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SOUTHEASTERN GEOLOGY

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CLAY MINERAL ASSEMBLAGES IN A SOUTH CAROLINA

LAKE-RIVER-ESTUARY COMPLEX

by

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ABSTRACT

Fifty-three bottom, suspended, and bank samples were collected from the Congaree-Wateree-Santee-Cooper river-lake system and from tidal streams and estuaries from Georgetown to Beaufort, South Carolina.

The clay minerals grouped into a kaolinite-dioctahedral vermiculite assemblage characteristic of the Piedmont river-lake environment, a montmorillonite-kaolinite assemblage characteristic of a Coastal Plain river-estuarine-tidal stream environment, and a kaolinite-vermiculite-montmorillonite assemblage characteristic of an estuarine environment in which there is a mixing of through-flowing Piedmont river waters with tidal streams.

A conceptual process-response model is set up to explain the origin, transportation, and deposition of clay minerals in waters of the South Carolina Coastal Plain.

INTRODUCTION

In 1963 and 1964 a total of 53 clay samples were obtained from the Santee-Cooper river-lake system and from tidal streams and estuaries from Georgetown to Beaufort, South Carolina (Figure 1). Clay mineral analyses of the samples were made at Duke University; and the resulting data, presented herein, allow the definition of several clay mineral environments and the establishment of a model of clay mineral origin and movement in South Carolina Coastal Plain waters in the present erosion cycle.

The Coastal Plain of South Carolina is composed of nearly flat-lying unconsolidated sands, clays, and soft limestones ranging in age from Upper Cretaceous to Pleistocene. The surface waters of the Coastal Plain may in general be divided into (1) through-flowing streams, having their origin in the crystalline rock terrane of the Piedmont, further to the northwest; (2) lakes, for the most part man-made; (3) streams originating and flowing entirely within the Coastal Plain; (4) estuaries of Piedmont streams (hereinafter called Piedmont river estuaries); and (5) estuaries of Coastal Plain streams (hereinafter called Coastal Plain river estuaries). In one instance (i. e., Charleston Harbor) waters of a through-flowing stream have been diverted by man into a Coastal Plain stream estuary (Figure 1).

Acknowledgements

Special thanks are due William W. Humphreys, Charleston Development Board, and Ben Heyward, South Carolina Division of Commercial Fisheries, for assistance in collecting clay samples in Charleston Harbor and the tributary Ashley and Cooper Rivers.

Field and laboratory work were supported financially in part by the Division of Geology, South Carolina State Development Board, and by National Science Foundation Undergraduate Science Education Grant GE-100.

Duke University student Timothy Brown and University of North Carolina student William Crow assisted with laboratory procedures.

FIELD AND LABORATORY PROCEDURES

Sampling Techniques

Three types of samples were taken: (1) bottom samples obtained by means of a simple clam type grab, (2) suspended samples obtained by means of a Selas type vacuum filter, and (3) bank samples collected from flood plain deposits adjacent to the water's edge.

Bottom samples high in clay were collected in quiet waters free from strong current action, such as the inside of bends in rivers, in abandoned channels adjacent to the main stream or channel, and in grassy areas of tidal marshes.

Suspended samples were collected (1) from the Congaree River above Lake Marion during a period of high (and consequently muddy) water and (2) in the Santee Diversion Canal during a period of relatively clear water. The river sample was obtained quickly as the clay in the sediment laden water rapidly coated the filter candle. The Diversion Canal sample required several hours of filtering to obtain a small

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spot checks were made to see if the 7 Å peak disappeared at 500° C. But other 7 Å peaks, such as some chlorites and vermiculites, also disappear at relatively low temperatures.

Illite was identified where a 10 Å peak occurred. This peak was commonly broad and poorly defined. Potassium saturation tends to sharpen it.

Dioctahedral vermiculite was identified where a 14 Å peak did not shift with ethylene glycol treatment or where a 14 Å peak appeared when the montmorillonite peak was moved out of the way with ethylene glycol. Many of the vermiculite-bearing samples were checked by a process of heating at 400° C for 12 hours and noting the collapse of the 14 Å peak to 11-12 Å (Warshaw and Roy, 1961, p. 1432).

Several samples showed a broad, weak peak in the 11-12 Å region. This was attributed to mixed layer clay. Since this material was not abundant no attempt was made to study its characteristics. Gibbsite was tentatively identified in a few samples, but no attempt was made to confirm this identification by differential thermal analysis.

The authors did not study the mineralogy of the clays in detail. The groups identified may be summarized as (1) 7 Å minerals (mainly kaolinite but possibly including some 2nd order reflections or possibly some halloysite), (2) 10 Å minerals (mainly illite but possibly including degraded illite, some hydrobiotite, or even glauconite), (3) 14 Å minerals that do not expand (mainly dioctahedral vermiculite but possibly including some chlorite), and (4) 14 Å minerals that expand (mainly montmorillonite).

Quantitative Studies

Samples that contain only well crystallized kaolinite, montmorillonite, and illite were studied quantitatively by a method modified after Freas (1962). The results are expressed in percent of the three clay minerals in terms of kaolinite. Error is believed to be generally less than 5%.

In some samples dioctahedral vermiculite interfered with the montmorillonite peak (even after ethylene glycol solvation), and quantitative studies could not be made.

No attempt was made to determine the percentage of dioctahedral vermiculite present because of (1) the difficulty of obtaining pure standard samples of the mineral and (2) the unclear nature of its chemistry and X-ray reflecting power.

CLAY MINERAL DATA

Data from the clay mineral analyses are summarized semiquantitatively in Table 1. A clear-cut grouping of the samples into kaolinite-vermiculite, montmorillonite-kaolinite, and kaolinite-vermiculite-montmorillonite assemblages was noted; and the samples are

Table 1
Semiquantitative Clay Mineral Analyses of 53 Samples

Group	Sample No.	Clay Minerals*	Sample Position	Sample Location
Kaolinite-Vermiculite Group	SR-1	K, v, i	Bottom	Santee River
	UC-1b	K, V	Bottom	Congaree River
	UC-1s	K, V, i	Suspended	Congaree River
	UC-2.1b	K, V, i, m(?)	Bottom	Bates Old River
	UC-2.2	K, V, i	Bank	Bates Old River
	UC-3	K, V, i, m(?)	Suspended	Congaree River
	UC-4b	K, V, i, m(?)	Bottom	Wateree River
	UC-5	K, V, i	Bottom	Wateree River
	UC-5.2	K, V, i	Bank	Wateree River
	UC-6	K, V, i	Bottom	Lake Marion
	UC-7	K, V, i(?)	Bottom	Lake Marion
	UC-8	K, V, i, ml	Bottom	Lake Marion
	UC-9	K, V, m, i(?)	Bottom	Lake Moultrie
	UC-10	K, V, i	Bottom	Lake Moultrie
	UC-11	K, V	Bottom	Lake Moultrie
	UC-12	K, V, i	Bottom	Lake Marion
	UC-13	K, V, i(?)	Bottom	Lake Marion
	UC-14	K, V, i(?)	Bottom	Lake Moultrie
	UC-15	K, V	Bottom	Lake Moultrie
	UC-16	K, V	Bottom	Lake Moultrie
	UC-17	K, V, m(?)	Suspended	Diversion Canal
Montmorillonite-Kaolinite Group	UC-18	M, K, i	Bottom	Cooper River
	UC-19	M, K, i	Bottom	Cooper River
	UC-20	M, K, i	Bottom	Cooper River
	CHS-1	M47, K42, I11	Bottom	Cooper River
	CHS-2	M46, K43, I11	Bottom	Cooper River
	CHS-3	K54, M39, i7	Bottom	Cooper River
	CHS-4	K51, M39, I10	Bottom	Cooper River
	CHS-5	M47, K42, I11	Bottom	Cooper River
	CHS-6	K, M, V, i	Bottom	Wando River
	CHS-7	K, M, V, i	Bottom	Charleston Harbor
	CHS-8	K57, M39, i4, v(?)	Bottom	Charleston Harbor
	CHS-9	K55, M35, I10	Bottom	Ashley River
	CHS-10	K, M, i, v	Bottom	Ashley River
	ED-1	M46, K46, i8, v	Bottom	Adams Creek
	ED-3	M62, K30, i8	Bottom	Stono River
	ED-4	M52, K40, i7	Bottom	Dawho River
	ED-5	M67, K30, i3	Bottom	Combahee River
	ED-6	M58, K30, I12	Bottom	Whale Branch
	ED-7	M57, K35, i8	Bottom	Broad River
Kaolinite-Vermiculite-Montmorillonite Group	WB-1	K, V, m, ml, i	Bottom	Winyah Bay
	WB-2	K, V, m, i	Bottom	Black River
	WB-3	K, V, i, m	Bottom	Peedee River
	WB-4	K, V, i, m(?)	Bottom	Black River
	WB-5	K, V, M, I	Bottom	Waccamaw River
	WB-6	K, V, i, m(?)	Bottom	Waccamaw River
	WB-7	K, V, m, i	Bottom	Winyah Bay
	WB-9	K, V, m, i	Bottom	Mud Bay
	WB-10	K, V, m, i	Bottom	Winyah Bay
	SD-1	K, M, V, i	Bottom	North Santee Bay
	SD-2	K, V, m, i	Bottom	North Santee Bay
	SD-3	K, V, M, i	Bottom	South Santee Bay
	SD-4	K, M, V, i	Bottom	South Santee Bay

*Minerals listed in approximate order of abundance. Where one mineral is very dominant, the letter symbol is underlined. Where a mineral occurs in quantities judged to be less than 10% the letter symbol is in small type. Where a mineral identification is questionable owing to very small quantities the letter symbol is queried. Where quantitative results were possible percentages are listed beside the letter symbol. M = montmorillonite, K = kaolinite, V = dioctahedral vermiculite, I = illite, and ML = mixed layer.

listed accordingly in the table. In the kaolinite-vermiculite assemblage kaolinite is strongly dominant. In the montmorillonite-kaolinite assemblage the two are present in roughly equal amounts, either being dominant. In the kaolinite-vermiculite-montmorillonite group kaolinite is strongly dominant but appreciate montmorillonite is also present.

CLAY MINERAL DISTRIBUTION

Comparison of the clay mineral assemblages defined in Table 1 with the geographic distribution of the samples shows a good relationship between the three assemblages and three different provinces or environments.

The kaolinite-vermiculite mineral assemblage is clearly related to a Piedmont river-lake province.

The montmorillonite-kaolinite assemblage is clearly related to a Coastal Plain estuarine-tidal stream province. Vermiculite is usually absent or present in only minor amounts.

The kaolinite-vermiculite-montmorillonite assemblage is apparently related to an estuarine province in which there is a mixing of through-flowing Piedmont river waters with tidal streams (i.e., a Piedmont river estuary). In the samples obtained from this environment in Winyah Bay and the Santee River delta, kaolinite is dominant, vermiculite is present in significant amounts, and a strong affinity to the kaolinite-vermiculite assemblage of the river-lake province is evident.

It is interesting to note that the clay mineral assemblage of samples from the Charleston Harbor area shows no similar mixing effect in spite of the influx of diverted Piedmont river water through the Santee-Cooper River system.

While collecting the clay samples it was noted that through-flowing Piedmont rivers carry far more suspended clay material during times of freshet than at normal water stages. In the Santee River system much of the suspended load settles out in the waters of Lake Marion and Lake Moultrie, and the lake waters are noticeably clearer than the river at its point of entrance. During spring flood periods, however, the muddy Santee waters pass entirely through both lakes with a proportion of the clay load still in suspension.

In contrast to the through-flowing Piedmont streams those that rise and flow entirely within the Coastal Plain carry no noticeable clay in suspension, even during periods of high water. The bottoms and banks of these streams are characterized by clean white sand until they reach the tidal environment along the coast, where clays of the montmorillonite-kaolinite assemblage suddenly become abundant.

CLAY PROCESS-RESPONSE MODEL

From the fore-going it is possible to set up a conceptual <u>process-response model</u> (Whitten, 1964, p. 455) explaining the origin, transportation, and deposition of clay minerals in waters of the South Carolina Coastal Plain in the present erosional cycle. Such a model may be expected to evolve into a statistical model and perhaps eventually into a deterministic model as additional quantitative field and laboratory data become available.

