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CLAY MINERAL TRANSPORT ON THE INNER
CONTINENTAL SHELF OF GEORGIA

A THESIS

Presented to

The Faculty of the Division of Graduate

Studies and Research

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CLAY MINERAL TRANSPORT ON THE INNER
CONTINENTAL SHELF OF GEORGIA

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SUMMARY

Ninety-three suspended-matter samples were collected from 52 stations on the inner continental shelf of Georgia during the summer of 1970. Bottom sediment, along with near-surface and near-bottom suspended-matter samples were also taken and salinity, temperature, and current direction and velocity measurements were made to determine the nature of shelf-sediment transport processes on the inner continental shelf of Georgia. Sediments and suspended matter were analyzed by x-ray diffraction to determine clay mineralogy. It has been previously established that the Georgia rivers contribute kaolinite, smectite and minor illite to the coastal region, while a kaolinite-illite clay mineral suite is transported southward by longshore drift so that net transport direction may be inferred from suspended-matter clay mineralogy patterns.

The shelf-water circulation pattern during the summer months appears to be a complex system of tidal-current and wind generated eddies superimposed on a predominantly southward drift.

Clay mineral differential settling characteristics were used to explain the suspended clay mineral distribution and to establish a 'zone of deposition' which extends three to ten miles offshore. The 'zone of deposition' is considered to be the maximum seaward extent of Georgia river-derived detritus.

CHAPTER I

INTRODUCTION

The present study was undertaken to determine the nature of transport processes on the inner continental shelf of Georgia. Previous work has established that the Georgia estuaries and salt marshes form an effective sediment trap for detritus contributed to the coast by the Georgia rivers. Studies of the Georgia continental shelf sand-size sediments have shown recent sediments to be restricted to a narrow nearshore band adjacent to the coast. It is therefore of interest to determine whether clay-size sediments are also restricted to a similar nearshore band or are transported across the shelf to the open ocean. Clay minerals were used as natural tracers because their extremely small particle size allows them to be the most easily transported lithogenous sediment once suspended. The distribution of clay minerals is therefore the most sensitive indicator of transport processes.

In addition to collecting temperature and salinity data, the clay mineralogy of suspended-matter and bottom sediment clay-size fraction was determined and compared to establish the significance of various transport processes.

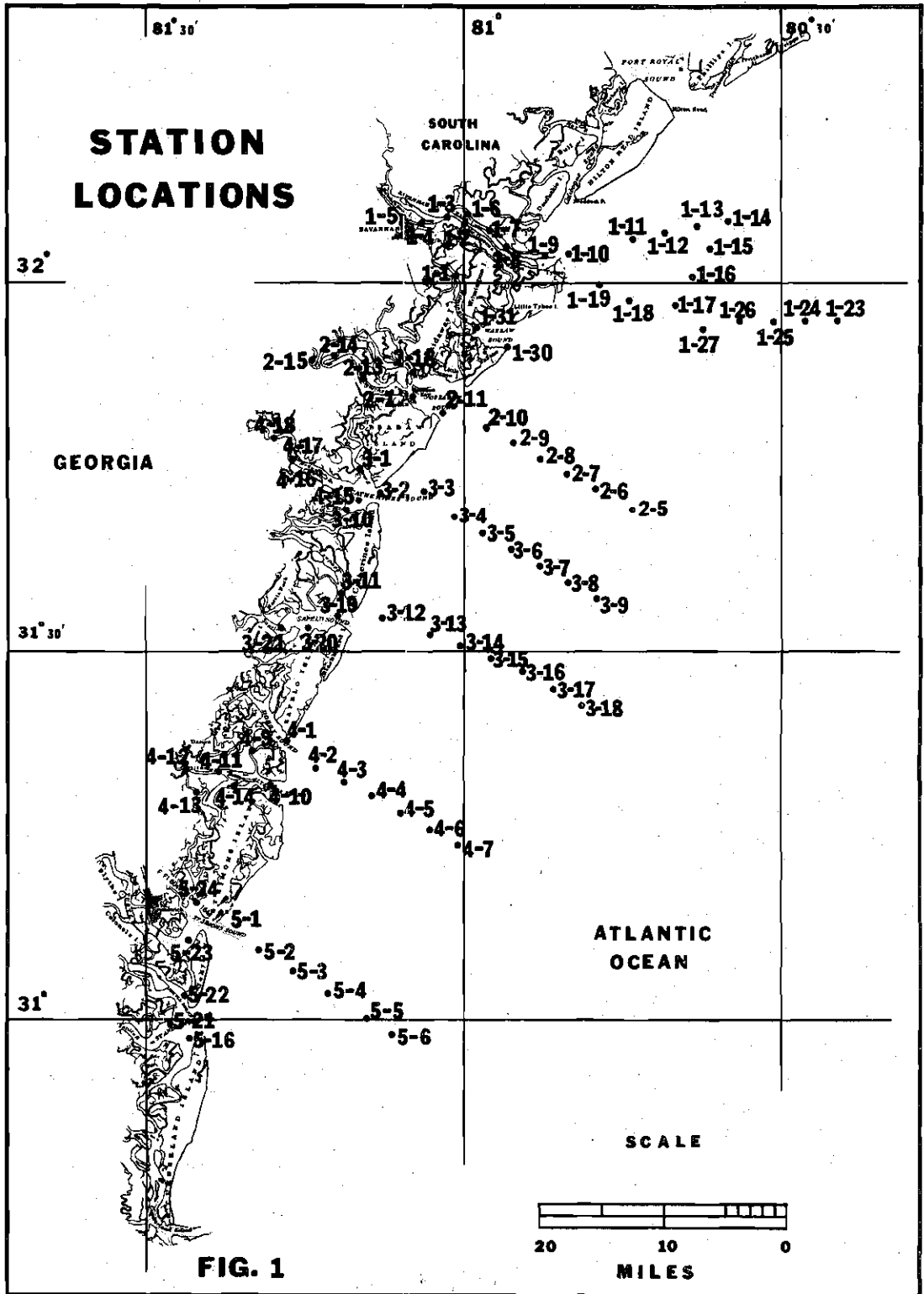
The continental shelf of Georgia is conspicuously lacking in relief and extends 70 to 80 miles offshore. The shelf is an extension of the Atlantic Coastal Plain with slopes averaging less than one degree (Pilkey and Giles, 1965). The shelf-slope break occurs abruptly in the southern portion of the shelf near the

50 meter contour and is less well defined in the northern portion near the 80 meter contour. In their study of the topography of the shelf, Pilkey and Giles (1965) reported that the major topographic feature is a filled valley formed by the Altamaha River during the Pleistocene. In another study of the shelf topography, Henry and Hoyt (1968) suggested that as many as five "terraces" are probably associated with 'static periods' during the present marine transgression. The various aspects of the Georgia continental shelf sediments have been studied by several authors. A complete review has been presented by Henry and Hoyt (1968). The present report is apparently the first detailed description of the clay mineralogy of the Georgia inner continental shelf sediments.

Neiheisel and Weaver (1967) investigated the clay mineralogy of the source areas in the Southeastern U. S. in relation to the clay mineralogy of sediments and suspended matter in the Southeastern rivers and estuaries. In Georgia, Neiheisel and Weaver found smectite to be the predominant coastal plain province clay mineral and kaolinite to be the most abundant piedmont clay mineral. They also found the clay mineral suite, kaolinite/smectite ratio, being transported by the Savannah and Altamaha Rivers to be directly dependent on the percentages of the Coastal Plain and Piedmont provinces composing the drainage basin. Biscay (1965) found the clays in the surficial continental shelf sediments to be predominantly illite derived from the central and northern Appalachians and carried southward by longshore currents. Windom, Neal and Beck (1971) studied mineral transport in coastal Georgia estuaries in detail. Analytical data on the clay mineral and heavy mineral fraction of bottom sediments and suspended estuarine clay

minerals from the Altamaha, Satilla and Ogeechee Rivers concur with the earlier work of Neiheisel and Weaver (1967). Windom, et al. (1971) found illite, from the continental shelf, was transported into the estuaries and contributed to the estuarine sediments. Manheim, Meade and Bond (1970) investigated the quantitative aspects and size distribution of surface suspended matter on the continental shelf from Cape Cod to the Florida Keys. They found that detrital particles contributed to the shelf region tended to travel longshore rather than seaward and concentrations greater than 1.0 milligrams total suspended matter per liter were generally restricted to within 10 kilometers of the Atlantic coast. The detailed nature of circulation patterns on the Georgia shelf is not known. All authors are generally agreed that there is a predominantly southward drift observed along the inner shelf of the southeast U.S. Near surface and near bottom current velocity and direction measurements were taken for the purpose of the present research; however, such measurements give only a synoptic pattern at best.

The area investigated extends from immediately north of the Savannah River estuary to immediately south of the Altamaha River estuary and seaward to approximately 30 miles (Figure 1).



CHAPTER II

METHODS

Collection

76 stations were occupied from mid-July to mid-September. At each offshore station, bottom sediment, near bottom suspended matter and filtered water, and near surface suspended matter and filtered water samples were collected. In addition, water temperature, near bottom current, near surface current, and water depths were measured. At estuarine stations, mid-depth sampling was carried out. Each station was occupied only once. Appendix I lists data collected at each station.

Bottom sediments were collected with a Van Veen grab sampler and stored in plastic, 1-quart freezer cartons. Water samples were collected with 4.4-liter PVC van Dorn bottles. In some cases, surface water samples were collected using a plastic bucket. Water samples of known volume were immediately put into a 7-liter plexiglas cylinder for filtering. Approximately 60 psi nitrogen pressure was applied to force the water through a 142 mm, 0.45 μ m millipore filter. Filter papers were then stored in plastic petri dishes for later analysis. Salinity and dissolved oxygen were determined on aliquots of the water samples by the modified Knudson method (Martin, 1968, p. 67) and by Winkler titration (Martin, 1968, p. 87) respectively. Surface water temperatures were measured directly with a thermometer and temperatures at depth were measured

with a calibrated thermistor probe.

Analytical Methods

Sediments

Since the bottom sediment samples were, in some cases, of a larger volume than necessary, the samples were first homogenized in their containers by stirring. The volume of the aliquot for separation of the less than 2 micron size fraction depended on the amount of clay size material visually estimated to be present. The aliquot was then put in a blender to facilitate dispersion. Although shell fragments were destroyed, the blender was operated no longer than 15 seconds to minimize grain size alteration of lithogenous particles. The sediment was then wet sieved using a 63 μm sieve to separate the very fine sand and the silt-clay fractions. The sand fraction was air dried and stored. The clay-silt fraction was then washed to remove NaCl and other water soluble compounds. After washing, the sample was dispersed in a liter cylinder with distilled water only. The amount of clay-silt size material present was determined by the pipette method. A sample of the less than 2 μm fraction was then taken using the settling velocity method. Again, the amount of the less than 2 μm material taken depended on the concentration. The clay size fraction was concentrated by centrifugation and then left to stand in 5% sodium hyperchloride (chlorox) for at least 24 hours to oxidize organic material (Anderson, 1961). The sample was then washed three times in an ultra-centrifuge to remove the chlorox. The centrifuge was operated at 10,000 rpm for 30 minutes to assure that there would be no loss of clay size particles. A portion of this sample was then sedimented onto a

glass slide to produce an oriented sample for x-ray diffraction analysis.

Suspended Matter

Suspended matter was analyzed to determine the weight of total suspended matter per liter of seawater, percentage of combustible organics, and clay mineralogy. The filter papers were first carefully cut into half sections and then one half section was further divided into two quarter sections.

