Organic and Trace-Element Content of Holocene Sediments in Two Estuarine Bays, Pamlico Sound Area, North Carolina

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By HENRY L. BERRYHILL, JR., VERNON E. SWANSON, *and* A. HAROLD LOVE

CONTRIBUTIONS TO GEOCHEMISTRY

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The distribution and interrelations of total organic matter and soluble organic components in sand and mud deposited in shallow brackish-water parts of the large complex Pamlico Sound estuarine environment

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By HENRY L. BERRYHILL, JR., VERNON E. SWANSON, and A. HAROLD LOVE

ABSTRACT

Jarrett Bay and South River are small estuaries within the Pamlico Sound area, North Carolina. Jarrett Bay is an inland extension of the marine water of Core Sound; South River is a drowned tributary of the Neuse River, and its waters are brackish.

Most of the 102 samples from Jarrett Bay and the 53 samples from South River are of the uppermost 10–15 centimeters of sediment; some are from several cores about 60 centimeters in length that were also collected. Bottom sediments in both study areas, except for sediments in narrow belts of sand in the very shallow nearshore waters, typically are fine grained and poorly sorted. Clay-sized particles make up about 20 percent of the sediments in the deeper parts of both areas, but the mineralogy of clays differs markedly: Illite, chlorite, and chlorite-mica predominate in Jarrett Bay; kaolinite, illite-mica, and aluminum-vermiculite predominate in South River. Marine macrofauna remains are abundant in Jarrett Bay, but only brackish-water clams were found in South River. Foraminifera in samples from Jarrett Bay are mostly arenaceous types; nine genera were identified, and the number of specimens per 10 cubic centimeters of sample material ranged from a few hundred to 3,000.

Organic-carbon content of the bottom sediments of Jarrett Bay is 0.1–4.4 percent, and in South River it is 0.1–12.9 percent. The amount is typically highest in the finer grained sediments and lowest in the sands. The organic matter in both estuaries is high in alkaline-soluble humic substances (humic and fulvic fractions) and low in bitumen content, reflecting the major source of organic matter from nearby marshes and forests. The soluble humic fraction makes up as much as 2.68 percent of the sediment in Jarrett Bay and 5.44 percent in South River; the fulvic fraction (organic substances remaining in solution after precipitation of humic fraction) is generally less than one-half the amount of the humic fraction from both areas. From headwaters to mouth in both estuaries, however, the ratio of the fulvic fraction to organic carbon increases and that of the humic fraction to organic carbon decreases. The range in bitumen content of the sediment in both areas is similar, 0.003–0.086 percent in Jarrett Bay and 0.006–0.086 in South River, and the bitumen content generally parallels the organic-carbon content of the sediment. Sand

has the lowest content of both organic carbon and bitumen, but the ratio of bitumen to organic carbon in the sand is about twice that in mud rich in organic matter.

Trace-element analyses of the whole samples indicate no anomalous concentrations of specific elements that might have environmental significance. Analyses of trace elements in the ash of the humic and the fulvic fractions show characteristic concentration of the metals Co, Cu, Mo, Ni, Pb, and V.

INTRODUCTION

Many sequences of ancient sedimentary rocks, perplexing in both vertical and lateral relationships, have strikingly similar counterparts in modern sediments in several coastal areas of the United States. The Pamlico Sound area of eastern North Carolina (fig. 1) is an excellent example of an area where diverse and complex sediment types and relationships can be studied today.

This area, which covers several thousand square miles, includes closely adjacent fluvial, lacustrine, estuarine, marsh, littoral, and marine depositional environments, where grossly different but time-equivalent sediments can be studied and mapped in detail. Fluvial sediments are being deposited in the Pamlico and Neuse Rivers and, toward their mouths, the fluvial sediments grade into the generally estuarine sediments of Pamlico Sound (fig. 1). Lacustrine fresh-water limy muds are being deposited in the 70 square miles of Lake Mattamuskeet, less than 10 miles inland from Pamlico Sound. Lagoonal and estuarine sands and muds are being deposited in hundreds of square miles of Pamlico and Core Sounds, which are behind the ever-changing linear offshore bars of the Outer Banks that include Core Banks and Hatteras and Ocracoke Islands. Bay- and bayou-type estuaries, ranging in area from a few to many tens of square miles, adjoin these major bodies of marine and brackish water to form a maze of smaller areas where carbonaceous muds are being deposited. Adjacent to all these are tidal marshes, covering more than 1,000 square miles, where peat and carbonaceous mud are accumulating.

Two small bay-type estuaries, Jarrett Bay and South River, were selected in the Pamlico Sound area as representative of an environment, relatively rich in organic matter, that might yield knowledge on the genesis of organic fuels. Jarrett Bay is an inland extension of Core Sound, and South River is a drowned tributary of the larger Neuse River estuary (fig. 1). Both bodies of water are shallow, generally less than 12 feet (3.7 m) deep, and are fringed by many square miles of spear-grass marshes. Seasonal changes in the salinity and temperature of water are given in table 1; Jarrett Bay water has a general salinity range of 20–35 parts per thousand, and South River 12–20 parts per thousand. Bottom sediments in Jarrett Bay and especially in South River are fine grained and poorly sorted, except for narrow nearshore belts of sand. These poorly sorted sediments have a fairly heterogeneous mineralogy, mainly derived from the lithologically complex metamorphic rocks of the Piedmont and the sedimentary Tertiary formations in central and eastern North Carolina.

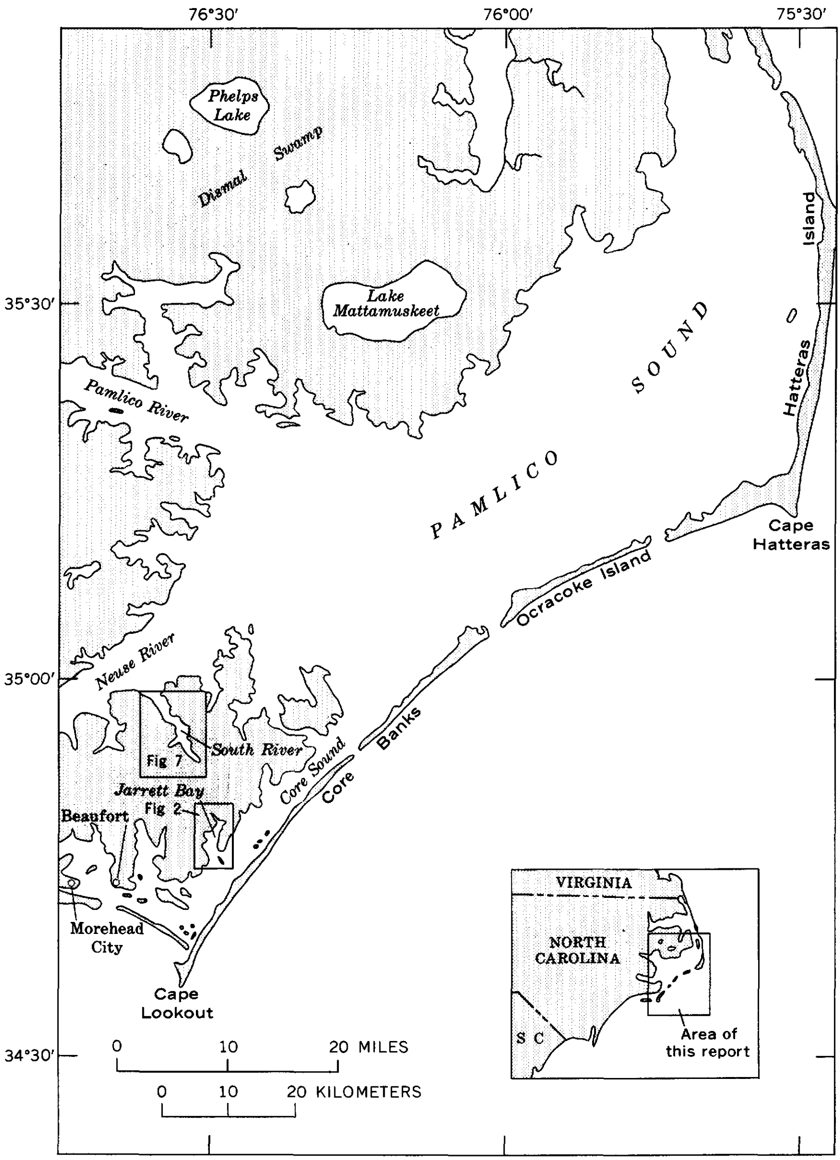

FIGURE 1.—Index map of Pamlico Sound area, North Carolina, showing location of Jarrett Bay and South River.

This study is part of a broader investigation, concerned with the types and amounts of organic matter in sediments representing a variety of modern environments of deposition, that will add to our knowledge of the genesis of coal, petroleum, and related fossil fuels (Swanson and others, 1967; Palacas and others, 1968). The amount of organic matter that accumulates and is preserved in sediments is affected by the type of organic matter, type of sediment, and type of basin; by physiographic conditions in adjoining areas; by basin hydrography; and by physical and chemical conditions in the water. Similar data from a wide spectrum of modern depositional environments eventually will be compared and evaluated in detail as a means of understanding the chemical changes of the organic material in sediments through the general degradational and decompositional processes that take place during transport, deposition, and burial.

TABLE 1. — *Summary of salinity and temperature of water at selected localities in Jarrett Bay and South River*

[Data are for the period June 15, 1952, through Dec. 31, 1953, and are from Williams (1955)]

Locality	Water depth (ft)	Bottom salinity (parts per thousand)		Annual range of bottom temperature (°C)
		Winter	Summer	
Jarrett Bay (fig. 2):				
Howland Creek	3	24.9–26.0	27.2–36.0	6.8–31.2
Williston Creek at Williston	3	19.4–25.0	27.4–36.2	6.6–30.2
Wade Creek	3	19.1–25.5	31.7–36.2	6.8–31.4
South River (fig. 7):				
Middle of river	12	[1]13.8	14.4–20.5	10.6–31.4
Mouth of Big Creek	8	[1]13.9	13.9–16.5	11.0–31.4
Upstream on Big Creek	3	[1]12.0	12.8–14.4	11.4–32.2

[1]Average value.

This paper is a synthesis of factual information on estuarine deposits that eventually will be integrated with comparable information on nearby depositional environments. Interpretations and interrelations in this initial report on the Pamlico Sound area thus are minimal inasmuch as the studies of nearby areas have been temporarily postponed.

ACKNOWLEDGMENTS

Grateful acknowledgment is extended to Elmer Willis for loan of a skiff and motor for work in Jarrett Bay and to Stuart Berryhill who operated the skiff and assisted during work in South River. Foraminiferal data were supplied by Louise R. Berryhill. Special thanks are also extended to James G. Palacas for his detailed and constructive review of this paper.

FIELD AND LABORATORY METHODS

Field investigations in Jarrett Bay, in October 1965, and in South River, in July 1966, included the collection of a series of bottom-sediment samples and the determination of water depth, temperature of bottom water, and water salinity at each station sampled. Measurements of pH and Eh of the surface and bottom water and of the topmost few centimeters of sediment were made at several stations in Jarrett Bay. Samples of approximately the uppermost 15 cm (0.5 ft) of sediment were obtained by either a clam-shell grab sampler or a coring tube. Five cores, each about 60 cm long, were also taken with a piston corer in Jarrett Bay. To prevent bacterial decay, the samples were frozen within a few hours after they were collected and were kept frozen until they were analyzed.

