Read at the Annual Conference of the Ussher Society, January 1981

Spatial variation in beach sediments at Morte Bay, north Devon

J. GERRARD
M. DAWSON

J. Gerrard and M. Dawson 1981. Spatial variation in beach sediments at Morte Bay, north Devon. *Proc. Ussher Soc., 5,* 206-216.

The spatial variability of sediments on Woolacombe Beach, Morte Bay, north Devon has been examined using the standard size parameters of mean, sorting, skewness and kurtosis. Trend surface analysis was used to determine the spatial components of these parameters. The dominant spatial component is normal to the shoreline. Mean size decreases, sorting increases and the sediments become less skewed away from low water mark. Slight trends along the beach seem to indicate a limited northerly longshore drift component. Sediments in the backshore and foreshore zones were markedly different, the former being characterised by a finer, grain size and better sorting.

John Gerrard, Department of Geography, Birmingham University, Birmingham BI5 2TT; Martin Dawson, Department of Geography, The University of Alberta, Edmonton, Alberta, Canada.

Introduction

The size characteristics of beach sediments are rarely uniform spatially and tend to show distinct variations both across and along the beach. These variations are the result of differences in the type and magnitude of transportational power inputs over the nearshore, foreshore and backshore areas. In this paper, trend surface techniques and sub-population analysis are used to identify the spatial variability of size-frequency characteristics in a beach foreshore-backshore complex on Woolacombe Beach, Morte Bay, Devon.

Geomorphological setting

Woolacombe Beach is an example of an Atlantic coast surf beach and is the northernmost of four such beaches in this part of north Devon (Fig. 1). The material appears to have been deposited by wave-generated currents on the foreshore and by wind action in the backshore and limited dune zones. The beach extends for approximately 3400m with an axial orientation of NNE/SSW and at low tide 400m of beach are exposed with an average slope of 2 degrees. The beach material is predominantly quartz sand but significant amounts of shale and carbonates are also present.

Waves on this part of the north Devon coast are generated by significant local westerly winds of more than 10 knots and by storm waves and Atlantic swells from the WSW (Willis and others 1959). Wave data provided by Darbyshire (1963), for the Bristol Channel, indicated predominantly short-period waves (5-7 sec) but with approximately 10% Atlantic swell waves (maximum period 11 sec). More recent information, however, suggests that more prominence should be given to the longer period waves. At the time of the study (Spring 1979), spring tides and westerly gales had caused extensive erosion at the base of the dune zone revealing dune structures and resulting in extensive redeposition of sand in the backshore zone. Under more normal conditions the dune and upper backshore zones are rarely affected by marine action. At the time of the survey the beach possessed a relatively uniform low angle profile with no significant variation in profile form along the beach.

Methodology

The areas sampled were the backshore zone (the area of the beach above the high water limit extending landward to the dune zone) and the foreshore zone (the area exposed at low tide and extending from high water mark to the upper limit of the swash at low tide). 160 samples were collected from the top 5cusing a systematic random sampling design based on 5 rows along the beach. This resulted in a sample spacing of 95m (Fig. 2). The samples were subjected to standard dry sieving at 0.25 ϕ intervals to determine the size-frequency distributions. The measures most commonly used to describe the size-frequency distributions of sediments are mean, sorting, skewness and kurtosis. Although the moments method is the mathematically more elegant way of calculating these measures, very little allowance can be made for faulty sieve screens and it is difficult to deal with open-ended distributions. For these reasons, graphical measures have been used.

