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FIGS. 1–2, DECEMBER, 1966

A PROFILE OF THE FOUR MOMENT MEASURES PERPENDICULAR TO A SHORE LINE, SOUTH HAVEN, MICHIGAN[1]

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ABSTRACT

A series of fourteen samples was taken along a profile crossing a beach, berm, foreshore slope, plunge point, nearshore, offshore bar, and offshore area to study the changes in the first four moments. The mean grain size and standard deviation reached a maximum in the plunge zone and were also high on the offshore bar. Skewness and kurtosis values were highest in the nearshore and offshore area. The beach represents a phi normal distribution of fine sand which is mixed with varying amounts of coarser material to form the sediments in the other environments.

INTRODUCTION

A strip of sand beaches encompasses the southern end of Lake Michigan and extends inland for several miles in the area of the Indiana Dunes. The beaches vary from a few feet to several hundred feet wide and are composed of well rounded, fine-grained sand. The sand is distinctively coarser on the gentle foreshore slope which extends from the beach to a pebble zone at the water line. The dominant wind direction is out of the southwest with major storms coming out of the north and northwest. The waves are usually 1 to 3 feet high but may reach heights of 10 to 12 feet in large storms. During and after a storm, the waves first break on the offshore bar, then reform and break again in the plunge zone.

A series of fourteen sand samples was taken along a profile perpendicular to the shore line of Lake Michigan to study changes in the characteristics of the sand in moving from an offshore bar into shallow water and across a plunge zone and onto a beach. The four moment measures—mean, standard deviation, skewness, and kurtosis—were selected for studying changes in the sand-size distribution. By making a traverse across an area which has been under the control of a single set of environmental conditions, including the direction and size of the waves and the velocity of the wind, it should be possible to get a clearer understanding of the sedimentological meaning of the four moments in response to different energy levels across a series of depositional environments.

Several workers in the field of sedimentary petrology have used moment measures as a basis for distinguishing beach, dune, and river sands. Krumbein and Pettijohn (1938) discuss the method of computing the first four phi moments and their significance. Friedman (1961) has shown that the third moment (skewness) is a sensitive environmental indicator. He plotted skewness against mean grain size for dune and beach sands and ended up with a separation of fields for the two depositional environments. He also plotted skewness against standard deviation, which gave less complete separation of river sands and beach sands. Inman (1952) introduced a graphic method for computing the four moments directly from plots of cumulative frequency distribution. Folk and Ward (1957) used a modified version of the graphic method to determine graphic inclusive measures of the mean, standard deviation, skewness, and kurtosis for the Brazos River bar in Texas. Mason and Folk (1958), using the graphic method, concluded that the differences between beach, dune, and aeolian flats on Mustang Island, Texas, were almost entirely in the tails of the curves which affected skewness and kurtosis. They made an interpretation of the depositional environments by plotting changes in skewness and kurtosis in four traverses across the three environments.

PROCEDURE

Fourteen samples were collected along a 350-foot traverse about 1 mile north of the pier at South Haven, Michigan, which is located on the southeastern shore of Lake Michigan. The profile includes samples from beach, berm, foreshore, plunge point, nearshore, offshore bar, and offshore areas. The sample locations are not evenly spaced but were selected to most effectively demonstrate the differences in the various environments. The fourteen samples were sieved for 15 minutes each on a rotop using a half phi unit sieve interval.

A FORTRAN program to compute the first four moments, including mean, standard deviation, skewness, and kurtosis, was written and compiled, using the IBM 7094 computer at the Massachusetts Institute of Technology. The moment measures were computed according to the method outlined in Krumbein and Pettijohn (1938, p. 251).

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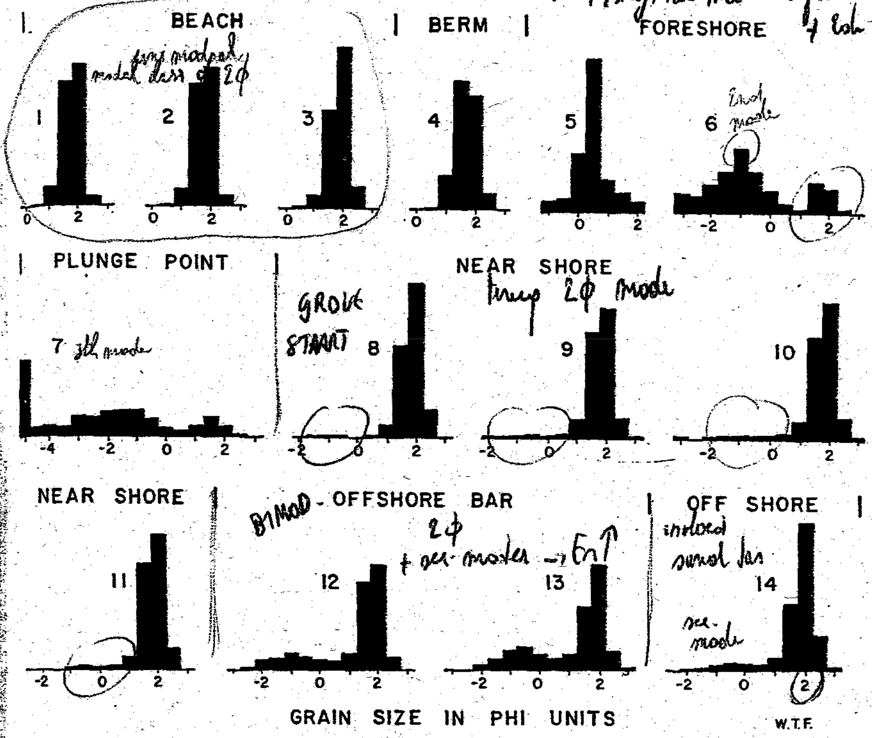

