

GEOLOGY OF ORGANIC-RICH MUD
IN SLOCUM AND HANCOCK CREEKS,
CRAVEN COUNTY, NORTH CAROLINA

by

Thomas Anthony Duque

APPROVED BY:

THESIS COMMITTEE

Pei-lin Tien

Dr. Pei-lin Tien, Supervising Professor

Michael P. O'Connor

Dr. Michael P. O'Connor

Stanley R. Riggs

Dr. Stanley R. Riggs

C. Q. Brown

Dr. C. Q. Brown

CHAIRMAN OF THE DEPARTMENT OF GEOLOGY

Michael P. O'Connor

Dr. Michael P. O'Connor

DEAN OF THE GRADUATE SCHOOL

Joseph G. Boyette

Dr. Joseph G. Boyette

GEOLOGY OF ORGANIC-RICH MUD
IN SLOCUM AND HANCOCK CREEKS,
CRAVEN COUNTY, NORTH CAROLINA

A Thesis

Presented to

the Graduate Faculty of the Department of Geology

East Carolina University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Geology

by

Thomas Anthony Duque

May, 1978

J. Y. JOYNER LIBRARY
EAST CAROLINA UNIVERSITY

QE
148
SS
D8x

A B S T R A C T

Slocum and Hancock creeks are parallel, northward draining tributaries of the Neuse River estuary and are located 20 and 25 (12.4 and 15.5mi) km. respectively, southeast of New Bern, North Carolina. The northern-most portions of both creeks are embayed as a result of rising sea level during the Holocene transgression.

Bottom sediments in these embayed tributaries consist primarily of dark brown to black, slightly sandy, strongly odoriferous organic-rich mud. The thickness of the mud increases downstream and away from the shoreline but decreases near the mouths of the creeks, delineating restricted, elongate basins of deposition. Accumulations of mud in excess of 6 m (19.7 ft.) are common in both creeks and maximum accumulations are thought to exceed 7 m (23 ft.). The mud is underlain by a relatively hard sandy substrate. The distribution and thickness of the mud is controlled by the topography of this pre-mud, sandy surface.

The sand fraction of the mud consists of moderately to well sorted, fine to very fine sand and averages 5% by weight. Organic matter in the mud averages 16% by weight and increases with depth and with distance upstream.

X-ray diffraction analysis of the clay fraction of the mud indicates that kaolinite and dioctohedral vermiculite are the dominant clay minerals in the lower reaches of both creeks, but that their relative abundance decreases rapidly upstream. Smectite and illite are present in minor amounts in the lower reaches and also decrease in abundance upstream, but at slower and more constant rates than kaolinite and

dioctohedral vermiculite.

Bottom sediments in the adjacent Neuse River estuary constitute the chief source of the mud present in Slocum and Hancock creeks.

Shallow bottom sediments in the river are re-suspended by intense wave action and vertical mixing and are carried into the creeks by wind tides that raise the water level in the river. The protected and relatively quiescent waters of Slocum and Hancock creeks allow the trapped suspended load to settle out on the bottom of the creeks.

Shoreline erosion in the two creeks is not widespread, and the contribution of eroded bank strata to the bottom sediment is minor.

A C K N O W L E D G M E N T

I am sincerely indebted to Dr. Pei-lin Tien, who introduced me to and tutored me in clays, served as my thesis advisor, and faithfully supported my efforts in this study. I am grateful to Drs. Stanley R. Riggs and Michael P. O'Connor whose encouragement is appreciated, and I thank Dr. C. Q. Brown for his suggestions.

Partial funding for this study was provided by a grant from the Institute of Coastal Marine Resources, East Carolina University.

Many thanks to my friend, Scott Hartness for his assistance in the field. I would also like to thank the many people at the United States Marine Corps Air Station, Cherry Point for making my field work pleasurable. Special thanks to Steve Benton for the use of his fine personal library.

Lastly, I thank my wife, Leigh, for her continuous support and patience, and for the home and family "in waiting" that I at last will have time to enjoy.