Table of Contents

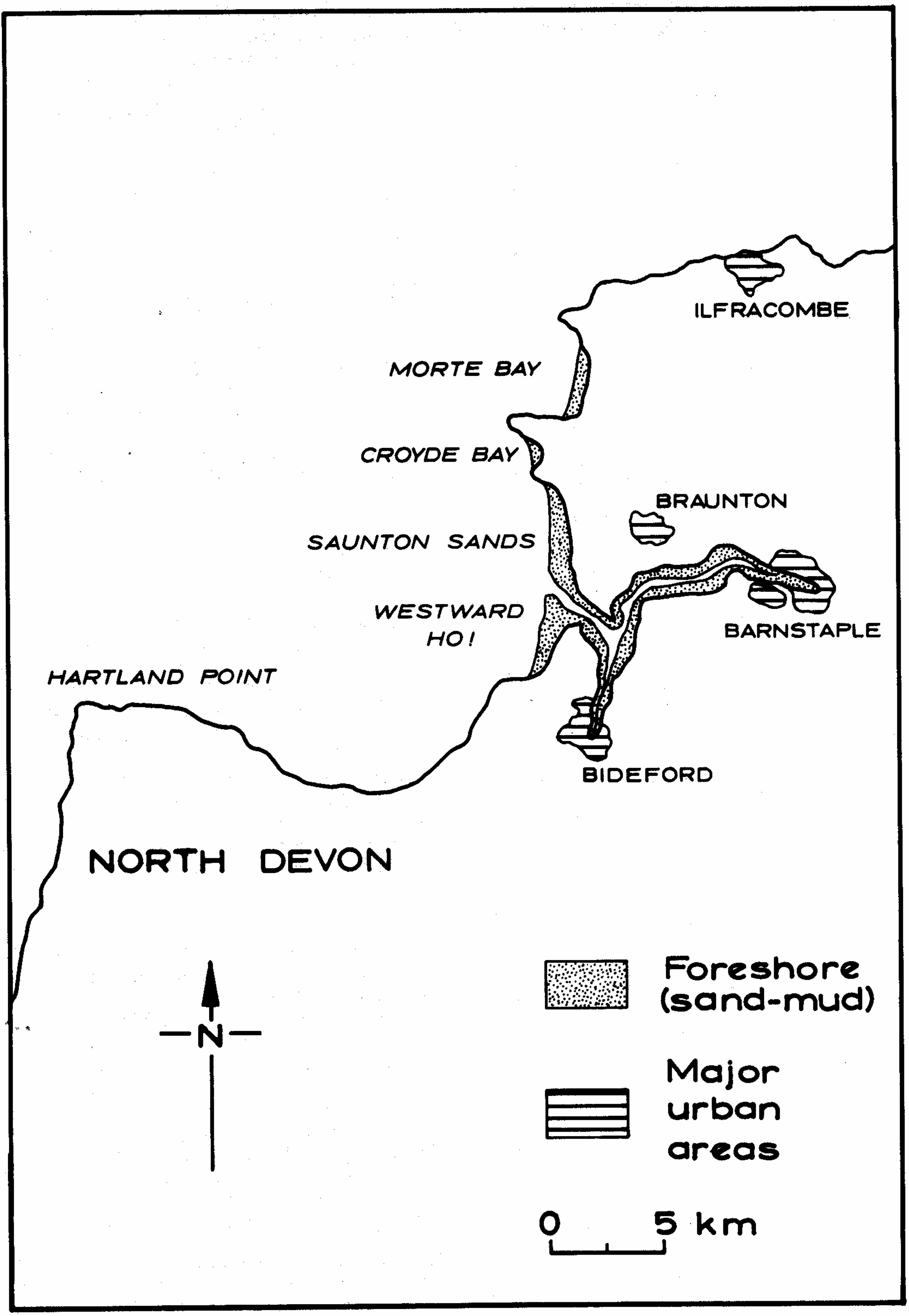


Figure 1. Location map of Morte Bay, north Devon

Table of Contents

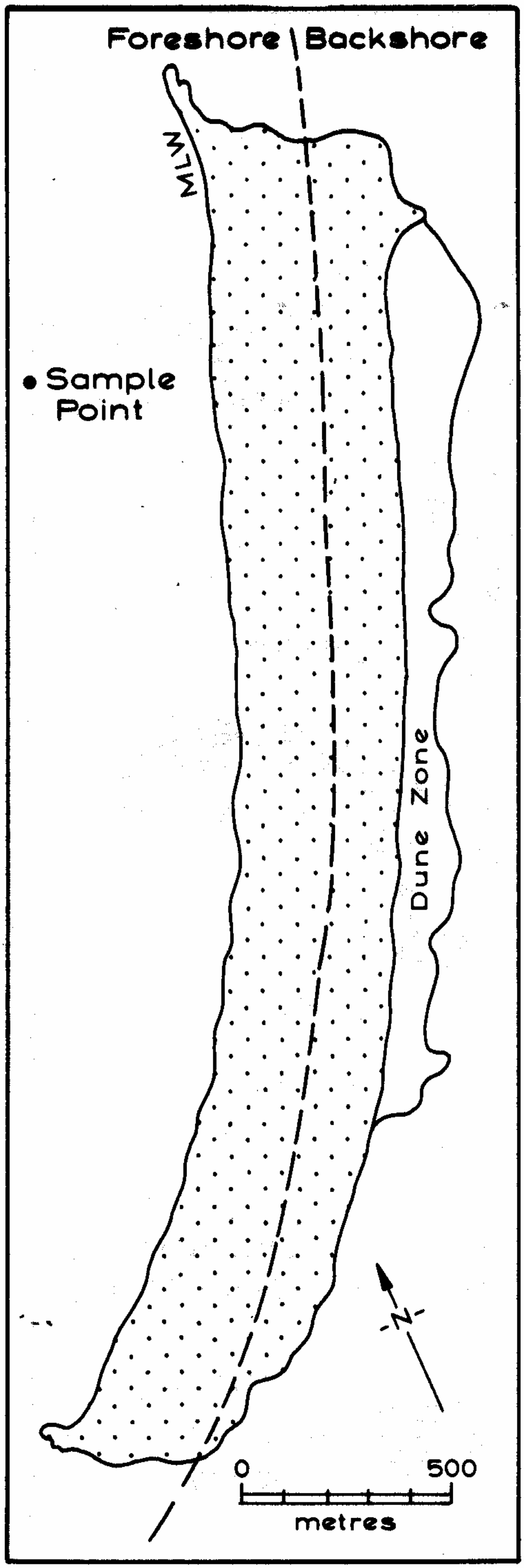


Figure 2. Location of sample points in relation to the beach zones

A number of graphical measures have been proposed and have been reviewed by Folk (1966). The measures adopted in this study were:

$$\text{Mean} = \frac{ø5 + ø15 + ø25 + ø35 + ø55 + ø65 + ø75 + ø85 + ø95}{10}$$

(McCammon 1962)

$$\text{Sorting} = \frac{ø70 + ø80 + ø90 + ø97 - ø3 - ø10 - ø20 - ø30}{9.1}$$

(McCammon 1962)

$$\text{Skewness} = \frac{(ø84+ø16-2ø50)}{2(ø84-ø16)} + \frac{(ø95+ø5-2ø50)}{2\,(ø95-ø5)}$$

(Folk and Ward 1957)

$$\text{Kurtosis} = \frac{ø95-ø5}{2.44\,(ø75-ø25)}$$

Using the Folk and Ward formula for kurtosis normal curves have a value of 1.00. Values below 1.00 indicate a relatively flat or platykurtic distribution and values above 1.00 indicate a peaky or leptokurtic distribution.

