1983

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Robbins, Amy T. and Whittecar, G. Richard. 1983. Cluster Analysis of Grain Size Parameters from a Beach Ridge Complex, Cape Henry, Virginia. Pp. 110-126 In: Tanner, W.F. (editor). Near-Shore Sedimentology. Proc. Sixth Symposium on Coastal Sedimentology. Geology Department, Florida State University, Tallahassee, Florida. 242 pg. ISBN: 0-938426-04-4

NEAR-SHORE SEDIMENTOLOGY

1983

PROCEEDINGS OF THE SIXTH SYMPOSIUM ON COASTAL SEDIMENTOLOGY

ISBN: 0-938426-04-4

PUBLISHED BY THE
DEPARTMENT OF GEOLOGY
FLORIDA STATE UNIVERSITY
TALLAHASSEE, FLORIDA

Cluster Analyses of Grain Size Parameters from a Beach Ridge Complex, Cape Henry, Virginia

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Abstract

Cape Henry is a Holocene beach ridge complex at the mouth of the Chesapeake Bay. Analyses of cross-cutting relationships visible on aerial photographs divide the complex into five geomorphic zones. Low, arcuate beach ridges, ornamented in places with small dunes, characterize the four oldest zones. The youngest zone consists of large irregular-shaped dunes which bury the margins of all older zones. Locations of 102 samples taken from 1 m depths on ridge crests were based upon a random stratified sampling grid covering all of Cape Henry. The use of half-phi size data generated standard sediment parameters. Weighted-pair cluster analyses of these data indicate that some topographically notable zones have sediments with distinguishing characteristics. A major statistical difference exists between samples from most coastal dunes and those from most beach ridges. Other distinctions separate frontal dunes from back-beach dunes, and coastal dunes from dunes ornamenting beach ridges. The influx of a coarse sand sediment source late during Cape Henry's

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Tanner, W.F. (editor), 1983. Near-Shore Sedimentology. Proc., Sixth Symposium on Coastal Sedimentology; Geology Dept., Florida State University, Tallahassee, FL 32306 USA.

development produced a measurable difference in features on the northwest portion of the study area. These data suggest that the change in sediment supply in this area probably resulted from the exhumation of Pleistocene deposits and the episodic reworking of Holocene features.

Introduction

Cape Henry, Virginia, is a prograded complex of dunes, ridges, and wetlands projecting northward into the mouth of the Chesapeake Bay (Figure 1). The central portion of this cuspate foreland spit (Kraft *et al.*, 1978) consists of a series of arcuate beach ridges and intervening marshes. Most ridges are continuous, narrow hills of relatively uniform relief, although many ridge crests are irregular, rising to 20 meters elevation. Pine-oak forests line the ridges. Stands of cypress and black gum cover most of the intervening marshes. Near the lagoons to the south, saltwater marshes are found along tidal creeks.

The coastal edges of the beach ridge plain are overrun by eolian dunes. Where undisturbed, the landward margin of the younger dune area is stabilized by a mature pine forest and forms a continuous scarp with up to 15 meters of relief. Large dunes within this zone tend to be coast-parallel but are much more irregular in shape than the relict beach ridges farther inland.

Previous Studies at Cape Henry

Although early observers at Cape Henry noted the ridges and dunes (e.g., Darton, 1902), no one recognized that the features had important differences in age. Bass and colleagues (1937) compared the ridge pattern at the Cape to buried shoestring sands in Oklahoma oil fields. Using analyses of the linear trends and cross-cutting relationships visible on aerial photography, Fisher (1967) concluded that at least five groups of ridges comprise the Cape Henry complex. He proposed episodic deposition and erosion of the beach ridges to explain the existing pattern.