CONTENTS

	Page
INTRODUCTION.....	1
THE NEUSE RIVER DRAINAGE BASIN.....	5
Geologic Setting.....	5
Hydrologic Setting.....	5
THE SLOCUM-HANCOCK REGION.....	8
Geologic Setting.....	8
Hydrologic Setting.....	10
PREVIOUS CLAY MINERALOGIC INVESTIGATIONS.....	12
Neuse River Drainage Basin.....	12
Neuse River-Estuary and Pamlico Sound.....	13
BOTTOM SEDIMENTS IN SLOCUM AND HANCOCK CREEKS.....	15
Distribution.....	15
Composition.....	21
Sand content.....	21
Organic content.....	24
Clay minerals.....	26
Quantification.....	27
Distribution.....	28
DISCUSSION.....	31
SUMMARY AND CONCLUSIONS.....	37
SUGGESTIONS FOR FURTHER RESEARCH.....	38
REFERENCES.....	39
APPENDICES.....	43
Appendix A: Field Methods.....	43
Appendix B: Laboratory Procedures.....	46
Appendix C: Identification of Clay Minerals by X-ray Diffractometry.....	50
Appendix D: Presentation of Raw Data.....	53

TABLES

<u>Table</u>	Page
1. Hydrologic character of the Neuse River west of New Bern...	6

<u>Table</u>	Page
2. Susceptibility of estuarine shoreline types to erosion.....	34
3. Field data.....	53
4. Laboratory data.....	53
5. Clay minerals in channel samples.....	54

ILLUSTRATIONS

<u>Figure</u>	Page
1. Regional location map.....	2
2. Study area location map.....	4
3. Discharge rates for the Neuse River.....	6
4. Location of probing traverse, channel samples, and cores, Slocum Creek.....	16
5. Location of probing traverses, channel samples, and cores, Hancock Creek.....	17
6. Structure contour map of the pre-mud surface in Slocum Creek.....	in pocket
7. Structure contour map of the pre-mud surface in Hancock Creek.....	in pocket
8. Relationship of bank strata, sandstrip, and mud.....	18
9. Sequence of infilling of Slocum and Hancock creeks.....	19
10. Isopach map of the mud in Slocum Creek.....	in pocket
11. Isopach map of the mud in Hancock Creek.....	in pocket
12. Typical cross sections in Slocum and Hancock creeks.....	20
13. Sand and organic content of the mud in Slocum and Hancock creeks.....	23
14. Clay mineral distribution in Slocum, Tucker, Hancock, and Cahoon creeks.....	29
15. Laboratory flow chart.....	46

INTRODUCTION

Throughout the Pleistocene, eastern North Carolina was under the influence of a series of marine transgressions and regressions resulting from the pulsating glacial advances and retreats. The present configuration of North Carolina's coastal zone was developed by events and processes taking place in the 35,000 years since the beginning of the most recent cycle of glaciation. At that time, sea level was very nearly at its present level (Bellis, O'Connor, and Riggs, 1975). As sea level dropped in response to advancing Wisconsin ice sheets, Coastal Plain sediments deposited during previous interglacial periods were subjected to subaerial erosion. Between 18,000 and 15,000 years B. P. (Riggs and O'Connor, 1974), eustatic sea level rise in response to melting glacial ice, resulted in the progressive inundation of Coastal Plain river systems and the formation of North Carolina's estuarine system (Figure 1).

Numerous tributaries empty into the main or trunk estuaries. The embayed portion of these tributaries form the lateral estuaries and are also the result of the Holocene transgression which continues today, with sea level rising at an estimated 0.1 m/century (Riggs and O'Connor, 1974). As inundation continues, the progressively broadening estuaries and their embayed laterals serve as settling basins for incoming sediment. A recent study of the sediments in the Pamlico River estuary (Hartness, 1977) indicates that the embayed laterals of the Pamlico River have accumulated sediments that are mineralogically and texturally similar to those in the main river. Although the sediments in the