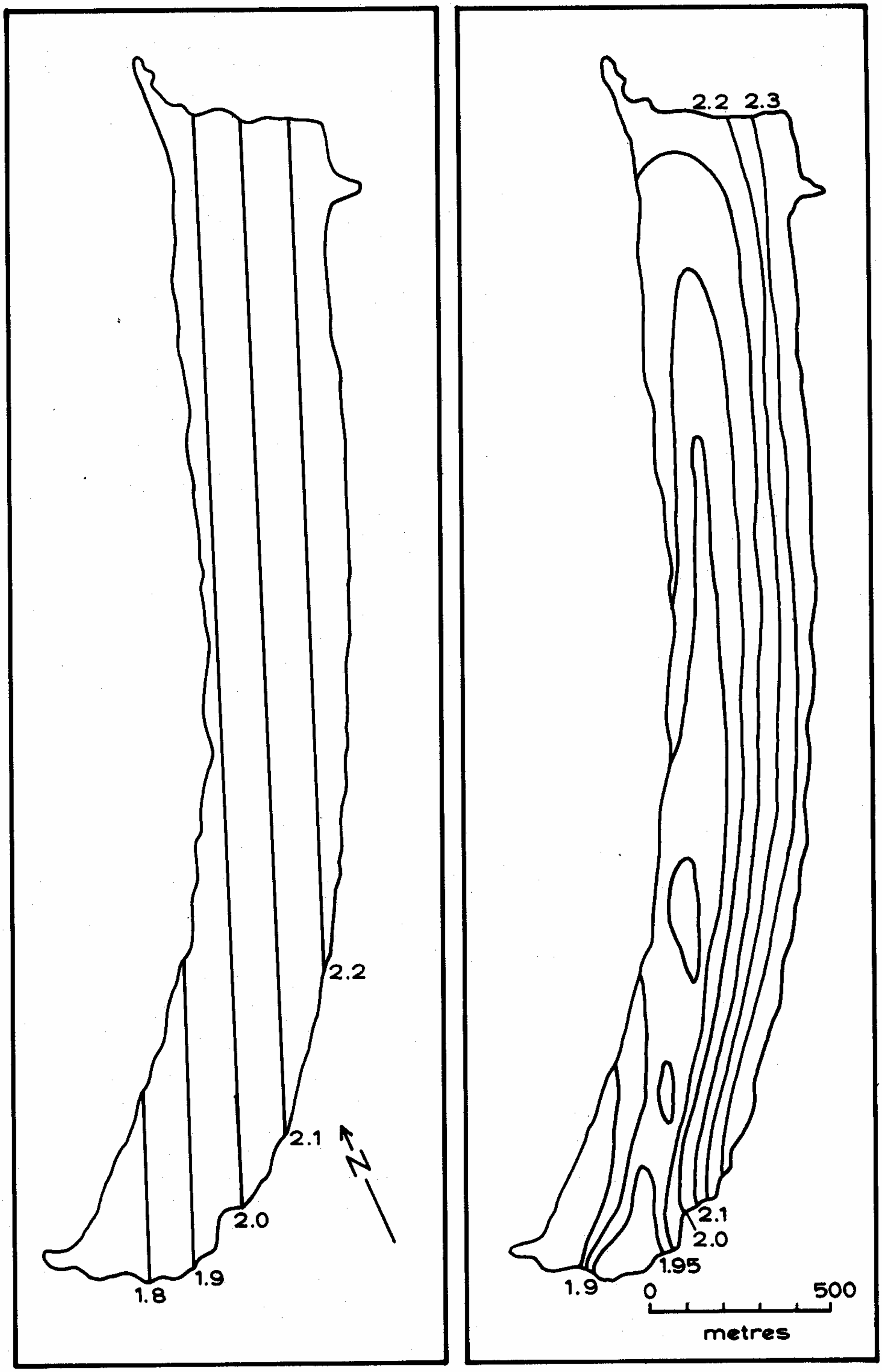
Trend surfaces

Trend surfaces have been calculated to determine the spatial variation of each of the four graphical measures used. The trend surfaces are not necessarily definitive of the spatial relationships of beach sediments but represent a method of indicating the scale of these relationships, as an aid to interpretation. Two vectors of potential sediment variability may be recognised on any beach. The dominant vector, in an equilibrium beach situation, is usually normal to the shoreline and should be identified on a first order trend surface. Components of change. alongshore, such as grading away from a single source of material, should be identified by using higher order surfaces.

Chaynes (1970) has pointed out that the use of successively higher order trend surfaces may not always be valid and that significance tests should he applied to each order to indicate whether the higher percentage sum of squares accounted for by each higher order surface is significantly greater than that of the next lower order surface. This has been done in this instance and all the surfaces are significant at the 5% level. In addition, both Norcliffe (1969) and Baird and his co-workers (1971) argue that the order of surface used should be determined by substantivebackground knowledge. The distinct possibility of longshore components of change seem to validate the use of third or fourth order surfaces. In this study the fourth order surface has been used.

