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Figs. 1–8, December, 1961

DISTINCTION BETWEEN DUNE, BEACH, AND RIVER SANDS FROM THEIR TEXTURAL CHARACTERISTICS

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ABSTRACT

Criteria for the recognition of the depositional environment of sandstones are important in the reconstruction of paleoenvironments. Petrographic characteristics of recent sands from dune, beach, and river environments have been studied to determine if there are mineralogical or textural characteristics which will permit diagnosing the environment of deposition. At present satisfactory depositional petrographic criteria are nonexistent. Since near-shore sands are shifted from one environment to the other, it is necessary to relate the petrographic characteristics to the terminal environment.

The mineralogy of clastic sediments for the most part seems to reflect the nature of the source rock, whereas textural parameters are chiefly related to the mode of transportation and the energy conditions of the transporting medium. Grain-size distribution analyses represent a plot of abundance or frequency against grain-size. Dune sands commonly can be distinguished from beach sands on the basis of such plots. The distinction between the sand types can be numerically stated by computing the third moment (skewness) of the distribution curve. On the phi scale the third moment (skewness) for dune sands is generally positive, whereas that of beach sands is generally negative. This seems to hold whether the dune samples are from barrier islands, coasts, lakes, rivers, or deserts. Beach sands of positive skewness occur on Padre Island, Texas, near the delta of the Rio Grande River, and on Horn Island, Mississippi. Sporadic positively-skewed beach sands have been found elsewhere, but for medium- to fine- and very fine-grained sands these appear to be relatively uncommon. Within the widely scattered samples a number of dune samples with slight negative skewness (-0.28 or less) have also been found. A plot of mean grain-size against third moment (skewness) results in an almost complete separation of the fields representing dune sands and beach sands. The sign of the skewness is not affected by the mineralogy of the sample. Sands of quartz, carbonate, gypsum, and olivine all follow the same general rule.

The distribution curves of river sands like those of dune sands are generally positively skewed, but a number of exceptions to this rule have been noted. Within limitations, medium- to fine- and very fine-grained river sands can be distinguished from beach sands on the basis of plots of third moment (skewness) against standard deviation (sorting). The third moment (skewness) of coarse-grained sand is inconclusive as an indicator of depositional environment. Dune sands can commonly be distinguished from river sands by their sorting characteristics; dune sands tend to be better sorted than river sands. Since dune and river sands are skewed in the same direction, a further criterion is needed for distinguishing river from dune sands which have overlapping sorting characteristics. This has been found by separating the light mineral grains from those of the heavy minerals and determining the mean grain-size ratio of quartz and that of a specific heavy mineral in the same sand, such as garnet or magnetite. The ratio of the radius of quartz to that of a specific heavy mineral is usually larger for river sands than for dune sands. For one Mid-Continent drainage system (Arkansas River and tributaries), plots of ratio of mean grain-size of heavy to light minerals (using the phi system) against the ratio of sorting (standard deviation) of heavy to light minerals show points representing river sands to lie in a different area of the graph from those for dunes.

Transportation of dune and river sands represents, for the most part, unidirectional flow. The upper size range of grains carried in suspension or by saltation is governed by the competency of the transporting medium. Such limitation does not affect fine particles in transport. The result of this limiting competency is reflected at the coarse-grained end of the frequency distribution curve by the lack of a "tail" usually present in a normal curve, resulting in positive skewness.

In beach sands the fine-grained particles of sand are removed by winnowing. The distribution curve of a winnowed sand appears to have a "chopped off" tail at the fine-grained end in comparison to a normal curve, thus indicating negative skewness.

INTRODUCTION

Criteria for recognition of the environments of deposition of ancient sands are of considerable importance in connection with the search for stratigraphic oil traps. However, reliable criteria have proved elusive. Even attempts to distinguish between sands of such widely different origin as beach, dune, and river sands have generally been ineffective. A useful criterion for distin-

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guishing between beach and dune sands and between beach and river sands and between some dune and river sands has recently been developed and is reported here. A method proposed by von Engelhardt (1940) can be used to distinguish river from dune sands.

A number of workers have tried to distinguish beach from dune sands and beach from river sands (Alimen and Bender, 1960; Beal and Shepard, 1956; Bradley, 1957; von Engelhardt, 1940; Nanz, 1954; Schneider and Cailleux, 1959; Guggenmoos, 1934; Shepard and Moore, 1955; Shepard, 1960; Zimdars, 1958).

Methods which have been proposed in the literature for distinguishing these types of environment by studying the texture or morphology of sand or sand grains are not satisfactory. A method reported by Rogers and Strong (1959) proved useful in distinguishing some Texas river and beach sands. Mason and Folk (1958) showed how it is possible to distinguish dune from beach sands on Mustang Island, Texas. The F:C ratio study of Keller (1945) indicated that dune sands can be distinguished from beach sands on the basis of shape of size-frequency curves.

In a near-shore environment sands may be transported from beaches to dunes and back again to the beaches. Each sand grain may have been deposited many times either by water or by wind. These movements may recur again and again for a considerable period of time, perhaps millions of years. To determine the environment of deposition from the petrographic characteristics of sands and sandstones, one must relate these characteristics to the terminal environment.

Textural parameters have been selected for study which reflect the mode of transportation and the energy conditions of the transporting medium.

Samples for this project have been obtained through the cooperation of the following persons and institutions: Mlle. Henriette Alimen (Centre National de la Recherche Scientifique, France), Tj. H. van Andel (Scripps Institution of Oceanography), William S. Cooper and C. O. Morgan, Wakefield Dort (University of Kansas), Richard H. Durrell and Ronald G. Schmidt (University of Cincinnati), William M. Fairley and Erhard M. Winkler (Notre Dame University), Oswalt C. Farquhar (University of Massachusetts), Gordon A. Macdonald and Robert M. Moberly, Jr. (University of Hawaii), Robert M. Norris (University of California), William Odynsky (Research Council of Alberta), and John J. W. Rogers (Rice University).

PROCEDURE

Samples were collected from dunes, rivers, ocean beaches, and Great Lakes beaches. One sample was obtained from a large lake which is not part of the Great Lakes system. Table 1 (*see* APPENDIX) indicates the location of the samples studied.

A total of 267 samples was studied from widely scattered locations in the United States, Canada, Mexico, the Bahamas, Bermuda, Hawaii, and North Africa. Of this total, 114 samples were collected from dunes, 80 from ocean beaches, 18 samples from lake beaches, and 55 from rivers.[2] The several dune types sampled include barrier island dunes, coastal dunes, lake dunes, river dunes, and desert dunes. Quartz sands, carbonate sands, gypsum sands, and olivine sands were investigated. Carbonate sands were represented by 18 samples (16 beach sands and 2 dune sands) from Bermuda, North Bimini and Andros Islands in the Bahamas, and the Islands of Hawaii. A total of seven gypsum dune sands was collected at White Sands National Monument near Alamogordo, New Mexico, and at Salt Flat, West Texas. Four samples of olivine beach sands were obtained from the islands of Hawaii. Most of the sands examined (240 samples) are composed of quartz. In the field, samples were taken parallel to the bedding, where possible, to avoid mixing of populations. Beach sands were sampled from the swash zone or close to the swash zone.