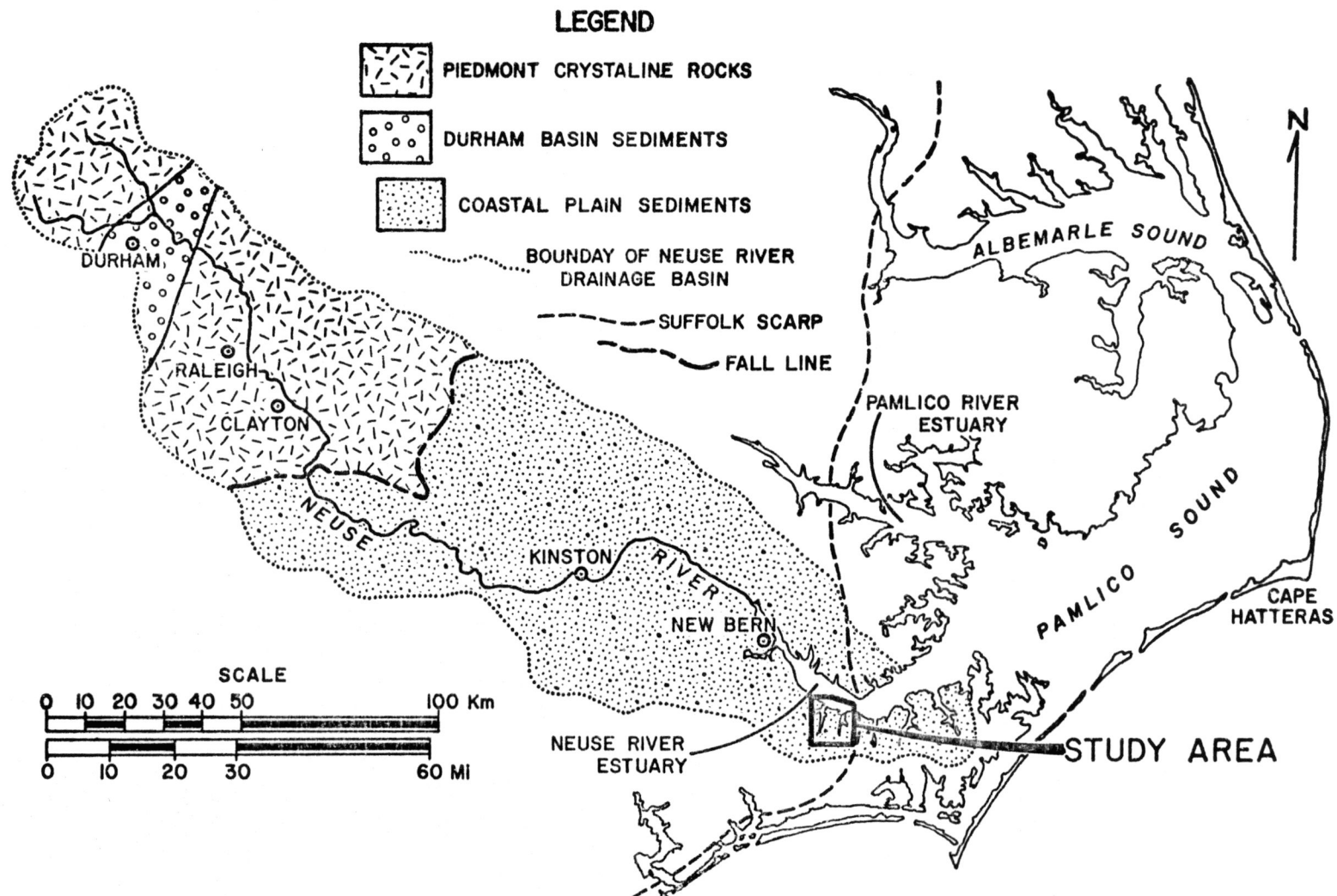


Figure 1. Regional location map.

trunk estuaries have been the subject of several investigations, the sediments within their embayed lateral estuaries have been widely neglected.

