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FIGS. 1–6, SEPTEMBER 1977


# THE USE OF GRAIN SIZE STATISTICS TO DISTINGUISH BETWEEN HIGH- AND MODERATE-ENERGY BEACH ENVIRONMENTS[1]

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ABSTRACT: Swash zone sediments on two oceanside and two bayside beaches on Sandy Hook spit are examined to determine whether distinct differences exist among grain size parameters on beaches which have very different wave regimes.

The differences are subtle due to the inherent similarity of swash zone processes and the overall similarity of the source sediments. Differences in grain size statistics are noticeable, however, and they appear to be related to differences in wave energy and beach mobility on each beach. Measures of dispersion offer one means of discriminating among beaches. Examination of plots of changes in grain size statistics through time are also useful. Bivariate plots appear to be of limited value, however.

## INTRODUCTION

The purpose of this paper is to determine whether distinct differences exist among grain size parameters on beaches which have very different wave regimes. Sandy Hook, New Jersey was selected as the study area because the spit affords a wide variety of wave climates in a small geographical region. Comparisons are made of swash zone sediments on the two oceanside beaches and the two bayside beaches identified in Fig. 1.

Comparisons of depositional environments in terms of their sediment characteristics have not been an unqualified success—even when comparisons are made of deposits created by such very different processes as waves and winds. It was anticipated that the basic similarity of swash zone processes on beaches in general and the similarity of source sediments on the Sandy Hook beaches in particular would tend to produce similarities among the grain size statistics. However, it was further assumed that distinctions would result from the different wave regimes and different equilibrium conditions identified in several distinct portions of the shoreline continuum. In an earlier study (Nordstrom, 1975) it was found that these sample beaches exhibited very different profile form changes as a result of their different exposures. The differences in beach response were primarily related to the energy level of the waves and the frequency of the ocean swell. It was therefore hypothesized that these basic differences in the wave regimes would produce identifiable characteristics of the grain size parameters.

Initially, one would expect that the sediments on the high-energy, swell-dominated, oceanside beaches would be coarser, better sorted, less skewed and more mesokurtic than the bayside sediments. These anticipated results were not confirmed for a number of reasons, and it was found that the variability of grain size statistics was a better diagnostic criterion that the absolute values.

## PROCEDURES

Beach process and response data were gathered during the winter storm season in February 1972 and from September 2, 1972 to April 18, 1973. Samples were taken to a depth of one centimeter on the upper foreshore surface at a random point between mean sea level and the upper limit of swash (stratified random method). One hundred gram splits were run through a set of sieves separated by half-phi intervals from $-8\ \phi$ to $3.75\ \phi$. Each fraction was weighed to 0.01 gram. Grain size statistics for the mean ($M_Z$), standard deviation ($\sigma_I$), skewness ($SK_I$), and kurtosis ($K_G$), were obtained using Folk's graphic method (Folk, 1965, p. 44–49). The means and standard deviations of these grain size statistics are

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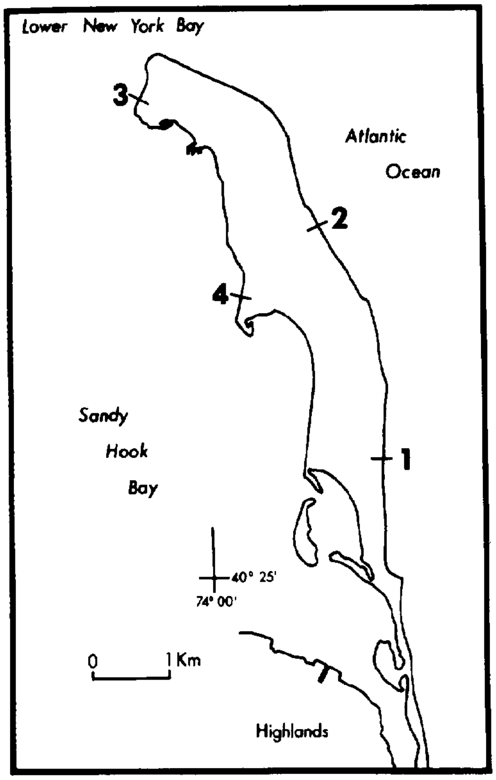


FIG. 1.—Sandy Hook, N.J., showing location of sample sites.

presented in Table 1. Beach process data are presented in Table 2.

