HEAVY MINERAL BEARING SANDS FROM THE WICOMICO TO THE PRINCESS ANNE PALEOBARRIER COMPLEXES ALONG THE GEORGIA COASTAL PLAIN

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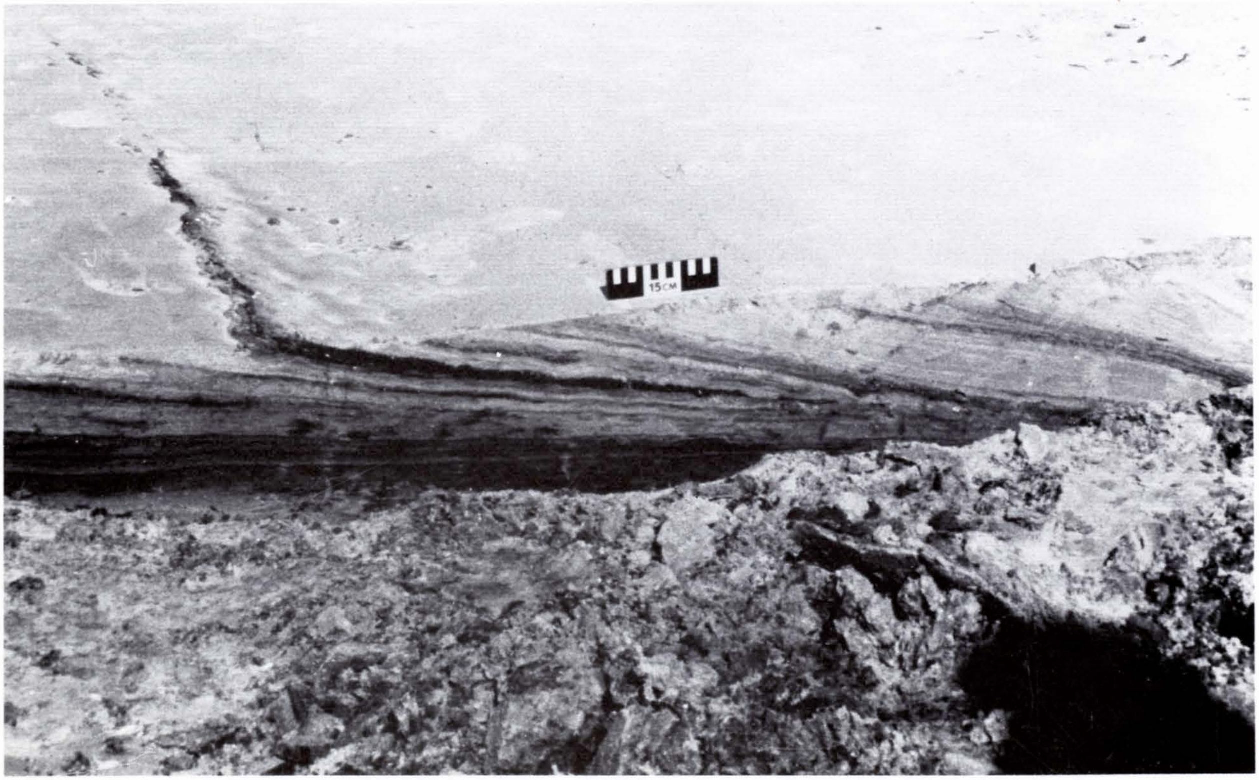

DEPARTMENT OF NATURAL RESOURCES
ENVIRONMENTAL PROTECTION DIVISION
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Cover: Heavy mineral layers in beach deposits at Jekyll Island, Georgia.

Heavy Mineral Bearing Sands from the Wicomico to the Princess Anne Paleobarrier Complexes along the Georgia Coastal Plain

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Accelerated Economic Minerals Program

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by
Jeffery A. Kellam, McKenzie Mallary and Michael K. Laney

Abstract

The lower or seaward portion of the Coastal Plain of Georgia contains a series of sand bodies interpreted as remnant barrier island shorelines. These sand bodies typically are composed of sediments containing some detrital heavy mineral constituents. A total of 200 samples were collected from five traverses across these shorelines, ranging in elevation from 90-95 feet above mean sea level to about 10 feet above mean sea level. These paleobarrier complexes, from oldest to youngest, are the Pleistocene-aged Wicomico, Penholoway, Talbot, Pamlico and Princess Anne. Samples were analyzed for the total heavy mineral sand fraction, by weight. Ninety-three of these samples were examined petrographically. Thirty-nine of these ninety-three samples contained greater than or equal to one percent heavy mineral concentration. The general trend established from analyses revealed an increase in ambient percentage of titanium-bearing minerals with increasing age of the complex sampled. However, the youngest complexes, the Pamlico and Princess Anne, contain the highest ambient total heavy mineral fraction percentages.

Introduction

General Statement

Concentrations of heavy mineral sands have been documented to occur in the sediments of fluvial-marine environments, such as the tidal inlet/barrier island complexes along the Georgia coast (Neiheisel, 1962; Giles and Pilkey, 1965; Woolsey et al, 1975). These concentrations are the result of the interaction of depositional and erosional processes favorable for heavy mineral sand accumulations. Heavy minerals are defined as accessory detrital mineral constituents with a specific gravity $\geq$2.85.

The heavy mineral suite in coastal Georgia, as well as along the entire southeastern coast of the United States, commonly contains magnetite, ilmenite, epidote, hornblende, leucoxene, staurolite, zircon, sillimanite, rutile, kyanite, tourmaline, garnet, monazite and other less frequently occurring minerals (Neiheisel, 1962; Hails and Hoyt, 1972). The probable sources of these minerals are the metamorphic and igneous rocks of the Piedmont and Blue Ridge Provinces in Georgia. The Savannah, Ogeechee and Altamaha Rivers transport the heavy minerals from Piedmont and Blue Ridge sources to the coast where both nearshore marine and subaerial processes influence deposition. Some of the heavy mineral occurrences are the result of erosion and redeposition of the Coastal Plain sediments by these rivers, as well as by smaller, indigenous Coastal Plain rivers. Kellam and Bonn (in preparation) concluded that concentrations of heavy minerals are low in the immediate vicinity of the source river. Wave activity in the backshore is apparently an important cause of heavy mineral placer concentration (Reineck and Singh, 1980). Subsequent activity, such as high energy storms and aeolian processes, further concentrate these heavy mineral sands.

The active dune subenvironments, wave and tidal, have the greatest concentration of heavy minerals (Kellam and Bonn, in preparation). This abundance of heavy minerals in the active dunes is because the dunes are formed by the progressive reworking of sediments by longshore currents, wave activity, tide activity and aeolian processes. Heavy minerals are concentrated in the erosional/transgressive subenvironment downdrift of the delta front and the erosional portion of the barrier islands where winnowing is common. In other words, winnowing serves to create higher concentrations of heavy minerals in the subenvironments downdrift and adjacent to the source river, with relative decreases in concentrations farther from the source river (Kellam and Bonn, in preparation).

Similar concentrations downdrift and adjacent to the source river have been found on Pleistocene barrier island shorelines in Georgia up to 50 miles inland (Smith, et al, 1967).

Objective

This study represents a second phase of the Heavy Mineral Sands Project of the Accelerated Economic Minerals Program. This program is being conducted by the Georgia Geologic Survey to investigate the long-term potential of Georgia's mineral resources. The first phase was designed to primarily develop a depositional model for heavy minerals; this study currently is in preparation and will be published as Georgia Geologic Survey Bulletin 110. The third phase, which as of the date of this publication has not been initiated, will be directed at actually evaluating the heavy mineral economic geology of the barrier island complex.

The objective of this present study is to assess the ambient occurrence of heavy minerals of the five higher Pleistocene paleobarrier island complexes in coastal Georgia (Wicomico, Penholoway, Talbot, Pamlico and Princess Anne). (Note: Seaward of the Princess Anne shoreline complex lies the Silver Bluff shoreline complex (at 4.5 feet elevation) as well as the Holocene islands which make up the present shoreline. As a result of the decision by the Georgia Department of Natural Resources that the coastal environment is of great intrinsic value in an undisturbed state, it has been decided that mining should not occur on these coastal barrier islands. For this reason, the Silver Bluff and present barrier islands were not sampled for this study.)

Previous Work

Origin and Development of Barrier Islands

There are three generally accepted theories of the origin of barrier islands as illustrated in Figure 1. One of the earliest theories, presented by DeBeaumont (1845), postulated that locally derived sediments are eroded from the breaker zone and deposited landward as shore-parallel bars. These bars eventually build-up to become emergent, forming incipient barrier islands. Gilbert (1885) credited the creation of barrier islands to the accretion of spits from existing islands. The spits are eventually breached by tidal creeks or rivers and become detached. Hoyt (1967) attributed the formation of barrier islands to transgressive progresses. According to Hoyt's theory, as sea level rises the shore is drowned, detaching dune ridges. It is these dune ridges that form the basis for the new barrier islands. Other recent studies have suggested that barrier island formation is a result of a complex combination of these processes (Leontyev and Nikiforov, 1966; Hoyt, 1967; Cooke, 1968; Schwartz, 1971; Oertel, 1972, 1979; Leatherman, 1983; Stubblefield, et al, 1983; Griffin and Henry, 1984; and Kellam, 1986).

Georgia's Paleobarrier Island Shorelines

A series of Pleistocene paleobarrier island shorelines, trending parallel or sub-parallel to the present coastline, extends across the Coastal Plain of Georgia (see 1:500,000 Geologic map of Georgia, 1976). (Note: in this manuscript the terms islands, complexes or barrier islands will be used interchangeably. We view the words as synonyms.) These shorelines range in age from early Pleistocene to Recent. A total of 13 shorelines have been described in Georgia, with elevations from sea level to 260 feet above sea level. In order of increasing age and elevation they are: Holocene (Recent), Silver Bluff, Princess Anne, Pamlico, Talbot, Penholoway, Wicomico, Okefenokee, Waycross, Argyle, Claxton, Pearson and Hazlehurst (Huddlestun, 1988). The seven most recent shorelines, from the present barrier island (Holocene) to the Wicomico-age shoreline are relatively well defined. These relatively large, unconsolidated surficial sand bodies have been of interest as potential sources of mineral resources, most notably heavy mineral sands. One such body was mined near Folkston in Charlton County, Georgia; and several similar shorelines in northern Florida, adjacent to the study area, are currently being mined.

Previous works (Hoyt and Hails, 1967; Hails and Hoyt, 1972; and Georgia Geologic Survey, 1976) have mapped the approximate positions and outlines of the paleobarrier island shorelines. The existing maps, however, are lacking in detail and did not resolve questions in areas where topographic or morphologic information is inconclusive. The present study provides somewhat greater detail and a clearer definition of the geographic extent of each of the shorelines from the Wicomico to the present. Data for more detailed mapping of the paleoshorelines was derived from several sources.

The primary sources for locations of the shorelines were topographic contours, based on the accepted elevations for each shoreline delineated by Huddlestun (1988). The topographic quadrangle maps on 1:100,000 and 1:24,000 scale were examined and the shorelines were plotted using the elevations to delimit the general shape of the various paleobarrier islands. In areas where topographic criteria were inconclusive, field checks were made to distinguish between paleobarrier sand bodies and other types of sand bodies resulting from subsequent processes, such as the aeolian sand dunes commonly found on the northeastern side of Coastal Plain rivers. A principal feature of interest for the field checks was the presence or ab-

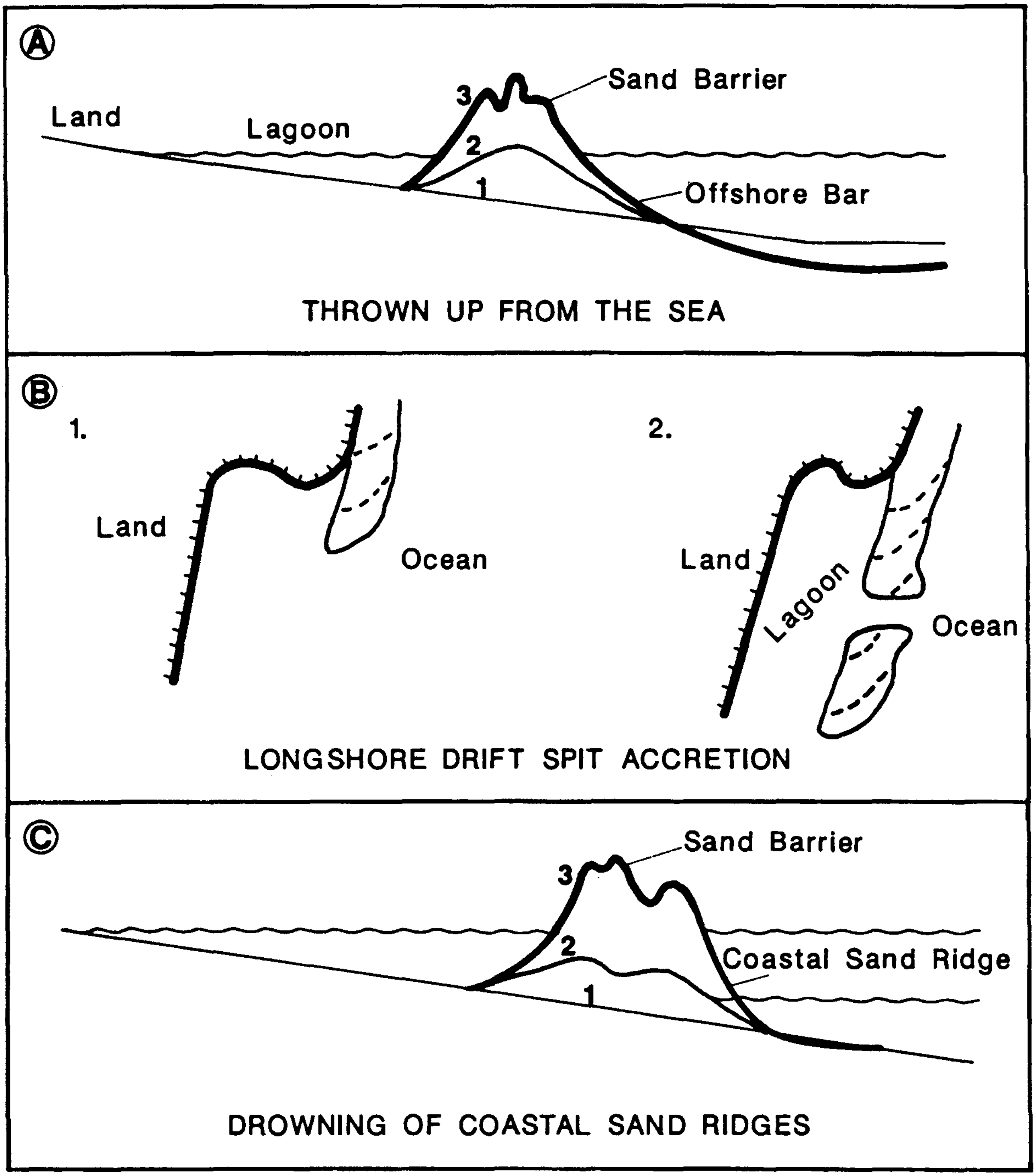

Figure 1. Basic theories of barrier island formation: A. Evolving from an offshore bar (De Beaumont, 1845). B. Evolving from longshore drift-spit accretion (Gilbert, 1885). C. Evolving from the drowning of coastal sand ridges (Hoyt, 1967). For A and C, the numbers 1, 2, & 3 generally refer to initial, intermediate, and final stages of development. For B, 1 represents the initial stage of development and 2 represents the final stage of development.

sence of "scarps" at the appropriate elevations. These "scarps" are the best evidence of the shoreline of the paleobarrier island. The presence or absence of surficial sediments of thicknesses to indicate original deposition in a barrier island environment was used to clarify contacts. In addition to new information collected by the authors, unpublished data developed by P.F. Huddlestun of the Georgia Geologic Survey, and unpublished data developed by V.J. Henry and M.W. Rhea, on file at Georgia State University, were evaluated. The location and configuration of the Wicomico, Penholoway, Talbot, Pamlico and Princess Anne shoreline complexes are shown in Figures 2, 3, 4, 5, and 6 respectively. Plate A shows these same shorelines as well as the 200 sample locations identified in Appendix A.

The primary evidence for assigning a sand body to a specific paleobarrier shoreline is elevation. The individual shorelines maintain a fairly consistent elevation throughout the Georgia coastal area. Where the topography does not provide a definitive answer, mapping of the shoreline can be difficult. An example of this occurs in Charlton County south of Folkston, in the southeastern portion of the study area. Here, there is an extensive, linear sand body extending the length of the county having an elevation ranging from about 70 feet to over 95 feet. Such elevations are within the expected ranges for both the Penholoway and Wicomico shorelines. "Scarps" can be seen at the 70-75 and 90-95 foot elevations, suggesting that this sand body is a composite of a Penholoway-age feature welded onto the front of a Wicomico-age feature. Moreover, sedimentary structures, such as crossbedding, generally are absent in the paleobarrier sands of the study area (one exception has been documented by Hoyt and Weimer, 1963). Without sedimentary structures to distinguish, for example, a Penholoway interior dune sand from a Wicomico shoreline beach facies, a final determination is not possible.