Slocum and Hancock creeks are parallel, northward draining, embayed tributaries flowing into the Neuse River estuary 20 and 25 km (12.4 and 15.5 mi.), respectively, southeast of the city of New Bern, North Carolina (Figure 2 on page 4). Field investigations of the creeks made by the author in December, 1975, and in the spring of 1976, revealed that the bottom sediment was primarily a brown to dark gray, slightly fossiliferous, silty to sandy, organic-rich mud, and that the mud varied in thickness and was underlain by a relatively hard, sandy substate. The primary objectives of this study were: 1) to map the vertical and lateral distribution of the mud in Slocum and Hancock creeks; 2) to characterize the sediment types in the two creeks, especially with respect to the clay minerals; and 3) to consider the potential source areas for the mud in the two creeks.

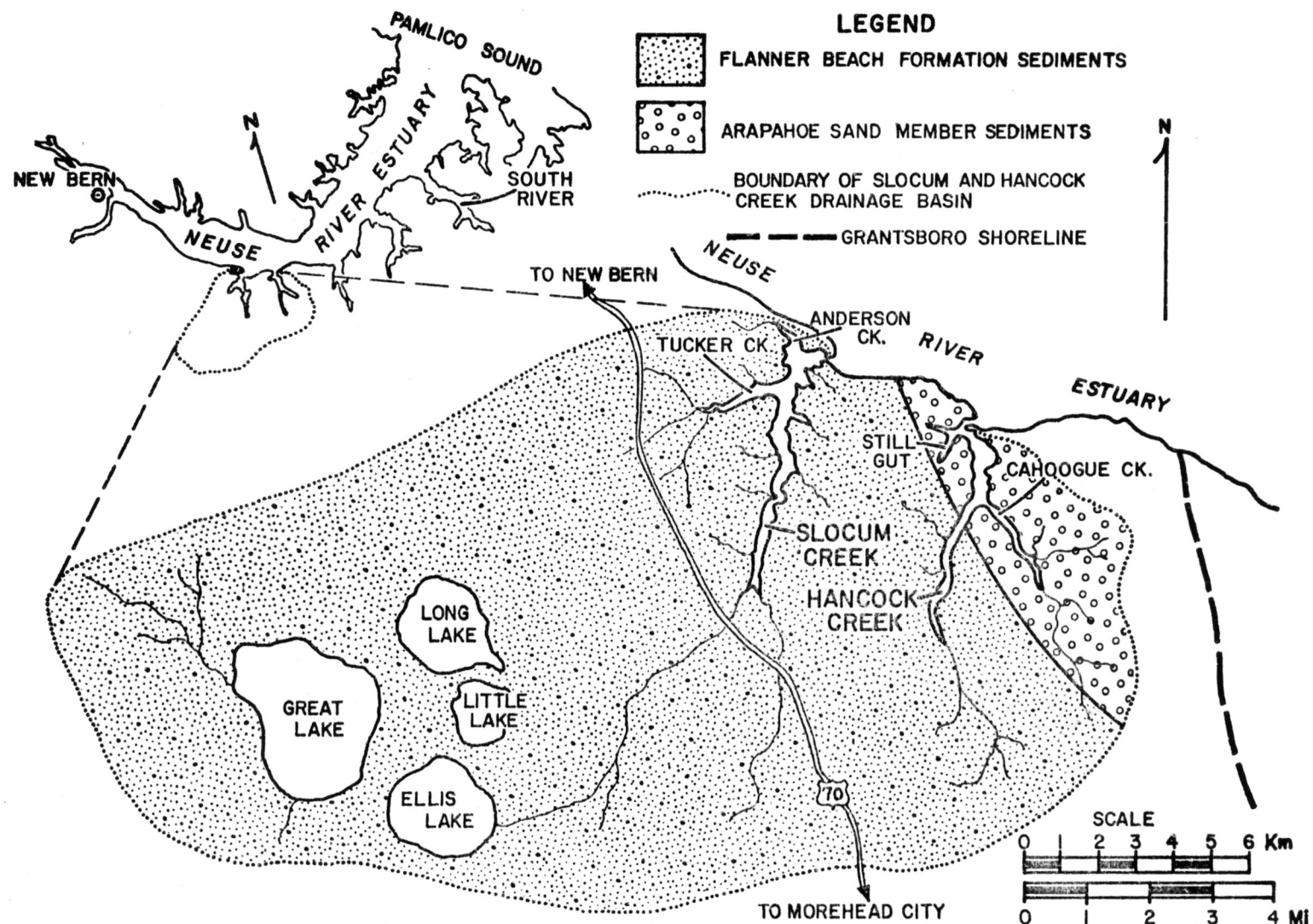


Figure 2. Study area location map (modified from Mixon and Pilkey, 1976).