FIG. 1.—Histograms of fourteen samples collected along a profile perpendicular to the shore line at South Haven, Michigan.

In the early stages of this project, the four moments were computed using the graphic method outlined by Folk and Ward (1957) modified after the method suggested by Inman (1952). In order to compute the graphic moments, cumulative curves were plotted using the sieve data. From these curves, mean, standard deviation, skewness and kurtosis were computed according to the formulas given in Folk and Ward (1957). The mean and standard deviation values based on the graphic method corresponded quite closely to the first two computed moments. However, the skewness and kurtosis values, especially for the nearshore and offshore areas, differed significantly in the two methods. The large negative skewness values in the nearshore area which were prominent in the computed moments were not observed when the graphic method was used. The tail of coarse material was not detected when the 5th and 95th percentiles were used in the graphic method. The kurtosis values in the nearshore area are also much higher in the computed moments than in the graphic method. For finding mean grain size and standard deviation, the graphic method is perfectly suitable. However, in this study it was not sensitive enough for accurate determination of skewness and kurtosis.

RESULTS

A preliminary interpretation of the energy conditions can be made from a visual inspection of the modal classes and tails on the histograms in figure 1. Samples 1, 2, and 3 which were taken on the beach are unimodal with a modal class of 2 phi units. In moving from the berm across the foreshore to the plunge point in samples 4 through 7, there is a shift in the modal class to the coarser sizes, representing an increase in the energy level and an introduction of a second mode in sample 6 and a third mode in sample 7. Samples 8, 9, 10 and 11, from near shore between the plunge point and the offshore bar, once again display a mode in the 2-phi-unit size like the beach and dune samples, but show distinctive tails in the coarse and of the histogram. Samples 12 and 13 from the offshore bar have the primary mode in the 2-phi-unit class, but show secondary modes in the -1.0 and -0.5 phi classes. These secondary modes are the result of an increase in wave energy on the offshore bar. Sample 14, taken off shore from the sandbar, also shows a primary mode of 2 phi units and a much smaller secondary mode of -0.5 phi units. This sample shows the beginning of the influence of the sand bar on the grain-size distribution in the offshore area.

The distance from the shore line, height above mean lake level, and the four computed moments for each sample are given in table 1. Plots of the topographic profile and the four moments against distance are given in figure 2. The top curve is a 2.5X vertical exaggeration of the topographic profile with a circle for each sample location and a zero line indicating the mean lake level. The sample elevations range from 6.0 feet above, to 5.3 feet below mean lake level.

The second graph in figure 2 is a plot of mean grain size in phi units against distance with zero phi used as a reference line. The mean grain size is plotted with the negative phi units representing the coarser material at the top and the positive phi units or finer material below the zero line. Moving across the beach to the berm (samples 1–4), the mean grain size remains fairly constant, hovering about 1.8 phi units. In moving down the fore shore, the mean grain size increases from 1.68 ϕ at the berm to -0.64 ϕ at lake level. The mean gram size reaches its highest value of -2.25ϕ at the plunge point which represents the highest energy environment. In the nearshore area between the plunge point and the offshore bar, the mean grain size decreases to about 1.6 ϕ, which is only slightly coarser than the values for the beach. On the offshore bar, where the waves first break, the mean size again increases to about 1.2 ϕ and drops off to about 1.6 ϕ beyond the bar.