The boundaries (contacts) for specific sand bodies have been obscured as a result of syn- and post-depositional processes, including bioturbation, aeolian re-working, and agricultural activity. Within the Holocene barrier island shoreline, the sand bodies are in some cases welded directly onto the Silver Bluff. Such processes have apparently occurred throughout much of the depositional history the paleobarrier shorelines. In most locations where this has occurred, precise definition of the boundary between shorelines may not be possible. In some cases a reoccupation of the older shoreline as a result of a sea level rise may have occurred without significant deposition during the younger event. The present-day geomorphic expression of the direct welding of the younger sand body on to the older would be, in many cases, indistinguishable from the expression of the reoccupation without additional deposition.

Large sand bodies also parallel major rivers that cut through the paleobarrier shoreline. These sand bodies are roughly perpendicular to, and extend landward of the shore-parallel sand bodies at elevations approximately equal to that of the paleoislands. Rhea (1986) interpreted these as being contemporaneous with the adjacent paleobarrier island complexes. Huddlestun (personal communication) believes that these river-parallel sand bodies are the result of activity subsequent to barrier island formation. The lack of definitive sedimentary features, however, prohibits a definitive interpretation, at present.

An additional cause of difficulty in identifying shorelines is the subsequent aeolian erosion as well as the transport and mixing of sands from the shorelines. Such erosion can result in features resembling the extensive frontal shoal systems characteristic of barrier islands of the present shoreline. Outcrops and vertical exposures are extremely limited in the coastal area. In those few exposures that do exist, sedimentary structures, such as dune or shoreface crossbeds, are very rarely preserved. The lack of sedimentary structures inhibits making a distinction between paleo-shoals and aeolian deposited dune sands. Examples of these paleo-shoal systems occur fronting the Talbot complex in Bryan County between the Ogeechee and Canoochee Rivers, and further north, fronting the Penholoway complex.

A striking variation in the geomorphology of the shoreline complexes exists between the three older shorelines (Wicomico, Penholoway, Talbot) and the two younger shorelines (Pamlico, Princess Anne). The older shorelines are long, linear and relatively undissected. The younger shorelines are short, stubby and intricately dissected. These morphologies are the result of very different sedimentary regimes. The linear barrier islands result from voluminous sediment supply, wave-dominated energy regimes, and/or steep continental shelf morphology (Hayden and Dolan, 1979; Hayes, 1979). An example of this type of morphology is the coastline of North Carolina, with its extremely narrow, deeply eroded barrier island system. The shorter, dissected barrier islands result from restricted sediment supply, tide-dominated energy regimes, and/or relatively shallow continental shelf (Hayden and Dolan, 1979; Howard and Frey, 1980). This stubby type of barrier island system is represented by the modern coasts of Georgia and South Carolina.

The stream valleys in the lower Coastal Plain are as much as 1/2 mile wide in some cases. This suggests that in the past coastal rivers were larger and more efficient in carrying sediment. As mentioned in Hails and Hoyt (1972), many of the present day rivers and creeks passing through the older barrier islands appear to be underfit or smaller than necessary to cut the stream valleys in which they lie. With the present state of knowledge of the Pleistocene stratigraphy, it is not possible to determine whether or not the gradient has been altered sufficiently to result in the morphological changes that are seen in the study area.

Previous Studies in Georgia and northern Florida

Previous investigations into the history of the exploration and mining of heavy minerals in Georgia and Florida, include Martens (1935) and Garner (1978). Neiheisel (1962, 1965) and Woolsey and others (1975) examined heavy mineral concentrations on the present Georgia barrier islands. These studies suggest that concentrations tend to occur on the backshore and dune front of the present islands. Kellam and Bonn (in preparation) report that the concentration of the heavy minerals occurs most frequently in the backshore and dune areas, with the highest concentrations occurring in the frontal dunes. Mateer (1961), Abercrombie (1965) and Furlow (1966) evaluated a Pamlico barrier sand body in Glynn County. Friddell (1980) utilized aeroradiometric data and samples from Pamlico and Princess Anne sand bodies in Glynn and McIntosh Counties in the same general area as the studies by Moxham (1954), Mateer (1961) and Abercrombie (1965). These workers generally agreed that heavy minerals are present in quantities in the range considered minable, but apparently not in quantities sufficiently large to be economically viable, at that time. It should be pointed out, however, none of the studies were directed at actually locating an orebody thus economic viability of the mineralization could not be adequately addressed.

Giles and Pilkey (1965) collected 90 samples in the coastal area from North Carolina to Florida. Of theses samples, 50 were beach and dune, 40 were fluvial. Giles and Pilkey found that: 1) beach sands contained relatively greater quantities of elongate heavy mineral grains and dune sands contained relatively more equidimensional grains; and 2) the rivers carrying sediments derived from the Coastal Plain contained a more mature suite of heavy mineral sands than those carrying sediments derived primarily from the Piedmont. Giles and Pilkey as well as Hails and Hoyt (1972) confirmed that the Piedmont served as a source for the sediments.

Moxham (1954) was the first to locate an economic concentration of heavy mineral sands in Georgia. Through the use of aeroradiometric data, a concentration of radioactive minerals was located on a Penholoway-age paleobarrier sand body in the Folkston area of Charlton County. This area was mined for heavy minerals until the mid-1970's when mining ceased.

As a part of the South Georgia Minerals Program, Smith and others (1967) analyzed 80 randomly located borings in the paleobarrier islands for heavy mineral sands (Figure 7). Of these borings, 24 contained $\geq$1.0% heavy mineral sands. Seven samples contained heavy mineral concentrations of >2.0% from the upper 9 feet. A total of seventeen sample locations yielded averages of between 1.0% and >2.0% heavy mineral sands. An addendum to Smith and others (1967) described twelve core holes drilled by Southern Railroad in Charlton County, Georgia. Five of these samples contained deeper zones (> 9 feet deep) of greater than 2% heavy minerals. Mineralogic analysis made during the study suggest an increase in relative abundance of both titanium-bearing minerals and radioactive minerals with increasing overall heavy mineral percentages.

Extensive investigations of barrier island terraces have been made in Florida (Pirkle, et al, 1974; Pirkle, et al, 1984; and Force and Garner, 1985). Northeastern Florida heavy mineral deposits have been intensively mined for more than 30 years (Figure 8). As a result, more study has been done on the environments of deposition in Florida than these environments in Georgia. Both the Georgia and Florida paleobarrier systems have similar provenance, were created and modified by similar processes, and were formed during the same sequence of Pleistocene shoreline fluctuations.

Four ore bodies have been studied in northeastern Florida (Figure 8). They are, in order of increasing age: the Yulee deposits north of Jacksonville; the Boulougne and Green Cove Springs deposits northwest and southwest of Jacksonville, respectively; Trail Ridge, west of Jacksonville; and Trail Ridge, west of Green Cove Springs. Force and Garner (1985) described high angle dune crossbedding in the face of the mine dredge pond at Trail Ridge. This suggests the importance of aeolian processes in concentrating heavy mineral sand deposits. Force and Garner also noted that most of the exploration effort has been directed at paleoshoreline placers, thereby possibly overlooking interior dunefields as prospects.

The Green Cove Springs and Boulougne ore bodies are considered to be beach ridges formed on a regressional beach plain, during either a stillstand or minor transgression (Pirkle et al, 1974; Pirkle et al, 1984). The Yulee deposits are found on a Pamlico

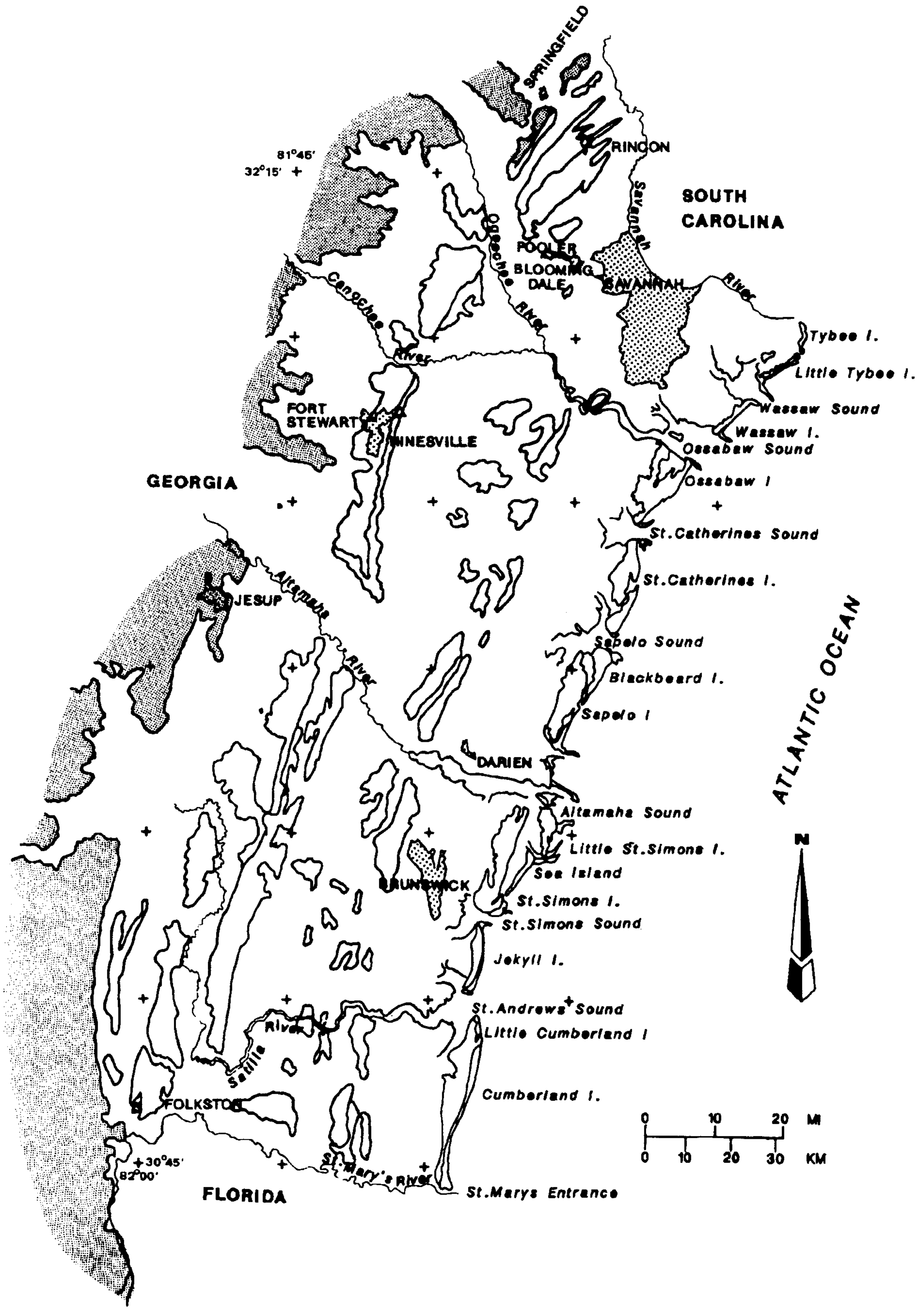

Figure 2. Wicomico paleobarrier island shoreline relative to the present and past shorelines.

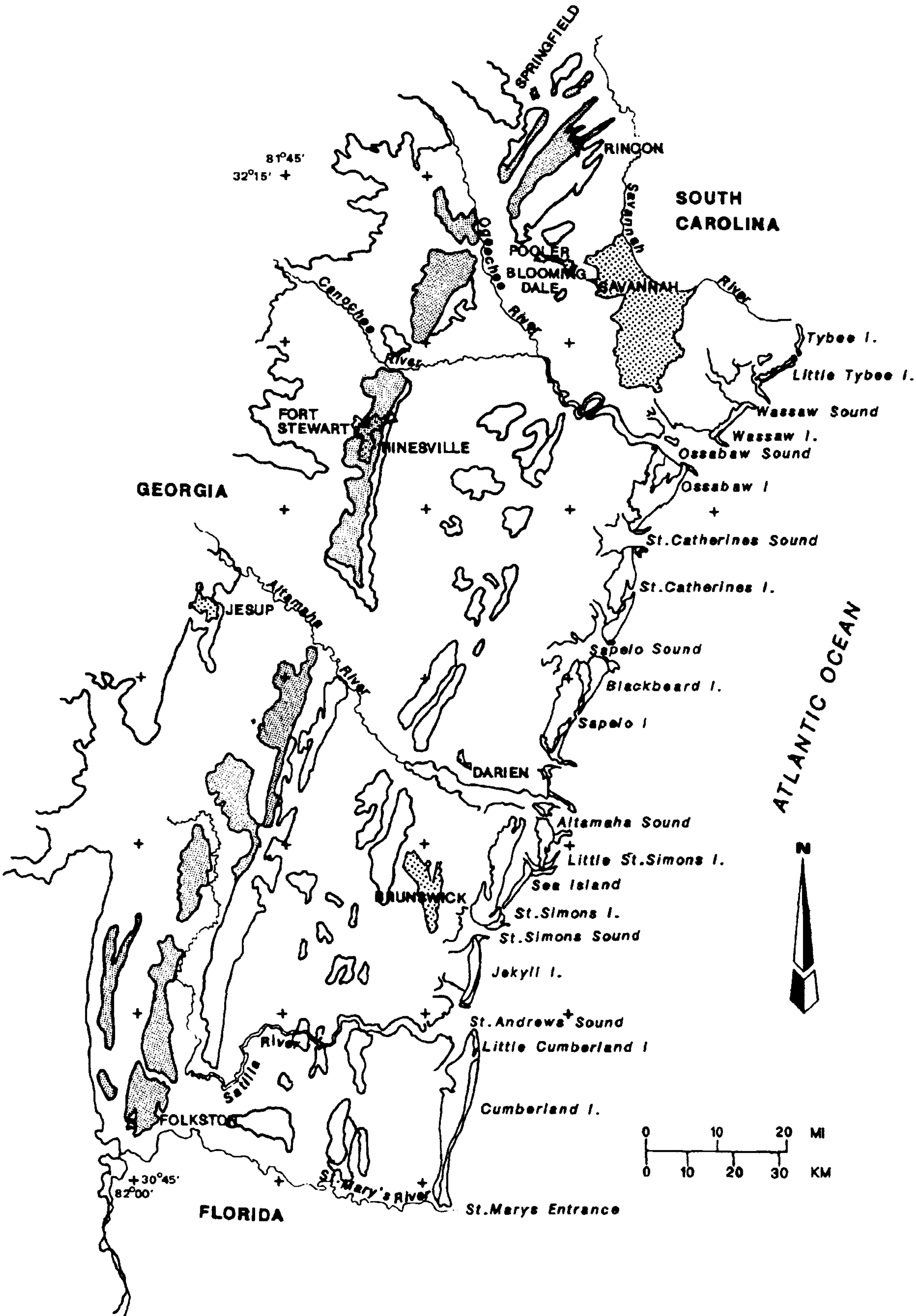

Figure 3. Penholoway paleobarrier island shoreline relative to present and past shorelines.

