ENVIRONMENTS OF DEPOSITION ON AN OFFSHORE BARRIER SAND BAR, MORICHES INLET, LONG ISLAND, NEW YORK

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CONTENTS

I. ABSTRACT

Environments of deposition associated with an offshore barrier sand bar system at Moriches Inlet, Long Island, New York, were studied by mechanical analysis and heavy mineral analysis. Samples collected from six traverses normal to the barrier trend were statistically defined by measurement of mean diameter ($M\phi$) and standard deviation ($\sigma\phi$). Variations in heavy mineral content in different parts of the sand bar are related to the concept of hydraulic equivalent size in sedimentation. By relating threshold velocity (V_t) to grain characteristics, the concept of hydraulic equivalent size, developed for water-transported sands, can be effectively extended to wind-blown particles.

Two distinct sedimentary regimes are defined by the methods used in this study, namely, a forebar and a backbar. The small dimensions of the environments studied preclude further subdivision by these methods.

Results are discussed with reference to fossil shoestring sand bodies found in the geologic record. It is concluded that lateral mineralogical and textural variations should be combined with gross geometric properties in studies involving the genesis of shoestring sands.

II. INTRODUCTION

A. Purpose and Scope

The purposes of this study are to delineate environments of sedimentation associated with an offshore barrier sand bar by the study of grain size distribution, degree of sorting, and heavy mineral variations. The study was designed to test the applicability of these parameters in the delineation of sedimentary environments in the sand bar system.

The Moriches Inlet area, Long Island, New York, was chosen for this study because it includes several recognizably distinct environments of deposition in proximity. In addition, it is clear that a single source accounts for detrital materials found within this system of environments. It is probable that if only one suite of materials was introduced into the environmental system, then any variation found within that suite would indicate local environmental change only, and would not reflect influences of materials from different sources.

Rittenhouse's (1943) concept of hydraulic equivalent size is used to explain the variation in heavy mineral content. If this concept can be extended to explain variations of heavy minerals in beach and dune sands, then such explanations as "selective sorting", or, "lag concentrate" would be modified by a more quantitatively useful interpretation.

The writer contends that if studies of heavy mineral concentrations in sedimentary materials lend more emphasis to the concept of hydraulic equivalent size, then heavy minerals may assume greater importance as sensitive and reliable indicators of depositional conditions.

B. Location, Extent, and Description of Area

The Moriches Inlet area is part of an offshore barrier sand bar system on the south shore of Long Island, New York. The barrier island system is separated from the mainland by approximately one mile at Moriches Inlet. The area of study (Figure 1) is bounded on the north by Moriches Bay and on the south by the Atlantic Ocean. The area is bisected by the 800-900 foot wide Moriches Inlet and extends 3000 feet west and 3000 feet east from the shores of the inlet. The barrier is between 1000 and 2000 feet wide in the study locality. Moriches Inlet truncates Fire Island to the west and Cupsoque Beach to the east, and lies within Brookhaven Township, Suffolk County, New York.

Sand dunes average 15-20 feet in elevation and form the most conspicuous features of the barrier system. The dunes consist of two or three main ridges trending parallel to the barrier. Along the traverses across the barrier, the first dune ridge was encountered at distances varying between 360 and 480 feet across the berm from the ocean swash zone. The dunes are in most places well anchored by grasses and bushy plants. The only other notable topographic feature is the ocean beach face (ocean beach swash zone), which has a gradient of between five and ten percent.

Moriches Bay is from one to three feet deep at mean sea level, at distances from 2000 to 3000 feet into the Bay from the barrier margin. Several small, marshy islands are present in the Bay, and inlet delta accumulations are situated in the Bay immediately north of Moriches Inlet. During average tidal fluctuations considerable portions of these delta accumulations remain subaerial.

During the three day sampling period, winds were from the south and southwest at an average velocity of about 10 mph. Tidal fluctuation was between 1.07 feet and 1.29 feet, as measured on the north shore of Moriches Bay.

C. Geologic Setting and Regional Patterns of Sedimentation

The south shore of Long Island forms a transition zone between Pleistocene glacial deposits of the Island to the north and the continental shelf to the south. Geologic formations available for erosion by either drainage or wave action consist entirely of glacially-derived sediments. A geologic map is presented in Figure 2.

Regional patterns of sedimentation on the south shore of Long Island have been determined in several previous studies. Colony's (1932) study of littoral materials of the south shore shows a net westward drift of sand. Beach erosion and engineering studies show accretion and westward migration of the east sides of inlets present on the southern coastline of Long Island. The Beach Erosion Board, Corps of Engineers, U.S. Army (1961) estimates that the annual littoral transportation rate is of the order of 450,000 cubic yards per year along most of the coast, and that 300,000 cubic yards per year (822 cubic yards per day) westward drift occurs in the vicinity of Moriches Inlet. The headlands physiographic province (Figure 2) is the chief source of clastic materials on the south shore of Long Island.

Lucke (1934) and Nichols (1964) show that the contribution of sediments by streams to the barrier beaches is negligible. Accumulations of fine clastic materials are found in the estuaries of the small streams that enter Moriches Bay from the north. However, the bulk of sediment in the south shore bays is derived from the barriers and inlets.

Although the presence of some sand in the barrier system may result from the near shore bottom drag of incoming waves, the amount of attrition due to this process is difficult to ascertain.