The third graph in figure 2 is a plot of standard deviation which is a measure of sorting against distance with a standard deviation of 0.0 used as a reference line. Although mean grain size and standard deviation are theoretically independent, there is a close similarity between the plots of the first two moments. Where there is an increase in mean grain size, there is a corresponding increase in standard deviation. On the beach, the standard deviation values are relatively stable at about 0.36 ϕ, indicating a very well sorted sand. There is a steady increase of the standard deviation across the fore shore to a maximum of 2.26 ϕ at the plunge point. In the near shore area between the plunge point and the bar, the standard deviation values vary around 0.7 ϕ, showing a significant increase over the beach values. On the sand bar, the standard deviation values increase to about 1.25 ϕ and then drop off to about 0.85 ϕ in the offshore area. The three areas of relatively low standard deviation found on the beach near shore and off shore are separated by areas of high standard deviation representing the offshore bar and the plunge point-foreshore areas where energy is concentrated when the waves break. In moving from off shore to near shore and on to the beach, there is a progressive decrease in the standard deviation, indicating an improvement in the sorting.

The fourth graph in figure 2 is a plot of skewness against distance with skewness values ranging from 0.232 to -1.464. The beach samples have a slight negative skewness of about -0.2 which can be recognized in the small tail on the coarse side of the histograms in figure 1. Samples 5, 6 and 7 across the fore shore to the plunge point are positively skewed, reaching a maximum at sample 6 with a skewness of 0.232. The positive skewness indicates a tail in the finer material. In sample 6, the coarser mode at -1.0 ϕ has become dominant and the finer mode at 1.5 ϕ to 2.0 ϕ has decreased in amount and is acting like a tail of fine material. In the nearshore samples (8, 9, 10 and 11), the long tail of coarse material gives the sand high negative skewness values close to -1.4. In the offshore bar samples which are bimodal, the finer mode is dominant and the coarser mode is secondary, giving negative skewness values of about -0.6. Off shore, the negative skewness value once more increases to about -1.0. The largest negative skewness values represent long tails of coarse material which usually contain less than 5 percent of the sample. The positively skewed samples are bimodal with the largest mode in the coarser grain sizes.

The lowest plot on figure 2 is a graph of the fourth moment, kurtosis, against distance with kurtosis value of a normal distribution which is 3.0 used as a reference line. The kurtosis values are plotted with zero at the top and 15 at the bottom, so that the general trend of the curve would parallel the trends of the first three moments. Kurtosis values less than 3.0 are considered platykurtic according to Krumbein and Pettijohn (1938, p. 252) and usually result from a bimodal sample. Kurtosis values greater than 3.0 are leptokurtic and indicate a peaked distribution or exceptionally long tails. In contrast with skewness, which indicates on which side of the primary mode the tail is located, kurtosis is a measure of bimodality (platykurtic) or long tails (leptokurtic). The first five samples across the beach and on to the fore shore have kurtosis values slightly greater than 3.0, indicating that they are leptokurtic. Samples 6 and 7 at the bottom of the fore shore and at the plunge point are platykurtic with kurtosis values of less than 3.0. The nearshore samples have kurtosis values greater than 10, resulting from the long tails of coarse material. The long tails make the center of the distribution appear more peaked and

TABLE 1.—*Location and moment measures for 14 samples taken along a traverse perpendicular to the shore line of Lake Michigan at South Haven, Michigan*

Sample Number	Seaward Distance from Shore Line	Height Above Mean Lake Level	Mean Grain Size	Standard Deviation	Skewness	Kurtosis
	(feet)	(feet)	(phi)	(phi)		
1	−120	6.0	1.723	.359	−.207	3.532
2	−90	3.0	1.738	.359	−.218	3.896
3	−60	3.0	1.818	.361	−.241	3.972
4	−30	3.0	1.680	.401	−.100	3.131
5	−15	1.5	0.469	.596	.060	3.998
6	0	0	−0.640	1.426	.232	2.441
7	3	−1.2	−2.253	2.259	.150	1.948
8	15	−2.0	1.749	.606	−1.419	14.795
9	30	−2.5	1.595	.761	−1.270	10.895
10	100	−3.5	1.593	.857	−1.464	13.594
11	160	−5.2	1.661	.679	−1.232	11.358
12	170	−2.0	1.122	1.247	−.670	3.683
13	200	−2.4	1.063	1.265	−.517	2.979
14	230	−5.3	1.645	.850	−1.011	7.294