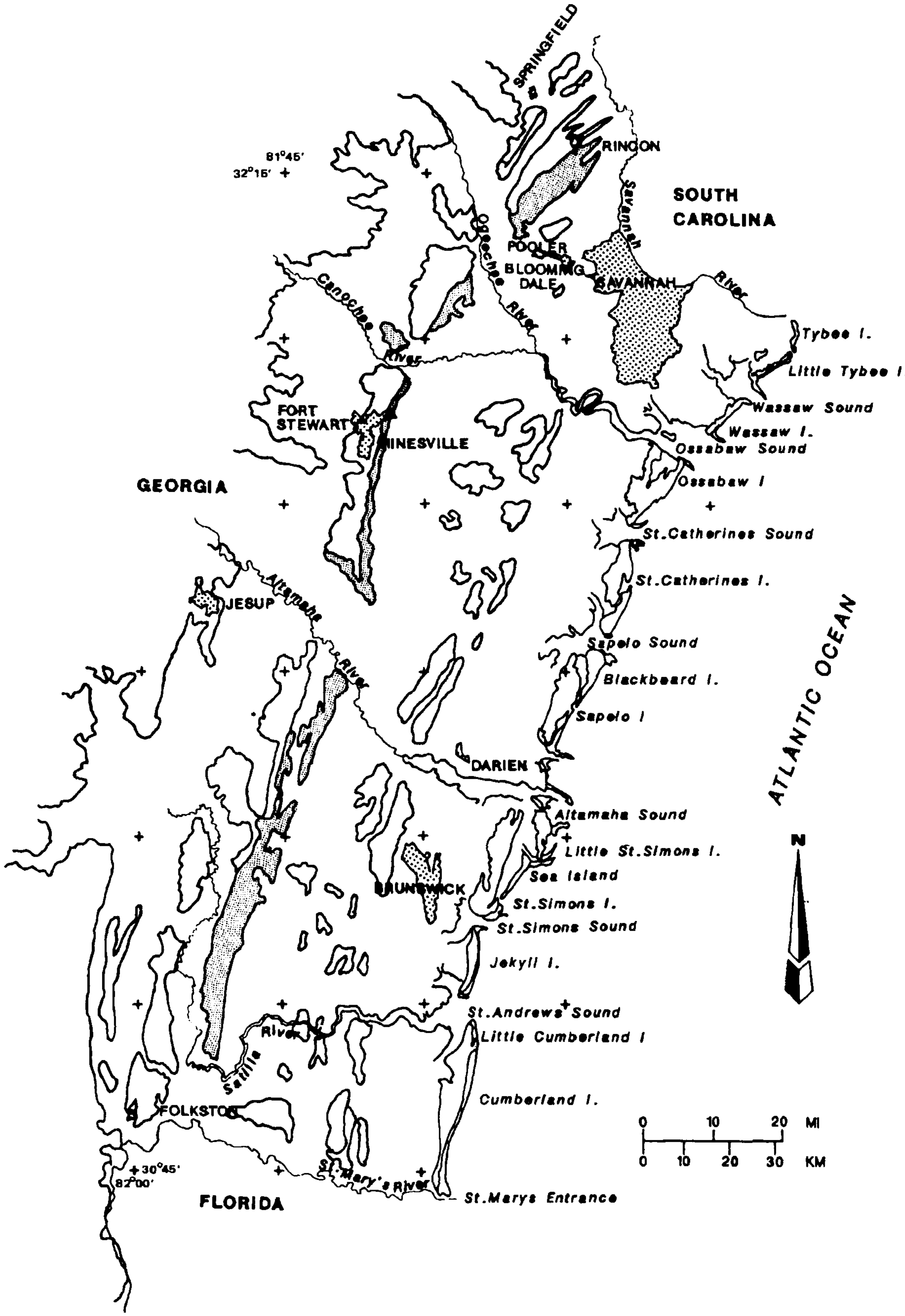

Figure 4. Talbot paleobarrier island shoreline relative to present and past shorelines.

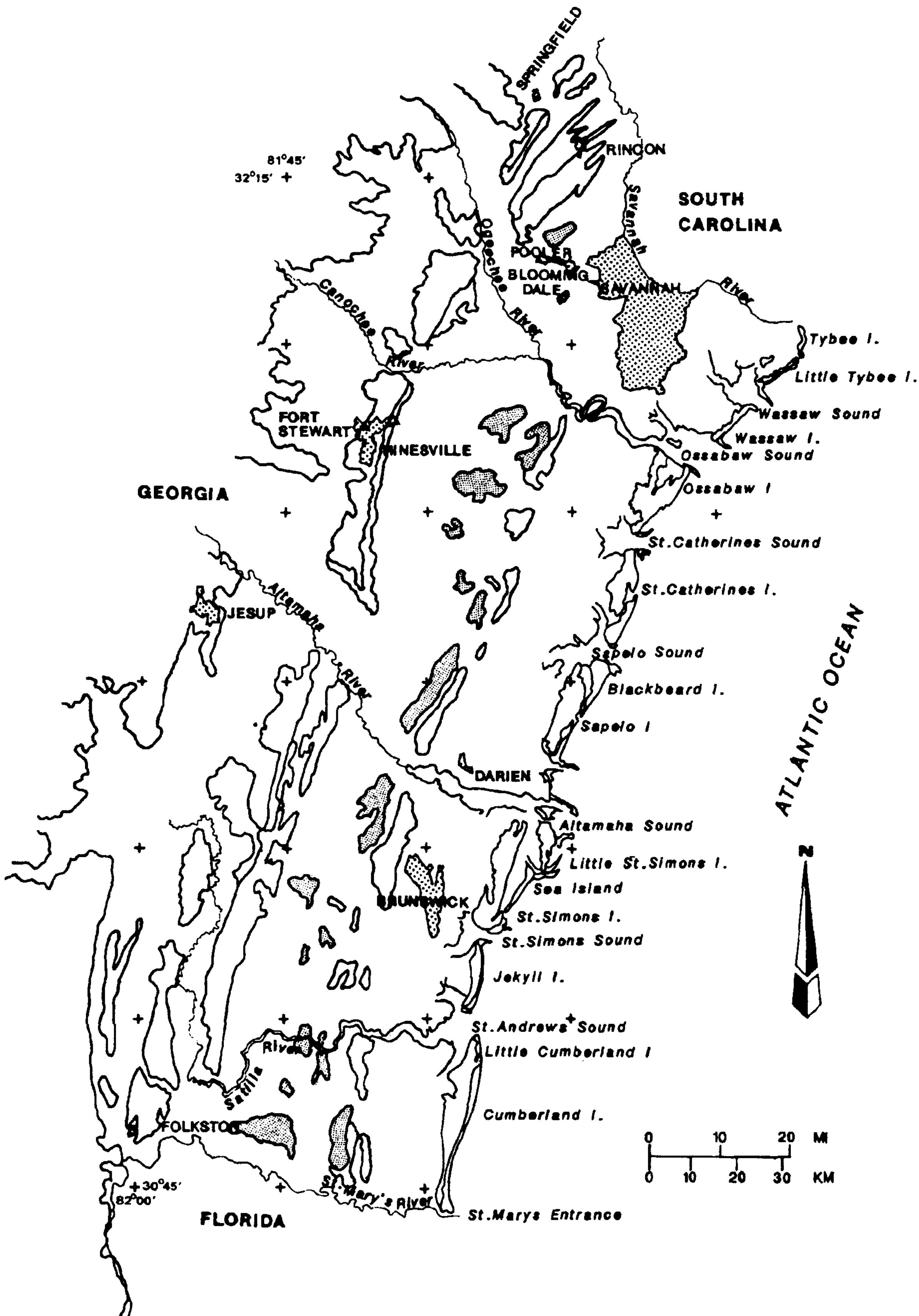

Figure 5. Pamlico paleobarrier island shoreline relative to present and past shorelines.

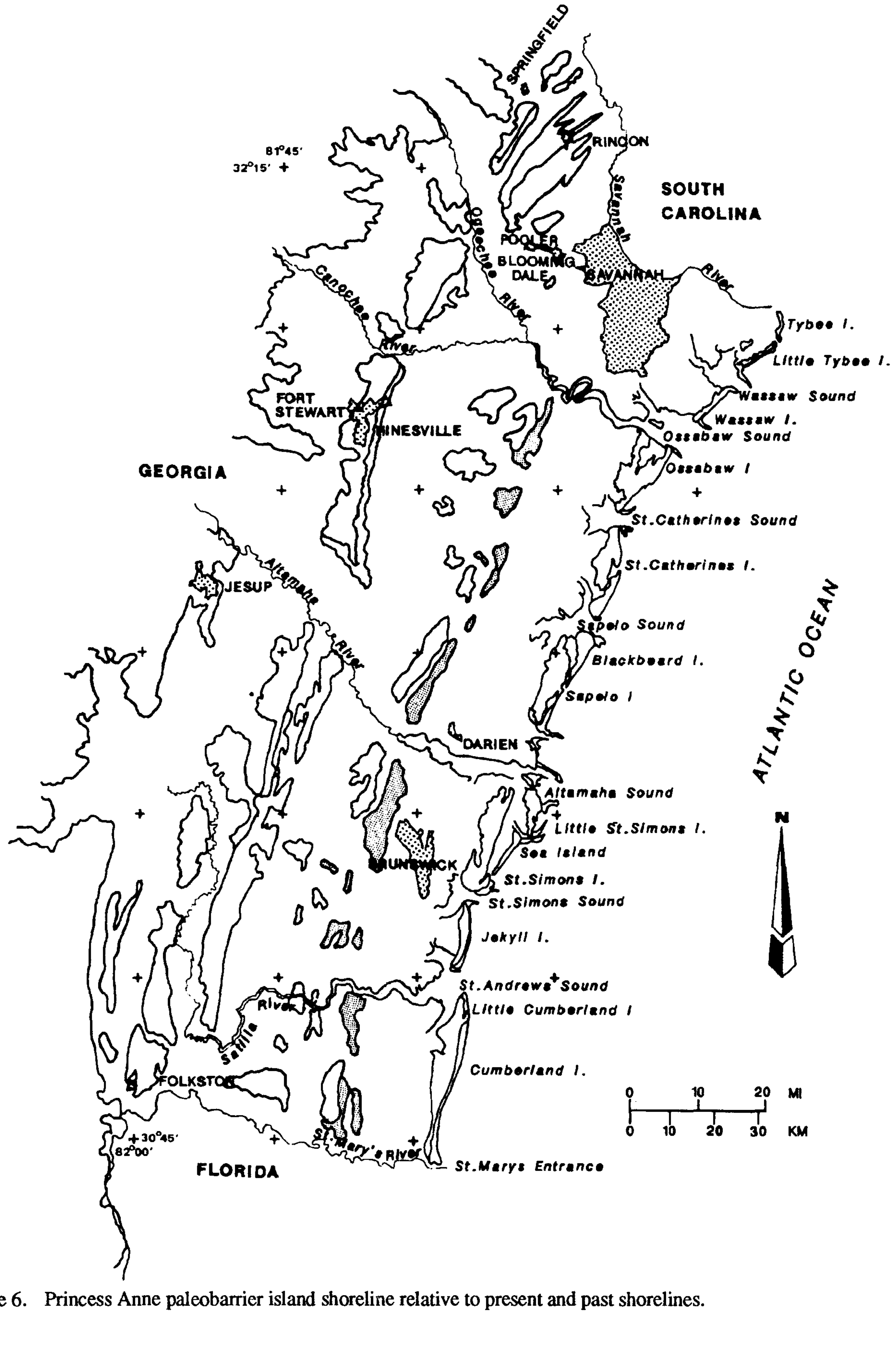

Figure 6. Princess Anne paleobarrier island shoreline relative to present and past shorelines.

terrace south and down-longshore drift of the ancestral St. Mary's River. The economic concentration of heavy minerals in the Florida deposits is believed to be the result of sorting caused by the interaction of ocean currents and sediment-bearing river currents. These deposits were further concentrated by wind and wave action (Pirkle, et al, 1984).

Geologic Background

The general area under investigation in this study is the southeastern portion of the Georgia Coastal Plain along the Atlantic Ocean. The study area encompasses two tiers of coastal counties (Figure 9). The Coastal Plain extends southeastward from the Fall Line to the Atlantic Coast. The general lithology of the Coastal Plain consists of sediments ranging in age from Cretaceous near the Fall Line to Holocene along the present coast. These seaward-dipping strata overlie older basement rocks ranging in age from Paleozoic to Triassic/Jurassic. Overlying the Tertiary Formations are a total of 13 shorelines located at elevations ranging from 0 to 260 feet above present sea level (Huddlestun, 1988). This study involves the five segmented paleobarrier complexes ranging in elevation from 95 feet above present sea level (Wicomico terrace) to approximately 13 feet above present sea level (Princess Anne terrace). Based on stratigraphic and morphologic evidence, Hails and Hoyt (1972) placed the elevations of these five Pleistocene barrier complexes as follows: Wicomico (90 to 100 feet), Penholoway (70 to 75 feet), Talbot (40 to 45 feet), Pamlico (24 feet), and Princess Anne (13 feet)(see Figures 2 through 6).

The paleobarrier island sand bodies generally are believed to have been deposited during intervals of standstill in the overall regression which occurred in the Pleistocene epoch. Mean paleo-sea level for each barrier island sequence is based on the upper limits of remnant lagoon-marsh sediments, the fossilized burrows of the marine decapod *Callianassa major Say* (Hoyt and Weimer, 1963), the interpretation of the present topography, and on the stratigraphic relationships of the sand bodies to each other and to adjacent sediments.

The morphological differences between various Pleistocene barrier island shorelines along the Georgia coast have been studied most recently by Rhea (1986) and Huddlestun (1988). A complicated process of barrier island development prevailed throughout the Pleistocene. Huddlestun proposed that these differences resulted from variations in sediment volume, in the relative dominance of erosional versus depositional regimes, and in the direction of sediment transport affecting each shoreline. The geomorphic configuration of each shoreline is the result of several interactive dynamic processes, including currents, wind and wave action, as well as sediment source and supply. Two distinct classes of paleo-shorelines are present. The first consists of relatively large, linear, undissected sand bodies, characterized by the Wicomico, Penholoway and Talbot Shorelines. The second consists of small, stubby and complexly dissected sand bodies, characterized by the Pamlico, Princess Anne, Silver Bluff and present day shorelines. The large linear, undissected complexes are probably the result of combination of greater sediment supply, wave-dominated energy regime and steeper continental shelf. The "stubby" morphology is probably the result of a combination of such factors as decreased sediment supply, tide-dominated energy regime and flatter continental shelf (Rhea, 1986; Huddlestun, 1988; Kellam, 1986).

The shoreline configuration of the southeastern United States and the various depositional processes operating in the coastal environment are key factors in understanding the morphology of the Holocene and Pleistocene barrier islands of Georgia's coastal counties. The present-day coast of Georgia is located in the middle of the Georgia Bight, extending from North Carolina to Florida. The continental shelf is broadest and shallowest in the bight adjacent to Georgia. The result is a mesotidal, mixed-energy, dynamic regime which is largely tide-dominated and modified by low wave energy. Tidal fluctuations range from approximately 6.5 feet on a diurnal basis to 10 feet during spring tide. Wave heights average about one foot. The variable interaction of tide and wave activity has produced a continuum of barrier island tidal inlet morphologies from North Carolina to Florida. Wave energies are highest along the North Carolina and Florida coasts, and decrease to a minimum along the Georgia coast (Tanner, 1960). As a result, the morphology of barrier islands along the southeastern United States ranges from long, narrow "shoe-string" islands in North Carolina and Florida to short, stubby "drumstick" islands along the South Carolina and Georgia coasts (Hayes and Kana, 1976).

Description of the Paleobarrier Island Shorelines

Wicomico Shoreline

The Wicomico Shoreline is represented by only a few geographically limited sand bodies interpreted as paleobarrier islands (Figure 2). To the north of the Altamaha River, the Wicomico Shoreline, based on the assumed elevations of 90 to 95 feet above pre-

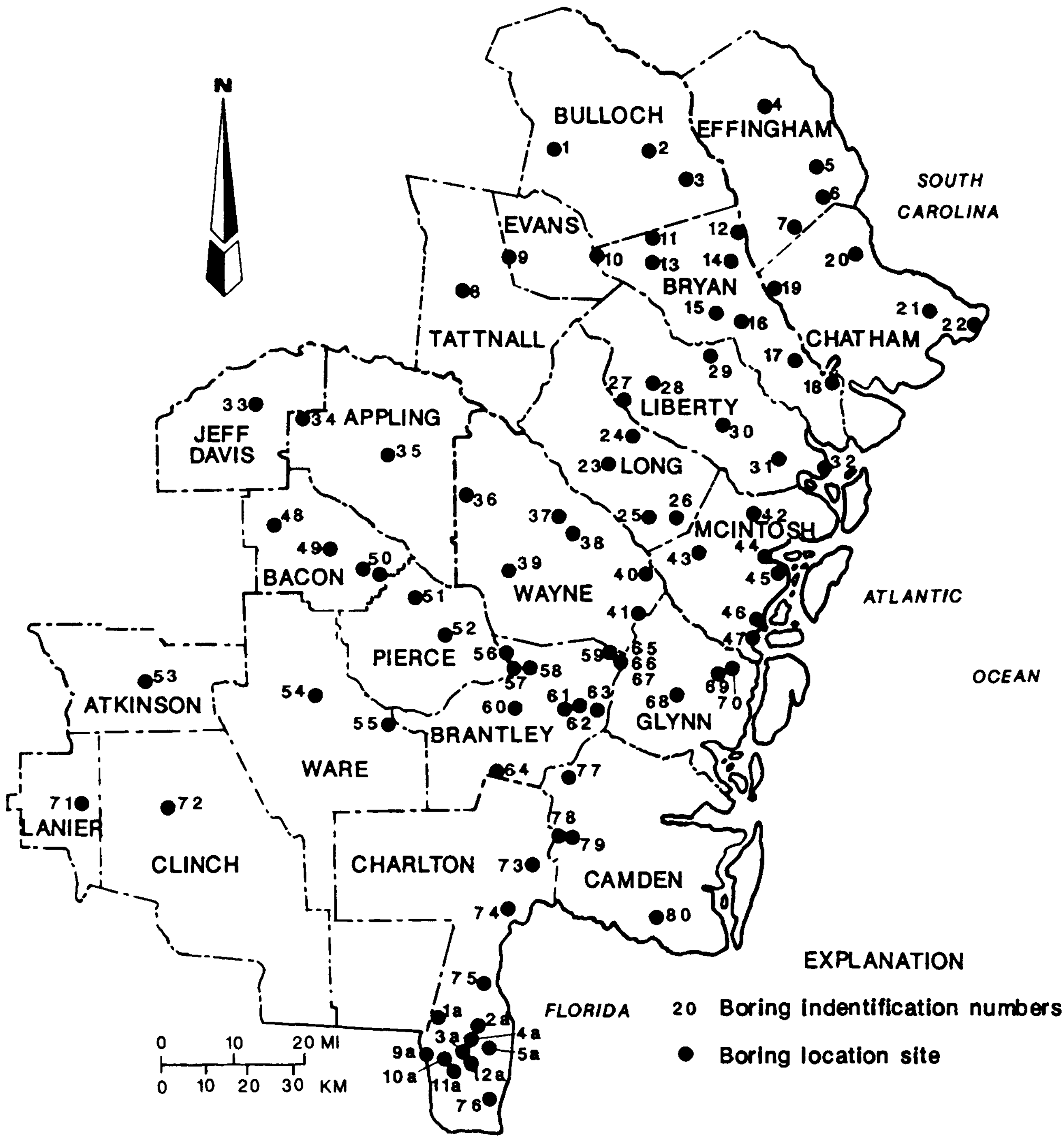

Figure 7. County outline map of southeastern Georgia showing boring localities from the South Georgia Minerals Program (modified from Smith, et al., 1967). Borehole identification numbers denoted by "a" in Charlton County were collected by Southern Railway System.