Using soil chemical data from transects of well-drained sites, Whittecar and colleagues (1982, unpublished) suggested that three areas of Cape Henry are of markedly different ages. The youngest area is the zone of coastal eolian dunes with virtually no soil horizons. Soils on beach ridges in the oldest zone have accumulated significantly more iron, aluminum, and organic material than soils on beach ridges within the intermediate zone. Although no radiocarbon dates exist for Cape Henry samples, these groups of ridges are presumed to be Holocene in age based upon their similarities with other dated beach ridge sequences on the U.S. Atlantic Coast (e.g., Stapor, 1973; Barwis, 1978; Moslow and Colquhoun, 1981).

Previous Work on Beach Ridges and Dunes

Most workers dealing with beach ridges suggest that factors such as sediment supply or sea level control beach ridge formation. At various locations, beach ridge sediments are reported to be supplied by rivers and estuaries (Curray and Moore, 1964; Psuty, 1967; Alexander, 1969), longshore drift (Gilbert, 1890; Johnson, 1919; Fisher, 1967), and from offshore (Stapor, 1973). The first step in beach ridge formation is the deposition of a berm or storm ridge by waves or current action.

Further deposition by washover (Psuty, 1967), swash action (Davies, 1957; Stapor, 1973), or longshore currents (Biggarella, 1965; Fisher, 1967) may promote growth of the ridge.

Three sea level situations have been related to coastal progradation and ridge building. A recent fall in sea level in eastern Malaya induced construction of a beach ridge coast (Nossin, 1965). Beach ridge plains on the Outer Banks of North Carolina prograded under a stable sea level, according to Fisher (1967). Stapor (1973) proposed that an abundant sand supply reworked by an oscillating sea level caused progradation of beach ridge plains on the coast of northwest Florida. He hypothesized that during a regression, additional sand became available due to lowering of the wave base; a rise in sea level could then move the new sand shoreward for deposition.

After the berm or ridge is established, wind can modify its surface. Beach ridges owe much of their height to wind deposits (Davies, 1957; Psuty, 1967; Alexander, 1969). Davies (1957) thought that frontal dunes may begin as berms or ridges but are greatly augmented and modified by wind and storm waves. The more irregular the ridge, the greater the proportion of windblown sand in that ridge. Goldsmith (1973) recognized that vegetation, especially beach grass, is important in the formation of coastal dunes in humid climates.

Characteristics of Beach Ridge and Coastal Dune Sediments

Little work has been done on beach ridge textural characteristics. In Stapor's (1973) report on the beach ridges of northwest Florida, he found them to be fine grained, yet coarser than nearby coastal dunes, very well sorted, near normally skewed, and very leptokurtic.

Review of the literature on coastal dunes indicates that textural characteristics of dune sediments are similar in many locations. In general, the following observations were found:

(1) Coastal dunes are fine grained,commonly finer grained than nearby beach sediments (Friedman, 1961; Shideler, 1974). The low competency of wind compared to water was cited as the cause for the smaller grain size.

(2) Coastal dunes tend to be well sorted, and better sorted than beach sediments (Mason and Folk, 1958;

Fisher, 1969; Shideler, 1974). Better sorting in dune material may be the result of the combined action of both the hydraulic and the eolian regimes (Shideler, 1974).

(3) Coastal dune sediments are positively skewed whereas beaches tend to be negatively skewed (Mason and Folk, 1958; Friedman, 1961; Duane, 1964; Visher, 1969). According to Friedman (1961) the unidirectional flow of wind may provide an explanation for the positive skewness of dune sands. Coarser material would lag behind during wind transport and therefore an excess of fine material would show on the frequency distribution curve.

(4) Coastal dune sands are either mesokurtic or slightly leptokurtic (Mason and Folk, 1958; Shideler, 1974). Although the dynamic significance of this parameter is a topic of speculation, most authors believe it reflects various degrees of mixing from different sources.

Methods of Analysis

Samples were collected by hand auger or shovel from 0.8-1.0 m depths along the crests of ridges. This standard sample depth and landscape position was selected in order to minimize the effects of sediment disturbance by blowouts and slope processes. Use of modified systematic stratified sampling scheme (Berry, 1962) with a 0.4 km x 0.4 km grid produced a "random" but dispersed pattern of sample sites.

