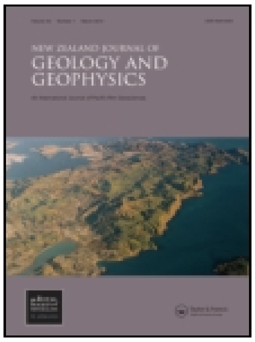

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THE RIVERS AND THE FORESHORE SEDIMENT OF PEGASUS BAY, SOUTH ISLAND, NEW ZEALAND

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ABSTRACT

The analysis of a series of mid-foreshore sediment samples for particle size and mineral content indicates that the sediment forming the foreshore of the Pegasus Bay coastal plain, east coast South Island, New Zealand, is derived almost entirely from its hinterland river catchments. Of the statistical parameters used the mean grain size of samples increased northwards as shingle replaced sand, though sorting decreased. Skewness is related to the positions of the river mouths. The contribution of sediment to the coast is closely related to the individual rivers despite active littoral processes.

INTRODUCTION

The east coast of the South Island, New Zealand, includes a prograded coastal plain 32 miles in length. The plain has as its northern boundary the folded and faulted Cass Range Tertiary complex and as its southern boundary Banks Peninsula, a zone of Late Tertiary and Pleistocene volcanics (Fig. 1).

The plain is 4 miles wide in the south narrowing to half a mile in the north, and is crescent shaped. This gives the impression that progradation has occurred in an anticlockwise direction about the northern extremity. Its age is approximately 6,000 yr B.P. dating from the peak of the Flandrian transgression (Suggate, 1958) and since sea level has remained relatively static during this period (Fairbridge, 1961), and isostatic adjustment has been negligible despite proximity to a fault block (Speight, 1911; Jobberns, 1927), it appears that more extensive progradation in the south is closely related to variation in the sediment supply along the coast.

This paper studies the origin and distribution of the sediment forming the plain by defining trends in the particle size, and the mineral content, of a population of foreshore samples collected during one autumn low-tide period. The foreshore, for this purpose, is defined as the zone of unconsolidated material, between "the backshore and the low water mark, that is traversed by the swash of the waves as the tide rises and falls" (U.S. Army, 1961).

THE RIVERS AS A SEDIMENT SOURCE

A classification of the sources of foreshore sediment by Johnson (1959) was applied, with slight modification, to Pegasus Bay. It includes (*a*) major streams or rivers; (*b*) small streams; (*c*) cliffs, slides, and gullies; (*d*) on-shore movement by wave action; (*e*) wind action.