The interpretation of the surfaces needs also to take into consideration the level of explained variance attributable to those surfaces (Table 1). The most marked feature is

Table of Contents



a.

b.

Figure 3. Trend surfaces for ø mean grain size: (a) linear, (b) quartic

Table of Contents

Table 1. Percentage sum of squares explained by different order trend surfaces

	Linear	Quadratic	Cubic	Quartic
Mean	42.44	62.83	74.75	78.57
Sorting	60.04	66.83	61.10	71.70
Skewness	19.37	30.38	35.02	41.91
Kurtosis	17.43	38.60	45.73	52.33

the very poor fit of the linear surfaces for skewness and kurtosis. The high values of explained variance for the quartic surfaces, especially mean size and sorting, suggests that valid statements concerning the spatial variability of the beach sediments can be made.

The linear surfaces indicate the trends normal to the shoreline inferred earlier (Figs. 3a, 4a, 5a and 6a). Mean grain size shows a progressive decrease from the lower foreshore area to the backshore zone. Sorting shows a somewhat similar trend with the best sorting in the backshore and poorest sorting in the foreshore zones. The sediments are generally negatively skewed, with skewness increasing towards the low water mark. These trends are similar to those identified on Saunton Sands by Greenwood (1978) except that skewness values are greater on the Saunton Beach complex.

Three main factors control the mean grain size of beach sediments, namely the sediment source, the wave energy level and the general offshore slope on which the beach is constructed. On Woolacombe Beach the main sediment sources are material eroded from the adjacent cliffs and dunes and material moved onshore from the offshore zone. The low angle, uniform beach profile appears to have little influence on the processes involved and the decrease in mean size from the foreshore to the backshore is probably related to the migration of the wave system and therefore to the migration of energy inputs across the beach (Trask and Johnson 1955). Energy expenditures are greater near low water mark and decrease towards the high tide swash limit. More intense wave activity would increase the percentage of coarse material and decrease the percentage of fines to produce the high negative skewness values obtained (Greenwood 1976).

The fourth-order surface for mean grain size indicates a difference between the backshore and lower foreshore zones (Fig. 3b). The predominant trend over the backshore is still normal to the shoreline but over the lower foreshore there is a slight trend from coarse to fine away from the cliffs at the southern end of the beach. This may reflect the introduction of new material onto the beach as a result of erosion of these cliffs, but it may also reflect a higher wave energy level in this area because of slight wave refraction by offshore contours. Some northerly longshore drift does occur because waves approaching south of 280°W break obliquely on the beach. The fourth-order surface for sorting indicates similar trends to that of mean grain size with slightly better sorting at the north end of the beach (Fig. 4b). Trends for skewness are quite complex but again a distinction can be made between material in the backshore zone, which shows little skewness, and that in foreshore areas where a marked negative skewness occurs, increasing from south to north (Fig. 5b). Kurtosis values are greatest near low water mark at the north end of the beach and lowest in the backshore zones at both ends of the beach (Fig. 6b). The high, leptokurtic values at the north end indicate the existence of extensive amounts of material in the tails of the distribution.

The major trend component, identifiable on both linear and quartic surfaces, is that normal to the shoreline. Mean size increases, sorting decreases and skewness increases from backshore to foreshore. Such changes have been noted previously and indicate sediment movement and sorting by waves as they migrate up and down the beach with each tidal cycle (Strahler 1966). However, there is no indication of a transition zone of coarse material as has been noted on some beaches by Schiffman (1965).A similar trend in sorting was recognised by Miller and Zeigler (1958) who suggested it resulted from finer grains being trapped by the interstices of coarser grains. Some of these characteristics and suggested mechanisms can be assessed more clearly by what has become known as sub-population analysis.

Sub-population analysis

Many workers have suggested that grain size distributions, when plotted on probability paper, show a series of straight line segments (e.g. Visher 1978, Sagoe and Visher 1977). Visher (1969) has argued that each segment represents separate, but truncated, log-normal populations which are joined by the next population to form a single distribution. The identification and interpretation of these segments, however, is not without its problems (Clark 1976). Notwithstanding the problems involved, a hydraulic explanation for the separate sub-populations is increasingly suggested (Moss 1972; Middleton 1976). Three major sub-populations can be identified. These are a suspension (interstitial) population of fine material, a bedload (contact) population at the coarse end of the grain size distribution and a saltation (framework) population in between. It may be possible, in some instances, to identify a swash-backwash break in the saltation population. Variations in these sub-populations across the beach would be expected if particle size characteristics were related to energy levels and transportational mechanisms. To examine this, a sub-population analysis was conducted on samples from the lower foreshore, upper foreshore and the backshore zones. Representative diagrams for these zones are shown in Fig. 7.