One quarter section of each sample was used to determine the weight per liter. The suspended matter was carefully scraped off the filter paper with a rubber policeman and distilled water into a pre-weighed crucible. The material was then dried at 110 C and weighed to determine the concentration of suspended sediment. To determine the percentage of combustible organic matter, the dried material was heated to 600 C for 3 hours and after cooling, reweighed. The cooling of samples was carried out in a dessicator.

For x-ray analysis, the remainder of each suspended-matter sample was scraped into a centrifuge tube with chlorox, instead of distilled water, and allowed to react for at least 24 hours. The inorganic residue was washed and oriented slides were prepared with the same procedure used on the bottom sediment.

X-Ray Analysis

Mineral analysis consisted of determination of minerals present and estimation of the relative percentages of kaolinite, illite, smectite, and chlorite. All analysis were made with a Phillips x-ray diffraction unit at 45 Kv and 20 mA with nickel filtered Cu Ka radiation.

The term smectite is used here as a group name which includes all

montmorillonite-like clay minerals. Although the clay mineral montmorillonite most likely is the predominant smectite group clay mineral in the study area, no distinction was made during analysis between montmorillonite and other smectite minerals such as beidellite, nontronite, saponite, hectorite or sauconite. The use of the group name smectite therefore seems appropriate. Smectite group minerals were identified by their (001) reflection at 14A, for air dried samples, which expanded to 17A after glycolation.

The term illite is used here as the mica group clay minerals. It was identified on the basis of its sharp (001) reflection at 10A and (002) reflection at 5A. All samples contained quartz so that the (003) reflection at 3.33A merged with the quartz peak at 3.35A. Sufficient suspended clays were not available for a random pack sample to determine the specific illite polytype.

The presence of kaolinite was based on its (001) reflection at 7.15 to 7.20A and the (003) reflection at 2.38A.

The (003) 4.75A peak of chlorite was the only one not masked by peaks of other, more abundant, clay minerals. The (001) peak at 14A was obscured by the smectite and vermiculite peaks, the (002) of chlorite was masked by kaolinite around 7A, and the chlorite (004) at ~ 3.50A by the kaolinite (002) at 3.58A.

The identification of vermiculite was based on the broadening of the 17A glycolated smectite peak to 14A.

Attapulgite was identified by its 10.5A peak which appeared as a broadening of the base of the 10A illite peak.

Talc/pyrophyllite was identified by its (001) 9.4A reflection (Pierce et al., 1971). No distinction between the two minerals was made.

The weak peak at 8.4A was considered to be an amphibole (Jackson, 1956) (Biscaye, 1965), gibbsite was identified by its (002) reflection at 4.85A and quartz was identified by peaks at 4.26A (100) and 3.34 (101). Orthoclase feldspar was present at about 3.24A and plagioclase feldspar at about 3.20A. Reflections greater than 17A were due to mixed-layer clays. Only one sample exhibited any second or third order peaks from which to determine the nature of layering.

Semi-Quantitative Estimates

To compare the clay mineralogy of individual sediment and suspended-matter samples, the relative percentages of illite, smectite, kaolinite and chlorite in each sample was determined. The areas under the kaolinite (001), illite (001), smectite (001) and chlorite (003) were measured with a polar planimeter. Appropriate weighing factors, as discussed below, were applied to each peak and the percentage of the sum of the areas was taken as the percentage of the clay mineral in the sample. Appendix II is a compilation of the mineralogy and relative abundance percentages for all samples. As suggested by Naidu, et al. (1971), the basic peak areas are presented so that further use of the data may be made using different weighing factors.

Weighing factors are necessary to account for differences in diffraction potential among different clay minerals (Weaver, 1958). In addition, weighing factors must be further adjusted due to varying degrees of crystallinity. Due to poor crystallinity, the area under the smectite peak was divided by 3.5 rather

than 4.0, the 7A peak was divided by 2.5 (Weaver, 1961), and the 10A illite peak was used as standard. All areas were measured on diffractograms of glycolated samples. Several methods have been employed to determine the ratio of chlorite to kaolinite contributing to the 7A peak. Johns et al. (1954) heated the sample to remove chlorite and Biscayne, (1964) used low scanning speeds to resolve the 3.54 chlorite (004) and 3.58A kaolinite (003) doublet. Weaver (1958) states that the chlorite to kaolinite ratio may be obtained by using the chlorite 4.75A peak area compared to one half the 2.38A kaolinite peak area. This method has the advantage that the peaks are not obscured by peaks of other minerals and all measurements are made on the same diffractogram with no additional sample preparation required.