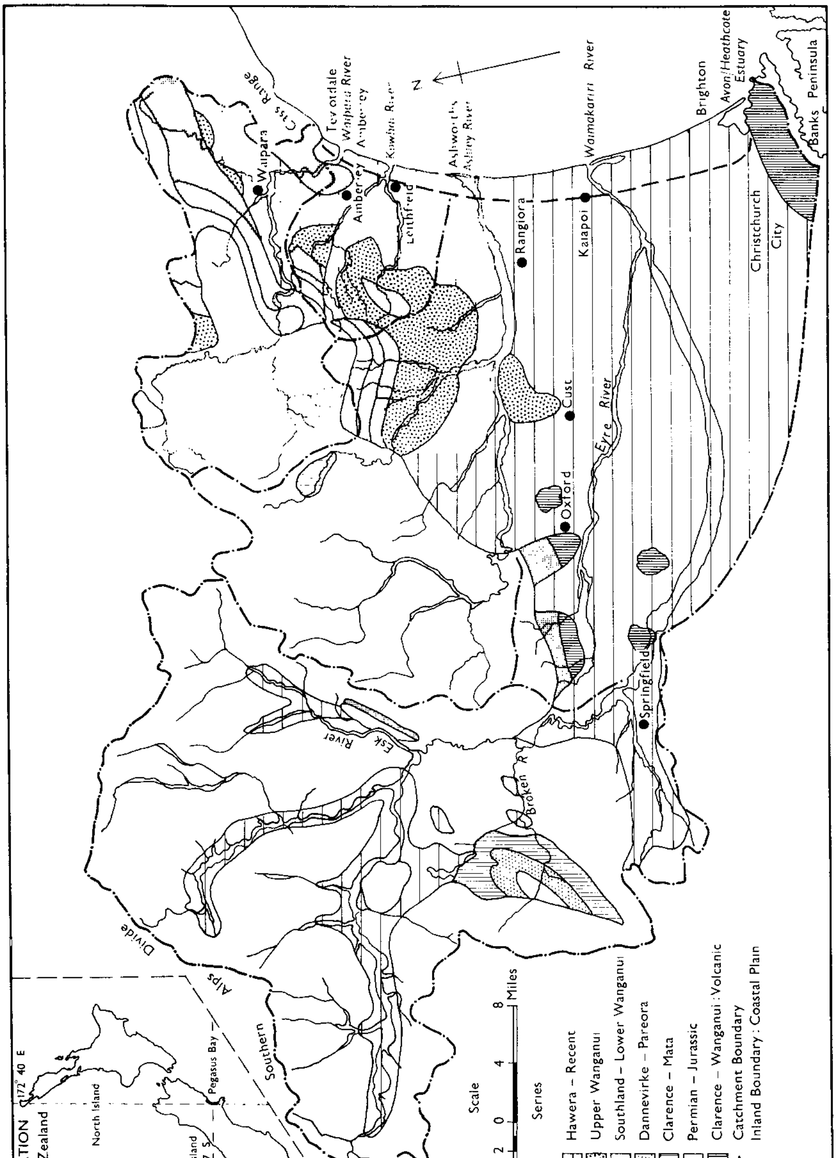

FIG. 1—The locations of rivers flowing into Pegasus Bay, and the geology of their catchment areas. Drawn from N.Z. Geological Survey Map Series 1 : 250,000, Sheet 21.

Rivers appear to provide most of the foreshore sediment in Pegasus Bay. This was verified by evidence of erosion within their headwaters and the quantities of bed load in their channels. Reed (1951) collected sediment samples from south of the Waimakariri River mouth and found a favourable correlation with the geology of its catchment. Small streams are of minor importance and cliff, slide, and gully erosion probably contributed during early stages of progradation. Onshore movement and wind action are relatively unimportant.

Of the rivers, only the Waimakariri has tributaries that rise on the main divide of the Southern Alps. Its annual suspended sediment discharge has been estimated by Benson (1946), at between 2 and 3 million tons. More recent information suggests that most of this sediment could be discharged during the annual flood of about 40,000 cusecs.* The channel slope, from the 100 ft contour to sea level, of 0·0018 ft/ft, together with the diurnal tidal effect, permits the deposition of sand only at the river mouth. Shingle deposition normally terminates 2 miles upstream.

Next in importance is the Ashley River which has built a small fan between the alluvial fan of the Waimakariri River and the downland of North Canterbury. It has a down-stream channel slope of 0·0034 ft/ft and sand is deposited at the mouth with the down-stream shingle limit half a mile upstream. During floods gravel may be transported to the mouth and deposited on the adjacent foreshore. North of the Ashley River shingle replaces sand as the dominant foreshore sediment. Both the Kowhai and Waipara rivers move considerable bed load, although sediment discharge to the foreshore is limited to periods when flooding opens the barriers separating their river mouth lagoons from the sea. Flow in the Kowhai is intermittent and sediment movement in both rivers is largely restricted to flood periods. Both rivers have down-stream channel slopes of 0·0054 ft/ft. The presence of the river mouth barrier, by excluding tidal effects, assists the passage of larger material to the mouth. This is most effective following the closing of the breach in the barrier, but diminishes as the lagoon refills.

The Heathcote River, largely spring fed and of minor importance, does carry loess sediment in suspension from Banks Peninsula during floods. A recent flood of 60 cusecs yielded 0·0000837 tons/second.* This settles out in the estuary which the Heathcote shares with the Avon River. Tidal reworking of the estuarine sediment could cause a little of it to reach the foreshore.