In order to determine the chemical characteristics of the bottom sediment, the following analyses were made: Total carbon, mineral carbon, organic carbon (by difference), bitumen, alkaline-soluble humic and fulvic fractions, total sulfur, and semiquantitative emission spectrographic analyses for trace elements. The organic composition of the humic and fulvic fractions of 11 representative samples was also determined by ultimate analysis. The laboratory procedures followed are those described by Palacas, Swanson, and Love (1968, p. C99–C100).

As used in this report, the alkaline-soluble humic substances are that part of the organic material in the sediment soluble in 0.1 *N* NaOH. On acidification, the humic fraction is precipitated, and the organic substances remaining in solution are referred to as the fulvic fraction. These alkaline-soluble humic substances are believed to represent mainly the previously soluble organic substances in the natural tea-colored water that were precipitated or flocculated and incorporated in the sediment. These natural soluble substances are derived from decomposing land-plant debris.

To establish some understanding of the manner in which environmental factors influence organic material in recent sediments during movement, deposition, and burial, the physical properties of the sediments in selected samples were determined so that clues might be obtained and applied in studies of organic materials in ancient sediments. The grain size for the >0.062-mm fractions was determined by sieving; the particle-size distribution for the <0.062-mm fraction was determined by standard pipet method. Clay minerals for selected samples were identified by X-ray diffraction. Foraminifera were identified in some samples to complement other environmental and chemical data for the study sites.

JARRETT BAY

Jarrett Bay is elongate north to south; length is slightly more than 4 miles, and average width is about one-half mile. Its greatest depth, 8.3 feet (2.5 m), is in the south-central part (loc. 71, fig. 2).

The bay has a generally symmetric bottom profile, and the deepest parts are along the axis of the bay. The water in the bay, as noted during the summer, is a very dark tea color, especially toward the north end of the bay. Salinity measurements of the bottom water during the period of field studies averaged 26.8 parts per thousand and ranged from 13.9 to 33.1 parts per thousand; the salinity was less than 20.0 parts per thousand at only one locality (loc. 9, fig. 2). The pH of the bottom water, measured a few centimeters above the sediment at five localities, ranged from 7.6 to 8.0 and averaged 7.8; the water was reducing at two localities and oxidizing at three localities (table 2).

TABLE 2.—*pH and Eh of bottom water and sediment at five localities in Jarrett Bay*

Locality (fig. 2)	Depth of water (ft)	Sediment type	Bottom water pH	Bottom water Eh (millivolts)	Bottom Sediment pH	Bottom Sediment Eh (millivolts)
7	2.6	Organic-matter-rich mud	7.6	−155	7.2	−310
11	2.0	Peaty silt	7.7	−180	7.3	−285
39	3.5	Silty sand	8.0	+125	7.2	−120
62	4.0	Organic-matter-rich mud	8.0	+150	7.2	−180
84	3.8	Silty sand	7.8	+100	7.5	−130

BOTTOM SEDIMENT

Bottom sediments were sampled at 102 localities in Jarrett Bay (fig. 2), and analyses of 62 of these samples are shown in table 5. The bottom sediment is largely a mixture of clay-, silt-, and sand-sized particles. The percentage of sand decreases sharply from the shoreline toward the center of the bay, and clay-sized particles make up more than 20 percent of the bottom sediments in the deepest part of the bay (fig. 3). The most abundant clay minerals are illite, chlorite, and chlorite-mica (table 3). Slimy flocculated material high in organic matter forms a soupy transition zone as much as 30 cm (1 ft) thick between water and bottom sediment, except at those localities where the sediment is mainly sand. Cumu-

TABLE 3.—*Clay mineralogy of <2-micron fraction of selected samples from Jarrett Bay and South River*

[Leaders (....) in figure columns indicate amounts less than 10 percent. Analysts, H. C. Starkey and P. D. Blackmon]

	Percentage of given clay type for indicated sample locality																	
	Jarrett Bay (fig. 2)												South River (fig. 7)					
Clay type	1	2	13	30	32	33	39	88	91	92	98	99	3	10	17	38	48	49
Illite	10	10	20	10	10	10	....	10	....	10	....	10	....	....	....	....	....	....
Illite-mica	....	....	....	....	....	....	....	....	....	....	....	....	10	10	10	10	20	30
Chlorite	10	10	10	20	10	10	....	10	....	10	10	10	....	....	....	....	....	....
Chlorite-mica	....	10	20	20	10	10	10	10	20	10	10	10	....	....	....	....	....	....
Chlorite-montmorillonite	....	....	....	10	20	10	10	10	....	10	20	....	....	....	....	....	....	....
Montmorillonite	....	....	....	....	10	....	....	10	10	10	....	10	....	....	....	....	....	....
Kaolinite	....	....	10	....	....	....	10	10	20	10	....	....	50	60	60	40	50	40
Aluminum-vermiculite	....	....	....	....	....	....	....	....	....	....	....	....	10	10	10	10	10	10

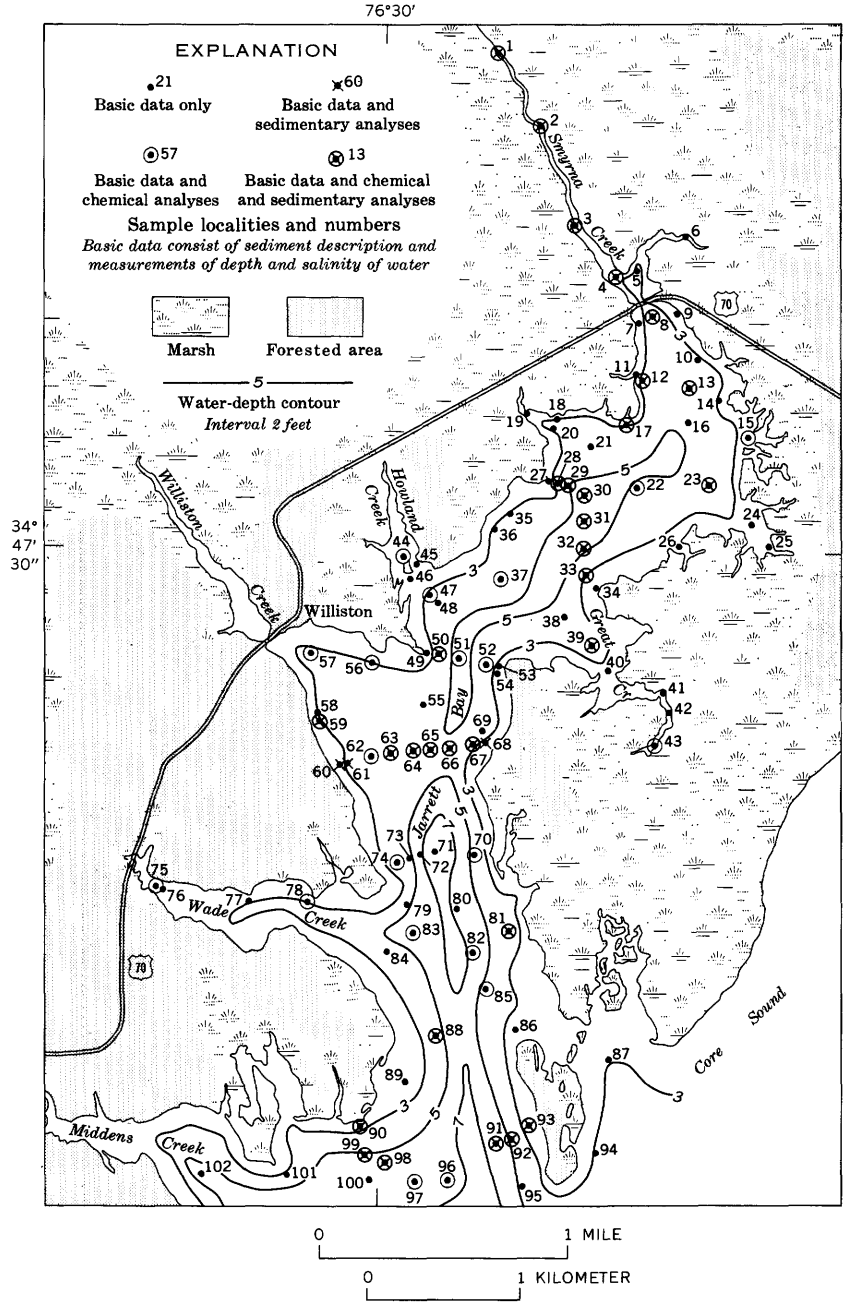

FIGURE 2. — Sample localities and depths of water in Jarrett Bay.

lative curves showing the distribution of grain size for five selected samples are shown in figure 4. The samples that consisted mostly

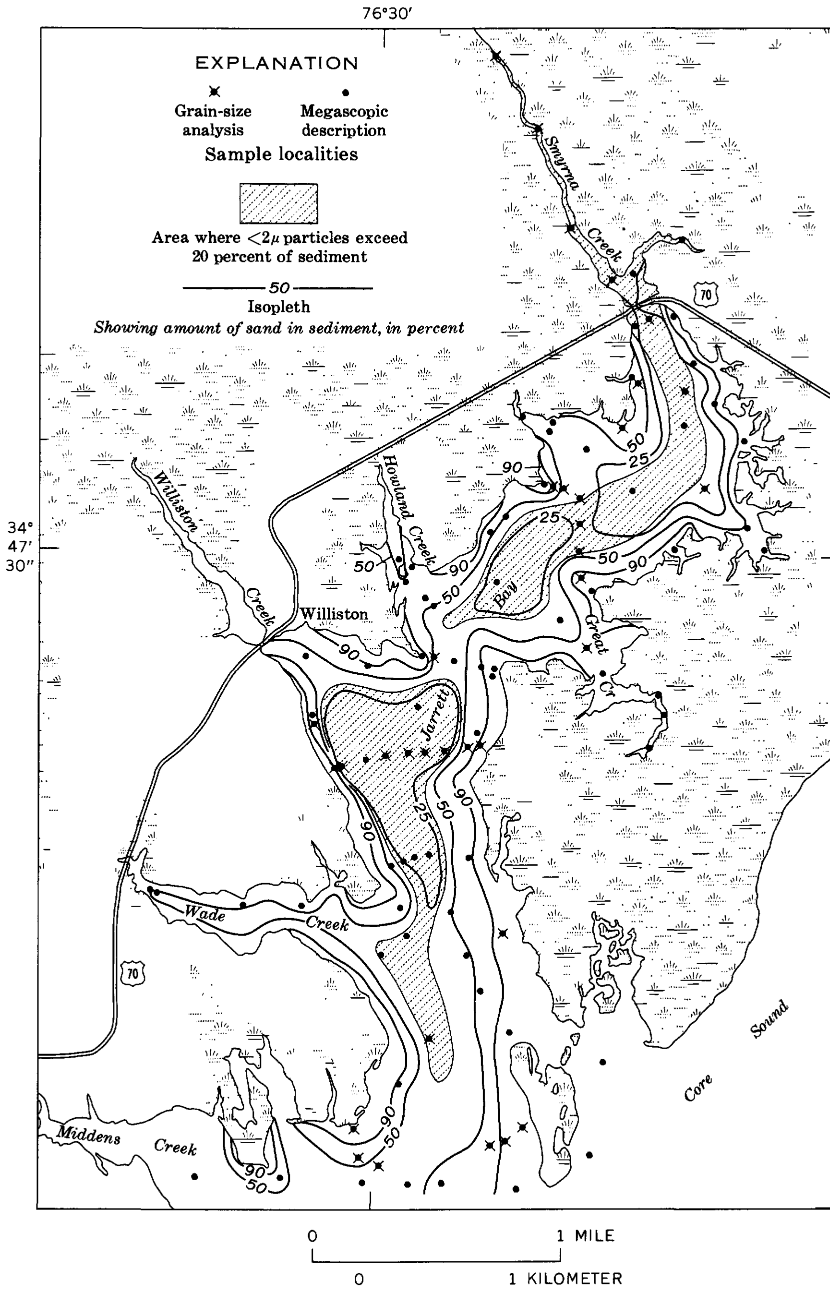

FIGURE 3. — Distribution of sediment by grain size in Jarrett Bay. For this report, clean sand contains more than 90 percent sand-sized grains, silty clayey sand contains 50–90 percent sand-sized grains, and mud contains less than 50 percent sand-sized grains.