THE NEUSE RIVER DRAINAGE BASIN

Suspended sediments in the Neuse River and its estuary constitute a potential source of the sediments deposited in the embayed estuaries of Slocum and Hancock creeks. For this reason, a description of the Neuse River drainage basin is necessary.

The Neuse River drains an area of over 16,000 km² (6,170 mi²) (Hobbie and Smith, 1975) and flows for a distance of approximately 320 km (200 mi) from its headwaters at the confluence of the Flat and Eno rivers, northeast of Durham, North Carolina, to the Pamlico Sound (Figure 1). The lower 73 km (45 mi) (from 8 km west of New Bern to the Pamlico Sound) is embayed and is referred to as the Neuse River estuary. Elevations within the drainage basin range from 290 m (950 ft.) to sea level.

GEOLOGIC SETTING

The Neuse River rises west of the Fall Line that marks the boundary between the Piedmont Province to the west and the Coastal Plain Province to the east (Figure 1). Rock types of the Piedmont exposed in the Neuse River drainage basin consist predominantly of highly weathered crystalline rocks (saprolites), and partly of Triassic claystones, siltstones, sandstones, and conglomerates found within the Durham Basin. East of the Fall Line, the Neuse River drains Cretaceous, Tertiary, and Quaternary sediments which comprise the Coastal Plain.

HYDROLOGIC SETTING

The hydrologic character of the Neuse River west of New Bern, North

Carolina, is summarized in Table 1. Discharge rates in the Neuse

USGS station # and location	discharge rate (m ³ /sec)	Ph	dissolved O ₂ (mg/l)	suspended sed. (mg/l)	range in temp. (°C)
02087500 near Clayton	33.6 49 yr. avg.	6.4	8.1	14.0	2.3-28.0 (in 1976)
02089500 Kinston	81.9 46 yr. avg.	6.7	9.1	28.6	2.5-28.0 (in 1976)

Table 1. Hydrologic character of the Neuse River west of New Bern, North Carolina. See Figure 1 for station locations (from U. S. Geol. Survey, Water-Data Rep. NC-76-1, 1977).