CATCHMENT GEOLOGY

The Waimakariri catchment (1,250 sq. miles) (Fig. 1), apart from some Quaternary alluvium, consists almost entirely of undifferentiated Lower Mesozoic feldspathic siltstone and sandstone (greywacke). An extensive area of upper and lower Tertiary sediment occurs in the Broken River catchment, with smaller deposits in the Esk and Eyre catchments which yield some volcanics. The Ashley catchment (450 sq. miles) has a higher percentage of

*T. Chinn, pers. comm., former hydrologist, North Canterbury Catchment Board.

greywacke with some Tertiary sediment. This extends into the Kowhai catchment (95 sq. miles) which is dominated by alluvium. The Waipara catchment (285 sq. miles) rises in Lower Mesozoic greywacke and rapidly moves into lower and upper Cretaceous sedimentaries, separated by greywacke bands, before passing through Tertiary and alluvial material to the coast.

FORESHORE GEOLOGY

Size Analysis of Foreshore Sediment Samples

Sampling Method

The length of the coastline and the great variation in particle size distribution between the low-tide mark and the base of the beach ridge necessitated a rigid sampling technique. Sampling was confined to the mid-tide zone, at 1-mile intervals (Fig. 2) along the foreshore, during one low-tide period to ensure a uniform sampling environment. A grid, 3 yd square, was marked out at each sampling station and four 2 in.-diameter core samples of the surface 6 in. (one from each corner) were mixed and sealed in plastic bags.

All samples were treated by standard washing and sieving techniques. Samples, averaging 40 gm, were shaken for 30 minutes in an "Endrock" sieve shaker through A.S.T.M. sieves arranged in $0{\cdot}5\phi$ intervals. Cumulative frequency curves were constructed for each sample and the following sedimentary parameters calculated (Inman, 1952) (Table 1): (*a*) mean; (*b*) median; (*c*) sorting; (*d*) skewness; (*e*) kurtosis.

Mean and Median

The mean $M\phi = 0{\cdot}5\ (\phi 84 + \phi 16)$ and the median $Md\phi = \phi 50$ were used to measure the property of central tendency within each sample. Size distribution histograms of the samples produced normal frequency polygons (Fig. 3) although the coarser samples from the shingle foreshore were strongly negatively skewed and bimodal, because of the high percentages in the largest size groups. Each parameter (ordinate) was plotted against location, north along the foreshore (abscissa). Regression lines were fitted using "least squares" and tested with "students *t*". For both mean and median the distribution was significant, implying an increase in sediment size northwards.

This procedure was applied to the remaining parameters, but excluded samples from the shingle foreshore because of the extreme range of particle sizes within samples. (See p. 230 for alternative method of sampling.)

Sorting

Sorting, an approximation to the standard deviation, showed a highly significant decrease northwards, which continues into the shingle foreshore ($\sigma\phi = 0{\cdot}5\ (\phi 84 - \phi 16)$). The sorting trend was clearly marked in the cumulative frequency curves which ranged from the steep, highly sorted sand samples to the near horizontal shingle samples. The well sorted sample 31, in the extreme north at Teviotdale, was anomalous, owing to