In the laboratory, grain-size determinations were made on these samples by con-

[2] The 55 river sand samples are medium-, fine- and very fine-grained sands with a size range comparable to that of the dune and beach sands studied. In addition, coarse-grained sands, gravelly sands, and gravels were collected from rivers (refer to Table 1 under hearding of "River Sands").

ventional sieving methods, using $\frac{1}{4}\phi$ sieve intervals. On some of the river and dune sands, the heavy minerals were separated out, and grain-size analyses were made on the heavy mineral fractions. The first, third, and fourth moments (mean, skewness and kurtosis) of the grain-size distribution curve were computed for each sample.

The first moment (mean) is defined by the equation $\bar{x}_\phi = 1/100\ \Sigma f m_\phi$, where $\bar{x}_\phi$ is the mean grain-size (in phi), f is the frequency or abundance of the different grain-size grades present in the sediment, and m_ϕ is the midpoint of each grain-size grade in phi values. The third moment (skewness) which describes the symmetry of the grain-size distribution curve is defined statistically as the average of the cubed deviations from the mean divided by the cube of the standard deviation[3] and is expressed by the equation

$$\alpha_{3\phi} = (1/100)\sigma_\phi^{-3}\Sigma f(m_\phi - \bar{x}_\phi)^3$$

where $\alpha_{3\phi}$ is the skewness and σ_ϕ is the standard deviation in phi values. The fourth moment (kurtosis) which measures the peakedness of the grain-size distribution curve is expressed by the equation

$$\alpha_{4\phi} = (1/100)\sigma_\phi^{-4}\Sigma f(m_\phi - \bar{x}_\phi)^4$$

where $\alpha_{4\phi}$ is the kurtosis.

RESULTS

In figure 1 the third moment (skewness) for dune sands and for ocean and lake beach sands is plotted against the first moment (mean grain-size) for these samples using the phi (ϕ) scale. Between the dune sands and the ocean beach sands a nearly complete separation is found for the two depositional environments, the dune sands being for the most part positively skewed, and the ocean beach sands generally negatively skewed. Lake beach sands, like the ocean beach sands, are mostly negatively skewed. However, four of the lake beach samples overlap into the field of the dune sand samples. Dune sands generally are positively-skewed, irrespective of whether the dunes are barrier island, coastal, lake, river, or desert dunes. Of the 114 sand samples collected from dunes only eight samples are slightly negatively skewed (-0.28 or less). In the widely scattered sampling, one area was discovered where beacn sands show positive skew. This area is located on southern Padre Island, Texas, opposite the Rio Grande delta.[4] It is believed that the beach sands in that area have "inherited" the positive skew of river sands and have apparently not yet come to equlibrium with the new environment. Sporadic positively-skewed beach sands have been found elsewhere, but for medium to fine and very fine-grained sands these appear to be relatively uncommon. Coarse-grained beach sands may be either positively or negatively skewed. One anomalous beach sand sample with a high positive skewness was collected on Andros Island in the Bahamas. A second sample taken 40 feet away from it showed "normal" negative skewness.

The mineralogy of the sands does not affect the tendency for sand dunes to be positively-skewed or beach sands to be negatively-skewed. Quartz, carbonate, and gypsum dune sands and quartz, carconate and olivine beach sands were studied. The skewness for all the sands reflects the environment of deposition and is not altered by the mineralogy of the sand.

In figure 2 the third moment (skewness) for beach and dune sands is plotted against the mean (first moment) using the millimeter scale. The points representing beach sands lie for the most part in a different area of the graph from those for dunes.

The lower limit of mean grain-size of the dune sand samples studied is 1.49ϕ. In contrast 40 percent of the beach sand samples have mean grain-size values lower than 1.49ϕ. Newell and Boyd (1955) describe very coarse eolian sands of the Ica Desert of Peru which may have mean grain-size values considerably below 1.49ϕ.

[3] The standard deviation is the square root of the mean of the squared deviations from the mean and is expressed by the equation

$$\sigma_\phi = (\Sigma f(m_\phi - \bar{x}_\phi)^2/100)^{1/2}.$$

[4] Since this study has been completed, a second area of positively skewed beach sands has been found. This area appears to include all of Horn Island, Miss., in the Gulf of Mexico. The anomalous skewness of the sands collected along Horn Island may be the effect of proximity to the mouth of the Mobile River, or some unknown factor such as exceptionally strong longshore currents.

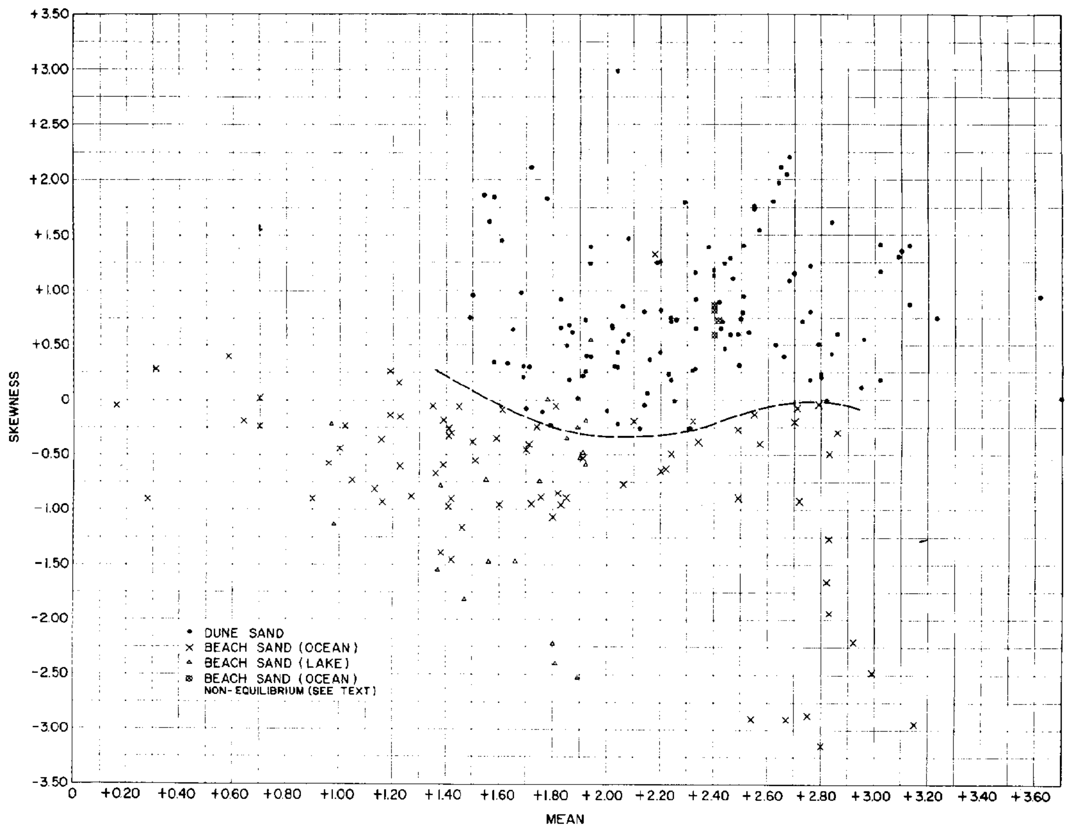

FIG. 1.—Plot of first moment (mean) and third moment (skewness), using phi (ϕ) scale, for beach and dune sands.