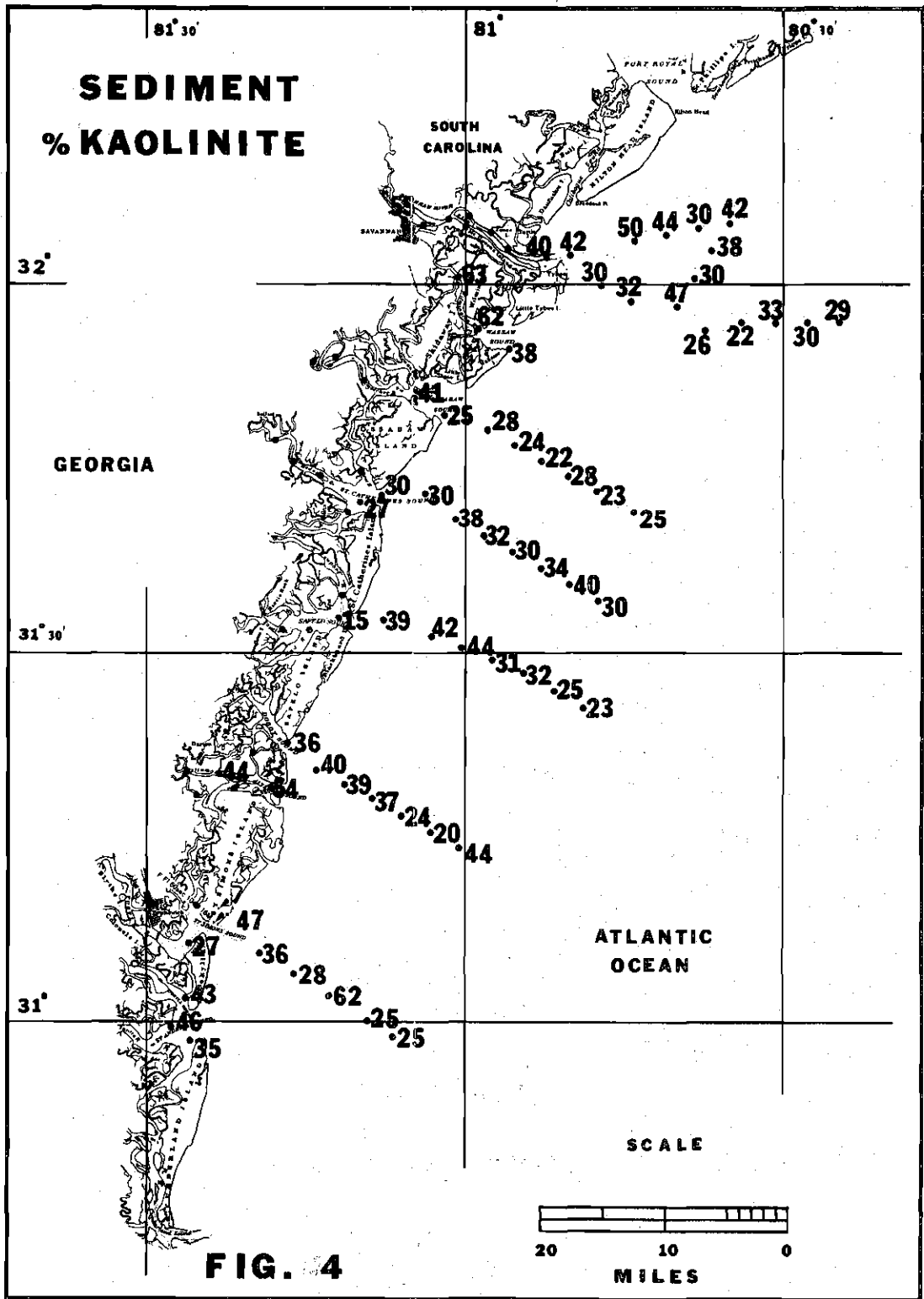
CHAPTER III

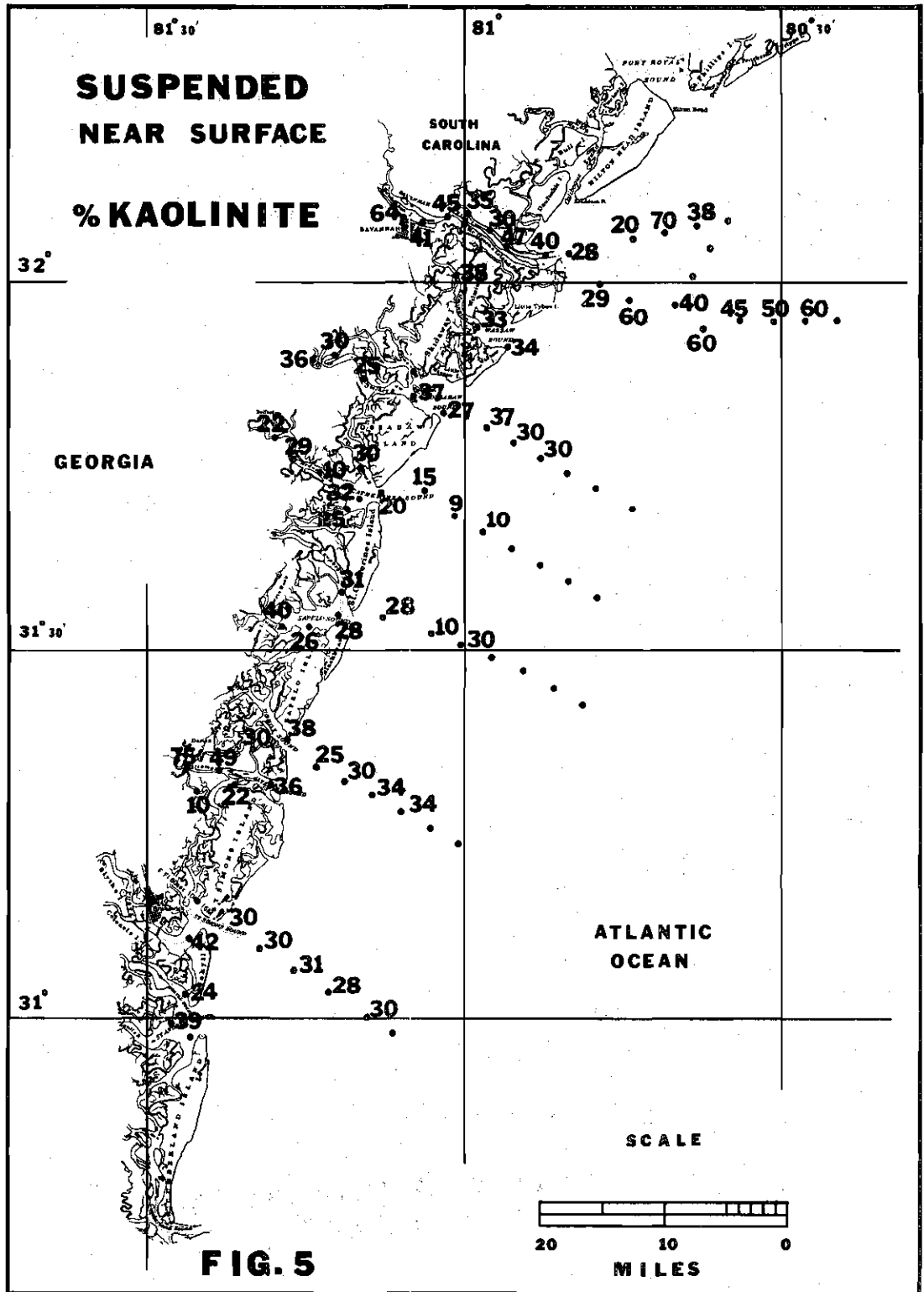
RESULTS

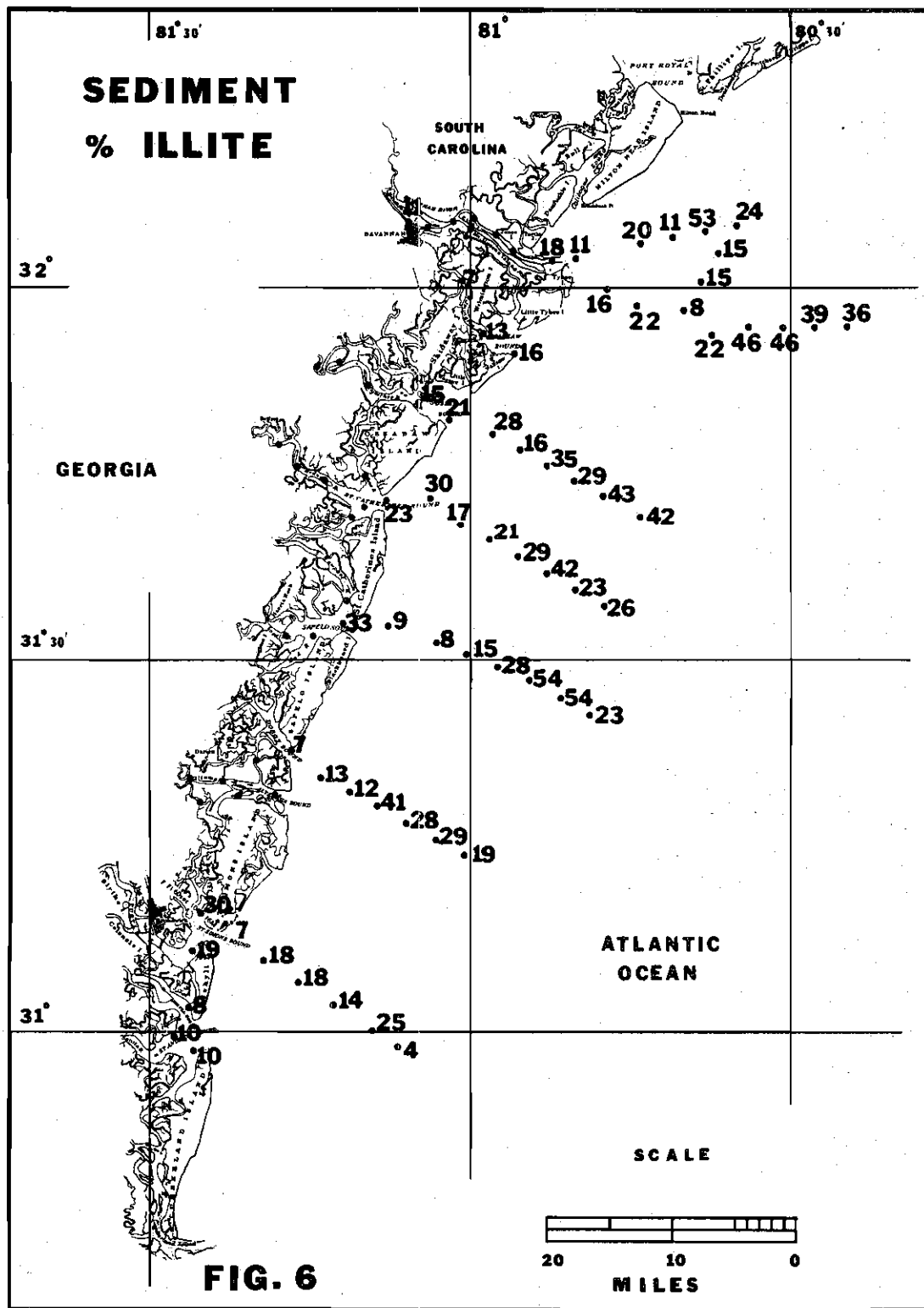
Composition of Transported Sediments

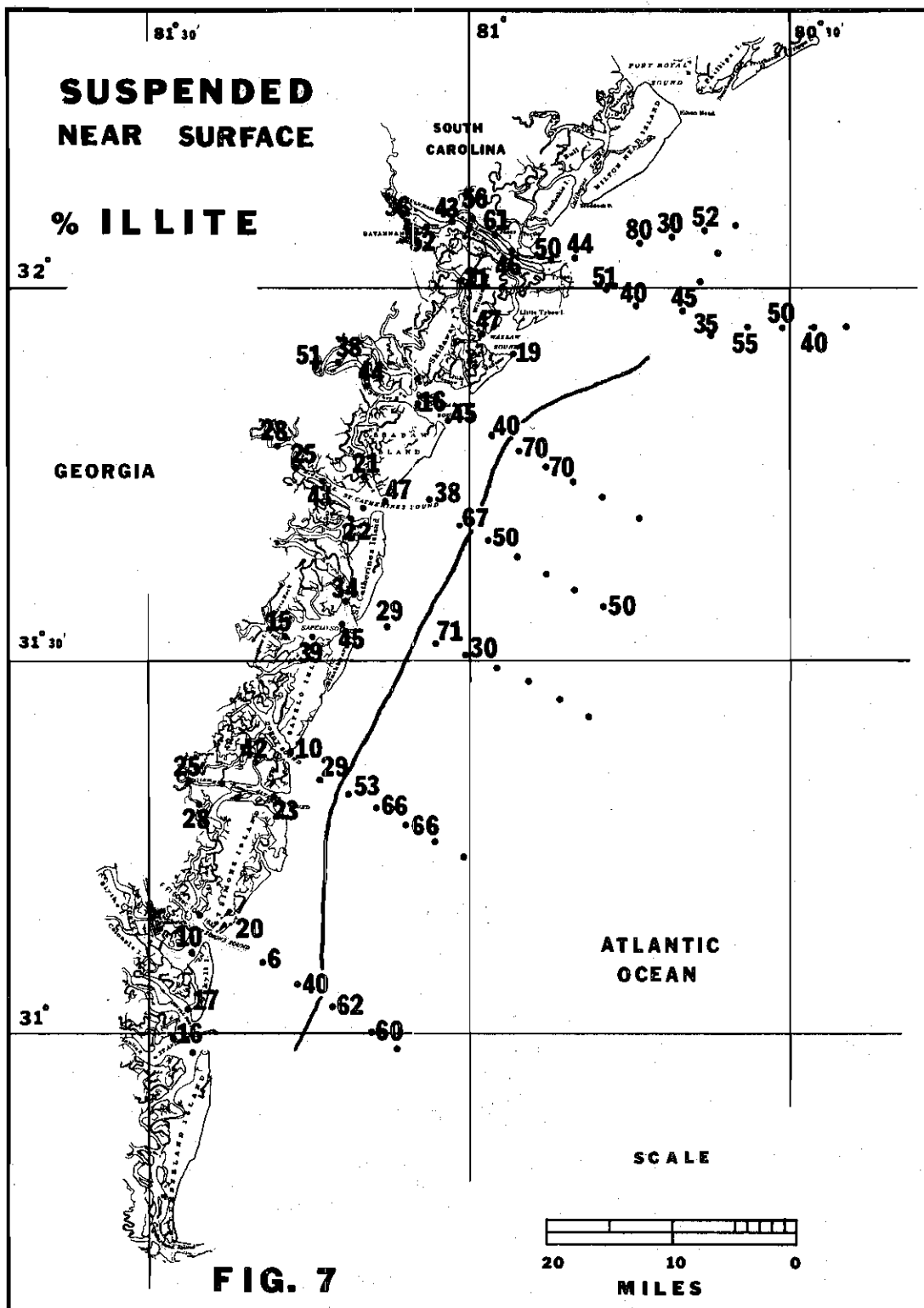
Presented in Figures 2 through 9 are the distribution patterns of chlorite, kaolinite, illite and smectite in suspension and in the bottom sediments of the sampling area. Although data on the clay mineralogy of the shelf sediments is presented, the following discussion is primarily concerned with the distribution of clay minerals suspended in seawater. Interpretation of the sediment clay mineralogy has not been done due to the clay-size particles comprising less than one percent of the sediment. Grain size determinations that were made on a few of the offshore sediment samples indicated that clay-size particles were on the order of 0.001 percent of the sediment by weight. In view of these low percentages, interpretation of this data would have little significance. Also, bottom sediment clay mineral distribution may not reflect present transport patterns due to reworking, possible contributions from outcrops of sedimentary rocks or possible alteration of clay minerals during digestion by detritus feeding organisms. Figure 10 presents the results of grain-size analysis made by the Woods Hole Oceanographic Institute (Hathaway, 1971). The Woods Hole station numbers and locations are presented in Appendix III.

Chlorite exhibits an uneven distribution generally comprising 10 percent or less of the suspended and bottom clay minerals (Figures 2 and 3). In addition,