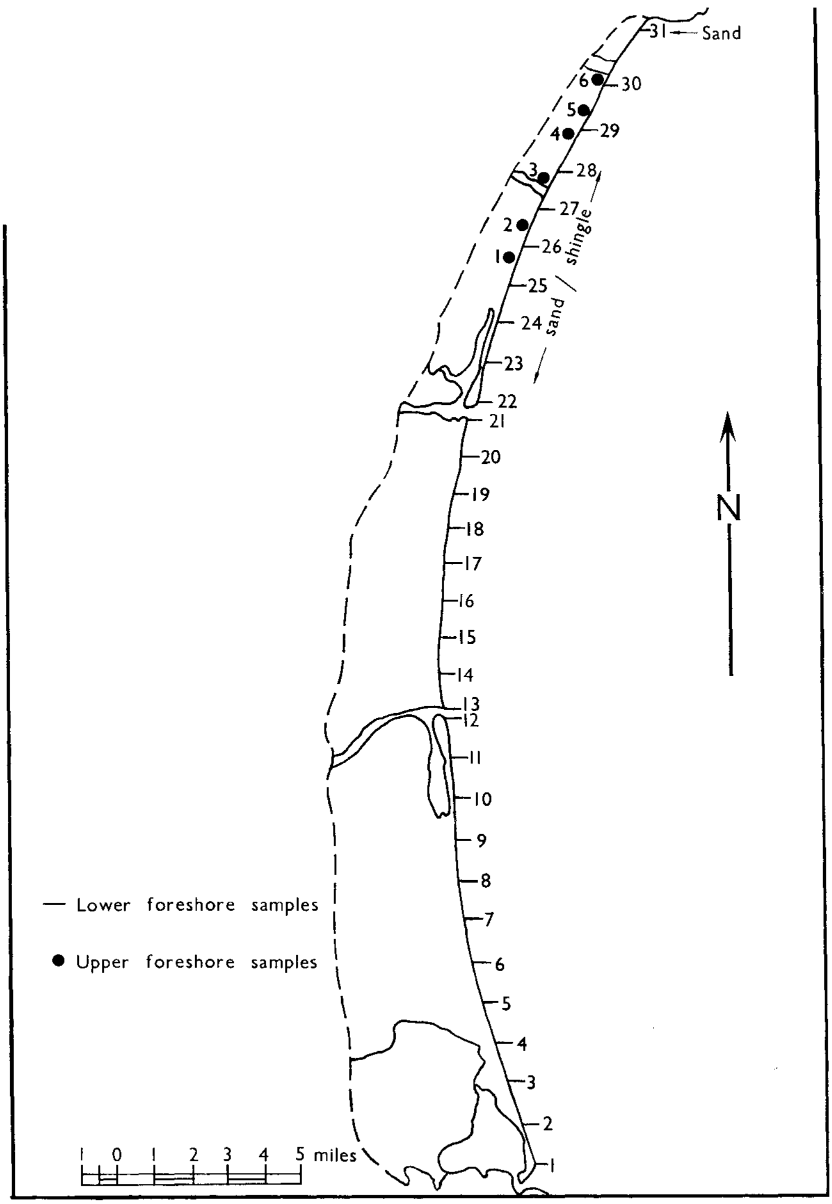

FIG. 2—Location of foreshore sediment samples.

a sudden return to a sand foreshore over the last 400 yd of coastal plain. This is the result of a local ponding effect which is induced by the northern marine cliffs when littoral drift is in this direction.

Skewness

Skewness, a measure of the departure of the mean from the median, has a value of zero in symmetrical distributions and is negative if the mean is less than the median

$$\alpha = \frac{0{\cdot}5\ (\phi 84 + \phi 16) - Md(\phi)}{\sigma\phi}$$

$$= \frac{M\phi - M(\phi)}{\sigma\phi}$$

Until recently the skewness parameter has been of unknown value in the description of foreshore sediment samples. Friedman (1961) and Sevon (1966) in comparisons of foreshore, dune, and river sands have found that skewness is negative in foreshore samples and positive in dune and river samples. A different mode of transport is a possible explanation. Foreshore sands are subject to oscillatory flow whereas dune and river sands experience unidirectional movement. The Pegasus Bay samples from either side of the Waimakariri mouth produced a marked change from positive to negative skewness north and south of the mouth. The change was not as obvious around the Ashley mouth.

Kurtosis

Kurtosis, another parameter, relates the average spread of the distribution to the standard deviation of the distribution.

$$\beta\phi = \frac{0{\cdot}5\ (\phi 95 - \phi 5) - \sigma\phi}{\sigma\phi}$$

The value for a normal distribution is 0·65 and a value exceeding this represents a distribution less peaked than the normal. Sevon (1966) showed a relationship in kurtosis between backshore and dune sands, and between foreshore and dune sands. The Pegasus Bay samples showed no internal relationship for the foreshore.

Additional Foreshore Samples

Because of the unsatisfactory results obtained by mechanical analysis of shingle foreshore samples, additional samples of larger aggregate, were collected near the high-tide mark. The three major axes of 50 greywacke pebbles were measured in each sample to give an approximate volume, and four size groups based on the major axes were used in the construction of size distribution histograms.*

*British Standard Institution Classification (1947): Boulders, 200 mm+; cobbles, 60 mm < 200 mm; coarse gravel, 20 mm < 60 mm; medium gravel, 6 < 20 mm.