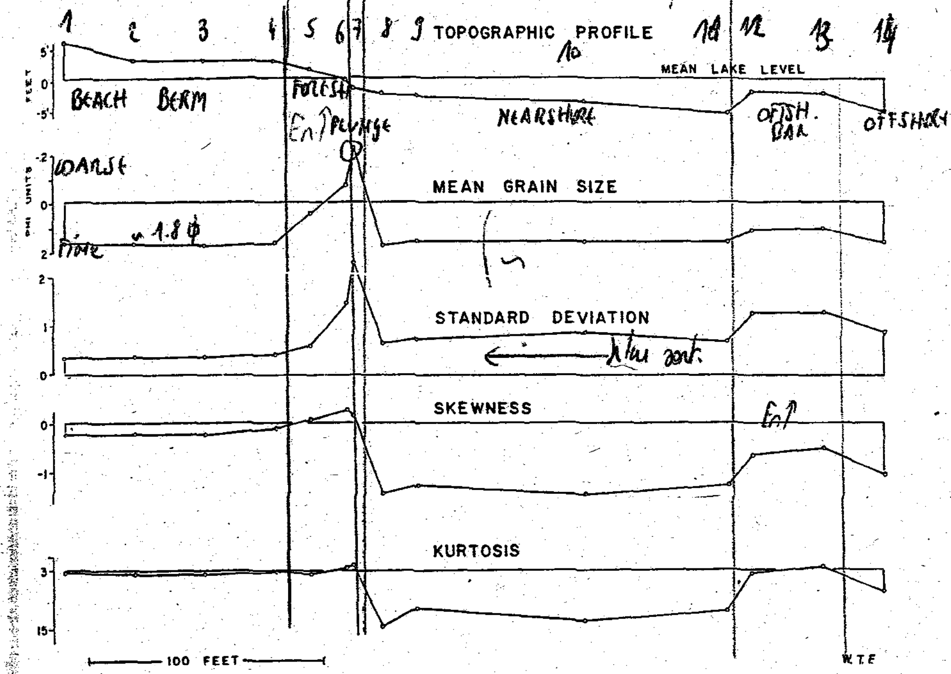

FIG. 2.—Graphs of the topographic profile and the first four moments—mean, standard deviation, skewness, and kurtosis—plotted against distance.

therefore give high kurtosis values. The samples on the sand bar have low kurtosis values near that of a normal distribution. The low kurtosis values and negative skewness indicate a bimodal distribution with the dominant mode in the finer grain size. Off shore, the kurtosis value increases again to about 7.3 and resembles the nearshore samples which have high kurtosis values.

CONCLUSIONS

The plots of the four moments against distance are similar in some respects but show their own distinctive characteristics. The mean grain sizes in the beach, nearshore and offshore areas are close to 1.6 ϕ. There are increases in mean grain size where the waves break on the offshore bar and on the beach. The areas of poor sorting, as measured by high standard deviation values, occur on the offshore bar and plunge point-foreshore areas. The standard deviation decreases in steps from the offshore to the near shore areas and on to the beach, indicating progressively better sorting as the material is carried across the sand bar and the plunge zone. The skewness shows slightly negative values on the beach and high negative values in the nearshore and offshore areas. The skewness values are less negative on the bar and positive in the plunge zone. The negative skewness values in the nearshore and offshore areas are probably the result of a tail of coarse material which was swept off the sand bar by the waves, or swept outward from the plunge zone by the backwash of the waves. The positive skewness values at the plunge point are the result of a concentration of coarse granule and pebble-size material in the surf zone, with a secondary mode of fine-sand size. The kurtosis values are slightly leptokurtic across the beach and berm and platykurtic, indicating bimodal distribution in the lower foreshore and plunge zone. The high kurtosis values in the nearshore area are a result of the long tails of coarse material which give the curves a peaked appearance. The offshore bar also shows near normal kurtosis values close to 3.0 with a leptokurtic reading in the offshore area. Whereas positive or negative skewness values indicate a tail of fine or coarse material, high kurtosis values are the result of an exceptionally long tail in either the coarse or fine end.

Based on a study of the four moments, it is possible to interpret the changes in energy conditions along a line across a beach through the plunge zone and out to a shallow offshore bar. The four moments reflect the bottom topography and the dissipation of wave energy across the profile. The wave energy is first released on the sand bar where the waves break and move into the near-shore area. The bottom profile in the nearshore area is concave upward, representing equilibrium conditions for the waves encountered. In the nearshore area the waves form again but are smaller because of the energy spent in breaking on the offshore bar. The waves once again break at the plunge point, creating an area of maximum turbulence and release of energy. There is a decrease in energy up the foreshore as indicated by the smaller grain size and better sorting with the maximum of onlap of the waves marked by the berm. On the beach, material from the berm is sorted by the wind, giving a well sorted, fine-grain sand with a small amount of coarse material. In essence, the beach represents a phi-normal distribution of fine sand which is mixed with varying amounts of coarser material to form the sediments in the other environments.

A traverse of closely spaced samples across a shore line is quite effective in interpreting the effects of both wave-energy dissipation and topographic profile on sand-size distribution. Although each moment has its own significance, the four moments must be considered together in making the final interpretation of the energy profile.

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mean D near de golven breken op de offshore bar & op het strand
sort. of slecht → off bar + plunge
sort. ... – off — nearshore