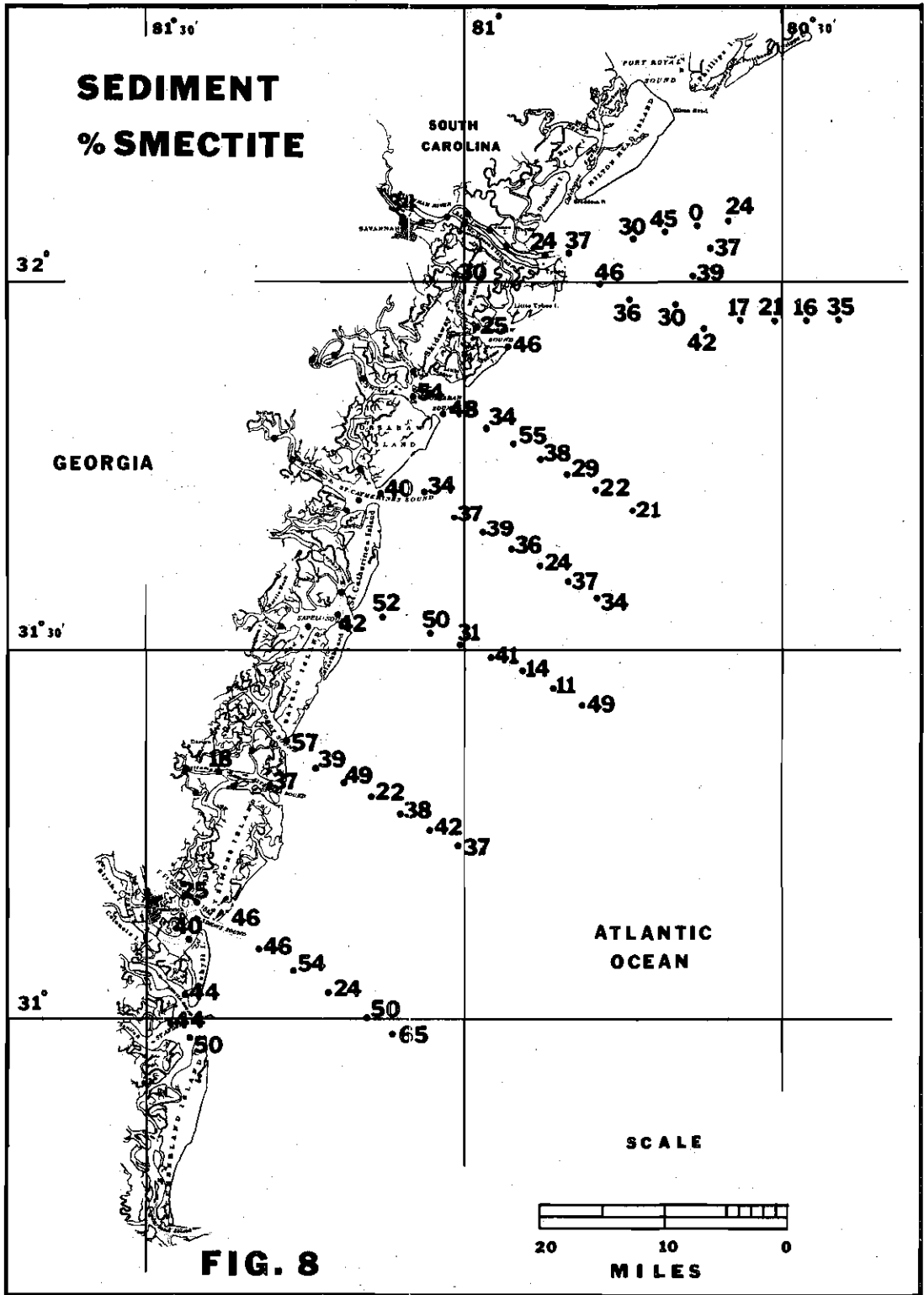
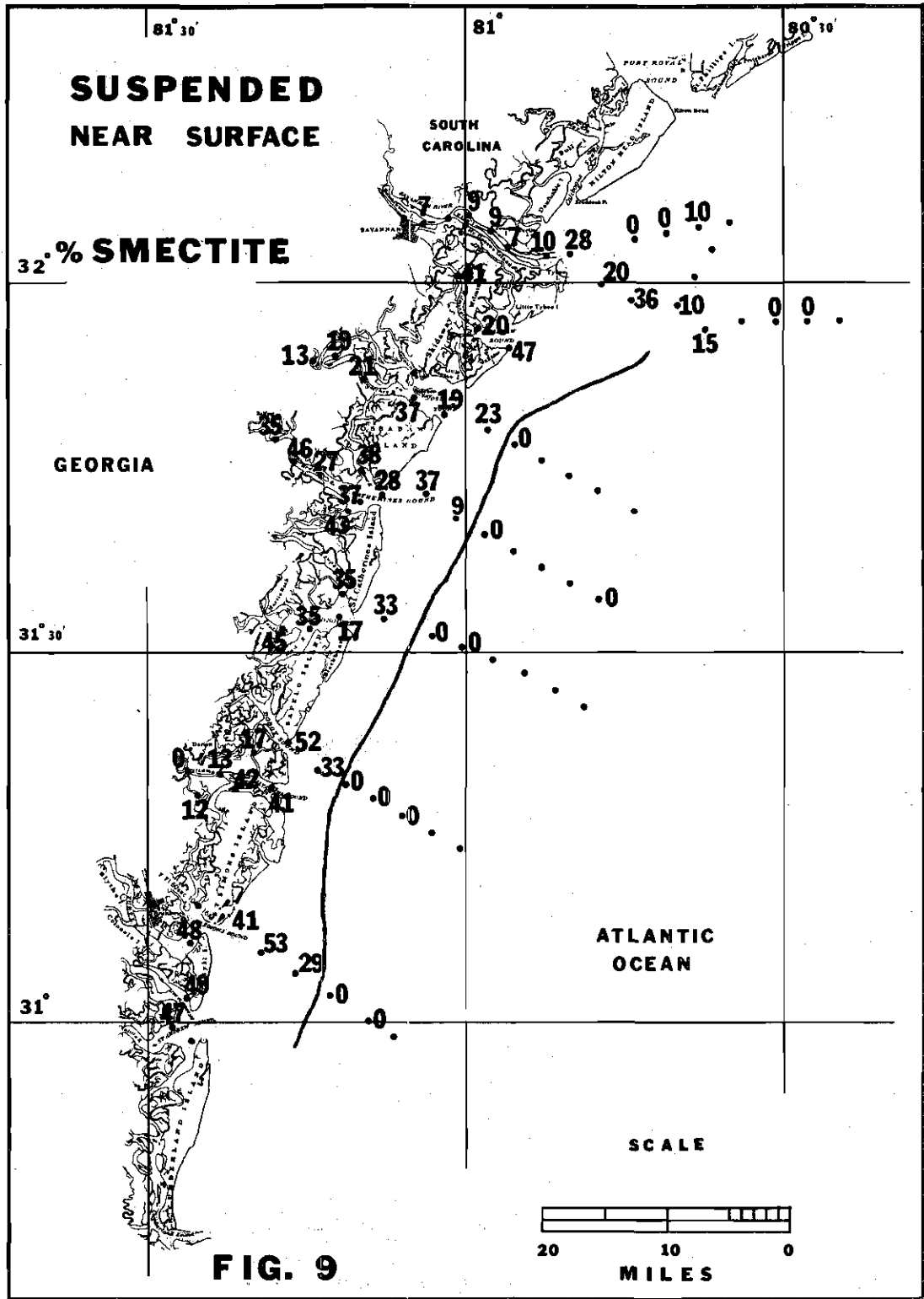
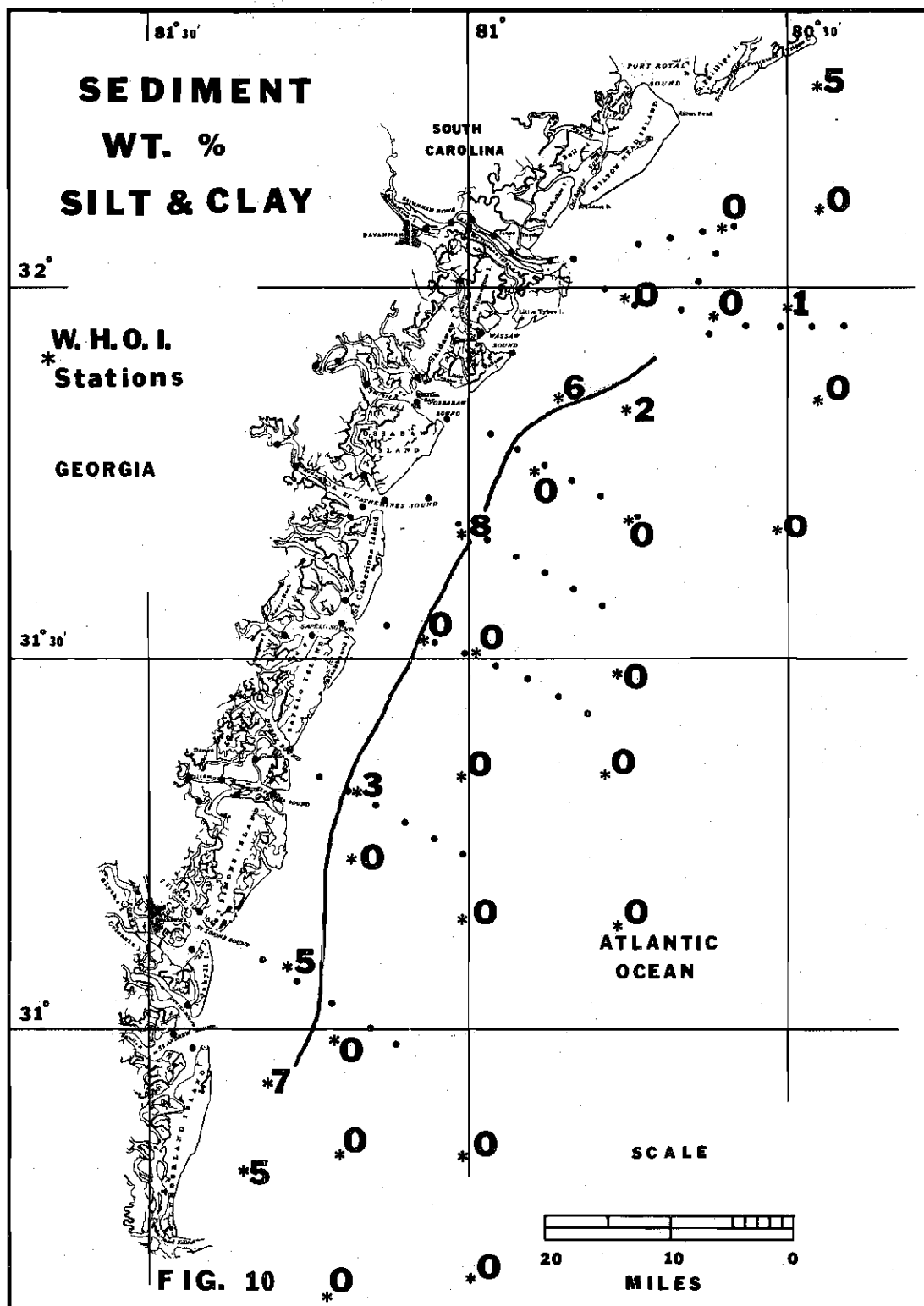


FIG. 8



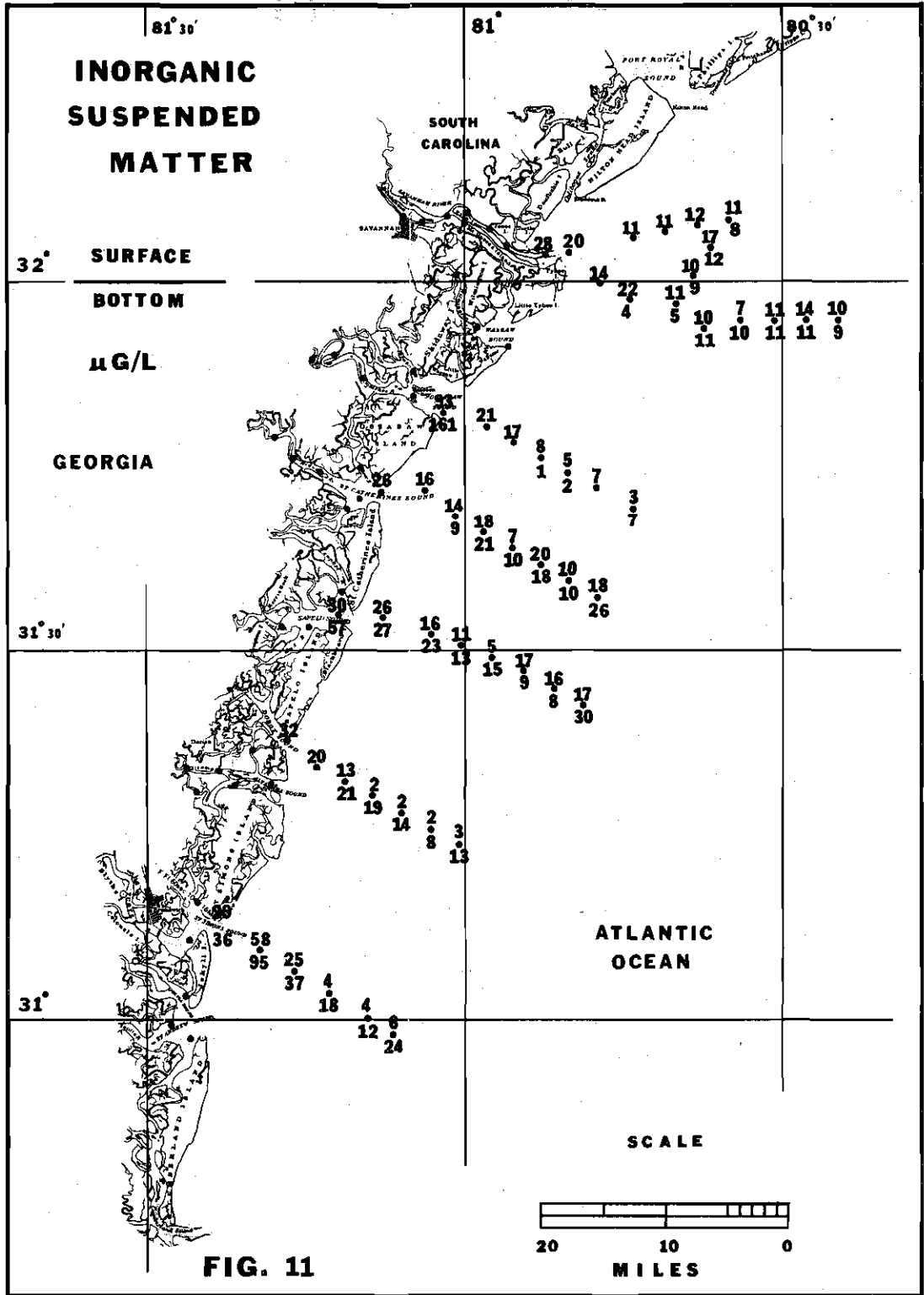


the sediment-chlorite content tends to decrease slightly from north to south.