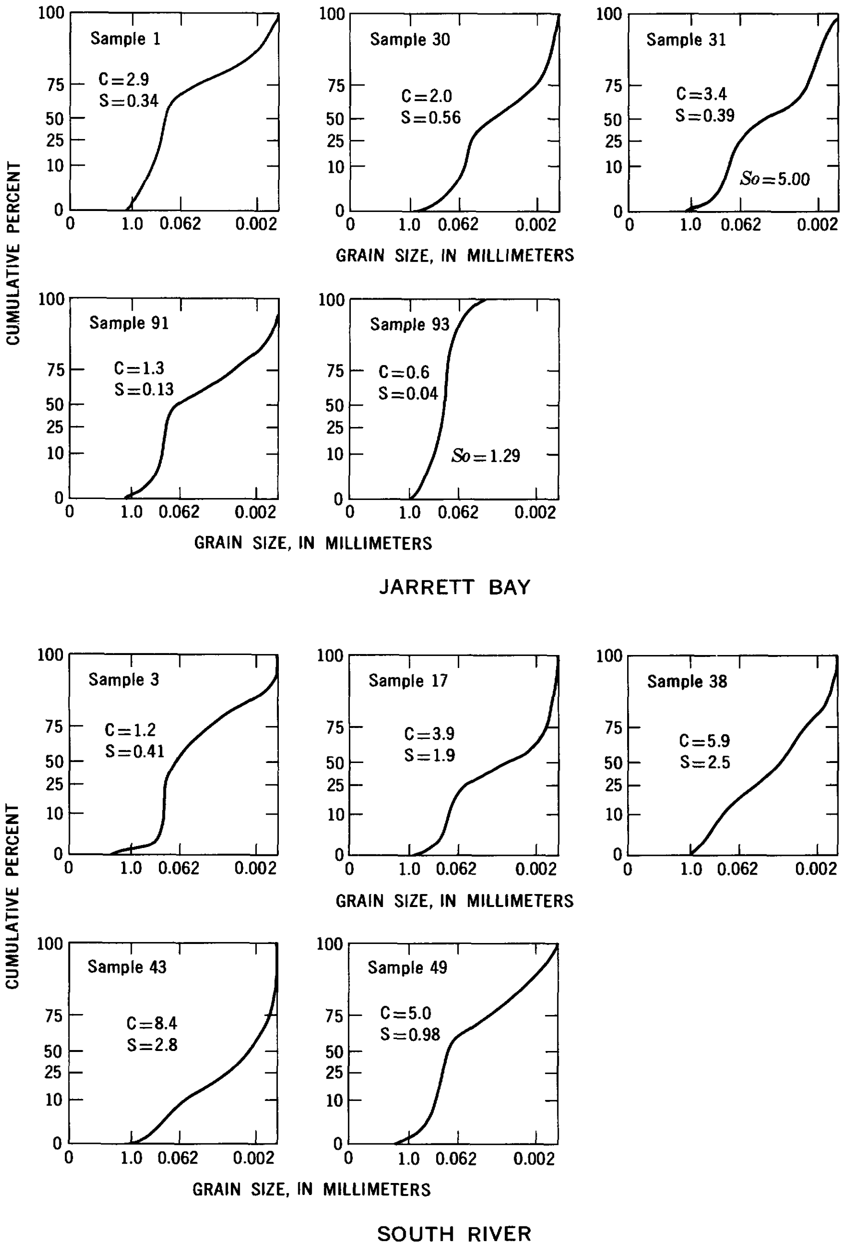

FIGURE 4. — Cumulative curves showing grain-size distribution in representative bottom-sediment samples (R. F. Gantnier, analyst). Sample localities in Jarrett Bay are shown in figure 2, those in South River, in figure 7. C, organic carbon, in percent; S, total sulfur, in percent; So, sorting index, based on the first and third quartiles.

of sand were very light brown; all the other samples were greenish gray. Eh readings for the upper 2.3 cm (0.1 ft) of bottom sediments at five localities ranged from −120 to −310 millivolts and averaged −205, indicating reducing conditions (table 2). The pH of these sediment samples ranged from 7.2 to 7.5 and averaged 7.3.

Spectrochemical analyses of 20 sediment samples from Jarrett Bay showed neither major value differences in elements among the samples nor anomalous concentrations of specific elements that might have environmental significance. Three representative analyses are shown in table 4. The amounts of B, Cr, Ga, and V shown by these analyses are within the range reported by Shimp, Witters, Potter, and Schleicher (1969, table 3) to be indicative of marine muds, although the amount of Ni is lower in the Jarrett Bay samples than the amount reported by those authors.

The percentage of heavy minerals in the bottom sediments of Jarrett Bay ranged from less than 0.01 to 2.0 in the sieved fraction (0.125–0.062 mm). The principal minerals are ilmenite, tourmaline, leucoxene, amphibole, and zircon.

Fragments of oyster and other marine mollusk shells are common, and plant debris is abundant. Most of the plant material is unidentifiable, but some grass, wood, and bark fragments and shreds were observed in samples from tributaries.

Foraminifera in a set of samples collected in the north half of Jarrett Bay were identified and counted by Louise R. Berryhill as an additional means of establishing the characteristics of the sediments. Arenaceous forms were either the predominant or the only Foraminifera in all samples, but many of the specimens were unidentifiable because they were very small or broken. The most abundant arenaceous genera were *Ammotium* and *Ammobaculites; Miliammina, Trochammina, Arenoparrella,* and *Haplophragmoides* were also present. At the north end of Jarrett Bay, calcareous forms of the genus *Ammonia* were abundant; these, together with *Protelphidium,* which were common, and a few *Elphidium,* were the only nonarenaceous Foraminifera in the samples studied.

Each sample processed for foraminiferal study had a volume of approximately 10 cm^3 and was washed through 35-, 80-, and 200-mesh sieves. In the samples for which the total number of Foraminifera was counted, the number of specimens ranged from 200 to 3,000. These counts are considerably higher than those recorded by Grossman (1967, p. 34) in samples from Nelson Bay, an estuarine environment similar to Jarrett Bay, 7 miles to the northeast. His counts ranged from 0 to 265 specimens in samples having a volume of 120 cm^3 (12 times the volume used for this study), which he interpreted as indicating the relative scarcity of Foraminifera in the Pamlico Sound area. The most obvious factor contributing to the observed difference in abundance of Foraminifera was that Grossman used 20-, 40-, and 100-mesh sieves. Actually specimens in the less-than-100-mesh size far outnumber the larger ones.

ORGANIC AND RELATED MATERIALS

Organic carbon

The amount of organic carbon (table 5) in the upper 10–15 cm (0.3–0.5 ft) of bottom mud (clay-silt content greater than 50 percent) in Jarrett Bay (fig. 5) ranges from 1.0 to 4.4 percent and averages 2.1 percent. The highest organic-carbon values are generally for the mud samples from the northern and middle parts of the bay. In the relatively clean sand (clay-silt content less than 10 percent), which is the common bottom sediment in the shallow-water nearshore areas, the organic-carbon content ranges from 0.1 to 0.6 percent and averages 0.4 percent. In the silty sand (silt-clay content 10–50 percent), the amount of organic carbon ranges from 0.5 to 2.9 percent and averages 1.3 percent. Wherever there appears to be an anomalously high organic-carbon content with respect to depth of water and grain-size distribution, the irregularity commonly is due to particulate organic substances such as grass and plant fragments in the sample.

Mineral carbon

The mineral-carbon, or carbonate, content of the sediment is generally less than 0.1 percent, but it ranges from less than 0.01 to as much as 1.50 percent (table 5). The inclusion of mollusk shells or shell fragments in the samples probably explains all analyses for mineral carbon exceeding 0.1 percent. Mud and silty sand samples most commonly contain shell material.

Sulfur

Sulfur is a product of decomposition of organic remains in sediments and, volumetrically more important, a product of reduction of sulfate in interstitial water and, for some areas, in the bottom water. In general, the greater the amount of decomposing organic matter in the sediment, the greater the reducing action that results in precipitation of the sulfide ion. The reduced sulfur commonly combines with metal ions, particularly iron, to form metal sulfide minerals in the sediment. Sulfur minerals were not observed in the sediment samples studied but probably are finely dispersed in an amorphous hydrous form. In two cores (locs. 39 and 62, fig. 2), total sulfur increases with depth; at locality 39, for example, it increases from 0.10 percent in the upper 10 cm to 0.89 percent in the sample 40–50 cm below the sediment surface (table 5). The total sulfur content of the upper 10–15 cm of sediment ranges from 0.02 to 0.95 percent — sand contains an average of 0.06 percent; silty sand, 0.29 percent; and mud, 0.48 percent (table 5). Very clearly, the smaller the grain size of the upper 10–15 cm of sediment, the greater the amount of organic carbon and total sulfur in the sediment.

Bitumen

The bitumen content of the upper 10–15 cm (0.3–0.5 ft) of bottom sediment ranges from 0.003 to 0.086 percent (table 5) and averages 0.0175 percent. This average value is very similar to the 0.0170 average bitumen content of the estuary muds of Choctawhatchee Bay, Fla. (Palacas and others, 1971).

In Jarrett Bay, the average bitumen contents of sand, silty sand, and mud are 0.013, 0.014, and 0.020 percent, respectively. Thus, there is a slight increase of average bitumen content with decreasing grain size and, as previously noted, the average organic-carbon content also increases with decreasing grain size. The amounts of bitumen in the sediment are generally greater in the northern end of the bay, but the pattern of decrease southward is irregular. However, it should be emphasized that the individual values for bitumen, classified either by lithology, by organic-carbon content, or by geographic distribution, have very wide ranges. The analyses of samples from two cores (table 5) show no pattern of increase or decrease of bitumen content with depth.

Bitumen, as determined on the basis of ratios of bitumen to organic carbon, makes up an estimated average of 1 percent of the sparse organic matter in Jarrett Bay sand and about 0.5 percent in the silty sand. The bitumen fraction of the organic matter of the mud has a wide range, 0.1–2.0 percent, but also averages about 0.5 percent.