The drainage basin associated with streams

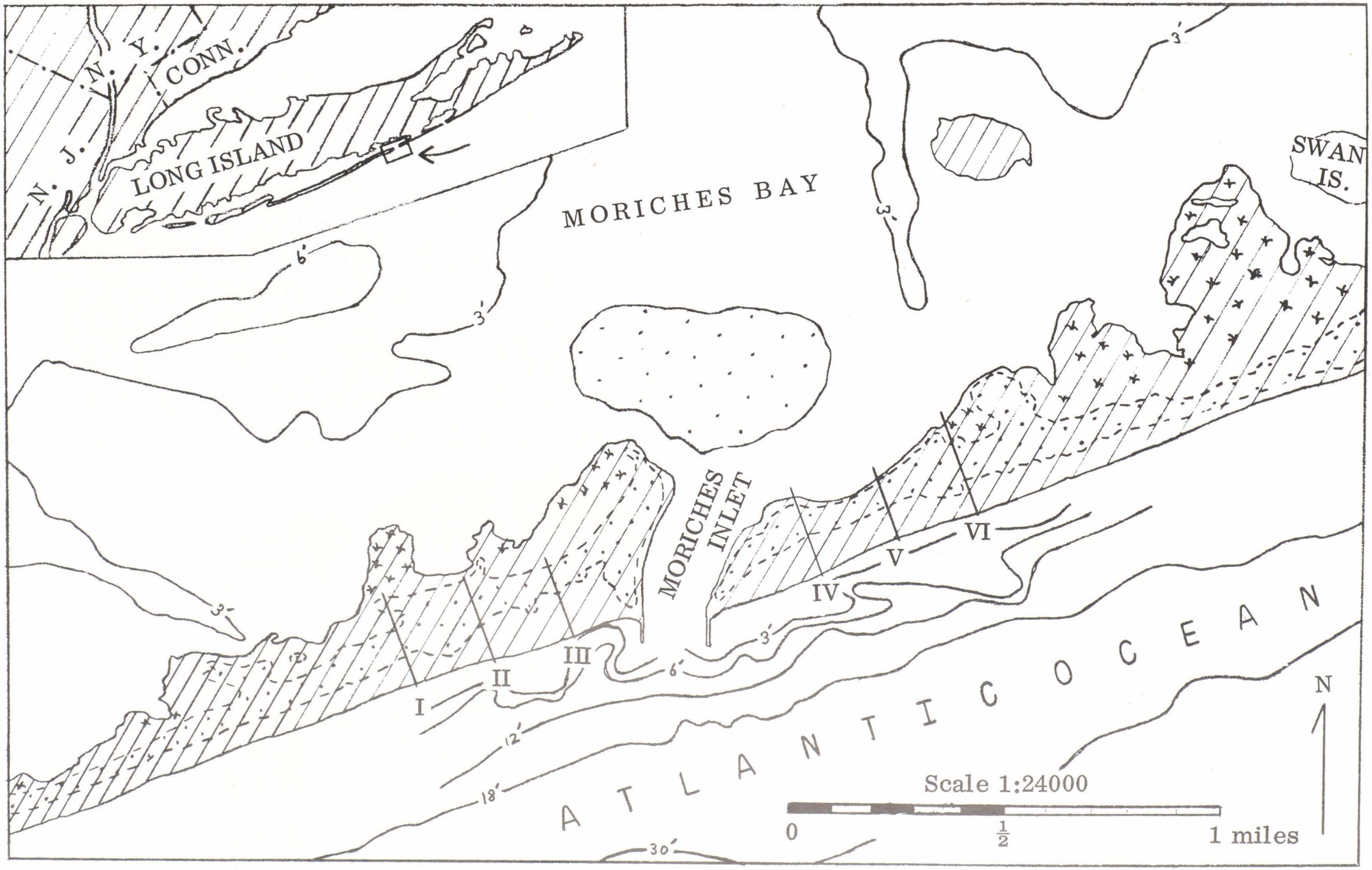


Figure 1. Map and Inset Map (1 inch = 37 miles) of Moriches Inlet area and sampling traverses. Dotted area = sand dunes; "planted" area = marsh; irregular dotted area = subaerial sand deposit. (after USGS, 1957)

that flow into Moriches Bay is underlain by the Manhasset Formation and by the Ronkonkoma Moraine and sediments derived as outwash from the Ronkonkoma Moraine. Clastic materials derived by littoral drift from the shoreline east of Moriches Inlet are also eroded from the Manhasset and Ronkonkoma units. Compositions of these source formations are shown in the legend description of Figure 2.

III. Acknowledgments

Acknowledgment is expressed for helpful criticism by the faculty of the Department of Geology at New York University. Thanks are extended to Dr. A. W. McCrone, thesis advisor, and to Dr. L. E. Spock for aid in mineral identification. Dr. Garrett Briggs, Dr. J. P. McDowell, and Dr. H. C. Skinner, faculty members in the Department of Geology at Tulane University, are acknowledged for their constructive criticism. Miss Jeanne Danker contributed x-ray analyses towards the identification of the finer-sized clastic particles. Messrs. D. A. Ravenhall of Brookhaven National Laboratory and S. B. Cross, Department of Public Works, County of Suffolk, New York, supplied wind and tide data. Mr. W. H. Hillicker acted as field assistant.

IV. Methods of Study

On September 23, 24, and 25, 1961, 30 surface samples were collected to a depth of 2 cm along six traverses normal to the long axis of the barrier. Three traverses were located on each side of the inlet at 1000 foot intervals. Sampling on all six traverses includes samples from the following environments (traverse locations and the sampling pattern are shown in Figures 1 and 4):

a. Intertidal ocean beach swash zone
b. Midpoint of berm (between swash zone and foredune)
c. Foredune slope
d. Backdune (fronting bay) slope

The three traverses east of the inlet include samples from two additional environments:

e. Intertidal bay (protected) beach swash zone
f. Bay bottom samples (approximately 100 feet from barrier)

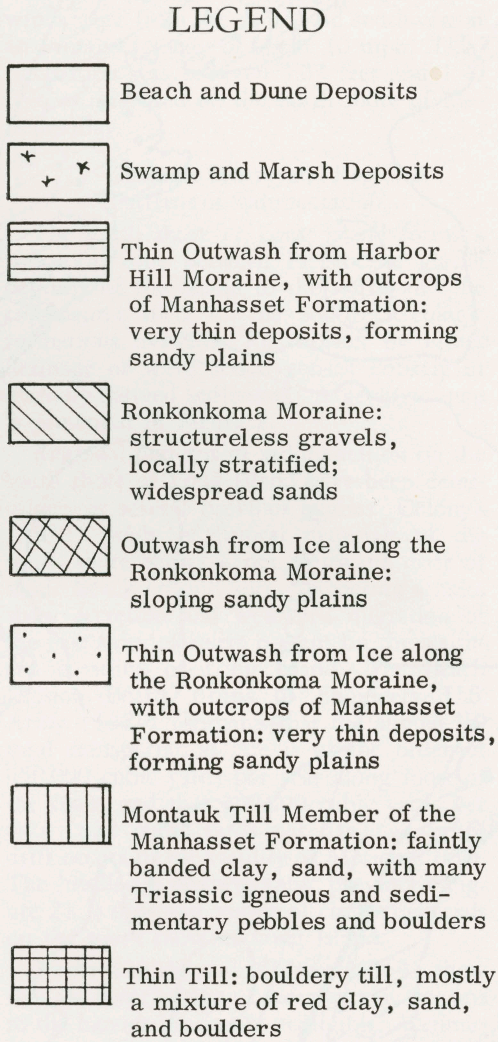


Figure 2—Legend. Description of surface deposits and key to lithologic symbols used on the geologic map of eastern Long Island (page 71).