Table of Contents

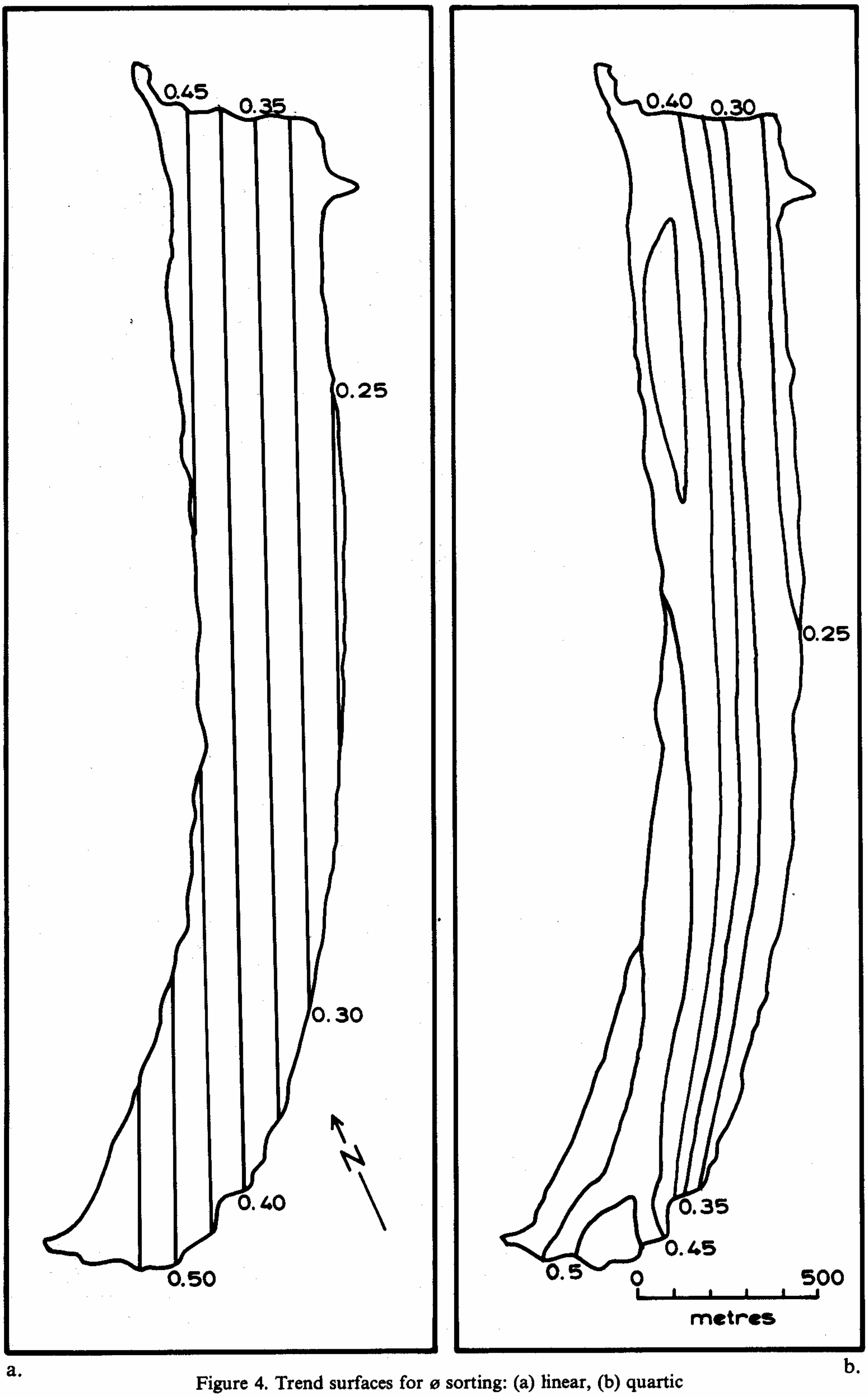
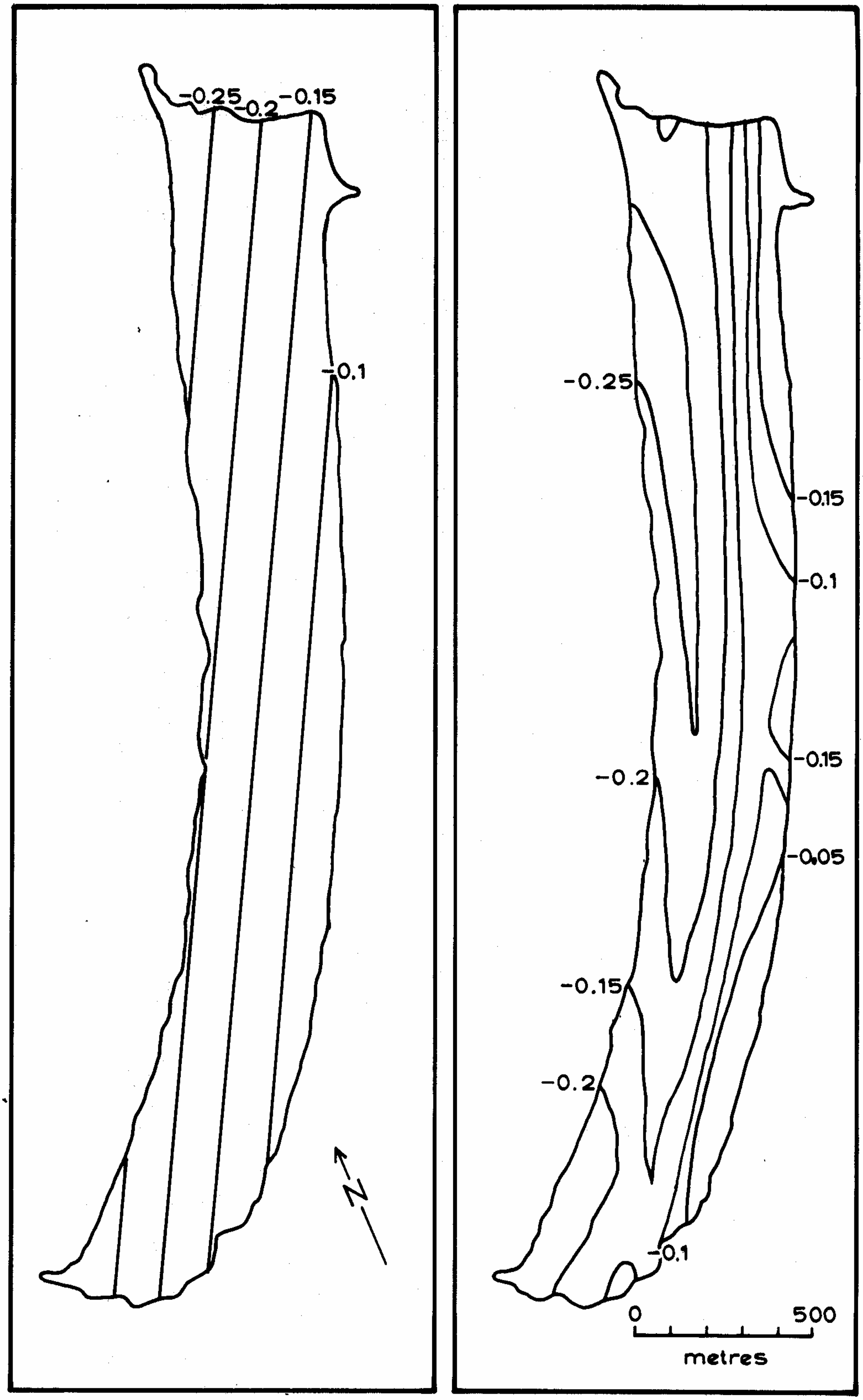