Samples were dried and sieved with a Ro-Tap using half-phi size intervals. Sedimentary parameters were calculated using techniques of both Folk (1974) and Friedman (1961). Graphic mean, inclusive graphic standard deviation (sorting), inclusive graphic skewness, and graphic kurtosis were compared using Q-mode weighted-pair cluster analyses (Davis, 1973); identical analyses were run using the first four moment measures.

Comparison of the clusters derived from both graphic and moment measures indicate only minor differences. Since the graphic measure clusters lead to the most straightforward geological interpretations, we will confine our present discussion to data and conclusions derived from graphic measures.

Purpose of Research

A major goal of the research underway at Cape Henry is to relate the sedimentary characteristics of the dunes and ridges with their topographic forms and geomorphic positions. The specific aim of the grain size analyses reported in this paper is to test the following hypotheses:

Hypothesis 1: Surficial sediments on ridges within the beach ridge plain differ significantly from those found on coastal dunes.

Hypothesis 2: Surficial sediments on ridges within the beach ridge plain differ significantly between individual ridges or groups of ridges.

Hypothesis 3: Parameters of surficial sediment from groups of landforms can be predicted by quantifying the topographic elements of those landscapes.

The first two hypotheses are discussed below in detail; Hypothesis 3 is still being tested and will be evaluated later.

Textural Characteristics and Locations of Clustered Samples

The 102 samples collected at Cape Henry exhibit a wide range of textural characteristics. Evenly split between medium and fine sand, the samples are either well- or moderately-well sorted (Folk, 1974). Eighty percent of the samples have nearly symmetrical distributions about their means, the rest being either coarse- or fine-skewed. Kurtosis values range from platykurtic to leptokurtic with 70% having near normal kurtosis.

The cluster analysis of the four textural parameters distinguished seven groups of samples with correlation coefficients greater than 0.500 (Figure 2). Most coefficients between members of a cluster were greater than 0.850. As seen in the dendrogram, two groups of clusters have very low degrees of similarity (-0.27) whereas correlations between certain pairs of clusters (e.g., 1 and 2; 5 and 6) are much higher.

The use of bivariate plots and sample location maps helps to clarify the distinctions between these clustered samples. The major separation between groups 1-2-3-4 and 5-6-7 (Figure 3) appears to be higher kurtosis and skewness values of group 1-2-3-4. Geographically, samples in group 1-2-3-4 come mostly from throughout the beach ridge plain with a smaller number from the coastal dunes to the northwest and southeast. Groups 5, 6, and 7 fall either on the northeastern coastal dunes or along certain ridges within the Cape's interior.

Important distinctions exist between individual clusters. In Figure 4a, note that samples in clusters 1 and 2 are mostly medium sands, coarser than the fine sands in clusters 3 and 4. Further breaks between clusters 1 and 2 and between 3 and 4 are based upon more subtle differences in grain size and kurtosis (Figure 4a).

Most of the samples in the closely related clusters 1 and 2 come from the northwestern region of the study area (Figure 4b). Group 1 characteristics predominate in the coastal dunes of that area whereas group 2 samples come from many of the youngest beach ridges at the Cape. Cluster 3 samples are almost exclusively beach ridge samples from throughout the rest of the study area.

The scatter plot of sorting versus skewness shows good separation between clusters 5, 6, and 7 (Figure 5a). Group 7 samples are better sorted than those in group 5 whereas group 6 data are more negatively skewed. The locations of these samples are also clustered (Figure 5b). Group 5 samples characterize the massive back beach dunes; group 6 data are mostly from smaller dunes close to the present beach. The several bech ridges that produced most group 7 samples tend to have greater relief and more irregularity along their crests than commonly found on other beach ridges.