Kaolinite and dioctahedral vermiculite are the dominant clay minerals in the soils of the mountain region, Piedmont, and Coastal Plain of the Southeast (Hathaway, 1955; Rich and Osenshain, 1955; Weed and Nelson, 1962). Erosion of these soils provides the kaolinite-vermiculite clay mineral assemblage of the through-flowing Piedmont rivers. Erosion is relatively insignificant in the low-lying, heavily vegetated Coastal Plain; and rivers that rise and flow entirely within it are supplied only minor amounts of clay and apparently transport only insignificant quantities to the lower coastal area.

The bulk of the clays transported from the Piedmont to the Coastal Plain by through-flowing rivers is carried principally in times of freshet. In the case of the Congaree-Santee-Cooper system, part of the clay brought into the Coastal Plain by the rivers settles out in the quiet waters of Lake Marion and Lake Moultrie and part is carried on to the ocean via the Santee and Cooper Rivers. No data are available on the percentage of total clay left in the lakes, but they appear to trap a considerable portion of the bottom and suspended sediments brought in by the Congaree and Wateree Rivers.

Upon mixing with the saline waters of the Piedmont river estuaries, a portion of the river assemblage clays are flocculated because of the electrolitic action of the sea water. Some grains escape flocculation and are carried seaward by currents. Some of the flocculated clay lumps are also carried seaward by strong tidal currents. In some instances clay may be rafted into the estuary environment from the sea. The net result is a suite of clay minerals typified by the kaolinite-vermiculite-montmorillonite assemblage of the Winyah Bay and Santee Delta areas. The kaolinite and vermiculite are clearly of Piedmont river origin (i.e., brought in by the Pee Dee and Santee Rivers). The montmorillonite has another source, which is discussed below.

Estuary and tidal areas not influenced by through-flowing Piedmont streams (e.g., Edisto River, Broad River, and Port Royal Sound), and the Charleston Harbor area, only recently influenced by diverted Piedmont river waters, have a clay mineral assemblage entirely different from that of the Piedmont river estuaries. The abundance of montmorillonite and the essential absence of vermiculite in the Coastal Plain river estuaries and tidal streams (as opposed to Piedmont river estuaries) indicates that this environment does not receive clays in significant amounts from Piedmont or Coastal Plain rivers.

The source of the montmorillonite in the Coastal Plain estuarine-tidal stream province is not clear. There appear to be four possibilities:

(1) Some of the montmorillonite comes from local wave and current erosion of Pleistocene marine sediments in the immediate area of the Coastal Plain river estuarine-tidal stream province. These Pleistocene marine sediments are known to be high in montmorillonite (Heron, Robinson, and Johnson, 1964).

(2) Possibly some of the montmorillonite comes from erosion of older Cenozoic marine sediments of the Coastal Plain. These sediments are also high in montmorillonite (Heron, Robinson, and Johnson, 1964). Quantitatively this source should not be significant because of the general low erosion rate in intra-Coastal Plain streams, as indicated by the lack of muddy river waters and the difficulty of obtaining clayey bottom samples from these streams above the tidal regions. However, Nelson (1960, p. 142) attributed the occurrence of montmorillonite in the Rappahannock Estuary (Piedmont river estuary) to erosion of montmorillonite-bearing Coastal Plain sedimentary rocks bordering the estuary.

(3) Some of the montmorillonite may be derived from diagenesis of dioctahedral vermiculite. This vermiculite has a three layer lattice and is thought to have a mica precursor (Weed and Nelson, 1962). It is one of the common present day soil clay minerals and is important in suspended sediments of modern Piedmont rivers; but it is unknown in unweathered Cenozoic and Cretaceous sediments, at least in the Atlantic Coastal Plain (Heron, 1961; Heron and Wheeler, 1964; Heron, Robinson, and Johnson, 1964). This clearly suggests that it is unstable and slowly changes to a similar three layer mineral (i. e., montmorillonite) by loss of interlayer aluminum and iron.

(4) Some of the montmorillonite may be swept into the estuarine-tidal province by tidal currents from the sea. Such a process is known to be in effect in the Gulf Coastal Plain area (Griffin, 1960, p. 82-83).

Kaolinite is common to all three environments. Its presence in the Coastal Plain river estuary environment is probably due to one or more of the processes outlined in numbered paragraphs (1), (2), and (4) above.

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BEACH PROFILES OF A GEORGIA BARRIER ISLAND*

by

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ABSTRACT

Seasonal beach profiles were obtained from seven stations at the south end of Sapelo Island, Georgia, during 1963. Except for accreation at the extreme south tip of the island, most of the study area is being eroded. Unlike other beaches reported in the literature, the seasonal and observed storm changes of the Sapelo Island beach are slight.

INTRODUCTION

From October, 1962, to January, 1964, a series of beach profiles were taken at the south end of Sapelo Island, Georgia. The purpose of the investigation was to ascertain the nature and extent of barrier island beach changes.

Sapelo Island is a barrier island on the central coast of Georgia (Figure 1). It is approximately 6 km by 15 km in areal extent and lies between St. Simons Island to the south and St. Catherines Island to the north. Because of the moderate wave energies of the central Georgia coast and extensive protective nearshore shoals, the low angle beaches of Sapelo Island are subjected to generally low wave energies. The largest waves observed during the period of study occurred at the height of storms and were between 120 and 150 cm in height. Typically, waves are between 30 and 60 cm in height and become relatively smaller at low tide. Tidal amplitude throughout the study area averages approximately 2 meters.

Beach profiles and related studies have been carried out by a number of workers including Shepard and LaFond (1940), Shepard and Inman (1951), Inman (1953), Weigel et al (1954), Johnson (1956), Zeigler et al (1959), and Emery (1960). These studies have dealt with seasonal and storm changes on beaches and have related such changes to various wave characteristics. In particular, the seasonal beach changes of Southern California are sometimes large; extensive erosion

* Contribution No. 71 of the University of Georgia Marine Institute, Sapelo Island, Georgia.

occurring during the winter and deposition during the summer. Along the west coast of Florida seasonal beach changes are slight (Donn S. Gorsline, personal communication).

The Sapelo Island study area differs from other previously studied beaches in that wave energy in the area is lower and seasonal changes in wave energy are relatively slight.

Acknowledgements

The writers wish to acknowledge the aid of Robert Giles, Bruce Hanson, Jerry Kier, and Steve Winzer in measuring beach profiles; sometimes under adverse conditions. Donn S. Gorsline critically read the manuscript and offered many helpful suggestions.

METHODS

Eight beach stations were set up on Sapelo Island between Big Hole Creek and the south tip (Figure 1). Each station was marked by a 10-ft. long section of one-inch diameter pipe driven into the upper beach. During the course of the study, one station (Station 7) was lost by erosion, but all others survived.

Beach profiles were measured by a modification of the technique described by Emery (1961). The original technique involved a simple leveling procedure in which the horizon and the top of one of two 5-foot long vertically held rods spaced 5 feet apart are aligned by eye and the elevation or depression of the other rod noted with respect to this reference. The modification was developed by Vernon J. Henry and John Hoyt of the University of Georgia Marine Institute, and consists of connecting the two 5-ft. "Emery rods" with two 5-ft. long, permanently attached spacers. This allows beach profiles to be taken (in good weather) by a single person but introduces a small error in horizontal distance measurement. However, on very low angle beaches, such as those under consideration here, this horizontal error is not of relative importance and can be ignored.

ANNUAL CHANGES

Figures 2 and 3 are a plot of the one year changes at all seven stations. It is important to note that the vertical exaggeration in this and all other similar figures is 50X the horizontal scale, which greatly over-emphasizes the extent of erosion and deposition. Approximate mean high tide elevation on each profile is marked by a horizontal line labeled MHT.

It is apparent from Figures 2 and 3 that the net result of 1963 natural beach activities has been deposition at the extreme south end, at Stations 1 and 2, and erosion at all other stations. In general, the

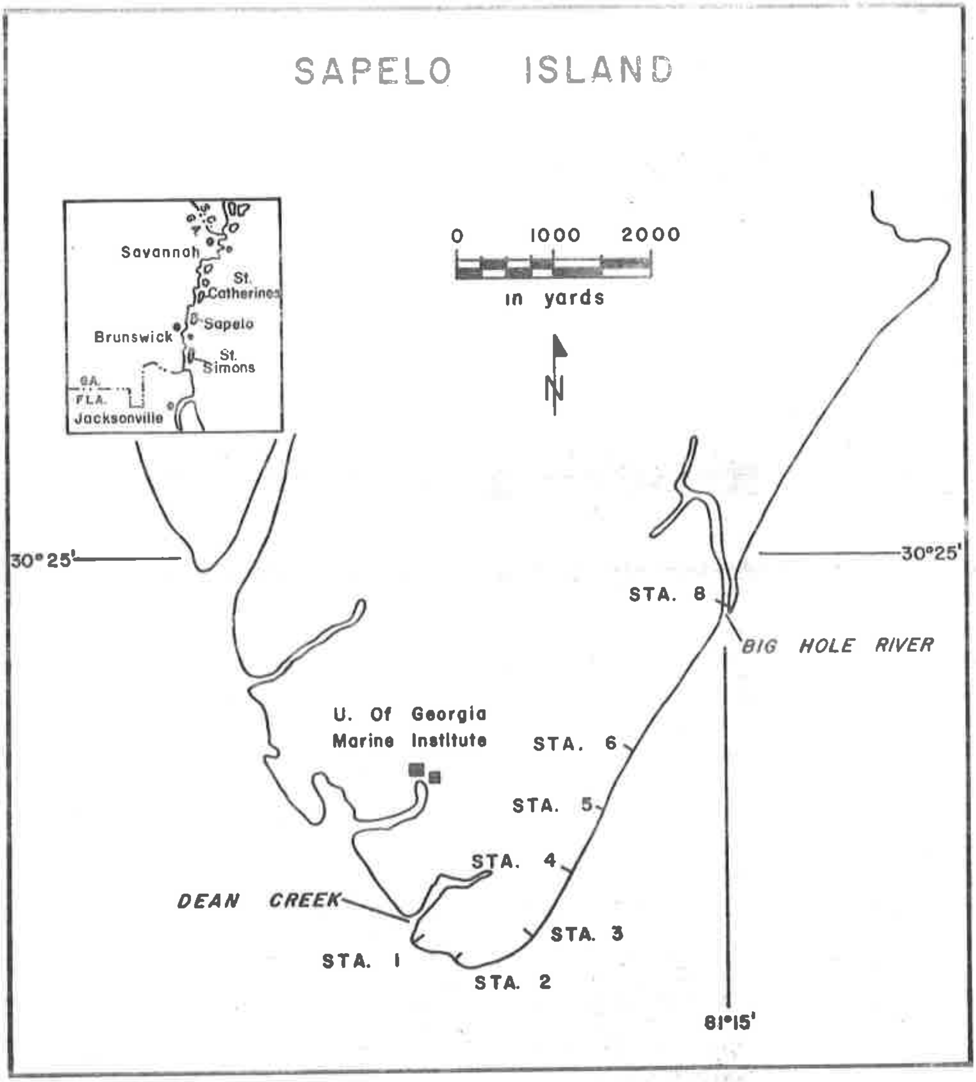

Figure 1. Map showing location of Sapelo Island and the south end of the island.

amount of erosion increases northward and probably reaches a maximum between Stations 6 and 8 where recent marsh deposits have been exposed (and Station 7 marker lost) by erosion. The erosion of Station 8 is not entirely a reflection of wave and longshore current energy but rather is due to the landward migration of the cross-beach channel of a tidal river (Big Hole Creek).

