Project Report No. 8
South Georgia Minerals Program

State Department of Conservation
Department of Mines, Mining and Geology

A. S. Furcron, Director

HEAVY MINERAL BEARING SAND OF THE COASTAL REGION OF GEORGIA

By

J. W. Smith and S.M. Pickering, Jr.
J. Roger Landrum

August 1967

PROJECT REPORT NO. 8

SOUTH GEORGIA MINERALS PROGRAM

Georgia
State Division of Conservation
Department of Mines, Mining and Geology

A. S. Furcron, Director

Heavy-Mineral-Bearing Sand of the Coastal Region of Georgia

by

James W. Smith
Samuel M. Pickering, Jr.
J. Roger Landrum

July 1967

ERRATA

The following corrections are applicable to Project Report No. 8:

Page iii, line 20. . . . . .for Wells read Holes

Page iv, line 7. . . . . .for Trial read Trail

Page vii, paragraph 3, line 7. . . . . .for amonazite read monazite

Page 12, paragraph 2, line 1 . . . . . .for Otton read Otto

Page 12, paragraph 3, line 1 . . . . . .for Teax read Teas

Page 35, paragraph 5, line 1 . . . . . .for mandellic read mandelic acid

Page 36, paragraph 2, line 5 . . . . . .for mandellic read mandelic

Page 44, line 1. . . . . .for WELLS read HOLES

Page 44, paragraph 1, line 8 . . . . . .for loosing read losing

Page 62, paragraph 1, line 5 . . . . . .for starolite read staurolite

CONTENTS

Page

ABSTRACT -- v

ACKNOWLEDGMENTS -- vii

INTRODUCTION -- 1

Definition and Uses --- 1
Purpose of Report --- 1
Area of Report -- 2
Previous Work --- 12

GEOLOGY --- 18

KNOWN DEPOSITS -- 19

METHOD OF STUDY --- 21

Field Methods --- 21
Laboratory Procedures --- 22
Determination of Heavy-Mineral Percentages -------------------- 22
Determination of Titanium-Mineral Percentages in Heavy-Mineral Fractions ---------------------------------- 23
Chemical Analyses of the Heavy-Mineral Fractions -------------- 35
Radiometric Monazite Analysis --------------------------------- 36

CONCLUSIONS --- 41

SUGGESTIONS TO FUTURE WORKERS --- 43

ADDENDUM 1: Wells Drilled by Southern Railway System in Charlton County -- 44

ADDENDUM 2: Petrographic Analysis of Core from Effingham County by James Neiheisel -------------------------------------- 51
Laboratory Procedure --- 52
Petrographic Description --------------------------------------- 59
Conclusions on Effingham County Well -------------------------- 62

REFERENCES CITED -- 64

TABLES

Page

1. Locations of auger holes given by geographic descriptions and by Georgia coordinates ---------- 4

2. Physical properties of samples ---------- 24

3. Mineral percentages of selected samples ---------- 31

4. Chemical analyses results on heavy-mineral concentrates ---------- 38

5. Percentages of heavy minerals and clastic sizes from holes drilled on Trial Ridge by Southern Railway System ---------- 46

6. Mechanical sieve analysis and composition of sediment samples from Effingham County, Georgia ---------- 54

7. Average acid insoluble heavy-mineral suite as fractional percent samples from Effingham County, Georgia ---------- 57

FIGURES

1. County outline map of Southeast Georgia showing auger hole locations ---------- 3

2. Map of coastal region of Georgia showing large areas of heavy-mineral concentrations and auger hole localities with greater than 2% heavy minerals ---------- 20

3. Map of southern part of Charlton County, Georgia, showing locations of holes drilled by Southern Railway System ---------- 45

ABSTRACT

The area of sand in Georgia similar to that mined near Folkston, Georgia, for titanium, zircon and monazite was determined from the literature. Covering this area is a surface sheet of Recent and Pleistocene sand which extends for about 100 miles inland from the Atlantic coast. Eighty holes were augered to an average depth of about eight feet. Core was divided into one- to three-foot interval samples.

The percentages by weight of clay, sand and silt, and larger grains were determined. The sand and silt portion was separated into light and heavy fractions. The percentage of titanium minerals was determined by counting grains, and titanium and zirconium were determined by wet chemical analysis. Monazite content was estimated by radiometric techniques.

Heavy-mineral content was also determined for 12 deep holes fishtail drilled on Trail Ridge, and data are included for one deep hole in Effingham County.

Large areas of heavy-mineral concentrations occur at Folkston, Cumberland Island, Jekyll Island, six miles east of Woodbine, and six miles north of Brunswick.

Holes with samples containing greater than two percent heavy minerals were also augered at Savannah Beach, near Marsh Island, near Walthourville, near Ridgeville, and near Kingsland. No sample of Pleistocene sand containing greater than one percent heavy minerals was found west of Trail Ridge and the approximate 125-foot contour extending northward from the ridge. Concentrations of heavy minerals are generally associated with fine-grained quartz sand.

The higher level Pleistocene sands tested have been leached of some of the undesirable heavy-mineral species, such as the amphiboles and epidote.

Preliminary chemical analyses suggest that the titanium minerals in these sands have been leached of iron. Consequently, these sands are probably of more economic interest than the lower level Pleistocene sands to the east or the Recent sands along the coast and along the Altamaha and Savannah Rivers.

ACKNOWLEDGMENTS

A. S. Furcron suggested and directed the project. This report was prepared by the Georgia Department of Mines, Mining and Geology with the assistance of numerous full and part-time employees.

This report was prepared by James W. Smith, Geologist III, and S. M. Pickering, Jr., Geologist II, of the Department of Mines, Mining and Geology between the summer of 1964 and June of 1967. Vance L. Hendrix, Gerald B. Garr, and Robert E. Hunter assisted the authors in the drilling phase of the work. Gerald B. Garr, Steven C. Englebright, Robert E. Hunter, Anna M. Conn, Martha A. Green, and Claudia O. Storey assisted in the physical and petrographic analyses, and J. Roger Landrum did the chemical analyses. A. S. Furcron and Jesse H. Auvil assisted in editing the report. Claudia O. Storey did the drafting and assisted in editing.

Prior to field work on this project, Thomas E. Garnar, Jr., geologist for E. I. DuPont de Nemours Company near Starke, Florida, discussed and demonstrated many of the aspects of sampling, analyzing, mining, and processing heavy-mineral-bearing sands. Milton E. McLain and Dorsey Smith of the Nuclear Sciences Division, Engineering Experiment Station, Georgia Instititue of Technology, analyzed selected samples radiometrically to determine amonazite content. Eugene V. Whittle, Plant Engineer of Humphreys Mining Company at Folkston, kindly arranged for comparison analyses of several samples. H. W. Straley, III, Professor of Geology at the Georgia Institute of Technology, and John E. Husted and Maximo F. Munoz of the Mineral Engineering Branch, Georgia Institute of Technology, discussed methods of exploration and analyses with the authors. James Neiheisel, geologist with the U. S. Army Corps of Engineers, Marietta, Georgia, suggested methods of sampling and analysis, assisted in editing the report, and analyzed the core from the Effingham County hole, Addendum 2. Norman K. Olson, geologist for Southern Railway System, made available the samples discussed in Addendum 1.

INTRODUCTION

Definition and Uses

Heavy-mineral-bearing sands are predominately quartz containing a small percentage of minerals which have considerably higher specific gravities than quartz and, therefore, are easily separated from the quartz. A concentration of the titanium minerals ilmenite-leucoxene and rutile is at present the most likely type of heavy-mineral deposit of economic potential in the sands of the coastal region of Georgia. The major use for the titanium in these minerals is in the production of white paint pigment. Titanium is also used extensively for welding-rod coatings. The demand for titanium metal for aircraft and missile manufacture is increasing.

Other heavy minerals of possible value are monazite and xenotime for their rare earth elements and thorium; zircon principally for refractories, foundry sand and facings, ceramics, and zirconium metal; staurolite for portland cement additive; garnet for abrasives; and kyanite and sillimanite for refractory material.

These clastic sediments probably have value other than for the heavy minerals. Of possible potential would be the quartz sand for glass and construction, gravel for construction, and the clay minerals. Clay minerals are now being separated economically from sand in North Florida.

Purpose of Report

The major aim of this work, which utilized only shallow, hand-augered holes, is to familiarize the authors with the problems of heavy-mineral exploration in the coastal region of Georgia so that a more extensive exploration program may be undertaken utilizing a power drill capable of drilling to 50 feet. Also, it is hoped that the hand-operated augering program will be sufficient to narrow the area of search, and thus indicate to industry the possible location of areas of heavy-mineral concentrations of high quality.

Area of Report

The area studied is a north-south strip adjacent and parallel to the Atlantic Coast, about 150 miles long and 100 miles wide. This includes the following twenty-two counties: Appling, Atkinson, Bacon, Bullock, Brantley, Bryan, Camden, Charlton, Chatham, Clinch, Effingham, Evans, Glynn, Jeff Davis, Lanier, Liberty, Long, McIntosh, Pierce, Tattnall, Ware, and Wayne (Figure 1 and Table 1).

Figure 1. County outline map of Southeast Georgia showing auger hole locations.

TABLE 1

LOCATIONS OF AUGER HOLES GIVEN BY GEOGRAPHIC DESCRIPTIONS AND BY GEORGIA COORDINATES

The Georgia Coordinate System's two base points are just southwest of the State for the western part of the system, and just south of the State for the eastern part. Localities in Georgia can be expressed as being so many feet north and east from these base points. Tic marks of the Georgia Coordinate System appear on the margin of the more recent quadrangle topographic maps and the State Highway Department of Georgia county maps. The quadrangle maps used for the coordinates in this table are the 1:250,000 scale topographic maps prepared by the Army Map Service.

The Georgia Coordinate System is divided into two zones--the East Zone and the West Zone. The dividing line between these zones is an irregular north-south line, following county boundary lines, approximately through the middle of the State. Each of these zones has been assigned a central meridian which approximately divides each zone in half. These central meridians are 82°10' west longitude for the East Zone and 84°10' west longitude for the West Zone. The central meridians for each zone have arbitrarily been assigned the value of 500,000 feet east for the x-coordinate. The base line for both zones has been assigned to 30°00' north latitude. This, therefore, puts all numbers in the Georgia Coordinate System in a northeast quadrant and, thus, are positive.

To determine the x, y coordinate, it is necessary to state the zone (East or West) and the coordinates then calculated:

y = ft. north of 30°00' north latitude
$x = 500{,}000 + x'$ where x' is feet east of central meridian
$x = 500{,}000 - x'$ where x' is feet west of central meridian

Table 1 - (continued)

Hole No.	Geographic Location	Georgia Coordinates, East Zone
	BULLOCH COUNTY	
1.	East side of Ga. Highway 73, 5.7 miles southwest of Statesboro city limit.	860,500 North 598,600 East
2.	North side of Ga. Highway 26, 7.3 miles southeast of Statesboro city limit.	869,300 North 656,300 East
3.	East side of County Road S-1845, 0.7 mile north of Stilson.	849,900 North 690,000 East
	EFFINGHAM COUNTY	
4.	Northeast side of Ga. Highway 21, 6.5 miles northwest of Springfield	889,900 North 744,800 East
5.	East side of Ga. Highway 21, 3.3 miles north of Rincon.	848,800 North 784,000 East
6.	East side of Ga. Highway 21, 3.0 miles south of Rincon.	821,000 North 795,500 East
7.	North side of Ga. Highway 30, 3.2 miles west of Chatham County line	799,000 North 766,900 East
	TATTNALL COUNTY	
8.	North side of Ga. Highway 23, 0.8 mile southeast of Reidsville.	754,700 North 521,500 East
	EVANS COUNTY	
9.	North side of Ga. Highway 30, 8.5 miles northeast of Reidsville.	783,900 North 567,300 East
	BRYAN COUNTY	
10.	North side of Ga. Highway 30, 8.2 miles west of Pembroke.	782,900 North 624,500 East
11.	East side of County Road S-1838, 3.3 miles north of Pembroke.	795,800 North 671,500 East
12.	North side of U. S. Highway 280, 0.2 mile west of Effingham County line.	798,300 North 731,200 East