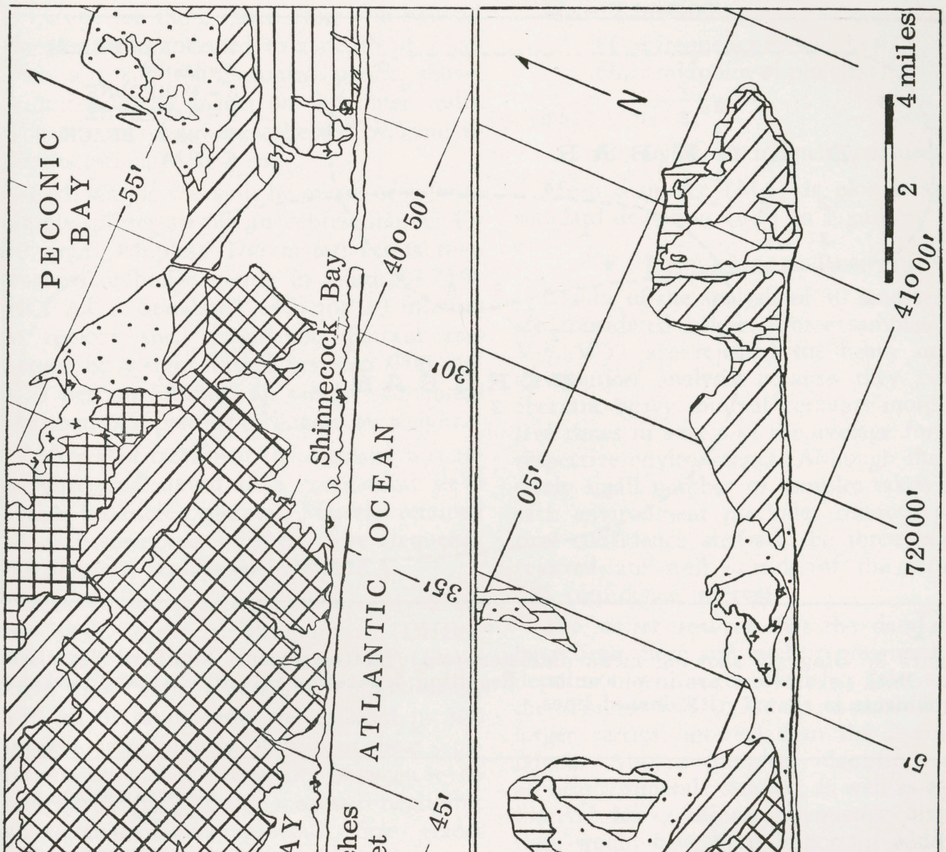


Figure 2. Geologic map of eastern Long Island (after Beach Erosion Board, "Geomorphology", 1961).

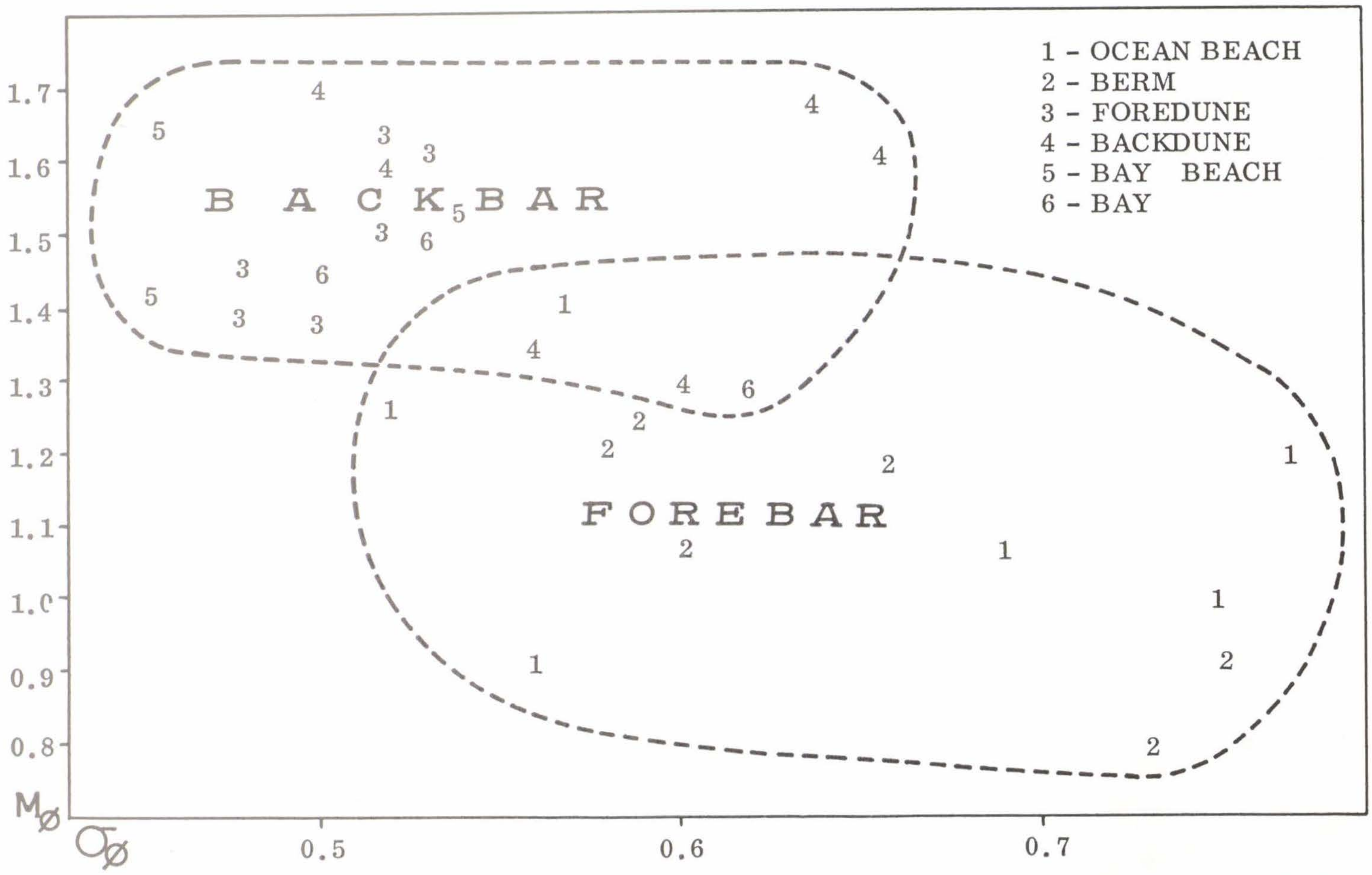


Figure 3. Diagram showing mean diameter (Mϕ) plotted against standard deviation ($\sigma\phi$). Both parameters are in phi units. Resulting separation into forebar and backbar environments is shown with dashed lines.