In figure 3 third moment (skewness) is plotted against the fourth moment (kurtosis) for beach and river sands using the phi (ϕ) scale. The kurtosis provides a second dimension for the plot, but is not diagnostic of depositional environment. A plot of skewness against mean could have been employed, but kurtosis was found to provide a wider spread of the points for the river data and the points were thus less crowded. River sands are generally positively skewed, as are dune sands; but a number of exceptions were found. Skewness is environment-sensitive, whereas kurtosis is not.[5]

In figure 4 the third moment (skewness) is plotted against the standard deviation, a measure of the degree of sorting, for beach and river sands in which less than 5 percent of the grains are larger than 0.500 mm. ($<+1.00\phi$). This figure indicates that the degree of sorting is of help in distinguishing beach from river sands. Beach sands of positive skewness, such as the sand samples from southern Padre Island, Texas, opposite the Rio Grande delta, have a low numerical value for the standard deviation and, as indicated in figure 4, can be distinguished from

[5] River sand samples with more than 5 percent of the grains in excess of 0.500 mm. ($<+1.00\phi$) size were not plotted in figure 2. River sands of coarse sand to gravel size can be either positively or negatively skewed and no predictable relationship could be determined.

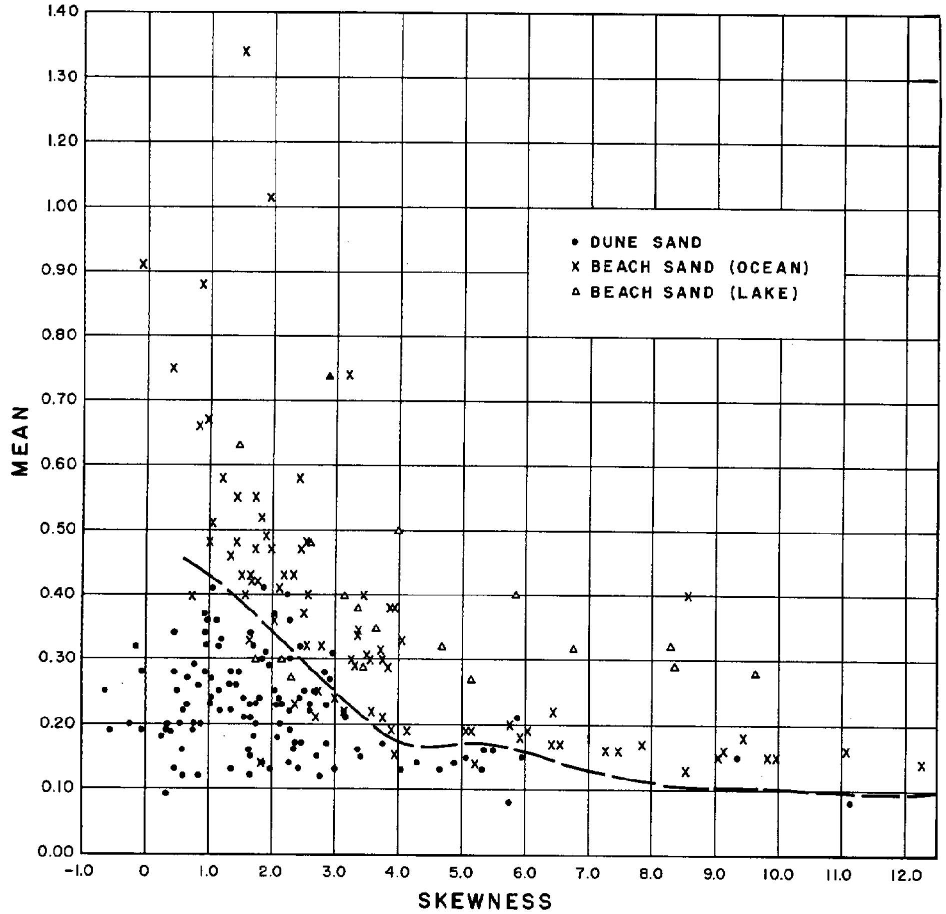

FIG. 2.—Plot of first moment (mean) and third moment (skewness), using millimeter scale, for beach and dune sands.

river sands.[6] Similarly some of the negatively-skewed river sands can be distinguished from beach sands on the basis of their high numerical value for the standard deviation. Two of the positively skewed beach sands which were considered "exceptions" in figure 3, since their points lie in the field of the river sands, fall in the field of the beach sands in figure 4, where the third moment (skewness) has been plotted against the standard deviation. Of the 108 points plotted in figure 4, which represent sands from twenty-nine different rivers and from beaches of the Atlantic and Pacific Oceans, Gulfs of Mexico and California, and the Great Lakes, only two samples of river sands were found to lie outside their field.

A plot of third moment (skewness) against another parameter, such as the standard deviation, for beach and river sands on the millimeter scale does not provide a good separation between two fields representing

[6] In figure 4 the southern Padre Island samples are represented by an x inside a square. The positively-skewed beach sands from Horn Island, Mississippi, referred to in footnote 4 fall within the field of the beach sands of figure 4.

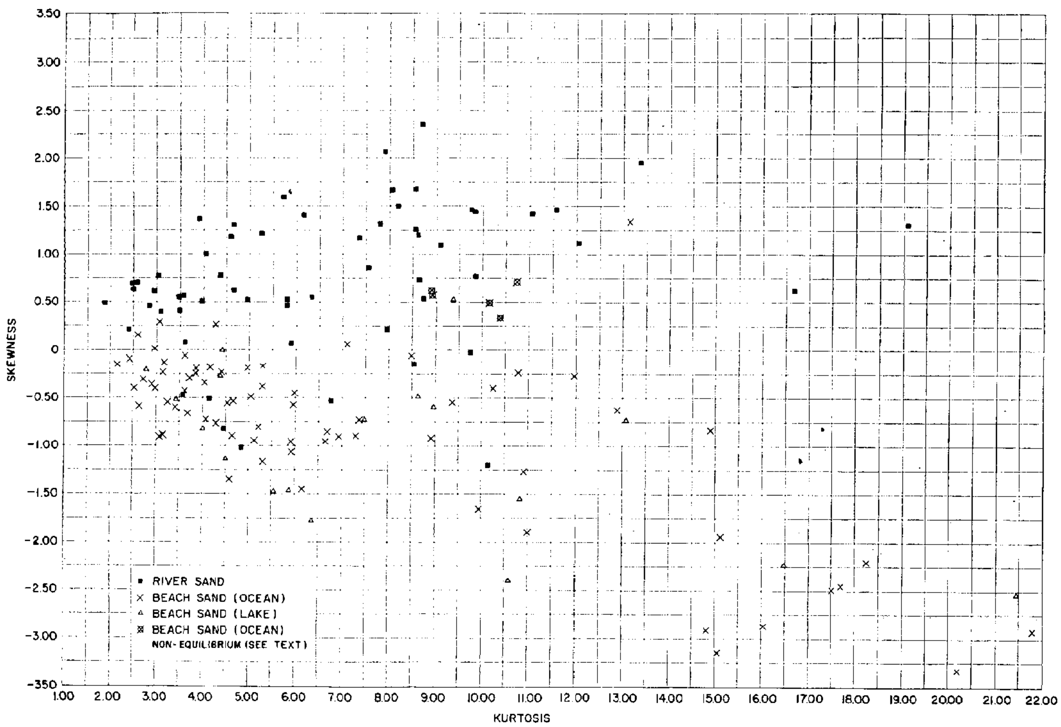

FIG. 3.—Plot of third moment (skewness) and fourth moment (kurtosis), using phi (ϕ) scale, for beach and river sands.

two different depositional environments. On the millimeter scale the third moment (skewness) apparently is not effective in distinguishing beach from river sands, and plots of moment measures for these environments using this scale are therefore not reproduced in this study.