At Station 1 the beach was extended southward a distance of well

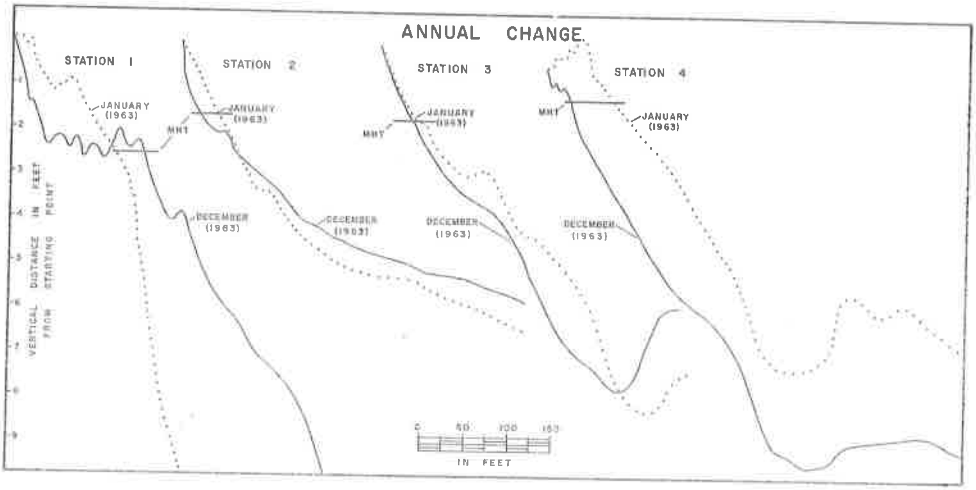

Figure 2. The one year beach change at Stations 1 through 4.

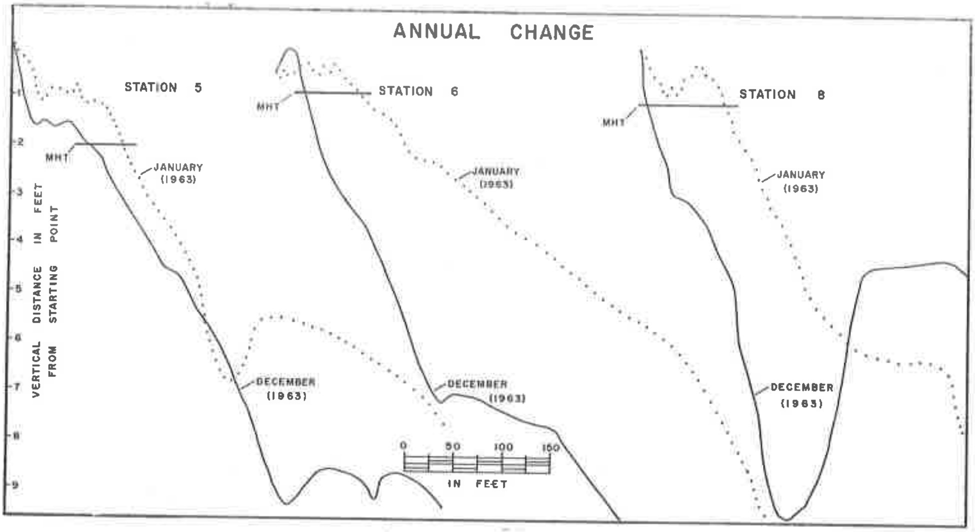

Figure 3. The one year beach change at Stations 5, 6, and 8.

over 100 feet. Simultaneously, the beach slope decreased slightly. At Station 2 the amount of deposition was considerably less. Considering the exact location of the various stations (Figure 1), it is apparent that the areal extent of the depositional regime is much less than that of the erosional regime.

The greatest amount of erosion was recorded at Station 6. Here, more of the erosion occurred on the lower foreshore than on the upper foreshore with the net result that the beach slope increased. None of the remaining four stations at which erosion occurred exhibited a significant beach slope change.

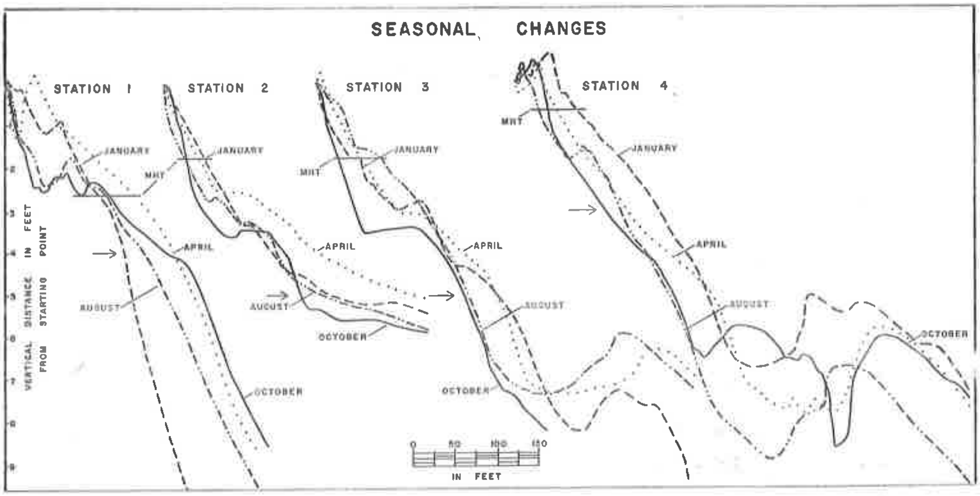

Figure 4. Seasonal beach changes at Stations 1 through 4.

SEASONAL CHANGES

Seasonal changes are shown in Figures 4 and 5. Beach profiles taken in January, April, October, and August of 1963 are plotted. No consistent seasonal effect is present at all seven stations. For example, there is no consistent difference in slope between winter and summer beaches, and the relative position of beach troughs also appears to be unrelated to season. In general, the seasonal changes are almost negligible when compared with areas such as Cape Cod (Ziegler et al, 1959) and Southern California (Shepard and Inman, 1951).

In order to aid in illustrating seasonal changes an arbitrary elevation on the upper foreshore of each profile was chosen and the distance from the station marker to this elevation was plotted for the various months of observation (Figure 6). The elevations chosen are shown by arrows in Figures 4 and 5. In the plotting of these lines data from a number of profiles now shown in any of the other figures were used. It is apparent from both Figure 6 and Figures 4 and 5 that deposition and erosion alternate at virtually every station. The particular elevation shown for Station 2 shows at least 5 alternations between erosion and deposition, whereas the elevations of Station 3 shows only 2 changes during the year. One strong time-correlation of erosional and depositional events is in evidence. During the month of

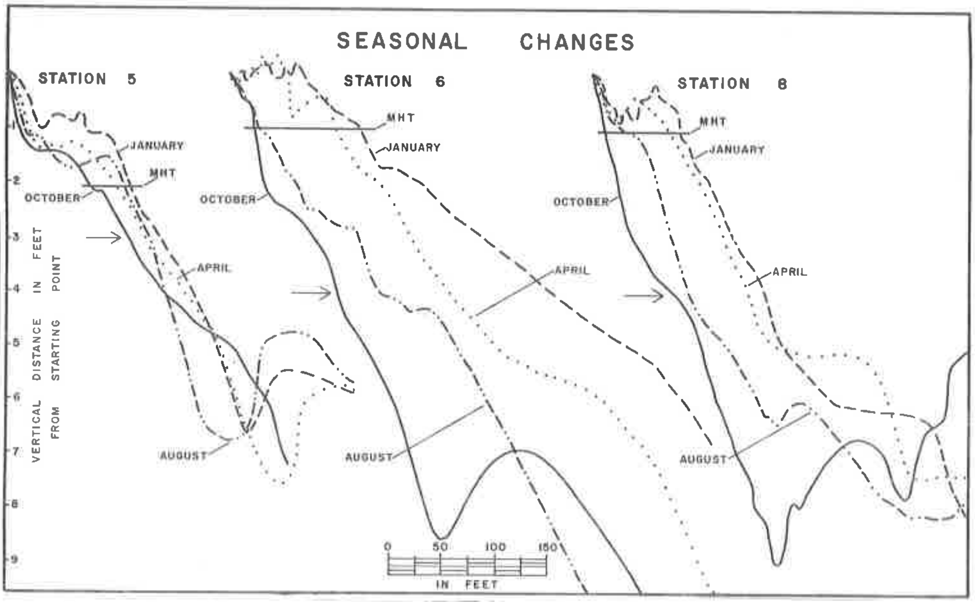

Figure 5. Seasonal beach changes at Stations 5, 6, and 8.

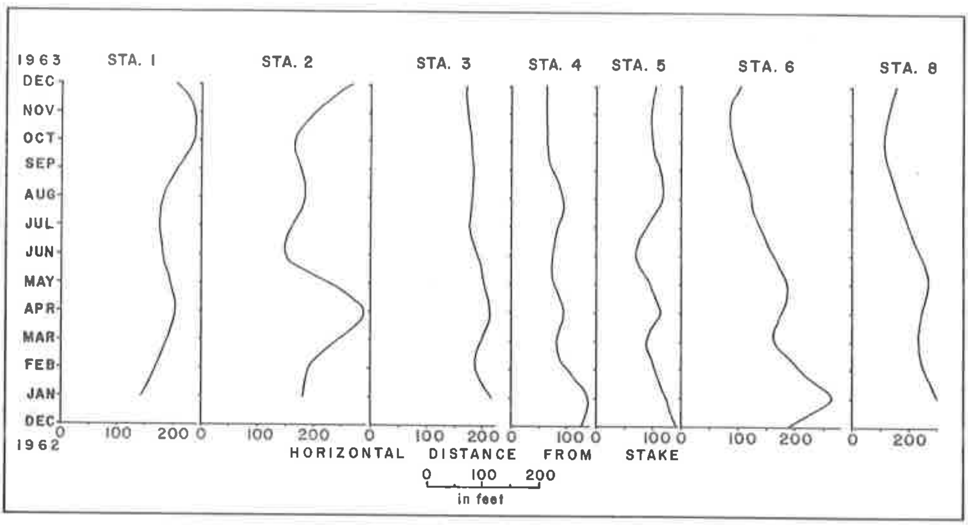

Figure 6. Plot of the horizontal distance of an arbitrarily chosen elevation on the upper foreshore at each station from the point of origin. Arrows shown on Figures 4 and 5 show the elevations chosen at each of the seven stations.

April the upper foreshores of Stations 1 through 5 were subjected to a depositional phase. Much more detailed plotting of different elevations at each station would be necessary to establish such time relationships accurately.

STORM CHANGES

No unusually severe storms occurred during the time period of this study. Two storms were, more or less, "bracketed" by before and after beach profiles and are shown in Figure 7. In both cases, Stations 1 and 4 were surveyed.

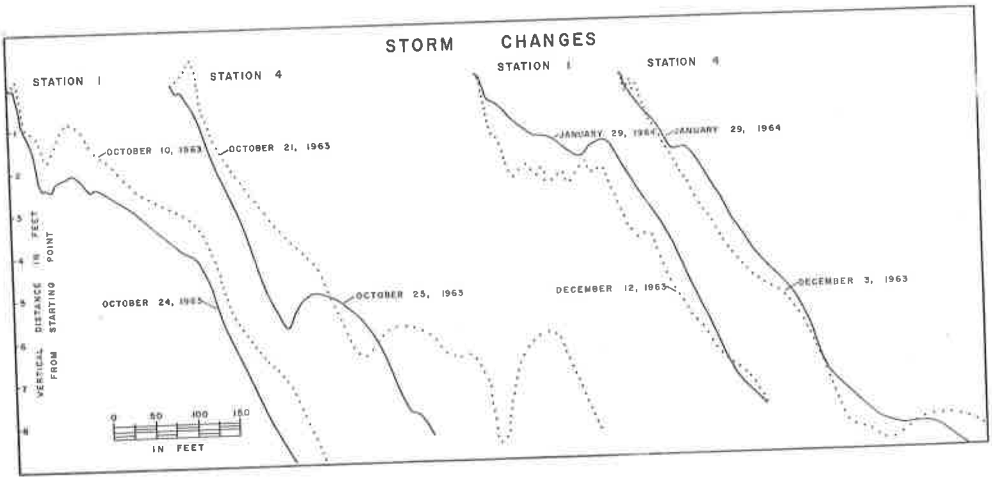

Figure 7. Changes observed at Stations 1 and 4 as a result of the two storms.

It is apparent from Figure 7 that only relatively small changes in beach profiles occurred during the storms. During the October, 1963, storm both profiles indicate a small amount of erosion occurred. Winds during the height of the storm were from the east.

The second storm which occurred in the second week of January, 1964, produced winds from the northeast and resulted in a small amount of deposition at the same stations that were eroded earlier.