## DISCUSSION

Table 2 reveals that there are several important differences between oceanside and bayside beach processes. Bayside waves are largely locally generated and thus subject to the effect of rapidly changing local wind conditions operating across limited fetch distances. The dominance of local wind-generated waves in the absence of swell results in lower wave heights and periods but higher wave steepnesses on the bayside beaches. With lower wave energies and periods the importance of departures from the mean become relatively more important. This is revealed in the high values for the coefficients of variability for these variables on the bayside sites.

Of the four sites, Oceanside Site 1 has the greatest exposure to ocean storm waves and swell. Longshore inputs of sand are high here and this beach experiences the most rapid volumetric and form changes. On Site 2, the combination of increased wave refraction and a well developed longshore bar acting as a filter against the largest waves reduce wave energy levels and the beach experiences less change. The tendency for this beach to maintain a long-term equilibrium has been previously noted in Strahler (1966). Bayside Site 3 is located near the distal terminus of the spit where refracted ocean waves and strong tidal currents contribute to the complexity of processes here. Site 4 has the lowest wave heights of the four sites. Tidal currents and refracted swell are not as effective here as at Site 3. An outcrop of marsh peat at midtide level further restricts sediment mobility and this site experiences the least beach change in terms of both form and volume.

Table 1 shows that there is a great similarity in the means of the grain size statistics on oceanside and bayside beaches. This is partly due to the similarity of the source sediments which are all inevitably derived from the erod-

TABLE 1.—*Averaged grain size values. Standard deviation in parenthesis*

| Site | No. of Cases | $M_z$ | $\sigma_I$ | $SK_I$ | $K_G$ |
|---|---|---|---|---|---|
| 1 | 78 | 1.42<br>(.29) | 0.48<br>(.14) | 0.04<br>(.17) | 1.00<br>(.12) |
| 2 | 78 | 1.17<br>(.23) | .41<br>(.09) | .02<br>(.12) | 1.11<br>(.22) |
| 3 | 79 | 1.11<br>(.32) | .44<br>(.23) | .00<br>(.20) | 1.22<br>(.34) |
| 4 | 78 | 1.05<br>(.30) | .37<br>(.14) | .06<br>(.19) | 1.16<br>(.27) |

TABLE 2.—*Average beach conditions on Sites 1–4. Values for arithmetic mean, standard deviation (in parenthesis), and coefficient of variability (marked with an asterisk)*

| Variable | Site 1<br>N = 109 | Site 2<br>N = 102 | Site 3<br>N = 109 | Site 4<br>N = 106 |
|---|---|---|---|---|
| Breaker Period (seconds) | 9.8<br>(1.9)<br>.199* | 9.4<br>(2.2)<br>.239* | 3.9<br>(1.8)<br>.463* | 3.6<br>(2.1)<br>.574* |
| Breaker Height (meters) | 0.82<br>(.43)<br>.510* | 0.58<br>(.34)<br>.565* | 0.21<br>(.18)<br>.912* | 0.18<br>(.18)<br>.963* |
| Breaker Steepness (dimensionless) | 0.006<br>(.004)<br>.607* | 0.005<br>(.003)<br>.653* | 0.013<br>(.013)<br>.984* | 0.013<br>(.013)<br>1.015* |
| Foreshore Slope at MHW Intercept (degrees) | 3.86<br>(1.83) | 4.77<br>(0.54) | 3.54<br>(1.24) | 6.27<br>(1.34) |

ing New Jersey coastal plain as well as to the similarity of depositional processes on the upper foreshore.

Differences in the standard deviations of the grain size parameters are more conspicuous than differences in the mean. The greater degree of dispersion on the bayside may be related to the variability in wave conditions (Table 1). Dispersion is particularly evident on Site 3 where processes are the most complicated due to strong tidal currents and the presence of both swell and local waves. This dispersion is not so conspicuous on the more sheltered Site 4.

There is a general relationship between mean slope and mean grain size (Tables 1 and 2). Site 3 seems to be somewhat of an exception to this generalization. This beach segment periodically receives sizeable inputs of sediment from oceanside sources. The gentler slopes are associated with these broad accretionary lobes. A considerable period of time is required before the equilibrium slope is obtained.