The percentage of kaolinite in the bottom sediments exhibits the lowest lateral variation of any of the clay minerals averaging about 25 to 40 percent (Figure 4). The percentage of kaolinite in suspension is relatively more irregular with the highest percentages near the Savannah River (Figure 5). Since 56 percent of the drainage basin of the Savannah River is within the kaolinite-rich Piedmont province, this is expected.

Suspended illite and smectite clay minerals exhibit the most abrupt changes in concentration. In all transects, the suspended illite concentration increases in the seaward direction by roughly 50 percent at a point on the transect 3 to 10 miles offshore (Figure 7). At all stations, illite also exhibits higher concentrations in suspension than in the bottom sediments. Smectite exhibits a marked decrease from 30 percent to zero (Figure 9). This abrupt change takes place along the transects at the same point as the illite increase.

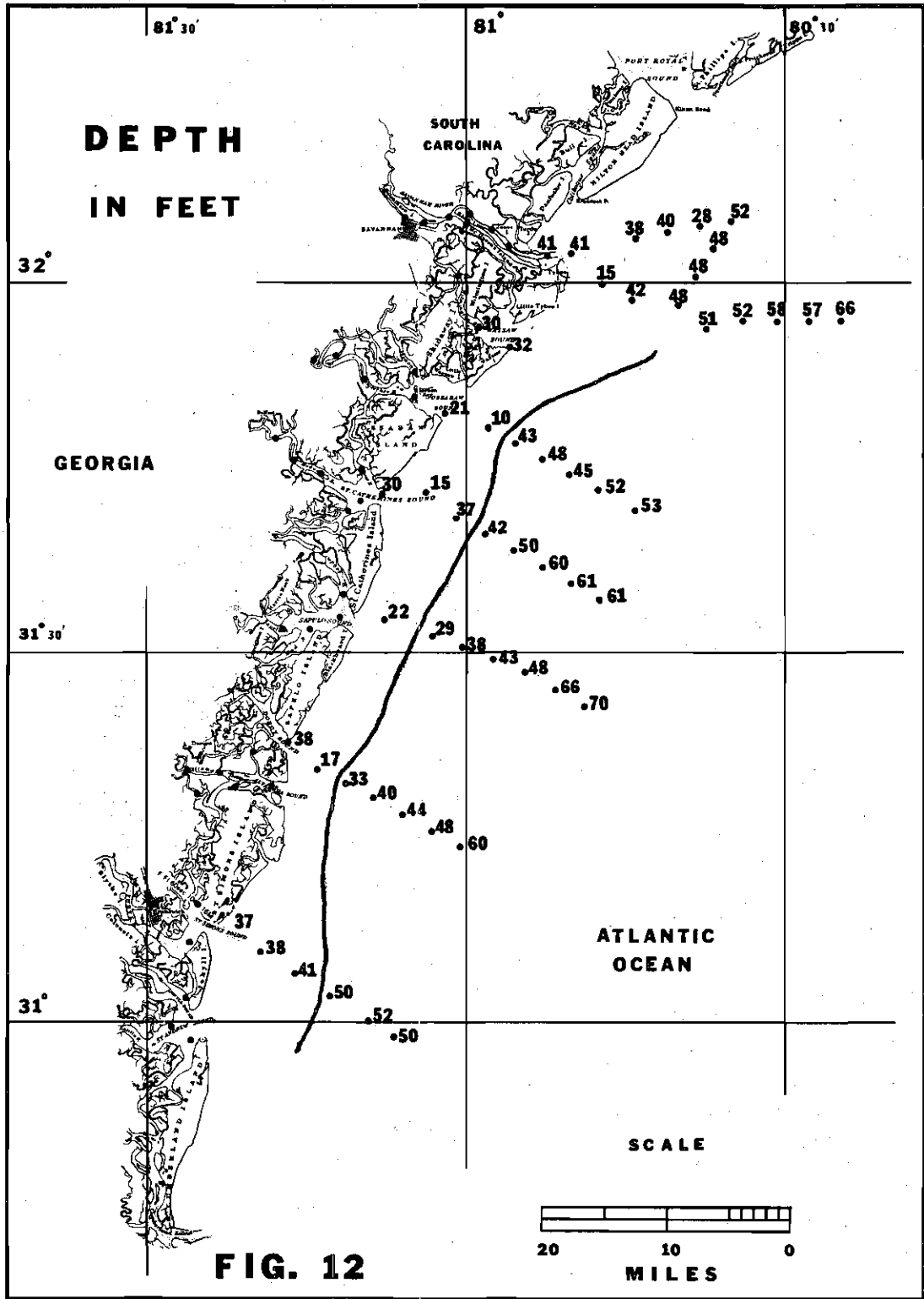
Figure 11 shows the concentrations of inorganic suspended-sediment over the, approximately 25-mile wide, sampling area. The contour shown in Figure 11 corresponds to the distinct changes in the suspended illite and smectite concentrations. At first inspection, the general decrease in suspended-matter concentration in the seaward direction, shown in Figure 11, could be explained as a simple dilution of river-borne detritus by sea water. From the data on the suspended-matter composition, however, it is apparent that the suspended clay mineral assemblage changes from kaolinite, smectite and minor illite in the near-shore zone to kaolinite and illite only, seaward of the zone. It is suggested here



that the nearshore, 3 to 10 miles wide, zone represents a 'zone of deposition,' as shown by the stippled area in Figure 13, of detritus that has been flushed-out of the Georgia estuaries. Seaward of the 'zone of deposition,' suspended-clay minerals have been derived from farther north and carried by the predominantly southward drift that is active over the Southeastern U. S. continental shelf.

With reference to the depths from the fathometer record (Figure 12), the seaward limit of the 'zone of deposition' corresponds with a water depth of between 20 and 30 feet. The depths within the tidal inlets from transects 1 and 5 are misleading due to sampling within a dredged ship channel. These would be shallower in the natural state. Depth information from navigation charts of the area suggest the water depths at the seaward boundary of the 'zone of deposition' to be near 24 feet or 4 fathoms.

Other lines of evidence support the idea that fine-grained sediment contributed by the Georgia rivers and estuaries is limited in its distribution on the continental shelf to a narrow nearshore band. Previous work by Stetson (1938), Gorsline (1963) and Pilkey (1964) has established the presence of a nearshore band of fine-grained bottom sediments flanked to seaward by coarser sediments. The nearshore band of fine-grained sediments has been considered to represent the full extent of modern sedimentation on the shelf and the seaward coarse-grained sediments have been considered as 'relict' sediments. That is, sediments deposited in response to a lower stand of sea level during the Pleistocene ice ages. Figure 13 presents mean grain size data from the Woods Hole study (Hathaway, 1971). In this diagram the increase in grain size with distance from



shore is clearly evident. The stipled area represents the 'zone of deposition' and the partially solid and partially dashed (inferred) line is the Recent-relict sediment boundary reported by Pilkey (1964).

The limitation of 'Recent' sediment to a nearshore band, whose seaward limit roughly corresponds to the 'zone of deposition,' adds further support to the idea that transport of clay-size, 'Recent' sediment is limited to the 'zone of deposition.' Referring back to Figure 10 shows that deposition of silt and clay size particles is also restricted to the area of 'Recent' sedimentation.

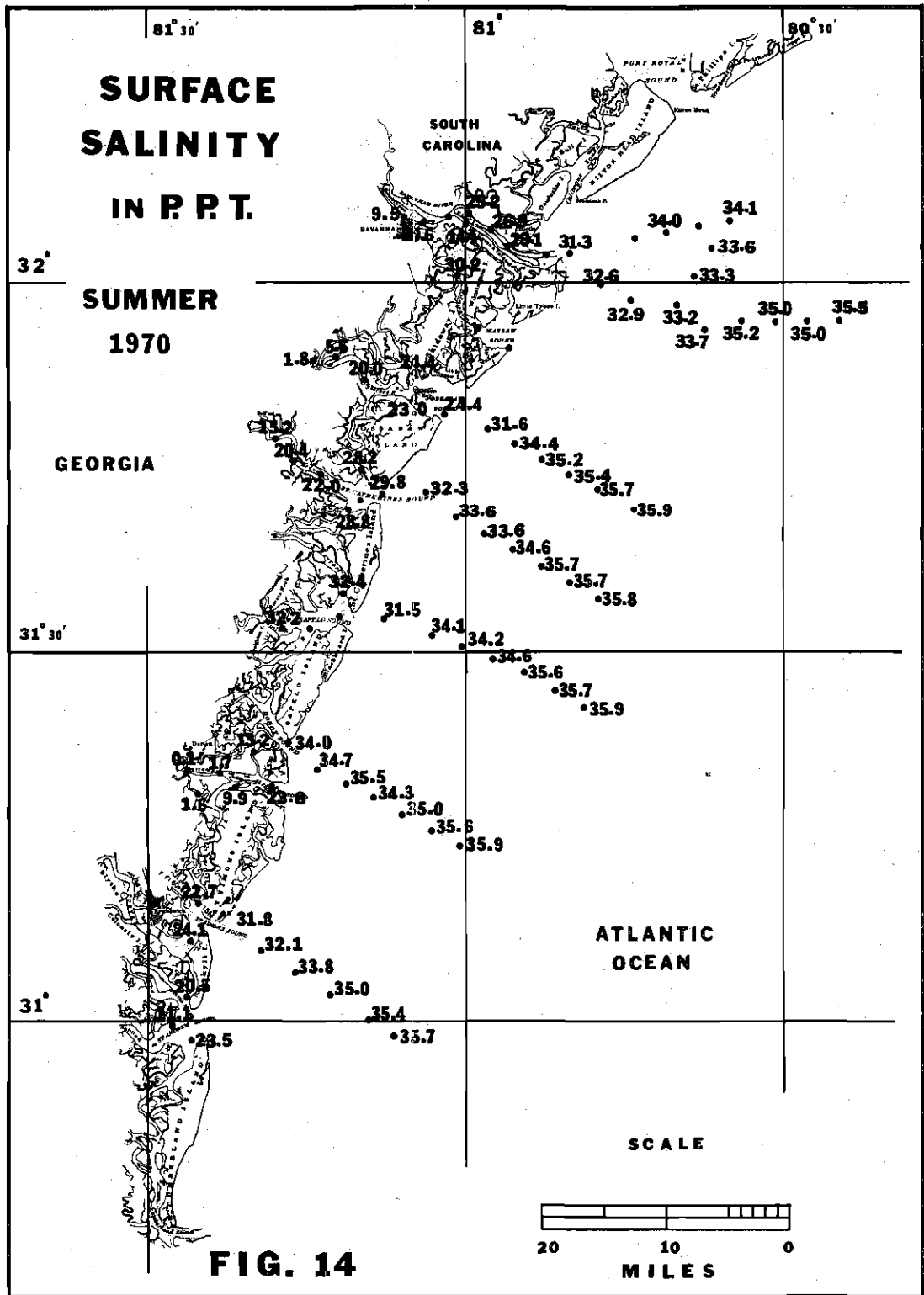
It is apparent that the deposition of sand and silt size sediment presently delivered by the rivers is restricted to the area of 'Recent' sedimentation. Evidence from this research indicates that much of the clay-size material, derived from the Georgia rivers and estuaries, is also not transported seaward of the 'zone of deposition.' It is still in question as to whether some of the clay-size particles are being transported in suspension seaward of the 'zone' to the outer shelf and deep ocean. This question is very important in determining whether the presently active transport processes are incompetent to carry the clay-size particles or whether the transport processes themselves are limited to the observed seaward boundary of the 'zone of deposition.' The latter case is more reasonable suggesting that the clay minerals and clay-size sediment observed seaward of the 'zone' are not derived from the Georgia rivers and estuaries but from farther north.