TABLE 1—The Sediment Parameters Obtained from the Mechanical Analysis of Foreshore Samples

Sample	Mean	Median	Sorting	Skewness	Kurtosis
Avon/Heathcote River					
1	2·61	2·65	0·35	−0·114	0·600
2	2·65	2·73	0·34	−0·235	0·972
3	2·42	2·48	0·43	−0·139	0·569
4	2·48	2·55	0·40	−0·175	0·587
5	2·16	2·10	0·45	0·133	0·550
6	2·24	2·24	0·44	0·000	0·512
7	2·39	2·45	0·37	−0·162	0·662
8	2·07	2·03	0·36	0·111	0·708
9	2·31	2·31	0·39	0·000	0·679
10	2·15	2·14	0·40	0·025	0·588
11	2·21	2·17	0·38	0·105	0·672
12	2·40	2·39	0·36	0·028	0·721
Waimakariri River					
13	2·51	2·52	0·39	−0·026	1·134
14	2·40	2·39	0·37	0·027	0·622
15	2·18	2·14	0·48	0·083	0·792
16	1·94	1·91	0·52	0·058	0·702
17	2·38	2·36	0·40	0·050	0·613
18	2·05	2·10	0·45	−0·112	0·944
19	2·30	2·29	0·47	0·021	0·596
20	2·01	2·14	0·65	−0·020	1·078*
Ashley River					
21	2·02	2·06	0·37	−0·108	0·877
22	1·86	1·96	0·66	−0·015	0·545*
23	1·70	2·05	0·90	−0·390	1·168*
24	2·27	2·28	0·44	−0·023	2·723*
25	2·56	2·58	0·39	−0·051*	0·641*
26	−4·63*	1·11*	6·96*	−0·505*	0·278*
27	−0·98*	0·38*	3·25*	−0·418*	0·479*
Kowhai River					
28	0·79*	1·48*	1·52*	−0·454*	0·365*
29	−2·53*	0·51*	5·02*	−0·605*	0·376*
30	−3·44*	−0·64*	4·64*	−0·603*	0·075*
Waipara River					
31	2·48	2·56	0·44	0·182	1·840*

All values are in phi (ϕ) units.
0·5 mm = 1·0 ϕ 0·125 mm = 3·0 ϕ
0·25 mm = 2·0 ϕ 0·062 mm = 4·0 ϕ

(i) The parameters are expressed in Phi units; (ii) Parameters marked * are approximate because of inadequate data; (iii) The accuracy of kurtosis is subject to the accuracy of the ϕ95 and ϕ5 values which for well sorted samples are located at either end of the frequency curves in an area of considerable error.

The samples were poorly sorted in the vicinity of the Waipara River. A decrease to the south in the boulder and cobble size groups was accompanied by a more erratic increase in the range of gravels. The percentage of coarse gravel was at a maximum near Amberley Beach, whereas the maximum for medium gravel occurred further south. All size fractions larger than sand were absent south of Ashworth's beach, 2 miles north of the Ashley mouth.

Mineral Analysis of the Foreshore Sediment

The 3·0–3·5 phi (ϕ) and 3·5–4·0 phi (ϕ) sand fractions in every second sample were separated, using bromoform, into light and heavy fractions and mounted in Canada balsam (R.I. 1·54) for counting.