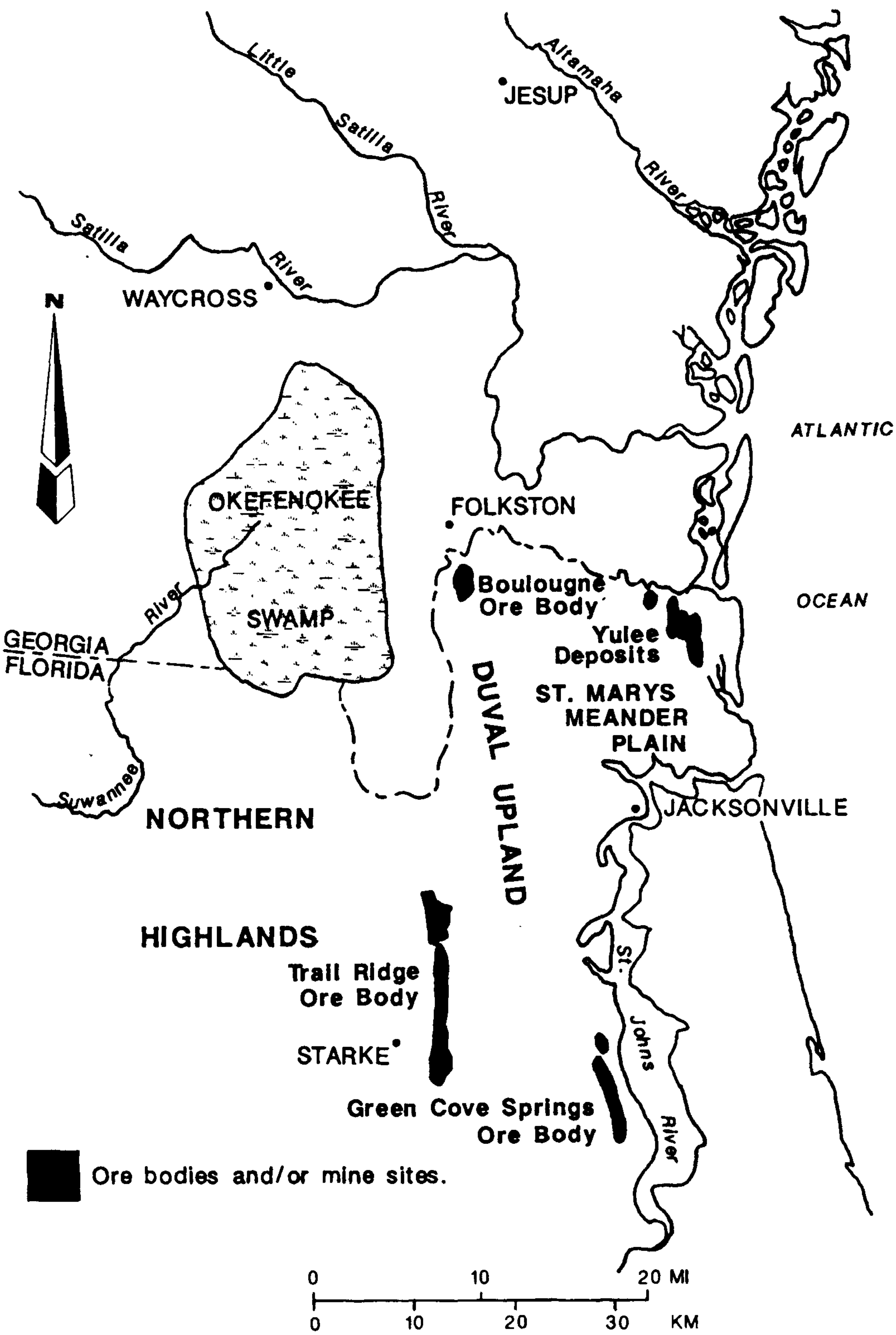

Figure 8. Location map of Florida heavy mineral deposits. (From: Pirkle, et al, 1984).

sent mean sea level, is configured as a set of intricately (fluvially) dissected cusps. This may represent the landward shoreline of a backbarrier-lagoonal system. Any fronting barriers that may have existed are no longer present, probably having been removed by erosion. A large scale modern analog of this situation can be seen along the present coast of North Carolina where the eroded barrier islands exist only a narrow, elongated cuspate sand bodies, separated from the mainland by large, shallow sounds. It can be speculated that a similar situation existed on the Wicomico shoreline where erosion, probably accompanying a transgression, continued and removed all vestiges of the fronting barrier islands.

Two relatively small sand bodies at the appropriate elevation are present near Springfield, in Effingham County. These sand bodies may be remnant Wicomico barrier islands. Immediately south of the Altamaha River a paleo-barrier island is seen at Jesup, in Wayne County. Further south in Charlton and Brantley Counties, a large sand body rims the older Trail ridge. Because the sands of the various Pleistocene barrier island shorelines cannot be differentiated, we could not determine whether the rimming sand body is a Wicomico deposit, or eroded from an older sand body (the Okefenokee Shoreline) or a combination of both processes. Definite scarps can be seen along Georgia Highway 23 in Charlton County, from the 90-95 foot elevation, up to the 125 foot elevation of the Okefenokee Shoreline, as well as down to the 70-75 foot elevation of the Penholoway Shoreline.

Penholoway Shoreline

Penholoway barrier island sand bodies are characterized by an elongate, linear morphology, and are relatively less dissected by paleo-drainage systems than are younger shorelines (Figure 3). This shoreline is composed of five main clusters of sand bodies ranging from 2.5 to 7.5 miles in width, separated by present day river courses. The elevation of the paleo-sea level was about 70 to 75 feet above present sea level. The Penholoway Shoreline is separated from the Wicomico Shoreline by a backbarrier lagoonal/estuarine environment which reaches a maximum width of about 12.5 miles in the Pembroke area of Bryan County, and about 15 miles south of Jesup, in Pierce County. Sand ridges in the southern backbarrier region may be intertidal shoals or beaches, as suggested by Huddlestun (personal communication).

In the southernmost part of Charlton County, the Penholoway Shoreline is manifested as a subtle terrace approaching the eastern edge of the Wicomico Shoreline. As in the case of the relationship between the Wicomico Shoreline and the Okefenokee Shoreline in this area, the erosion/deposition relationship between the Penholoway and Wicomico Shorelines is not clear.

The sand bodies of the Penholoway Shoreline north of the Altamaha River display a cuspate, relatively undissected configuration that, as discussed by Rhea (1986), is evidence of a wave-dominated regime, as opposed to the tide-dominated regime of the present coast. The northernmost Penholoway sand body in Georgia is terminated at its southern end by a large, low elevation sand body which may be a remnant inlet-mouth shoal system, such as those adjacent to present day barrier island inlets as described in Oertel (1972, 1979) and Kellam and Bonn (in preparation).

Talbot Shoreline

The Talbot Shoreline is a narrow band of sand deposits paralleling the Penholoway shoreline in four main clusters (Figure 4). Elevations range from about 40 to 50 feet above sea level. North of the Altamaha River, the Talbot exists as two relatively small paleobarrier islands developed on the seaward edge of the Penholoway Shoreline with little or no backbarrier region. On the seaward edge of the Talbot barrier island east of Pembroke, in Bryan County, an intricate, low relief sand lobe is present at an elevation of about 40 feet. This sand lobe may be a remnant of a shoal system similar to that seen seaward of Little St. Simons Island (Kellam and Bonn, in preparation). This shoal system is an extremely long, narrow, cuspate shoreline of about 0.5 to 1.5 miles in width and about 25 miles in length. South of the Altamaha River, Talbot paleobarrier islands are separated from the Penholoway Shoreline by a larger, but nevertheless narrow, backbarrier region; also south of the Altamaha, the Talbot exhibits a moderate amount of fluvial dissection.

Pamlico Shoreline

The Pamlico barrier island complex represents a paleo-shoreline much different from earlier shorelines (Figure 5). Although it occupies a large area within the coastal counties, individual sand bodies are generally much smaller than the older paleobarrier islands. There is a greater degree of fluvial dissection of the Pamlico-age features than is seen in the older complexes. The Pamlico backbarrier region is wide, 10 to 20 miles. Much of the backbarrier region is low enough (elevations of 15 to 25 feet) so that it was at or below sea level of that time (Huddlestun, 1988). Consequently, much of the backbarrier area may have

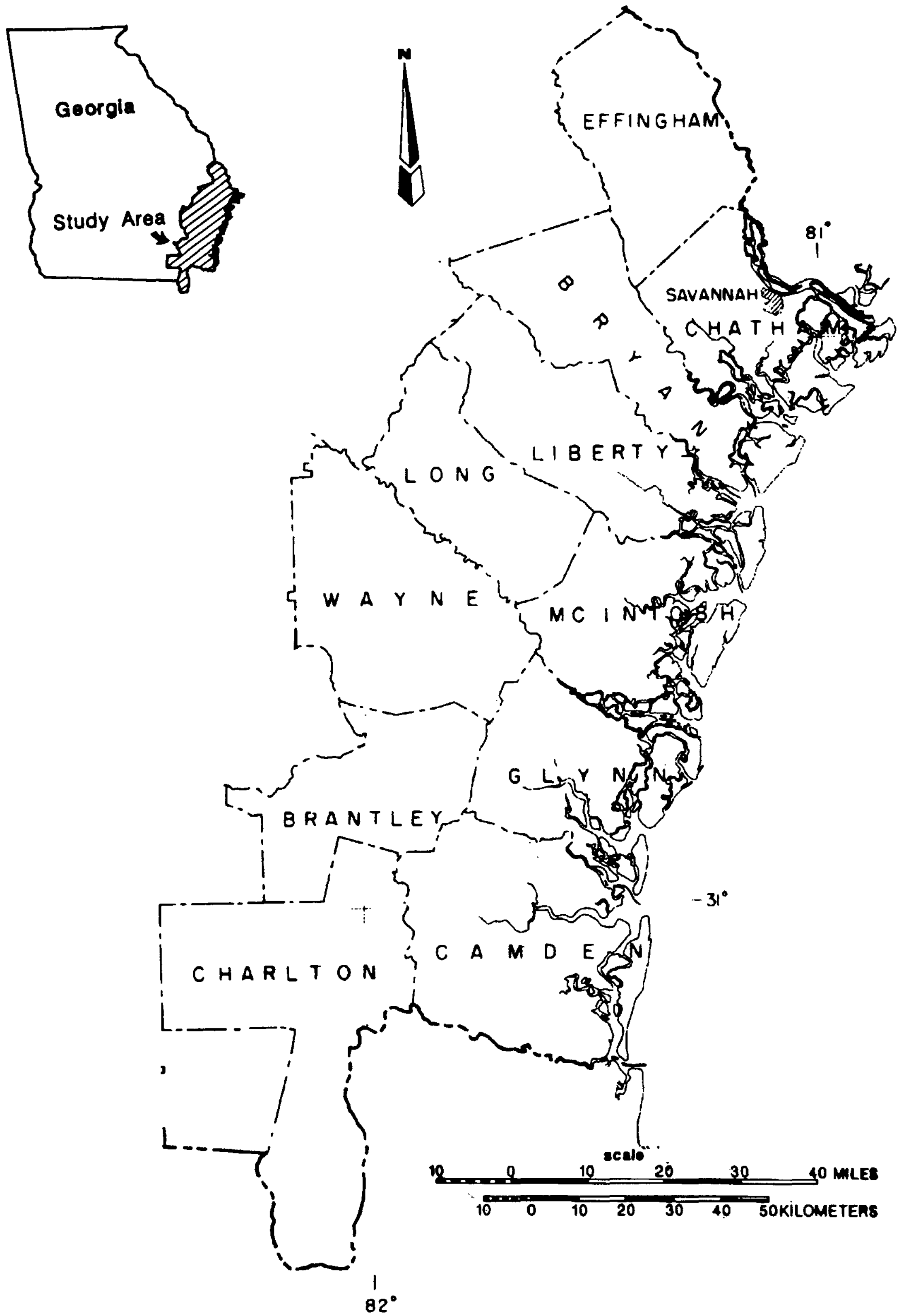

Figure 9. Location Map of Study Area.

been an open sound with fringing marsh. Within this area of paleo-backbarrier sound are a number of relatively small, poorly defined sand bodies with elevations at or slightly above Pamlico sea level. These may represent minor emergent islands or intertidal sand shoal systems.

Princess Anne Shoreline

Princess Anne paleobarrier shorelines, morphology and distribution are similar to that of the Pamlico Shoreline (Figure 6). That is, they are relatively small, stubby islands, complexly dissected by fluvial drainage systems. Paleo-sea level for Princess Anne sand bodies ranged around 10 to 15 feet above present sea level. In several places, Princess Anne sand bodies are welded directly onto the seaward edge of Pamlico paleobarrier islands. In others, a narrow strip of paleo-back barrier sediments separates the two shorelines. The Princess Anne Shoreline is poorly developed south of Brunswick, in Glynn and Camden Counties. Here it is present in small often poorly defined and intricately dissected sand bodies. The largest remnant sand bodies of the Princess Anne Shoreline border the Altamaha River on both the north and the south, suggesting a relatively significant influx of sediment derived from the Altamaha River during this time period.

Method of Study

Overview

The primary purpose of this study is to assess the ambient occurrence of heavy mineral sands using sampling traverses (Figure 10 and Plate 1) in order to provide a general assessment of the heavy mineral assemblages of the paleobarrier island complexes from the Wicomico age to Princess Anne age. The results of this study, therefore, will be a generalized model for the ambient occurrence of heavy mineral sands in Georgia paleobarrier island complexes.

This study is divided into three parts. Part one involves the collection of hand-augered samples at depths ranging from two to five feet depending on the thickness of the sand body and depth to the water table. The second part includes separating the heavy minerals from the light mineral fraction. Part three involves the petrologic analyses of these samples. The general results of these three parts were integrated and are reported herewith in the manuscript.

Field Methods

Sampling traverses were arranged in north-to-south and east-to-west directions depending on the sample's relative location on the sand body. The sampling equipment consisted of hand auger and shovel. Approximately 3 pounds of sand were collected for each sample. A total of 200 samples were collected along five east-west traverses (Figure 10, Plate A and also Appendix A). The five-foot maximum sample depth is based on local industry reconnaissance procedures. If fewer than 5 feet of potential ore sand are present, economic volumes of heavy minerals probably are not present. On the other hand, if more than 5 feet of sand are encountered, if economic concentrations of heavy minerals are present, and if the sand body is laterally extensive, the site is considered to have potential economic value. Coring of the sand body and collecting additional samples, however, would be required to evaluate ore body volume.

