves within environments	199	2	(100)	
Between counts within halves	5,125	16	(320)	
Between types	21,633	3	(7,211)	
Environments × types	5,604	3	1,868	2·25 NS
Halves × types	495	6	83	1·34 NS
Counts × types	2,968	48	62	22·71 **
Total	41,308	79		

there is a tendency for even greater concentration of the heavy minerals of the fine grain sizes in these sands and that they are probably derived from the dune area to the north.

The distribution of individual mineral species in the different environments of Farewell Spit requires careful consideration. Although the percentage of heavy minerals in the dune and backshore sands in the fine sizes may be greater than the percentage in the foreshore, one might expect the proportions of the minerals constituting the total to be the same. Since this is obviously not the case, some factor involving differential concentration or depletion must be at work. The shape of the mineral grains may be an important factor.

There are conflicting opinions in the literature as to whether or not the sphericity of dune sand grains tends to be higher than that of foreshore sand grains (i.e., Mattox, 1955; McCarthy and Huddle, 1938). There does, however, seem to be some shape sorting during aeolian transport. Unfortunately, little is known about the effect of shape during erosion of sand grains. Rittenhouse (1943) does not attribute any importance to the shape of grains as a factor during their transport, but he does suggest that shape would be important during the erosional stage. Briggs, McCulloch, and Moser (1962) show that shape has a very pronounced effect on the fall velocity of falling grains, and point out that this shape factor would have considerable effect on the sorting of heavy minerals with sediments. They indicate that shape would also be important during the erosional stage, but do not develop the idea. Kolbuszewski (1953) also mentions that shape is important in the erosion and deposition of sand, but does not develop the subject. It would seem to the writer that the equidimensional garnet and magnetite–ilmenite grains have a more favourable shape and are therefore carried away from the foreshore with greater frequency than the less favourably shaped amphibole–pyroxene grains, thus giving the existing distribution of heavy minerals in the sands of Farewell Spit.

A similar conclusion regarding the importance of shape during the erosional stage was reached by Lane and Carlson (1954) in their studies of river gravels. They concluded that flat particles resist movement more than spherical particles of equal weight. The basic similarity between the processes involved in the erosion of either a sand particle or a gravel particle by either wind or water suggests that the present writer's conclusions are supported by those of Lane and Carlson, and that particle shape is an important factor in the erosional stage of all particles larger than silt.

Another factor possibly also of importance in the grain-shape – wind-erosion relationship is the moisture content of the foreshore sand. Carroll (1939) in her observational study of sand erosion by wind noted considerable difference in rates of sand erosion from the foreshore with variation in moisture content. Presumably the same relative moisture content at the surface of the foreshore would have different cohesive force on grains of different shape. Thus, there would be less cohesive force acting on the smaller surface area of an equidimensional grain than there would be on a horizontally oriented flake-shaped grain: the flake-shaped grain would thus be bypassed, whereas the equidimensional grain would be eroded. The extent to which this factor is important is not known to the writer.

OCEANOGRAPHIC AND METEOROLOGICAL CONDITIONS

The Westland Current, which moves northwards along the west coast of the South Island (Brodie, 1960), transports the sediment that builds Farewell Spit. Furkert (1947) estimated that at least 4·5 million cubic yards of material are added to the spit each year. He indicates that a study of surveys made in 1851, 1867, and 1938 shows no appreciable extension of the high-water mark to the east, but that the average width of the spit has increased about 238 ft throughout its length, that the tip at low water has extended 2,000 ft, and that the outer 1,000 ft as depicted on the early surveys has widened considerably. He makes no reference to the direction of lateral growth, but it is logical that growth would be to the south as a result of deposition of wind-transported sand in the quiet tidal-flat environment rather than to the north on the open-sea side of the spit. Ongley and Macpherson suggested growth of the spit in this manner in 1923, and the size parameters and mineralogy of the sands examined in the present study support this theory.

The prevailing wind at Farewell Spit is south-westerly. As can be seen from the wind rose in Fig. 1, half of the wind blowing across the spit comes from a southerly direction (SE, S, SW) and only about 22% of the wind comes from a northerly direction (NE, N, NW). This wind distribution remains essentially the same for all wind velocities. Such a distribution of wind seems to be in opposition to a theory of bulk sand movement from north to south across the spit by wind transport. However, the north side of the spit is not favourable for sediment accumulation, since the Westland Current curves slightly to the east and sweeps it. The north side of the spit also faces the open sea and would be subject to more severe wave action than the shallower south side. Thus, it may be concluded that, regardless of the prevailing wind, the net growth is to the south as a result of a complex movement of sand eroded from the foreshore, moved back and forth in the dune area, and eventually coming to one of two sites of deposition. Either the sand is swept back into the water on the north side of the spit, or it is swept on to the tidal flat on the south side. The sand deposited on the tidal flat is trapped by moisture and is not carried away because of the inefficient wave action in the extremely shallow water. The sand that is swept back into the sea on the north side is (1) transported into deeper water and deposited, (2) carried by longshore currents to the end of the spit and deposited, or (3) returned to the foreshore to repeat the cycle.

CONCLUSIONS

The following conclusions may be drawn from this study:

1. The size parameters of mean, sorting, and skewness show distinctive differences between the sands of the foreshore, backshore, and dune environments of Farewell Spit, which may be attributed to the differences between wind and waves as agents of transportation and deposition.

2. The size parameter of kurtosis shows distinctive differences only between the sands of the backshore and dune environments. The reason for these differences is not known.

3. A comparison of the size parameters of the tidal flat sands on the south side of the spit and the dune sands suggests that the tidal flat sands have been derived from the dune sands and still maintain most of the dune sand characteristics.

4. The distribution of heavy mineral percentages and numbers of selected heavy mineral groupings show distinctive differences between the foreshore, backshore, and dune environments. These factors also support a theory of sand movement from north to south across the spit and derivation of the tidal flat sands from the adjacent dune areas.

5. The distribution of mineral species in the foreshore, backshore, and dune environments suggests that shape may be an important factor in wind erosion of sand grains and that equidimensional grains may be more easily eroded than flake-shaped grains.

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