Flocculation and settling velocity studies by Whitehouse, Jeffrey and Debbrecht (1960) with clay minerals in still water and in pipe flow have established

that clay minerals tend to deposit in a specific order. Flume studies by Krone (1962) support this work. Whitehouse et al. (1960) found that illite and kaolinite settling velocities were near 16 meters/day and 12 meters/day respectively, whereas smectite settles at velocities up to only 1.3 meters/day. These values, of course, vary with salinity and temperature, however the relative order remains the same. Shiozawa (1970) explained the distribution of clay minerals in Ishikari Bay as an example of differential settling. Van Andel and Postma (1954) likewise, explained the distribution of clay minerals in the Gulf of Paria by utilizing earlier work on differential flocculation and settling tendencies by Whitehouse and Jeffrey (1953).

That smectite clay minerals are observed to have a slow settling velocity and to be deposited after other clay minerals is very significant. This would imply that the limit of seaward transport of smectite clay minerals, as shown in Figure 9, is also the limit of all Georgia river contributed clay minerals and that kaolinite and illite clay minerals observed seaward of the 'zone of deposition' are derived from another source.

The differential settling and flocculation observed in quiet water (Whitehouse et al., 1960) were evident when the water salinity increased to around 4 ppt. From salinity data in Figure 14, it would appear that differential settling would take place in the estuaries and tidal rivers long before clay minerals could be transported seaward of tidal inlets. A study of the rivers and estuaries of the Southeastern U.S. by Meade (1968) has shown, however, that sufficient energy exists to keep the clay minerals suspended. This means that differential settling would take place



as soon as the clay mineral particles reached relatively quieter water--the inner continental shelf.

The general suspended clay mineral distribution pattern thus appears to be a predominantly smectite, kaolinite and illite suspended clay mineral suite, derived from the Georgia rivers, being superimposed upon an illite and kaolinite assemblage which is probably being transported generally southward on the continental shelf. The absence therefore, of evidence for differential settling near-shore of suspended illite and kaolinite, as is seen for suspended smectite, is probably due to the presence of illite and kaolinite suspended in the 'shelf waters.' The 'river derived' kaolinite and illite settle-out, however, their absence in the seaward direction is masked by kaolinite and illite from another source. The settling of smectite is well pronounced due to the virtual absence of suspended smectite in the 'shelf waters.' This absence of smectite and the predominance of illite and kaolinite in the 'shelf water' suspended-clay mineral suite has been reported earlier by Neiheisel and Weaver (1967) for an area off Port Royal Sound, South Carolina.

Transport Processes

At this point the exact nature of active transport processes is unknown. Current measurements were made only once at each station so that no current pattern in relation to time could be obtained. Current velocity and direction data for the entire water column and for long periods of time are essential for the complete understanding of sediment transport problems. Interpretation of the limited data, however, is possible.

Figure 15 presents current vectors of the near bottom current measured during the summer of 1970. Each current measurement of a particular transect was taken on the same day. Each transect was made roughly one week apart. The two transects of leg three, off St. Catherines and Sapelo Sounds, were completed on consecutive days. From the current data (Figure 15) for these two legs particularly, it is apparent that the shelf currents are highly variable eddies possibly driven by tidal current and the Florida current.

The clay mineralogy of the bottom sediments also reflects the variable currents. It must be stressed again that the delineation of the 'zone of deposition' is only for the summer of 1970. The exact boundaries of the 'zone of deposition' are undoubtedly very transient; changing in response to different wave energy, tidal current, and shelf-water current conditions. The clay minerals distribution in the bottom sediments in no way resembles the distribution of the clay minerals in suspension again suggesting the changing pattern of deposition. In addition, resuspension and transport of bottom sediment during periods of very high wave activity would act to alter previous deposition patterns of fine-grained sediment, as well as the contribution to the bottom sediments from 'relict' clay minerals or from sedimentary rock formations that crop-out on the continental shelf.

CHAPTER IV

CONCLUSIONS

Previous work has established that recent sand and silt-size sediment is restricted to a near-shore band along the coast of Georgia. The transport and deposition of clay-size sediment has been studied in this report. On the basis of clay minerals suspended in seawater, it has been found that clay-size sediment is restricted to a similar near-shore band, herein called the 'zone of deposition.' This has been established from the following evidence:

- 1) the change in the clay mineral suite from kaolinite, smectite and illite within the 'zone to illite and kaolinite seaward of the 'zone,'
- 2) the general seaward decrease of inorganic suspended matter and
- 3) from previous studies of clay mineral differential settling tendencies, the seaward extent of suspended smectite is taken to be the seaward extent of all suspended sediment derived from Georgia rivers.

Suspended clay minerals farther seaward are considered to be derived from another source.

Transport patterns indicated by clay mineral distribution are very significant in that they represent the transport or dispersal pattern of other materials as well. Particulate and dissolved pollutants would probably be restricted to the 'zone of deposition' as are clay minerals. An example of dissolved pollutants are the 12, 000 tons per week of 20 percent sulfuric acid that is introduced to the

Savannah River by the American Cyanamid Corporation. Although the sulfuric acid alone is not a major problem, if the heavy metals dissolved in the acid were to be concentrated in the coastal zone many deleterious effects could take place.

APPENDIX I

<u>Station</u>	<u>Date</u> <u>(1970)</u>	<u>Std.</u> <u>Time</u>	<u>Water</u> <u>Depth</u> <u>(Feet)</u>	<u>Sample</u> <u>Depth</u> <u>(Feet)</u>	<u>Salinity</u> <u>(p. p. t)</u>	<u>Dissolved</u> <u>O₂ (ppm)</u>	<u>pH</u>	<u>Current</u> <u>Direction</u>	<u>Velocity</u> <u>(knots)</u>	<u>Suspended</u> <u>Matter</u> <u>(mg/l)</u>	<u>Percent</u> <u>Organics</u>
I-1	7/24	1415	20	5	30.2	-	-	-	-	31.1	33
I-2	7/13	1613	12	7	14.4	4.7	6.42	-	-	11.1	43
I-3	7/13	1622	42	22	19.8	4.3	7.52	-	-	-	-
I-4	7/14	1735	41	22	20.6	3.9	7.38	-	-	19.8	38
I-5	7/13	1755	36	18	9.5	3.5	6.84	-	-	13.3	36
I-6	7/13	1900	45	22	25.2	4.9	7.68	-	-	20.5	32
I-7	7/13	1926	47	26	26.9	5.2	7.76	-	-	18.0	34
I-8	7/13	1947	45	23	29.1	5.8	7.90	-	-	35.2	37
I-9	7/13	2013	41	20	29.3	6.7	8.02	-	-	24.6	38
I-10	7/13	2045	41	20	31.3	6.8	8.08	-	-	29.2	31
I-11	7/14	1825	38	15	33.9	6.7	8.14	-	-	21.8	48
I-12	7/14	1746	40	15	34.0	7.0	8.15	-	-	22.0	51
I-13	7/14	1717	28	10	33.8	7.1	8.07	-	-	15.5	27
I-14	7/14	1625	52	10	34.1	6.6	8.10	-	-	16.6	33
				45	35.2	6.3	8.12	-	-	11.0	26
I-15	7/14	1523	48	10	33.6	-	8.06	-	-	19.5	13
				40	34.5	6.5	8.10	-	-	14.7	19
I-16	7/14	1434	48	6	33.3	7.0	8.08	-	-	15.2	35
				40	34.6	6.5	8.09	-	-	11.9	25
I-17	7/14	1225	48	10	33.2	7.2	8.10	-	-	13.8	19
				38	35.0	6.5	8.13	-	-	11.0	52
I-18	7/14	1131	42	6	32.9	6.9	8.10	-	-	28.0	21
				36	34.4	6.5	8.16	-	-	6.3	28
I-19	7/14	1038	15	7	32.6	6.5	8.02	-	-	19.2	25

APPENDIX I (CONTINUED)

Station	Date (1970)	Std. Time	Water Depth (Feet)	Sample Depth (Feet)	Salinity (p. p. t)	Dissolved O ₂ (ppm)	pH	Current		Suspended Matter (mg/l)	Percent Organics
								Direction	Velocity (knots)		
I-23	7/18	1529	66	6	35.5	6.9	8.23	250	0.40	14.8	33
				55	35.5	7.0	8.20	300	0.40	12.4	29
I-24	7/18	1430	57	6	35.1	6.8	8.22	210	0.25	20.3	28
				52	35.6	6.8	8.21	300	0.40	12.8	17
I-25	7/18	1337	58	12	35.1	6.7	8.21	155	0.35	12.2	8
				45	35.4	6.8	8.26	360	0.30	19.4	41
I-26	7/18	1237	52	6	35.2	6.8	8.10	335	0.45	11.1	35
				45	35.1	6.9	8.16	320	0.50	17.2	40
I-27	7/14	1331	51	6	33.7	6.9	8.12	-	-	14.1	30
				40	35.3	6.8	8.12	-	-	13.8	22
I-30	7/24	1624	32	25	32.6	-	-	-	-	69.4	28
I-31	7/24	1528	30	5	32.7	-	-	-	-	45.9	30
				25	33.8	-	-	-	-	49.1	33
II-5	7/21	1535	53	5	35.9	6.8	8.20	150	0.75	3.4	76.7
				48	36.0	6.6	8.20	16	0.80	4.6	62.5
II-6	7/21	1656	52	10	35.7	6.9	8.17	175	0.60	3.9	56.4
				40	35.7	6.8	8.20	200	0.40	-	-
II-7	7/21	1744	45	10	35.4	6.7	8.24	155	0.75	4.6	72.7
				30	35.6	6.8	8.24	135	0.50	4.7	89.0
II-8	7/21	1826	48	10	35.2	6.3	8.25	170	0.70	6.6	67.6
				40	35.4	6.4	8.20	225	0.45	3.9	97.8
II-9	7/21	1903	43	10	34.4	7.1	8.25	135	0.80	27.4	37.4
				34	34.9	6.6	8.23	185	0.50	1.2	9.8
II-10	7/21	1959	10	7	31.6	6.2	8.10	-	-	31.4	32.4
II-11	7/22	1830	21	5	24.4	-	7.65	-	-	120.8	23.0
				15	25.0	-	7.65	-	-	201.4	19.7