Laboratory Methods

All 200 samples were cleaned using standard sieving techniques as described by Carver (1971). For each sample, a >200 gram split was wet-sieved with a 230-mesh sieve to remove silt and clay. Each sample was dried, split to approximately 25 grams, weighed on a Mettler precision balance, and placed in a 250 milliliter separatory funnel filled with s-tetrabromethane (specific gravity = 2.97). Samples in the separatory funnels were stirred vigorously in order to allow a complete separation of the light and heavy mineral fractions. Heavy minerals were siphoned from the separatory funnel onto filter paper after 30 minutes. The sample was then stirred and the procedure repeated three times, until no dark heavy minerals were visible in the liquid. Acetone was used to clean each separatory funnel as well as the filter paper containing the heavy minerals. The heavy minerals were allowed to dry, and then weighed. The weight percentage of heavy minerals was calculated for each sample. Grain mount petrographic slides were made for 93 of the samples. Locations for these 93 samples are included in Appendix A. These samples were selected on the basis of two criteria: (1) 39 of the 42 samples with heavy mineral percentages of $\geq$1% were examined; and (2) for comparison, 54 were chosen from sites adjacent to and on the same sand body as those sites with $\geq$1%. (Table 1)

The use of a one percent cut-off for heavy mineral concentration was based on current industry exploration practices. Depending on the composition of the heavy mineral suites, two percent heavy minerals is the minimum concentration, generally used by industry as a minimum cut-off to determine potentially valuable areas, based on shallow and surface

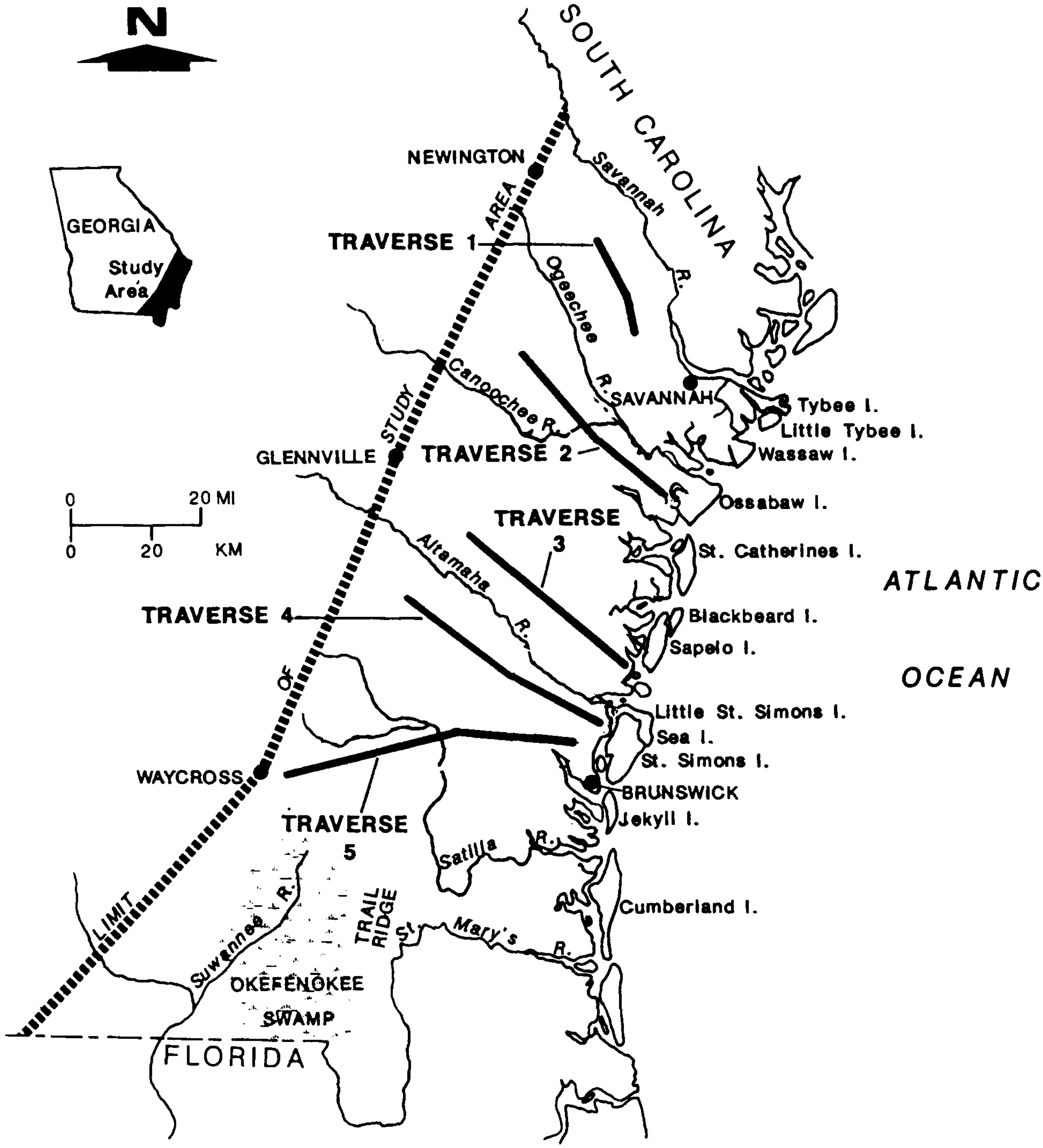

Figure 10. Generalized Traverse Map.

Table 1

Compilation of Results of the Present Study Illustrating the Number of Petrographically Examined Samples Containing < 1.0% Heavy Mineral Concentration, 1 to < 2% and ≥ 2.0%.

Heavy Mineral Content (% of grains)	Number of Samples	Mean Heavy Minerals %	Ferro-Titanium Minerals %	Radioactive Minerals %	Unstable/Other Minerals %
< 1.0%	54	0.59	48.89	7.74	43.37
1-2.0%	24	1.34	53.40	11.08	35.52
> 2.0%	15	4.65	55.54	11.50	32.96

93 Total Samples

sampling. Where <1% heavy minerals are found, no potentially economic deposits are considered to exist. Where ≥1% heavy minerals are found during reconnaissance sampling, a second, more thorough and detailed sampling program usually is initiated to further test the economic feasibility of the specific sand body.

Petrographic Analysis

Approximately 300 grains per slide were point-counted in order to estimate the percentages of each mineral present following Dryden (1931). Grains counted were those which fell on the crosshairs of each field-of-view. The mean was computed in order to compare concentration and suite for each discrete sand body. Prior to performing the petrographic analysis, reflected light was used to qualitatively assess the relative abundance of magnetite and other opaques versus ilmenite. This assessment indicated that the majority of opaques were ilmenite.

Results

General Statement

A brief description of the five shoreline complexes under investigation together with the results of this study are included in this section. Three mineral groups have been established to simplify the evaluation of the data. These groups can be characterized as follows: (1) ferro-titanium minerals (magnetite, ilmenite, leucoxene, and rutile), (2) radioactive minerals (zircon and monazite) and (3) less stable and other non-economic minerals (epidote, amphibole). The first two groups contain the heavy minerals of primary interest to industry.

Mean percentage of heavy minerals for the 93 samples petrographically analyzed are as follows: total heavy minerals, 1.44% by weight: ferro-titanium minerals, 51.16% of the heavy mineral fraction by grain count: radioactive minerals, 9.30% of the heavy mineral fraction grain count: and less stable/other minerals, 39.56% of the heavy mineral fraction by grain count. Appendix B shows a complete listing of the mineral constituents of the 93 samples petrographically examined. Fifteen of the 93 samples analyzed contained greater than 2 percent heavy minerals. Of these 15 samples, none was collected from the Wicomico shoreline, none was collected from the Penholoway shoreline, one was collected from the Talbot shoreline, ten were collected from the Pamlico shoreline, and four were collected from the Princess Anne shoreline. Table 2 is a summary of the ambient heavy mineral suite of the five barrier island complexes as estimated from the five traverses. (Note: seven of the 200 samples collected could not be assigned to a specific barrier complex. Three were collected along Traverse 1, two along Traverse 2 and two along Traverse 3. Their average heavy mineral percentage was 0.28%.)

In the present study, comparison of the heavy mineral suites for each of the five shoreline complexes shows several trends (Appendix B). There is a general increase in the percentage of leucoxene with increasing age of the sand body. The older deposits contain more mature heavy mineral suites dominated by altered ilmenite (leucoxene) and minerals that are generally relatively more resistant to weathering. A general decrease in the amount of epidote and amphibole from the Princess Anne to the Wicomico Shoreline also occurs. Smith and others, (1967) found that the titanium minerals contain less iron further west and near the surface, indicating the effects of chemical weathering. Another trend is the increase of titanium and radioactive minerals as percentages of heavy minerals increase. These trends suggest that the younger sands have less mature heavy mineral suites with relatively greater percentages of epidote and amphibole than the older deposits. Hails and Hoyt (1972) reported similar findings. No consistent heavy mineral suite or concentration trends in a north-to-south or east-to-west direction were observed for the individual sand bodies, indicating no systematic variation of heavy mineral concentration relative to the location of the sample sites within each sand body. For this reason, no definitive interpretation could be made regarding specific paleo-subenvironments and relative heavy mineral concentrations.

Wicomico Shoreline

Forty one samples collected along traverses 1, 2, 4, and 5 have an average heavy mineral percentage of 0.63% (Table 3). Thirteen samples collected along traverse 1 have an average heavy mineral percentage of 0.61%. One sample contained greater than one percent heavy minerals while the others contain less than one percent heavy minerals. Eight samples collected along traverse 2 have an average heavy mineral percentage of 0.19%, with no sample containing greater than one percent heavy minerals. Ten samples collected along traverse 4 have an average heavy mineral percentage of 0.67%. Only one sample from traverse 4 contained greater than one percent heavy minerals, the others contain less than one percent. Ten samples collected along traverse 5 have an average heavy mineral percent of 0.96%. Four samples contained greater than one percent heavy minerals, all others contain less than one percent.

Table 2

Summary of heavy mineralogy content of each barrier island complex. Number of petrographically examined samples in each barrier complex containing; < 1%, 1 to <2%, or $\geq$ 2% heavy minerals. See Appendix B for complete listing of data.

Barrier Complex	Heavy Mineral Content (WT %)	Number of Samples	Average Heavy Minerals %	Ferro-Titanium Minerals %	Radioactive Minerals %	Unstable/Other Minerals %
Princess Anne	< 1.0%	14	0.72	44.65	6.16	49.18
	1-2.0%	9	1.35	49.45	8.94	41.61
	> 2.0%	4	5.09	59.70	13.08	27.23
Pamlico	< 1.0%	8	0.74	48.63	8.12	43.24
	1-2.0%	6	1.39	51.21	9.40	39.39
	> 2.0%	10	4.05	52.76	10.96	36.28
Talbot	< 1.0%	10	0.48	49.19	8.61	42.20
	1-2.0%	1	1.18	67.18	14.11	18.71
	> 2.0%	1	8.84	67.00	18.00	15.00
Penholoway	< 1.0%	11	0.42	49.16	7.85	42.98
	1-2.0%	2	1.15	48.98	10.83	40.20
	> 2.0%	0	-	-	-	-
Wicomico	< 1.0%	11	0.59	53.97	8.63	37.39
	1-2.0%	6	1.36	61.01	15.57	23.42
	> 2.0%	0	-	-	-	-

93 Total Samples

Table 3

Heavy Mineral Suite of the Wicomico Complex.

Total heavy mineral sand fraction (by weight %) with Titanium, Radioactive and Unstable/Other mineral fractions (by point count %)

Traverse Number	Number of Samples	Heavy Mineral Fraction (WT %)	Samples Petrographically Analyzed	Titanium Mineral Fraction (%)	Radioactive Mineral Fractions Zircon (%)	Radioactive Mineral Fractions Monazite (%)	Unstable/Other Mineral Fraction (%)
1	13	0.61	6	53.62	6.31	0.50	39.55
2	8	0.19	No samples analyzed for constituents				
3	-	-	No samples collected on traverse 3				
4	10	0.67	5	58.55	8.96	0.39	32.11
5	10	0.96	6	57.55	15.40	1.38	25.67
Totals	41 Samples	0.63	17 Samples				

Of the total 41 samples, 17 samples collected along traverses 1, 4, and 5 were analyzed for their heavy mineral constituents (Appendix B). Eleven samples contain less than one percent heavy minerals, six samples contain less than one to two percent, and no samples contain greater than two percent heavy minerals (Table 2). As the heavy mineral content increases, so do the percentages of titanium and radioactive minerals. Both the titanium minerals and radioactive minerals are more abundant in samples collected south of the Altamaha River than in those collected adjacent to the Savannah River.

Penholoway Shoreline

Fifty-six samples collected along traverses 1, 2, 3, and 4 have an average heavy mineral percentage of 0.49 % (Table 4). Sixteen samples collected along traverses 1 have an average heavy mineral percentage of 0.44%. Only one sample contained greater than 1 percent heavy minerals. The seventeen samples collected along traverse 2 have an average heavy mineral percentage of 0.56%. Only one sample contained more than 1 percent heavy minerals. Thirteen samples collected along traverse 3 have an average heavy mineral percentage of 0.42%, none of which contained greater than one percent heavy minerals. Ten samples collected along traverse 4 have an average heavy mineral percentage of 0.56%. One sample contained greater than one percent heavy minerals.

Of the 56 Penholoway samples, 13 collected along traverses 1 and 4 were analyzed for their constituents (Appendix B). There is a slight decrease in the percentage of titanium minerals as the percentage of heavy minerals increases in the Penholoway samples (Table 4). The average percentage of radioactive minerals increases as the percentage of heavy minerals increases (Table 2). Only two of the three samples containing greater than one percent heavy minerals were analyzed. The overall heavy minerals percentages, as well as the percentages of titanium minerals, are lower than those of the Wicomico. No distinctive trend in variation of mineralogy is seen from north and south in the Penholoway complex.

Talbot Shoreline

A total of 44 samples collected along traverses 1-5 have an average heavy mineral percentage of 0.63% (Table 5). Fifteen samples collected along traverse 1 have an average heavy mineral percentage of 0.23%, but none contain greater than one percent heavy minerals. Nine samples collected along traverse 2 have an average heavy mineral percentage of 1.68%. Two of these samples contain over one percent heavy minerals. Five samples collected along traverse 3 have an average heavy mineral percentage of 0.14%, none of which contain greater than one percent heavy minerals. Seven samples collected along traverse 4 have an average heavy mineral percentage of 0.95%. Two samples contain greater than one percent heavy minerals. Eight samples collected along traverse 5 have an average heavy mineral percentage of 0.21%, none of which contain greater than one percent heavy minerals. Of these 44 samples, 12 samples collected along traverses 1, 2, and 4 were analyzed for their heavy mineral constituents. Only two of the four samples containing greater than one percent were analyzed (Appendix B).

The Talbot trend reflects an increase in overall heavy mineral fraction to the south. The Talbot samples directly south of the Savannah River, in traverse 1, have low overall heavy mineral percentages (0.25%) as well as low titanium constituent concentrations (42.47). Both percentages show a marked increase in traverse 2, (1.68 and 57.16 respectively). The average heavy mineral content for samples collected directly south of the Altamaha River along traverse 4 is much greater than the heavy mineral content of samples collected along traverse 1. Likewise, the average percentage of radioactive minerals in samples collected along traverse 4 is almost double the abundance of radioactive minerals in samples from traverse 1. The mineral monazite is three times more abundant in samples from traverse 4 than in samples from traverse 1.

Pamlico Shoreline

A total of 25 samples collected along the traverses 2-5 have a mean heavy mineral percentage of 2.20% (Table 6). Seven samples collected along traverse 2 have an average heavy mineral content of 2.45%. Five samples contain greater than one percent heavy minerals, the others contain less than one percent heavy minerals. Three samples collected along traverse 3 have a mean heavy mineral percentage of 4.69%. Two of these samples contain greater than one percent, the other sample contains 0.65%. Eight samples collected along traverse 4 have an average heavy mineral percentage by weight of 2.11%. Six of these samples contain greater than one percent heavy minerals. Seven samples collected along traverse 5 have an average heavy mineral percentage (by weight) of 0.97%. Three samples contain greater than one percent heavy minerals, the rest contain less than one percent heavy minerals.

Of the total of 25 samples collected along the Pamlico Shoreline complex, 24 samples were analyzed

Table 4

Heavy Mineral Suite of the Penholoway Complex.

Total heavy mineral sand fraction (by weight %) with Titanium, Radioactive and Unstable/Other mineral fractions (by point count %)

Traverse Number	Number of Samples	Heavy Mineral Fraction (WT %)	Samples Petrographically Analyzed	Titanium Mineral Fraction (%)	Radioactive Mineral Fractions		Unstable/Other Mineral Fraction (%)
					Zircon (%)	Monazite (%)	
1	16	0.44	7	49.77	8.07	0.66	41.50
2	17	0.56	No samples analyzed for constituents				
3	13	0.42	No samples analyzed for constituents				
4	10	0.56	6	48.38	7.55	0.28	43.80
5	-	-	No samples collected on Traverse 5				
Totals	56 Samples	0.49	13 Samples				

Table 5

Heavy Mineral Suite of the Talbot Complex.

Total heavy mineral sand fraction (by weight %) with Titanium, Radioactive and Unstable/Other mineral fractions (by point count %)

Traverse Number	Number of Samples	Heavy Mineral Fraction (WT %)	Samples Petrographically Analyzed	Titanium Mineral Fraction (%)	Radioactive Mineral Fractions		Unstable/Other Mineral Fraction (%)
					Zircon (%)	Monazite (%)	
1	15	0.23	5	42.47	7.16	0.20	50.16
2	9	1.68	5	57.16	9.53	1.28	32.03
3	5	0.14	No samples analyzed for constituents				
4	7	0.95	2	63.96	12.95	0.76	22.35
5	8	0.21	No samples analyzed for constituents				
Totals	44 Samples	0.63	12 Samples				

Table 6

Heavy Mineral Suite of the Pamlico Complex.