Alkaline-soluble humic substances

In most sediments of Holocene age, a large part of the organic matter has been decomposed so that it can be extracted in the laboratory by treatment with alkaline solutions. This organic matter, here termed soluble humic substances, is commonly divided in the laboratory into humic and fulvic fractions (table 5), by acidifying the solution. These soluble humic substances in the sediment of Jarrett Bay (fig. 6), calculated to an ash-free basis, range from 0.015 to 2.98 percent and generally parallel the total organic matter in the sediment, as indicated by the percentage of organic carbon (compare figs. 6 and 7). If the total organic matter is estimated by multiplying the percentage of organic carbon by the conversion factor of 1.9 (Palacas and others, 1968, p. C99), the

TABLE 4.—*Semiquantitative emission spectrographic analyses of sediment samples and organic extracts of sediment samples from Jarrett Bay*

[Analysts, Harriet Neiman and A. L. Sutton. Leaders (....) in figure columns indicate element not detected]

Element	Percentage of given element in sediment sample or extract of sediment sample from indicated locality (fig. 2)								
	Locality 3			Locality 8			Locality 32		
	Whole sample	Ash: Soluble humic fraction	Ash: Soluble fulvic fraction	Whole sample	Ash: Soluble humic fraction	Ash: Soluble fulvic fraction	Whole sample	Ash: Soluble humic fraction	Ash: Soluble fulvic fraction
Si	>10	10	3	>10	>10	5	>10	7	1.5
Al	5	10	>10	5	>10	>10	7	7	10
Fe	2	7	7	3	7	1.5	3	2	7
Mg	1	.5	.015	1	.7	.01	1.5	.3	.015
Ca	.5	.05	.1	.5	.07	.03	.7	.03	.03
Na	2	1	10	1.5	10	5	2	3	.7
K	2	1	....	2	1.5	....	2	....	....
Ti	.3	.3	.1	.3	.2	.07	.3	.2	.05
P	....	1	3	....	.5	1.5	....	.5	2
Mn	.015	.005	....	.02	.007	....	....	.0007	.0003
Ag	....	.0002	.0003	....	.0005	.0002	....	.0007	.0003
B	.01	.01	.02	.01	.015	....	.01	.015	.015
Ba	.03	.01	.001	.05	.01	.00015	.05	.01	.0005
Ce	....	.015	.0001	....	....	.03	....	....	.02
Co	.0005	.0015	.0005	.0005	.002	.0007	.0005	.0015	....
Cr	.007	.03	.03	.005	.05	.02	.007	.02	.01
Cu	.002	.03	.02	.002	.05	.03	.0015	.03	.03
Ga	.002	.007	.007	.002	.007	.007	.003	.002	.005
La	.005	.005	.03	.003	.007	.007	.003	.003	.005
Mo	.0003	.03	.01	....	.02	.007	....	.015	.005
Nb	....	.001	....	.001	....	....	.001	.001	....
Ni	.0015	.015	.003	.0015	.015	.003	.002	.015	.005
Pb	.002	.005	.03	.002	.001	.02	.0015	.002	.01
Sc	.001	.003	.001	.001	.002	.0005	.001	.0015	....
Sn	....	.005	.005	....	.007	.007	....	.003	.002
Sr	.01	.003	.003	.01	.007	.0005	.015	.002	....
V	.007	.03	.5	.007	.05	.5	.001	.015	.1
Y	.002	.003	.02	.003	.002	.01	.003	.0015	.005
Yb	.0003	.0005	.002	.0005	.0005	.001	.0003	.0002	.0007
Zr	.02	.02	.005	.03	.015	.003	.05	.02	.003
Nd	....	.015	.07	....	.015	.003	....	....	.015
Dy	....	....	.007	....	....	....	....	....	....

TABLE 5. — *Chemical and grain-size analyses, in percent, of sediment from Jarrett Bay*

[Carbon and sulfur analyses by I. C. Frost; grain-size analyses by R. F. Gantnier. Ash-free soluble and humic fractions calculated on the basis of average percentage of ash for 11 humic fractions (15.6 percent) and for 11 fulvic fractions (30.8 percent) from Jarrett Bay and South River. Leaders (....) indicate no analysis]

Locality (fig. 2)	Sediment type	Depth of water (ft)	Chemical analyses						Grain-size analyses		
			Organic carbon	Bitumen (sulfur-free)	Alkaline-soluble humic substances		Mineral carbon	Total sulfur	Sand	Silt	Clay
					Humic fraction (ash-free)	Fulvic fraction (ash-free)					
Upper 10–15 cm (0.3–0.5 ft) of sediment											
1	Silty sand	4.5	2.9	0.035	1.35	0.11	<0.01	0.34	72.6	19.1	8.2
2	Mud	4.2	4.4	.030	1.61	.22	.02	.66	47.6	29.9	22.5
3	do	3.9	4.4	.071	2.58	.40	.01	.71	20.9	55.3	23.7
4	do	2.3	3.5	.030	1.36	.30	.04	.95	18.8	64.5	16.7
8	do	3.6	2.0	.036	.88	.30	.03	.65	14.3	63.4	22.3
12	Silty sand	3.5	1.8	.025	.42	.41	.42	.40	60.3	25.5	13.2
13	Mud	4.6	2.1	.021	.92	.32	.06	.59	4.8	76.1	19.1
15	Sand	2.6	.3	....	....	....	.03	.08	....	....	....
17	Silty sand	3.6	1.5	.015	.43	.18	.09	.27	80.6	14.0	5.4
22	do	4.6	1.8	.008	.41	.26	.20	.72	....	....	....
23	Mud	4.0	1.8	.019	.24	.12	.15	.62	1.8	81.6	16.5
28	Sand	3.7	.1	.031	.005	.01	.03	.02	94.5	....	....
29	Silty sand	5.0	1.6	.017	.17	.12	<.01	.56	48.2	32.0	19.0
30	Mud	5.2	2.4	.049	.42	.17	.24	.51	37.6	44.2	18.5
31	do	5.2	1.4	.086	.39	.16	<.01	.39	25.5	46.7	27.5
32	do	5.2	1.7	.029	.48	.18	.14	.55	34.5	34.5	30.5
33	Sand	2.9	.5	.019	.03	.08	.38	.06	92.2	5.8	1.6
37	Mud	4.7	1.9	.006	.38	.22	.23	.46	....	....	....
39	Silty sand	3.5	.8	.009	.18	.15	.04	.10	73.0	19.4	7.5
43	Mud	1.4	2.9	.034	2.68	.24	.04	.58	....	....	....
44	do	1.7	2.4	.011	1.08	.35	.08	.89	....	....	....
47	Silty sand	4.4	1.9	.012	.52	.40	.06	.51	....	....	....
50	Sand	4.2	.6	.007	.12	.16	.06	.07	93.4	4.9	1.6
51	Mud	5.4	1.7	.003	.24	.23	.04	.16	....	....	....
52	Silty sand	3.3	.7	.006	.05	.10	.06	.07	....	....	....
56	do	3.4	1.2	.007	.24	.25	.08	.20	....	....	....
57	Mud	3.5	1.5	.010	.56	.17	.20	.58	....	....	....
59	do	2.9	1.0	.004	.13	.14	1.50	.33	41.8	32.0	26.2
62	do	4.0	2.3	.015	.23	.18	.05	.40	....	....	....
63	do	4.1	1.8	.010	.37	.22	.20	.31	13.1	57.3	29.5

64	........do	4.3	1.8	.004	.40	.25	.12	.40	5.1	71.1	23.7
65	........do	4.1	1.9	.015	.28	.14	.08	.48	7.0	70.2	22.8
66	........do	4.7	2.0	.011	.65	.31	.06	.47	6.8	67.0	26.1
67	Silty sand	3.0	.5	.009	.11	.11	.04	.04	69.2	17.2	13.5
70	........do	4.2	.5	.004	.24	.25	.01	.07	....	....	....
74	Mud	4.9	1.5	.007	.30	.24	.08	.26	....	....	....
75	........do	1.8	1.6	.013	.70	.33	.06	.85	....	....	....
78	Silty sand	3.9	1.7	.016	.33	.25	.06	.72	....	....	....
81	Sand	3.4	.3	.007	.02	.03	.03	.08	93.4	4.9	1.6
82	Mud	6.7	2.1	.014	.72	.36	.10	.48	....	....	....
83	........do	5.2	1.6	.012	.30	.24	.09	.40	....	....	....
85	Silty sand	4.4	1.0	.011	.29	.28	.03	.48	....	....	....
88	Mud	4.9	1.1	.016	.23	.22	.10	.25	28.5	52.3	19.2
90	Sand	3.3	.3	.007	.003	.04	.02	.10	94.2	4.3	1.4
91	Silty sand	6.6	1.3	.014	.17	.15	<.01	.13	52.8	28.8	18.4
92	Sand	4.2	.4	.011	.000	.05	.03	.04	96.3	1.7	2.0
93	........do	2.8	.6	.019	.003	.03	<.01	.04	99.0	1.0	.0
96	Silty sand	6.9	1.7	.014	.33	.25	.06	.26	....	....	....
97	Mud	6.6	1.8	.011	.46	.26	.11	.51	....	....	....
98	........do	6.5	1.2	.016	.13	.14	<.01	.16	28.5	55.0	16.4
99	Silty sand	5.4	.6	.020	.12	.15	.01	.06	63.0	19.6	17.4
					Sediment cores						
139[1]	Silty sand (0–10 cm)	....	0.8	0.009	0.18	0.15	0.04	0.10	73.0	19.4	7.5
	Shelly mud (10–20 cm)	....	1.3	.008	.09	.12	1.44	.20	67.1	20.4	12.5
	Silty sand (20–30 cm)	....	.8	.006	.08	.11	.39	.26	....	....	....
	Silty sand (30–40 cm)	....	.8	.007	.16	.12	<.01	.45	64.4	19.2	16.4
	Silty sand (40–50 cm)	....	.6	.018	.48	.07	.02	.89	60.2	21.5	18.3
	Silty sand (50–60 cm)	....	.5	.009	.02	.15	<.01	.79	54.2	28.9	17.0
262[2]	Mud (0–15 cm)	....	2.3	.015	.23	.18	.05	.40	....	....	....
	Mud (15–30 cm)	....	2.2	.028	.37	.27	.12	.48	....	....	....
	Mud (30–45 cm)	....	2.4	.028	.35	.24	<.01	.77	....	....	....
	Mud (45–60 cm)	....	2.5	.021	.24	.18	.03	.74	....	....	....
	Mud (60–75 cm)	....	2.1	.023	.33	.22	<.01	.75	....	....	....

[1]Core taken under 3.5 feet of water. [2]Core taken under 4.0 feet of water.