Hole No.	Geographic Location	Georgia Coordinates, East Zone
	BRYAN COUNTY (Con't)	
13.	East side of Ga. Highway 67, 0.2 mile south of Pembroke.	773,800 North 669,600 East
14.	South side of Ga. Highway 204, 13.5 miles east of Pembroke.	773,100 North 723,400 East
15.	North side of Ga. Highway 63, 11 miles southeast of Pembroke.	741,000 North 705,900 East
16.	North side of Ga. Highway 63, 7.3 miles northwest of Richmond Hill.	728,000 North 754,200 East
17.	North side of Ga. Highway 63, 1.2 miles northwest of Richmond Hill.	711,200 North 764,000 East
18.	Turn east off Ga. Highway 63 on road to Ft. McAllister (4.5 miles southeast of Richmond Hill). Sample taken from north side of road, 0.7 mile west of Ft. McAllister.	689,200 North 798,300 East
	CHATHAM COUNTY	
19.	North side of Ga. Highway 204, 6.5 miles northwest from intersection with Ga. Highway 25.	749,500 North 756,900 East
20.	West side of Ga. Highway 25, 2.0 miles south of Port Wentworth	768,200 North 814,700 East
21.	North side of Ga. Highway 26 on Wilmington Island, 4.0 miles east of Savannah.	735,600 North 866,000 East
22.	South end of Savannah Beach, dune sand.	725,300 North 908,000 East
	LONG COUNTY	
23.	West side of U. S. Highway 301 at Ludowici.	622,000 North 627,000 East
24.	West side of Ga. Highway 38, 7 miles northeast of Ludowici.	644,600 North 661,500 East

Table 1 - (continued)

Hole No.	Geographic Location	Georgia Coordinates, East Zone
	LONG COUNTY (Con't)	
25.	South side of Ga. Highway 99, 6.5 miles southeast of intersection with U. S. Highway 301 in Ludowici.	594,400 North 655,600 East
26.	North side of Ga. Highway 99, 11.5 miles southeast of Ludowici.	583,200 North 678,400 East
	LIBERTY COUNTY	
27.	North side of Ga. Highway 196, 11 miles west of Hinesville.	676,700 North 634,600 East
28.	East side of Ga. Highway 67, 0.8 mile north of Hinesville city limit.	690,000 North 667,000 East
29.	North side of Ga. Highway 144, 9.0 miles northeast of Hinesville city limit.	711,200 North 704,200 East
30.	North side of Ga. Highway 38, 1.6 miles west of Midway.	657,000 North 722,000 East
31.	North side of Ga. Highway 38, 8 miles southeast of Midway.	632,200 North 757,400 East
32.	West side of Ga. Highway 38, 15 miles southeast of Midway.	625,100 North 788,000 East
	JEFF DAVIS COUNTY	
33.	At Hazelhurst.	680,100 North 370,300 East
	APPLING COUNTY	
34.	North side of U. S. Highway 341, 7.5 miles southeast of Hazelhurst.	664,700 North 405,900 East
35.	South side of U. S. Highway 341, 4.0 miles southeast of Baxley.	637,100 North 463,600 East

Table 1 - (continued)

Hole No.	Geographic Location	Georgia Coordinates, East Zone
	WAYNE COUNTY	
36.	South side of Ga. Highway 27, 3.8 miles west of Odum.	609,400 North 524,500 East
37.	North side of U. S. Highway 341, 2.0 miles northwest of Jesup.	592,000 North 582,000 East
38.	South side of U. S. Highway 341, 2.0 miles southeast of Jesup.	574,500 North 596,200 East
39.	West side of U. S. Highway 82, 4.0 miles northeast of Screven.	556,000 North 555,000 East
40.	5.0 miles north of Mount Pleasant off Ga. Highway 27, near Altamaha River.	547,400 North 658,000 East
41.	West side of County Road S-615, 1.8 miles south of Mount Pleasant.	513,200 North 650,200 East
	MCINTOSH COUNTY	
42.	East side of Ga. Highway 25, 8.5 miles north of Eulonia	591,800 North 740,200 East
43.	North side of Ga. Highway 99 at Townsend	561,700 North 698,800 East
44.	West side of County Road S-1892, 0.5 mile north of intersection with Ga. Highway 99 in Crescent.	553,100 North 748,300 East
45.	East side of Ga. Highway 99, 10.0 miles northeast of Darien.	544,800 North 753,900 East
46.	East side of Ga. Highway 99, 4.5 miles northeast of Darien.	517,800 North 739,000 East
47.	West side of Ga. Highway 99, 0.8 mile northeast of Darien.	503,800 North 733,400 East
	BACON COUNTY	
48.	East side of County Road S-1589, 3.9 miles north of intersection with Ga. Highway 32.	582,200 North 384,200 East

Table 1 - (continued)

Hole No.	Geographic Location	Georgia Coordinates, East Zone
	BACON COUNTY (Con't)	
49.	South side of Ga. Highway 32, 2.8 miles east of Alma.	561,000 North 425,400 East
50.	North side of Ga. Highway 32, 9.5 miles southeast of Alma.	547,900 North 451,800 East
	PIERCE COUNTY	
51.	South side of Ga. Highway 32, 0.2 mile south of Bristol.	524,100 North 486,000 East
52.	South side of Ga. Highway 32, 0.6 mile northwest of Patterson	504,700 North 506,100 East
	ATKINSON COUNTY	
53.	Inside Pearson city limits near intersection U. S. Highways 82 and 441.	474,200 North 287,500 East
	WARE COUNTY	
54.	North side of U. S. Highway 82, 6.0 miles northwest of Waycross city limit.	455,800 North 459,500 East
55.	North side of U. S. Highway 84, 3.7 miles southeast of Waycross city limit.	434,100 North 464,500 East
	BRANTLEY COUNTY	
56.	North side of Ga. Highway 32, 1.2 miles from Pierce County line.	489,400 North 548,100 East
57.	North side of County Road S-1227, 1.2 miles west of intersection with U. S. Highway 301.	474,900 North 556,300 East
58.	East side of U. S. Highway 301, 0.8 mile north of intersection with County Road S-1227.	477,000 North 567,200 East

Hole No.	Geographic Location	Georgia Coordinates, East Zone
	BRANTLEY COUNTY (Cont'd)	
59.	On top of ridge on southwest side of Ga. Highway 32, 1.6 miles southeast of Browntown.	481,500 North 626,200 East
60.	North side of U. S. Highway 84, 0.6 mile west of intersection with U. S. Highway 301.	438,800 North 553,100 East
61.	South side of U. S. Highway 84, 5.9 miles east of intersection with U. S. Highway 301.	442,300 North 586,500 East
62.	North side of U. S. Highway 84 at Atkinson, 8.4 miles east of intersection with U. S. Highway 301.	444,800 North 598,400 East
63.	Sand pit, 25 feet north of U. S. Highway 84, 0.9 mile from Glynn County line.	448,500 North 622,200 East
64.	East side of U. S. Highway 301, 0.5 mile north of Charlton County line.	389,300 North 549,700 East
65.	South side of Ga. Highway 32, 50 yards from Glynn County line.	476,500 North 635,000 East
	GLYNN COUNTY	
66.	10 feet south of Ga. Highway 32, 0.2 mile from Brantley County line.	475,500 North 636,800 East
67.	South side of Ga. Highway 32, 0.4 mile from Brantley County line.	474,100 North 639,500 East
68.	South side of Ga. Highway 32, 1.1 mile west of intersection with U. S. Highway 341.	463,300 North 683,900 East
69.	Ga. Highway 99, 2.4 miles west of intersection with Ga. Highway 25.	471,000 North 718,900 East
70.	Near Ga. Boys Estate off Ga. Highway 99, 9.0 miles northeast of Brunswick.	476,600 North 718,900 East

Table 1 - (continued)

Hole No.	Geographic Location	Georgia Coordinates, East Zone
	LANIER COUNTY	
71.	North side of Ga. Highway 37, 2.4 miles east of intersection with U. S. Highway 129.	382,500 North 240,400 East
	CLINCH COUNTY	
72.	South side of Ga. Highway 37, 0.6 mile west of intersection with Ga. Highway 38.	374,000 North 300,200 East
	CHARLTON COUNTY	
73.	East side of Ga. Highway 252, 4.5 miles north of intersection with Ga. Highway 40.	321,000 North 561,900 East
74.	East side of Ga. Highway 23, 21.2 miles north of St. George.	292,100 North 543,900 East
75.	West side of U. S. Highway 301, 10.7 miles north of St. George.	245,300 North 531,400 East
76.	West side of Ga. Highway 23, 5.4 miles south of St. George.	165,200 North 529,900 East
	CAMDEN COUNTY	
77.	Under tower on west side of County Road S-1850, 1.7 miles northeast of intersection with Ga. Highway 259.	388,700 North 601,200 East
78.	West side of Ga. Highway 252, 1.4 miles east of Charlton County line.	352,000 North 589,200 East
79.	South side of Ga. Highway 252, 2.8 miles east of Charlton County line.	353,900 North 594,800 East
80.	North side of Ga. Highway 40, 0.5 mile east of Kingsland city limit.	291,300 North 654,700 East

Previous Work

The following reports, presented chronologically, cover at least a portion of the coastal region of Georgia and seem significantly related to this heavy-mineral exploration.

Otton Veatch and L. W. Stephenson (1911) outlined the "Pleistocene" deposits of Georgia--roughly the limits of the area covered in this report.

Teax (1921) reported heavy-mineral concentrations on St. Simons and Sapelo Islands, especially between low- and high-tide marks at the south end of the islands. He also reported a concentration three miles west of St. George, Charlton County, on the Georgia and Florida Railway. This is near the holes drilled by the Southern Railway System (Addendum 2, this report).

C. W. Cooke (LaForge, Cooke, Keith, and Campbell, 1925) divided the Recent and Pleistocene coastal deposits into "terraces", broad flatlands of similar elevation. The west side of their Penholoway terrace is the approximate western limit of areas the authors found to contain a high percentage of heavy minerals.

J.H.C. Martens (1928) reported a concentration of heavy minerals one mile from the north end of Long Island near the crest of the beach ridge. Martens (1935) studied heavy-minerals from three localities in Georgia and sampled to depths of six inches to two feet.

C. W. Cooke (1939, 1943) and F. S. MacNeil (1947) mapped the geology of the study area and revised the geologic interpretation somewhat.

V. E. McKelvey and J. R. Balsley, Jr. (1948), mapped from an airplane the distribution of coastal black sands in North Carolina, South Carolina, and Georgia. The black sand diminishes in abundance northward, and they are found only on beaches along the open ocean. The best concentrations are on the south end of islands. "Characteristically, the sands are concentrated on the back of the beach by storm waves and are generally best exposed just after a heavy storm." They mapped black sands along almost the entire length of open ocean beaches of Georgia.

F. S. MacNeil (1949) mapped a high terrace and four Pleistocene shorelines of Georgia and Florida.

John B. Mertie (1953, 1958) panned 13 samples from shallow depths in the southeastern part of the coastal region of Georgia. He reported that the greatest concentrations of heavy minerals in this area were about one percent, and these occur at a few places along the eastern margin of the Okefenokee Swamp.

The U. S. Geological Survey (1953) indicated in a very general manner radioactive anomalies along the Georgia and northeast Florida coast.

Geophysical work of practical application to heavy-mineral exploration is that of R. M. Moxham (1954), an airborne radioactivity survey in the Folkston area.

Sigmund J. Rosenfeld (1955) analyzed 130 auger and channel samples representing thicknesses up to five feet. His area covered roughly the northern half of the authors' area. He grouped limonite, which is likely secondary in many cases, with the other opaque minerals in his analyses; therefore, the authors could not compare titanium-mineral percentages with Rosenfeld. Also, Rosenfeld restricted his analyses to a fraction of the sand-size material.

Jesse A. Miller (1957) reported that titaniferous heavy-sand deposits have been observed near the southern end of Sapelo Island, at the northern end of Long Island, and near the southern end of St. Simons Island. Also, heavy-mineral exploration was undertaken during early 1955 by several companies along the beaches and coastal plain "terraces."

Evelyn Z. Sinha's (1959) report includes maps of the geomorphic features and sediment types at the surface in the northern part of the coastal region of Georgia.

John A. Doering (1960) mapped the Quaternary surface formations of the southern part of the Atlantic Coastal Plain, and he discussed the stratigraphy and geologic history.

Stephen M. Herrick (1961, 1965) studied well cuttings and determined the thickness of the Pleistocene sediments in the coastal region of Georgia. Maximum thickness is about 65 feet on the east side. He divided these sediments into three lithologic units.

James Neiheisel (1962, 1965) studied in detail samples collected from holes to depths of 14 feet from the Altamaha and tributary rivers, Jekyll Island, Brunswick Harbor and vicinity, and the Silver Bluff and Pamlico shoreline areas in Pleistocene sands near the Altamaha River.

George I. Whitlatch (1962) discussed the possibility of heavy-mineral exploitation in Georgia and commented on several references.

Donn S. Gorsline (1963) reported on samples collected with a small Hayward Orange Peel Grab. Several of the samples were from the Georgia continental shelf. All heavy-mineral concentrations were less than one percent.

J. H. Hoyt and R. J. Weimer (1963) and R. J. Weimer and J. H. Hoyt (1964) compared features of the modern beach with the older inland beaches.

They recognized areas of shallow marine water by animal (Callianassa major) burrows.