DISCUSSION

It is apparent from the foregoing figures and discussions that erosion has been the dominant process on the beaches of the Sapelo

Island study area during the year 1963. In fact, considering probable volumes lost at Stations 3 through 8 and the volumes added at Stations 1 and 2, it is obvious that a considerable net loss of beach sand has occurred. Since the entire Sapelo Island complex was not studied and since the investigation only covers a period of one year, it is difficult to speculate on the cause of the erosion. At the north end of the study area, at the mouth of Big Hole Creek (seaward of Station 8), the spit-like bar shown in Figure 1 appeared to have grown significantly during the course of the study. Since the dominant direction of longshore current in this area is south it may be that the building of this bar starved the downdrift areas to the south, causing erosion. On the other hand, there is some evidence, based on the examination of U. S. Coast and Geodetic Survey charts and smooth sheets as well as aerial photos, that erosion has been a fairly important process for a long time in the study area (Vernon J. Henry, personal communication); hence the observed changes may not be simply related to local and temporary bar-building.

The median grain size of the acid insoluble fraction of beach and dune sands of Sapelo Island tends to fall entirely within the fine-grained sand size range. Lower foreshore samples exhibit the most variation in grain size and sorting. A limited amount of seasonal sampling indicated no large seasonal variation in grain sizes, although this must be verified by further sampling.

The most interesting aspect of this study is the relative unimportance of seasonal changes in Sapelo Island beach profiles, particularly when compared with other open ocean beach studies. This is related to the aforementioned lack of significant seasonal wave energy differences.[1]

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[1]During the summer of 1964, Miss Joan Greaves studied in more detail the beach profiles of Sapelo Island. Preliminary analysis of her results indicates that daily changes occur in the beach profiles, some of which are of the same order of magnitude as the so-called seasonal changes observed in this study. The beach changes apparently are cyclic; corresponding mainly to changes in tidal amplitude with secondary effects due to changes in wind magnitude and direction.

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GEOLOGIC SECTION ALONG A CAROLINA BAY

SUMTER COUNTY, S. C.

by

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and

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ABSTRACT

Samples were collected at 5 foot intervals in power auger drill holes to characterize the mechanical and mineralogical properties of the underlying sediments of a Carolina Bay.

Three sand facies are recognized which are characteristically bimodal. All three beds show a full suite of heavy minerals as characterized by Groot and Glass (1960).

The lower contact of the upper bed is a regularly sloping surface which is in no way dependent on or related to the "bay", showing that whatever mechanism is postulated to develop a bay must form it without deforming the underlying strata even along the long axis of the bay.

INTRODUCTION

The Carolina Bays, which are elliptically shaped, sand rimmed, shallow depressions, having strongly southeast-trending oriented long axes and known only to the Atlantic Coastal Plain, are well developed in Sumter County, South Carolina. These features have been intermittently studied over the past 50 years by different persons. A comprehensive summary of the various hypotheses regarding the origin of these bays is given by Prouty (1952). Murray (1961) presents the basic descriptive facts as outlined by Prouty. As pointed out by Murray, various writers have suggested that the bays result from meteorites, solution, submarine scour and later wind action, artesian springs and ground water action, action of wind and current, earth rotation aided by currents and wind, multiple causes, and activity of schools of fish.

No deep sections across the bays have been previously reported.

Acknowledgments

This study was undertaken at Clemson University as a Senior thesis by C. D. Preston and made possible by the Division of Geology, S. C. State Development Board, and a grant from the Clemson University Faculty Basic Research Committee to C. Q. Brown. Our appreciation is expressed to C. J. Cazeau for his helpful advice and counsel on the heavy mineral analyses.

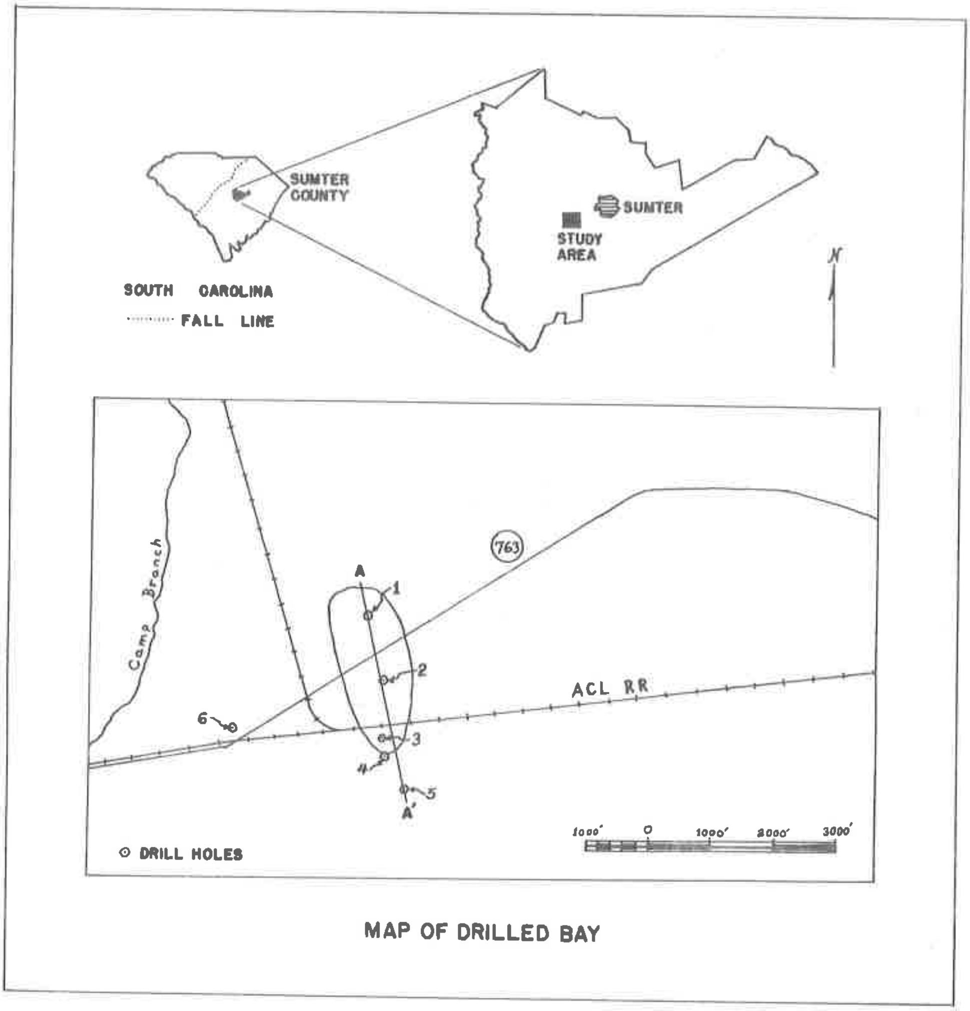

Figure 1. Index map showing location of area and drill hole sites.

AREA OF STUDY

The Carolina Bay studied is within the Sumter West quadrangle, Sumter County, South Carolina (Figure 1).

SCOPE

An analysis of the size parameters of the sediments underlying this bay and analysis of the mineralogy, including heavy minerals, is included in this study. In the absence of deep sections this approach was undertaken to characterize the mechanical and mineralogical properties of the underlying sediments.

PROCEDURES

Field work was done in the summer of 1962 in connection with geologic mapping of the Sumter West quadrangle, supported by the Division of Geology, S. C. State Development Board. Samples were collected at 5 foot intervals in power auger drill holes in the manner described by Smith (1961). Drill logs prepared in the field included megascopic descriptions of the sediments, possible formational contacts, and position of the water table.

Drill holes were located along the long axis of the bay. Holes 1, 2, and 3 were within the bay. Hole 4 was on the southeast rim of the bay. Hole 5 was southeast of the bay rim but in line with the bay axis.

Each sample was oven-dried at 40-50°C. The 0.063 mm fraction was sieved for 10 minutes on a Tyler Portable Sieve Shaker. A sieve nest was used consisting of screens with mm openings of 4.00, 2.830, 2.000, 1.410, 1.000, 0.710, 0.500, 0.350, 0.250, 0.177, 0.105, 0.088, and 0.063.

From these results cumulative and frequency curves were established. Quartile parameters were calculated according to Krumbein and Pettijohn (1938).

The sands are characteristically bimodal. For heavy mineral analyses only the modal grades were studied, and for all samples the 1.00 - 0.350 mm and the 0.177 - 0.063 mm fractions were used. Heavy minerals were separated from each of these recombined groups with bromoform as described by Krumbein and Pettijohn (1938).

RESULTS

Figure 2 shows a geological cross-section of the bay along the major axis (A-A' of Figure 1). Drill logs indicate three sand facies. Bed A is an argillaceous fine to medium sand. Bed B is a slightly argillaceous coarse to very coarse granular sand. Bed C is an argillaceous fine to medium sand which is commonly micaceous. The contact between beds B and C is not as well defined as that between A and B because of the shallow depths of holes 1 and 3 and, therefore, may be much more regular than indicated. However, it is worthy of note

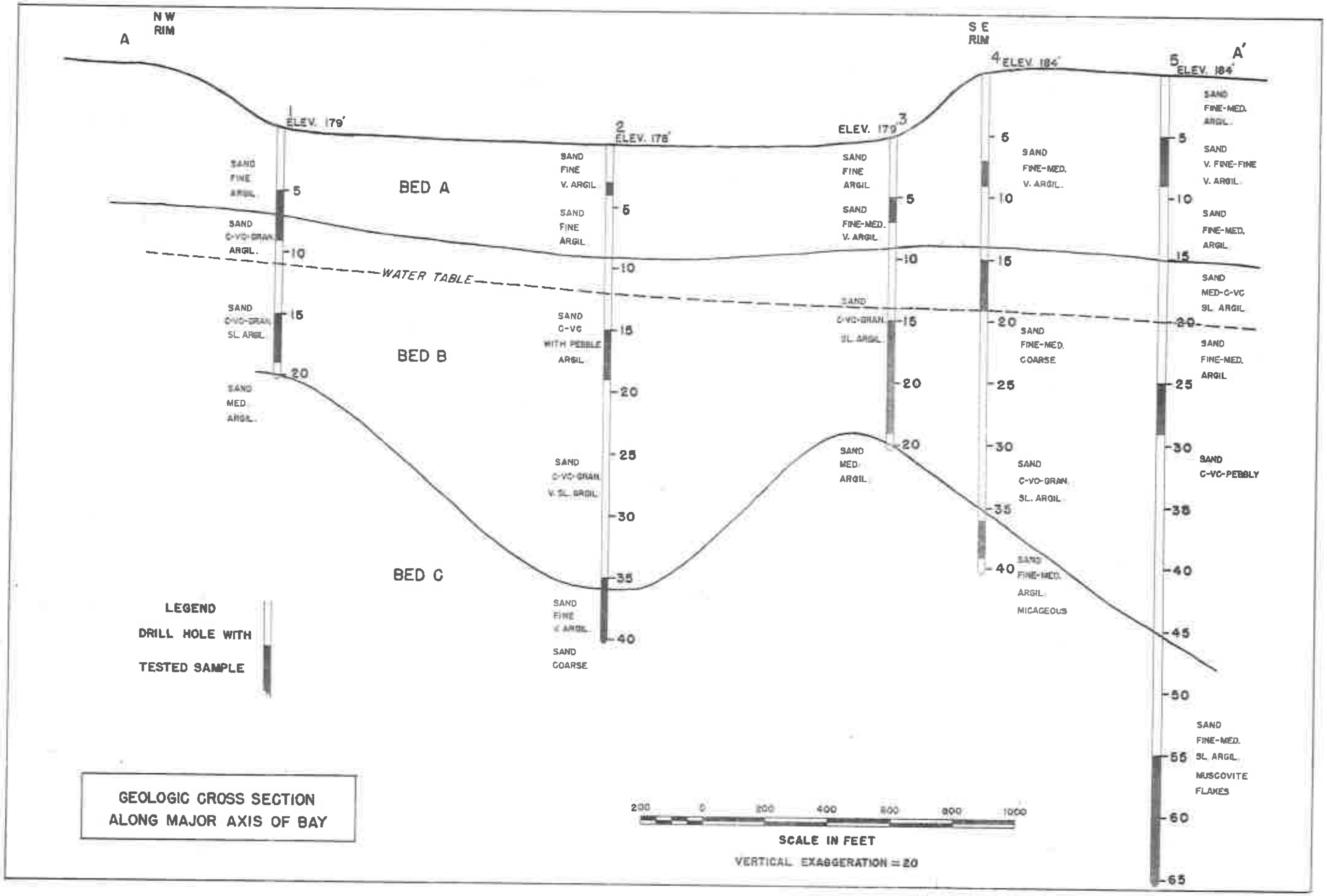

Figure 2. Section along the major axis of the Carolina Bay.