The generalization that mean size is a function of the amount of energy imparted to the sediment does not hold true for comparisons between different beaches since, on the Sandy Hook beaches, grain sizes become larger (lower phi values) with decreasing energy. Part of this difference is attributed to provenance since the oceanside beaches have a higher percentage of the fine-sized heavy mineral grains which are not transported around the tip of the spit (Yasso, 1962). A low degree of relationship between grain size and wave energy level on beach foreshores was also noted by Engstrom (1974) on Lake Superior beaches. There the low correlation was attributed to the limited availability of sediment in some of the size categories.

Figure 2 presents changes in mean grain size through time. The very coarse samples on Site 1 represent the gravel layer which may form on the flat storm profile of the beach above the swash bar but below the upper limit of swash. These samples are thus not truly representative of unaltered swash processes. However, they are included in the analysis since they would be present in the sedimentary unit.

The few very low $\phi$ values on Site 3 are due to the large amounts of lag gravel affecting the lower end of the grain size distribution. This gravel, resulting from storm wave deposition,

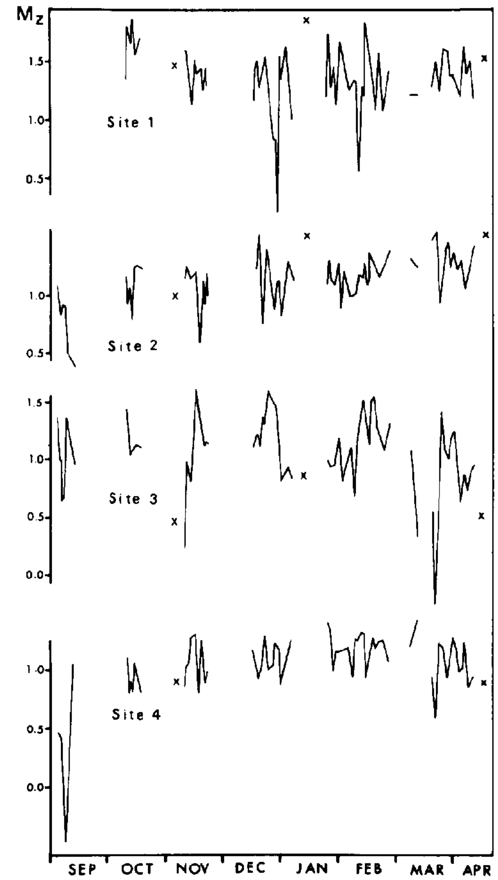


FIG. 2.—Change in mean grain size through time. Lines connect data days which are separated by three days or less. Data points marked with an "X" are considered to be too far separated from other days to be considered part of an unbroken time series.

is too heavy to be removed by lower, nonstorm wave energies on bayside beaches. Lag gravels are a common feature on bayside beaches and these coarser materials have a considerable effect upon all four statistics. The general absence of lag gravels on Site 4 results from the sheltering effect of the peat which acts as a barrier to the upward migration of coarser sediments. A series of sand samples gathered below the peat outcrop (not used in this study) contained a significantly greater proportion of these lag gravels. The effect of the elimination of the gravel fraction from the grain size analysis is discussed below in another section.

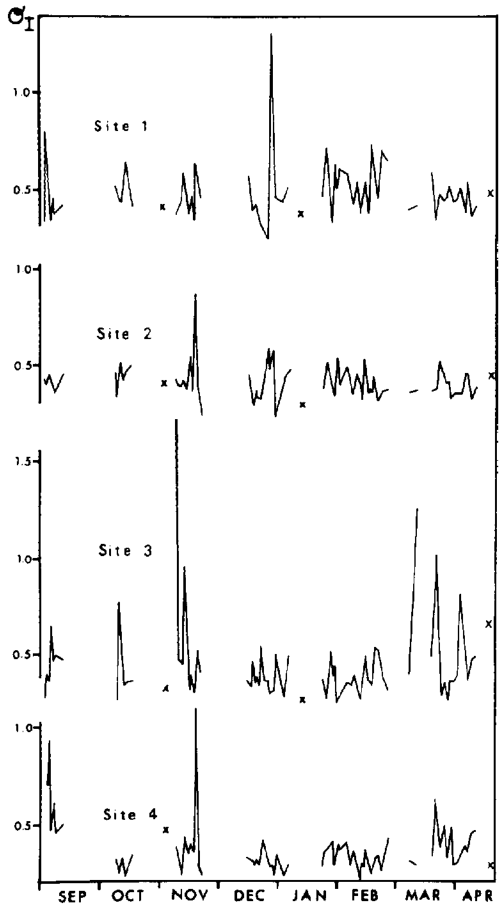


FIG. 3.—Change in sediment sorting through time.