Orrin H. Pilkey (1963) included in his work several shallow samples from the continental shelf off the Georgia coast. "The average concentration of heavy minerals in the South Atlantic shelf sediments is slightly less than 0.5 percent. No strong areal trend in these percentages was noted" (p. 643).

John H. Hoyt, Robert J. Weimer, and Vernon J. Henry, Jr. (1964), who studied the sediments of Sapelo Island and the nearby mainland, indicated the complexities involved in the formation of barrier islands. Their cross sections show that during the formation of barrier islands the tidal zone (thought to be a zone of heavy-mineral concentration) migrates vertically and horizontally; therefore, heavy-mineral concentrations may occur at many different positions beneath a barrier island.

Orrin H. Pilkey and Dirk Frankenberg (1964) delineated the boundary between relict, or Pleistocene, sediments and Recent sediments on the Georgia continental shelf.

Robert T. Giles and Orrin H. Pilkey (1965) included in their work the percentage of heavy minerals in the fine-grained fraction of several surface samples from Georgia dunes, beaches, and rivers. One of their significant observations corresponds with those of Dryden and Dryden (1956), Lincoln Dryden and G. A. Miller in Overstreet, Cupples and White (1956), Dryden (1958), and Neiheisel (1962, 1965). "Rivers deriving their load exclusively from Coastal Plain sediments are characterized by a stable heavy mineral suite. Sediments of rivers with headwaters extending into the Piedmont are characteristically mineralogically unstable" (Giles and Pilkey, 1965, p. 910).

Robert T. Giles (1966) made some general comparisons between heavy minerals of river, beach and dune sands of the southeastern Atlantic Coast.

John H. Hoyt and John R. Hails (1966) confirmed six Pleistocene shorelines in the coastal region of Georgia and attributed the prominent sand ridges to barrier island environments and the flat areas in-between as lagoonal salt-marsh flat environments.

John E. Husted, A. S. Furcron, and Frederick Bellinger (1966) included heavy-mineral data from four holes in Lanier County. Their highest concentration of heavy minerals was one percent.

The Minerals Engineering Group, Engineering Experiment Station, Georgia Institute of Technology and the Georgia Department of Mines, Mining and Geology (1966) included heavy-mineral data from 14 drill holes in Echols County. Their highest concentration was 1.8 percent.

Allan K. Temple (1966) studied the gradual alteration of ilmenite to rutile in the weathering environment. He found that in sand deposits the more weathered material is in and above the zone of the fluctuating water table, and that titanium-mineral concentrates are higher in titanium near the surface of the ground. A portion of his report on a drill hole from Folkston is as follows:

Footage	% TiO_2 in Titanium Minerals
0-4	75.6
4-6	71.8
6-8	68.5
8-10	67.2
10-12	66.6

Temple found that for sand deposits in general the titanium content of the titanium-mineral concentrate varies depending on the relative age of the deposit. That found near present sea level contains less titanium than that at higher levels. These results of Temple are similar to those obtained by the authors of this report.

GEOLOGY

Sand similar to that mined for heavy minerals near Folkston, Georgia, and in North Florida occurs in a surface sheet of clastic sediments from out on the continental shelf to about 100 miles inland. These sediments are Pleistocene and Recent in age and consist predominantly of sand and sandy clay. This sand sheet is up to 60 feet thick along the coast and wedges out to the west.

Along the coast, there are barrier islands composed predominantly of Recent and Pleistocene sand. Inland, paralleling the coast, are several ridges about the size and shape of the present-day barrier island chain. The ridges are up to 50 miles long and 5 miles wide. Between the ridges are flatlands which are progressively higher inland. These ridges and flatlands are former barrier islands and lagoonal areas which developed during stages of sea-level stabilization during Pleistocene time.

Several major rivers run roughly perpendicular to the coast. Along these streams there are Recent clastic deposits up to a few miles across and up to several feet deep.

KNOWN DEPOSITS

Heavy-mineral sands have been mined in Northeast Florida for many years, primarily for their titanium minerals. Zircon and monazite are usually recovered also. In 1965, Humphreys Mining Company began mining similar deposits near Folkston, Georgia, about three miles from the Florida line (Figure 2). A few companies have sporadically prospected the coastal region, but little information has been made public. However, it is general knowledge among local citizens that deposits have been extensively drilled about six miles east of Woodbine, Camden County, six miles north of Brunswick, Glynn County, and on Cumberland and Jekyll Islands (Figure 2).

Figure 2. Map of coastal region of Georgia showing large areas of heavy-mineral concentrations (large X) and auger hole localities with greater than 2% heavy minerals (small x).

METHOD OF STUDY

Field Methods

The area of sand in Georgia showing possible similarity to those areas which have been mined in Florida and Georgia was determined from geologic maps and reports. This area of study is a strip of land about 100 miles wide adjacent to and paralleling the coast (Figure 1). Sampling traverses were drawn along east-west roads on topographic maps (1:250,000 scale) across the area. In general, a hole was augured about every 10 miles along the traverse, preferably at rarely found road cuts. In the absence of outcrops, areas which appeared sandy and dry (on higher ground) were chosen where the water table should be lower. Where augering below the water table the hole usually closes. Frequently, where no outcrops or dry, sandy areas could be found for several miles distance along the chosen traverse, a hole was augered in swampy land. A total of 80 holes was augered (Figure 2).

Sampling equipment consisted of a man-powered auger which made a hole about three inches in diameter, a drive-pipe sample, a tub in which to collect the samples, a shovel, and cloth sample bags large enough to hold about 50 pounds of sand. The stem of the auger was 3 feet long, and additional 3 foot sections of 3/4-inch pipe were added as drilling progressed so that holes up to 18 feet deep were made. Where there was a near-vertical face of sand exposed, a thin-walled steel pipe, 3 1/2 feet long, was driven with a sledge hammer to collect a sample, and then the pipe was shoveled free. The entire sample from a 3 foot interval, about 40-50 pounds for the auger and 15-20 pounds for the drive-pipe, was combined where practical. Where there was a major change in lithology, the sample was divided.

In addition to holes augered by the authors, Southern Railway System drilled 12 holes in Charlton County (Addendum 1), and a deep well was drilled in Effingham County (Addendum 2).

Laboratory Procedures

Determination of Heavy-Mineral Percentages

The sample was first spread on paper to dry in the open air. Clods were crushed with a wooden rolling pin, and the sample was mixed on a square sheet of oilcloth by alternately pulling the corners. A Jones Splitter was used to reduce the sample to about 100 grams, and then it was weighed accurately.

To determine the amount of clay and eliminate it, the sample was placed in a quart jar and water containing a clay dispersing agent (0.07 percent by weight of sodium pyrophosphate) was added until the jar was almost filled. The water and sample were then stirred and allowed to stand for two hours. According to Stokes Law, this is about the time required for spherical particles greater than clay size (1/256 mm.), having a specific gravity equal to quartz to settle 10 centimeters in water at room temperature. The top 10 centimeters of fluid was then vacuumed off through a tube, and this process was repeated until the water was clear. The remaining sample was collected on filter paper, air dried, and weighed. This weight subtracted from the original weight equals the clay content (Table 2).

To determine the percent of material greater than sand size (2 mm.), the sample was then passed through a U. S. Standard mesh screen No. 10 and weighed (Table 2).

The sand and silt size portion of the sample was separated into heavy and light fractions by placing the sample in a heavy-mineral separatory funnel containing tetrabromoethane (specific gravity of about 2.96). The sample was stirred periodically until no mineral grains could be seen sinking from the lighter portion. After being washed and dried the lighter fraction was examined and approximate grain size and color were noted; thus, some idea of its possible use as glass sand, high silica sand, blasting sand, construction sand, and other uses could be determined (Table 2).

Determination of Titanium-Mineral Percentages in Heavy-Mineral Fractions

The heavy-mineral fraction of most of the samples containing greater than one percent concentration was screened to +100, +200, and -200 U. S. Standard sieve sizes to give three fractions of about equal grain size. Each of the three fractions was spread on millimeter-ruled graph paper and observed through a binocular microscope. The total number of grains and the titanium-mineral grains (ilmenite-leucoxene and rutile) were counted on random one-millimeter squares and a total of approximately 400 grains was tabulated for each size fraction. The size fractions were then weighed and an estimated weight percentage of titanium minerals in the heavy-mineral fraction was calculated (Table 3).

TABLE 2

PHYSICAL PROPERTIES OF SAMPLES

Percent clay, percent greater than sand size, color and average estimated grain size of light-weight portion of sand and silt fraction, and percent heavy minerals in sand and silt fraction.

Hole Number	Sampled Interval In Feet	% Clay Size	% +2 mm.	LIGHT-WEIGHT PORTION Estimated Color	LIGHT-WEIGHT PORTION Average Estimated Grain Size	% Heavy Minerals
1	0-3	3.6	0.0	White	Med.	0.1
	3-6	2.6	0.0	White	Med.	0.2
	6-9	1.4	0.0	White	Med.	0.2
	9-11	2.0	0.0	White	Med.	0.3
2	0-3	20.0	1.3	Tan	Fine	0.6
	3-6	24.8	1.4	Red-Brn.	Med.	1.8
3	0-3	10.0	0.0	White	Fine	0.7
	3-6	24.5	0.3	Tan	Fine	0.6
4	0-3	7.0	0.0	Tan	Coarse	0.3
	3-6	9.1	0.4	White	Coarse	0.4
	6-9	19.0	1.1	Tan	Med.	0.3
5	0-3	11.5	0.0	White	Fine	0.7
	3-6½	3.8	0.0	Dk. Brn.	Coarse	0.7
6	0-3	6.4	0.0	White	Med.	0.3
	3-6	24.3	0.0	White	Med.	0.3
	6-9	23.9	Trace	White	Med.	0.6
7	0-3	5.6	0.0	White	Fine	0.6
	3-6	20.2	0.0	Tan	Med.	0.6
	6-9	21.6	1.6	Tan	Coarse	0.5
8	0-3	12.7	0.7	White	Fine	0.6
9	0-3	7.8	0.0	White	Med.	0.3
	3-6	11.7	0.2	Tan	Med.	0.1
10	0-3	2.4	0.0	White	Med.	0.2
	3-6	1.9	0.0	White	Med.	0.2
	6-9	1.2	0.0	White	Med.	0.2
	9-12	1.4	0.0	Tan	Med.	0.2
	12-15	2.5	0.0	White	Med. to Coarse	0.2
	15-18	2.5	0.0	Tan	Med.	0.2

Table 2 - (continued)

Hole Number	Sampled Interval In Feet	% Clay Size	% +2 mm.	LIGHT-WEIGHT PORTION Estimated Color	Average Estimated Grain Size	% Heavy Minerals
11	0-3 3-6	20.0 35.0	0.0 0.0	Tan Dk.Tan	Med. Med.	0.4 0.6
12	0-3 3-6 6-9 9-12 12-15 15-18	4.2 6.7 24.6 17.5 2.6 5.8	0.0 0.0 0.0 0.0 0.0 0.0	White White White White White White	Fine Fine Fine Very Fine Very Fine Fine	0.7 0.6 0.6 1.1 1.2 0.7
13	0-3 3-6	22.3 19.6	0.2 0.7	Tan White	Med. Med.	0.4 0.4
14	0-3 3-6 6-9	4.4 8.9 34.9	0.0 Trace 0.0	White White White	Fine Fine Fine	0.8 0.8 1.1
15	0-3	7.1	0.0	White	Fine	1.5
16	0-3½	18.6	1.9	Gray	Very Fine	0.4
17	0-3 3-6 6-7	15.1 33.0 27.8	0.0 0.0 0.0	White Tan White	Very Fine Fine Fine to Very Fine	1.5 1.1 1.0
18	0-3 3-6 6-9	8.7 4.9 2.5	0.0 0.0 0.0	White White Tan	Fine Fine Fine	0.8 0.8 1.6
19	0-3 3-6 6-9 9-12 12-15 15-18	3.7 1.7 0.7 0.8 1.4 1.6	0.0 0.0 0.0 0.0 0.0 0.0	Tan White Tan Tan Tan Tan	Coarse Coarse Coarse Med. Med. Med.	0.5 0.5 0.5 0.4 0.4 0.4
20	0-3 3-6 6-9	9.2 18.0 32.5	0.0 0.0 0.0	White White Tan	Fine Fine to Very Fine Fine	1.6 1.9 1.0
21	0-3 3-6	5.7 1.2	0.0 0.0	White Dk.Tan	Fine Fine	1.6 1.8