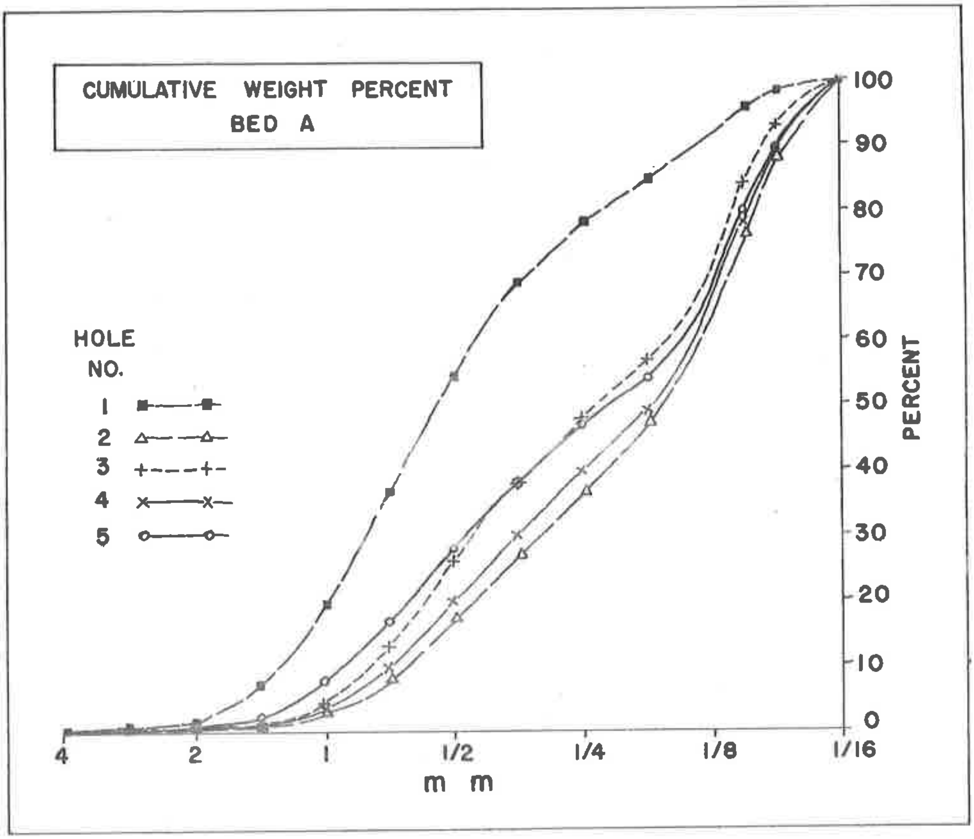

Figure 3. Cumulative curves for the sand fraction of sediments from Bed A.

that in holes 1 and 3 at the B-C contact the sands were rusty brown and in hole 4 a golden yellow. Figures 3, 4, and 5 show cumulative curves for samples from beds A, B, and C respectively. Figure 6 shows characteristic cumulative curves for sands from the three beds.

Drill hole 6 (Figure 1) is located west of the bay, and the contact of Bed A and B is at about the same elevation as along the axis of the bay. This is then a general and moderately regular surface which is not related to or affected by the bay itself.

Bed B has a variable mechanical composition and its lower contact is possibly irregular. These features seem consistent with the view that fluvial erosion and deposition are the primary agents responsible.

Hole 2 encountered Bed C in the shallow recess indicated in Figure 2. Sediments occurring here are somewhat anomalous in that they contain more coarse heavy minerals which is due in part to the presence of marcasite-pyrite. In addition, garnet is significantly more abundant than in other coarse heavy mineral fractions. Also a reduction in the percentage of fine sand and an increase in the proportion of clay is noted, all of which suggest a local control or sediment trap.

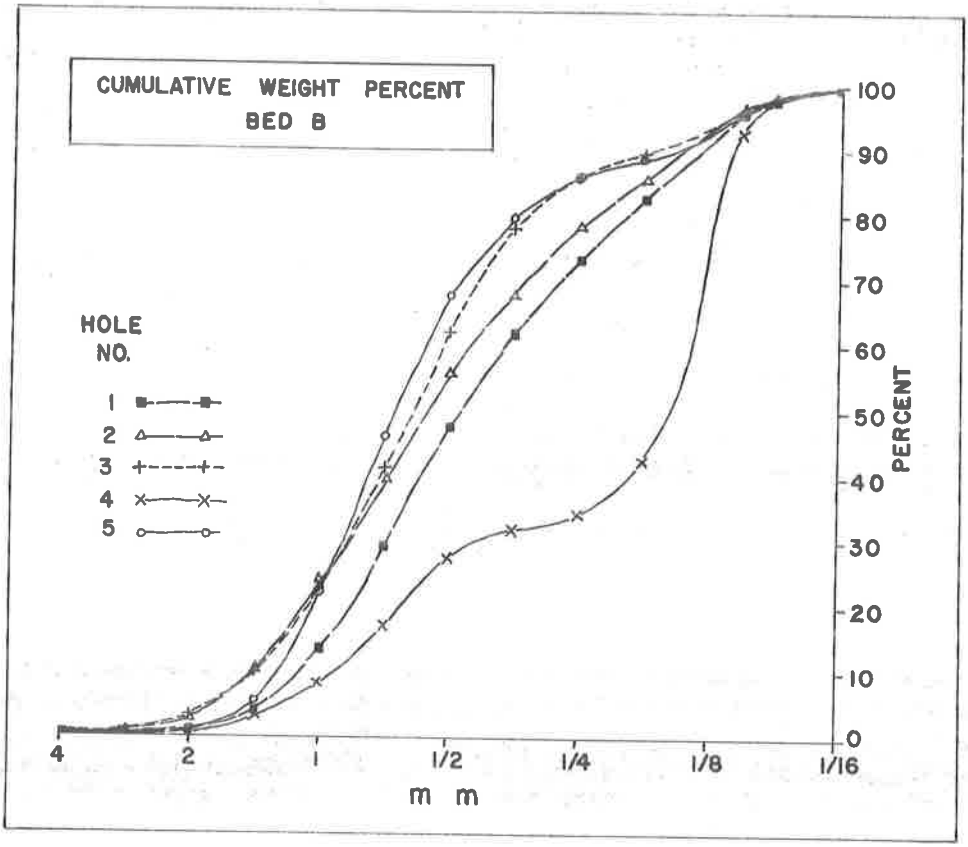

Figure 4. Cumulative curves for the sand fraction of sediments from Bed B.

All three beds show a full suite of heavy minerals as characterized by Groot and Glass (1960). Both the coarse and fine fractions are nearly identical. The suite includes primarily tourmaline, sillimanite, staurolite, kyanite, zircon, rutile, and epidote and lesser amounts of monazite, titanite, spinel and garnet.

Opaque heavy minerals include magnetite, ilmenite, hematite, leucoxene, opaque rutile, and authigenic marcasite-pyrite.

DISCUSSION OF THE RESULTS

In that the stability of the heavy mineral suites of all three beds is approximately equal and represented by nearly identical full suites,

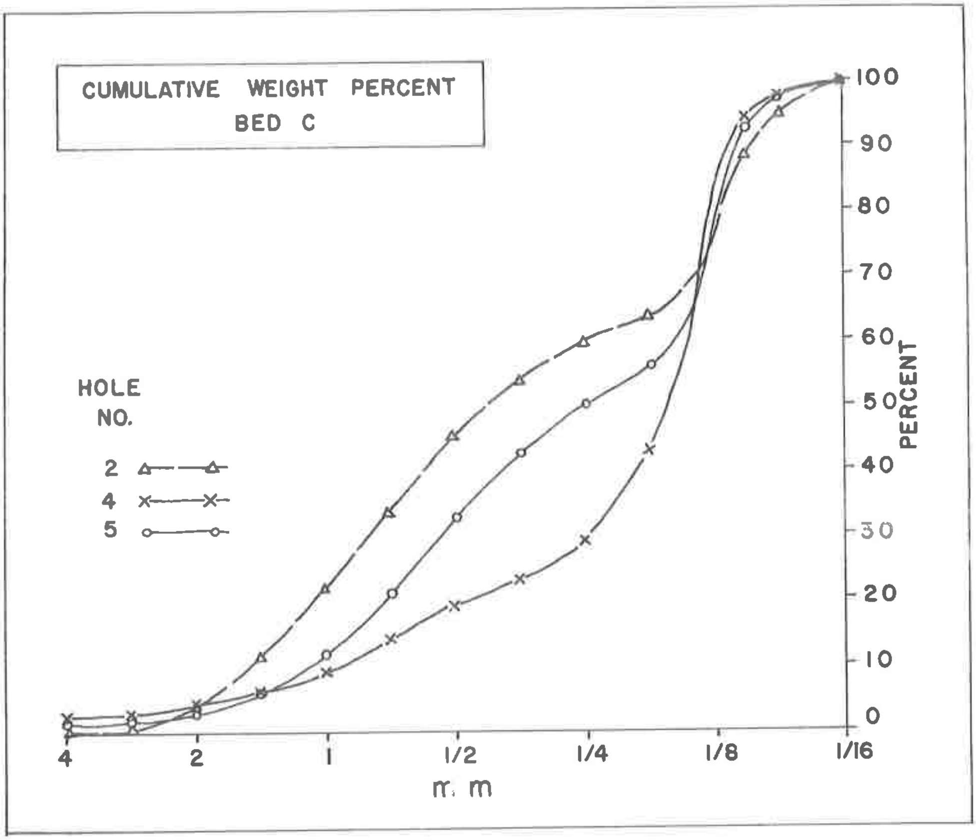

Figure 5. Cumulative curves for the sand fraction of sediments from Bed C.

a common sediment source and depositional environment may be inferred. The Piedmont probably served as the ultimate source for the sediments.

Variable mechanical characteristics and kaolinitic argillaceous components indicate fluvial deposition.

The topographic profile (Figure 2) shows a well-defined bay. Bed A underlies the bay and the lower contact of A is interpreted as a regularly sloping surface which is in no way dependent on or related to the bay.

This study does not suggest a new theory for the origin of the Carolina Bays. It does agree with conclusions drawn by Ingram, et al. (1959) that the surficial sediments of the bay interior are enriched with clay from peripheral sediments. Significantly, it shows that whatever mechanism is postulated to develop a bay must form it without deforming the underlying strata even along the long axis of the bay. That is,

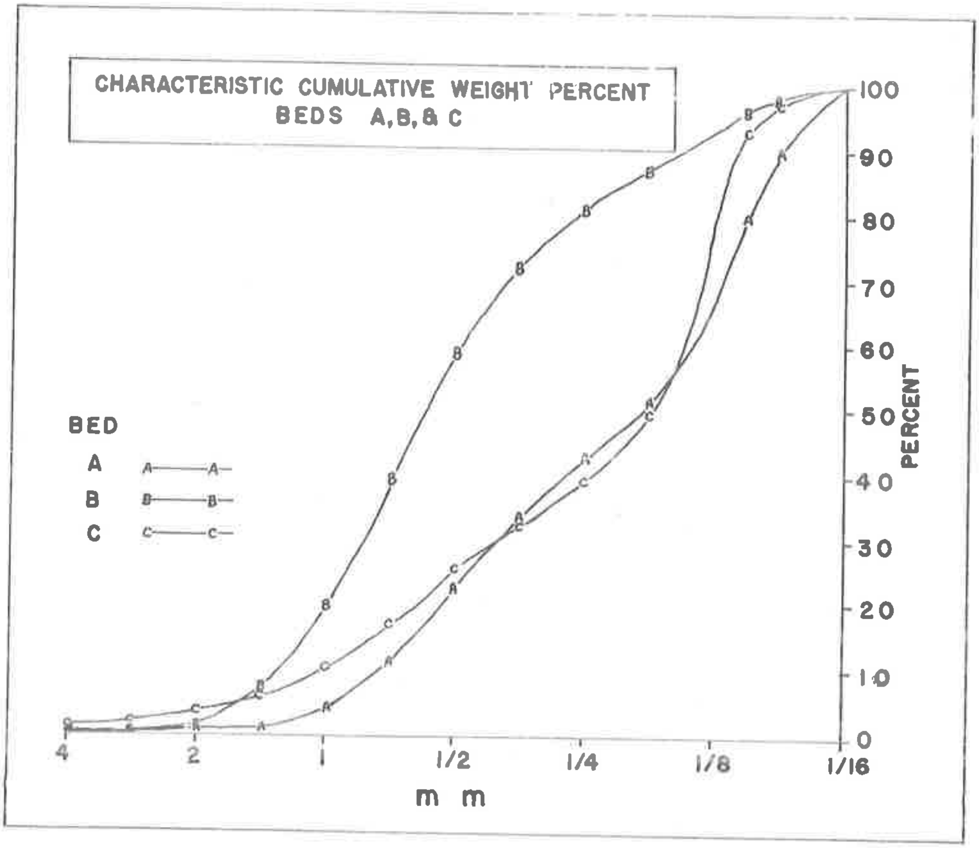

Figure 6. Comparison of cumulative curves for sand fractions of sediment from Beds A, B, and C.

an external or surficial mechanism is most consistent with the observed data.