Figure 4. Trend surfaces for ø sorting: (a) linear, (b) quartic

Table of Contents



a. Figure 5. Trend surfaces for ø skewness: (a) linear, (b) quartic b.

Table of Contents

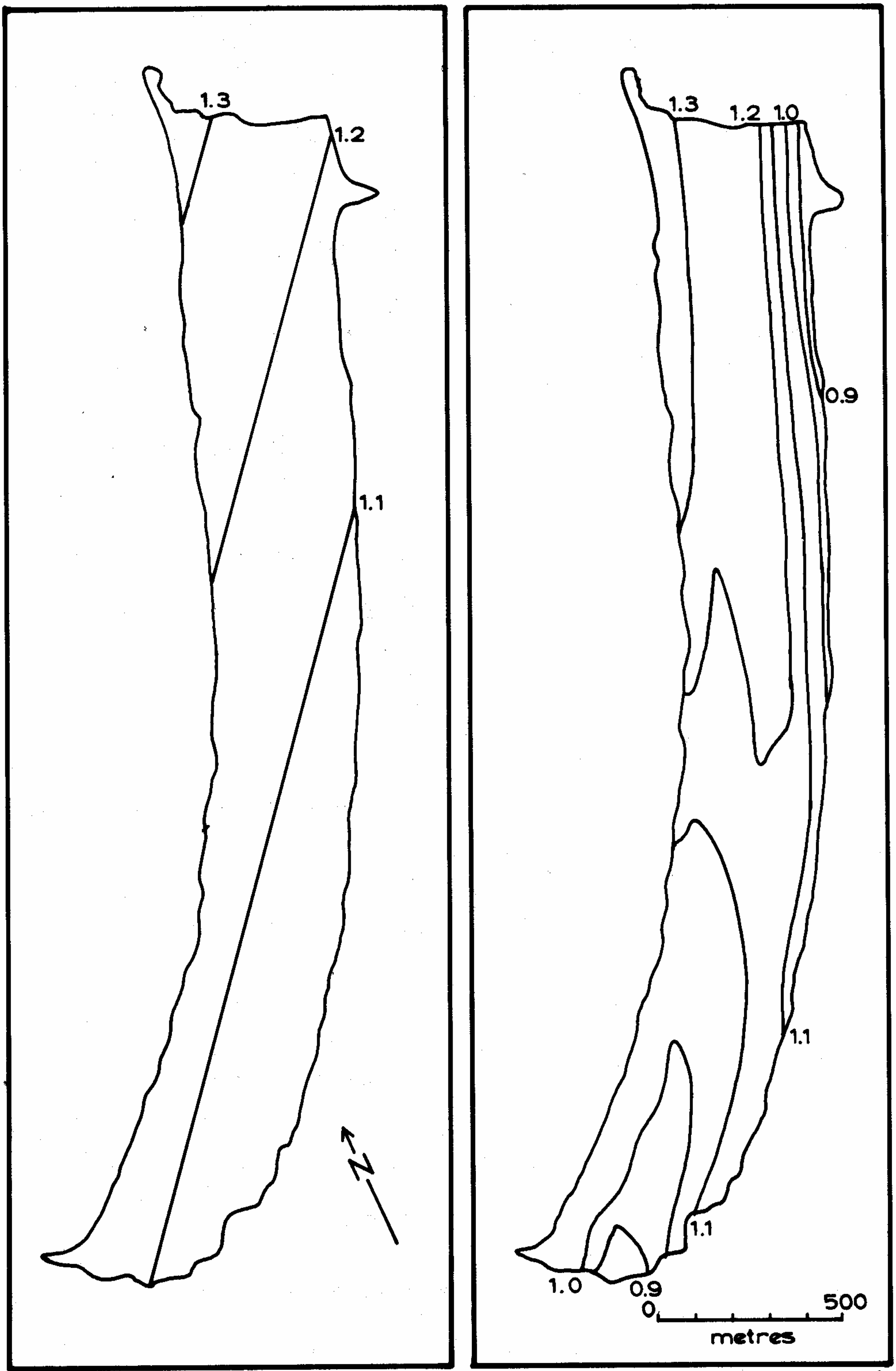


Figure 6. Trend surfaces for ø kurtosis: (a) linear, (b) quartic

Table of Contents

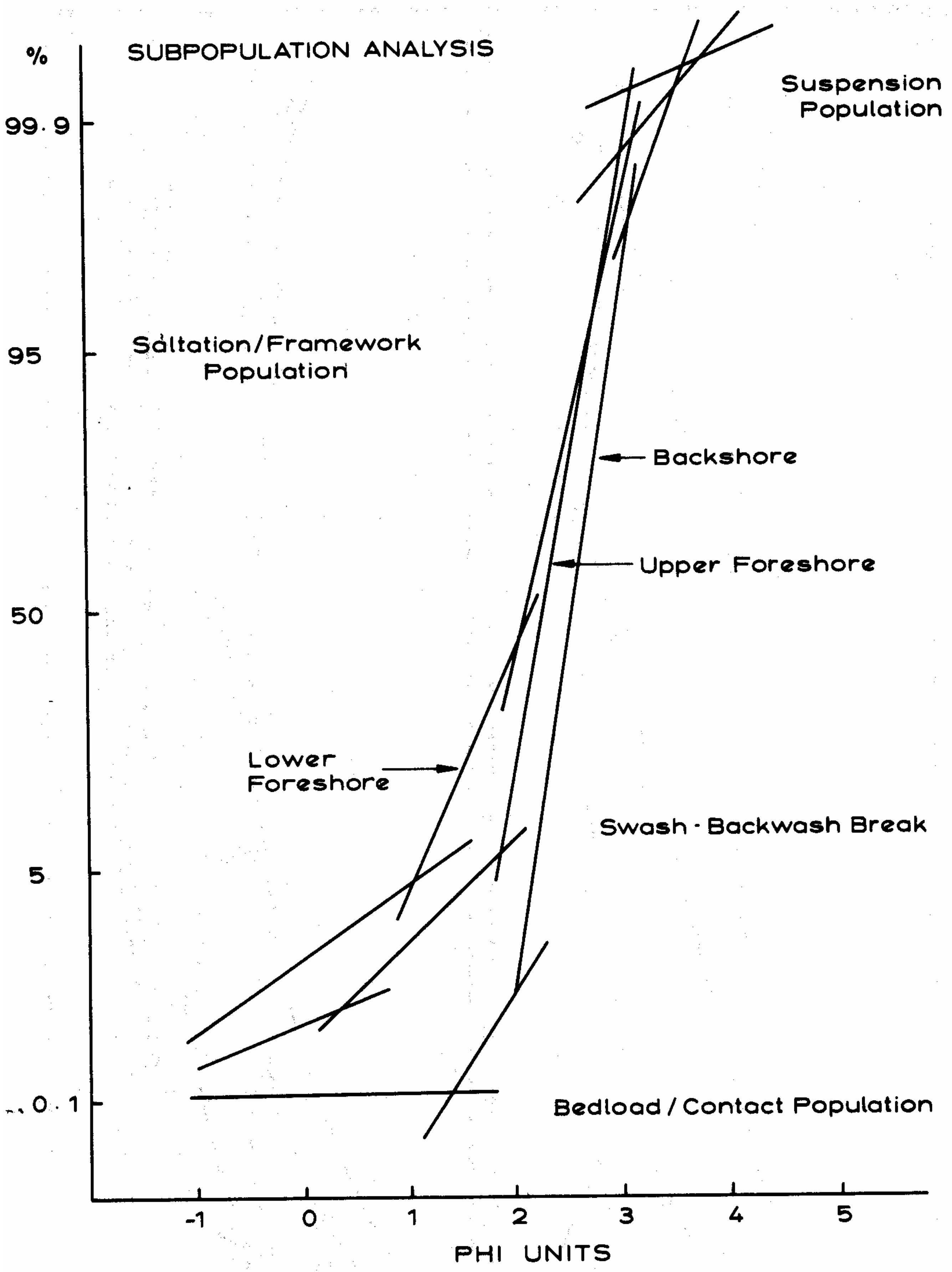


Figure 7. The major identifiable sub-populations within the grain-size distribution curves.

Table of Contents

Samples from the backshore zone were dominated by a saltation population with the bedload population being largely absent. The upper foreshore samples were dominated again by the saltation population with some indication of a swash-backwash break at 2.0ø. A small bed load population was also evident. On the lower foreshore the saltation population was again dominant but reduced in importance in comparison with the upper foreshore. The bed load population was considerably enhanced and accounted for 5-10% of the complete grain size distribution. The suspension population was poorly represented in all three zones.