Discussion and Conclusions

When examined with the position and shape of the landforms they represent, the grain size data from Cape Henry explain much about the area's sediment supply. At present, sediments move north along the Atlantic shore in Virginia Beach toward Cape Henry (Weinman, 1971); we suspect that similar sediment movement was the major source of Cape material during the Holocene. Along the Bay shore of the Cape, sediment movements are largely to the west although sediments reworked by currents in and near Lynnhaven Inlet have been transported east towards Cape Henry (Ludwick, 1979). The pattern of beach ridge development indicates that while the most recent progradation is on the northwest side of the Cape, older features built out in directions that suggest more southerly or offshore sources (Fisher, 1967).

During the latter stages of Cape growth, exhumation of Pleistocene(?) coarse sand deposit introduced a distinctive sediment population that has become partially incorporated into the Cape Henry complex. The medium sands in the beach ridges of cluster 3 are better sorted and finer grained than the northwestern dune sands of cluster 1. Also, the beach ridges of cluster 2 have values of sorting and mean size intermediate to those of clusters 1 and 3 (Figure 4). The most likely source of coarse sand in these landforms is a deposit of sand and sandy gravel, proposed by Ludwick (1979) to exist at depths of 5.5 to 9.1 meters near the southern shore of the Chesapeake Bay. Ludwick argued that deep scouring of this deposit by the Lynnhaven Inlet and ebb flow currents in the Bay plus wave action produced the pebbly coarse sand found along shores west of the Cape Henry prominence.

The anomalous coarse sands are concentrated in the Cape's northwestern features but they do appear elsewhere. If cluster 3 samples represent most beach ridges, then cluster 6 data characterize the frontal dunes at Cape Henry's tip (Figure 5). Although the cluster 6 dune sands are finer grained than the beach ridge sediments, perhaps indicating reworking by wind, they are also more coarsely skewed. The dunes of group 1 to the west are much coarser grained than either the group 6 dunes or the group 3 beach ridges. Therefore the coarse tail in the group 6 dunes must come from the addition of small amounts of coarser sands transported from offshore or from the west.

Some distinctions in sediments from geographically close features probably arose from different processes of transport. Group 3 beach ridges are less often ornamented by small dunes than are the group 7 ridges. Therefore as might be expected, ridge crest samples from group 3 are much coarser than the 2.00-2.25 phi sand found on beach ridges with higher relief. Ongoing research is attempting to quantify the relationships between topographic irregularities and sediment characteristics on beach ridges. Also, note that the group 7 dunes found upon the beach ridges do not have the coarse tails found in the modern dunes of group 6. This observation further supports the interpretation that the coarse sand supply must be a relatively recent source.

Hypothetically the large back beach dunes of group 5 could have formed by landward migration induced by on-shore winds. The data indicate that the back dune sediments are more finely skewed than the group 6 frontal dunes, yet they are also more poorly sorted. Wind winnowing during dune migration would explain the skewness differences; a change in source or a combination of sources for the windblown sand could explain the poorer sorting found in the back dunes.

In summary we find that sediments from the crests of coastal dunes and low relief beach ridges can be distinguished in an area with a uniform sediment supply. Data also support the contention of earlier workers that beach ridges with low relief have much less eolian sediment than do ridges with tall and irregular crests. At Cape Henry the introduction of a second, coarser sediment source masks textural distinctions caused by different surficial processes. Any textural variations between beach ridge groups defined by soil-geomorphic studies are explained by this more recent supply of coarse sand. Absolute dating of the geomorphically-based beach ridge groups may indicate the beginning of scouring into that coarse sand deposit by the Lynnhaven Inlet and bay-bottom currents.