Beach sands commonly may be distinguished from river sands and from dune sands primarily on the basis of textural parameters, chiefly third moment (skewness). However, river sands cannot often be distinguished from dune sands on the basis of the textural properties of the bulk sediments, since both types of sand exhibit positive skewness. Dune sands tend to be better sorted than river sands, and a plot of standard deviation (sorting) against mean grain-size (fig. 5) indicates three fields, one for river sands, one for dune sands (in which one exceptional river sand point is represented), and a third field of overlap. Only medium to fine and very fine-grained river sands have been plotted in figure 5. This figure points out that many river sands can be distinguished from dune sands and vice versa on the basis of their textural parameters but that a wide field of overlap exists. In practice this field of overlap is not necessarily a serious matter, since most coastal, barrier bar, and lake dune sands have a standard deviation of less than 0.40 and many desert and inland dune sands do not exceed 0.50, whereas most river sands have a standard deviation in excess of 0.50. Many of the dune sands in the field of overlap of figure 5 are from inland dunes, some of them stable dunes which may have been texturally modified since deposition.

In figure 6 the ratio of mean grain-size of heavy and light minerals has been plotted against the ratio of sorting (standard deviation) for heavy and light minerals. A separation of the fields representing river

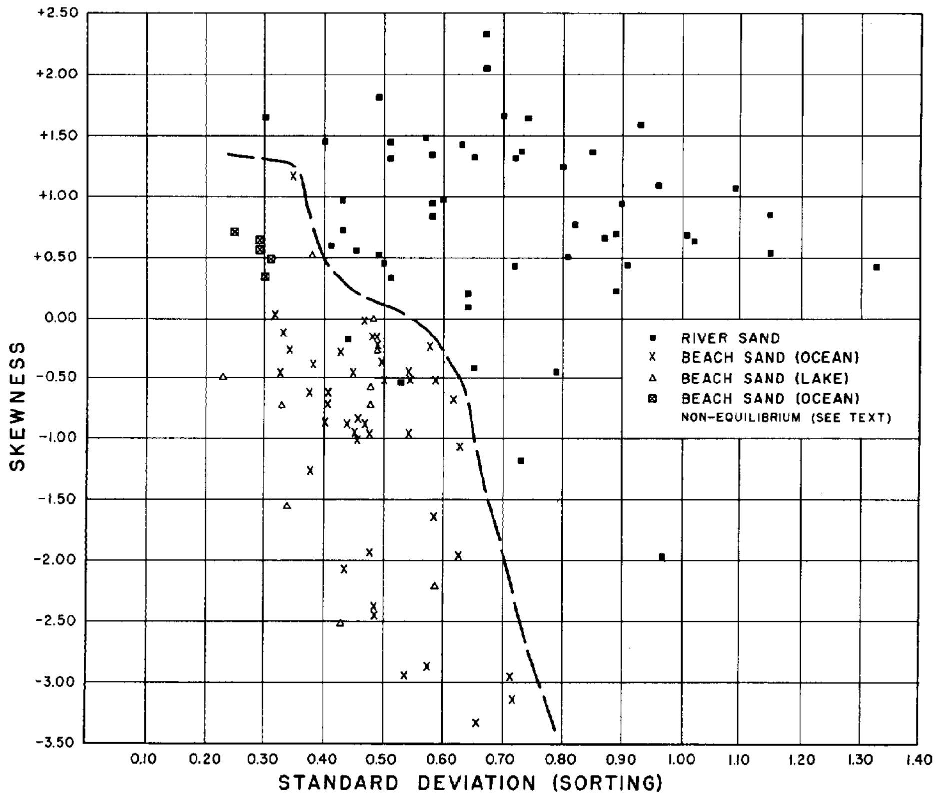

FIG. 4.—Plot of third moment (skewness) and standard deviation, using phi (ϕ) scale, for beach and river sands.

and dune sands results. These samples have been obtained from a Mid-Continent drainage system (Arkansas River and tributaries) and are only characteristic for the river and dune sands of that system. Dune and river sands from other drainage systems which have a different heavy mineral assemblage may give their own characteristic plot, although there is no certainty that for other drainage systems the distribution may not be random.

DISCUSSION OF RESULTS

The textural parameters of sands reflect the mode of transportation and the energy of the transporting medium. The waves which deposit sand on the beach have a greater competency than the wind transporting sand onto dunes or eolian flats. This difference in competency between water and wind explains why none of the dune sand samples studied show mean phi values of less than 1.49ϕ, whereas many beach sand samples do.

Wind and river transportation results from unidirectional flow and may be responsible for the generally positive skewness of dune and river sands. The grain-size distribution of a sand in transport is not known. The upper size limits of grains carried in suspension or by saltation are governed by the competency of the transporting medium. Such limitation does not affect fine particles in transport. This limiting competency may be graphically illustrated. Figure 7 illustrates three different curves of size frequency distribution. Figure 7a is a positively skewed distribution; figure 7b is a symmetrical distribution; and figure 7c is a negatively skewed distribution. The positively skewed curve (fig. 7a) illustrates the limiting competency of dune and river transportation. At the coarse-grained end of the frequency distribution curve the "tail" of the curve is "chopped off" in comparison with a normal distribution curve (figs. 7, a and b).

On a marine beach, sand is exposed to two forces of unequal strength acting in opposite directions. The incoming waves and outgoing wash remove the fine-grained particles. Such winnowing is characteristic of a beach environment. The frequency distribution curve of a winnowed sand lacks the "tail" at the fine-grained end of the curve, and the sand is negatively skewed (fig. 7c).

Accurate third moment (skewness) calculations are tedious and time-consuming to make. For rapid calculations of the sign of skewness, reference should be made to figure 7. In figure 7a, a positively-skewed distribution, the mean has a larger phi value than the median, and the difference (mean minus median) is positive. In figure 7b, mean and median are the same, and the difference is zero. In figure 7c, mean minus median results in a negative sign, and a sample which shows this type of distribution is negatively skewed. Since the median value can be obtained rapidly from a cumulative curve and the mean is not too time-consuming to compute, determination of median and mean constitutes a rapid method of obtaining the sign of the skew. This rapid method, however, is not very sensitive.