Thus the saltation population is large and relatively constant in all three zones but there is a general increase in the bedload population towards low water mark. These results seem to support the suggestion by Visher (1969) that reversing flow conditions with bedload traction and intermittent suspension associated with wave action produce three distinct populations. The increase in significance of the bedload population in the lower foreshore zone is a function of the high energy levels in this zone. The lack of fine particles in both the foreshore zones reflects, according to McKinney and Friedman (1970), repeated erosion and redeposition of beach face sediments under surf and upperflow swash zone regimes. The increase in the suspension population in the backshore zone possibly reflects an aeolian input, either directly by wind action or indirectly by reworking of the sand dune material.

It is interesting that these results and the spatial trends described earlier match almost exactly those obtained by Greenwood (1978) on nearby Saunton Sands. This suggests a measure of equilibrium has been achieved on this north Devon coast.

Conclusions

This analysis of the spatial variability of texture on Woolacombe Beach, Morte Bay indicates the following:

(1) The dominant spatial component in size characteristics is normal to the shoreline and is probably related to migration of the waves with each tidal cycle. Mean size decreases, sorting increases and the size, distributions become less skewed away from low water mark.

(2) Slight trends along the beach possibly indicate a sediment supply near the southern cliffs coupled with a limited northerly longshore drift.

(3) A distinction can be made between the backshore and foreshore sediments. Sediments in the backshore zone are characterised by a finer grain size, better sorting and little skewness. This may reflect some input of wind blown material. Sediments on the foreshore are coarser, with poor sorting and skewed distributions.

(4) Within the foreshore zone a further distinction exists between sediments in lower foreshore and those in the main swash-backwash zone.

References

Baird, A.L., Baird, K.W., and Morton, D.M. 1971. On deciding whether trend surfaces of progressively higher order are meaningful. *Bull. geol. Soc. Am., 82,* 1219-1234.

Chaynes, H. 1970. On deciding whether trend surfaces of progressively higher order are meaningful. *Bull. geol. Soc. Am., 81,* 1273-1278.

Clark,, M.W. 1976. Some methods for statistical analysis of multi-modal distributions and their application to grain-size data. J. *Int. Assoc. Math. Geol., 8,* 266-282.

Darbyshire, M. 1963. Wave measurements made by the National Institute of Oceanography. In C.L. Bretschneider (Ed.) *Ocean Wave Spectra,* Prentice-Hall, New York, 285-291.

Folk, R.L. 1966. A review of grain-size parameters. *Sedimentology, 6,* 73-93.

Folk, R.L. and Ward, W. 1957. Brazos River bar, a Study in the significance of grain size parameters. J. *Sediment. Petrol., 27,* 3-27.

Greenwood, B. 1978. Spatial variability of texture over a beach-dune complex, North Devon, England. *Sediment. Geol., 21,* 27-44.

McCammon, R.B. 1962. Efficiencies of percentile measures for describing the mean size and sorting of sedimentary particles. *J. Geol., 70,* 453-465.

McKinney, T.F. and Friedman, G.M. 1970. Continental shelf sediments of Long Island, New York. J. *Sediment. Petrol., 40,* 213-248.

Middleton, G.V. 1976. Hydraulic interpretation of sand size distributions. *J. Geol., 84,* 405-426.

Miller, R.L. and Zeigler, J.M. 1958. A model relating dynamics and sediment pattern in equilibrium in the region of shoaling waves, breaker zone and foreshore. J. G*eol., 66,* 417-441.

Moss A.J. 1972 Bed-load sediments. *Sedimentology, 18,* 159-219

Norcliffe, G.B. 1969. On the use and limitations of trend surface models. *Can. Geogr., 13,* 338-348.

Sagoe, K-M. O. and Visher, G.S. 1977. Population breaks in grain-size distributions of sand -a theoretical model. J. *Sediment. Petrol., 47,* 285-310.

Schiffman, A. 1965. Energy measurements in the swash-surf zone. *Limnol. Oceanog., 10,* 255-260.

Strahler, A.N. 1966. Tidal cycle of changes in an equilibrium beach, Sandy Hook, New Jersey. J. *Geol., 74,* 247-268.

Trask, P.D. and Johnson, C.A. 1955. Sand variations at Point Reyes, California. *Beach Erosion Board Tech. Memo., 65,* Corps of Eng., Washington, D.C.

Visher, G.S. 1969. Grain-size distributions and depositional processes. J. *Sediment. Petrol., 39,* 1074-1106.

Willis, A.J., Folkes, B.F., Hope-Simpson, J.P. and Yemm, E.W. 1959. Braunton Burrows: The dune system and its vegetation. *I. J. Ecol., 47,* 1-24.

Table of Contents

Discussion

Dr D.J.C. Laming asked if any of the sediments collected showed significant bimodality and, if so, whether one of those modes was about 2.2ø. This size was an important component of beach sediments collected farther south, and had been identified as being aeolian.
Authors' reply: Very few of the sediment samples showed any significant bimodality, but sediments in the size range 2. I to 2.3ø were very prominent in the backshore zone and have been tentatively related to an aeolian input.

Dr I.P. Tunbridge: The authors do not present any data on temporal variations in grain populations in their study area. What is the (i) monthly and (ii) seasonal variation over this area-does this relate to changing way energy over the year?
Authors' reply: The study was undertaken over a short period of time in Spring 1979 and the results only relate to the wave energy conditions at that time of the year. It is believed that the trends identified are reasonably constant but that the individual values of the size parameters vary with tide and seasonal cycles.

Table of Contents