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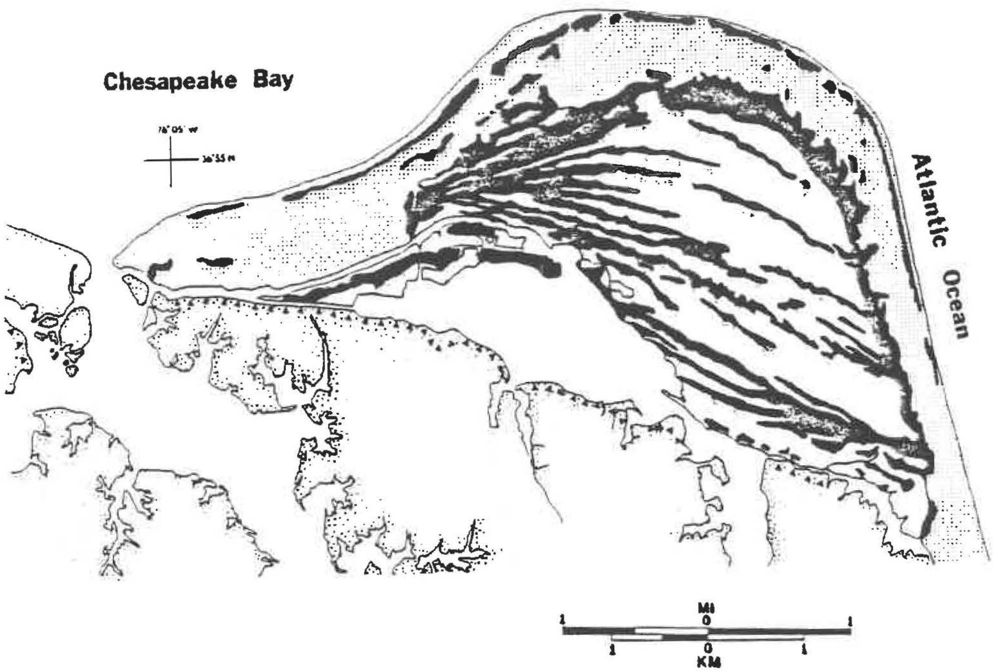
Figure 1. Map of Cape Henry showing outline of hills (black) within the zones of coastal dunes (regular stipple) and beach ridges (irregular stipple). Triangles mark the Diamond Springs scarp on the edge of a 30-foot high (9 meter) Pleistocene plain.

Figure 2. Dendrogram from cluster analysis showing strengths of association between groups of samples.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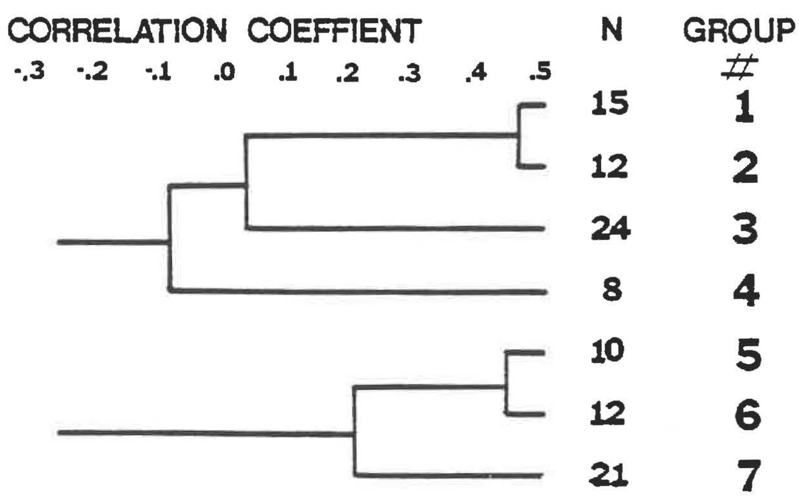
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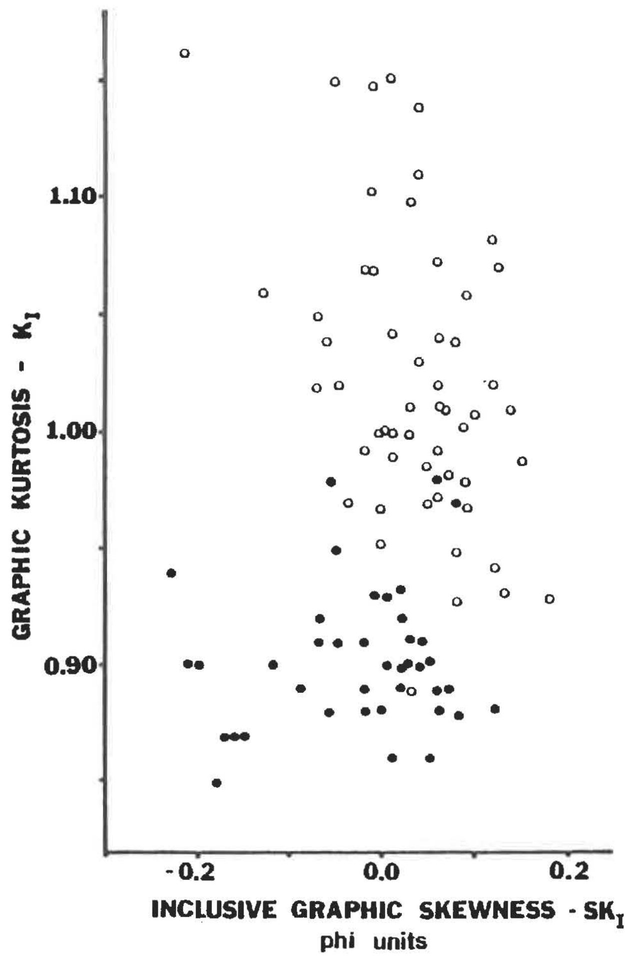
Figure 3. Textural characteristics and sample locations for groups 1,2,3, and 4 (circles) and groups 5,6, and 7 (dots).