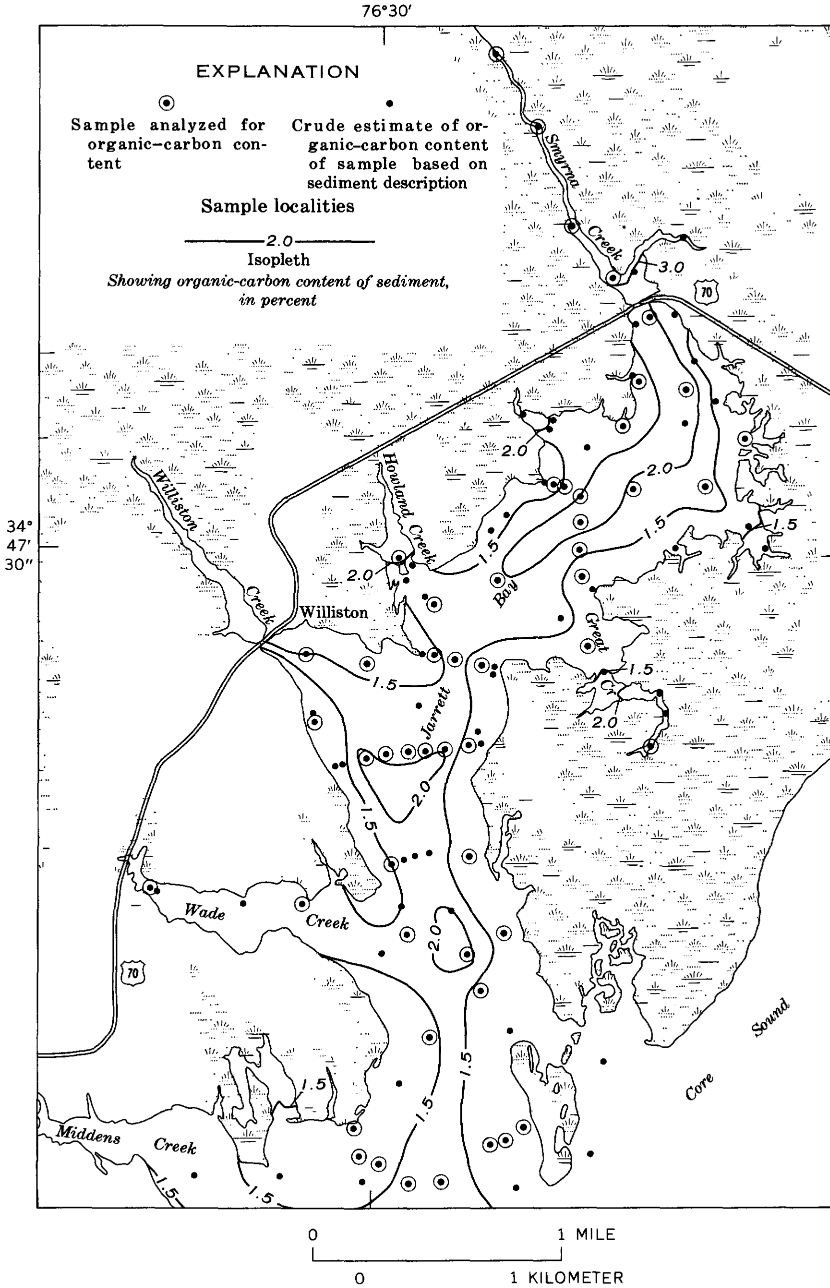

FIGURE 5. — Organic-carbon content, in percent, of sediment in Jarrett Bay.

soluble humic substances generally constitute about one-fourth of the organic matter in the Jarrett Bay sediment, the organic mat-

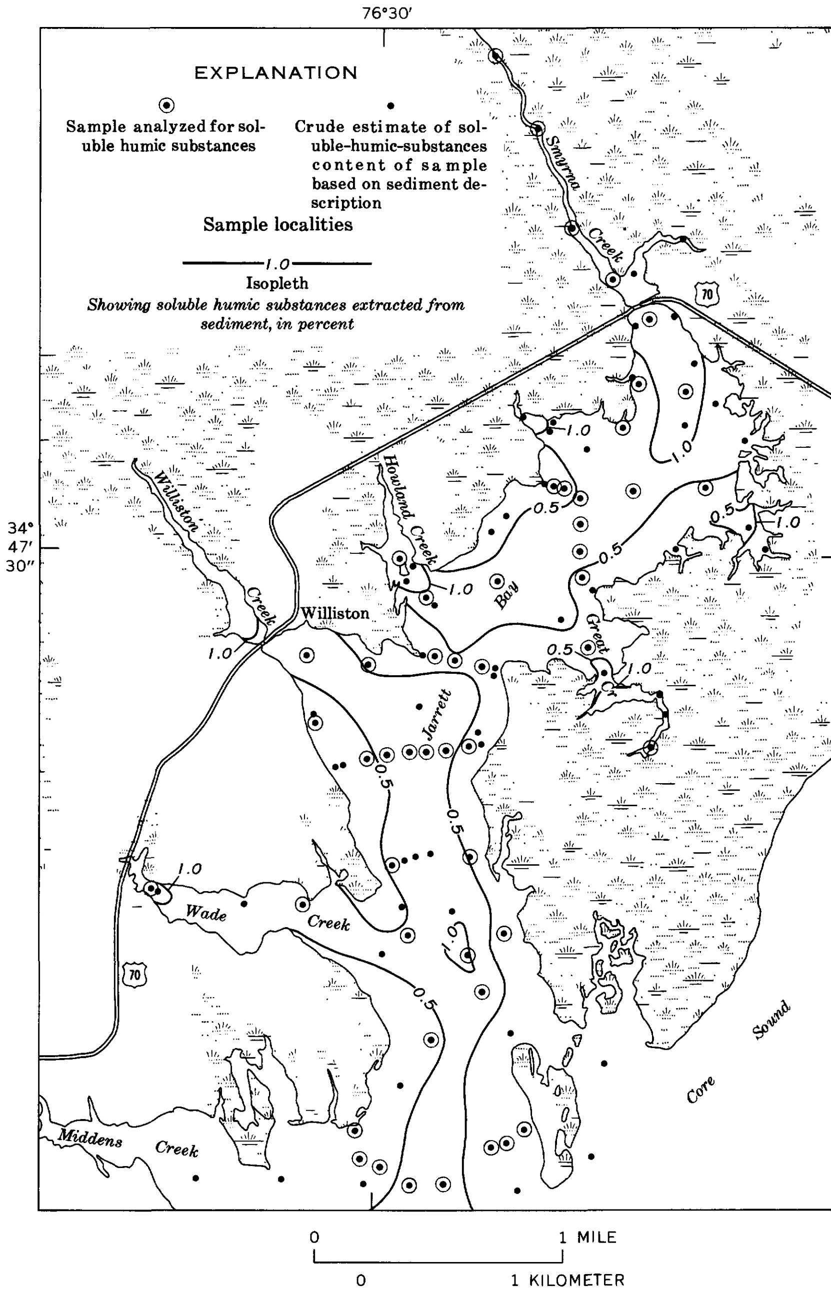

FIGURE 6.— Content of alkaline-soluble humic substances, in percent, in sediment in Jarrett Bay.

ter in the nearshore sand containing slightly less and the silty sand and muds slightly more.

The alkaline-soluble humic substances either are deposited as a dark-brown precipitate when the tea-colored water from the marshes encounters the saline water of the bay (Swanson and Palacas, 1965, p. 1), or they are formed in place from decomposing particulate matter within the bay sediment.

The amount of the soluble humic fraction in the samples, on an ash-free basis, averages 0.47 percent and is as much as 2.68 percent of the sediment (table 5). Content of the humic fraction is lowest in the sand along the eastern part of the bay and is highest in the mud within the drowned channels of the creeks that enter the bay. Locally high concentrations are generally related to higher percentages of organic carbon in muds in the tributaries, for example at localities 2, 3, 43, and 44 (fig. 2).

Analyses for organic carbon and hydrogen were made for the soluble humic fractions of eight samples, and complete organic composition was determined by ultimate analysis for four of the eight samples (table 6). The samples analyzed were selected so

TABLE 6. — *Organic-element composition, in percent, on ash-free basis, of soluble humic and fulvic fractions of sediments from Jarrett Bay*

[Average values for the elements are for samples with complete analysis only. All analyses by Huffman Laboratories, Inc., Wheatridge, Colo., except ash determinations for samples 3, 8, and 32 by I. C. Frost. Leaders (....) in element columns indicate no analysis]

Locality (fig. 2)	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Carbon-hydrogen ratio	Ash
			Humic fraction				
2	56.60	5.34	32.54	3.23	2.29	10.6	15.18
3	56.04	5.13	....	....	....	10.9	12.8
8	52.94	5.41	....	....	....	9.8	15.7
13	57.28	5.59	30.20	4.37	2.56	10.2	14.32
32	53.70	5.72	....	....	....	9.4	11.4
65	52.54	6.23	35.67	3.46	2.09	8.4	29.47
88	52.88	6.36	34.63	4.88	1.25	8.3	27.25
91	53.43	6.17	....	....	....	8.7	11.35
Avg	54.8	5.9	33.3	4.0	2.0	9.5	17.2
			Fulvic fraction				
2	46.65	4.90	....	....	....	9.5	30.59
3	42.81	5.11	....	....	....	8.4	31.0
8	38.16	5.72	....	....	....	6.7	32.2
13	44.04	5.74	44.18	4.82	1.22	7.7	34.14
32	42.98	5.43	....	....	....	7.9	27.3
65	42.87	5.68	....	....	....	7.6	31.32
88	39.79	5.11	50.48	3.78	0.83	7.8	17.34
91	43.15	7.49	....	....	....	5.8	34.04
Avg	41.9	5.5	47.3	4.3	1.0	7.7	29.7

as to represent a north-south spread along the bay to determine if any chemical changes take place during transport and increase in distance from probable source areas. Some general trends in compositional change are indicated, but exceptions also are evident; for example, carbon and sulfur contents tend to decrease toward the mouth of the bay, and hydrogen content increases slightly southward.

Trace-element content of the ash of the soluble humic fraction in three representative samples is shown in table 4. The Fe, Ag, Co, Cr, Cu, Mo, Ni, Sn, and V contents are higher in the ash of the humic fractions than in the whole samples at the localities listed.

The amount of the soluble fulvic fraction in the sediment ranges from 0.01 to 0.41 percent and averages 0.21 percent (table 5). The distribution is similar to that for the soluble humic fraction; the smallest amounts are in sand, and the largest concentrations are near the north end of the bay and in the finer grained sediment having higher organic-carbon content in the middle parts of the bay.

Of the total soluble humic substances, the humic fraction is generally twice the amount of the fulvic fraction. However, the percentage of the fulvic fraction has a wide range, from less than 10 percent to slightly more than 60 percent of the total alkaline-soluble material. The higher percentages of fulvic acid are generally confined to the cleaner sand, which has a relatively very low organic-carbon content. Beyond this general relation to grain size, there is also a general trend of increase of the fulvic fraction, as percentage of total soluble humic substances, from north to south, toward the mouth of Jarrett Bay. This trend is from 8 percent at Smyrna Creek (loc. 1, fig. 2), to 25 percent at the north end of Jarrett Bay (locs. 8 and 13), to 43 percent at the mouth of Jarrett Bay (average of data on samples from locs. 96, 97, and 98). The logical explanation for this trend is that the most soluble fraction of the alkaline-soluble organic substances, the fulvic fraction, is transported farthest before precipitation and deposition.

Comparison of organic composition of the fulvic fraction with that of the humic fraction reveals significant differences (table 6). The main differences are in the average carbon content of the soluble humic and fulvic fractions, 54.8 and 41.9 percent, respectively, and in the average oxygen content, 33.3 and 47.3, respectively. Obviously, two major groups of molecular structures are represented by the two fractions.