The overall similarity in sorting between the oceanside and bayside (Table 1) is not unexpected, as Folk has noted that there seems to be no difference in sorting between beaches with gentle wave action vs. those with vigorous surf (Folk, 1967, p. 111). Slightly poorer sorting on Site 1 may be attributed to the high mobility of the beach in response to the high wave and current energies since sediments on beaches receiving considerable sediment influx will generally be more poorly sorted than beaches receiving little sediment influx (Folk, 1965). The one very poorly sorted sample on Site 1 (Fig. 3) is one of the two samples taken behind the swash bar. The presence or absence of this sample would not alter the above generalization.

On Site 2 sediment sorting is aided by the filtering effect of the longshore bar on the highest waves which contributes toward a regularity of processes and little variability of beach slope. Relatively poor sorting on Site 3 may be partly attributed to complications introduced by refracted ocean waves and strong tidal currents operating against local waves, but the major cause of the difference is the effect of the lag gravels on sorting. The unusually high sorting values for Site 3 (Fig. 3) correspond to the samples with the unusually large grain sizes in Fig. 2. On Site 4 the limited inputs of sediment aid sediment sorting.

The low skewness values (Table 1) are expected since single source sediments, such as most beach sands, tend to have fairly normal curves (Folk, 1965, p. 7). No clear distinction between oceanside and bayside beaches may be made on the basis of averaged skewness values, since the two bayside sites have both the highest and lowest skewness values. Using the mean skewness value can be misleading, however, since this statistic is bi-directional and values to either side of zero may cancel each other out. This is the case at Site 3 where the mean skewness value indicates a symmetrical distribution but the standard deviation indicates a relatively great dispersion of skewness values as might be expected considering the variability of processes here. This dispersion is clearly revealed in Fig. 4. Site 2 has the most consistently low skewness values. This is attributed to the low variability of wave and beach form changes (Table 2). Comparison of Fig. 4 with Figs. 2, 3 and 5 reveals that skewness is the least discriminatory grain size parameter in describing the differences between oceanside and bayside beaches.

Kurtosis values are higher (more leptokurtic) on the bayside beaches than on the oceanside, indicating that sorting in the central part of the distribution is better than in the tails. This is caused by lag gravels. The effect of small amounts of gravel to the sand mode was noted by Folk and Ward (1957, p. 20).

The variability in kurtosis values (Fig. 5) appears to be strongly related to the variability and energy of the wave regimes (Table 2). Excepting a few extreme kurtosis values on Sites 2 and 3, the plots of change in kurtosis through time strongly reflect the mean breaker height and variability of breaker height on each site. Breaker heights are highest and least variable on Site 1 and the plot of the kurtosis values

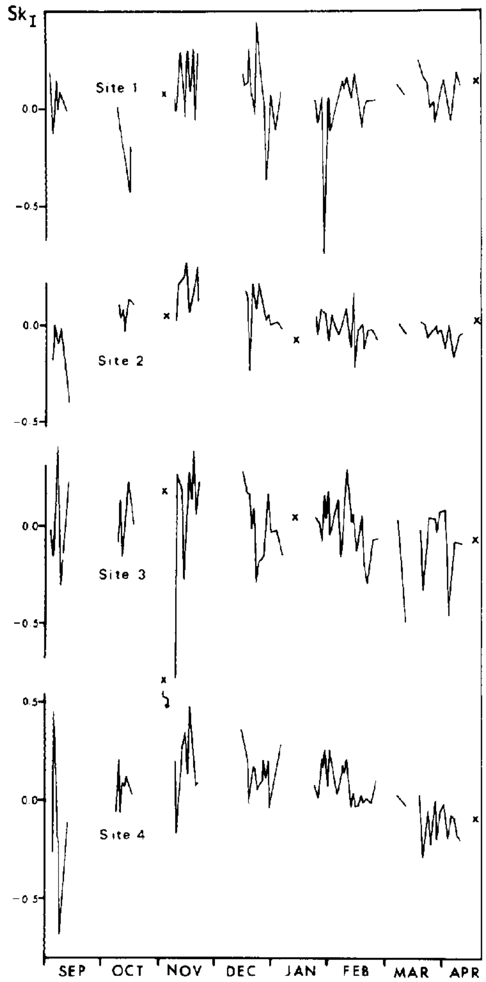


FIG. 4.—Change in skewness through time.