a. Graph of skewness vs. kurtosis.

b. Sketch map of Cape Henry showing sample locations.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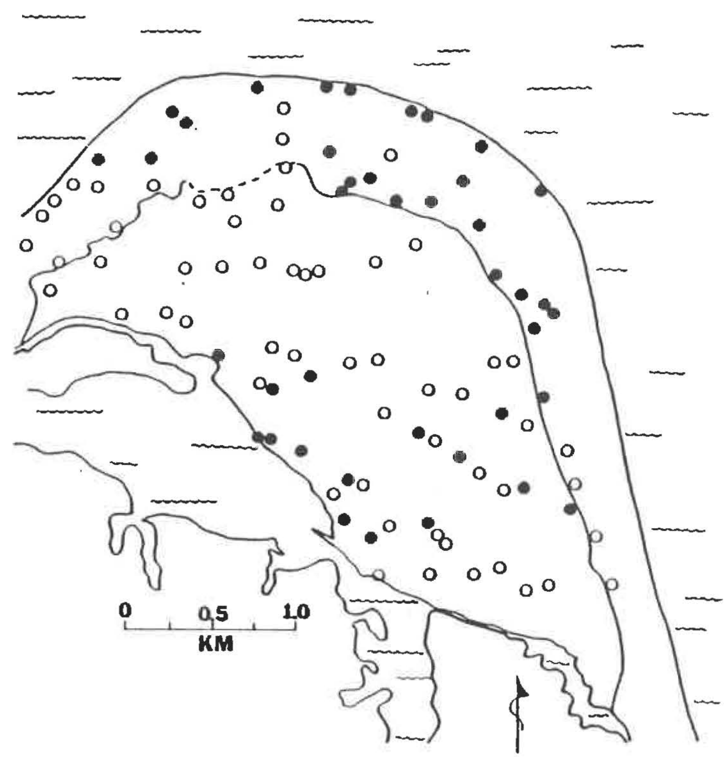
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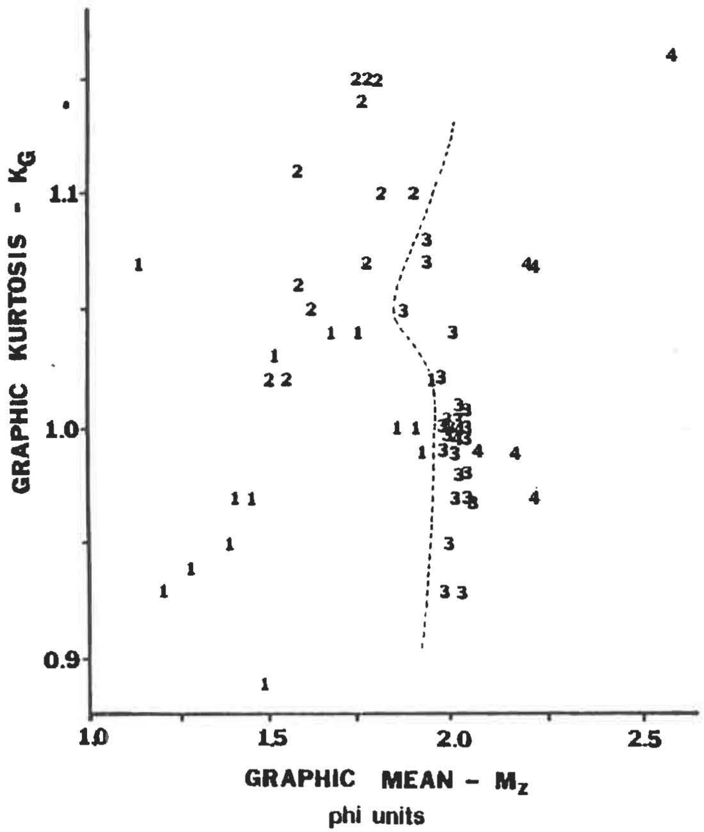
Figure 4. Textural characteristics and sample locations for groups 1,2,3, and 4.