River (Figure 3) show that, although rainfall is evenly distributed in

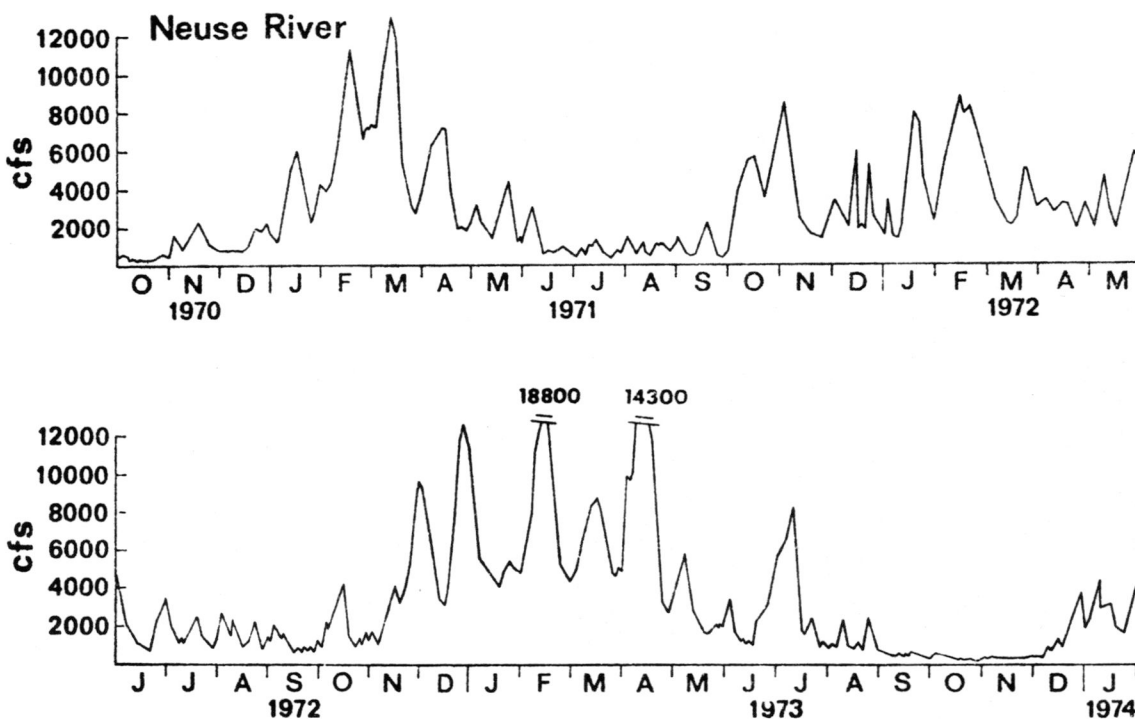


Figure 3. Discharge rates for the Neuse River at Kinston, North Carolina (from Hobbie and Smith, 1975).

the drainage basin over the entire year (Hobbie and Smith, 1975), flow in the Neuse is normally low in the summer and high in the late fall and winter. The low flow is caused by high evapotranspiration rates which greatly reduce run off during the summer and early fall (Hartness, 1977).

The Neuse River estuary is a dogleg-shaped, oligohaline water body extending from 8 km (5 mi) west of New Bern, North Carolina, to Pamlico Sound (Figure 2). Average water depths range from 3.0 m (9.8 ft.) in the upper reaches to 6.0 m (19.7 ft.) in the lower reaches. Annual temperature ranges from 0.5 to 35°C (Hobbie and Smith, 1975). Flow dynamics during the low flow period (Knowles, 1975) indicate that circulation in the estuary is complicated and slow (net flow rate: 1.81 cm/sec, or 0.75 in/sec). Although it is generally accepted that lunar tidal fluctuation is less than 15 cm (6 in), wind tides can cause fluctuations of up to 1.3 m (4.3 ft) above normal at New Bern (Knowles, 1975). Circulation in the Neuse River estuary is also controlled by wind tides.

Salinity in the Neuse River estuary is controlled primarily by the amount of inflowing fresh water. During periods of high flow, the western half of the estuary is dominated by low brackish water and the maximum salinity is 6 or 7‰ at the mouth of the estuary, while during low flow periods, salinities range from 2 to 3‰ at the west end to 20‰ at the mouth of the estuary (Hobbie and Smith, 1975). Surface and bottom salinity data indicate that vertical salinity stratification occasionally occurs during the late summer (Schwartz and Chestnut, 1973). Stratified conditions occur when physical mixing caused by winds is absent. This condition may last for several weeks if the weather is calmer than normal (Hobbie and Smith, 1975).

THE SLOCUM - HANCOCK REGION

Slocum and Hancock creeks are parallel, northward draining tributaries of the Neuse River estuary. Their combined drainage basins cover an area of approximately 290 km^2 (110 mi^2) (Figure 2), with Slocum Creek draining more than three-fourths of the area. A total of 21.1 km (13.1 mi), of embayed lateral tributary are included in this study; 8.7 and 12.4 km (5.4 and 7.7 mi) in the Slocum and Hancock creek drainage basins, respectively.