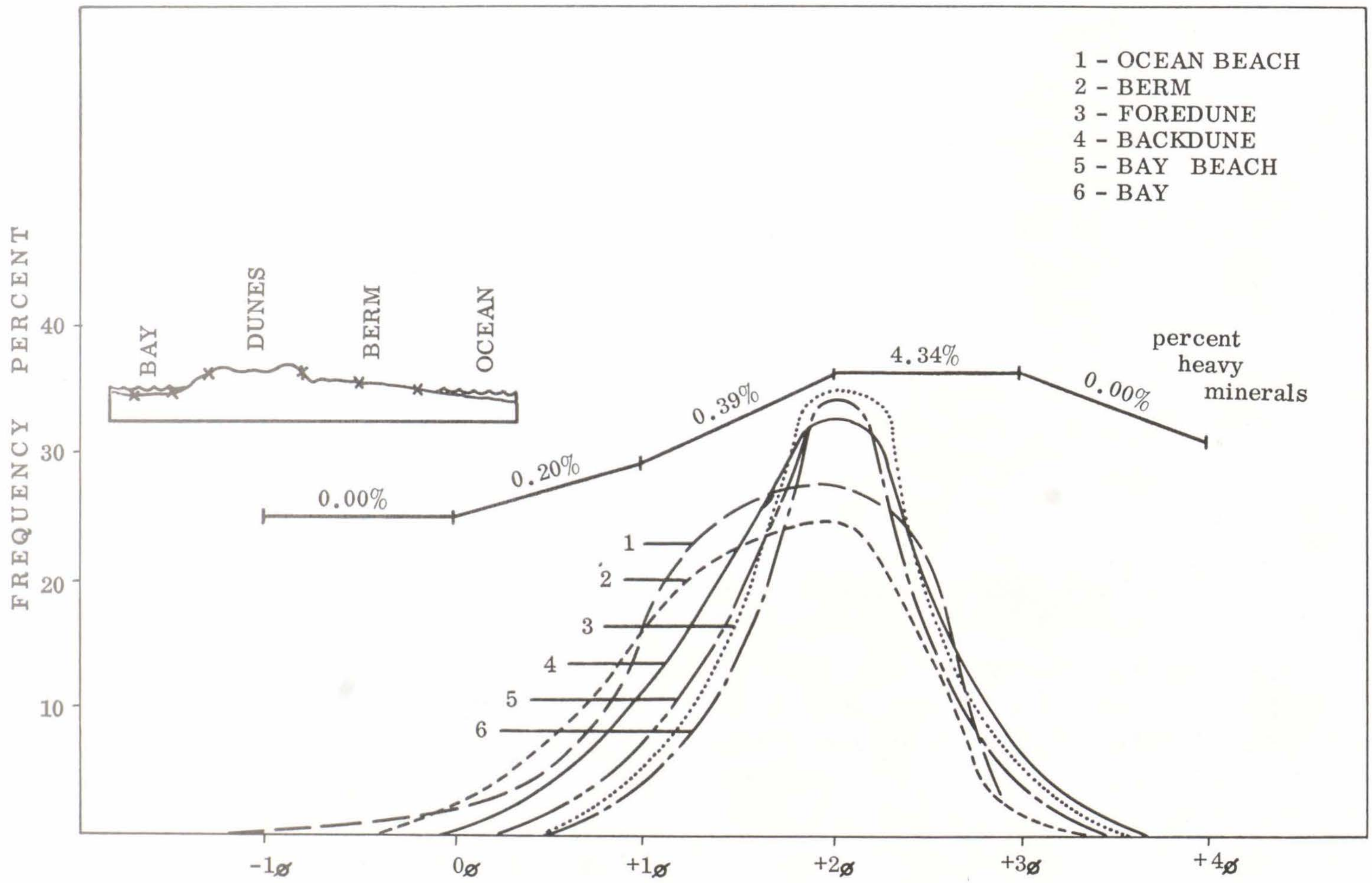


Figure 4. Diagram showing size frequency distribution of samples collected along six traverses in the Moriches Inlet area. Inset cross section shows localities (X) sampled along the traverses. The average heavy mineral percent by weight of each size grade is shown above curves.

Except for those taken from the bay, all samples were collected to a depth of 2 cm with a small, flat-bottomed plastic shovel with centimeter marks on the inner walls. The bay samples were collected by hand to depths estimated at 2 cm.

Each sample was split by means of a Jones sample-splitter to obtain representative 40-50 gram samples. The material was then warmed or boiled gently in dilute (3.75% HCl A.C.S. Standard) HCl for 20 minutes to remove shell fragments. Percent carbonate by weight varied between 0.00 and 4.50 percent. Almost all samples contained less than one percent carbonate by weight.

After acid treatment the material was reweighed and sieved in a mechanical sieve shaker for fifteen minutes. Material retained on each sieve was weighed. Size frequency distributions are shown in Figure 4.

Heavy mineral separations were made on the sieve fractions. Bromoform ($CHBr_3$; S.G. - 2.89 at 20° C) was the heavy liquid used. For each separation approximately 150 ml of bromoform were placed in 300 ml separatory funnels. Results of these separations show that size grades between —1ϕ and 1ϕ (2 mm - 0.5 mm) contain negligible amounts of heavy minerals. Size grades $>3\phi$ ($<1/8$ mm) were either absent or present in insignificant amounts Consequently the 1ø - 2ø and 2ø - 3ø size grades were the only ones used for heavy mineral analysis.

A mineralogical count was made of 563 grains from the heavy separates of samples from the ocean swash zone, dune, and protected swash zone. The mineralogical content of the light separates was cursorily examined.

The raw data for mechanical analysis are considered in terms of the phi scale ($\phi = -\log_2 d$, where d=diameter in mm) in order to allow use of basic statistical methods and to facilitate graphic representation. Because of similarity in the central tendencies of the size distributions of most of the samples, moment measures are used instead of quartile measures. For computing logarithmic means ($M\phi$) and logarithmic standard deviation ($\sigma\phi$), the following formulae were used:

$$M\phi = \Sigma fm/100$$

(f =frequency by weight)
(m=midpoint of phi class)

$$\sigma\phi = \sqrt{n_2 - n_1^2}$$

(n_1 and n_2 are moment measures)

Mean diameter ($M\phi$) is plotted against standard deviation ($\sigma\phi$) in Figure 3.

V. Discussion of Results

Results of the analysis of 30 sand samples are considered below. Three samples (I-2, V-3, V-5) are rejected for heavy mineral distribution analysis because they contain aberrant heavy mineral contents more than five times in excess of the average for their respective environments. Although the relatively small number of samples taken from each environment precludes rigorous statistical confidence analysis, the three samples rejected are well outside of the standard 5% confidence interval.

The writer realizes that the data might have been more accurately representative of deposition within the Moriches Inlet area if the samples had included material from a larger vertical interval than the 2 cm obtained. Also, a complete identification of all heavy minerals counted, as well as a 0.5ϕ interval heavy mineral frequency distribution, would have been important additions. However, the depositional trends found in this study indicate that these elaborations of procedure would only serve better to define the results herein presented.

A. Heavy Minerals

Table 1 shows the results of grain counts of the heavy mineral fraction of three samples collected from different environments. The heavy mineral suite found in the Moriches Inlet area is garnet-rich (average 50.9%). Staurolite (average 11.0%) and opaque minerals (magnetite and/or ilmenite, average 9.7%) are second and third in abundance.