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BARRIER-AND-LAGOON SETS ON HIGH TERRACES IN THE FLORIDA PANHANDLE

by

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ABSTRACT

An analysis of triple profiles, a reconstructed topographic map, and sand surface samples strongly suggest that barriers, lagoons, and off-shore flats are still preserved at least on some of the high marine terraces in the Florida Panhandle. These features, whose dimensions are analogous to modern St. George Island, are well developed on the 170 foot terrace in an area between the Ochlockonee and Apalachicola Rivers. The terraces, which broaden and thicken westward toward the Apalachicola River, have created a drainage pattern of "parallel" streams.

* * *

Many small streams on Pleistocene terraces in north Florida flow parallel with the present shore line and with the inferred Pleistocene shore line (Figure 1). This parallelism cannot be attributed to faulting (subsurface data do not support the suggestion) or to jointing (the parallelism is limited to the marine surfaces). A more likely explanation is that the terraces still exhibit the geometry of barrier island and lagoon, and that the "parallel" streams follow the deepest parts of the lagoons.

This concept has been investigated by means of map analysis, and by a study of sand surface samples, and by field observations.

The terraces described here are in Gadsden and Liberty Counties, Florida, in an area roughly between 20 and 40 miles west of Tallahassee. They have been studied in the field, over a period of about three years, as a part of a larger research program carried on by the senior author. This work has included field mapping, altimeter profiling, and spot sampling.

One procedure for map analysis was the construction of triple profiles. Two were drawn across the Hosford and Bristol quadrangles. The first one (A in Figure 2) was drawn across the Hosford quadrangle from Sec. 2 (T. 1 S., R. 6 W.) to Sec. 12 (T. 1 N., R. 6 W.), the second one (B in Figure 2) across the Bristol quadrangle from Sec. 24 (T. 1 S., R. 7 W.) to Sec. 12 (T. 1 N., R. 7 W.). Each profile

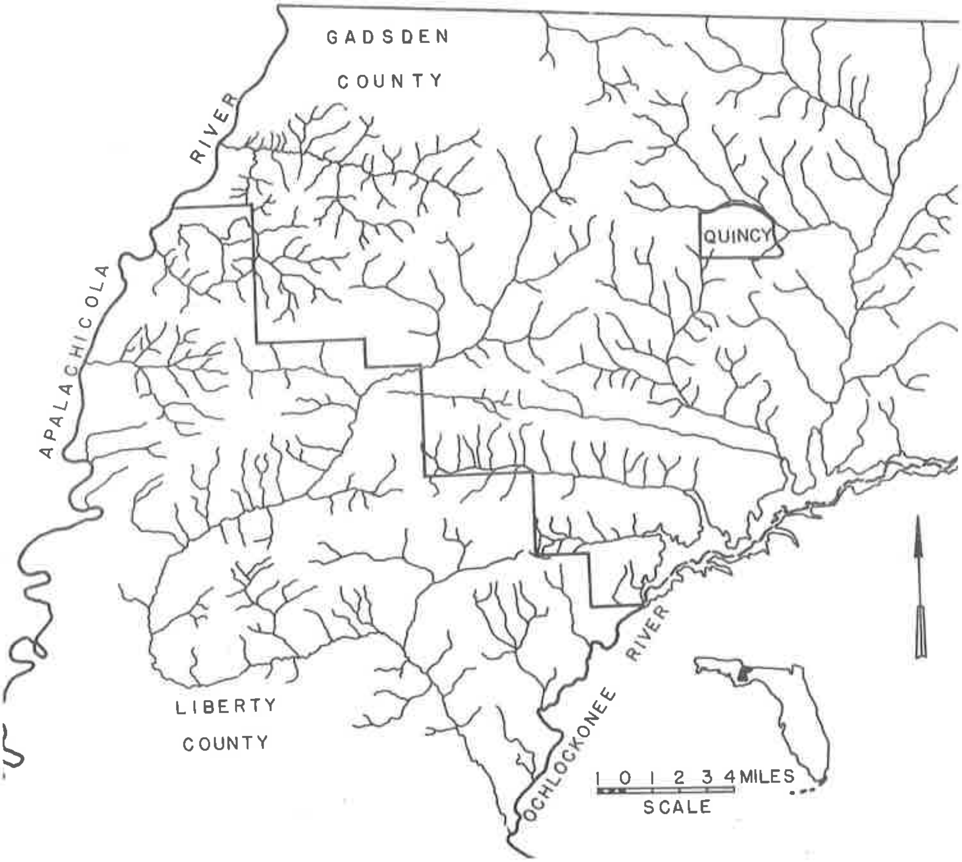

Figure 1. Map showing drainage pattern of sub-parallel, east-west streams which widen westward.

consisted of three separate profiles 0.5 mile apart. They were plotted on graph paper and superimposed on each other. The resulting composit is more meaningful than a single profile.

The two triple profiles were compared with each other and also with a profile across St. George Island and St. George Sound (a present day example of a barrier island and lagoon C in Figure 2). The two profiles reveal features which are strikingly similar to the off-shore flat and lagoon associated with modern St. George Island. Today's mean sea level is about 15 feet below the crest of St. George Island and about 20 feet above the off-shore flat. Using this figure, one can infer that mean sea level was at about 170 feet during the Pleistocene period when this terrace was formed (Figure 2).

The maximum elevation difference between the crest of St. George Island and the off-shore flat is about 35 feet. The same is true for profiles A and B. The difference is enough to lead some to think

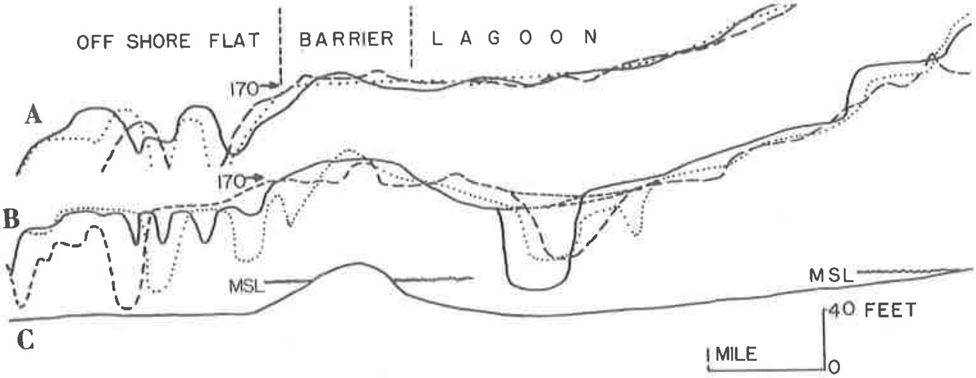

Figure 2. Triple profiles across the 170 foot terrace: (A) across the Hosford quadrangle, and (B) across the Bristol quadrangle. For comparison, a modern profile across St. George Island and St. George Sound is also included (C).

that perhaps two terraces exist, whereas in reality there is only one. This figure of 35 feet represents the approximate maximum thickness of Pleistocene sand for that particular terrace. Some ranges in the literature for a specific terrace include also the difference in elevation between the highest and lowest points of the off-shore flat, thus increasing the above figure by a few more tens of feet.

If a barrier island and lagoon can be found associated with a Pleistocene terrace, it is possible to infer a mean sea level which will coincide neither with the highest nor lowest point of the terrace. The younger terraces assigned by Cooke (1945) have smaller differences in elevations between them than what has been calculated as the maximum sand thickness for the 170 foot terrace. He recognized the Penholoway at 70 feet, Talbot at 42 feet, Pamlico at 25 feet, and Silver Bluff at 5 feet, producing differences respectively of only 28, 17, and 20 feet.

The second consideration in regard to graphic analysis was the construction of a map (Figure 3) representing, as closely as possible, the surface contours prior to erosion. This was accomplished by taking the highest elevation from each section of the topographic map and plotting it on tracing paper overlying a county road map. Each elevation was determined by taking the highest ten foot contour line, and recording it on that part of the tracing paper representing the center of the section. An interval of ten feet was chosen, starting at 105 feet, for contouring these points. Not all the contours are shown in Figure 3, but only those that represent the outlines of the terrace surface.

From the map it appears that there are three marine surfaces, having elevations of 105-125 feet, 155-190 feet and 255-285 feet, and inferred sea levels at about 120, 170, and 270 feet. The highest surface is still in question. It is also evident that the terraces broaden

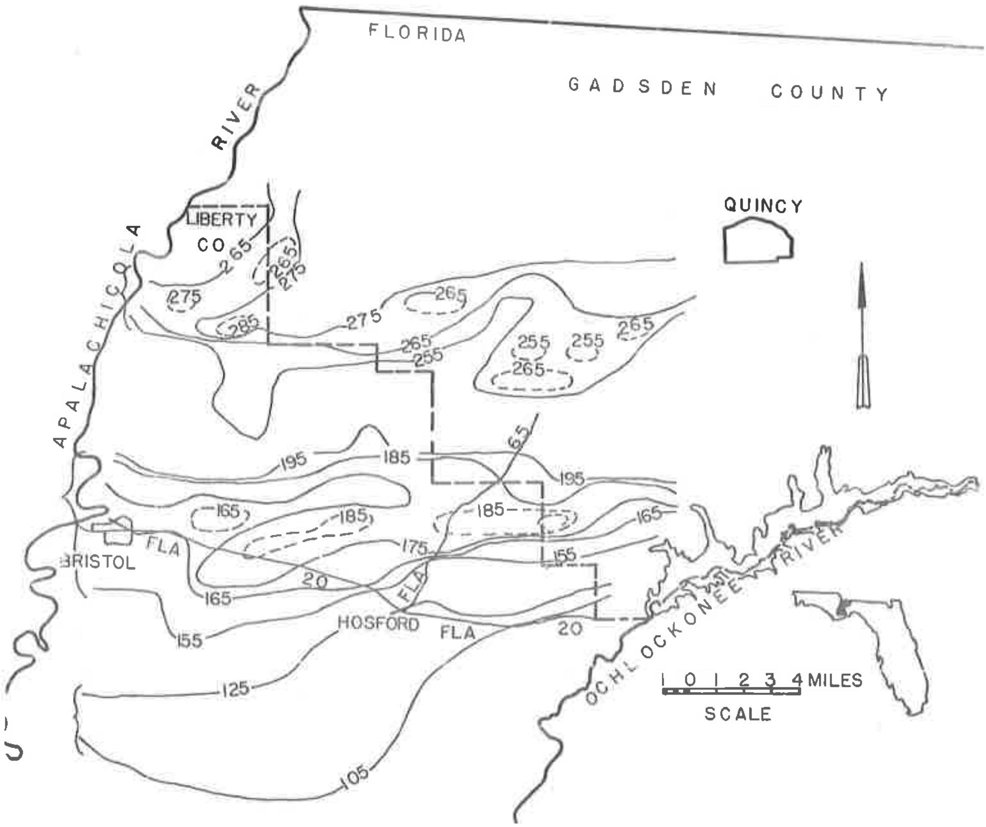

Figure 3. Map of the reconstructed ground surface of the area before Recent erosion. Three marine terraces are indicated by the configuration of the contour lines. The barrier island and lagoon are well preserved on the 170 foot terrace.

and thicken westward toward the Apalachicola River. Sediment was probably supplied by the ancient "Apalachicola River." The combination of the river extending its delta southward and sediment being dispersed away from the mouth of the river resulted in thick and wide terraces near the source of supply and thinner and narrower terraces down drift (both to the east and to the west). The high terrace sands (above the 170 foot terrace) pinch out in the vicinity of the Ochlockonee River and are not found in Leon County (immediately east of Gadsden County).