Hole Number	Sampled Interval In Feet	% Clay Size	% +2 mm.	LIGHT-WEIGHT PORTION Estimated Color	Average Estimated Grain Size	% Heavy Minerals
22	0-3	1.2	0.0	Lt. Brn.	Fine	3.5
	3-6	0.8	0.0	Tan	Fine	2.6
	6-9	0.0	0.0	White to Tan	Fine	2.5
	9-12	0.9	0.0	Tan	Fine	2.7
23	0-3	5.5	0.0	White	Med.	0.4
	3-6	12.7	Trace	White	Med.	0.4
24	0-3	7.3	0.0	White	Fine	2.5
25	0-3	6.6	0.8	White	Fine	0.4
	3-6	14.9	4.1	White	Coarse	0.3
26	0-3	3.7	0.0	White	Fine	0.3
	3-6	4.8	0.0	White	Med.	0.3
	6-9	3.8	0.0	White	Med.	0.3
	9-12	2.5	0.0	White	Med.	0.3
	12-15	8.1	0.0	White	Med.	0.4
27	0-3	16.3	1.0	White to Tan	Med.	0.3
	3-6	30.6	0.6	Tan	Med.	0.4
28	0-3	4.5	0.4	White	Fine	0.8
	3-6	7.8	1.1	White	Med.	1.0
	6-9	20.2	0.0	White	Fine	0.9
29	0-3	16.4	0.8	White	Fine	0.3
	3-6½	30.4	1.0	Tan	Med.	0.3
30	0-3	4.2	0.2	Tan	Fine	1.6
	3-6	8.4	0.0	White	Fine	1.8
	6-9	18.9	0.0	White	Fine	1.8
	9-11	13.3	7.1	White	Med.	1.0
31	0-3	13.5	0.0	White	Fine	1.6
	3-5½	23.1	0.0	White	Fine	1.2
32	0-3	5.3	2.6	Tan	Fine	2.1
	3-6	12.0	0.0	White	Fine	2.5
33	0-3	9.9	0.7	White	Fine	0.5
	3-6	26.4	1.4	Tan	Coarse	0.5

Table 2 - (continued)

Hole Number	Sampled Interval In Feet	% Clay Size	% +2 mm.	LIGHT-WEIGHT PORTION Estimated Color	Average Estimated Grain Size	% Heavy Minerals
34	0-3	11.4	1.4	Tan	Coarse	0.3
35	0-3 3-6	12.0 22.8	0.0 0.0	White Tan	Fine Fine	0.5 0.3
36	0-3	14.5	2.6	Tan	Med.	0.4
37	0-3 3-6 6-9 9-12	4.6 0.9 3.4 6.5	0.0 0.0 0.0 Trace	Tan White White White	Med. Med. Fine Fine	0.6 0.5 0.8 0.8
38	0-3 3-6 6-9	3.9 13.9 13.7	0.0 0.0 1.6	White Tan Lt.Tan	Med. Coarse Coarse	0.2 0.2 0.2
39	0-3 3-7	9.0 20.9	Trace 0.9	White Tan	Med. Coarse	1.9 1.0
40	0-3 3-6 6-9 9-12	9.1 38.6 19.8 19.8	0.0 0.0 Trace 0.0	White White White White	Fine Fine Med. Very Fine	1.2 1.1 0.2 0.7
41	0-3 3-6	5.1 4.8	0.0 0.0	White White	Coarse Fine	1.6 1.6
42	0-3 3-6	8.6 9.1	0.0 0.0	White White	Fine Fine	0.8 1.0
43	0-3 3-6	22.9 42.6	0.0 0.0	White Red-Brn.	Fine Fine	0.9 1.2
44	0-3	4.8	0.0	White	Fine	1.4
45	0-3 3-6	5.0 4.5	0.0 0.0	Tan Dk.Brn.	Med. Fine	0.9 0.4
46	0-3 3-6	4.1 2.4	0.0 0.0	White White	Fine Fine	2.0 2.2
47	0-3 3-6	5.0 3.4	0.0 0.0	White White	Fine Fine	1.5 1.7

Hole Number	Sampled Interval In Feet	% Clay Size	% +2 mm.	LIGHT-WEIGHT PORTION Estimated Color	Average Estimated Grain Size	% Heavy Minerals
48	0-3	5.5	0.4	Gray	Med.	0.5
	3-6	19.6	1.0	Tan	Coarse	0.4
	6-9	17.3	2.0	Tan	Coarse	0.3
	9-12	24.2	4.0	Tan	Coarse	0.2
	12-14	28.6	5.2	White	Coarse	0.4
49	0-3	7.5	Trace	White	Med.	0.3
	3-6	29.8	0.0	Tan	Med.	0.3
	6-9	24.5	0.7	Tan	Coarse	0.3
	9-12	18.0	3.4	Tan	Med.	0.3
50	0-3	3.9	0.3	White	Fine to Med.	0.3
	3-6	8.6	0.6	White	Med.	0.3
51	0-2½	7.0	0.3	White	Med. to Fine	0.4
52	0-1	2.9	0.0	White	Med.	0.4
53	0-3	4.7	1.2	Gray	Med.	0.5
54	0-3	11.4	3.8	White	Med.	0.7
	3-6	27.5	1.1	Tan	Coarse	0.7
	6-9	21.4	1.4	Tan	Coarse	0.5
	9-12	17.6	1.5	White	Coarse	0.3
55	0-3	4.4	0.0	White	Med.	0.7
	3-6	30.0	0.0	Tan	Med.	0.8
	6-9	24.8	Trace	Tan	Med.	0.7
56	0-3	3.2	0.0	Gray	Med.	0.3
	3-5	2.8	0.0	White	Med.	0.4
57	0-3	10.4	0.0	White	Fine	0.6
	3-4	21.7	0.0	White	Fine	0.3
	4-6	34.8	0.0	White	Fine	1.2
	6-9	23.9	0.0	Lt.Tan	Fine	1.2
	9-12	32.4	0.0	Lt.Tan	Fine	1.9
	12-15	52.3	0.0	Tan	Fine	5.8
58	0-2	8.5	0.0	White	Med.	0.5
	2-4	14.9	0.0	White	Med.	0.7
	4-5	10.9	0.0	White	Coarse	0.2
	5-7	4.1	Trace	White	Med.	0.5
	7-10	1.0	1.0	White	Coarse	0.3

Table 2 - (continued)

Hole Number	Sampled Interval In Feet	% Clay Size	% +2 mm.	LIGHT-WEIGHT PORTION Estimated Color	Average Estimated Grain Size	% Heavy Minerals
59	0-3	4.5	0.0	White	Fine	0.7
	3-6	3.3	Trace	White	Med.	0.7
	6-9	23.3	Trace	White	Fine	0.3
	9-12	22.0	0.0	White	Fine	0.6
	12-15	27.8	0.0	White	Fine	1.1
	15-16½	22.3	0.0	White	Fine	1.1
	16½-18	6.7	0.0	White	Med.	0.6
60	0-3	5.9	0.0	Gray	Med.	1.0
	3-4	11.2	0.0	White	Med.	0.9
61	0-3	6.0	0.0	White	Med.	0.6
	3-6	4.3	0.0	White	Med.	0.6
	6-9	2.5	0.0	White	Med.	0.4
	9-12	6.3	0.2	White	Med.	0.5
	12-15	3.0	0.2	Tan	Med.	0.6
	15-17	1.8	0.3	Dk.Brn.	Med.	1.1
62	0-3	4.6	0.0	White	Fine	0.4
63	0-3	4.0	0.0	White	Med.	0.4
	3-6	8.9	0.0	White	Med.	0.4
	6-9	25.8	Trace	White	Med.	0.3
	9-12	31.1	0.2	Tan	Fine	0.5
64	0-3	2.1	0.0	White	Fine	1.0
65	0-3	4.8	0.0	White	Med.	0.5
	3-6	3.3	0.0	White	Med.	0.5
	6-9	2.6	0.0	White	Med.	0.5
	9-12	2.4	0.0	White	Fine	0.5
	12-15	9.2	0.0	White	Med.	0.9
66	0-3	2.8	0.0	White	Med.	0.4
	3-6	3.5	0.0	White	Med.	0.4
	6-9	2.3	0.0	White	Med.	0.4
	9-12	1.3	0.0	White	Med.	0.5
	12-13	1.6	0.0	White	Med.	0.5
	13-15	1.6	0.0	White	Med.	0.8
67	0-3	4.5	0.0	Tan	Med.	0.5
	3-5	6.8	0.0	White	Coarse	0.3
68	0-3	16.2	0.0	White	Fine	0.7
	3-6	32.2	0.0	White	Fine	1.2
	6-9	22.6	0.0	White	Fine	1.3
	9-12	34.2	0.0	White	Fine	1.5
	12-14	46.5	0.0	White	Fine	1.6

Table 2 - (continued)

Hole Number	Sampled Interval In Feet	% Clay Size	% +2 mm.	LIGHT-WEIGHT PORTION Estimated Color	Average Estimated Grain Size	% Heavy Minerals
69	0-3	2.4	0.0	White	Med.	3.3
70	0-3	4.9	Trace	Tan	Fine	1.2
	3-6	2.5	0.0	Tan	Fine	1.0
	6-9	1.6	0.0	White	Very Fine	0.8
71	0-3	5.5	0.3	White	Med.	0.5
	3-6	20.8	0.7	Tan	Coarse	0.3
	6-9	18.4	0.3	White	Coarse	0.2
	9-12	20.2	0.3	White	Coarse	0.3
	12-15	18.1	0.6	White	Med.	0.3
	15-17½	21.7	Trace	White	Med.	0.4
	17½-18	43.6	0.0	White	Fine	0.3
72	0-3	3.8	0.0	White	Med.	0.4
	3-4	3.2	0.0	White	Fine	0.4
73	0-2	10.2	0.0	Gray	Fine	2.8
	2-4	3.4	0.0	Gray	Fine	2.9
	4-6	5.3	0.0	Gray	Fine	2.8
	6-8	6.4	0.0	White	Fine	4.1
74	0-3	2.8	0.0	White	Med.	0.6
	3-6	3.0	0.0	White	Fine	0.5
	6-9	1.5	0.0	White	Fine	0.5
	9-12	2.0	0.0	White	Fine	0.4
75	0-3	3.3	0.0	White	Med.	0.7
	3-6	20.3	0.0	Tan	Fine	1.0
76	0-3	2.9	0.0	White	Med.	1.0
	3-6	2.1	0.0	White	Med.	1.0
77	0-3	4.1	0.8	White	Coarse	0.4
78	0-3	4.7	0.0	White	Med.	0.7
	3-6	6.6	0.0	White	Med.	0.8
79	0-3	3.4	0.0	White	Med.	0.8
	3-6	2.5	0.0	White	Fine	0.8
	6-8½	5.0	0.0	White	Med.	0.7
80	0-3	5.3	0.3	White	Fine	6.0

TABLE 3

MINERAL PERCENTAGES
OF SELECTED SAMPLES

Percent heavy minerals in sand and silt fraction; percent titanium minerals, percent zircon and percent monazite in heavy-mineral fraction of samples selected for heavy-mineral concentrations of one percent or greater. Determinations are in weight percent.

Hole Number	Sampled Interval In Feet	% Heavy Minerals	% Titanium Minerals	% Zircon	% Monazite
1	0-3 6-9	0.1 0.2	51.7 50.4		
2	0-3 3-6	0.6 1.8			0.2 0.5
10	0-3 6-9 12-15	0.2 0.2 0.2	50.8 51.8 53.8		
12	0-3 9-12 15-18	0.7 1.1 0.7	56.2 62.6 61.3		
15	0-3	1.5	55.9	14.7	0.6
17	0-3 3-6 6-7	1.5 1.1 1.0	58.8	12.1	1.3 1.7 2.1
18	0-3 3-6 6-9	0.8 0.8 1.6	42.9 38.6 43.5	6.2 6.8 4.2	1.4 1.0 0.7
19	0-3 6-9 12-15 15-18	0.5 0.5 0.4 0.4	56.2 56.7 57.4 54.4		
20	0-3 3-6 6-9	1.6 1.9 1.0	48.4 55.6	8.9 8.6	0.7 1.1

Table 3 - (continued)

Hole Number	Sampled Interval In Feet	% Heavy Minerals	% Titanium Minerals	% Zircon	% Monazite
21	0-3 3-6	1.6 1.8	46.4 43.5	7.6 3.1	1.6 0.7
22	0-3 3-6 6-9 9-12	3.5 2.6 2.5 2.7	39.4 45.9 38.7 42.7	1.5 1.5 2.1 2.5	0.4 0.5 0.2 0.4
24	0-3	2.5	54.3	13.4	0.7
30	0-3 3-6 6-9 9-11	1.6 1.8 1.8 1.0	34.3 39.4 41.5 46.6	6.2 4.5 7.0 7.5	0.9 0.5 1.5 2.2
31	0-3 3-5½	1.6 1.2	48.0 50.3	7.4 6.3	1.5 2.1
32	0-3 3-6	2.1 2.5	58.1 51.3	10.3 9.0	1.6 1.5
39	0-3 3-7	1.9 1.0	44.5	7.6	1.2 2.1
40	0-3 3-6 6-9 9-12	1.2 1.1 0.2 0.7	56.2	14.0	2.5 3.0
41	0-3 3-6	1.6 1.6	58.5 66.2	14.1 14.9	2.5 2.1
44	0-3	1.4	58.5	9.8	1.2
46	0-3 3-6	2.0 2.2	62.7 62.8	10.9 12.6	1.6 1.1
47	0-3 3-6	1.5 1.7	62.7 64.5	8.9 8.6	1.3 1.4
48	0-3 6-9 12-14	0.5 0.3 0.4	46.3 45.0 64.8		
54	0-3 3-6 9-12	0.7 0.7 0.3	44.6 42.1 59.4		