The profile in Figure 5 shows the average percent by weight of heavy minerals found in the environments studied. The ocean beach swash zone and the berm show lowest values. The dune environment shows highest values whereas bay beach samples contain inconsistent percentages. Bottom samples from the bay contain heavy mineral concentrations intermediate between those in

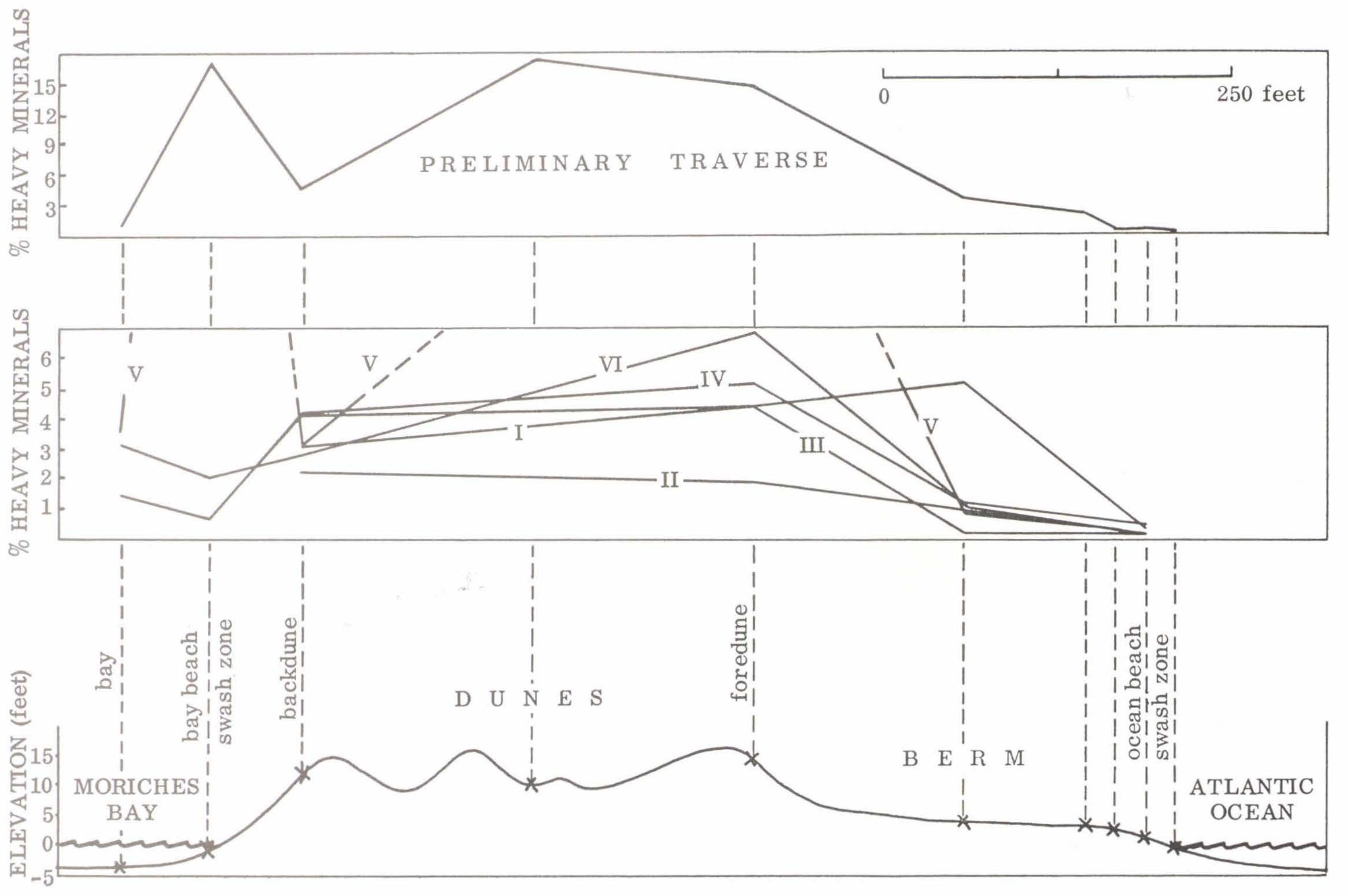


Figure 5. Schematic cross section of a typical traverse in the Moriches-Inlet area. Diagrams above section show heavy minerals as percent of total weight of each sample. Locations of sampling on preliminary traverse are shown on section (X).

the dune sands and those in berm and ocean beach sands.

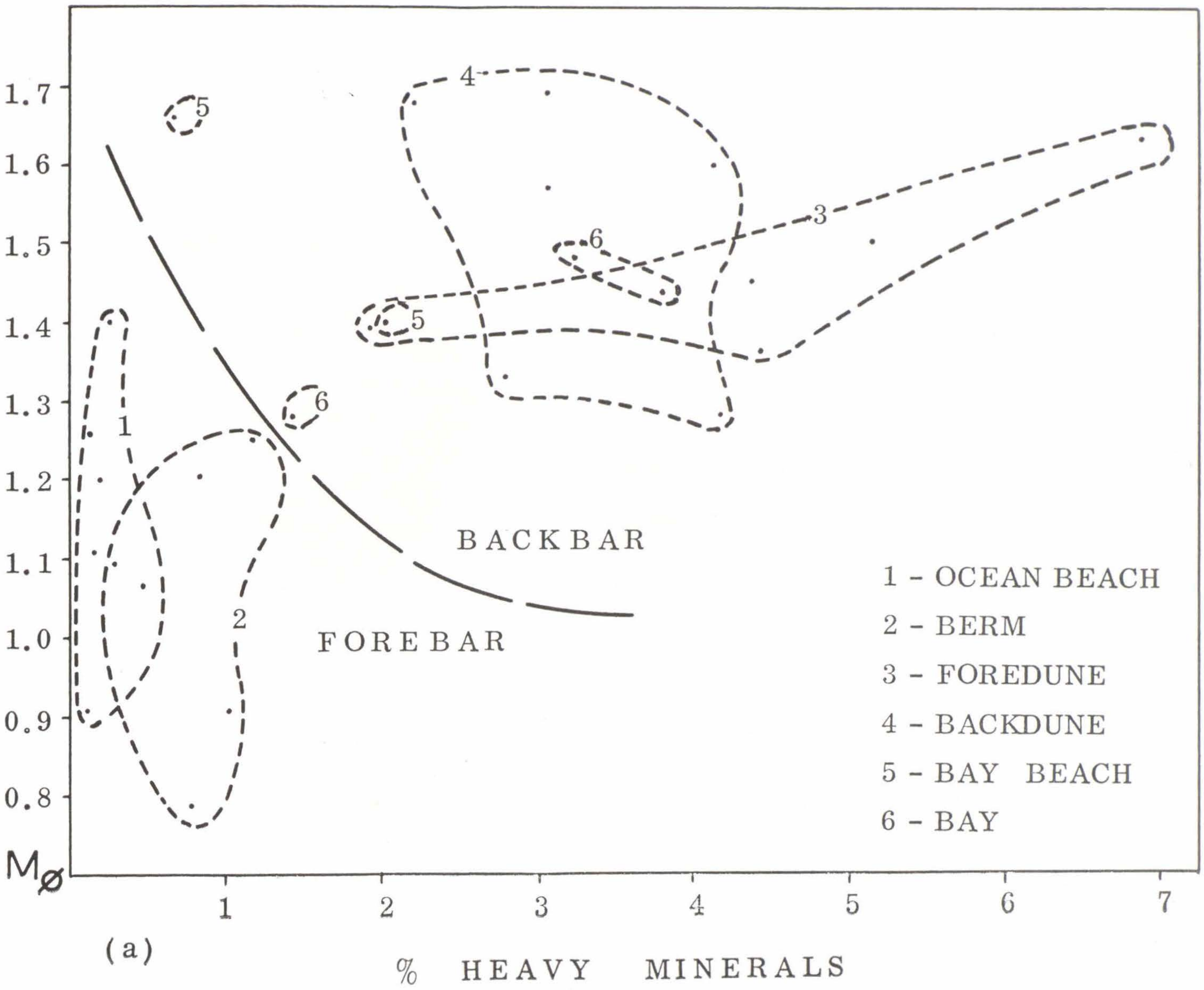
Figures 6a and 6b indicate that depositional regimes can be subdivided into a forebar (ocean beach and berm) and a backbar (dunes, bay sediments) when heavy mineral content by weight is compared with Mø and σø. The best separation occurs when heavy mineral percentages are plotted against Mø, in Figure 6a. The overlap of fields in Figure 6b may be partly explained by the fact that whereas degree of sorting is quite similar in both beach and dune sands, Mø shows a more marked contrast between the two environments.