Light Minerals

The most abundant mineral was quartz. It makes up 25% of the samples south of the Waimakariri River, but the amount increased steadily northwards to 35%–40% (Table 2). Feldspar, with a refractive index less

TABLE 2—Mineral Analyses of Foreshore Samples Expressed as Percentages of the Total Samples

LIGHT MINERALS

Mineral	Sample Numbers															
	1	3	5	7	9	11	13	15	17	19	22	25	27	29	30	31
Quartz	34	23	24	24	28	24	35	36	34	35	35	39	37	39	36	41
Feldspar (>1·54)	12	12	3	10	13	10	4	7	4	9	5	7	4	7	6	9
Feldspar (<1·54)	12	5	3	13	9	11	7	17	11	16	14	13	19	15	18	22
Glauconite	1	2	......	2	2	......	2	2	3	4	4	7	2	9	4	3
Calcite	......	1	......	1	1	1	......	......	1	2	......	3	6	3	6	3
Argillaceous rock frag.	23	23	27	17	20	21	16	16	20	11	13	12	13	12	13	11
Rock frag.	15	34	43	29	24	32	33	19	26	23	25	15	16	12	15	9
Unidentified	3	......	......	4	3	1	3	3	1	......	4	4	3	3	2	2

HEAVY MINERALS

Mineral	Sample Numbers															
	1	3	5	7	9	11	13	15	17	19	22	25	27	29	30	31
Magnetite, Hematite	13	10	11	15	14	10	15	7	15	17	7	1	12	5	9	9
Chlorite, Biotite	9	9	11	9	9	8	3	9	5	3	7	2	3	1	5	2
Garnet	3	1	......	......	1	3	1	......	1	1	......	......	1	3	......	1
Light and unidentified	75	80	78	76	76	79	81	84	79	79	86	97	84	91	86	88

than 1·54, varied from 23% north of the Waipara River to 10% at South Brighton. However, feldspar with a refractive index greater than 1·54 decreased in quantity north to the Waimakariri River and then remained relatively constant as far as the Waipara River. This particular feldspar is found on Banks Peninsula but, without exhaustive sampling, it is not certain that the large quantity in the south is supplied from this source.

Neither the glauconite nor the calcite content exceeded 10% and in most samples was much less. The percentage of both decreased southwards. In contrast arenaceous and argillaceous rock fragments were abundant in all samples, but showed a definite decrease northwards. Their presence could account for the lower quantity of feldspar ($>1{\cdot}54$) south of the Waimakariri River.

Heavy Minerals

Heavy minerals were difficult to count because of their variety and extremely low percentage per sample. The proportion of iron minerals, hematite and magnetite, showed a slight decrease northwards, but varied widely from one sample to the next, especially north of the Waimakariri River. Both chlorite and biotite percentages decreased northwards from the Waimakariri River. Garnet, the only other heavy mineral counted, averaged 1%–2% of the heavies in most samples, but the proportion increased at the mouths of most rivers.

CONCLUSIONS

Although the number of foreshore sediment samples studied was severely limited, both the mechanical and mineral analyses give some indication of the direction of sediment movement relative to the rivers flowing into Pegasus Bay. Both the mean and the median grain size of individual samples showed an increase north along the foreshore. This is explained by a progressive increase in river channel slope enabling larger particles to reach the foreshore. Conversely the sorting of samples improved southwards as the particle size decreased. The distribution of skewness indicated that aproximately half the foreshore is dependent on the Waimakariri River as a sediment source. The trend from positive to negative values away from the mouth can be interpreted two ways. It indicates either a recent spread of sediment along the foreshore, accompanied by active longshore movement, or an aged distribution and little longshore movement. The latter assumes a slow transfer of material from river to foreshore.

The mineral analysis revealed differences attributable to variations in basin lithology from north to south. The grey colour of samples increases as greywacke becomes dominant and Tertiary deposits diminish.

These results suggest that the position of the river mouths initially controls the foreshore sediment pattern. The increasing width south of the coastal plain is a function of both catchment flow and sediment yield, and there is a predominant littoral movement in this direction. Improved sorting and a decrease in particle size support the latter. However, the skewness distribution, and the fluctuations of the other parameters between