Table 3 - (continued)

Hole Number	Sampled Interval In Feet	% Heavy Minerals	% Titanium Minerals	% Zircon	% Monazite
57	0-3	0.6			
	3-4	0.3			
	4-6	1.2			3.2
	6-9	1.2			1.0
	9-12	1.9			0.9
	12-15	5.8			0.1
58	0-2	0.5	53.8		
	4-5	0.2	60.6		
	7-10	0.3	59.0		
60	0-3	1.0	56.5	17.1	1.5
	3-4	0.9	54.0	17.1	1.6
61	0-3	0.6	54.3		
	6-9	0.4	55.1		
	12-15	0.6	43.4		
64	0-3	1.0	50.1	3.9	3.0
66	0-3	0.4	54.9		
	6-9	0.4	60.1		
	13-15	0.8	63.7		
68	0-3	0.7	54.1	9.8	1.0
	3-6	1.2	57.6	10.6	2.3
	6-9	1.3	62.3	10.6	1.3
	9-12	1.5	45.0	10.9	1.3
	12-14	1.6	47.1	8.5	1.3
69	0-3	3.3	59.3	12.0	1.2
70	0-3	1.2	60.4	6.7	0.4
	3-6	1.0	51.1	5.7	1.0
	6-9	0.8	45.0	3.1	0.8
71	0-3	0.5	40.1		
	6-9	0.2	59.1		
	12-15	0.3	54.3		
73	0-2	2.8	62.9	7.4	1.2
	2-4	2.9	53.8	15.7	1.1
	4-6	2.8	61.2	15.7	1.2
	6-8	4.1	58.6	12.9	1.3

Table 3 - (continued)

Hole Number	Sampled Interval In Feet	% Heavy Minerals	% Titanium Minerals	% Zircon	% Monazite
76	0-3 3-6	1.0 1.0	44.1 47.2	4.8 4.5	0.0 0.0
80	0-3	6.0	57.0	4.2	1.2

Chemical Analyses of the Heavy-Mineral Fractions

The entire sample of heavy minerals from the tetrabromoethane separation was ground for analysis by an electric mortar grinder using an agate mortar and pestle. The powdered sample was dried overnight at 103° to 105° C .

Titanium Dioxide - TiO_2 (Furman, 1962) (Sandell, 1944).

The titanium dioxide percentage (Table 4) in the heavy-mineral fraction was determined colorimetrically by the hydrogen peroxide method. A 0.1000 gram sample was fused with potassium pyrosulfate, and the melt was dissolved in five percent sulfuric acid and made up to 1,000 milliliters. A portion of the solution not treated with peroxide was used as a blank. Hydrogen peroxide was added to the solution, and the optical density was measured on a Coleman Junior spectrophotometer set at a wavelength of 420 millimicrons. The optical density of the peroxidized titanium solution was corrected for the blank, and the percent titanium dioxide was read from a standard curve.

The color of the peroxidized titanium solution was bleached with hydrofluoric acid, and interference from vanadium was not noted by visual observation.

Values obtained for duplicate samples were reproducible to within two percent, and runs on a standard prepared in the laboratory were within two percent of the standard value.

Zirconium Dioxide - ZrO_2 and Zircon - $ZrSiO_4$ (Furman, 1962) (Hill and Miles, 1959).

Zirconium dioxide (Table 4) was determined by the mandellic method.

A 0.2000 gram sample was fused with anhydrous sodium carbonate and the melt dissolved in sulfuric acid (1+3). Three milliliters of 30 percent hydrogen peroxide was added and the solution evaporated to fumes of sulfur trioxide. The diluted solution was made alkaline with ammonium hydroxide, and the precipitated hydroxides were filtered to separate sulfate.

The hydroxide precipitate was dissolved in hydrochloric acid (1+3), and zirconium was precipitated as zirconium mandelate with 16 percent mandelic acid. The precipitate was filtered and washed with ammonium hydroxide (1+4) to dissolve zirconium mandelate and separate any titanium. The solution was made acid with hydrochloric acid and zirconium reprecipitated with mandellic acid.

The zirconium mandelate precipitate was ignited for one hour at 900° C. and weighed as ZrO_2. The percent zircon ($ZrSiO_4$) was found by multiplying the percent ZrO_2 by 1.4874.

Values obtained for duplicate samples were reproducible to within two percent, and runs on a standard prepared in the laboratory were within two percent of the standard value.

Radiometric Monazite Analysis (by Milton E. McLain and Dorsey Smith of the Georgia Institute of Technology.)

A radiometric method was used to determine monazite content of the heavy-mineral fraction (Table 3). Since monazite is the only thorium-radioactive mineral known to occur in the sands of the coastal region of Georgia in appreciable amounts, known percentages of pure monazite concentrate from North Florida were mixed with an ilmenite concentrate as standards, and the thorium radioactivity of these standards was compared to the thorium radioactivity of the heavy-mineral-fraction samples. Specifically, a standard curve was prepared by weighing known amounts of monazite concentrate mixed with several volumes of ilmenite concentrate in 25 cc. glass vials. These mixtures were counted for 40 minutes on the cap of the NaI crystal of a Technical Measurement Corporation analyzer. Counts were integrated under the .2386 mev. thorium peak. The standard curve was drawn by plotting milligrams of monazite versus integrated counts minus the base line.

The unknown heavy-mineral samples were analyzed in the same manner and compared to the standard curve, and the percent monazite was calculated.

A uranium source was used to check the uranium content of the samples. None was detected.

TABLE 4

CHEMICAL ANALYSES
RESULTS ON HEAVY-MINERAL
CONCENTRATES

Percent titanium dioxide in sand and silt fraction, in heavy minerals, and in titanium minerals. Percent zirconium dioxide in sand and silt fraction and in heavy minerals. Determinations are in weight percent.

Hole Number	Sampled Interval In Feet	% TiO_2 in Sand and Silt Fraction	% TiO_2 in Heavy Minerals	% TiO_2 in Titanium Minerals	% ZrO_2 in Sand and Silt Fraction	% ZrO_2 in Heavy Minerals
1	0-3		26.6	51.5		
	6-9		27.8	55.2		
10	0-3		28.2	55.6		
	6-9		27.8	53.7		
	12-15		28.2	52.4		
12	0-3		33.0	58.7		
	9-12		35.8	57.2		
	15-18		33 0	53.8		
15	0-3	0.56	37.0	66.2	0.15	9.8
17	0-3	0.46	30.6	52.0	0.12	8.1
18	0-3	0.19	24.2	56.4	0.03	4.0
	3-6	0.15	19.2	49.7	0.04	4.6
	6-9	0.36	22.8	52.4	0.04	2.8
19	0-3		32.0	57.0		
	6-9		32.0	56.5		
	12-15		30.8	53.7		
	15-18		30.8	56.7		
20	0-3	0.53	32.8	67.8	0.10	6.0
	3-6	0.62	32.8	64.8	0.11	5.8
21	0-3	0.40	25.0	53.9	0.08	5.1
	3-6	0.35	18.6	42.8	0.04	2.1
22	0-3	0.60	17.2	43.6	0.04	1.0
	3-6	0.43	16.4	35.7	0.03	1.0
	6-9	0.38	15.0	38.8	0.04	1.4
	9-12	0.50	18.6	43.6	0.04	1.6

Hole Number	Sampled Interval In Feet	% TiO_2 in Sand and Silt Fraction	% TiO_2 in Heavy Minerals	% TiO_2 in Titanium Minerals	% ZrO_2 in Sand and Silt Fraction	% ZrO_2 in Heavy Minerals
24	0-3	0.91	36.4	67.0	0.22	9.0
30	0-3 3-6 6-9 9-11	0.36 0.41 0.50 0.28	22.2 22.8 27.9 27.9	65.0 57.9 62.7 59.9	0.07 0.05 0.08 0.05	4.2 3.0 4.7 5.0
31	0-3 3-5½	0.45 0.36	27.9 30.2	58.2 60.0	0.10 0.05	5.0 4.2
32	0-3 3-6	0.73 0.68	34.8 27.0	59.9 52.6	0.14 0.15	6.9 6.0
39	0-3	0.57	30.1	67.6	0.10	5.1
40	0-3	0.43	35.6	63.4	0.11	9.4
41	0-3 3-6	0.63 0.60	39.2 37.8	67.0 60.7	0.15 0.16	9.5 10.0
44	0-3	0.53	37.8	64.6	0.10	6.6
46	0-3 3-6	0.81 0.88	40.6 40.2	64.6 64.0	0.15 0.19	7.4 8.5
47	0-3 3-6	0.57 0.64	37.8 37.8	60.4 58.6	0.10 0.10	6.0 5.8
48	0-3 6-9 12-14		37.9 31.0 35.2	81.9 68.9 54.3		
54	0-3 3-6 9-12		28.8 26.6 35.8	64.6 63.2 60.3		
58	0-2 4-5 7-10		35.6 35.0 35.0	66.2 57.7 59.4		
60	0-3 3-4	0.35 0.33	35.0 37.0	62.0 68.5	0.12 0.10	11.5 11.5

Hole Number	Sampled Interval In Feet	% TiO_2 in Sand and Silt Fraction	% TiO_2 in Heavy Minerals	% TiO_2 in Titanium Minerals	% ZrO_2 in Sand and Silt Fraction	% ZrO_2 in Heavy Minerals
61	0-3		31.0	57.1		
	6-9		28.2	51.2		
	12-15		20.8	48.0		
64	0-3	0.32	32.0	63.9	0.03	2.6
66	0-3		35.0	63.8		
	6-9		35.6	59.2		
	13-15		35.0	55.0		
68	0-3	0.26	37.4	69.1	0.05	6.6
	3-6	0.44	36.8	63.9	0.08	7.1
	6-9	0.49	37.4	60.0	0.09	7.2
	9-12	0.50	28.0	74.7	0.11	7.4
	12-14	0.49	30.6	64.9	0.09	5.7
69	0-3	1.22	37.0	62.4	0.26	8.0
70	0-3	0.39	32.8	54.3	0.05	4.5
	3-6	0.31	31.0	60.8	0.04	3.8
	6-9	0.18	22.0	48.9	0.02	2.1
71	0-3		34.2	85.4		
	6-9		35.4	59.9		
	12-15		28.2	52.0		
73	0-2	1.12	40.0	63.6	0.14	5.0
	2-4	1.14	39.2	72.8	0.31	10.6
	4-6	1.05	37.0	60.5	0.30	10.6
	6-8	1.26	30.7	52.4	0.35	8.6
76	0-3	0.32	32.0	72.5	0.03	3.2
	3-6	0.32	32.0	67.8	0.03	3.0
80	0-3	2.10	35.0	61.4	0.17	2.8

CONCLUSIONS

One area of heavy-mineral-bearing sand is presently being mined in Georgia near Folkston. There are at least four other large areas where there are known concentrations of heavy minerals (Figure 2). Elsewhere, five of our auger holes (Figure 2, Nos. 22, 24, 32, 45, and 80) were found to contain intervals of between two to six percent heavy minerals. To be profitably mineable, a deposit will probably have to contain at least three percent heavy minerals and one percent TiO_2. The deposit should be several feet thick and within a few feet of the surface of the ground. There was no concentration greater than one percent heavy minerals west of Trail Ridge and the approximate 125-foot contour which runs north-south and divides the studied area about in half (Figure 2). Higher percentages of heavy minerals occur near the shoreline areas of MacNeil (1949).

The major heavy mineral mined in South Georgia and North Florida is ilmenite and its alteration products. The other minerals recovered are by-products. The titanium-mineral concentrates vary greatly in their iron content. That with a low iron content and consequent high titanium content is less expensively processed to a titanium dioxide product. It is presently desirable for the ilmenite-leucoxene concentrate to contain greater than 60 percent titanium dioxide, and those with about 70 percent are very desirable.

From the few titanium analyses (Table 3) it appears that the titanium minerals with less iron are found furthest west and near the surface of the ground. The lower iron content is probably due to leaching by ground water.

Previous workers have shown that the more recently deposited sands along the coast and along the Altamaha and Savannah Rivers, with extensive head waters in the crystalline rocks to the west, are less leached of certain minerals by percolating ground water. These areas probably contain ilmenite with a high iron content.