Figure 7a shows heavy mineral content

TABLE 1

MINERALOGICAL GRAIN COUNTS, INDICATING NUMBER OF GRAINS AND PERCENT BY NUMBER OF TOTAL HEAVY MINERALS COUNTED

Sample Number	Garnet	Magnetite Ilmenite	Zircon	Kyanite	Rock Frag's	Epidote	Staurolite	Other
I-3	90 45.0%	21 10.5%	2 1.0%	1 0.5%	3 1.5%	6 3.0%	28 14.0%	49 24.5%
V-5	107 53.0%	24 11.8%	9 4.5%	2 1.0%	4 2.0%	3 1.5%	17 8.4%	36 17.8%
7	87 54.7%	11 6.9%	3 1.9%	2 1.3%	0 0.0%	5 3.1%	17 10.7%	34 21.4%
Average Totals	94.7 50.9%	18.7 9.7%	4.7 2.5%	1.7 0.9%	2.3 1.2%	4.7 2.5%	20.7 11.0%	39.7 21.2%



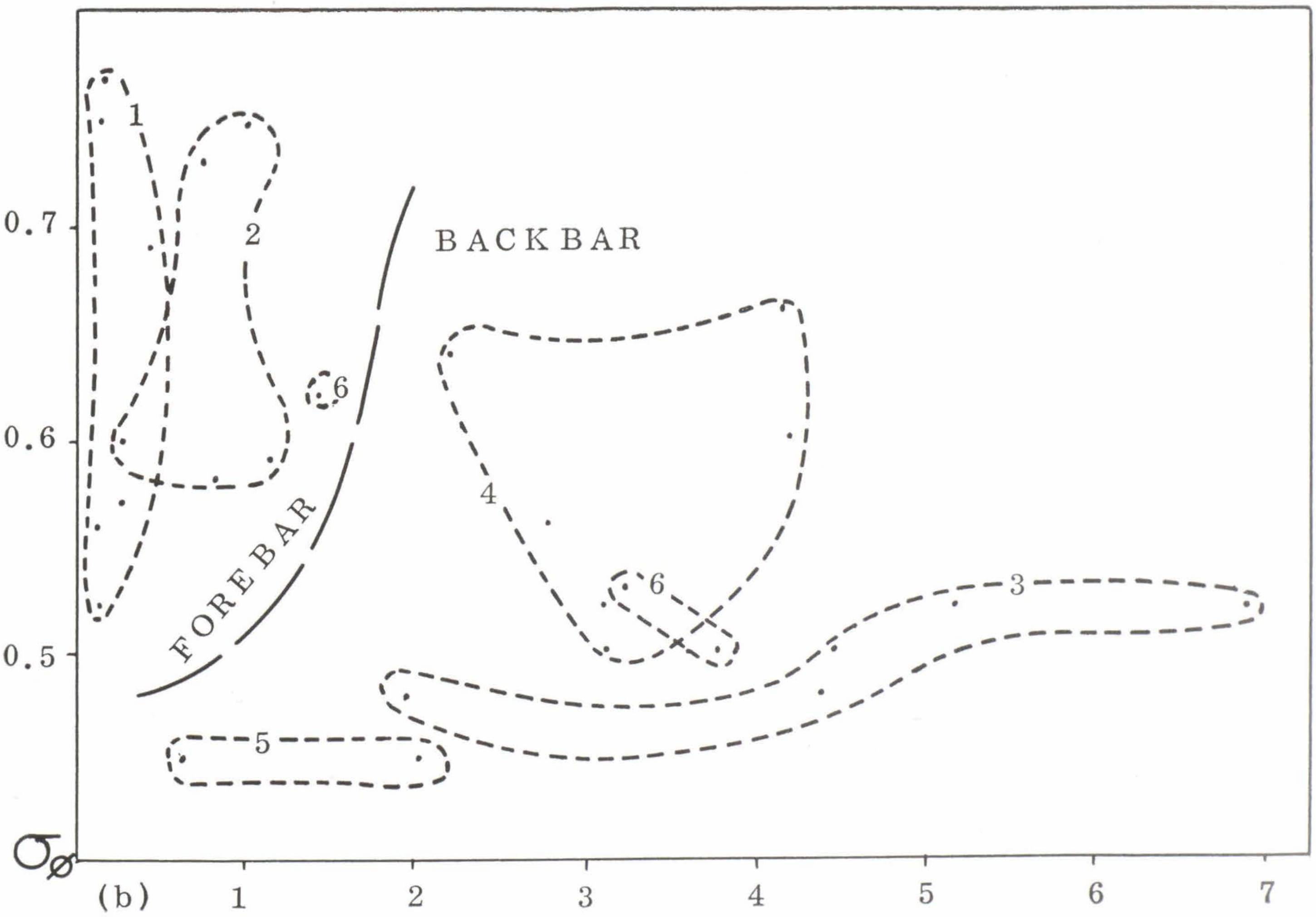


Figure 6. Diagrams showing heavy mineral percentage by weight plotted against mean diameter (a) and sorting (b).

compared with the percent by weight of the samples that occur in the size interval 1ø - 2ø (1/2 mm - 1/4 mm). Figure 7b is a similar plot utilizing the interval 2ø - 3ø. Figure 7a shows far better separation into a forebar-backbar system than does Figure 7b. The environments containing consistently higher percentages of heavy minerals (dune and bay) show, in Figure 7a, a much smaller degree of overlap with the environments containing lower percentages of heavy minerals (ocean beach, berm). There is no tendency for heavy mineral content to vary with the 2ø - 3ø size content of the samples, even though this size range contains a much greater amount of heavies per unit weight than any other size range (see Figure 4). There is a distinct tendency for heavy mineral content to vary with the sample content in the 1ø - 2ø size range; that is, one phi size lower (one Wentworth size larger) than the range wherein most of the heavies are concentrated.