a. Graph of mean vs. kurtosis.

b. Sketch map of Cape Henry showing sample locations.



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GRAPHIC MEAN - M_z
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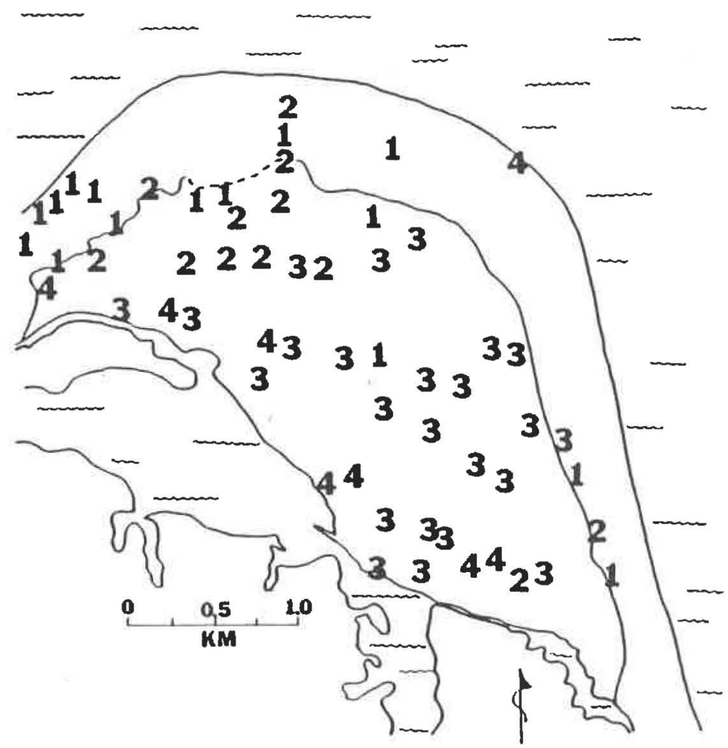