Concentrations of heavy minerals are more often found in fine-grained sand (Table 2).

SUGGESTIONS TO FUTURE WORKERS

Holes should be drilled to a depth of 50 feet to fully explore heavy-mineral deposits which may be mined in the near future. The deposits in North Florida are mined to about this depth. Use of a jet-rotary-type drill as described by Thoenen and Warne (1949) or the drive-pipe-jet rig presently used by Humphreys Mining Company at Folkston is suggested.

After checking the areas shown in this report to have a concentration of titanium minerals with a low iron content (Figure 2, localities 24, 45, 80), further exploration should probably begin at about the 125-foot contour and progress southeastward, excluding from the search the Recent sediments along the Altamaha River System and Savannah River. The shoreline areas of MacNeil (1949) should especially be checked.

There are indirect approaches to searching for heavy minerals which have not been thoroughly tested. Systematic surveys using a portable instrument to measure thorium radioactivity may outline areas of monazite concentration. Detailed ground magnetic maps may show concentrations of ilmenite.

Laboratory techniques can probably be expedited by centrifuging the heavy-liquid-sample mixture as described by Spencer (1948) and by applying x-ray diffraction and fluorescence and spectrographic techniques of analysis.

ADDENDUM 1

WELLS DRILLED BY SOUTHERN RAILWAY SYSTEM IN CHARLTON COUNTY

Part of the phosphate exploration by Southern Railway System in 1964 resulted in the drilling of 12 holes on Trail Ridge in Charlton County, Georgia (Figure 3) (Olson, 1966). This area is approximately 25 miles north of the heavy-mineral mining on Trail Ridge in Florida. Samples from the Southern Railway System drilling were made available to the authors for heavy-mineral analysis. Although these samples were not completely representative because they were washed up the hole and caught on a wire-screen strainer, thereby loosing the fines and slimes, they are of value, for they penetrated much deeper than the authors were able to auger by hand.

The samples were processed and analyzed in the same manner as the other samples in the main part of this report to give percent heavy minerals in the sand and silt fraction, percent clay, and percent greater than sand size. The results are in Table 5. Holes 4 and 11 are the only ones containing an interval of greater than 2 percent heavy minerals within 30 feet of the surface of the ground.

Hole four (4) was selected at random and mineralogical and chemical tests like those described in the main part of this report were run on the heavy mineral fractions at several depth intervals. The following results were obtained:

HOLE 4

Sampled Interval In Feet	% Titanium Minerals In Heavy Minerals	% TiO_2 In Heavy Minerals	% TiO_2 In Titanium Minerals
0-5	54.8	33.2	60.6
10-15	59.2	32.0	54.1
20-25	57.2	26.0	45.5
40-45	57.2	24.6	43.0
50-60	59.4	26.6	44.8

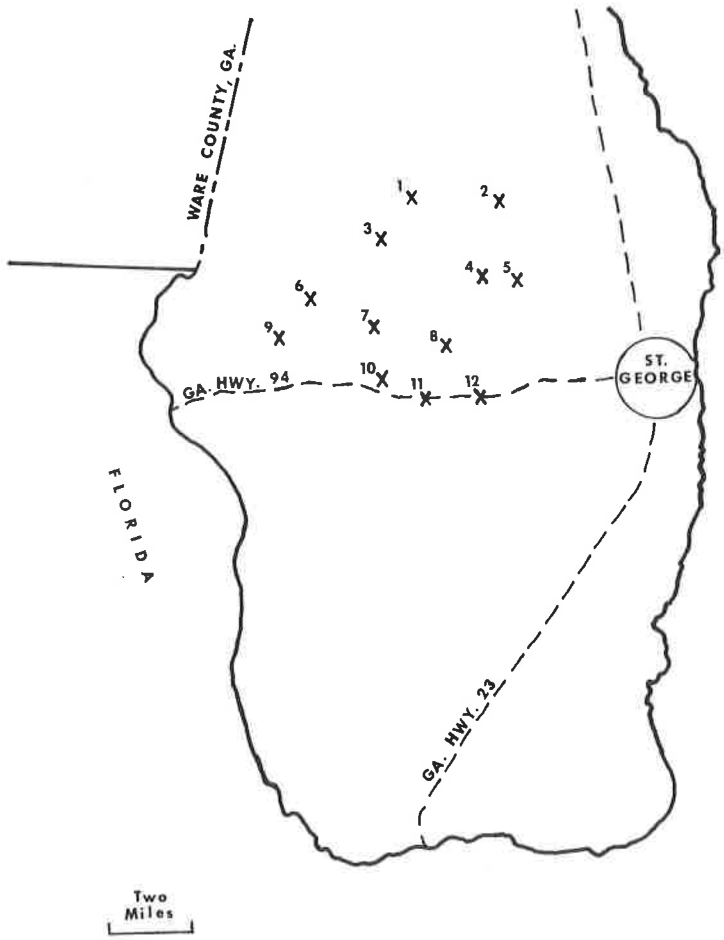

Figure 3. Map of southern part of Charlton County, Georgia, showing locations of holes drilled by Southern Railway System

TABLE 5

PERCENTAGES OF HEAVY MINERALS AND CLASTIC SIZES FROM HOLES DRILLED ON TRAIL RIDGE BY SOUTHERN RAILWAY SYSTEM

Hole Number (Figure 3)	Sampled Interval In Feet	% Clay	% +2 mm.	% Heavy Minerals In Sand and Silt Fraction
#1.	0-5	7.4	0.0	0.71
	5-10	3.0	0.0	0.61
	10-15	2.1	0.0	0.46
	15-20	1.5	0.0	0.46
	20-30	2.5	0.2	0.52
	30-40	13.5	0.6	1.02
	40-50	9.0	0.2	0.94
	50-60	3.5	0.1	0.66
	60-70	1.5	0.1	0.58
	70-75	3.5	0.6	0.80
#2.	0-5	1.7	0.0	0.60
	5-10	0.0	0.0	0.83
	10-15	1.0	0.0	1.00
	15-20	0.5	0.0	1.64
	20-30	2.0	0.0	1.40
	30-40	0.0	0.0	1.05
	40-50	1.0	0.0	2.87
	50-55	2.0	0.0	1.23
	55-60	1.2	0.0	1.01
	60-70	3.5	0.1	1.26
	70-75	3.2	0.0	1.50

Table 5 - (continued)

Hole Number (Figure 3)	Sampled Interval In Feet	% Clay	% +2 mm.	% Heavy Minerals In Sand and Silt Fraction
#3.	0-5	2.9	0.0	0.54
	5-10	2.6	0.0	0.67
	10-15	2.0	0.0	0.49
	15-20	1.9	0.0	0.62
	20-30	4.7	0.0	0.45
	30-40	5.6	0.0	0.77
	40-50	3.8	0.0	0.86
	50-60	2.8	0.0	0.70
	60-65	1.9	0.0	0.98
	70-75	14.6	1.7	0.95
#4.	0-5	2.0	0.0	0.98
	5-10	1.2	0.0	2.46
	10-15	0.0	0.0	2.66
	15-20	1.7	0.0	1.11
	20-25	2.1	0.2	0.76
	25-30	2.0	0.0	1.52
	30-40	1.5	0.0	1.99
	40-45	0.6	0.1	1.92
	45-50	1.0	0.0	2.21
	50-60	0.5	0.0	2.27
	60-65	1.0	0.0	1.45
	65-70	3.8	0.0	1.30
	70-75	9.8	0.0	1.26

Table 5 - (continued)

Hole Number (Figure 3)	Sampled Interval In Feet	% Clay	% +2 mm.	% Heavy Minerals In Sand and Silt Fraction
#5.	0-5	2.4	0.0	0.86
	15-20	1.5	0.0	1.15
	20-30	1.5	0.0	1.65
	30-40	1.0	0.0	1.28
	40-45	2.3	0.0	0.85
	45-50	2.0	0.0	0.89
	55-60	8.2	0.0	1.40
	60-70	1.4	0.0	0.84
#6.	0-5	2.0	0.0	0.82
	5-10	4.0	0.0	0.97
	10-15	4.6	0.0	0.92
	15-20	5.9	0.0	0.66
	20-30	4.8	0.0	0.84
	30-40	3.8	0.0	0.67
	40-50	3.4	0.0	0.95
	60-65	8.9	0.8	0.56
#7.	0-5	2.9	0.0	0.59
	5-10	9.0	0.0	0.52
	10-15	2.9	0.0	0.76
	15-20	8.8	0.0	0.74
	20-30	8.6	0.0	0.42
	30-40	5.0	0.0	0.94

Table 5 - (continued)

Hole Number (Figure 3)	Sampled Interval In Feet	% Clay	% +2 mm.	% Heavy Minerals In Sand and Silt Fraction
#8.	0-5	1.6	0.0	0.99
	5-10	1.0	0.0	0.76
	10-15	2.1	0.0	0.67
	15-20	1.3	0.0	0.97
	20-25	0.9	0.0	1.10
	25-30	0.9	0.0	1.64
	35-40	0.9	0.0	2.83
	40-50	1.0	0.0	2.55
	50-60	1.0	0.0	0.77
	60-65	1.1	0.0	0.83
	65-70	0.0	0.0	0.89
	70-75	0.5	0.0	1.10
#9.	0-5	8.1	0.0	0.57
	5-10	3.9	0.0	0.75
	10-15	8.1	0.0	0.78
	15-20	14.9	0.0	0.81
	20-30	6.5	0.1	1.01
	30-35	7.3	0.5	1.12
	40-45	limestone		
	60-70	limestone		
	70-75	limestone		

Hole Number (Figure 3)	Sampled Interval In Feet	% Clay	% +2 mm.	% Heavy Minerals In Sand and Silt Fraction
#10.	0-5	5.5	0.0	0.84
	5-10	5.5	0.0	1.15
	10-15	9.8	0.0	0.92
	15-20	9.7	0.0	0.81
	20-25	6.6	0.0	0.72
	25-30	4.1	0.0	0.49
	30-40	1.8	0.0	0.61
	40-45	3.4	0.0	0.80
#11.	5-10	1.0	0.0	1.26
	10-15	1.4	0.0	2.23
	15-20	0.9	0.0	1.65
	20-30	0.9	0.0	1.60
	35-40	1.2	0.0	1.77
	40-50	2.0	0.0	1.54
	50-60	2.7	0.0	0.97
	60-70	2.0	0.0	0.75
#12	0-5	0.8	0.0	0.40
	5-10	3.7	0.0	0.69
	10-15	1.0	0.0	0.83
	15-20	2.5	0.0	1.11
	20-25	3.0	0.0	0.55
	25-30	1.2	0.0	0.80
	35-40	1.1	0.0	1.50
	40-45	0.9	0.0	1.59
	45-50	1.6	0.0	2.00
	50-60	4.1	0.0	1.40
	60-70	7.0	0.0	1.30
	70-75	4.0	0.0	0.91

ADDENDUM 2

PETROGRAPHIC ANALYSIS OF CORE FROM EFFINGHAM COUNTY

by James Neiheisel

Core from a 300-foot hole drilled in Effingham County, Georgia, by the Mineral Engineering Branch, Georgia Institute of Technology, and Georgia Department of Mines, Mining and Geology (Husted, Furcron and Bellinger, 1966) was examined mechanically and petrographically. The hole is 3.2 miles north-northwest of the intersection of Georgia Highways 119 and 17 in Guyton. Analysis results are in Tables 6 and 7.

Laboratory Procedure

A series of representative samples was obtained for each 5 feet of core hole and the sample was reduced by a microsplitter into 2 representative samples weighing between 25 and 50 grams each.

The first sample was washed through a set of sieves and the fines (less than 325 sieve size) collected in a large vessel. The sand was dried and passed through a set of small sieves by hand screening for five minutes and the percent of total sample computed for each sieve size. The fines were reduced in volume by decantation and then evaporated to dryness and this weight added to the previous screenings. Each individual sieve size was examined for composition under the binocular and petrographic microscopes and an average percent composition, based on a 200 point count per sieve size and weighted size fraction, recorded. Clay was estimated from the -325 sieve size fraction. Where abundant calcite was present, acid leaching was employed to separate the clay from the carbonate minerals.

The second sample was acid leached with dilute hydrochloric acid and carbonate and phosphate minerals decanted through the -325 sieve along with the clay minerals. Comparison with the first sample and visual microscopic examination enabled an estimate of percent clay and carbonate and phosphate in the sediment sample.

The -40 sieve size and +325 sieve size portion of the acid-leached sample was weighed, the heavy minerals separated with bromoform, washed, dried, and weight percent of heavy minerals in the total sample computed. The dried heavy minerals were sieved through 100, 200, and 325 sieves and the weight percent of each sieve size determined. A representative portion of each sieve size was placed on a glass slide in index oil and another representative portion of each sieve size placed in Lakeside Plastic No. 70 on a glass slide; the latter provides a permanent record of the heavy-mineral suite. Each slide was examined under the petrographic microscope and at least a 200 count per size fraction made. A weighted average was computed for each heavy-mineral species and results tabulated in Table 7.