Mason and Folk (1958) have proposed a formula for obtaining a measure of symmetry of the distribution curve. This measure, which they term skewness (SK_I) (p. 217), is useful since it can be determined rapidly and for the most part indicates correctly the direction of skewness, whether positive or negative; but it lacks the sensitivity of the true third moment.[7]

The bulk properties of the sands, such as the grain-size distribution or measures derived from the grain-size distribution, are ineffective in distinguishing some river sands from dune sands. The fact that river

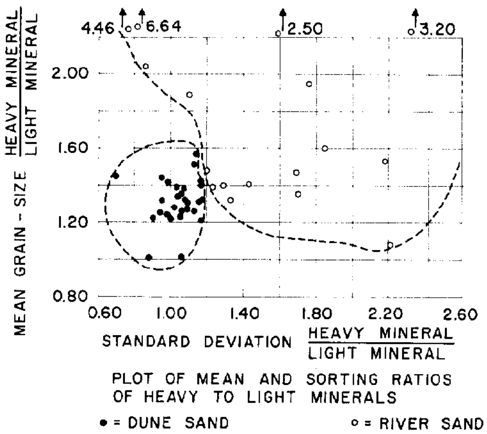

FIG. 6.—Distinction between river and dune sands.

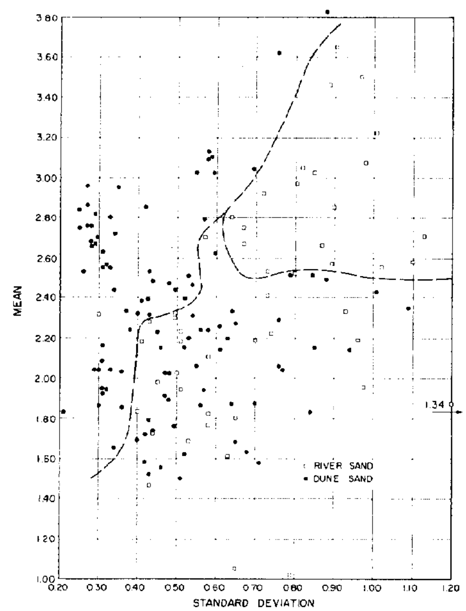

FIG. 5.—Plot of mean and standard deviation, using phi (ϕ) scale, for dune and river sands.

[7] Mason and Folk's skewness formula:

$$SK_I = \frac{\phi16 + \phi84 - 2\phi50}{2(\phi84 - \phi16)} + \frac{\phi5 + \phi95 - 2\phi50}{2(\phi95 - \phi5)}$$

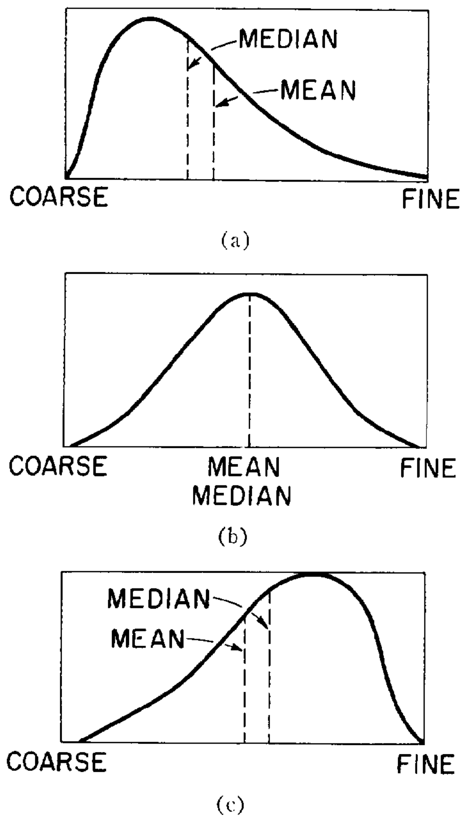

FIG. 7—Curves showing positively skewed (7a), symmetrical (7b), and negatively skewed (7c) distributions.

and dune sands are skewed in the same direction came as a surprise, since the physical characteristics of the media (viscosity and density) depositing the two types of sand are greatly different. To develop a method which will distinguish between dune and river sands, it is necessary to select properties which reflect the fundamentally different physical characteristics of the two media.

Von Engelhardt (1940) has studied the ratios of the grain-size of quartz to magnetite and quartz to garnet and concludes that it is possible to distinguish dune sands from river and beach sands by this method. On a theoretical basis the ratio of the mean grain-size of heavy to light minerals will differ in wind- and water-laid deposits. The relationship between grain-sizes of different minerals under water transportation can be expressed as follows (Gaudin, 1939, p. 186):

$$\frac{r_1}{r_2} = \frac{D_2 - K}{D_1 - K}$$

where r_1 and r_2 are the radii of particles (spheres) for minerals 1 and 2 (quartz and any heavy mineral), D_1 and D_2 are the specific gravities of the two minerals, and K is the specific gravity of the medium (water). Since the specific gravity of air is negligible in comparison with that of the minerals, it can be neglected and the following equation holds for windlaid materials:

$$\frac{r_1}{r_2} = \frac{D_2}{D_1}.$$

For quartz and magnetite, one of the most abundant of the heavy minerals in sands and sandstone, the following relationship holds:

Settling in water:

$$\frac{r(\text{quartz})}{r(\text{magnetite})} = \frac{5.18 - 1.00}{2.65 - 1.00} = 2.56$$

Settling in air:

$$\frac{r(\text{quartz})}{r(\text{magnetite})} = \frac{5.18}{2.65} = 1.96$$

The ratio $r(\text{quartz})/r(\text{magnetite})$ is much greater for water than for wind. The same kind of relationship can be shown for other heavy minerals (table 2).[8]

To effectively distinguish river sands from dune sands which fall within the field of overlap in figure 5, it is necessary to determine the mean grain-size ratio of quartz and a specific heavy mineral, such as garnet or magnetite. The heavy minerals are separated by conventional techniques, and the grain-size distribution of one or several heavy minerals is determined under the petrographic microscope. The grain-size distribution of quartz can be obtained

[8] These ratios have reference to the movement of quartz and heavy minerals that can be rolled along by water and wind at the same velocity. A second equation which is of importance in comparing water- and wind-laid sands governs the settling velocity of minerals. This equation, which is the Oseen modification of Stokes Law, is more complex than the equation for rolling particles, but it also shows that the ratio $r(\text{quartz})/r(\text{magnetite})$ is much greater for water than for wind.

TABLE 2.—*Ratios of Radii of Quartz and Heavy Minerals of Equal Rolling Velocity*

Mineral	Ratio in Water $\left(\frac{r(\text{quartz})}{r(\text{heavy mineral})}\right)$	Ratio in Air $\left(\frac{r(\text{quartz})}{r(\text{heavy mineral})}\right)$
Magnetite	2.56	1.96
Pyrite	2.39	1.87
Garnet (Almandite)	1.94	1.58
Zircon	2.24	1.78
Tourmaline	1.26	1.16

by sieving, in thin-section according to the method described by Friedman (1958, in press), or by size analysis under the petrographic microscope.

It should be noted that in figure 6 the size ratio of quartz and heavy minerals seems reversed from that given in table 2. In table 2 the size of the heavy mineral is given in the denominator, whereas in figure 6 it is shown in the numerator. This is explained by the fact that the phi (ϕ) system has been employed in figure 6.