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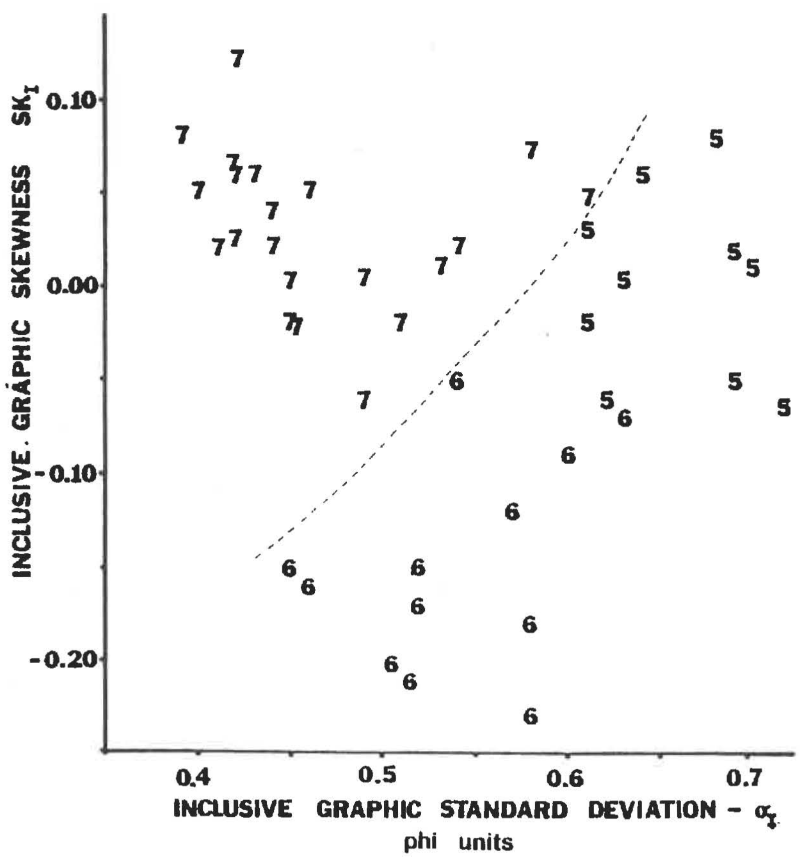
Figure 5. Textural characteristics and sample locations for groups 5,6, and 7.

a. Graph of sorting vs. skewness.

b. Sketch map of Cape Henry showing sample locations.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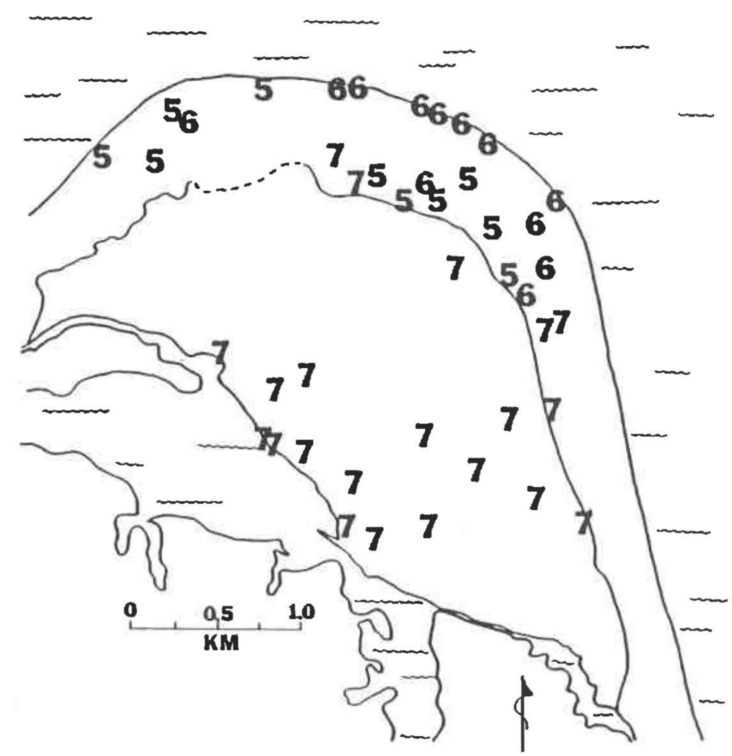
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