The composition of the sediment is listed in Table 6. Some materials are more accurately computed than others; for example, the clay mineral content is at best an approximation while acid-insoluble heavy minerals are known very accurately. Acid-leached carbonate rock enabled more accuracy as to weight percent than point count could have afforded. Because of its flat shape, mica percent is at best an approximation. Feldspar and quartz are believed to be accurate as regards weight percent distribution.

TABLE 6 MECHANICAL SIEVE ANALYSIS AND COMPOSITION OF SEDIMENT SAMPLES FROM EFFINGHAM COUNTY, GEORGIA

DEPTH (ft.)	% RETAINED					MEDIAN[1] DIAMETER (mm.)	AVERAGE PER CENT COMPOSITION						
	40	80	100	200	PAN		QUARTZ	FELDSPAR	CALCITE	PHOSPHATE	CLAY[2]	H.MINERAL	MICA
8-15	93.2	6.0	0.4	0.4	Tr	1.31	98.8	1.0	-	-	0.1	0.1	Trace
15-24	80.4	12.8	1.6	2.4	2.8	1.20	96.9	1.0	-	-	2.0	0.1	Trace
24-28	89.8	4.4	0.8	2.0	3.0	1.25	96.9	1.0	-	-	2.0	0.1	Trace
28-32	15.2	39.2	17.6	5.6	21.6	0.22	70.8	10.0	-	-	18	1.2	Trace
38-45	13.2	16.8	15.6	35.6	18.8	0.15	74.4	6.0	-	-	17	1.6	1
45-49	14.0	6.8	24.0	49.8	5.4	0.17	83.9	6.0	Tr	Tr	6	3.1	1
49-52	8.0	6.4	22.8	50.4	12.4	0.13	85.2	6.0	-	-	5	2.8	1
52-57	2.4	6.8	24.0	52.0	7.2	0.14	79.8	10.0	-	-	7	2.2	3
57-61	0.2	4.4	9.2	58.6	27.6	0.09	61.5	12.0	-	-	20	1.5	5
61-65	4.0	2.4	2.8	59.2	32.6	0.09	61.4	10.0	-	Tr	25	1.6	2
65-78	35.6	3.0	1.0	34.8	25.6	0.12	67.8	4.0	15	2	10	1.2	Trace
78-93	18.3	41.7	6.7	12.5	20.8	0.18	74.8	8.0	Tr	5	11	1.2	Trace
93-100	52.4	22.4	12.8	8.4	4.0	0.48	66.7	8.0	2	20	3	0.3	Trace
100-108	29.3	59.8	8.7	1.6	0.6	0.41	54.6	5.0	36	2	2	0.4	Trace
108-128	35.8	42.0	9.3	8.7	4.2	0.20	47.8	6.0	40	2	3	1.2	Trace
128-145	8.3	8.2	4.2	10.7	68.6	0.06	20.7	6.0	68	3	2	0.3	Trace

Table 6 - (continued)

DEPTH (ft.)	% RETAINED					MEDIAN[(1)] DIAMETER (mm.)	AVERAGE PER CENT COMPOSITION						
	40	80	100	200	PAN		QUARTZ	FELDSPAR	CALCITE	PHOSPHATE	CLAY[(2)]	H. MINERAL	MICA
145-150	54.8	15.8	4.8	10.0	15.2	0.50	71.7	4.0	20	2	2	0.3	Trace
150-155	34.5	23.1	11.1	9.3	22.0	0.28	55.3	3.0	20	3	18	0.7	Trace
155-160	24.2	28.2	15.3	8.4	24.2	0.20	64.6	5.0	17	2	11	0.4	Trace
165-170	31.2	9.6	9.6	10.8	38.8	0.18	57.7	3.0	7	2	30	0.3	Trace
170-175	27.2	14.2	14.2	10.0	34.4	0.17	54.6	5	8	2	30	0.4	Trace
175-180	22.0	6.0	9.2	16.0	46.8	0.09	52.8	4	10	3	30	0.2	Trace
180-185	21.2	7.5	8.6	14.5	48.2	0.09	55.7	2	5	2	35	0.3	Trace
185-190	20.0	7.2	6.0	10.8	56.0	0.06	46.9	2	5	2	44	0.1	Trace
190-195	35.8	14.0	6.0	12.0	32.2	0.20	68.8	4	3	2	22	0.2	Trace
195-200	40.0	2.1	2.7	7.2	48.0	0.10	62.6	2	2	Tr	33	0.4	Trace
200-205	40.0	12.8	12.0	17.6	18.6	0.20	77.5	5	4	Tr	13	0.5	Trace
205-210	28.6	3.2	9.2	16.8	42.8	0.13	62.6	3	4	Tr	30	0.4	Trace
210-215	28.0	4.4	2.8	22.0	42.8	0.11	54.4	5	3	2	35	0.6	Trace
215-220	34.8	8.0	8.8	10.8	37.6	0.17	53.6	3	8	2	33	0.4	Trace
220-225	62.2	20.4	5.3	7.9	4.2	0.42	55.5	3	38	1	2	0.5	Trace

Table 6 - (continued)

DEPTH (ft.)	% RETAINED					MEDIAN(1) DIAMETER (mm.)	AVERAGE PER CENT COMPOSITION						
	40	80	100	200	PAN		QUARTZ	FELDSPAR	CALCITE	PHOSPHATE	CLAY(2)	H.MINERAL	MICA
225-230	56.8	8.1	4.0	5.6	25.7	0.45	71.8	5	18	3	2	0.2	Trace
230-235	62.0	12.0	3.2	9.2	13.6	0.60	47.9	4	42	4	2	0.1	Trace
235-240	48.0	12.0	8.4	8.8	20.8	0.38	43.6	4	48	3	1	0.4	Trace
240-245	47.2	12.0	10.4	7.2	23.2	0.38	50.9	5	41	2	1	0.1	Trace
245-250	53.2	12.8	8.0	6.8	19.2	0.41	41.7	4	48	4	2	0.3	Trace
250-255	56.8	12.0	8.4	7.2	15.6	0.44	46.9	4	45	3	1	0.1	Trace
255-260	60.8	11.2	6.0	6.0	24.0	0.48	47.6	4	42	3	3	0.4	Trace
260-265	50.4	15.2	8.8	8.0	21.6	0.42	49.8	5	40	4	1	0.2	Trace
265-270	48.0	8.0	4.0	4.4	35.4	0.41	47.6	6	40	3	3	0.4	Trace
270-275	60.0	13.0	2.2	3.2	21.6	0.56	33.7	6	56	3	1	0.3	Trace
275-280	58.2	11.6	3.4	3.0	23.8	0.48	33.5	2	60	2	2	0.5	Trace
280-285	56.0	14.4	3.6	0.8	25.2	0.45	25.8	2	68	2	2	0.2	Trace
285-290	88.1	4.0	1.2	2.4	4.3	1.02	24.8	1	70	2	2	0.2	Trace
290-295	78.4	8.4	2.8	3.6	8.4	1.00	22.8	2	72	2	1	0.2	Trace
295-300	68.0	9.6	3.6	6.8	12.0	0.62	23.8	2	70	2	2	0.2	Trace

NOTES: 1. MEDIAN DIAMETER IN MILLIMETERS AS OBTAINED FROM THE CUMMULATIVE CURVE.
2. PER CENT COMPOSITION OF CLAY ESTIMATED AS -325 (ACID INSOLUBLE) MESH SIEVE SIZE.

TABLE 7. AVERAGE[(2)] ACID-INSOLUBLE HEAVY-MINERAL SUITE AS FRACTIONAL PER CENT SAMPLES FROM EFFINGHAM COUNTY, GEORGIA

DEPTH (FT.)	0-28	28-32	38-45	45-49	49-52	52-57	57-61	61-65	65-78	78-93	100-108	108-128	128-145	145-150	150-155	155-160	160-165	165-170	170-175	175-180	185-190	190-195
ILMENITE-LEUCOXENE	57	57	41	21	28	25	39	33	34	44	54	49	51	51	44	48	36	46	50	51	46	51
EPIDOTE	3	5	25	47	42	46	39	35	38	23	20	20	16	22	20	16	30	16	19	24	18	17
ZIRCON	7	13	11	6	5	6	11	12	12	14	10	10	7	11	8	9	6	10	8	7	12	13
SILLIMANITE	12	13	14	13	9	10	5	8	6	6	5	5	6	6	12	11	10	10	6	8	8	7
STAUROLITE	10	2	1	2	1	1	1	1	1	3	3	9	9	3	6	5	7	7	6	4	8	4
GARNET	Tr	Tr	1	2	1	Tr	1	1	1	2	2	3	3	1	2	2	2	2	2	1	2	2
TOURMALINE	2	2	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	3	2	1	2	1
HORNBLENDE	Tr	Tr	Tr	6	10	8	Tr	5	1	1	Tr	Tr	1	2	1	1	4	1	2	Tr	Tr	Tr
RUTILE	5	5	5	1	1	2	2	3	4	3	2	1	3	2	4	4	1	3	3	3	3	4
KYANITE	2	2	Tr	Tr	1	Tr	Tr	Tr	Tr	1	1	Tr	Tr	Tr	1	1	1	1	1	Tr	Tr	Tr
OTHER [(1)]	2	1	1	1	1	1	1	1	1	1	1	1	2	Tr	Tr	1	1	1	1	1	1	1

NOTES: TR = TRACE AMOUNTS LESS THAN 0.5% HEAVY-MINERAL FRACTION.

1. OTHER INCLUDES APATITE, MONAZITE, MAGNETITE, BERYL, ETC.
2. AVERAGE BASED ON WEIGHTED POINT COUNT OF THREE-SIEVE SIZES.

Table 7 - (continued)

DEPTH (FT)	195-200	200-205	205-210	210-215	215-220	220-225	225-230	230-235	235-240	240-245	245-250	250-255	255-260	260-265	265-270	270-275	275-280	280-285	285-290	290-295	295-300
ILMENITE-LEUCOXENE	42	47	46	42	48	42	43	33	34	34	34	32	31	34	39	30	50	38	41	50	42
EPIDOTE	14	20	15	20	17	21	19	32	27	30	26	28	27	32	23	27	9	28	29	22	34
ZIRCON	18	12	16	18	11	10	10	5	9	5	10	10	8	7	5	9	11	8	6	10	5
SILLIMANITE	9	7	9	9	10	12	9	10	11	11	12	11	15	8	11	13	12	9	8	4	4
STAUROLITE	4	3	2	3	4	4	4	4	3	3	4	2	5	4	3	5	4	5	5	4	4
GARNET	2	3	3	2	5	6	8	9	11	12	10	12	10	10	13	8	6	7	6	6	4
TOURMALINE	3	1	2	1	1	2	2	3	2	2	1	2	1	2	1	3	2	1	2	Tr	1
HORNBLENDE	2	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	1	3	Tr	Tr	1	2
RUTILE	4	5	5	4	3	2	4	3	2	2	2	2	2	2	3	2	2	3	2	2	2
KYANITE	1	1	1	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	1	Tr	Tr	1	1
OTHER (1)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	Tr	Tr	1	1	Tr	1

NOTES: TR = TRACE AMOUNTS LESS THAN 0.5% HEAVY-MINERAL FRACTION.
1. OTHER INCLUDES APATITE, MONAZITE, MAGNETITE, BERYL, ETC.
2. AVERAGE BASED ON WEIGHTED POINT COUNT OF THREE-SIEVE SIZES.

Petrographic Description

The sediment from the surface to 45 foot depth consists of clean, fine- to medium-grained, angular sand (top 32 feet) overlying a clayey, fine-grained, micaceous, limonitic sand (32 to 45 foot depth). Average mineral composition approximates the following:

Sand, 0-32 Foot Depth

Quartz	97.5
Feldspar	1.0
Clay	1.4
Heavy Minerals	0.1
Mica	Tr
	100

Fine Sand, 32-45 Foot Depth

Quartz	73.1
Feldspar	8.0
Clay	17.0
Heavy Minerals	1.4
Mica	0.5
	100

Median Diameter in mm.

Range	1.20 - 1.31
Average	1.25

Median Diameter in mm.

Range	0.15 - 0.22
Average	0.18

The lithologic unit from the 45 to 65 foot depth is an olive-green, micaceous, feldspathic, clayey silt which is unique in containing abundant hornblende in the heavy-mineral fraction and higher values of mica and feldspar than any of the other sediments of the core.