If the heavy mineral assemblage in a given drainage system does not vary greatly, a graph of the type shown in figure 6 may be useful in distinguishing dune from river sands. The mean grain-size for the heavy minerals in figure 6 takes in the entire heavy mineral suite and does not discriminate between the mean grain-size of the different mineral species. The same applies to the ratio of the standard deviation. This type of analysis is rapid but crude and is not reliable where there are significant changes in the heavy mineral suite. A more useful method of distinguishing dune from river sands employs the size ratios of quartz and a specific heavy mineral. Von Engelhardt (1940) has shown that for water-laid sands which he studied the r (quartz) $/r$ (garnet) ratio varied between 1.67 and 2.03, whereas in dune sands it ranged from 1.41 to 1.54. For quartz and magnetite, the respective values are 2.14 to 2.38 for water-laid sands and 2.00 to 2.08 for wind-laid sands. Von Engelhardt employed the mode of the grain-size distribution instead of the mean. Figure 8 presents a diagram which indicates how water- and wind-laid sands can be distinguished with the aid of heavy minerals. This figure suggests that the grain-size distribution of the light fraction is of importance in distinguishing between the two types of sand.

CONCLUSIONS

1. Mean grain-size for dune and beach sands is plotted against the third moment (skewness) for these samples. For dune and beach sands, an almost complete separation of the fields representing the two depositional environments results.

2. The grain-size distribution of dune sands is for the most part positively-skewed, whereas that of beach sands is for the most part negatively-skewed, if the phi (ϕ) scale is used in computation.

3. The third moment (skewness) for beach and river sands is plotted against fourth moment (kurtosis) for these samples.

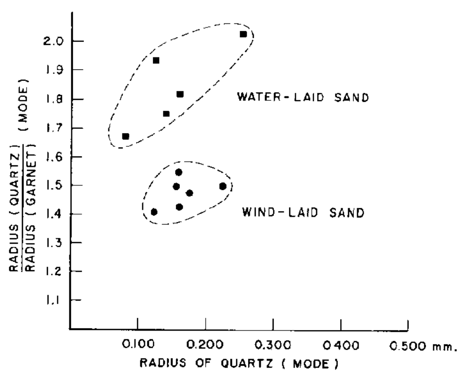

FIG. 8.—Distinction between water- and wind-laid sands (modified from v. Engelhardt).

River sands, like dune sands, are generally positively-skewed, but a number of exceptions to this rule have been observed. The kurtosis is employed to provide a second dimension for the plot, but does not contribute information diagnostic of depositional environment. Skewness is environment-sensitive, whereas kurtosis is not.

Within limitations, river sands can be distinguished from beach sands on the basis of plots of third moment (skewness) against standard deviation (sorting). Beach sands tend to be better sorted than river sands, and thus tend to have lower numerical standard deviation values. Only medium to fine and very fine-grained sands have been employed in this plot since the third moment (skewness) of coarse-grained river sands is inconclusive as an indicator of depositional environment.

4. The positive skewness of dune sands and the negative skewness of beach sands is independent of the mineralogy of the sands. Quartz, carbonate, and gypsum dune sands have been studied as well as quartz, carbonate, and olivine beach sands. For all these sands, the sign of the skewness tends to reflect the environment and does not change with the mineralogy of the sands.

5. None of the dune sand samples studied shows a mean grain-size value lower than 1.49ϕ, whereas almost 40 percent of the beach sand samples have mean values lower than this amount.

6. The fact that wind and river transportation results from unidirectional flow is believed to provide an explanation for the generally positive skewness of dune and river sands. The grain size distribution of the sand that is being transported is not known. However, the upper size limits of the grains that are carried in suspension or by saltation are governed by the competency of the medium, whereas no such limitation affects the fine particles in transport. The result of this limiting competency at the coarse-grained end of the frequency distribution curve is the lack of a "tail," and the "chopped off" appearance at the coarse end in comparison with a normal distribution.

On a marine beach, sand is exposed to two forces of unequal strength acting in opposite directions. These forces are the incoming waves and outgoing wash. They cause the removal of fine-grained particles by winnowing, which is characteristic of the beach environment. Comparison of a normal curve with the distribution curve of a sand that has been winnowed suggests that the "tail" at the fine-grained end of the distribution curve of the sand has been "chopped off" resulting in negative skewness.

7. Dune sands tend to be better sorted than river sands and a plot of standard deviation (sorting) against mean grain-size indicates three fields, one for river sands, one for dune sands, and a third field of overlap. This figure points out that many river sands can be distinguished from dune sands and vice versa on the basis of their textural parameters but that a wide field of overlap exists. In practice this field of overlap is not necessarily a serious matter, since most coastal, barrier bar, and lake dune sands have a standard deviation of less than 0.40 and many desert and inland dune sands do not exceed 0.50, whereas most river sands have a standard deviation in excess of 0.50.

To distinguish river sands from dune sands which fall within the field of overlap, it is necessary to determine the mean grain-size ratio of quartz and a specific heavy mineral, such as garnet or magnetite. A plot of the ratio of mean grain-size of heavy to light minerals against the ratio of sorting (standard deviation) for heavy and light minerals has been found satisfactory to distinguish between dune and river sands of several Mid-Continent rivers.

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APPENDIX

TABLE 1.—*Location of sample*

Sample No.	Location
	BEACH SANDS (OCEAN)
	Massachusetts
1	Nauset Beach, Cape Cod, Massachusetts
	New York
2	Fire Island, So. of Mastic Beach, Long Island, N. Y.
3	Fire Island, So. of Mastic Beach, Long Island, N. Y.
4	Fire Island, So. of Mastic Beach, Long Island, N. Y.
5	Westhampton Beach, Long Island, N. Y.
6	Westhampton Beach, Long Island, N. Y.
7	Captree State Park, Long Island, N. Y.
8	Captree State Park, Long Island, N. Y.
9	West Tobay Beach, South Oyster Bay, Long Island, N. Y.
10	West Tobay Beach, South Oyster Bay, Long Island, N. Y.
11	Jones Beach, Jones Beach State Park, Long Island, N. Y.
12	Jones Beach, Jones Beach State Park, Long Island, N. Y.
13	Ocean Parkway and Brighton Beach, Brooklyn, Long Island, N. Y.
14	Coney Island and Brighton Beach, Brooklyn, Long Island, N. Y.
15	Brighton Beach, Brooklyn, Long Island, N. Y.
16	Brighton Beach, Brooklyn, Long Island, N. Y.