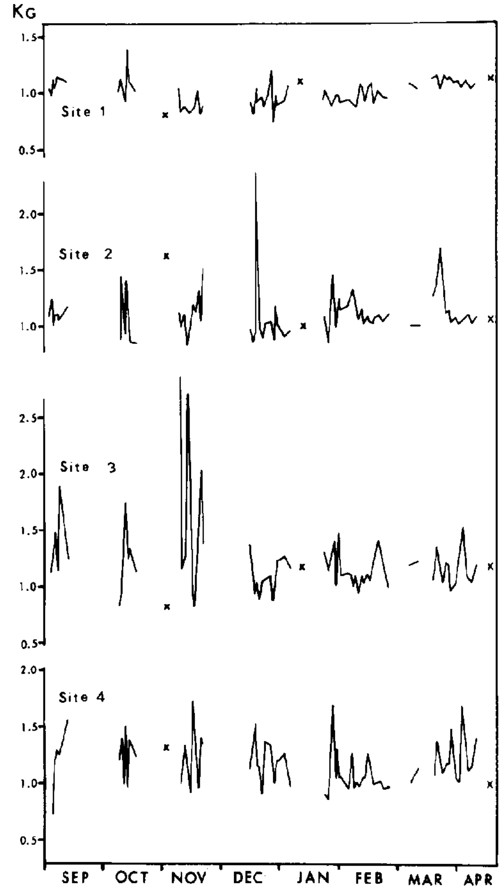


FIG. 5.—Change in kurtosis through time.

shows the least change. There is a general increase in variability among kurtosis values on the sites as breaker height decreases and variability of breaker height increases.

## BIVARIATE RELATIONSHIPS

Table 3 shows the correlations among the grain size parameters. The values on Site 3 are conspicuously higher than on the other sites. Inspection of Fig. 6 reveals that this high degree of correlation is largely due to a few extreme cases and that these cases represent the poorly sorted samples affected by the lag gravel deposits.

Numerous studies have used bivariate plots to distinguish between depositional environments. Accordingly, this technique was investigated as a means of identifying differences among foreshore sediment samples. For a review of the rationale and techniques employed, the reader is referred to Friedman (1967). None of the plots of the six combina-

TABLE 3.—*Pearson product-moment correlation coefficients for grain size parameters*

| Variables | Site 1 (N = 84) | Site 2 (N = 79) | Site 3 (N = 87) | Site 4 (N = 82) |
|---|---|---|---|---|
| $M_Z\sigma_I$** | $-0.390^+$ | $-0.160$ | $-0.600^+$ | $-0.385^+$ |
| $M_Z SK_I$ | −.016 | .114 | .306* | $.409^+$ |
| $M_Z K_G$ | .277 | −.252 | .324* | −.302* |
| $\sigma_I SK_I$ | −.301* | .024 | $.659^+$ | −.047 |
| $\sigma_I K_G$ | −.196 | −.056 | $.664^+$ | .119 |
| $SK_I K_G$ | −.122 | −.271* | $-.446^+$ | −.065 |

* Significant at the .01 level.
$^+$ Significant at the .001 level.
** Plotted in Fig. 6.