Total heavy mineral sand fraction (by weight %) with Titanium, Radioactive and Unstable/Other mineral fractions (by point count %)

Traverse Number	Number of Samples	Heavy Mineral Fraction (WT %)	Samples Petrographically Analyzed	Titanium Mineral Fraction (%)	Radioactive Mineral Fractions: Zircon (%)	Radioactive Mineral Fractions: Monazite (%)	Unstable/Other Mineral Fraction (%)
1	-	-	No samples collected on Traverse 1				
2	7	2.45	7	52.86	8.08	1.31	37.74
3	3	4.69	3	46.28	9.97	1.06	42.68
4	8	2.11	8	56.21	8.27	1.32	34.21
5	7	0.97	6	44.23	7.46	1.79	46.53
Totals	25 Samples	2.20	24 Samples				

Table 7

Heavy Mineral Suite of the Princess Anne Complex.

Total heavy mineral sand fraction (by weight %) with Titanium, Radioactive and Unstable/Other mineral fractions (by point count %)

Traverse Number	Number of Samples	Heavy Mineral Fraction (WT %)	Samples Petrographically Analyzed	Titanium Mineral Fraction (%)	Radioactive Mineral Fractions Zircon (%)	Radioactive Mineral Fractions Monazite (%)	Unstable/Other Mineral Fraction (%)
1	-	-	No samples collected on Traverse 1				
2	6	0.94	6	45.07	5.66	1.62	47.65
3	13	1.85	13	49.53	7.80	1.80	40.87
4	8	1.61	8	49.33	4.61	1.71	44.33
5	-	-	No samples collected on Traverse 5				
Totals	27 Samples	1.58	27 Samples				

for their heavy mineral constituents. Ten of these 24 samples had >2% heavy minerals. Six samples contained 1-2% percent heavy minerals and eight samples contained less than one percent heavy minerals (Table 2).

Pamlico sand bodies, in general have higher concentrations of heavy minerals than the older terrace sands. The second traverse shows an overall heavy mineral percent of 2.45%, with high percentages of titanium and radioactive minerals. The percentages of heavy minerals also are relatively high along traverses 3 and 4, but overall heavy mineral and titanium bearing mineral fractions decrease along traverse 5 (See Appendix B).

Princess Anne Shoreline

A total of 27 samples collected along traverses 2, 3, and 4 were analyzed for heavy mineral constituents. They contain an overall heavy mineral percentage by weight of 1.58% (Table 7). Titanium minerals make up 48.47% of the heavy mineral suite, and the radioactive minerals account for 8.11% (Appendix B).

Six samples collected along traverse 2 have an average heavy mineral percentage of 0.94% (Table 7). Two samples contain greater than one percent heavy minerals. Thirteen samples collected along traverse 3 have an average heavy mineral percentage by weight of 1.85%. Eight of these samples contain greater than one percent heavy minerals. The five remaining samples contain less than one percent heavy minerals (Appendix B). Eight samples collected along traverse 4 have a mean average heavy mineral percentage by weight of 1.61%. Three samples contain greater than one percent heavy minerals, the others contain less than one percent.

In samples from Princess Anne sand bodies, the overall heavy mineral concentration (1.58%) is somewhat lower than that of the Pamlico sand bodies (2.20%). In the Princess Anne Shoreline as a whole the percentage of titanium and radioactive minerals increases as overall heavy mineral percentage increases (Table 2). however, no systematic mineralogic trend occurs in a north-to-south direction.

Conclusions

The present study considers heavy mineral data from the surface down to depths of five feet over a broad area of the Atlantic Coastal Plain in Georgia. Several conclusions can be drawn from these data.

(1) Approximately 21% of the 200 samples analyzed contained >1% heavy minerals.

(2) Where trends can be detected, percentages of titanium minerals and radioactive minerals generally increase as heavy mineral content of the sand increases.

(3) Older Pleistocene deposits contain mature heavy mineral suites with relative increases of titanium-bearing minerals and zircon. The titanium-bearing suite is enriched in titanium due to leaching of iron from ilmenite with concomitant increase in leucoxene. Monazite fractions decrease from the younger to the older shorelines. The less stable and generally less valuable minerals, such as epidote, amphiboles and staurolite, tend to weather more rapidly and are relatively less abundant in older shorelines.

(4) No definite overall patterns for the variations in the heavy mineral suite and concentration were detected in a north-to-south direction in the shorelines of the study area. Samples from traverse 1, south of and adjacent to the Savannah River, generally contain lower total heavy mineral concentration than those from traverse 4, south of and adjacent to the Altamaha River. This may indicate a variation in the mineralogy of the provenances of the two rivers, or could reflect a variation in the depositional dynamics of the paleo-Altamaha and paleo-Savannah Rivers. Samples from traverse 2, adjacent to the Ogeechee River, are generally more economically valuable than those of traverse 1, with overall relatively higher total heavy mineral fractions (Appendix B). It can be speculated that the higher concentrations of heavy minerals in traverse 2 are a result of a greater degree of reworking and maturation of sediments on traverse 2, down longshore current from traverse 1. This effect is seen on a smaller scale in the modern Altamaha Sound (Kellam and Bonn, in preparation).

(5) The Pamlico and the Princess Anne shorelines contain appreciably higher total heavy mineral fractions than are found in the older complexes. Of the five barrier island shorelines, the Pamlico shoreline contains the greatest number of samples with heavy minerals concentrations in the potentially economic range (≥1%).

(6) The older shorelines, from Talbot to Wicomico-age, show a more variable distribution of economically valuable heavy mineral concentrations than in the Pamlico and Princess Anne shorelines. The Talbot complex yielded the smallest number of sample sites with heavy mineral concentrations, and appears to be the least promising in regard to locating minable heavy mineral deposits; on the other hand the Penholoway and Wicomico shorelines appears more favorable for locating potentially minable sites.

(7) There is no consistent, overall pattern of heavy mineral distribution within individual sand bodies. The general lack of discernible sedimentary structures in the Pleistocene paleo-barrier island complexes renders paleo-environmental interpretations difficult if not impossible. Systematic variations in heavy mineral suites and concentration did not occur in the samples collected within each discrete sand body.

(8) In general, the more economically favorable heavy mineral concentrations in the three older shorelines are clustered in the southern portion of the study area.

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Appendix A

Heavy Mineral Sample Locations

Traverse #1 - From Springfield to Savannah

SAMPLE NUMBER	LOCATION	LATITUDE LONGITUDE	HEAVY MINERAL %
T1-1	Approx. 2 miles south of Pineora. 100 ft north of Midland Rd. on dirt road called Helmey Rd.	N32 16'04" W81 22'12"	1.56
T1-2	Intersection of Midland Rd. and dirt road which parallels Wicomico on map	N32 15'40" W81 21'52"	0.59
T1-3	1/4 mile off same dirt road next to crossing of logging road	N32 17'31" W81 20'08"	0.65
T1-4	1/4 mile west of T1-3	N32 17'44" W81 20'19"	0.50
T1-5	2 1/4 miles north of T1-4	N32 19'32" W81 19'44"	0.89
T1-6	1/4 mile SE of T1-5	N32 19'18" W81 19'22"	0.64
T1-7	1/4 mile SE of T1-6	N32 19'10" W81 19'34"	0.67
T1-8	1 mile NE of T1-7	N32 19'28" W81 18'16"	0.39
T1-9	About 1/3 mile north of T1-8	N32 19'46" W81 18'16"	0.70
T1-10	1 1/2 miles north of T1-9	N32 21'06" W81 18'30"	0.50
T1-11	2 miles SE of T1-8 at intersection of McCall Rd. and Little McCall Rd.	N32 17'58" W81 17'15"	0.33
T1-12	1/4 mile SE of T1-11	N32 17'41" W81 16'56"	1.10
T1-13	1/4 mile SE of T1-12	N32 17'23" W81 16'30"	0.35
T1-14	1/4 mile SE of T1-13	N32 16'58" W81 16'14"	0.47

Appendix A (cont.)

SAMPLE NUMBER	LOCATION	LATITUDE LONGITUDE	HEAVY MINERAL %
T1-15	1/4 mile SE of T1-14	N32 16'40" W81 15'50"	0.54
T1-16	1 1/2 miles SE of T1-15	N32 15'52" W81 14'38"	0.35
T1-17	1 mile SE of T1-16	N32 15'22" W81 13'45"	0.19
T1-18	3/4 mile east of T1-17	N32 15'19" W81 13'06"	0.24
T1-19	about 4 miles west of T1-17 just above Blandford Rd.	N32 15'08" W81 17'56"	0.48
T1-20	2 1/2 miles SW of T1-19	N32 13'50" W81 19'58"	0.59
T1-21	a little over 5 miles south of T1-20	N32 09'27" W81 20'37"	0.40
T1-22	on Hwy. 17 about 1/4 mile NW of T1-21	N32 09'50" W81 20'48"	0.29
T1-23	about 1 mile NW of T1-22	N32 10'44" W81 21'10"	0.20
T1-24	1 mile West of T1-23	N32 10'31" W81 20'14"	0.43
T1-25	2 miles NW of T1-23	N32 12'17" W81 21'39"	0.35
T1-26	1/3 mile SE of T1-25	N32 12'05" W81 21'15"	0.33
T1-27	1/3 mile SE of T1-26	N32 11'48" W81 20'50"	0.44
T1-28	3/4 mile SE of T1-27	N32 11'34" W81 20'13"	0.19
T1-29	1 1/3 miles east of T1-28	N32 11'06" W81 19'10"	0.16
T1-30	2 miles NE of T1-29	N32 12'02" W81 17'31"	0.28

Appendix A (cont.)

SAMPLE NUMBER	LOCATION	LATITUDE LONGITUDE	HEAVY MINERAL %
T1-31	3/4 mile NW of T1-30	N32 12'30" W81 18'03"	0.23
T1-32	1 1/2 miles east of T1-31	N32 12'44" W81 16'39"	0.16
T1-33	1 miles NE of T1-32	N32 13'12" W81 15'43"	0.25
T1-34	1 3/4 miles NE of T1-33	N32 14'14" W81 14'35"	0.22
T1-35	a little over 2 miles NE of T1-34	N32 15'00" W81 12'39"	0.21
T1-36	Hwy. 119 between Guyton and Springfield	N32 21'04" W81 20'53"	0.31
T1-37	about 2 miles north of Rincon	N32 19'57" W81 13'25"	0.36
T1-38	Hwy. 119 about 2 miles NE of Springfield	N32 24'28" W81 16'45"	0.27
T1-39	Hwy. 119 about 1 mile north of Springfield	N32 23'15" W81 19'33"	0.27
T1-40	Hwy. 30 about 4 miles NW of Bloomingdale	N32 11'36" W81 20'05"	0.25
T1-41	east side of Hwy. 17 about 1 1/2 miles SW of T1-40	N32 10'27" W81 20'58"	0.42
T1-42	Hwy. 119 immediately west of Guyton	N32 19'29" W81 24'11"	0.42
T1-43	1 mile west of T1-42	N32 19'26" W81 25'25"	0.30
T1-44	3 miles SW of T1-43	N32 17'21" W81 27'45"	0.19
T1-45	2 miles east of T1-22	N32 09'39" W81 18'33"	0.36
T1-46	2 miles east of T1-21	N32 09'18" W81 18'49"	0.10

Appendix A (cont.)

SAMPLE NUMBER	LOCATION	LATITUDE LONGITUDE	HEAVY MINERAL %
T1-47	2 miles east of T1-45	N32 09'55" W81 16'16"	0.33
Traverse #2 - from Pembroke to Kilkenny			
T2-1	1 1/2 miles NE of Ellabell	N32 08'36" W81 28'19"	0.46
T2-2	5 miles SE of T2-1 immediately west of Hwy. 204	N32 05'43" W81 25'31"	0.57
T2-3	1/5 mile west of T2-2	N32 05'45" W81 25'45"	0.76
T2-4	2 miles west of T2-3	N32 05'31" W81 27'31"	8.84
T2-5	1 mile west of T2-2	N32 05'49" W81 26'30"	0.59
T2-6	1/4 mile west of T2-3	N32 05'54" W81 26'09"	0.62
T2-7	2 miles north of T2-1	N32 10'20" W81 28'37"	1.12
T2-8	1 1/2 miles SE of T2-1	N32 07'47" W81 27'07"	0.80
T2-9	3/4 mile east of T2-8	N32 07'42" W81 26'29"	0.77
T2-10	1/2 miles north of T2-3	N32 06'11" W81 25'40"	1.19
T2-11	1 miles north of T2-10 where powerline intersects Hwy. 204	N32 06'55" W81 25'59"	0.99
T2-12	approximately 3 miles west of T2-11	N32 07'06" W81 29'08"	0.39
T2-13	1/2 mile south of T2-12	N32 06'43" W81 29'02"	0.96
T2-14	1 1/4 miles SE of T2-13	N32 05'57" W81 27'58"	0.60

Appendix A (cont.)

SAMPLE NUMBER	LOCATION	LATITUDE LONGITUDE	HEAVY MINERAL %
T2-15	1/5 mile NW of T2-14	N32 06'09" W81 28'09"	0.25
T2-16	3/4 mile NW of T2-15	N32 06'34" W81 28'43"	0.45
T2-17	1/2 mile north of T2-12	N32 07'31" W81 29'11"	0.82
T2-18	1 1/8 miles west of T2-17	N32 07'29" W81 30'14"	0.43
T2-19	1/2 mile south of T2-18	N32 07'05" W81 30'21"	0.74
T2-20	1 3/4 miles south of T2-19	N32 05'40" W81 30'20"	0.83
T2-21	1/4 mile east of T2-20	N32 05'39" W81 30'07"	0.31
T2-22	little over 2 miles north of Pembroke	N32 10'03" W81 37'12"	0.16
T2-23	1/4 mile east of T2-22	N32 09'58" W81 36'49"	0.17
T2-24	1/4 mile east of T2-23	N32 09'57" W81 36'30"	0.22
T2-25	1 1/5 miles east of T2-24	N32 10'00" W81 35'14"	0.20
T2-26	1 mile south of T2-23	N32 09'05" W81 37'00"	0.17
T2-27	1 1/5 miles NE of T2-24	N32 10'51" W81 35'49"	0.19
T2-28	1/4 mile NW of T2-27	N32 11'01" W81 35'59"	0.19
T2-30	approximately 1 1/4 miles south of Kilkenny	N31 46'27" W81 12'29"	0.95
T2-31	1/2 way between T2-30 and Kilkenny	N31 46'48" W81 12'23"	1.64

Appendix A (cont.)

SAMPLE NUMBER	LOCATION	LATITUDE LONGITUDE	HEAVY MINERAL %
T2-32	400 yards north of Kilkenny on small dirt road	N31 47'37" W81 12'14"	0.68
T2-33	just to the west of Belle Island	N31 46'02" W81 13'42"	0.64
T2-34	1 mile north of T2-33	N31 46'55" W81 13'22"	1.04
T2-35	3/4 mile north of T2-34	N31 47'33" W81 12'52"	0.71
T2-36	1 mile west of T2-35	N31 47'57" W81 13'47"	0.87
T2-37	1 mile west of T2-36 on Kilkenny Road	N31 48'15" W81 14'42"	4.26
T2-38	intersection of Cottonham Trail and Oak Level Trail immediately east of Richmond Hill	N31 51'18" W81 12'40"	2.59
T2-39	on Cottonham Trail near gate to the Redbird Creek Hunting Club	N31 51'35" W81 12'12"	0.96
T2-40	on Jake Brown Trail 3/4 miles south of T2-39	N31 50'46" W81 12'57"	1.83
T2-41	on Jake Brown Trail 1 mile south T2-40	N31 49'52" W81 13'17"	2.21
T2-42	On Jake Brown Trail 1 mile south T2-41	N31 48'58" W81 14'03"	4.44
T2-43	1 mile north of Ellabell at sand pit	N32 08'13" W81 29'23"	0.12
T2-44	2 miles south of Blitchton	N32 10'23" W81 25'49"	0.55
T2-45	1 mile SE of T2-44	N32 09'40" W81 25'26"	0.29
T2-46	1/4 mile south of T2-45	N32 09'28" W81 25'24"	0.68
T2-47	1/4 mile south of T2-46	N32 09'08" W81 25'22"	0.51

SAMPLE NUMBER	LOCATION	LATITUDE LONGITUDE	HEAVY MINERAL %
T2-48	200 yards east of T2-24	N32 10'01" W81 36'27"	0.24
T2-49	6 miles NW of Pembroke	N32 11'51" W81 43'56"	0.24
T2-50	3 miles south of T2-49	N32 09'22" W81 44'22"	0.21
Traverse #3 - from Ludowici to Meridian			
T3-1	in Meridian along Hwy. 99 on dirt road located on Ridgeville Quad.	N31 27'08" W81 22'43"	0.96
T3-2	same dirt road 1/4 mile from T3-1	N31 27'19" W81 22'57"	0.58
T3-3	same dirt road 1/4 mile from T3-2	N31 27'29" W81 23'35"	1.48
T3-4	same dirt road 1/4 mile from T3-3	N31 27'34" W81 24'05"	0.36
T3-5	same dirt road 1/4 mile from T3-4	N31 27'28" W81 24'32"	10.52
T3-6	same dirt road 1.4 mile from T3-5	N31 27'31" W81 25'12"	2.90
T3-7	on old Barrington Rd. north of Hwy. 99 (also called Hwy. 57) where powerline crosses road.	N31 40'05" W81 41'56"	0.33
T3-8	1/3 mile north of T3-7	N31 40'30" W81 41'49"	0.29
T3-9	3/4 mile NE of T3-8	N31 40'50" W81 41'11"	0.80
T3-10	1 mile SE of T3-9	N31 40'13" W81 40'14"	0.67
T3-11	1 mile north of T3-10	N31 40'59" W81 40'03"	0.77

Appendix A (cont.)