TABLE 1.—(*Continued*)

Sample No.	Location
	New Jersey
17	Sandy Hook, N. J.
18	Sandy Hook, N. J.
19	Long Branch, N. J.
20	Belmar, N. J.
21	Pt. Pleasant, N. J.
22	Spring Lake, N. J.
23	Mantoloking, N. J.
24	Normandy Beach, N. J.
25	Seaside Park, N. J.
26	Asbury Park, N. J.
27	Ship Bottom, N. J.
	Florida
28	Miami Beach, Florida
29	Miami Beach, Florida
30	Miami Beach, Florida
31	Miami Beach, Florida
32	Dania, Florida
33	Dania, Florida
34	Coral Gables, Florida
	Alabama
35	Dauphin Island, Alabama
36	Dauphin Island, Alabama
37	Dauphin Island, Alabama
38	Dauphin Island, Alabama
39	Dauphin Island, Alabama
40	Dauphin Island, Alabama
	Louisiana
41	Holly Beach, Louisiana

TABLE 1.—(*Continued*)

Sample No.	Location
	Texas
42	High Island Beach, High Island, Texas
43	Galveston Beach, Galveston Island, Texas
44	Galveston Beach, Galveston Island, Texas
45	Mustang Island, Texas
46	Mustang Island, Texas
47	Mustang Island, Texas
48	Mustang Island Texas
49	Mustang Island, Texas
50	Mustang Island, Texas
51	Northern Padre Island, Texas
52	Northern Padre Island, Texas
53	Northern Padre Island, Texas
54	Northern Padre Island, Texas
55	Southern Padre Island, Texas
56	Southern Padre Island, Texas
57	Southern Padre Island, Texas
58	Southern Padre Island, Texas
59	Del Mar and Boca Chica Beach, Brazos Island, Texas
60	Del Mar and Boca Chica Beach, Brazos Island, Texas
	Bermuda
61	Long Beach, Fort St. Catherine, St. George's Island, Bermuda
62	John Smith's Beach, Bermuda
63	Marley Beach, Bermuda
64	Church Bay, Bermuda
65	Somerset Island, Bermuda
66	Ireland Island, Bermuda
	Bahamas
67	North Bimini Island (west shore)
68	North Bimini Island (west shore)
69	North Bimini Island (west shore)
70	Andros Island (east shore)
71	Andros Island (east shore)
	Mexico
72	Eldesemboque del Rio Concepcion, Gulf of California, Baja, California, Mexico
73	Eldesemboque del Rio Concepcion, Gulf of California, Baja, California, Mexico
	Hawaii
74	Waimanalo Beach, Oahu, Hawaii
75	Diamond Head Beach, Oahu, Hawaii
76	Kahuku Beach, Oahu, Hawaii
77	Makua Beach, Oahu, Hawaii
78	Hanauma Bay near Koko Head, Oahu, Hawaii
79	Hanauma Bay near Koko Head, Oahu, Hawaii
80	Puu Mahana Beach, 3 miles northeast of South Point, Hawaii Island, Hawaii

TABLE 1.—(*Continued*)

BEACH SANDS (LAKE)

Sample No.	Location
	Lake Michigan
1	Straits of Mackinac, Mackinac City, Michigan
2	Straits of Mackinac, Mackinac City, Michigan
3	Indiana Dunes State Park, Indiana
4	Indiana Dunes State Park, Indiana
	Lake Erie
5	Toledo, Ohio
6	Toledo, Ohio
7	Toledo, Ohio
8	Pelee Point National Park, Ontario Canada
9	Pelee Point National Park, Ontario, Canada
	Lake Ontario
10	Hamilton, Ontario, Canada
11	Hamilton, Ontario, Canada
12	Selkirk Shores State Park, Pulaski, New York
13	Selkirk Shores State Park, Pulaski, New York
	Lake Huron
14	Georgian Bay, Parry Sound, Ontario, Canada
15	Georgian Bay, Parry Sound, Ontario, Canada
	Lake Superior
16	Point des Chenes, Sault Ste. Marie, Ontario, Canada
17	Point des Chenes, Sault Ste. Marie, Ontario, Canada
	Lake Simcoe
18	Barrie, Ontario, Canada
	DUNE SANDS (COASTAL AND BARRIER BAR DUNES)
	New York
1	Fire Island, South of Mastic Beach, N. Y.
2	Fire Island, South of Mastic Beach, N Y.
	New Jersey
3	Between Mantoloking and Normandy Beach, N. J.
4	Between Mantoloking and Normandy Beach, N. J.
	North Carolina
5	Between Nag's Head and Kitty Hawk, North Carolina
	Alabama
6	Dauphin Island, Alabama
7	Dauphin Island, Alabama
8	Dauphin Island, Alabama

TABLE 1.—(*Continued*)

Sample No.	Location
	Texas
9	Galveston Beach, Galveston Island, Texas
10	Galveston Beach, Galveston Island, Texas
11	Mustang Island, Texas
12	Mustang Island, Texas
13	Mustang Island, Texas
14	Mustang Island, Texas
15	Mustang Island, Texas
16	Northern Padre Island, Texas
17	Northern Padre Island, Texas
18	Northern Padre Island, Texas
19	Northern Padre Island, Texas
20	Southern Padre Island, Texas
21	Southern Padre Island, Texas
22	Southern Padre Island, Texas
23	Del Mar and Boca Chica Beach, Brazos Island, Texas
24	Del Mar and Boca Chica Beach, Brazos Island, Texas
25	Del Mar and Boca Chica Beach, Brazos Island, Texas
	Oregon
26	Winchester Bay, Oregon
27	Winchester Bay, Oregon
28	Winchester Bay, Oregon
29	Winchester Bay, Oregon
	Bermuda
30	Elbow Beach, Bermuda
31	Elbow Beach, Bermuda
	Mexico
32	Eldesemboque del Rio Concepcion, Gulf of California, Baja, California, Mexico
	LAKE DUNES
	New York
33	Selkirk Beach, near Port Ontario, N. Y.
34	Selkirk Beach, near Port Ontario, N. Y.
35	Selkirk Beach, near Port Ontario, N. Y.
	Michigan
36	Straits of Mackinac, Mackinac City, Michigan
37	Straits of Mackinac, Mackinac City, Michigan
	Indiana
38	Gary, Indiana
39	Michigan City, Indiana
40	Mt. Tom, Indiana Dunes State Park, Indiana
41	Mt. Tom, Indiana Dunes State Park, Indiana
42	Mt. Tom, Indiana Dunes State Park, Indiana
43	Mt. Tom, Indiana Dunes State Park, Indiana

TABLE 1.—(*Continued*)

Sample No.	Location
	INLAND DUNES (RIVER DUNES, DESERT DUNES, ETC.)
	Oklahoma
44	Guthrie, Oklahoma
45	Guthrie, Oklahoma
46	Gate, Oklahoma
47	Gate, Oklahoma
48	Gate, Oklahoma
49	Gate, Oklahoma
50	May, Oklahoma
51	Near Beaver Creek, Cimarron County, Oklahoma
52	Near Beaver Creek, Cimarron County, Oklahoma
53	Near Canton, Oklahoma
54	Bixby, Oklahoma
55	Bixby, Oklahoma
	Texas
56	Monahans Sand Hills State Park, Texas
57	Salt Flat, West Texas
58	Salt Flat, West Texas
	Wyoming
59	Muddy Creek, So. of Rawlins, Wyoming
	New Mexico
60	Cienequilla Creek, near Seneca, New Mexico
61	White Sands National Monument, near Alamogordo, N. M.
62	White Sands National Monument, near Alamogordo, N. M.
63	White Sands National Monument, near Alamogordo, N. M.
64	White Sands National Monument, near Alamogordo, N M.
65	White Sands National Monument, near Alamogordo, N. M.
	Colorado
66	Near Holly, Colorado
67	Great Sand Dunes National Monument, San Luis Valley, Colo.
68	Great Sand Dunes National Monument, San Luis Valley, Colo.
	Kansas
69	Near Garden City, Kansas
70	Near Garden City, Kansas
71	Kendall, Kansas
72	Kendall, Kansas
73	Kendall, Kansas
74	Syracuse, Kansas
75	Syracuse, Kansas
76	Syracuse, Kansas
77	Syracuse, Kansas
	Idaho
78	Near Terreton and Mud Lake, Snake River Plain, Idaho