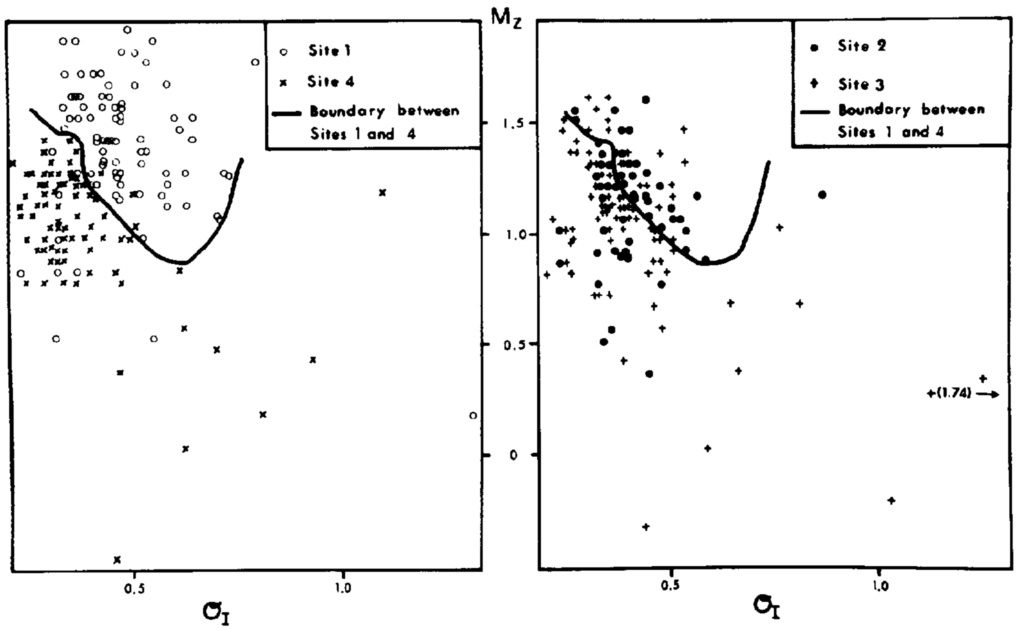


FIG. 6.—Plots of mean grain size against sorting.

tions of variables presented in Table 3 are particularly useful in separating oceanside from bayside beaches. The most clear distinction between beaches was found in the plots of mean grain size against sorting particularly on Sites 1 and 4. These plots are presented in Fig. 6. The visual estimate of the boundary between Sites 1 and 4 is presented in both portions of the figure as an aid to location.

The higher wave heights and longer wave periods on Site 1 result in a flatter foreshore which, in turn, results in finer sediments. The rapid removal and deposition of foreshore sediments as a result of these high wave energies results in consistently poorer sorting. Site 4 is the most sheltered of all beaches. Here lower wave heights and periods result in steeper foreshore slopes and low beach mobility. These conditions result in larger grain sizes and better sorted sediments.

Sites 2 and 3 are between these two extremes in terms of wave energy and beach mobility and the plots for these two sites reveal this fact. The center of mass of the points for Site 2 lies directly on the boundary line which separates Sites 1 and 4. The plots for Site 3 also straddle the line, but a slightly higher percentage of the points of this central cluster fall below the line. In addition, there are nine points which fall in the lower half of the diagram.

This general relationship among all sites was demonstrated in the other five plots. Sites 1 and 4 differed the most from each other, and the center of mass of the points for the other two sites fell upon the boundary line between Sites 1 and 4 with Site 2 having more points closer to Site 1. Site 2 showed the least scatter in all plots except those with kurtosis where Site 1 had the least scatter. The two bayside sites always had more scatter than the oceanside sites. Despite greater scatter on the bayside, correlations were higher (Table 3). This indicates that the theoretical independence of grain size parameters is demonstrated on equilibrium beaches such as Site 2, but on beaches subject to greater variability of processes (such as Site 3) unusual cases will introduce a higher degree of correlation. (Jones, 1970, p. 1207–1208 has presented other evidence that the grain size parameters are not, in fact, independent.)

## APPLICATIONS

It was found that energy and mobility were critical factors in determining whether these four sample beaches behaved in a cyclic or seasonal manner and that these factors were related to exposure (Nordstrom, 1975). Energy referred to wave energy and mobility referred to the rapidity of inputs of sediments into the system by any source (wind, wave, current) with the resulting changes in beach slope, beach orientation, grain size parameters, and other response variables. The four sample beaches were classified as follows:

Site 1 High energy—high mobility
Site 2 High energy—low mobility
Site 3 Moderate energy—high mobility
Site 4 Moderate energy—low mobility

These energy mobility factors are seen to have an important effect upon mean grain size and sorting. A decrease in energy generally results in steeper slopes and coarser grain sizes. A decrease in beach mobility reflects the limited inputs of sand from outside sources which results in a tendency to retain better sorted sediments. Decreasing energy further tends to increase the importance of processes which are not related to the dominant wave regime such as tidal currents, local (or in the case of bay beaches, refracted) waves and wind effects. This results in lag effects which strongly affect the variability of grain size statistics, particularly kurtosis. Decreasing beach mobility, however, may reduce these lag effects as is seen on Site 4.