APPENDIX (CONTINUED)

Station	Date (1970)	Std. Time	Water	Sample	Salinity (p. p. t)	Dissolved O ₂ (ppm)	pH	Current		Suspended	Percent Organics
			Depth (Feet)	Depth (Feet)				Direction	Velocity (knots)	Matter (mg/l)	
II-12	7/22	1905	20	6	23.0	-	7.65	-	-	110.1	25.0
II-13	7/22	1845	-	5	20.0	-	7.60	-	-	80.4	26.0
II-14	7/22	1630	-	5	5.6	-	7.09	-	-	42.2	27.4
II-15	7/22	1505	-	5	1.8	-	6.77	-	-	19.7	26.2
II-18	7/22	1925	20	10	23.8	-	7.65	-	-	97.6	24.1
III-1	7/29	1042	18	10	28.3	4.6	7.88	-	-	36.9	42.5
III-2	7/29	0923	30	15	19.8	5.3	7.81	-	-	35.3	27.4
III-3	7/29	0951	15	7	32.2	5.5	8.02	-	-	32.0	51.3
III-4	7/27	2022	37	5	33.5	6.6	8.02	170	0.75	19.5	30.7
				30	33.7	7.0	7.98	190	0.65	19.6	55.1
III-5	7/27	1949	42	10	33.6	7.5	8.28	140	0.70	24.7	26.5
				30	34.7	6.4	8.28	170	0.90	31.7	33.4
III-6	7/27	1905	50	6	34.6	6.9	8.16	140	0.50	15.2	51.8
				35	35.4	6.4	8.16	160	1.15	26.9	63.4
III-7	7/27	1822	60	10	35.7	6.9	8.22	140	0.70	23.7	26.1
				50	35.6	7.2	8.26	180	0.60	21.5	25.6
III-8	7/27	1733	61	6	35.6	6.6	8.24	095	0.70	19.2	45.0
				50	35.6	7.0	8.30	145	0.75	18.1	47.0
III-9	7/27	1646	61	6	35.8	-	8.22	115	0.55	23.5	25.3
				55	35.8	7.6	8.22	090	0.65	34.5	25.2
III-10	7/29	0908	26	10	28.8	5.0	7.56	-	-	67.3	23.9
III-11	7/28	1928	45	20	32.4	7.1	8.12	-	-	39.0	34.2
III-12	7/28	1106	22	5	31.5	5.4	7.96	-	-	44.0	40.4
				18	31.6	5.2	7.82	-	-	35.7	25.3
III-13	7/28	1147	29	7	34.1	6.3	8.12	285	0.29	23.9	33.9

APPENDIX I (CONTINUED)

<u>Station</u>	<u>Date</u> (1970)	<u>Std.</u> <u>Time</u>	<u>Water</u> <u>Depth</u> (Feet)	<u>Sample</u> <u>Depth</u> (Feet)	<u>Salinity</u> (p. p. t)	<u>Dissolved</u> <u>O₂</u> (ppm)	<u>pH</u>	<u>Current</u> <u>Direction</u>	<u>Velocity</u> (knots)	<u>Suspended</u> <u>Matter</u> (mg/l)	<u>Percent</u> <u>Organics</u>
III-14	7/28	1220	38	22	34.0	6.2	8.11	285	0.29	34.3	32.0
				10	34.2	6.4	8.16	265	0.20	17.6	37.0
				35	35.0	6.2	8.12	310	0.35	22.4	40.1
III-15	7/28	1248	43	5	34.6	6.7	8.12	335	0.55	22.1	78.7
				30	35.4	6.4	8.10	335	0.80	21.6	32.1
III-16	7/28	1336	48	10	35.6	6.9	8.06	340	0.45	22.9	26.0
				30	35.7	6.5	8.24	320	0.55	14.0	36.5
III-17	7/28	1417	66	10	35.7	6.6	8.29	290	0.25	36.1	55.7
				55	35.7	6.9	8.28	340	0.50	15.5	42.8
III-18	7/28	1503	70	10	35.9	6.5	8.26	340	0.40	28.4	38.5
				65	35.9	6.9	8.30	70	0.65	39.9	24.3
III-19	7/28	1736	31	10	32.1	5.8	8.04	-	-	40.1	24.6
				20	32.8	6.4	8.09	-	-	76.6	22.6
III-20	7/28	1808	20	10	31.0	4.8	7.90	-	-	45.8	26.8
				22	31.0	4.9	7.88	-	-	107.4	27.9
III-21	7/28	1835	25	12	32.2	4.3	7.69	-	-	81.6	30.4
IV-1	8/23	1640	38	15	34.0	5.9	8.00	-	-	43.4	25.6
IV-2	8/23	1717	17	8	34.7	6.3	8.10	-	-	44.6	56.0
IV-3	8/23	1740	33	8	24.4	6.2	8.20	225	1.20	21.5	41.0
				25	35.6	6.2	8.20	225	0.80	33.2	36.3
IV-4	9/17	1909	40	5	34.3	-	8.30	270	0.60	12.0	69.0
				35	34.6	-	8.28	300	0.50	31.8	40.3
IV-5	9/17	1822	44	5	35.0	-	8.28	265	0.60	9.6	76.8
				40	35.2	-	8.26	300	0.45	35.2	60.6
IV-6	9/17	1733	48	5	35.6	6.3	8.30	215	0.65	12.8	84.8

APPENDIX I (CONTINUED)

<u>Station</u>	<u>Date</u> (1970)	<u>Std.</u> <u>Time</u>	<u>Water</u> <u>Depth</u> (Feet)	<u>Sample</u> <u>Depth</u> (Feet)	<u>Salinity</u> (p. p. t)	<u>Dissolved</u> <u>O₂</u> (ppm)	<u>pH</u>	<u>Current</u> <u>Direction</u>	<u>Velocity</u> (knots)	<u>Suspended</u> <u>Matter</u> (mg/l)	<u>Percent</u> <u>Organics</u>
				40	-	6.3	8.28	250	0.35	27.6	73.3
IV-7	9/17	1643	60	5	35.9	6.4	8.27	180	0.80	11.1	71.8
				55	35.7	6.7	8.27	205	0.40	33.1	61.5
IV-9	8/26	0929	-	5	13.2	5.5	7.60	-	-	45.4	27.1
IV-10	8/24	1910	-	10	23.8	5.6	8.10	-	-	57.9	29.1
IV-11	8/24	1507	16	10	1.7	6.0	8.31	-	-	39.5	27.8
IV-12	8/25	1346	15	8	0.1	4.8	8.25	-	-	12.7	35.0
IV-13	8/24	1153	17	8	1.6	5.2	8.16	-	-	25.7	25.2
IV-14	8/24	1530	20	10	9.9	5.2	8.48	-	-	153.3	21.3
IV-15	8/26	1251	-	5	25.4	4.6	7.70	-	-	11.2	37.4
IV-16	8/27	1125	13	5	22.0	4.4	7.55	-	-	20.6	35.2
IV-17	8/28	1145	12	5	20.4	4.0	7.53	-	-	34.0	31.7
IV-18	7/28	1225	16	5	15.2	4.0	7.36	-	-	28.3	28.5
V-1	9/15	1102	37	5	31.8	6.0	8.00	slack		32.5	12.1
				32	32.2	6.2	8.18	175	0.50	62.4	41.7
V-2	9/17	1013	38	5	32.1	-	8.13	315	1.00	89.7	36.0
				35	33.2	6.2	8.13	315	1.00	127.5	25.7
V-3	9/17	1101	41	5	33.8	6.5	8.21	280	0.70	28.1	9.6
				35	34.3	-	8.19	225	0.50	47.2	22.3
V-4	9/17	1206	50	5	35.0	6.2	8.20	-	-	15.0	76.4
				45	35.4	6.3	8.18	200	0.55	32.8	45.7
V-5	9/17	1312	52	5	35.4	6.4	8.28	180	0.65	9.9	61.9
				45	35.5	6.4	8.27	145	0.55	29.0	58.1
V-6	9/17	1307	50	5	35.7	6.7	8.27	225	0.55	10.6	44.4
				45	35.7	6.0	8.29	225	0.60	29.1	17.3

APPENDIX I (CONCLUDED)

<u>Station</u>	<u>Date</u> (1970)	<u>Std.</u> <u>Time</u>	<u>Water</u> <u>Depth</u> (Feet)	<u>Sample</u> <u>Depth</u> (Feet)	<u>Salinity</u> (p. p. t)	<u>Dissolved</u> <u>O₂</u> (ppm)	<u>pH</u>	<u>Current</u> <u>Direction</u>	<u>Current</u> <u>Velocity</u> (knots)	<u>Suspended</u> <u>Matter</u> (mg/l)	<u>Percent</u> <u>Organics</u>
V-16	9/16	1933	52	5	23.5	4.5	7.52	-	-	46.8	31.1
				50	16.5	5.3	7.53	-	-	276.6	22.8
V-21	9/16	1844	15	5	11.1	3.7	7.00	-	-	38.9	30.8
V-22	9/16	1810	11	5	20.5	4.3	7.46	-	-	45.8	32.3
V-23	9/16	1720	28	5	24.1	3.8	7.48	-	-	109.2	32.8
V-24	9/16	1555	20	5	22.7	4.5	7.44	-	-	134.1	17.8

APPENDIX II

Station	Sample Depth (feet)	Peak Area				Calculated Percentage			
		<u>Kaol.</u>	<u>Ill.</u>	<u>Smec.</u>	<u>Chlor.</u>	<u>Kaol.</u>	<u>Ill.</u>	<u>Smec.</u>	<u>Chlor.</u>
I-1	3	40	9	60	0	38	21	41	0
	sed.	105	5	70	0	63	7	30	T
I-3	3	26	10	10	0	45	43	12	0
I-4	3	26	13	6	0	41	52	7	T
I-5	3	18	4	0	0	64	36	0	0
	sed.	100	8	86	0	55	11	34	T
I-6	3	14	9	5	0	35	56	9	T
I-7	3	12	10	5	0	30	61	9	T
I-8	3	18	7	3	0	47	46	7	T
I-9	3	12	6	4	0	40	50	10	T
	sed.	56	7	32	31	40	18	24	18
I-10	3	14	9	20	0	28	44	28	T
	sed.	48	4	49	19	42	11	37	10
I-11	15	Estimated			0	20	80	0	0
	sed.	37	6	30	0	50	20	30	T
I-12	15	Estimated			0	70	30	0	0
	sed.	39	4	55	0	44	11	45	T
I-13	10	9	5	3	0	38	52	10	0
	sed.	9	4	0	36	30	53	T	17
I-14	45	14	3	0	0	65	35	0	0
	sed.	16	3	10	19	42	24	24	10
I-15	sed.	48	6	53	21	38	15	37	10
I-16	sed.	30	4	36	35	30	15	39	16
I-17	10	5	2	1	11	40	45	10	5

APPENDIX II (CONTINUED)