TABLE 1.—(*Continued*)

Sample No.	Location
79	Near Hamer, Snake River Plain, Idaho
80	Near St. Anthony, Snake River Plain, Idaho
	California
81	Algodones Dunes, Imperial County, California
82	Algodones Dunes, Imperial County, California
83	Algodones Dunes, Imperial County, California
84	Algodones Dunes, Imperial County, California
85	Algodones Dunes, Imperial County, California
86	Algodones Dunes, Imperial Count California
87	Algodones Dunes, Imperial County, California
88	Algodones Dunes, Imperial County, California
	Canada
89	Ft. Vermilion, Tsp. 107, R14W of 5, Alberta, Canada
90	Ft. Vermilion, Tsp. 108, R14W of 5, Alberta, Canada
91	Culp, Tsp. 77, R23W of 5, Alberta, Canada
92	Iosegun Lake, Tsp. 64, R20 W of 5, Alberta, Canada
93	Nestow, Tsp. 60, R24W of 4, Alberta, Canada
94	Winterburn, Tsp. 52, R26W of 4, Alberta, Canada
95	Wainwright, Tsp. 43, R6W of 4, Alberta, Canada
96	Hays, Tsp. 12, R13W of 4, Alberta, Canada
97	Hays, Tsp. 12, R13W of 4, Alberta, Canada
98	Bindloss, Tsp. 20, R2W of 4, Alberta, Canada
99	Medicine Hat, Tsp. 12, R4W of 4, Alberta, Canada
100	Grande Prairie, Tsp. 70, R6W of 6, Alberta, Canada
101	Smith, Tsp. 70, R27W of 5, Alberta, Canada
102	Whitecourt, Tsp. 61, R13W of 5, Alberta, Canada
103	Jasper, Tsp. 45, R1W of 6, Alberta, Canada
104	Bickerdike, Tsp. 51, R19W of 5, Alberta, Canada
105	Morningside, Tsp. 42, R26W of 4, Alberta, Canada
106	Red Deer, Tsp. 38, R27W of 4, Alberta, Canada
107	Rocky Mountain House, Tsp. 40, R8W of 5, Alberta, Canada

TABLE 1.—(*Continued*)

Sample No.	Location
108	Retlaw, Tsp. 13, R19W of 4, Alberta, Canada
	Sahara Desert, French North Africa
109	Foum Seiada, Valée de la Saoura, French North Africa
110	Foum Seiada, Valée de la Saoura, French North Africa
111	Foum Seiada, Valée de la Saoura, French North Africa
112	Foum Seiada, Valée de la Saoura, French North Africa
113	Erg Djemel, French North Africa
114	Erg Djemel, French North Africa
	RIVER SANDS[9]
	Alabama
1	Mobile River, ¼ mile downstream from Tombigbee River, Ala.
2	Alabama River, south of Gainestown, Alabama
3	Alabama River, about ½ mile west of Clairborne, Alabama
4	Styx River, about 5 miles ENE of Rosinton, Alabama
	Arkansas
5	Arkansas River, Fort Smith, Arkansas
6	Arkansas River, Fort Smith, Arkansas
	Florida
7	Escambia River, on State Highway 184 about 4 miles east of junction with U. S. Highway 29, Florida
8	Escambia River, about 2 miles east of Century, Florida
9	Yellow River, about 7 miles SE of Milton, Florida
10	Shoal River, about 4 miles south of Crestview, Florida
	Georgia
11	Coosa River at Coosa, Georgia
12	Tallapoosa River at Tallapoosa, Georgia
	Illinois
13	Illinois River, Havana, Illinois
14	Illinois River, Havana, Illinois

[9] The 55 river sand samples listed in this table are comparable in size range to the dune and beach sands studied. In addition samples of coarse-grained sand, gravelly sand, and gravel were collected from the Hudson River in New York, Arkansas River in Colorado, and Kansas, and Ohio and Little Miami Rivers in Ohio. These coarse-grained river sands and gravels had variable, unpredictable skewness characteristics and could not be employed in characterizing the terminal environment. They are therefore not included in this table.

TABLE 1.—(*Continued*)

Sample No.	Location
15	Quiver Beach, 2½ miles north of Havana, Illinois
16	Mississippi River, Hamilton, Illinois
17	Mississippi River, Hamilton, Illinois
18	Mississippi River, Hamburg, Illinois
19	Mississippi River, Hamburg, Illinois
	Kentucky
20	Ohio River, Ghent, Kentucky
21	Ohio River, Ghent, Kentucky
22	Ohio River, Carrollton, Kentucky
23	Ohio River, Carrollton, Kentucky
	Louisiana
24	Bogue Chitto River, 6 miles east of Mc-Comb, Mississippi
25	Bogue Chitto River, 1 mile west of Clifton Louisiana
	Mississippi
26	Tohoutacatouffa River, north of Biloxi, Mississippi
27	Pascagoula River, about 2 miles east of Benndale, Mississippi
28	Pearl River, 2 miles west of Columbia, Mississippi
	Missouri
29	Mississippi River, near Boschertown, Missouri
30	Mississippi River, near Boschertown, Missouri
31	Missouri River, Dutzow, Missouri
32	Missouri River, Dutzow, Missouri
33	Missouri River, Dutzow, Missouri

TABLE 1.—(*Continued*)

Sample No.	Location
	Oklahoma
34	Arkansas River, Jenks, Oklahoma
35	Arkansas River, Jenks, Oklahoma
36	Small creek flowing into Arkansas River, 6 miles south of Sallisaw, Oklahoma
37	Arkansas River, Webbers Fall, Oklahoma
38	Arkansas River, Webbers Fall, Oklahoma
39	Cimarron River, Oilton, Oklahoma
40	Cimarron River, Oilton, Oklahoma
41	Cimarron River, 2 to 3 miles north of Guthrie, Oklahoma
42	Beaver Creek, 3½ miles south of Gate, Oklahoma
43	North Canadian River, near Eufaula, Oklahoma
44	North Canadian River, Oklahoma City, Oklahoma
45	North Canadian River, Oklahoma City, Oklahoma
46	Small Creek, near Broken Arrow, Okla-homa
47	Small Creek, near Broken Arrow, Okla-homa
48	Small Creek, near Broken Arrow, Okla-homa
	Texas
49	Brazos River, Texas
50	San Antonio River, Texas
51	Nueces River, Texas
52	Frio River (tributary of Nueces River), Texas
53	Guadalupe River, Texas
54	Colorado River, Texas
	Virginia
55	North River, near Stokesville, Virginia