Percentages of P, Ag, Cr, Cu, Mo, Pb, V, and Y are significantly higher in the ash of the soluble humic and fulvic fractions than in the whole sediment samples (table 4). This observation indicates that the cited elements are for the greater part associated with the alkaline-soluble organic matter in the sediment, though this organic matter is only a small part of the whole sediment sample.

SOUTH RIVER

South River, which is about 10 miles southwest of the main part of Pamlico Sound, is a northwest-trending drowned creek channel about 7½ miles long and ¼–¾ mile wide; its outline and the sample localities are shown in figure 7. Depth of water along the axis of the channel averages about 11 feet (3.3 m) along two-thirds of the stream and becomes shallower southeastward (fig. 7). A shallow sill of sand, having a narrow deep channel near its center, crosses the river mouth near its junction with the Neuse River. The linear channel of South River is U-shaped in profile and has shallow bordering shelves. The water, like that in Jarrett Bay, is dark tea colored, particularly in the southern part of the estuary. Salinity measurements for bottom water during the period of study in August 1966 averaged 10.5 parts per thousand and ranged from 8.9 to 18.0; most of the readings (86 percent), however, were in the range 9.0–11.0 parts per thousand. The seasonal averages for salinity and the annual range in the temperature of bottom water are shown in table 1, where comparison can be made with similar data for Jarrett Bay. Neither pH nor Eh measurements were made in South River because of malfunction of equipment.

BOTTOM SEDIMENT

Bottom sediments were sampled at 53 localities in South River (fig. 7), and 31 of the samples were analyzed (table 7). The upper 10–15 cm (0.3–0.5 ft) of bottom sediment is in general very poorly sorted but mainly of silt size (fig. 4; table 7). Sand borders the channel on the shallow submerged shelves and forms shallow-water crossbars, or sills, across the mouths of the small tributaries to South River. Similarly, the mouth of the South River itself has a broad crossbar of sand that is cut by a very narrow channel.

Clay-sized particles compose more than 20 percent of the bottom sediment along the deepest part of the bay. The most abundant clay minerals are kaolinite, illite-mica, and aluminum-vermiculite (table 3). As in Jarrett Bay, a layer about 30 cm (1 ft) thick of soupy flocculated material high in organic matter forms an indefinite water-sediment interface in the deeper parts of the channel. Grain-size distribution of sediments is shown in figure 8.

Both calcareous shell fragments and living small clams are abundant in South River. A living specimen of a calcareous shelled worm similar to *Spirorbis* was attached to a fragment of tree bark

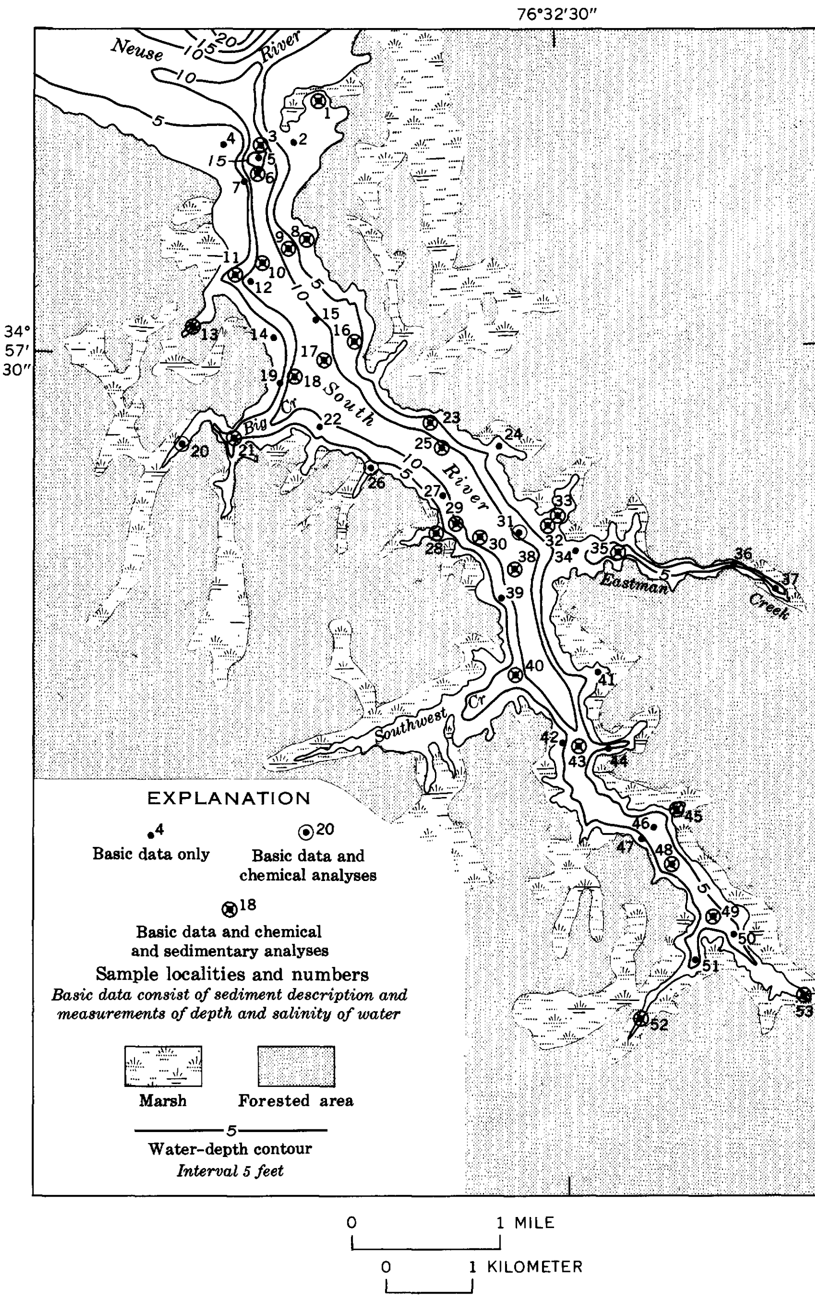

FIGURE 7.— Sample localities and depths of water in South River.

collected at locality 33. Wood fragments, particularly pine bark, and plant fibers are abundant in the sediment in many minor

TABLE 7. — *Chemical and grain-size analyses, in percent, of upper 10–15 cm (0.3–0.5 ft) of sediment from South River estuary*

[Carbon and sulfur analyses by I. C. Frost; grain-size analyses by R. F. Gantnier. Ash-free soluble humic and fulvic fractions calculated on the basis of average percentage of ash for 11 humic fractions (15.6 percent) and for 11 fulvic fractions (30.8 percent) from Jarrett Bay and South River. Leaders (....) in figure columns indicate no analysis]

Locality (fig. 7)	Sediment type	Depth of water (ft)	Chemical analyses						Grain-size analyses		
			Organic carbon	Bitumen (sulfur-free)	Alkaline-soluble humic substances: Humic fraction (ash-free)	Alkaline-soluble humic substances: Fulvic fraction (ash-free)	Mineral carbon	Total sulfur	Sand	Silt	Clay
1	Sandy mud	4.0	2.7	0.017	1.01	0.33	0.03	0.95	26.9	59.2	13.9
3	do	13.2	1.2	.017	.39	.19	.02	.41	45.6	47.3	7.1
6	do	14.6	1.9	.021	.75	.27	.03	.93	30.3	55.8	13.9
8	Sand	1.9	.1	.007	.02	.04	.01	.93	99.1	.9	.0
9	Sandy mud	9.6	2.4	.015	1.05	.31	.03	1.10	37.0	51.0	12.0
10	Mud	10.4	3.0	.017	1.14	.29	.04	1.46	22.6	51.8	25.6
11	Silty sand	6.3	.2	.007	.17	.11	.03	.31	83.8	13.6	2.6
13	Mud	2.4	9.3	.086	3.64	.56	.08	3.24	14.9	63.1	21.0
16	Sand	8.6	.7	.006	.18	.09	.04	.18	90.9	6.4	2.7
17	Mud	11.3	3.9	.021	1.64	.25	.03	1.91	20.4	44.6	35.0
18	do	12.1	6.2	.027	1.90	.18	.03	2.17	7.6	65.6	26.7
20	do	4.3	12.9	.080	5.39	.49	.10	3.76	....	....	....
21	do	6.5	5.2	.033	2.40	.31	.05	2.37	13.7	68.1	18.3
23	Sand	6.4	.8	.006	.19	.11	.04	.32	91.7	6.6	1.7
25	Mud	10.9	5.9	.032	2.86	.28	.08	2.18	16.8	65.7	17.5
26	Silty sand	4.7	7.3	.043	2.09	.19	.06	2.48	....	....	....
28	Mud	3.9	10.1	.055	4.40	.38	<.01	3.52	22.3	71.5	6.2
29	Sandy mud	8.3	4.1	.024	2.03	.36	.02	1.54	34.8	58.0	7.1
30	Mud	12.1	6.5	.034	3.26	.20	.09	2.73	6.0	62.0	32.0
31	do	8.5	3.6	.022	1.57	.43	.02	1.07	....	....	....
32	Sand	3.0	.3	.007	.02	.06	.01	.06	99.0	1.0	.0
33	Sandy mud	4.8	8.7	.043	3.46	.73	.04	3.14	34.2	49.5	16.3
35	Mud	6.8	8.8	.046	4.96	.47	.05	2.44	19.1	53.8	27.0
38	do	11.4	5.9	.034	2.94	.29	.13	2.49	17.8	58.3	23.8
40	Sandy mud	2.6	4.9	.024	2.26	.39	.02	1.48	38.7	38.6	22.6
43	Mud	9.4	8.4	.036	4.15	.13	.07	2.80	9.1	51.8	39.1
45	Silty sand	3.3	9.6	.069	5.44	.76	<.01	1.98	62.5	24.4	13.1
48	do	7.6	6.5	.049	3.24	.16	.03	1.23	66.9	23.6	9.5
49	do	6.6	5.0	.029	2.75	.15	.04	.98	62.1	26.1	11.8
52	Sand	6.8	1.4	.014	.45	.08	<.01	.10	99.1	.9	.0
53	do	2.8	.4	.008	.15	.07	<.01	.08	99.5	.5	....