The sediment from 65 to 100 foot depth consists of dark-green, phosphatic pebble-bearing, clayey sand. This lithologic unit is unique in containing black, rounded, polished pellets and pebbles up to 2 cm. size and concentrations up to 20 percent of the sample from 93 to 100 foot depth. The black color of the phosphorite is caused by inclusions of pyrite and carbonaceous matter and may reflect the reducing conditions in typical estuarine environments.

Some of the phosphorite clearly reveals teeth and bone fragment origin. The similar size relation with quartz suggests that all the phosphorite pellets are detrital.

The sediment from 100 to 160 foot depth is cream to light-gray clastic carbonate and shell hash, feldspathic, slightly phosphatic sand. From 25 to 50 percent of the carbonate fraction is shell fragments.

Average mineral composition and sedimentary parameters approximate the following percentage distribution:

Sandy Silt 45 to 65 foot depth		Phosphatic Sand 65 to 100 foot depth		Calcareous Sand 100 to 160 foot depth	
Quartz.............	74.5	Quartz...............	69.1	Quartz...........	51.2
Feldspar...........	8.5	Feldspar.............	7.0	Feldspar.........	5.0
Clay...............	12.4	Clay.................	8.0	Clay.............	6.3
Heavy Minerals.....	2.2	Heavy Minerals.......	0.9	Heavy Minerals...	0.6
Calcite............	Tr	Calcite..............	6.0	Calcite..........	34.6
Mica...............	2.4	Mica.................	Tr	Mica.............	Tr
Phosphorite........	Tr	Phosphorite..........	9.0	Phosphorite......	2.3
	100		100		100

Median Diameter in mm.		Median Diameter in mm.		Median Diameter in mm.	
Range........	0.09 - 0.17	Range..........	0.12 - 0.48	Range.....	0.06 - 0.50
Average......	0.10	Average........	0.26	Average...	0.28

The sediment from 160 to 220 foot depth is comprised of greenish-gray, clayey, feldspathic, slightly phosphatic, calcareous-shelly sand. Both the amber and black phosphorite pellets of similar grain size as quartz occur in amounts up to 3 percent. All the samples display remarkable uniformity in texture. Approximately half of the carbonate fraction consists of shell fragments.

Average mineral composition and sedimentary parameters approximate the following percentage distribution:

Clayey, Shelly Sand, 160 to 220 Foot depth	
Quartz	56.5
Feldspar	3.5
Clay	31.3
Heavy Minerals	0.4
Calcite	6.6
Phosphorite	1.7
Mica	Tr
	100.0

Median Diameter in mm.	
Range	0.09 - 0.20
Average	0.14

The sediment from the 220 to 300 foot depth is comprised of uniform, light-grey, sandy, slightly phosphatic, shelly limestone. The mineral composition and physical character of the limestone is remarkably uniform. This uniformity may be demonstrated by superimposing cumulative weight distribution curves or computing individual sedimentary parameters for comparison purposes. Inspection of the heavy-mineral suite also reveals uniform garnet distribution in the limestone which is several times that experienced in any other sediment unit in the core. This garnet concentration appears related to environmental factors. Phosphorite also occurs in both the amber and black, round, polished pellets of similar grain size as quartz.

Average mineral composition and sedimentary parameters approximate the following percentage distribution:

Sandy Limestone, 220 to 300 foot depth	
Quartz	42.0
Feldspar	3.4
Clay	1.7
Heavy Minerals	0.3
Calcite	50.0
Phosphorite (black & amber)	2.6
Mica	Tr

Median Diameter in mm.	
Range	0.38 - 1.00
Average	0.53

Conclusions on Effingham County Well

Heavy minerals, exclusive of phosphorite, average about 0.6 percent of the total sediment. The greatest concentration of heavy minerals (1.5 to 3.1 percent) is in the 38 to 65-foot interval. The average heavy-mineral suite in percent of the heavy-mineral fraction is as follows: 43% ilmenite-leucoxene, 24% epidote, 9% zircon, 9% sillimanite, 4% starolite, 4% garnet, 3% rutile, 2% tourmaline, 1% hornblende, 1% magnetite, monazite, apatite, beryl, hypersthene and others.

Anomalous amounts of hornblende occur in olive-green, clayey silt at 45 to 65 feet. Garnet, while insignificant in most heavy-mineral suites, occurs in appreciable amounts at 220 to 300 feet. Hornblende and garnet are the least stable of the heavy minerals and their relative abundance is related to environmental factors favoring preservation. Staurolite, on the other hand, is one of the more stable heavy mineral species, and its erratic distribution is more related to size preference. Staurolite is always in greater population in larger sieve sizes which tends to support this view. Rutile, zircon, and ilmenite-leucoxene, on the other hand, are finer grained. Greater than 10 percent feldspar occurs in the olive-green, clayey silt, at 45 to 65 feet, where the feldspars are relatively fresh with well defined twinning. In all sediment, K-feldspar, as orthoclase and microcline, is more abundant than plagioclase varieties.

Calcite, as clastic shell fragments, comprises but very minor amounts of the sediment to 100 foot depth. Below 100 foot depth, calcite occurs in abundance. The most indurated calcite occurs in the sample from 100 to 108 foot depth and the least indurated where clastic shell comprises the major portion of the carbonate fraction. There is no interlocking-granular limestone or crystalline limestone in the sediment.

In most sediment samples quartz is the most abundant constituent and second only to calcite in limestone-rich sediment. The largest quartz particles occur as smooth, flattened, pebbles up to 3 cm. in size in the phosphate-rich horizons.

Mica is locally abundant only in clayey silt or fine sands from the 32 to 65 foot depth.

Median diameter values for sediment are readily computed and useful in correlating strata. Other sedimentary parameters could also prove of value in correlation, if computed.

REFERENCES CITED

Cooke, C. Wythe (1939), Coastal Plain portion: Geologic Map of Georgia, prepared by the Ga. Dept. of Mines, Mining and Geology in cooperation with the U. S. Geological Survey.

____________ (1943), Geology of the Coastal Plain of Georgia: U. S. Geol.Survey Bull. 941.

Doering, J. A. (1960), Quaternary surface formations of the southern part of the Atlantic Coastal Plain; Jour. Geology, v. 68, no. 2, p. 182-202.

Dryden, Lincoln (1958), Monazite in part of the Southern Atlantic Coastal Plain: U. S. Geol. Survey Bull. 1042-L, p. 393-429.

Dryden, L. and Dryden, C. (1956), Coastal Plain heavy minerals: A speculative summary: 20th Inter. Geol. Cong., Mexico, p. 16.

Furman, N. H. (1962), Standard methods of chemical analysis: Van Nostrand, New York, 6th ed., v. 1.

Giles, Robert T. (1966), River, beach and dune sands of the southeastern Atlantic Coast of the United States: Geol. Soc. America, Southeastern Section, Field Trip No. 1 Guidebook, University of Ga. Marine Institute, p. 71-76.

____________ and Pilkey, O. H. (1965), Atlantic beach and dune sands of the southern United States: Jour. Sed. Petrology, v. 35, p. 900-910.

Gorsline, D. S. (1963), Bottom sediments of the Atlantic shelf and slope off the southern United States: Jour. Geology, v. 71, no. 4, p. 422-440.

Herrick, Stephen M. (1961), Well logs of the Coastal Plain of Georgia: Ga. Geol. Survey Bull. 70.

__________ (1965), A subsurface study of Pleistocene deposits in Coastal Georgia: Ga. Geol. Survey Information Cir. 31.

Hill, J. H., and Miles, M. J. (1959), Gravimetric determination of zirconium in titanium: Analytical Chemistry, v. 31, no. 2, p. 252-254.

Hoyt, J. H., and Hails, J. R. (1966), Formation and modification of Pleistocene shorelines in coastal Georgia (abs.): Geol. Soc. America, AAAS Program, Sec. E., Washington, D. C., p. 20.

__________ and Weimer, R. J. (1963), Comparison of modern and ancient beaches, central Georgia coast: Am. Assoc. Petroleum Geologists Bull. 47, p. 529-531.

__________ Weimer, R. J., and Henry, V. J., Jr., (1964), Late Pleistocene and Recent sedimentation, central Georgia coast, U.S.A., _in_ L.M.J.U. Van Straaten (ed.), Developments in Sedimentology, v. 1, Deltaic and Shallow Marine Deposits, p. 170-176.

Husted, John E., Furcron, A. S., and Bellinger, Frederick (1966), Project report No. 3, South Georgia minerals program: Mineral Engineering Branch, Engineering Experiment Station, Georgia Institute of Technology and Georgia Dept. of Mines, Mining and Geology.

LaForge, Laurence, Cooke, C. Wythe, Keith, Arthur, and Campbell, Marius R. (1925), Physical geography of Georgia: Ga. Geol. Survey Bull. 42.

MacNeil, F. S. (1947), Geologic map of the Tertiary and Quarternary formations of Georgia: U. S. Geol. Survey Oil and Gas Prel. Map 72.

____________ (1949), Pleistocene shorelines in Florida and Georgia: U. S. Geol. Survey Prof. Paper 221-F.

Martens, J. H. C. (1928), Beach deposits of ilmenite, zircon and rutile in Florida: Fla. State Geol. Survey, 19th Annual Rept., p. 124-154.

____________ (1935), Beach sands between Charleston, South Carolina and Miami, Florida: Geol. Soc. America Bull., v. 46, no. 10, p. 1563-1596.

McKelvey, V. E., and Balsley, J. R., Jr. (1948), Distribution of coastal black-sands in North Carolina, South Carolina, and Georgia, as mapped from an airplane: Econ. Geol., v. 43, no. 6, p. 518-524.

Mertie, J. B. (1953), Monazite deposits of the Southeastern Atlantic States: U. S. Geol. Survey Circ. 237.

____________ (1958), Zirconium and hafnium in the Southeastern Atlantic States: U. S. Geol. Survey Bull. 1082-A.

Miller, Jesse A. (1957), Titanium, a materials survey: U. S. Bur. Mines I. C. 7791.

Minerals Engineering Group, Engineering Experiment Station, Georgia Institute of Technology and Georgia Department of Mines, Mining and Geology (1966), Ga. Dept. of Mines Proj. Rept. No. 2.

Moxham, R. M. (1954), Airborne radioactivity survey in the Folkston area, Charlton County, Georgia, and Nassau County, Florida: U. S. Geol. Survey Geophys. Inv. Map GP 119.

Neiheisel, James (1962), Heavy mineral investigation of Recent and Pleistocene sands of lower Coastal Plain of Georgia: Geol. Soc. American Bull., v. 73, no. 3, p. 365-374.

__________________ (1965), Source and distribution of sediments at Brunswick Harbor and vicinity, Georgia: U. S. Army Coastal Eng. Research Center Tech. Man., no. 12.

Overstreet, W. C., Cuppels, N. P., and White, A. M. (1956), Monazite in Southeastern United States: U. S. Geol. Survey Prof. Paper 300, p. 597-617.

Pilkey, O. H. (1963), Heavy minerals of the U. S. South Atlantic continental shelf and slope: Geol. Soc. American Bull., v. 74, no. 5, p. 641-648.

__________________ and Frankenberg, Dirk (1964), The relict-recent sediment boundary on the Georgia continental shelf: Ga. Academy of Science Bull. 22, no. 1, p. 37-40.

Rosenfeld, Sigmund J. (1955), A study of the Pleistocene shorelines between the Altamaha and Savannah Rivers in Georgia: unpublished M. S. Thesis, Emory University.

Sandell, E. B. (1944), Colorimetric determination of traces of metals: Interscience Publishers, New York.

Sinha, E. F. (1959), Geomorphology of the lower Coastal Plain from the Savannah River area, Georgia to the Roanoke River area, North Carolina: unpublished Ph. D. Thesis, Univ. of N. C.

Spencer, Robert V. (1948), Titanium minerals in Trail Ridge: U. S. Bur. Mines Rept. Inv. 4208.

Teas, L. P. (1921), Preliminary report on the sand and gravel deposits of Georgia; Ga. Geol. Survey Bull. 37.

Temple, Alan K. (1966), Alteration of ilmenite: Econ. Geol., v. 61, no. 4, p. 695-714.

Thoenen, J. R., and Warne, J. D. (1949), Titanium minerals in central and northeastern Florida: U. S. Bur. Mines Rept. Inv. 4515.

U. S. Geological Survey (1953), airborne radioactivity anomalies map: Southern Chemical Industry, Nov.-Dec., p. 18.

Veatch, Otto and Stephenson, L. W. (1911), Geology of the Coastal Plain of Georgia: Ga. Geol. Survey Bull. 26.

Weimer, R. J., and Hoyt, J. H. (1964), Burrows of Callianassa major Say, geologic indicators of littoral and shallow neritic environments: Jour. of Paleontology, v. 38, no. 4, p. 761-767.

Whitlatch, George I. (1962), Georgia's mineral resources, Project No. E-233-3: Engineering Experiment Station, Georgia Institute of Technology, Atlanta, Ga.