SAMPLE NUMBER	LOCATION	LATITUDE LONGITUDE	HEAVY MINERAL %
T3-12	1/4 mile east of T3-11	N31 40'56" W81 39'45"	0.41
T3-13	3/4 mile east of T3-12	N31 40'55" W81 39'01"	0.33
T3-14	1/4 mile east of T3-13 on Curry Ford Rd.	N31 41'07" W81 38'29"	0.14
T3-15	1/2 mile east of T3-14	N31 41'11" W81 38'51"	0.21
T3-16	1/2 mile south of T3-15	N31 40'43" W81 38'07"	0.29
T3-17	1/3 mile south of T3-16	N31 40'21" W81 38'15"	0.43
T3-18	on Reedie Branch Rd. 1/4 mile off Tibet Rd. 1 1/2 miles north of T3-15	N31 42'17" W81 38'05"	0.34
T3-19	intersection of Tibet Rd. and powerline 1 1/2 miles north of T3-18	N31 43'25" W81 37'41"	0.42
T3-20	intersection of Nunnery Place Rd. and Tibet Rd. 1 1/2 miles SE of T3-17	N31 39'51" W81 36'58"	0.17
T3-21	Tibet Rd. 2 miles north of Hwy. 99	N31 38'00" W81 36'51"	0.08
T3-22	1 mile SE of T3-21 east of Tibet Rd.	N31 37'32" W81 35'50"	0.11
T3-23	3/4 mile south of T3-22 in NW corner of Townsend Quad.	N31 36'57" W81 36'07"	0.16
T3-24	south side of Hwy. 99 in sand pit 1 1/2 miles south of T3-23	N31 35'55" W81 36'03"	0.16
T3-25	in Meridian just on east side of Hwy. 99	N31 27'03" W81 22'32"	0.48
T3-26	intersection on Hwy. 99 with road leading east to Sapelo Dock	N31 27'41" W81 22'12"	0.90

Appendix A (cont.)

SAMPLE NUMBER	LOCATION	LATITUDE LONGITUDE	HEAVY MINERAL %
T3-27	on Hwy. 99 on north side of Hudson Cemetery	N31 26'49" W81 22'57"	1.38
T3-28	on dirt road leading east from Carnigan off Hwy. 99	N31 25'48" W81 23'19"	2.44
T3-29	on paved road leading east to marina from Ridgeville	N31 24'30" W81 23'53"	1.88
T3-30	1 1/2 miles SW of T3-29 on road connecting Hwys. 17 and 99	N31 23'36" W81 25'04"	1.01
T3-31	3/4 mile west of T3-30 100 ft. east of Hwy. 17	N31 23'35" W81 25'51"	1.25
T3-32	2 1/2 miles north of T3-31 on Hwy. 17	N31 25'15" W81 25'44"	9.89
T3-33	1 mile south of T3-32	N31 24'28" W81 25'55"	1.42
T3-34	1/6 mile east of *I-95* 3/4 mile west of T3-31	*N31 23'38"* W81 26'45"	*0.65*
T3-35	3 miles NE of Ludowici	N31 43'40" W81 41'50"	0.35
T3-36	3 miles SE of Ludowici	N31 40'59" W81 42'11"	0.28

Traverse #4 - from Jesup to Brunswick

SAMPLE NUMBER	LOCATION	LATITUDE LONGITUDE	HEAVY MINERAL %
T4-1	Hwy. 301 south of Jesup on powerline	N31 34'30" W81 52'39"	0.50
T4-2	approximately 1/4 mile west of T4-1 just east of Palm Street	N31 34'48" W81 53'12"	0.38
T4-3	on S. Brunswick Rd. 3 telephone poles from railroad tracks	N31 34'55" W81 53'28"	0.79
T4-4	on powerline 4 poles from T4-1	N31 35'04" W81 53'40"	0.73
T4-5	taken next to railroad tracks which parallel Macon St.	N31 35'15" W81 53'13"	0.97

Appendix A (cont.)

SAMPLE NUMBER	LOCATION	LATITUDE LONGITUDE	HEAVY MINERAL %
T4-6	between Sunset Blvd. and Macon St.	N31 35'32" W81 54'25"	1.06
T4-7	on powerline in Mt. Pleasant on 25 ft. contour	N31 24'55" W81 40'39"	0.47
T4-8	approximately 1/4 mile from T4-7	N31 25'01" W81 40'50"	0.88
T4-9	approximately 1/4 mile from T4-8	N31 25'13" W81 41'03"	1.82
T4-10	approximately 1/4 mile from T4-9	N31 25'17" W81 41'09"	0.92
T4-11	dirt road off Post Rd. where T4-3 and T4-4 were taken	N31 25'25" W81 41'16"	0.55
T4-12	Jet Port Rd. in Brunswick just west of Hwy. 17	N31 16'43" W81 26'29"	0.58
T4-13	Jet Port Rd. beginning of first curve	N31 16'38" W81 26'52"	0.46
T4-14	approximately 1/4 mile west from T4-13	N31 16'46" W81 27'22"	0.97
T4-15	approximately 1/4 mile west from T4-14	N31 16'40" W81 27'41"	3.86
T4-16	at right angle turn in Jet Port Rd.	N31 16'27" W81 27'58"	4.15
T4-17	between Brunswick-Altamaha Canal Rd. and Petersville Rd.	N31 16'43" W81 28'23"	1.07
T4-18	1/4 mile west from T4-17	N31 16'43" W81 28'42"	0.86
T4-19	1/4 mile west from T4-18	N31 16'44" W81 28'59"	0.96
T4-20	on Canal Rd. about 500 yards east of I-95	N31 15'44" W81 29'25"	1.15
T4-21	on Canal Rd. about 50 yards off I-95	N31 15'53" W81 29'35"	2.49

Appendix A (cont.)

SAMPLE NUMBER	LOCATION	LATITUDE LONGITUDE	HEAVY MINERAL %
T4-22	intersection of Cate Rd. and Canal Rd.	N31 16'05" W81 29'43"	4.09
T4-23	Canal Rd. about 100 ft. east of intersection with Cate Rd.	N31 16'10" W81 29'53"	0.31
T4-24	1/4 mile west of T4-23	N31 16'23" W81 30'02"	4.80
T4-25	1/4 mile west of T4-24	N31 16'43" W81 30'29"	0.78
T4-26	Canal Rd. 1/4 mile west of intersection with Hwy. 99	N31 16'56" W81 30'38"	1.63
T4-27	intersection of Canal and Race Horse Rds.	N31 17'13" W81 31'02"	1.65
T4-28	2 miles south of Hwy 341 from Grangerville on powerline	N31 27'29" W81 43'48"	0.27
T4-29	1/4 mile NW of T4-28	N31 27'36" W81 43'58"	0.46
T4-30	1/4 mile NW of T4-29	N31 27'40" W81 44'06"	0.40
T4-31	1/4 mile NW of T4-30	N31 28'00" W81 44'27"	0.46
T4-32	1/4 mile NW of T4-31	N31 28'09" W81 44'38"	1.19
T4-33	1/4 mile NW of T4-32	N31 28'23" W81 44'57"	0.90
T4-34	1/4 mile NW of T4-33	N31 28'33" W81 45'07"	0.51
T4-35	1/4 mile NW of T4-34	N31 28'43" W81 45'16"	0.42
T4-36	intersection of Hwy. 301 and Sunset Blvd. south of Jesup	N31 33'51" W81 53'26"	0.52
T4-37	Jesup Airport Rd. at end of runway	N31 33'02" W81 52'52"	0.62

Appendix A (cont.)

SAMPLE NUMBER	LOCATION	LATITUDE LONGITUDE	HEAVY MINERAL %
T4-38	about 1/4 mile west of T4-37	N31 33'11" W81 53'35"	0.58
T4-39	about 2 miles south of T4-38	N31 31'52" W81 54'15"	0.57
T4-40	Dirt road leading south from Grangerville	N31 28'49" W81 44'12"	0.35
T4-41	Dirt road leading south from Grangerville	N31 27'04" W81 44'35"	0.62
T4-42	Post Rd. leading south from Mt. Pleasant	N31 23'31" W81 41'54"	0.83
T4-43	Sansatilla Rd. leading north from Mt. Pleasant	N31 27'00" W81 40'29"	1.18

Traverse #5 - through Nahunta and Waynesville along Hwy. 82

SAMPLE NUMBER	LOCATION	LATITUDE LONGITUDE	HEAVY MINERAL %
T5-1	Old Post Rd. just east of Waynesville between Golden Isle speedway and railroad tracks	N31 14'18" W81 45'30"	0.57
T5-2	1/4 mile south of T5-1	N31 10'08" W81 45'31"	0.32
T5-3	1/4 mile south of T5-2	N31 13'55" W81 45'33"	0.07
T5-4	1/4 mile south of T5-3	N31 13'32" W81 45'43"	0.17
T5-5	1/4 mile south of T5-4	N31 13'13" W81 45'50"	0.16
T5-6	3 1/2 mile south of T5-5	N31 10'33" W81 46'34"	0.12
T5-7	1 1/2 miles north of T5-6	N31 11'36" W81 46'15"	0.23
T5-8	1 mile north of T5-7	N31 12'16" W81 45'58"	0.07

Appendix A (cont.)

SAMPLE NUMBER	LOCATION	LATITUDE LONGITUDE	HEAVY MINERAL %
T5-9	on Hwy. 84 about 3/4 mile east of I-95	N31 07'55" W81 33'54"	0.13
T5-10	on Hwy. 84 about 1/2 mile north of intersection with Hwy. 17	N31 08'48" W81 35'30"	1.04
T5-11	Emanuel Church Rd. north of Hwy. 84 about 1 3/4 miles NW of T5-9	N31 10'22" W81 35'58"	0.57
T5-12	intersection of Emanuel Church Rd. and Hwy. 84	N31 10'04" W81 36'12"	0.82
T5-13	on Myers Hill Rd. on north side of Springhill Church	N31 09'14" W81 36'47"	2.22
T5-14	intersection of Myers Hill Rd. and Buck Swamp Rd. in SW corner of Brunswick West Quad.	N31 07'57" W81 37'25"	1.06
T5-15	on Hwy. 84 on east-central area of Bladen Quad.	N31 10'42" W81 37'45"	0.95
T5-16	2 1/2 miles south of Hwy. 84 at intersection with E-W trending road in south central portion of Hoboken East Quad.	N31 09'15" W82 04'21"	1.27
T5-17	1 1/2 miles NW of T5-15	N31 10'03" W82 05'03"	0.53
T5-18	1 mile north of T5-16	N31 10'53" W81 04'59"	0.52
T5-19	1 mile north of T5-15	N31 10'12" W82 04'16"	1.37
T5-20	intersection of N-S trending dirt road and Hwy. 84, 3 miles east of Hoboken	N31 11'23" W82 04'15"	1.83
T5-21	north-central portion of Hoboken Quad. 3 miles north of Hwy. 84	N31 13'15" W82 03'35"	1.09
T5-22	3/4 mile from T5-21	N31 12'44" W82 03'50"	0.81

Appendix A (cont.)

SAMPLE NUMBER	LOCATION	LATITUDE LONGITUDE	HEAVY MINERAL %
T5-23	1/2 mile south of T5-22	N31 12'22" W82 03'59"	0.75
T5-24	1/4 mile NE of T5-20	N31 11'41" W82 03'55"	0.68
T5-25	1 1/2 miles west of T5-20	N31 11'16" W82 05'37"	0.76

* NOTE: Sample T2-29 was collected but in the process of evaluating all the samples the data sheet was lost, instead of resampling this one location it was decided just to delete the entry. However there is on file at the Georgia Geologic Survey the location of this sample site.

APPENDIX B
HEAVY MINERAL CONSTITUENTS BY TRAVERSE

Heavy Mineral Percentages of Petrographically Examined Samples from Traverse 1

Barrier Complex	Sample No.	Heavy Min'l %	Identity of Heavy Mineral Fraction (%)											
			Ilmenite-Magnetite	Leucoxene	Rutile	Zircon	Monazite	Tourmaline	Staurolite	Garnet	Epidote	Amphibole	Kyanite Silmnite	Misc Hvys
Wicomico	T1-1	1.56	33.66	24.75	6.60	11.55	1.32	3.30	6.60	0.33	0.00	0.00	11.88	0.00
Wicomico	T1-2	0.59	32.22	16.61	5.32	4.98	0.33	4.98	8.97	1.33	0.00	0.00	23.92	1.33
Wicomico	T1-3	0.65	40.32	14.19	3.55	5.81	0.00	4.52	9.35	0.65	0.00	0.00	20.96	0.65
Wicomico	T1-7	0.67	25.18	23.74	5.04	6.47	0.48	6.71	7.91	1.20	0.24	0.00	22.78	0.24
Wicomico	T1-10	0.50	18.58	19.95	4.37	5.74	0.55	9.56	10.66	1.37	0.27	0.82	27.58	0.55
Wicomico	T1-38	0.27	22.00	20.00	5.67	3.33	0.33	5.67	6.33	0.33	0.00	1.00	35.33	0.00
Average		0.71	28.66	19.87	5.09	6.31	0.50	5.79	8.30	0.87	0.09	0.30	23.74	0.46
Penholoway	T1-11	0.33	32.67	12.21	6.93	6.27	0.33	5.28	13.20	1.98	0.00	0.33	20.79	0.00
Penholoway	T1-12	1.10	29.18	18.36	4.59	9.51	0.98	3.93	10.49	0.00	0.33	0.33	20.98	1.31
Penholoway	T1-13	0.35	18.04	19.88	4.28	3.67	0.31	5.81	14.37	1.53	0.00	0.92	30.58	0.61
Penholoway	T1-14	0.47	12.20	16.77	5.49	4.57	0.00	12.80	12.20	1.52	0.00	0.00	32.93	1.52
Penholoway	T1-19	0.48	30.00	22.00	7.00	8.00	0.67	6.33	9.33	1.00	0.33	0.33	15.00	0.00
Penholoway	T1-27	0.44	29.00	17.00	11.33	15.00	1.00	5.67	8.67	0.67	0.00	0.00	10.99	0.67
Penholoway	T1-37	0.36	27.36	14.66	9.45	9.45	1.30	3.91	7.17	0.33	0.00	0.00	26.37	0.00
Average		0.50	25.49	17.27	7.01	8.07	0.66	6.25	10.78	1.00	0.09	0.27	22.52	0.59
Talbot	T1-16	0.35	24.59	12.13	9.18	5.57	0.00	7.21	11.48	0.66	0.00	0.33	28.52	0.33
Talbot	T1-17	0.19	14.46	10.54	3.61	6.33	0.00	9.34	12.05	1.81	0.30	0.00	40.36	1.20
Talbot	T1-18	0.24	27.15	19.21	5.96	9.93	0.66	4.30	13.91	0.66	0.00	0.00	16.89	1.32
Talbot	T1-29	0.16	29.94	13.38	6.05	8.28	0.32	4.14	12.10	0.96	0.00	0.64	23.55	0.64
Talbot	T1-35	0.21	20.73	13.01	2.44	5.69	0.00	8.13	10.57	2.03	3.66	0.81	32.11	0.81
Average		0.23	23.37	13.65	5.45	7.16	0.20	6.62	12.02	1.22	0.79	0.36	28.29	0.86

APPENDIX B (CONT.)