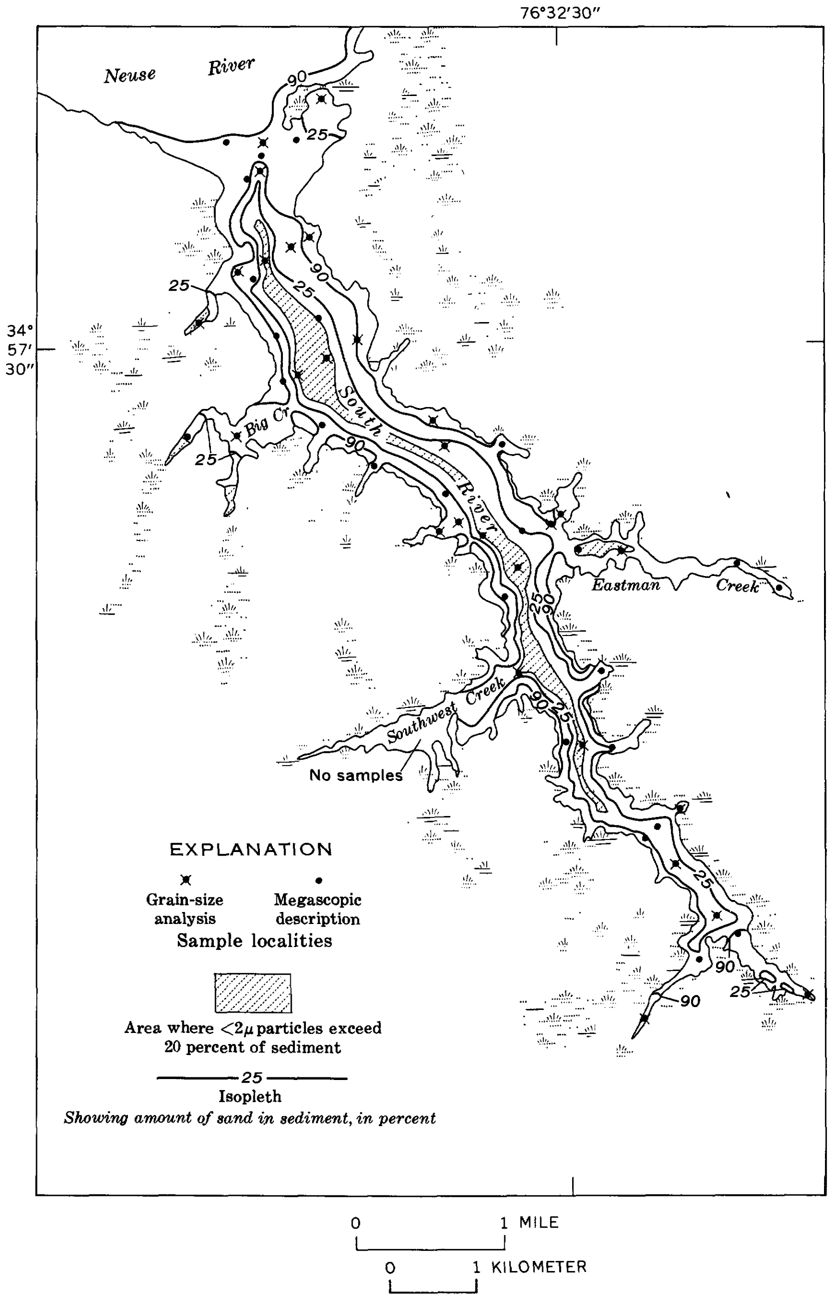

FIGURE 8.—Distribution of sediment by grain size in South River. For this report, clean sand contains more than 90 percent sand-sized grains; all other sediment is either muddy sand or sandy mud.

depressions along the longer tributaries to South River. All sediments are greenish gray except the sand, which is very light brown; the odor of hydrogen sulfide was evident in most samples at the time of collection.

The chemical composition was determined for 25 samples from South River by semiquantitative emission spectrographic analysis, and the results for six representative samples are given in table 8. No conspicuous anomalies were noted but, comparing the 20 spectrographic analyses of Jarrett Bay samples with the 25 of South River samples, Fe, Ti, Ba, Co, Cr, Cu, Mo, Ni, Pb, and V are significantly higher in the clayey silts and sandy mud from South River than in sediments of similar grain size from Jarrett Bay.

The heavy-mineral content of sediment from South River is similar to that of Jarrett Bay; concentrations ranged from 0.3 to 1.3 percent in the fraction <0.125 and >0.062 mm. Heavy minerals are most abundant in sands that form low sills across tributary channels.

ORGANIC AND RELATED MATERIALS

Organic carbon

In South River, as in Jarrett Bay, of all the sediment types the sand (sediment greater than 90 percent sand) has the lowest organic-carbon content — an average of 0.6 percent and a range of 0.1–1.4 percent (table 7). In contrast to Jarrett Bay, however, the rest of the sediment in South River is very poorly sorted, and the general increase in organic carbon with decrease in grain size noted in sediments in Jarrett Bay and in many other aquatic environments is very erratic in South River sediment. Rather, the amount of organic carbon in the bottom mud (sediment less than 50 percent sand) is related to geomorphic position in South River, here divided into the following three areas: (1) The mouth of the estuary, (2) the central linear part of the estuary where the water is more than 10 feet deep, and (3) the small tributaries. The mud near the mouth of South River (locs. 1, 3, and 6 in fig. 7) has a relatively very low organic-carbon content, which ranges from 1.2 to 2.7 percent and averages 1.9 percent. The organic-carbon content of mud along the central deep part of the bay averages 5.0 percent and ranges from 3.0 to 6.5 percent; in the tributaries it averages 9.2 percent and ranges from 5.2 to 12.9 percent.

Undoubtedly, a detailed study of the mud samples from the three areas would reveal significant differences in the type and state of decomposition of the organic matter that would explain the different averages of 1.9, 5.0, and 9.2 percent organic carbon in these muds. From megascopic descriptions those samples with the higher organic-carbon contents contained a variety of organic substances, including grass and tree-bark fragments, minute wood shreds, some living and dead mollusks, mainly clams, and flocculent organic material that has a consistency of "liver mud." None of these materials, however, seemed to predominate or be confined to one geomorphic area or sediment type, though wood fragments were observed in almost all tributary sediment samples.

TABLE 8.—*Emission spectrographic analyses of sediments from South River estuary*

[Analyst, G. W. Sears. Leaders (....) in figure columns indicate element not detected]

Element	Percentage of given element in sediment sample (Indicated are locality, shown in fig. 7; sediment type; and organic-carbon content, in percent)					
	Locality 3; sandy mud; 1.2	Locality 8; sand; 0.1	Locality 17; clayey silt; 3.9	Locality 38; clayey silt; 5.9	Locality 48; silty sand; 6.5	Locality 53; sand; 0.4
Si	>10	10	>10	>10	>10	>10
Al	7	3	>10	>10	7	2
Fe	3	2	>10	>10	5	.7
Mg	.7	.2	1.5	3	1	.15
Ca	1.5	1	1.5	2	2	.5
K	7	1.5	5	7	1.5	....
Ti	2	3	1.5	1.5	1	.5
Mn	.07	.07	.07	.07	.05	.015
B	.015	.007	.015	.02	.001	.007
Ba	.2	.1	.15	.3	.07	.07
Be	....	....	.0003	.0003	....	....
Co	.0007	....	.002	.002	.0007	....
Cr	.007	.0015	.01	.015	.003	.001
Cu	.007	.0007	.01	.015	.01	.007
Ga	.003	.001	.007	.007	.0007	....
La	.007	....	.01	.01	....	....
Mo	....	....	.001	.0015	.001	....
Nb	.002	.002	.002	.002	.002	.002
Ni	.001	.0007	.007	.007	.0015	.0007
Pb	.005	.003	.007	.007	.005	....
Sc	.002	.001	.003	.003	.0015	....
Sr	.03	.015	.03	.05	.015	.005
V	.007	.003	.015	.015	.005	.0015
Y	.003	....	.005	.003	.002	....
Yb	.0007	.0003	.0007	.0007	.0003	....
Zr	.5	.3	.1	.05	.3	.007

Mineral carbon

The mineral-carbon, or carbonate, content of the sediment, regardless of grain size, is relatively low; it averages less than 0.05 percent and ranges from less than 0.01 to 0.13 percent. There is no specific correlation between organic- and mineral-carbon contents but, on the average, the mud in the tributaries and in deeper water in the middle of the bay contains 0.01–0.03 percent more mineral carbon than the more sandy nearshore sediment. This probably is a result of there being slightly more shell fragments in samples from these areas.

Sulfur

The total sulfur in South River sediment ranges from 0.06 to 3.76 percent (table 7), and its distribution is somewhat analagous to that of organic carbon but not quite so clear cut as in Jarrett

Bay sediments. The sand contains an average of 0.28 percent total sulfur; and, as in the geomorphic areas described for organic carbon, the mud near the mouth of South River contains an average of 0.76 percent total sulfur; the mud along the central deep part of the bay, 1.94 percent; and the tributary mud, 3.08 percent.

Bitumen

The bitumen content of South River sediment clearly parallels the distribution of the organic carbon. In the six sand samples (table 7) the bitumen content averages 0.008 percent and ranges from 0.006 to 0.014 percent. The bitumen in the sediment, excluding the sand, also appears to be related to the three geomorphic positions in the estuary. The bitumen content of mud near the mouth of South River averages 0.018 percent and ranges from 0.017 to 0.021 percent. In the mud in the deeper water along the axis of the estuary, it averages 0.026 percent and ranges from 0.017 to 0.034 percent. In the tributary muds, which have the highest organic-carbon content and also the highest bitumen yield, the bitumen content averages 0.059 percent and ranges from 0.033 to 0.086 percent. In South River, bitumen, as determined on the basis of ratios of bitumen to organic carbon, consistently makes up about 0.3 percent of the organic matter in the mud but about 1 percent in the sand poor in organic matter.

Alkaline-soluble humic substances

The alkaline-soluble organic material in the bottom sediment of South River has a wide range in content, 0.06–5.88 percent, just as does the organic carbon in the sediment. These soluble organic substances constitute about one-fourth of the organic matter in the sediment, very similar to the amount of soluble humic substances derived from the organic matter in Jarrett Bay sediment. Because the pattern of distribution of alkaline-soluble humic substances almost exactly parallels that of organic-carbon content of sediments in South River (fig. 9), no separate map showing this distribution is included.

The soluble humic fraction makes up 70–97 percent of the alkaline-soluble organic material in South River sediment, except in the sand. The humic fraction in the six sand samples (table 7, Nos. 8, 16, 23, 32, 52, and 53) averages 57 percent of the alkaline-soluble material; these results, however, are possibly due to analytical error in analyses of sediment containing less than 1 percent organic carbon. For comparison, the humic fraction in the mud near the mouth of the estuary averages 72 percent of the soluble organic material; in the mud along the axis of the estuary, 87 percent; and in the tributary mud, 89 percent.