The concept of hydraulic equivalence among particles in a fluid medium permits a quantitative expression of factors governing the distribution of heavy minerals in the Moriches Inlet area.

In 1943, Rittenhouse published a comprehensive review of factors controlling heavy mineral transportation and deposition. He expanded the idea of equivalency, and considered the relationships between light and heavy minerals from the standpoint of "hydraulic equivalent size" and "hydraulic ratio". In his discussion of variations found in sediments collected along a stream traverse, Rittenhouse defines three factors that affect size distributions in the same sample or in different samples taken from the traverse (Rittenhouse, 1943, p. 1743):

1. The hydraulic conditions which vary with time and position and are a composite of many interacting conditions
2. The hydraulic equivalent size which is also the net effect of several factors
3. The relative availability for deposit of the different sizes of each mineral

Rittenhouse also stated that the size distributions of light and heavy minerals in a deposit will reflect the net effect of temporal changes in hydraulic conditions. He indicates that (referring to the above factors):

"At any instant, however, all kinds and sizes of mineral grains that are accumulating will be subject to the same hydraulic conditions, whatever they may be. At other instants, this will also be true.

"Consequently, the differences in size distribution of different minerals in the same sample will be due to the second and third factors."

Within the Moriches Inlet area it is axiomatic that hydraulic conditions must change with time at any given point. While this is also indicated in Rittenhouse's study (for deposits found along a stream traverse), a consideration of the relatively small dimensions sampled enabled Rittenhouse to assume little variation between samples in the relative availability for deposit of each size grade of each mineral.

Many factors must be considered in attempting to explain sediment variations found in the Moriches Inlet area. It has been stated above that several environments of deposition are recognized in the offshore barrier system. It is known that sediment found in all the local environments is directly and indirectly derived from materials brought into the area by ocean wave action. Also, because these materials undergo net migration from the ocean beach to the bay, each environment must have a distinctive sediment assemblage introduced into it that will in part be deposited within that environment and in part be deposited elsewhere. If this were not true, no selectivity would exist, and no environments could be differentiated. It was thought that these environments would be recognizable by means of methods employed in this study.

Because it was found that the concept of hydraulic equivalent size can be used to explain the distribution of heavy minerals at Moriches Inlet, the obvious differences between a stream traverse (Rittenhouse's study) and a barrier sand bar must be noted. Moreover, the sand dunes are wind-blown. It seemed that differences in effect on sediments between the two fluid transporting media might be accounted for by considering a theoretical relationship established by Bagnold (1941). Bagnold found empirical indications that the threshold velocity (V_t= velocity in a turbulent flow of air over a rough surface needed to start a sand grain moving from rest) in air varies as the square root of the grain diameter:

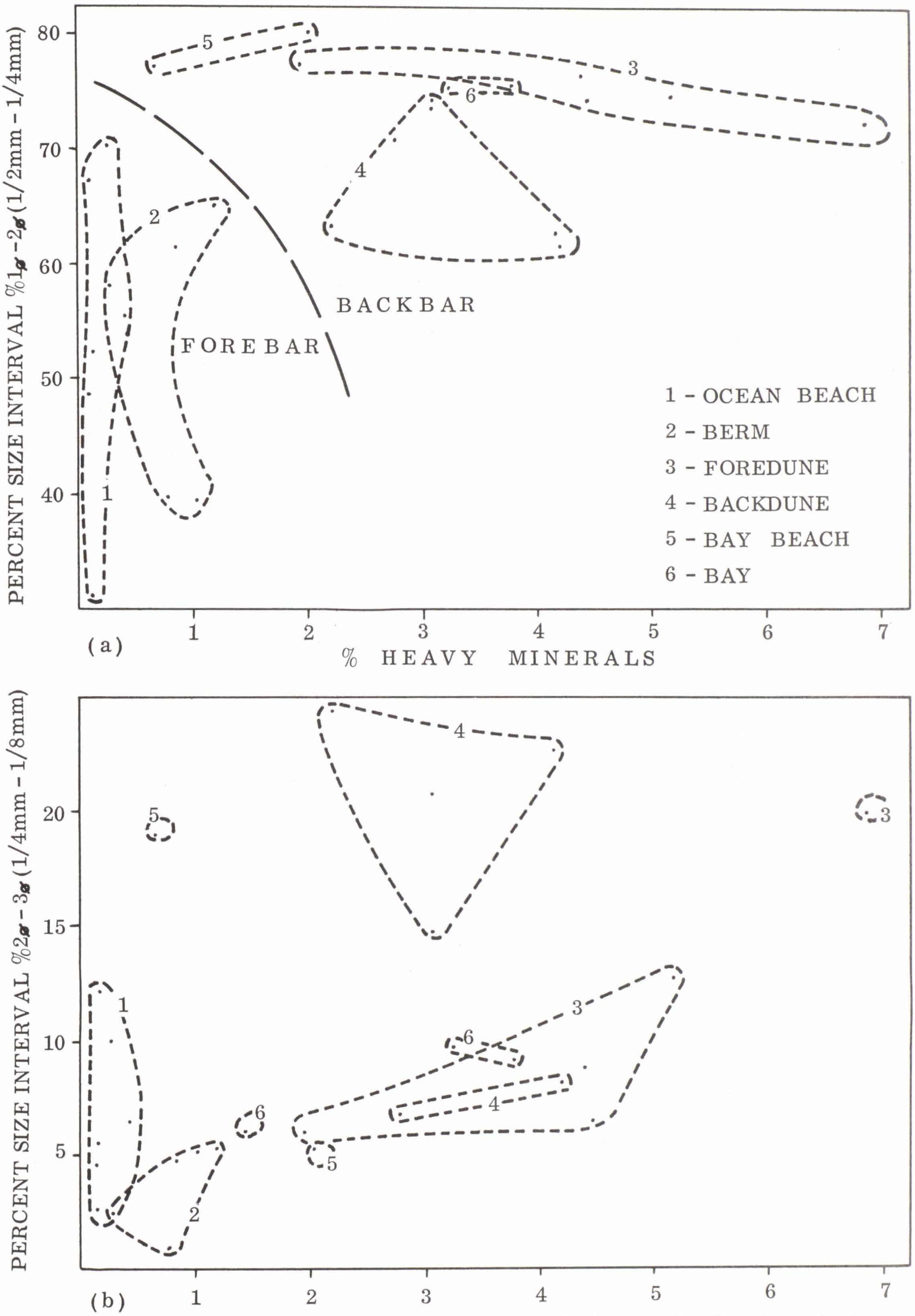


Figure 7. Total percent by weight of heavy minerals in sample plotted against percent of sample in the given size ranges.