Station	Sample Depth (feet)	Peak Area				Calculated Percentage			
		Kaol.	Ill.	Smec.	Chlor.	Kaol.	Ill.	Smec.	Chlor.
	40	3	3	1	0	30	60	10	0
	sed.	91	5	63	10	47	8	30	5
I-18	5	Estimated			0	60	40	0	0
	sed.	49	10	58	24	32	22	36	10
I-19	7	7	5	7	0	29	51	20	0
	sed.	36	6	60	21	30	16	46	8
I-23	sed.	6	3	10	0	29	36	35	T
I-24	3	Estimated			0	60	40	0	0
	46	Estimated			0	30	70	0	T
	sed.	20	7	10	33	30	39	16	15
I-25	12	Estimated			0	50	50	0	0
	45	Estimated			0	40	60	0	0
	sed.	9	5	8	0	33	46	21	T
I-26	10	Estimated			0	45	55	0	0
	46	Estimated			0	30	70	0	T
	sed.	6	3	4	41	22	46	17	15
I-27	6	4	4	2	0	60	35	15	0
	sed.	46	11	76	37	26	22	42	10
I-30	3	27	6	53	0	34	19	47	0
	sed.	30	5	50	0	38	16	46	T
I-31	5	12	7	10	0	33	47	20	0
	30	26	5	37	0	40	19	41	T
	sed.	62	13	25	0	62	13	25	T
II-5	sed.	11	5	9	32	25	42	21	12
II-6	sed.	12	6	11	34	23	43	22	12
II-7	sed.	23	6	23	33	28	29	29	14

APPENDIX II (CONTINUED)

Station	Sample Depth (feet)	Peak Area				Calculated Percentage				
		Kaol.	Ill.	Smec.	Chlor.	Kaol.	Ill.	Smec.	Chlor.	
II-8	40	Estimated				0	30	70	0	0
	sed.	15	8	30	19	22	35	38	5	
II-9	3	3	3	0	0	30	70	T	0	
	34	6	3	27	0	30	20	*	T	
II-10	sed.	28	6	74	17	24	16	55	5	
	3	18	8	16	0	37	40	23	T	
II-11	sed.	20	6	25	26	28	28	34	10	
	12	14	7	10	25	27	45	19	9	
II-12	20	12	9	14	19	22	51	22	5	
	sed.	30	8	65	19	25	21	48	6	
II-13	3	60	8	66	21	37	16	37	10	
	sed.	106	5	200	0	41	5	54	0	
II-14	3	34	17	29	20	25	44	21	10	
II-15	3	28	10	18	30	30	38	19	13	
III-1	3	12	7	6	0	36	51	13	0	
III-2	10	34	7	44	27	30	21	38	11	
	15	16	10	18	33	20	47	23	10	
III-3	sed.	54	14	84	17	30	23	40	6	
	7	15	9	30	40	15	38	37	10	
III-4	sed.	9	3	12	17	30	30	34	6	
	5	7	8	4	63	9	67	9	15	
III-5	35	10	7	0	83	6	64	T	30	
	sed.	40	6	111	17	38	17	37	8	
III-5	10	4	2	0	80	10	50	0	40	

* Estimated 50% regular interlayered 24 A illite-vermiculite.

APPENDIX II (CONTINUED)

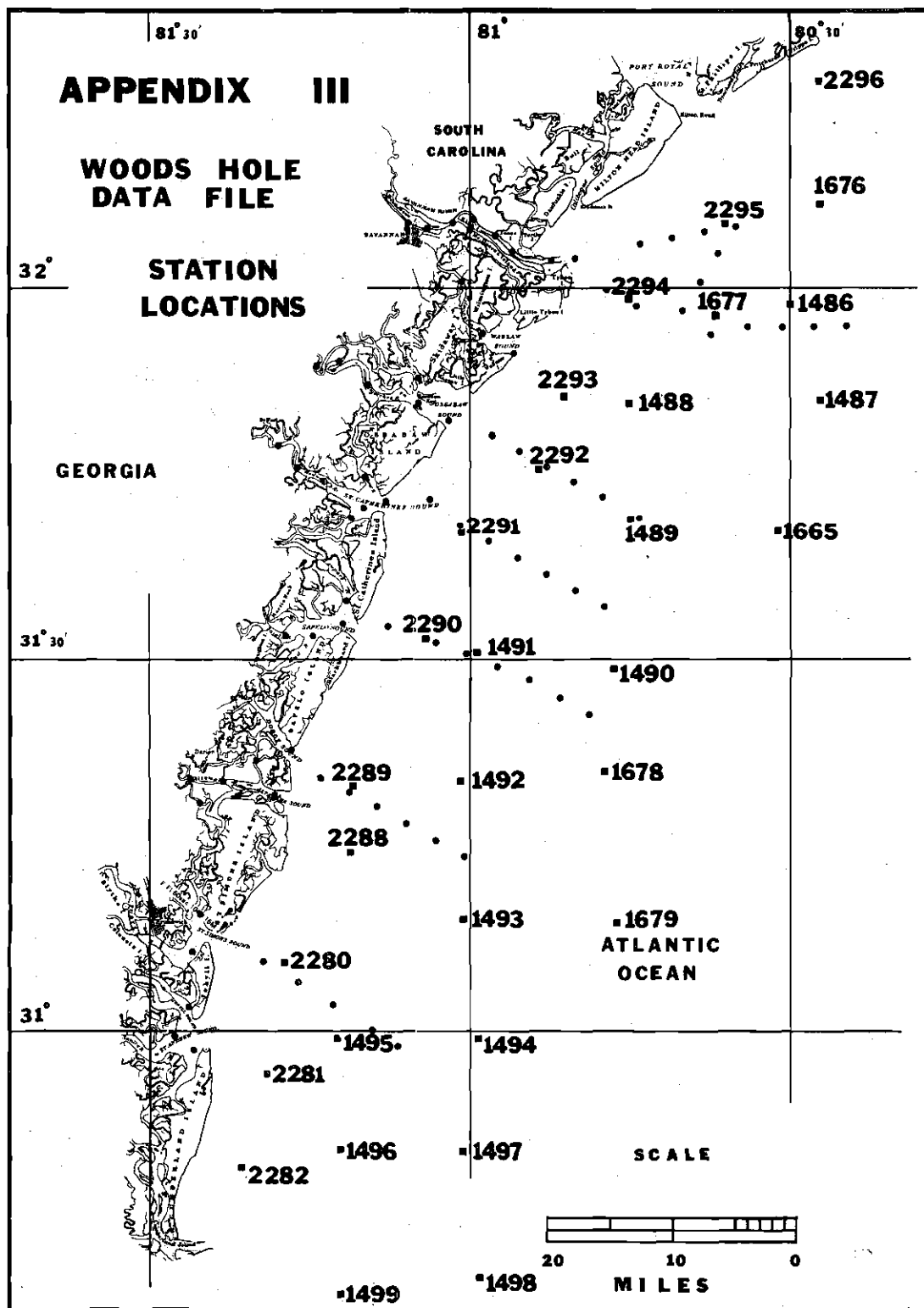
Station	Sample Depth (feet)	Peak Area				Calculated Percentage			
		Kaol.	Ill.	Smec.	Chlor.	Kaol.	Ill.	Smec.	Chlor.
	30	6	6	0	61	13	67	0	20
	sed.	19	4	26	20	32	21	39	8
III-6	sed.	9	3	13	14	30	29	36	5
III-7	sed.	8	4	8	0	34	42	24	0
III-8	sed.	18	4	23	0	40	23	37	0
III-9	50	4	2	0	60	20	50	0	30
	sed.	38	10	45	25	30	26	34	10
III-10	12	24	6	41	29	25	22	43	10
	sed.	77	10	190	16	27	11	57	5
III-11	20	20	9	32	0	31	34	35	0
III-12	5	23	7	28	26	28	29	33	10
	18	25	6	38	19	30	22	41	7
	sed.	46	4	85	0	39	9	52	T
III-13	7	5	6	0	66	10	71	T	19
	22	11	10	6	63	10	62	11	17
	sed.	64	5	104	0	42	8	50	0
III-14	10	4	1	0	57	30	30	0	40
	sed.	45	5	36	19	44	15	31	10
III-15	sed.	11	4	20	0	31	28	41	T
III-16	sed.	6	4	3	0	32	54	14	T
III-17	sed.	8	5	3	29	25	54	11	10
III-18	sed.	12	4	30	18	23	23	49	5
III-19	10	17	8	26	26	28	45	17	10
	20	34	5	42	41	30	16	40	14
	sed.	30	16	70	40	15	33	42	10

APPENDIX II (CONTINUED)

Station	Sample Depth (feet)	Peak Area				Calculated Percentage			
		Kaol.	Ill.	Smec.	Chlor.	Kaol.	Ill.	Smec.	Chlor.
III-20	10	17	10	31	0	26	39	35	0
	24	35	4	66	0	38	11	51	T
III-21	12	26	4	41	0	40	15	45	T
IV-1	28	28	3	54	0	38	10	52	T
	sed.	36	7	57	0	44	38	18	T
IV-2	8	20	6	24	34	25	29	33	13
	sed.	54	6	62	17	40	13	39	8
IV-3	8	9	4	0	36	30	53	0	17
	25	18	10	7	47	20	52	10	18
	sed.	80	10	141	0	39	12	49	T
IV-4	3	3	2	0	0	34	66	0	0
	sed.	11	5	9	0	37	41	22	T
IV-5	3	3	2	0	0	34	66	0	T
	sed.	9	3	14	29	24	28	38	10
IV-6	sed.	10	4	20	31	20	29	42	9
IV-7	sed.	17	3	20	0	44	19	37	T
IV-9	3	17	7	10	27	30	42	17	11
IV-10	10	32	8	50	0	36	23	41	T
	sed.	118	8	113	0	54	9	37	T
IV-11	10	60	15	20	9	49	33	13	5
	sed.	42	15	25	0	44	38	18	T
IV-12	8	10	1	0	0	75	25	0	0
IV-13	8	21	4	6	0	60	28	12	T
IV-14	3	45	10	70	40	22	21	42	15
IV-15	3	16	6	26	0	32	30	37	T
IV-16	3	14	8	17	67	10	43	27	20

APPENDIX II (CONTINUED)

Station	Sample Depth (feet)	Peak Area				Calculated Percentage			
		Kaol.	Ill.	Smec.	Chlor.	Kaol.	Ill.	Smec.	Chlor.
IV-17	3	20	7	45	0	29	25	46	T
IV-18	3	23	7	30	40	22	28	35	15
V-1	3	24	5	35	23	30	20	41	9
	37	18	4	44	50	15	17	53	15
	sed.	34	2	47	0	47	7	46	0
V-2	3	36	2	64	27	30	6	53	11
	35	65	3	63	18	45	7	38	10
	sed.	10	2	18	0	36	18	46	0
V-3	3	19	10	25	0	31	40	29	T
	35	12	10	13	62	10	54	20	16
	sed.	12	3	32	0	28	18	54	0
V-4	3	3	2	0	26	28	62	T	10
	sed.	50	6	30	0	62	14	24	T
V-5	3	5	3	0	25	30	60	T	10
	sed.	5	2	14	0	25	25	50	0
V-6	sed.	5	T	7	17	25	4	65	5
V-16	sed.	50	5	87	13	35	10	50	5
V-21	3	23	4	40	0	37	16	47	T
	sed.	82	7	110	0	46	10	44	T
V-22	3	20	4	40	29	24	17	49	10
	sed.	76	5	97	0	48	8	44	0
V-23	3	32	3	51	0	42	10	48	T
	sed.	54	10	73	0	27	19	40	15
V-24	sed.	63	17	50	0	45	30	25	T



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