Another means of investigation was the analysis of sand surface samples. Nine samples were taken along Highway 65 which was considered the most accessible traverse across the 170 foot terrace. A sieve analysis was made of seven samples taken from various points believed to represent the ancient lagoon, barrier island and

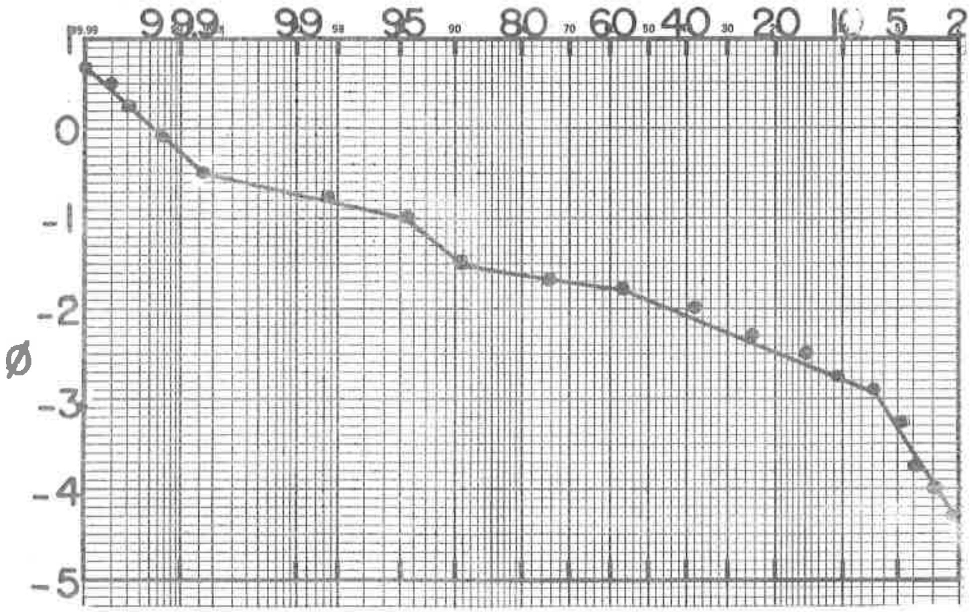

Figure 4. Probability plot of possible surf zone. Sand samples were taken from the 170 foot terrace. The surf zone is indicated by the break in the curve near -1 phi.

surf zone. A plot on probability paper revealed the data shown in Table I. The graph of the sample representing the "surf zone" is shown in Figure 4. The top break in the graph is probably the surf break.

Table I

Analysis of Sand Surface Samples from the Inferred Surf Zone, Barrier, and Lagoon of the 170-Foot Terrace

	"Surf Zone"	"Barrier"	"Lagoon"
Md (in mm)	0.275	0.26	0.13; 0.15
So	1.24	1.25	1.56; 1.45
$D_k \approx (\sigma)$	0.55	0.55	$\approx$ 1; $\approx$ 1

A generalized profile from Greensboro (in Gadsden County) to the coast reveals another interesting feature about this ancient terrace. It indicates how the wave energy has changed on a given reach of coast, with time. Breaker energy depends in part on the steepness of the off-shore bottom slope. High wave energy is associated with a steep bottom profile and low wave energy with a gentle profile other factors being equal. The 170 foot barrier island had a steeper off-shore profile than did lower terraces and, therefore, was probably formed under higher energy conditions. The same probable energy levels today are found farther west, along St. George Island, rather than due south along what appears to be the modern counterpart of the study area.

CONCLUSIONS

Several conclusions have been made after investigating the Pleistocene terraces in Gadsden and Liberty Counties, Florida. An examination of the triple profiles across the Hosford and Bristol quadrangles indicates that a barrier island, lagoon, and off-shore-flat existed at the time the 170 foot terrace developed. It is strikingly similar to modern St. George Island. A reconstructed surface contour map, as well as sand surface samples from various parts of the terrace, further substantiate the existence of these features. The presence of the off-shore flat, barrier and lagoon has profoundly affected the drainage pattern of this area. A number of small streams have originated along the deepest parts of the lagoon and adjacent to the seaward toe of the barrier, creating a drainage pattern of subparallel streams. Swamps have formed in the lagoons where streams did not develop.

Not all of the terraces exhibit these features to such a high degree. The sediment supply is one of the controlling factors. However, parallel drainage is quite common in the Florida Panhandle, and much of it probably can be explained in this way.

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GEOMORPHIC ELEMENTS OF THE AREA BETWEEN THE CAPE FEAR AND PEE DEE RIVERS, NORTH AND SOUTH CAROLINA

by

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Division of Geology

and

Jules R. Du Bar
Humble Oil Company

ABSTRACT

Geomorphic elements of the area between the Cape Fear and Pee Dee Rivers are described and interpreted. The sequence of events is thought to be: (1) Orangeburg Scarp formed by Miocene marine transgression, (2) Duplin Formation deposited (Late Miocene), (3) sea retreats, Duplin Formation partially stripped back, and alluvial fans built eastward from Orangeburg Scarp, (4) sea advances to Surry Scarp, (5) Waccamaw Formation deposited, (6) Horry Cape complex formed in slowly falling sea ("Penholoway Stage"), (7) Wando Bar formed ("Talbot Stage"), (8) Wampee Cape formed, (9) Green Swamp Lake formed, (10) Pamlico Formation deposited, (11) Myrtle Beach Bar formed in slowly falling sea, (12) Carolina Bays formed, (13) sea retreats ("Wisconsin Stage"), (14) sea returns to present level.

INTRODUCTION

Biostratigraphic investigations have been carried on for several years by the authors in the Cape Fear and Pee Dee River basins of the Carolinas with the support of the National Science Foundation and the Division of Geology, South Carolina State Development Board (Du Bar, 1960, 1962a, 1962b; Du Bar and Solliday, 1961; Du Bar and Chaplin, 1963; Du Bar and Howard, 1963; and Du Bar and Johnson, 1964). Power auger drilling has provided general sub-surface stratigraphic control and unweathered samples for paleontological studies. To guide drilling and provide a working hypothesis of the geologic framework of the region the authors studied aerial photo mosaics (scale approx. 1 inch = 1 mile) of the area. The following remarks are based primarily on these studies and on power auger drilling control in Horry, Marion, and Dillon Counties, South Carolina, and rotary drilling in Robeson, Bladen, Columbus, and Brunswick Counties, North Carolina.

In the following summary no attempt has been made at a complete survey of existing literature on the subject. We recognize that some of the ideas expressed may have been stated previously by others. Our sole purpose in this summary is to set the stage for further detailed investigations to test the model herein set up and to guide future drilling.

GEOMORPHIC ELEMENTS

Figure 1 shows geomorphic elements of the Cape Fear - Pee Dee area, North and South Carolina, as interpreted by the authors from study of aerial photo mosaics and the results of reconnaissance stratigraphic investigations. The various elements are described roughly in the order in which they are encountered in moving from northwest to southeast across the area. Probable time and sequence of events are given in table form at the end of the paper.

Orangeburg Scarp

The Orangeburg Scarp (Figure 1, A; Citronelle Escarpment of Doering, 1960) bounds the area of study on the northwest. It is a relatively straight northeast-trending escarpment that abruptly divides the Coastal Plain into a hilly upper section and a relatively flat lower section. The hilly area west of the Orangeburg Scarp is underlain for the most part by Cretaceous beds, but Eocene sediments are also present in some areas (e.g., in Richland, Sumter, Calhoun, and Orangeburg Counties, South Carolina). The scarp has 50 to 150 feet of relief; and power auger drilling by the Division of Geology, S. C. State Development Board, in Sumter, Calhoun, and Orangeburg Counties has shown Cretaceous and Eocene beds to the west of the scarp to be sharply truncated by it (Colquhoun, 1962, p. 69-70 and Figure 2). Late Miocene marine deposits are present against the toe of the scarp in places but do not occur to the west of it. Our interpretation is that the Orangeburg Scarp is a sea cliff cut in Miocene time.

Coalescing Alluvial Fan Area

Southeast of the Orangeburg Scarp is an area (Figure 1, B) approximately corresponding to the Coharie and Sunderland terraces as mapped by Cooke (1936). This surface slopes from the toe of the Orangeburg Scarp (about 220 to 250' elevation) in the northwest to an

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Pleistocene shoreline feature. The belt

sponds to the Surry Scarp, as extended into South Carolina by Flint (1940). It divides the Coalescing Alluvial Fan Area (B) from northeast-southwest trending geomorphic features of marine, littoral, or deltaic origin in the lower Coastal Plain. The southeastward-trending dentritic drainage system of the Coalescing Alluvial Fan Area terminates approximately at the Surry Scarp, some of the streams having formed deltas such as the one at the junction of the Lumber River and Big Swamp (Figure 1, F). Apparently the southeast-flowing streams emptied into essentially standing water here.

Big Swamp - Lumber - Little Pee Dee Drainage

The very wide, straight floodplain along the southwestward course of the Big Swamp - Lumber - Little Pee Dee drainage (Figure 1, G) today indicates that this was once a major stream or old lagoon, as big as today's Cape Fear or Pee Dee. It is interesting to note that the divide between this Big Swamp - Lumber - Little Pee Dee drainage and the Cape Fear River is less than a mile wide at a point about 12 miles northwest of Elizabethtown, N. C. It would seem possible that the Cape Fear may have come through this narrow point at one time and thus have been responsible for the great size of the Big Swamp - Lumber - Little Pee Dee flood plain. Field reconnaissance by the authors in the critical area where the two drainages are so close showed, however, that the south bank of the Cape Fear here is composed of Upper Cretaceous rocks to elevations at least as high as 100 to 125'. If the Cape Fear ever came through into the southwestward drainage here it was apparently only by shallow overflow, and no deep channel seems to have been cut. Careful drilling would be necessary to test this interpretation thoroughly. A more probable explanation is that the Big Swamp - Lumber - Little Pee Dee area was slowly changed from shallow, open shelf to a lagoon as sediments from the Cape Fear River extended the Horry Cape complex southward, cutting off the open ocean.

Horry Cape Complex

From the vicinity of Elizabethtown on the Cape Fear River southward almost to Conway in Horry County, South Carolina, is an area in which elevations above 100' are common (Figure 1, H). At the southwest end, north and northwest of Conway, this higher ground fans out into westward-trending parallel low sand ridges and sloughs. The sand ridges consist of fine-grained well sorted sand overlying clayey sand cores.

It is thought that the northern part of this higher ground represents alluvial and deltaic deposits of the Cape Fear River deposited when sea level stood at or a little below 100' elevation. The parallel sand ridges at the southwest end of this higher ground closely resemble regressive beach ridges deposited in a slowly falling sea. Drilling indicates the northern part of this cape complex in places overlies beds containing a shelf fauna of Waccamaw age (Pliocene (?) - Pleistocene) and that the parallel ridges of non-fossiliferous sand in the southern part of this cape complex lie directly on Cretaceous beds. Fossiliferous sands thought to be a beach facies of the Waccamaw Formation interfinger with or abut against these parallel sand ridges along the eastern edge of the Horry Cape Complex in Horry County.

Carolina Bays are present in the area of the cape complex but are normally not well developed.

Wando Bar

Trending northeastward through Conway in Horry County, South Carolina, is a narrow ridgelike feature (Figure 1, I) that at elevations of about 45 to 55' is higher than the adjacent land surface to the northwest and southeast. This ridge can be traced southwestward in long sweeping curves to Charleston County, South Carolina, where it is particularly well developed near the community of Wando. The ridge is apparently a barrier bar that formed when sea level was about 45 to 60 feet higher than today. Cooke (1936, Plate 1) mapped this bar and interpreted it as marking the shore of the Pamlico Formation (Pleistocene). Carolina Bays are clearly superimposed on the bar deposits in places.