$$V_t = A \sqrt{\frac{\sigma - p}{p} Gd}$$

where:

V_t=threshold velocity

A =a constant (for grain sizes considered here)

σ =grain density

p =fluid density

d =grain diameter

G =gravitational constant

The expression is especially interesting from the viewpoint of the present study as the grain density σ is included. To apply the threshold velocity relationship to this study, the following is noted:

$$V_t = A \sqrt{\frac{\sigma - p}{p} Gd} \qquad (1)$$

but because $p = 1.22 \times 10^{-3}$, then, effectively,

$$V_t = A \sqrt{\frac{\sigma}{p} Gd}$$

but A, p. and G are constants, and

$$V_t = \sqrt{\sigma d} \qquad (2)$$

If the principles of hydraulic equivalent size apply, then there should be some threshold velocity that is the same for a given heavy mineral particle as it is for a hydraulically equivalent light mineral so that

$$V_t = \sqrt{\sigma_1 d_1} = \sqrt{\sigma_2 d_2}$$

or,

$$\sigma_1 d_1 = \sigma_2 d_2 \qquad (3)$$

Hence, if $\sigma_1 > \sigma_2$, then $d_1 < d_2$, and vice versa.

The relationship may seem oversimplified, but it is adapted as a working formula. The concept of hydraulic equivalence may be tested, as Rittenhouse points out, without knowledge of rounding, sphericity, grain surface features, or other such parameters. If a distinct grain size relationship is found between heavy minerals and light minerals in sedimentation processes, then the concept is valid, regardless of the various factors inherent in producing that relationship.

Using quartz on the one hand and heavy minerals on the other hand, expression (3) has been calculated for the most common heavy minerals that were found in the sands of the Moriches Inlet area.

Table 2 shows the computed hydraulic equivalent sizes corresponding to the given sizes of the identified heavy minerals as calculated for wind-blown particles. The distribution of the heavy minerals in the dunes is significant when related to the computed hydraulic equivalent sizes which predict the relationship shown in Figure 7, namely, the variation of heavy mineral content with the content of light minerals of relatively larger diameters (hydraulic equivalent sizes). These data indicate that the concept of hydraulic equivalent size is applicable to wind-blown sands, as well as to water-transported sands, and explains the distribution of heavy minerals found in the Moriches Inlet area.

B. Mechanical Analysis

Sands in the dunes and along the barrier margin of the bay show better sorting and finer texture than sands in the berm and ocean beach environments. Although there is approximately a 0.5ϕ difference in the $M\phi$ of samples between the forebar and backbar areas, all samples but three taken from the ocean beach are fine-grained sands (2ϕ - 3ϕ). Sands from the ocean beach and berm environments yield a $\sigma\phi$ only 0.12ϕ

TABLE 2

EQUIVALENT DIAMETERS (CALCULATED IN MM) OF WIND-BLOWN PARTICLES. VALUES AT LEFT ARE THE DIAMETERS OF THE HEAVY MINERALS FOR WHICH THE HYDRAULIC EQUIVALENT DIAMETERS HAVE BEEN CALCULATED

	Garnet	Magnetite Ilmenite	Zircon	Kyanite	Epidote	Staurolite
1.5ϕ (0.375 mm)	0.542	0.699	0.662	0.511	0.481	0.524
2.0ϕ (0.250 mm)	0.361	0.466	0.442	0.341	0.321	0.349
2.5ϕ (0.188 mm)	0.272	0.350	0.332	0.256	0.241	0.262

units larger than do sands found in the backbar area. When $M\phi$ is plotted against $\sigma\phi$, a good separation becomes apparent between the forebar sediments and the sediments associated with the bay and with the dunes (see Figure 3). The size frequency curves in Figure 4 also show good separation.

Little difference can be expected between the physical properties of samples collected from the bay and samples collected from the bay beach. Moreover, only three samples were collected from both the bay and the bay beach. It is probable that the similarity of the bay samples to the dune samples is caused by the effective sorting action of the constantly fluctuating shallow tidal currents that are especially strong along the interior margin of the bar. Similarity between bay beach and dune materials is expected because part of the dunes is undergoing active erosion by the bay waters.

Ocean beach and berm materials are almost identical mechanically. This uniformity is probably a result of the migration of sand across the relatively narrow berm (average width 420 feet). The berm is probably not broad enough to enable sediments derived from the ocean beach to acquire a texture distinct from that of the local provenance, or, ocean beach.

The ocean beach and berm samples show negative skewness. This may in part be due to the fact that offshore bottom samples in this area may be negatively skewed (Beach Erosion Board, Corps of Engineers, 1961). The dune sands yield normal frequency curves whereas the curves for bay and bay beach samples are slightly negatively skewed. Because only the forebar and the backbar sedimentary regimes can be delineated by mechanical analysis, inter-environmental inheritance of textural characteristics must be a strong factor in sedimentary patterns in the Moriches Inlet area.

C. Shoe-String Sand Bodies

The origin of fossil shoe-string sand bodies is of long-standing interest to petroleum geologists. Lenticular sand bodies have been explained as fossil stream channels or ancient sand bars. The problem of origin has been pursued by stratigraphers, but there are few accounts of lateral sedimentary variation within the sand bodies. Bass (1936) and Bass, Leathereck, Dillard, and Kennedy (1937) give data on texture and mineralogy, but these data are ascribed to the sand body as a whole. There has been no attempt to describe local lateral textural changes.

Shoe-string sands that represent ancient barrier bars may contain textural and mineralogical variations similar to those found in this study. Because similar heavy mineral species are present throughout a local barrier section, diagenetic solution of less stable species would not mask primary differences due to sedimentation. Dune sands will remain relatively enriched in the residual stable species.

VI. Conclusions

This study leads to the following conclusions concerning sediments in the Moriches Inlet area:

A. Because of the relatively small geographic dimensions (normal to the barrier trend) of the environments studied, only two regimes of sedimentation, the forebar and the backbar, can effectively be differentiated by the methods used in this study. Subdivisions of these regimes must be delineated by other means

B. Backbar sands (bay and dunes) are better sorted and finer-grained than sands in the forebar regime (berm, ocean beach)

C. The concept of hydraulic equivalent size is applicable to wind-blown sands as well as to water-transported sands

D. Heavy mineral content by weight increases with better sorting and smaller mean diameter

E. Studies of lateral changes in mineralogy and mechanical properties of sands will aid in the interpretation of the history of formation of fossil shoestring sand bodies.

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