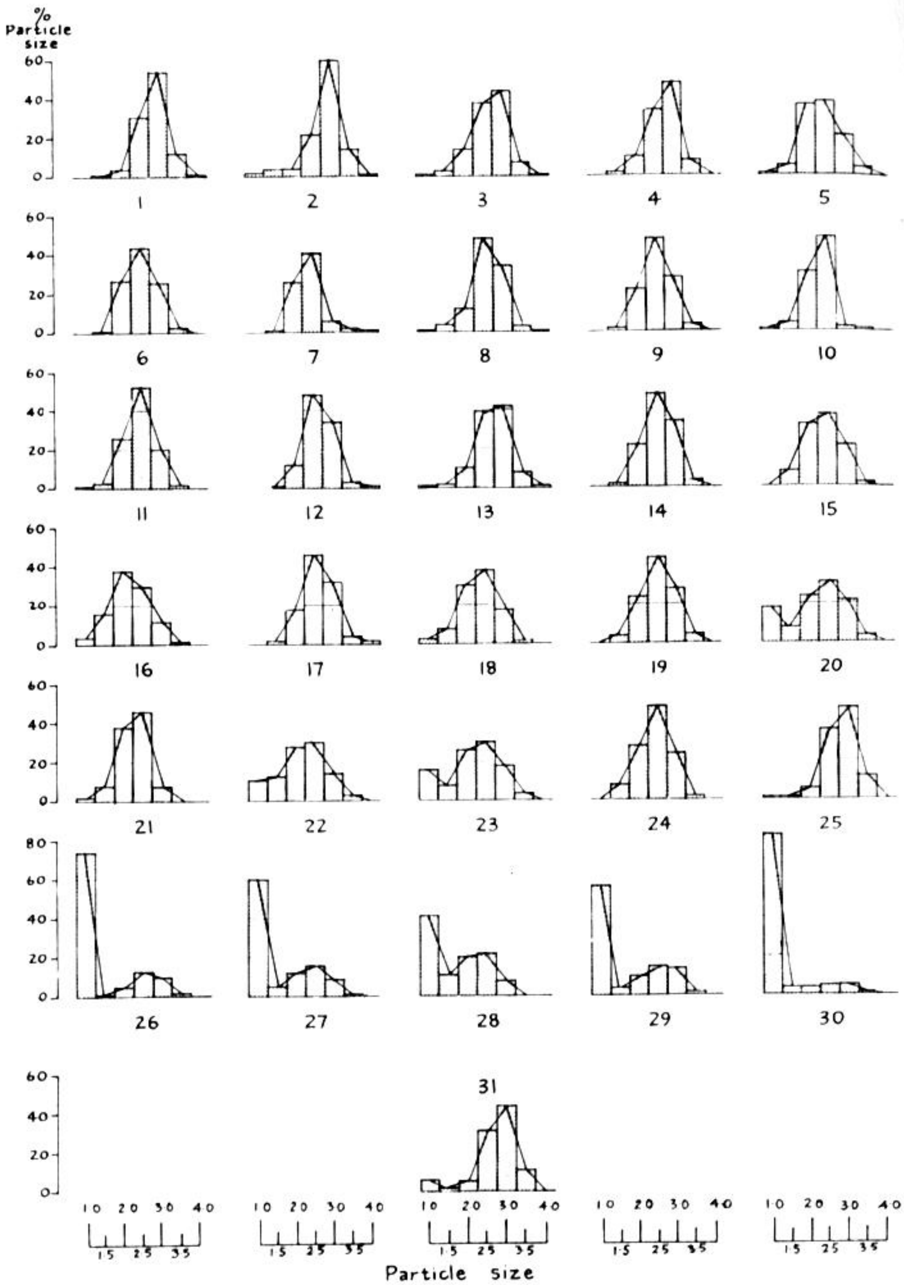

FIG. 3—Size distribution of lower foreshore sediment samples.

individual samples (allowing for sampling error) and a return to a sand foreshore at Teviotdale are reminders that the direction of littoral drift can be variable. The lack of deltas and the presence of spits and barriers all imply active littoral movement although it would seem that the magnitude of this is less than anticipated in earlier works. It is most unlikely that sediment from the northern rivers readily traverses the mouth of the Waimakariri River which is marked by a salient bulge in the coastline.

Finally, the present source and character of the foreshore sediment indicates that coastal progradation is still active, although future conservation work in the river catchments, use of flood protection methods to stabilise the position of the mouths, and an increasing depth of water offshore (assuming land and sea levels remain constant), will reduce the sediment contribution and render it less effective as a cause of coastal progradation.

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