Wampee Cape

Between Waccamaw River drainage and Cape Fear River and Atlantic Ocean drainage in Brunswick County, North Carolina, and Horry County, South Carolina, is a curving, southwestward trending belt of relatively higher ground (Figure 1, J). Higher elevations along the belt are 50' and above, and there is a general rise of the ground northward toward the Cape Fear River. The general shape of the belt is somewhat similar to the outline of the Horry Cape complex (H), and the authors think it represents sediment distribution southward from the mouth of the Cape Fear River when sea level was about 50 feet higher than today.

Position of the Wampee Cape relative to the Wando Bar (I) indicates it must be a younger feature than the bar. One power auger hole (26AH49) near the southwest end of the Wampee Cape suggests it may locally interfinger with fossiliferous marine deposits of late Pleistocene ("Pamlico") age. However, many other power auger holes in eastern Horry County show "Pamlico" deposits to be present lapping on and east of the Wampee Cape and not under or west of it. The eastern boundary of the cape is therefore essentially the "Pamlico" shoreline.

Drilling of 19 power auger holes in the Wampee quadrangle in eastern Horry County showed the Wampee Cape there to be composed of about 40 feet of fine grained clayey sand overlying fossiliferous limestone of the Waccamaw Formation (Pliocene (?) - Pleistocene). It is difficult to trace the boundaries of the Wampee Cape northward across Green Swamp in Brunswick County, North Carolina, from topographic maps and aerial photo mosaics alone; but in general the divide between the Waccamaw and Cape Fear drainages is thought to represent the central portion of the cape. Carolina Bays are present on the ancient cape surface but normally are not well developed.

Sandy Island Spit

Along the north bank of the Pee Dee River from the line of the Wando Bar (I) to the junction of the Pee Dee and Waccamaw rivers is a southward curving belt of sand dunes (Figure 1, K). Some of the dunes are 50 feet or more above sea level, much higher than the surrounding country. The sand deposits are fine to coarse grained, up to 40 feet thick, and in river bank exposures can be seen to overlie bluish gray clays and shelly sands of probable late Pleistocene ("Pamlico") age. The belt is thought to represent a spit formed where sand-laden waters of the Pee Dee River debouched into the shallow "Pamlico" sea. Dune orientation resembles that of the Ancient Flood Plain area and indicates reworking of the sands by strong southwesterly winds.

Jaluco Delta

Between Conway and Myrtle Beach in Horry County, South Carolina, is an area of fine to coarse grained brown carbonaceous sand (Figure 1, L). Drilling shows the carbonaceous sands to be up to 35 feet thick and to overlie fossiliferous marine deposits of late Pleistocene ("Pamlico") age. Exposures in drainage ditches in the area show abundant small scale cross-bedding and scour and fill structures in the sand. Bedding planes dip southward at angles up to 10°, and the general aspect indicates fluvial deposition. These carbonaceous sands are interpreted as deltaic deposits that were built up where Waccamaw River drainage entered a fresh to brackish water lagoon between the Myrtle Beach Bar (M) and the Wampee Cape (J) and Wando Bar (I). The name Jaluco Delta is applied informally from typical exposures in ditches at the now abandoned Jaluco Station on the Atlantic Coast Line Railroad between Conway and Myrtle Beach. Along the Intracoastal Waterway north of Myrtle Beach, brown carbonaceous sands of the Jaluco Delta interfinger eastward with "Pamlico" lagoonal and bar deposits.

Aerial photographs of the surface of the Jaluco Delta area show well developed westward and southwestward curving parallel sand ridges. These are interpreted as strand line deposits of the slowly receding restricted body of water into which the Jaluco Delta sands were deposited. The sand ridges are so superficial as to be difficult to recognize on the ground. Ditch exposures in the area show that they are nowhere more than about 3 feet thick over the cross-bedded carbonaceous sands below. They do make a gentle ridge and slough topography, however, that controls vegetation noticeably. Pines predominate on the ridges; and cypress, gum, and moisture-loving deciduous trees are common in the sloughs.

Many large, well developed Carolina Bays are present in the area of the Jaluco Delta. These are clearly younger than the surficial sand ridges.

Myrtle Beach Bar

A narrow belt of sand dunes (Figure 1, M) can be traced southwestward from the North Carolina state line through Myrtle Beach to Georgetown, South Carolina, and beyond. Elevations of the higher portions of the belt are 25 to 35 feet above sea level, in general higher than the adjacent country to the east and west. Drilling at several places along the belt has shown that the non-fossiliferous, fine grained dune sands overlie or grade downward into shelly sands of late Pleistocene ("Pamlico") age. The dune belt is interpreted as a barrier bar that formed in "Pamlico" time. It is herein termed the Myrtle Beach Bar. Bar sands interfinger westward with "Pamlico" lagoonal deposits and brown carbonaceous sands of the Jaluco Delta in the area between Myrtle Beach and the North Carolina state line. Longshore coquina deposits along the seaward edge of the Myrtle Beach Bar have been discussed by Du Bar and Johnson (1964). At Murrells Inlet, 13 miles southwest of Myrtle Beach, a submerged delta on the sea floor suggests that the Waccamaw River once passed through the Myrtle Beach Bar in this area.

Green Swamp

Green Swamp (Figure 1, N) is a roughly circular area about 22 miles in diameter in Brunswick and Columbus Counties, North Carolina. It is bounded on the north and east by the divide between Waccamaw River drainage and Cape Fear River and Atlantic Ocean drainage. Its approximate limits are marked on the south and west by low, curving sand ridges that are thought to be strandline deposits of an ancient lake or lagoon.

Fossiliferous Miocene and Pliocene (?)-Pleistocene beds (Duplin and Waccamaw Formations) crop out at about 45 to 50 feet above sea level on the shore of Lake Waccamaw on the northwest margin of Green Swamp and at about 35 feet elevation near Old Dock on the west margin. Cretaceous beds are present only a few feet lower in these areas. A rotary drill hole put down by the junior author about 7 miles southeast of Lake Waccamaw in the approximate center of the Green

Swamp area collared at about 60' elevation and went through 110 feet of surficial sands, Waccamaw Formation, and Duplin Formation before encountering Cretaceous beds at about -48' elevation. The thickest section of Waccamaw Formation known to the authors was found here. Cretaceous beds crop out in bluffs along the Cape Fear River north of Green Swamp at an elevation of about 35 feet above sea level. Eocene limestone (Castle Hayne Formation) is present essentially at the surface about 10 miles east of Green Swamp, in the area a few miles south of Wilmington.

Green Swamp, therefore, seems spacially related to an abnormal depression in the top of Cretaceous beds. It is not clear whether this depression is erosional, structural, or possibly extraterrestrial in origin. Green Swamp also is spacially related to the Wampee Cape (J) inasmuch as the postulated cape forms the low rim around the eastern margin of the area. The ancient lake or lagoon indicated by strandline sand ridges around the southern and southwestern margins of Green Swamp may have formed on the landward side of the cape as it built up and as sea level slowly fell during the Pleistocene epoch. Later, the south rim of Green Swamp lake was breached, and the waters drained southward between the Wampee Cape (J) and the Wando Bar (I) to form the Waccamaw River.

Carolina Bays are poorly defined and sparsely distributed over most of the Green Swamp area. The principal exception to this generalization is Lake Waccamaw on the northwest margin of the Green Swamp area. Lake Waccamaw is about 5 miles long and 3 miles wide and is the largest elliptical depression of the Carolina Bay type known to the authors.

Limestone Terrane

Extending for several miles south and southwest of Wilmington is an area (Figure 1, O) which on aerial photographs is seen to be characterized by many irregularly shaped ponds and lakes. The state geologic map of North Carolina (Stuckey, et al., 1958) shows Castle Hayne Limestone (Eocene) here, and the ponds and lakes are undoubtedly related to solution phenomena.

Overlapping the limestone terrane at the southwest end and extending several miles further to the southwest is a series of low, parallel sand ridges that are interpreted as strandline deposits of late Pleistocene ("Pamlico") age. Well developed Carolina Bays are present in the area. They are superimposed on and are clearly younger than the strandline sand ridges and in the limestone terrain can be seen to bear no relation to the ponds and lakes of probable solution origin.

Cape Fear

Twenty five miles south of Wilmington is Cape Fear (Figure 1, P), one of the classic cuspate capes of the Carolinas. Extending an additional 20 to 30 miles south-southeast is Frying Pan Shoals, a submarine continuation of the cape. The seaward side of Cape Fear is a barrier bar that is being extended southward by strong longshore drift, Apparently the southwestward-flowing littoral current along this part of the Carolina coast has been deflected by Cape Fear River currents with resultant buildup of Cape Fear and Frying Pan Shoals south to south-southeastward.

Carolina Bays

Widely scattered over the Coastal Plain of the Carolinas are the frustrating oriented elliptical depressions known as Carolina Bays. Douglas Johnson (1942) has discussed them in considerable detail. Many hypotheses of origin have been proposed, but none seems to satisfy completely all the observed features of the Bays.

In the area between the Cape Fear and Pee Dee Rivers Carolina Bays are present on all surfaces except Recent Flood Plain and the very youngest coastal features. They are clearly, therefore, late Pleistocene ("Pamlico") or younger in age. Also, they bear no relation to the calcareous, non-calcareous, fluvial, or marine character of the underlying sediments. Eolian sand deposits associated with the Bays are indicated by outline and position to have been deposited by southwesterly winds. Other eolian features of approximately the same age, still well preserved in Ancient Flood Plain areas (Figure 1, D), also indicate winds from the southwest. Evidence is lacking for northwesterly winds which might conceivably have had something to do with the northwest-southeast elongation of the Bays.

SEQUENCE OF EVENTS

The following sequence of geologic events is tentatively proposed for the area between the Cape Fear and Pee Dee rivers on the basis of work to date.

Event	Time
(1) Sea advances and cuts Orangeburg Scarp (A)	Miocene
(2) Duplin Formation deposited up to Orangeburg Scarp	Late Miocene
(3) Sea retreats and alluvial fans build out across Coalescing Alluvial Fan Area (B), the Duplin Formation first having been largely removed from the fan area by erosion	Late Miocene(?) - early Pleistocene (?)

Event	Time
(4) Sea advances to Surry Scarp (E), cutting off eastern ends of coalescing alluvial fans	
(5) Waccamaw Formation deposited to Surry Scarp	Pliocene (?) - Pleistocene (?)
(6) Horry Cape complex (H) builds east and south from mouth of Cape Fear River (at Surry Scarp), and Big Swamp - Lumber - Little Pee Dee area (G) is cut off from open sea. Sea slowly falls. Small deltas (F) form where southeastward-flowing streams enter the lagoon. Waccamaw deposition continues	Pleistocene ("Penholoway Stage")
(7) Sea slowly recedes, leaving parallel regressive beach ridges along southern part of Horry Cape. Waccamaw deposition continues	
(8) Wando Bar (I) formed. Mainland shore essentially along east edge of Horry Cape complex	Pleistocene ("Talbot Stage")
(9) Wampee Cape (J) formed. Sediment derived from Cape Fear River	
(10) Sea level slowly falls. Green Swamp (N) cut off from open sea, gradually changing from salt water lagoon to fresh water lake.	
(11) Sea slowly falls. Green Swamp lake breached on southwest, and Waccamaw River drainage established between Wampee Cape (J) and Wando Bar (I).	
(12) Marine deposits of late Pleistocene ("Pamlico") age deposited in shallow sea bounded on west by Wampee Cape (J) and Wando Bar (I)	Late Pleistocene ("Pamlico Stage")
(13) Myrtle Beach Bar (M) formed as sea slowly recedes. Lagoon west of the bar changes from salt to brackish water, and Jaluco Delta (L) builds south and east from Waccamaw River. Delta deposits interfinger with brack-	

Event	Time
ish and salt water "Pamlico" deposits. Ancient Flood Plain Areas formed (D). Sandy Island Spit (K) formed. Ancestral Cape Fear formed (P).	
(14) Carolina Bays formed. Most are filled with water, and wave washed sands accumulate in strandline deposits. Southwesterly winds form elongate northeast-trending dunes in Ancient Flood Plain areas and on the northeast side of Carolina Bays.	
(15) Sea level falls	Late Pleistocene ("Wisconsin Stage")
(16) Sea return to present level.	

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