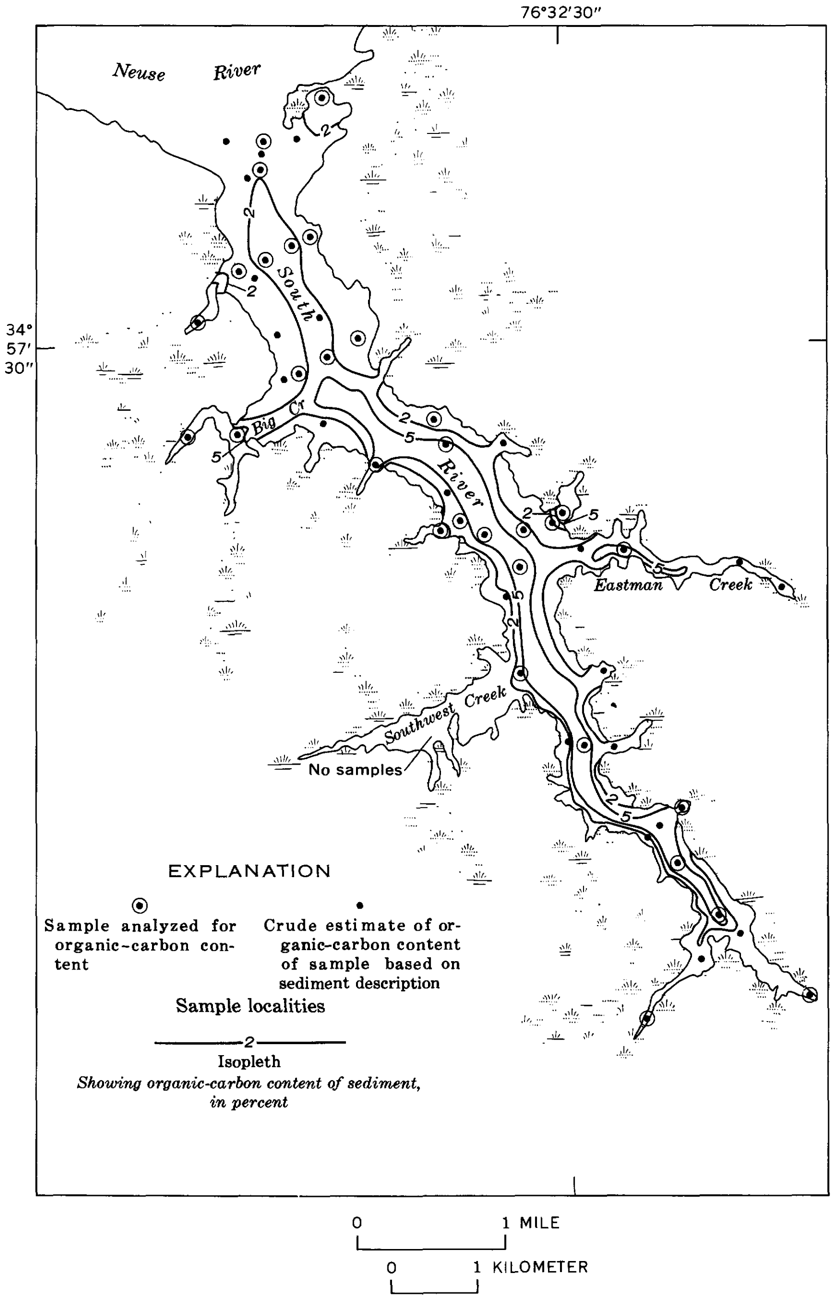

FIGURE 9. — Organic-carbon content, in percent, of sediment in South River.

Complete organic-element analyses of the humic fraction were made for three samples spaced from the upper reaches of South

River toward the mouth (table 9). The carbon content is almost identical in the three samples, the contents of hydrogen and nitrogen increase toward the mouth, and sulfur apparently decreases.

The amount of the fulvic fraction extracted from the sediment ranges from 0.04 to 0.76 percent. Highest concentrations are in sediment along the deepest part of the main channel of South River and in several of the tributary channels, and they correspond in general to the content of organic matter in the sediment.

A comparison of the organic-element composition of the fulvic fraction with that of the humic fraction (table 9) shows that the differences noted for Jarrett Bay also are evident for South River — for the fulvic fraction the carbon content is lower, the oxygen content is higher, and the amount of ash is considerably higher. Trace-element content of the ash of the fulvic and humic fractions was not determined for South River sediments.

TABLE 9.—*Organic-element composition, in percent, on ash-free basis, of soluble humic and fulvic fractions of sediments from South River*

[Analyses by Huffman Laboratories, Inc., Wheatridge, Colo.]

Locality (fig. 7)	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Carbon-hydrogen ratio	Ash
			Humic fraction				
17	57.17	5.11	32.00	4.34	1.37	11.2	15.33
35	57.66	4.59	32.76	3.80	1.17	12.6	12.72
48	57.97	4.30	31.92	2.84	2.95	13.5	6.68
Avg	57.6	4.7	32.2	3.7	1.8	12.4	11.6
			Fulvic fraction				
17	41.65	4.68	48.66	3.38	1.63	8.9	32.02
35	41.98	4.01	50.11	2.54	1.35	10.5	36.59
48	42.20	4.75	48.48	2.29	2.28	8.9	32.03
Avg	41.9	4.5	49.1	2.7	1.8	9.4	33.5

COMPARISONS AND CONCLUSIONS

The foregoing data and descriptions can be summarized and interpreted as follows in terms of the relationship of organic matter to the depositional environments:

1. The estuarine bottom sediments of both Jarrett Bay and South River are predominantly poorly sorted silt and fine sand that are mineralogically complex. The sand and silt content is consonant with the proximity and association of sediment types and distribution patterns in the river, the estuary, and the barrier-island environments of the Pamlico Sound area. Most of the organic matter in the bottom sediment of the two small estuaries is derived from plants in the large adjacent marsh areas and the predominantly pine and deciduous tree forests farther inland. The proportion of algal remains is unknown, though conspicuous "algal blooms"

were observed during summer field studies. Especially indicative of plants being the primary source of the organic matter was the medium- to dark-brown color of the water in the estuaries; the very dark water in the upper reaches of the bays and in the many broad-mouthed tributaries was very similar to the waters in many peat bogs and tidal marshes.

Faunal remains associated with the bottom sediments are closely related to the environment. Arenaceous Foraminifera are typical of bays along the inshore side of lagoons and the associated marshes; oyster shells and remains of other marine mollusks indicate the direct connection of Jarrett Bay to the saline lagoon water of Core Sound. Small brackish-water clams are relatively abundant in South River. The salinity of Jarrett Bay water ranges from 20 to 35 parts per thousand, and the salinity of South River water ranges from 12 to 20 parts per thousand.

It should be borne in mind that these two relatively small estuarine bodies of water lie but a few miles apart and are in many respects similar; they represent shallow estuarine extensions of broader environments in the interrelated and complex suite of depositional environments of the Pamlico Sound coastal area.

2. The amount of organic carbon in the upper 10–15 cm of sediment in Jarrett Bay and in South River averages 1.6 percent (51 samples) and 4.8 percent (31 samples), respectively. The higher content of organic carbon in the sediment of South River is probably best explained by the fact that South River is a narrower trough, separated from the Neuse River by a sand sill that partly prevents outflow of much of the suspended organic materials. Jarrett Bay, on the other hand, has a broad open mouth, and much of both the suspended and dissolved organic matter either entering the bay or generated in it is dispersed into Core Sound.

Generally, the percentage of organic carbon increases with decreasing grain size of sediment in both estuaries. In Jarrett Bay the sand, silty sand, and mud have average carbon contents of 0.4, 1.3, and 2.1 percent, respectively. This inverse correlation between organic-carbon content and grain size is markedly masked by geographic position of sediment in South River. This geographic control is best illustrated by the distinctly different organic-carbon content of the mud. The average organic-carbon content in mud is 1.9 percent near the mouth of South River, 5.0 percent along the axis of the bay, and 9.2 percent in the tributaries.

The sand forms the shallow-water sediment along the margins of both bay-type estuaries and generally contains 0.1–0.7 percent organic carbon. Even this small amount of organic matter in the sand produces an anaerobic environment, a few centimeters below the sediment-water interface, having a negative Eh and an odor of hydrogen sulfide. The water several centimeters above mud rich in organic matter also can be reducing, even in water less than 3 feet (1 m) deep.

No attempt is made here to relate the organic-carbon content of Jarrett Bay and South River sediment to that of recent sediment in many other depositional environments. It is interesting to note, however, that the carbon values for sediment types reported here are comparable to those reported for the much larger Choctawhatchee Bay estuary in northwest Florida, where the average organic-carbon content is 0.15 percent in sand and 3.6 percent in mud (James G. Palacas, written commun., 1970).

3. A high content of alkaline-soluble humic substances characterizes the sediment of both the Jarrett Bay and South River estuaries and indicates the large contribution of plant material from surrounding marsh and forest areas, relative to a low contribution of animal material. In South River, for example, sediment that has an organic-carbon content of more than 5 percent (14 samples, range of 5.2–12.9 percent) has a relatively low average bitumen content (0.048 percent), but the alkaline-soluble organic matter averages 3.9 percent. In the same samples, the soluble humic fraction makes up an average of 91 percent of the alkaline-soluble organic material, and the fulvic fraction 9 percent. Similar relations would hold for a similar set of Jarrett Bay sediment samples, though all Jarrett Bay values would be about one-half those presented in the South River example. Thus, a high content of alkaline-soluble organic material, having an exceptionally high humic fraction, and a relatively low bitumen content are characteristic of these two marsh-bordered estuarine environments.

The data on samples from Jarrett Bay show a trend of increase in the proportion of the fulvic fraction, compared to the soluble humic fraction, from north to south. At the head, or north end, of Jarrett Bay, the fulvic fraction is 8 percent of the total alkaline-soluble organic matter, and the percentage increases to 43 percent at the mouth of the estuary. The logical explanation for this trend is that the more soluble organic material, represented by the fulvic fraction, is transported farthest before precipitation and deposition.

4. The organic-element compositions of the extracted humic and fulvic fractions from both estuaries are quite different in several respects. The average composition of the humic fraction from Jarrett Bay sediment, in percent on an ash-free basis, is 54.8 C, 5.9 H, 33.3 O, 4.0 N, and 2.0 S; for South River, the average composition is 57.6 C, 4.7 H, 32.2 O, 3.7 N, and 1.8 S. The slightly lower carbon content and higher hydrogen content of the humic fraction from Jarrett Bay are the obvious differences, but neither of these compositions is significantly different from those of humic fractions reported for other areas. (See Swanson and Palacas, 1965, table 3; Palacas and others, 1968, table 2.) One apparently significant observation can be made, however, on the change in composition of the humic fraction from headwaters to the mouth of both estuaries — namely, a very slight decrease in carbon content and an increase in hydrogen content.

   Typically, the composition of the fulvic fraction greatly differs from that of the humic fraction, primarily in having a much lower carbon content and correspondingly higher oxygen content. The twofold difference in percentage of ash (see table 5) between the humic fraction (15.6) and fulvic fraction (30.8) is considered a result of the laboratory method used and thus is not of geochemical significance. The average composition of the fulvic fraction extracted from Jarrett Bay sediment, in percent on an ash-free basis, is 41.9 C, 5.5 H, 47.3 O, 4.3 N, and 1.0 S; for South River, the average composition is 41.9 C, 4.5 H, 49.1 O, 2.7 N, and 1.8 S.

   As in other areas, the soluble humic and fulvic fractions show concentration of certain metals. Analyses of the ash of these fractions from Jarrett Bay sediment show that the following metals are significantly concentrated: Ag, Co, Cr, Cu, Mo, Ni, Pb, Sn, and V. No comparable data were obtained on South River samples, but probably a similar suite of metals would be shown to be concentrated in the alkaline-soluble organic substances from South River sediment as well.

5. The clay minerals from the two areas represent two distinct suites which may indicate two different source areas involved in the delivery of clay minerals to the two areas. The clay minerals in sediments of Jarrett Bay probably are similar to those in sediment of the barrier islands which is transported

from the north by longshore currents in the Atlantic Ocean; clays in sediments of South River probably come principally from the Neuse River effluence whose drainage lies within the Piedmont and Coastal Plain physiographic provinces of North Carolina. As also shown by the differences in the macrofaunas, the marked difference in the clay-mineral suites of the two areas indicates the dissimilarities that can occur between two closely spaced estuarine environments in the Pamlico Sound coastal area.

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