## SEASONAL TRENDS

High energy-high mobility beaches respond rapidly to short-term changes in wave characteristics. They, therefore, display a marked cyclic form of development, in contrast to the low energy and low mobility beaches such as Site 4, which experience seasonal development. Trends displayed in the plots of the selected response variables on these four beaches (see Nordstrom, 1975) were clearly related to the degree of responsiveness of these variables as well as the energy of the wave regimes. Changes in beach slope are more responsive to short-term process changes than changes in sediment quantity, for example, and plots of the former are more likely to reflect short-term weather cycles than the latter. Grain size statistics are so responsive that seasonal and storm cycles are largely obscured on all four sites by daily changes. There are two exceptions to this generalization, however. The first is that bayside lag gravels may, at times, tend to mask daily changes. The second exception is the slight seasonal trend of development in mean grain size and skewness on all sites except Site 1. This indicates that these variables are better descriptors of long-term beach change than the other grain size parameters.

TABLE 4.—*Averaged grain size values with gravel fraction omitted. Standard deviation in parenthesis*

| Site | No. of Cases | No. of Recomputed Samples | $M_z$ | $\sigma_I$ | $SK_I$ | $K_G$ |
|---|---|---|---|---|---|---|
| 1 | 78 | 7 | 1.43 (.27) | 0.48 (.13) | 0.04 (.18) | 1.00 (.11) |
| 2 | 78 | 17 | 1.17 (.23) | 0.40 (.07) | 0.03 (.11) | 1.11 (.22) |
| 3 | 79 | 49 | 1.14 (.28) | 0.39 (.10) | 0.05 (.21) | 1.10 (.18) |
| 4 | 78 | 36 | 1.06 (.29) | 0.35 (.12) | 0.06 (.16) | 1.12 (.21) |

## EFFECT OF ELIMINATING THE GRAVEL FRACTION

The grain size statistics for the samples containing gravel were recomputed using only the data for the sand fraction. Although this involved the recomputation of slightly over one third of the original samples, the quantities of gravel were small in most cases and the new statistics differed very little from the original values. The means and standard deviations for the new data matrices are presented in Table 4. A comparison of this table with Table 1 reveals that there is little change in the statistics on the two oceanside sites but the values for the bayside sites have been substantially changed. This is particularly true for Site 3 where the lag gravels were seen to have the strongest effect. The greatest differences occur in the values for the standard deviation and it is no longer possible to discriminate between the ocean and bay environments using this measure of dispersion. There is a slight increase in the discriminating ability of the mean values, however.

The recomputed correlation coefficients for the combinations of grain size parameters presented in Table 3 were also considerably lower. The highest coefficient on any site was −.458 on Site 3 and only two of the 24 values were significant at the .01 level. The effect upon the plots of changes through time was less conspicuous. Only a few of the prominent spikes in Figs. 2–5 were eliminated and the general appearance of the curves remained the same.

These results confirm the importance of the lag gravels in grain size analysis of sheltered beach environments presented earlier in the paper. It may be argued that eliminating the lag gravels will enable more meaningful correlations to be drawn between daily wave processes and sediment response of these beaches. However, considering the common occurrence of these gravels on bayside beaches any complete analysis should include their effects.

## CONCLUSIONS

There is a great similarity of the means of grain size statistics among beaches which have very different exposures to sea and swell. If summarizing measures are employed in describing beach sediments, measures of dispersion appear to be more useful in isolating moderate-energy, high-mobility beaches where lag gravels have a very strong effect on these statistics. The lag gravels also have an important effect upon the linear correlation coefficients. The gravels do not appear to have a strong effect upon kurtosis. The effect of these lag gravels may be eliminated altogether by simply omitting this coarse fraction from the grain size analysis.

The changes in grain size parameters among the four beaches examined in this study appear to be related to the specific energy-mobility category of the beach, thus confirming the validity of this type of classification scheme. In turn, this implies that a description of the energy-mobility relationships of past beach environment may be afforded by grain size analysis of a sedimentary unit. However, there seems to be so much daily and seasonal variation in the parameters that a large number of sets of graphical measures would be required to identify the appropriate environment. The differences in the grain size statistics among beaches are not as conspicuous as might be expected considering the rather obvious differences in beach processes.

## ACKNOWLEDGMENTS

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