Heavy Mineral Percentages of Petrographically Examined Samples from Traverse 2

Barrier Complex	Sample No.	Heavy Min'l %	Identity of Heavy Mineral Fraction (%) Ilmenite-Magnetite	Leucoxene	Rutile	Zircon	Monazite	Tourmaline	Staurolite	Garnet	Epidote	Amphibole	Kyanite Silmnite	Misc Hvys
Talbot	T2-2	0.57	44.00	7.69	4.00	7.38	2.77	4.62	17.85	0.92	1.23	0.31	9.23	0.00
Talbot	T2-3	0.76	27.67	17.33	5.00	5.67	0.67	10.33	10.67	2.33	0.00	0.00	20.33	0.00
Talbot	T2-4	8.84	57.67	4.00	5.33	16.00	2.00	4.00	5.00	0.00	0.00	0.00	6.00	0.00
Talbot	T2-6	0.62	35.10	13.91	2.32	7.62	0.33	7.62	14.24	1.32	0.00	0.00	17.54	0.00
Talbot	T2-8	0.80	44.20	10.97	6.58	10.97	0.63	4.70	8.46	0.31	0.00	0.00	13.17	0.00
Average		2.32	41.73	10.78	4.65	9.53	1.28	6.25	11.24	0.98	0.25	0.06	13.25	0.00
Pamlico	T2-36	0.87	36.86	10.58	6.73	10.58	0.64	4.49	9.94	0.96	2.56	0.00	16.66	0.00
Pamlico	T2-37	4.26	35.67	9.67	9.67	10.33	2.33	3.33	11.33	0.67	3.33	0.67	13.00	0.00
Pamlico	T2-38	2.59	37.00	9.67	7.67	6.67	2.33	3.33	7.67	0.67	11.33	2.00	11.33	0.33
Pamlico	T2-39	0.96	34.38	9.46	7.89	5.36	0.63	4.73	11.67	1.58	11.04	1.26	11.99	0.00
Pamlico	T2-40	1.83	38.22	10.51	5.73	7.32	0.64	4.46	12.10	1.59	0.32	0.96	17.83	0.32
Pamlico	T2-41	2.21	35.83	11.21	9.97	9.97	1.25	3.74	9.97	0.62	1.87	1.25	13.70	0.62
Pamlico	T2-42	4.44	30.00	6.67	6.67	6.33	1.33	4.00	14.67	1.33	10.00	2.00	16.00	1.00
Average		2.45	35.42	9.68	7.76	8.08	1.31	4.01	11.05	1.06	5.78	1.16	14.36	0.32
Princess Anne	T2-30	0.95	28.29	4.61	5.26	10.86	3.62	4.28	5.92	0.33	9.87	5.92	20.71	0.33
Princess Anne	T2-31	1.64	27.33	4.33	3.00	5.33	1.67	2.33	7.33	1.67	21.00	11.00	15.00	0.00
Princess Anne	T2-32	0.68	30.93	9.31	5.41	4.50	1.20	4.20	11.41	1.20	6.31	3.60	21.92	0.00
Princess Anne	T2-33	0.64	31.48	8.33	5.25	2.47	0.62	3.09	11.73	1.54	9.26	3.40	22.83	0.00
Princess Anne	T2-34	1.04	42.11	6.58	7.57	7.57	0.99	2.30	9.54	1.64	5.92	0.33	13.81	1.64
Princess Anne	T2-35	0.71	30.19	13.64	6.82	3.25	1.62	4.87	10.39	0.65	1.62	0.32	26.62	0.00
Average		0.94	31.72	7.80	5.55	5.66	1.62	3.51	9.39	1.17	9.00	4.10	20.15	0.3

APPENDIX B (CONT.)

Heavy Mineral Percentages of Petrographically Examined Samples from Traverse 3

Barrier Complex	Sample No.	Heavy Min'l %	Identity of Heavy Mineral Fraction (%) Ilmenite-Magnetite	Leucoxene	Rutile	Zircon	Monazite	Tourmaline	Staurolite	Garnet	Epidote	Amphibole	Kyanite Silmnite	Misc Hvys
Pamlico	T3-5	10.52	43.00	4.56	10.10	18.57	1.63	2.61	7.17	0.00	0.00	0.00	12.03	0.33
Pamlico	T3-6	2.90	31.29	6.13	5.81	7.74	0.65	7.42	12.26	1.29	5.81	1.29	19.66	0.65
Pamlico	T3-34	0.65	23.19	10.24	4.52	3.61	0.90	6.93	14.16	1.20	3.31	3.31	28.61	0.00
Average		4.69	32.49	6.98	6.81	9.97	1.06	5.65	11.20	0.83	3.04	1.53	20.10	0.33
Princess Anne	T3-1	0.96	29.11	9.49	6.33	6.96	0.32	5.38	16.77	0.00	0.00	2.22	23.42	0.00
Princess Anne	T3-2	0.58	32.23	11.30	6.98	9.63	1.00	2.66	13.29	0.66	0.00	1.66	20.59	0.00
Princess Anne	T3-3	1.48	36.36	12.23	6.90	12.85	0.94	1.57	13.79	0.00	0.00	1.57	13.48	0.31
Princess Anne	T3-4	0.36	28.70	11.42	5.25	5.86	0.62	5.56	15.43	0.93	0.00	1.23	24.69	0.31
Princess Anne	T3-25	0.48	28.03	12.72	6.36	2.31	1.45	5.49	13.01	0.87	0.58	0.58	28.31	0.29
Princess Anne	T3-26	0.90	26.33	8.00	6.67	5.33	3.00	2.67	14.33	2.00	6.33	0.33	24.67	0.33
Princess Anne	T3-27	1.38	33.64	6.42	6.12	4.59	2.14	3.36	11.62	1.83	14.98	1.83	12.54	0.92
Princess Anne	T3-28	2.44	44.97	3.77	9.75	9.12	4.09	2.52	12.89	1.26	4.72	1.26	5.65	0.00
Princess Anne	T3-29	1.88	42.33	6.33	11.00	6.00	1.33	3.33	14.67	0.67	1.67	1.00	11.67	0.00
Princess Anne	T3-30	1.01	33.12	3.47	2.84	5.36	1.58	7.57	14.83	3.79	1.58	2.52	22.39	0.95
Princess Anne	T3-31	1.25	36.48	8.79	5.86	9.45	2.61	3.58	8.14	0.65	7.82	0.65	15.64	0.33
Princess Anne	T3-32	9.89	46.08	3.27	8.82	14.71	1.63	1.31	6.86	0.33	9.80	2.29	4.57	0.33
Princess Anne	T3-33	1.42	34.77	5.96	5.63	9.27	2.65	3.64	13.91	1.32	2.98	1.32	18.54	0.00
Average		1.85	34.78	7.94	6.81	7.80	1.80	3.74	13.04	1.10	3.88	1.42	17.40	0.29

APPENDIX B (CONT.)

Heavy Mineral Percentages of Petrographically Examined Samples from Traverse 4

Barrier Complex	Sample No.	Heavy Min'l %	Identity of Heavy Mineral Fraction (%)											
			Ilmenite-Magnetite	Leucoxene	Rutile	Zircon	Monazite	Tourmaline	Staurolite	Garnet	Epidote	Amphibole	Kyanite Silmnite	Misc Hvys
Wicomico	T4-1	0.50	39.10	12.82	6.73	6.41	0.64	4.81	11.22	2.24	0.00	0.64	15.06	0.32
Wicomico	T4-3	0.79	12.06	35.24	10.48	12.06	0.63	6.35	5.71	2.54	0.00	0.00	14.60	0.32
Wicomico	T4-6	1.06	13.53	42.24	11.22	13.20	0.66	0.66	3.30	0.00	0.00	0.00	14.19	0.99
Wicomico	T4-37	0.63	21.17	22.56	10.03	8.08	0.00	7.52	11.14	1.39	0.00	1.11	16.43	0.56
Wicomico	T4-39	0.57	19.87	29.63	6.06	5.05	0.00	7.74	11.78	2.02	0.00	1.35	16.50	0.00
Average		0.71	21.15	28.50	8.90	8.96	0.39	5.42	8.63	1.64	0.00	0.62	15.36	0.44
Penholoway	T4-28	0.27	23.43	23.10	4.95	6.60	0.33	5.61	9.90	3.63	0.00	0.00	21.78	0.66
Penholoway	T4-30	0.40	25.66	19.41	5.26	8.88	0.33	10.20	8.88	1.64	0.00	0.00	19.41	0.33
Penholoway	T4-32	1.19	22.31	17.53	5.98	10.76	0.40	13.15	11.55	3.19	0.00	0.00	14.73	0.40
Penholoway	T4-34	0.51	14.60	18.32	1.86	4.66	0.31	14.91	13.04	1.86	0.00	0.00	29.81	0.62
Penholoway	T4-40	0.35	25.83	18.21	7.95	9.27	0.00	8.94	9.93	1.99	0.00	0.33	16.89	0.66
Penholoway	T4-41	0.62	25.68	22.66	7.55	5.14	0.30	5.74	11.18	1.81	0.00	0.00	19.34	0.60
Average		0.56	22.92	19.87	5.59	7.55	0.28	9.76	10.75	2.35	0.00	0.06	20.33	0.55
Talbot	T4-10	0.92	29.00	20.85	10.88	12.39	0.91	3.63	6.95	1.81	0.00	0.30	12.37	0.91
Talbot	T4-43	1.18	39.57	16.87	10.74	13.50	0.61	2.15	7.06	0.61	0.00	0.00	7.97	0.92
Average		1.05	34.29	18.86	10.81	12.95	0.76	2.89	7.01	1.21	0.00	0.15	10.17	0.92

APPENDIX B (CONT.)

Heavy Mineral Percentages of Petrographically Examined Samples from Traverse 4 (cont.)

Barrier Complex	Sample No.	Heavy Min'l %	Identity of Heavy Mineral Fraction (%) Ilmenite-Magnetite	Leucoxene	Rutile	Zircon	Monazite	Tourmaline	Staurolite	Garnet	Epidote	Amphibole	Kyanite Silmnite	Misc Hvys
Pamlico	T4-20	1.15	40.66	10.16	8.20	11.15	0.66	2.95	8.20	0.33	1.64	1.31	14.74	0.00
Pamlico	T4-21	2.49	41.67	9.33	6.67	7.67	1.00	4.00	10.67	0.67	1.00	1.67	15.65	0.00
Pamlico	T4-22	4.09	42.71	9.35	6.54	9.35	1.87	2.18	11.53	0.93	1.25	1.87	12.11	0.31
Pamlico	T4-23	0.31	28.06	17.61	8.36	10.75	1.19	3.88	10.75	0.90	0.60	2.39	15.21	0.30
Pamlico	T4-24	4.80	47.00	5.68	4.73	7.26	1.89	4.10	14.20	0.63	1.26	0.95	12.30	0.00
Pamlico	T4-25	0.78	37.15	12.29	5.03	5.03	1.68	5.59	11.45	0.84	0.28	0.84	19.54	0.28
Pamlico	T4-26	1.63	33.66	12.30	4.53	4.53	1.29	5.50	15.21	0.65	0.00	1.62	20.39	0.32
Pamlico	T4-27	1.65	41.69	10.42	5.86	10.42	0.98	5.21	7.49	0.65	1.95	1.95	13.36	0.00
Average		2.11	39.08	10.89	6.24	8.27	1.32	4.18	11.19	0.70	1.00	1.58	15.41	0.15
Princess Anne	T4-12	0.58	30.00	10.59	6.76	0.88	0.29	9.71	2.35	1.18	24.41	4.41	9.41	0.00
Princess Anne	T4-13	0.46	31.44	13.38	7.36	4.68	0.67	6.69	5.35	1.00	13.71	5.69	10.03	0.00
Princess Anne	T4-14	0.97	26.03	12.06	7.94	2.54	1.90	6.03	1.90	0.95	25.08	6.35	9.21	0.00
Princess Anne	T4-15	3.86	40.89	8.63	13.42	6.39	6.39	1.28	5.11	0.96	10.54	2.56	3.51	0.32
Princess Anne	T4-16	4.15	44.55	7.48	7.17	7.79	2.18	3.12	4.98	1.56	3.43	3.12	13.37	1.25
Princess Anne	T4-17	1.07	39.94	10.71	5.19	5.52	0.65	2.27	7.14	1.62	8.77	2.60	14.61	0.97
Princess Anne	T4-18	0.86	11.76	6.54	3.59	2.29	0.00	4.25	13.73	1.63	14.38	5.56	35.94	0.33
Princess Anne	T4-19	0.96	37.54	9.06	2.59	6.80	1.62	3.88	9.71	0.00	2.27	1.62	24.26	0.65
Average		1.61	32.77	9.81	6.75	4.61	1.71	4.65	6.28	1.11	12.82	3.99	15.04	0.44

APPENDIX B (CONT.)

Heavy Mineral Percentages of Petrographically Examined Samples from Traverse 5

Barrier Complex	Sample No.	Heavy Min'l %	Identity of Heavy Mineral Fraction (%) Ilmenite-Magnetite	Leucoxene	Rutile	Zircon	Monazite	Tourmaline	Staurolite	Garnet	Epidote	Amphibole	Kyanite Silmnite	Misc Hvys
Wicomico	T5-16	1.27	26.00	31.67	3.67	13.00	4.67	4.00	5.33	1.67	0.00	0.00	9.99	0.00
Wicomico	T5-17	0.53	18.30	28.76	8.50	17.32	0.98	7.19	8.17	1.96	0.00	0.00	8.82	0.00
Wicomico	T5-19	1.37	22.01	30.10	5.83	17.80	0.65	4.53	9.06	1.29	0.00	0.00	8.73	0.00
Wicomico	T5-20	1.83	24.93	26.71	7.42	16.32	0.30	3.26	7.42	2.97	0.00	0.00	10.08	0.59
Wicomico	T5-21	1.09	28.14	22.40	5.19	12.57	1.37	3.55	11.20	2.19	0.00	0.00	12.84	0.55
Wicomico	T5-23	0.75	18.87	30.50	6.29	15.41	0.31	4.09	9.75	2.83	0.00	0.00	11.64	0.31
Average		1.14	23.04	28.36	6.15	15.40	1.38	4.44	8.49	2.15	0.00	0.00	10.35	0.24
Pamlico	T5-10	1.04	32.47	7.47	2.27	9.74	1.30	3.25	9.74	0.97	14.61	0.32	17.86	0.00
Pamlico	T5-11	0.57	25.30	7.14	5.36	8.33	1.49	6.55	13.39	0.30	4.46	2.68	25.00	0.00
Pamlico	T5-12	0.82	42.00	7.00	7.33	10.33	1.00	2.67	13.00	1.00	0.00	1.33	14.33	0.00
Pamlico	T5-13	2.22	35.60	2.79	4.95	7.74	3.72	2.79	7.43	0.93	14.86	3.10	16.09	0.00
Pamlico	T5-14	1.06	29.26	6.43	7.40	5.79	2.57	5.14	13.83	1.93	2.89	1.29	22.83	0.64
Pamlico	T5-15	0.95	26.81	10.73	5.05	2.84	0.63	6.31	18.93	1.26	0.95	0.95	24.91	0.63
Average		1.11	31.91	6.93	5.39	7.46	1.79	4.45	12.72	1.07	6.30	1.61	20.17	0.21

APPENDIX B (CONT.)

SUMMARY OF TRAVERSES BY BARRIER COMPLEX

Barrier Complex	No. of Samples	Average Heavy Min'l %	Identity of Heavy Mineral Fraction (%)											
			Ilmenite-Magnetite	Leucoxene	Rutile	Zircon	Monazite	Tourmaline	Staurolite	Garnet	Epidote	Amphibole	Kyanite Silmnite	Misc Hvys
Wicomico	17	0.86	24.47	25.40	6.59	10.30	0.78	5.20	8.46	1.55	0.03	0.29	16.55	0.38
Penholoway	13	0.53	24.30	18.47	6.36	7.83	0.48	7.87	10.76	1.63	0.05	0.17	21.51	0.57
Talbot	12	1.24	32.84	13.32	6.01	9.11	0.74	5.85	10.86	1.12	0.43	0.20	19.00	0.51
Pamlico	24	2.28	35.40	9.06	6.54	8.23	1.40	4.38	11.53	0.91	3.97	1.46	16.88	0.24
Princess Anne	27	1.58	33.50	8.46	6.51	6.38	1.73	3.96	10.23	1.12	7.67	2.78	17.31	0.34
TOTAL ALL COMPLEXES	93	1.44	30.97	13.74	6.45	8.13	1.17	5.09	10.40	1.22	3.32	1.28	17.87	0.38


MAP OF SAMPLE LOCALITIES AS RELATED TO PALEOBARRIER COMPLEXES IN THE GEORGIA COASTAL REGION
Wicomico?
Penholoway?
Pamlico?
Penholoway?
Pamlico?
Talbot?
Penholoway?
EXPLANATION
Wicomico paleobarrier island complex
Penholoway paleobarrier island complex
Talbot paleobarrier island complex
Pamlico paleobarrier island complex
Princess Anne paleobarrier island complex
Sample location with <1% heavy minerals
Sample location with 1 to 2% heavy minerals
Sample location with >2% heavy minerals
Samples not assigned to any complex. All have <1% heavy minerals
Contours represent morphology of each (paleo) shoreline barrier island complex, and related sandbodies at approximate sea level at time of formation of each complex.
Dashed lines represent portions of contour where boundary is indefinite.
N
GEORGIA
STUDY AREA
0 5 10 15 Statute Miles
0 5 10 15 Kilometers
Base map from U.S. Geological Survey 1:250,000 maps: Macon GA. 1953, Savannah GA.-S.C. 1978, Waycross GA. 1988, Brunswick GA. 1977, Valdosta GA.-FLA. 1965 and Jacksonville FLA.-GA. 1966.

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Dk. Purple	Piedmont and Blue Ridge mapping and structural geology
Maroon	Coastal Plain mapping and stratigraphy
Lt. Green	Paleontology
Lt. Blue	Coastal Zone studies
Dk. Green	Geochemical and geophysical studies
Dk. Blue	Hydrology
Olive	Economic geology Mining directory
Yellow	Environmental studies Engineering studies
Dk. Orange	Bibliographies and lists of publications
Brown	Petroleum and natural gas
Black	Field trip guidebooks
Dk. Brown	Collections of papers

Colors have been selected at random, and will be augmented as new subjects are published.

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