GEOLOGIC SETTING

The surface sediments of the Coastal Plain in North Carolina were deposited during higher Pleistocene sea levels and consist of a thin blanket of marine and estuarine sands and clays. The surficial expression of these Pleistocene sediments is a series of terraces and scarps which are related to previous shoreline locations. Slocum and Hancock creeks are located approximately 10 and 5 km (6.2 and 3.1 mi), respectively, west of the Grantsboro shoreline, the southern and topographically lower extension of the Grantsboro scarp (Mixon and Pilkey, 1976) (Figure 2). The Grantsboro Scarp is a part of the more extensive Suffolk scarp (Figure 1) which formed during the Sangamon Interglacial about 100,000 years ago (Bellis, O'Connor, and Riggs, 1975). The Suffolk scarp separates the topographically higher Talbot terrace to the west from the lower Pamlico terrace to the east. Elevation within the Slocum-Hancock drainage basin averages 7.6 m (25 ft), with a maximum elevation of 12.5 m (41 ft) in the southwestern portion of the Slocum Creek drainage basin. Relief adjacent to Slocum Creek, where bank heights commonly

exceed 3.5 m (11.5 ft), is generally higher than that adjacent to Hancock Creek, where banks rarely exceed 1.5 m (4.9 ft.).

Pleistocene sediments exposed in the Slocum-Hancock region have been given four different formational names: Pamlico, Talbot, Flanner Beach, and Neuse (Stephenson, 1912; Richards, 1950; Dubar and Solliday, 1963; Fallaw and Wheeler, 1969). Lithologically, these sediments have been described similarly by all workers. The following description of the Flanner Beach Formation, summarized from Dubar, Solliday and Howard (1974), is exemplary of the descriptions of the exposed sediments in the western and southeastern portions of the Slocum-Hancock region (90% of the combined drainage basin) (Figure 2).

Facies within the Flanner Beach Formation are subtle and complex. Most facies consist of very fine to fine sands with minor amounts of medium to very coarse sand, and contain from 10 to 40 percent silt and clay. Mica, phosphatic grains, and heavy minerals are minor components of most facies. Calcium carbonate, 20 percent or more of some facies, is in the form of invertebrate fossils. Generally, lower beds are massive and commonly mottled, while upper beds commonly display faint, fine cross-stratification. Some upper units are composed of alternating thin layers of fine sand and clay, and contain no calcareous fossils. Most of the strata are only very slightly indurated. Weathered sediments range in color from yellowish-orange through reddish-brown. Unoxidized sediments are bluish-gray, olive gray or dark greenish-gray. With few exceptions, sorting is poor to very poor. Those units with the highest silt-clay content are the most poorly sorted. Pelecypods and gastropods are the most abundant invertebrate fossils. Mulinia lateralis and Nuculana acuta comprise 80 to 95 percent of the pelecypods of most samples, while 75 to 95 percent of most gastropod assemblages consist of Retusa canaliculata, Turbonilla interrupta, and Crepidula fornicata.

The following description of the Araphoe sand member, the easternmost facies of the Flanner Beach Formation (Mixon and Pilkey, 1974) is exemplary of the descriptions of the sediments in the northeastern portion of the Slocum-Hancock region (10% of the combined drainage basin) (Figure 2).

The Arapahoe sand member consists of fine to coarse, moderately to well-sorted, commonly crossbedded quartz sand. The western part includes more poorly sorted, siltier sands and overlaps or interfingers with clayly and silty sands and silt of the Beard Creek member of the Flanner Beach Formation.

HYDROLOGIC SETTING

Slocum and Hancock creeks are typical of black water creeks that rise and flow entirely within the Coastal Plain. Such creeks are noted for their clear, dark colored waters. Due to their low gradients and the low forested topography within their drainage basins, Slocum and Hancock creeks carry very little suspended load during normal flow conditions. Waters in the upper reaches were never observed to be turbid. The creeks were not investigated during extremely high discharge periods. It would be expected, however, that suspended loads in the upper reaches would be high and waters would be turbid during such periods since most erosion of upland areas takes place during periods of high precipitation (Riggs, 1974). The dark color of the water in the upper reaches is due to the presence of organic acid derived from the decomposition of organic matter within the drainage basin.

In the lower reaches of both creeks, waters periodically exhibit significant turbidity. Since the suspended sediment content is negligible during normal flow periods, the turbid conditions observed in the lower, more embayed reaches of the two creeks are explained by two processes. Reconnaissance salinity measurements indicate that the salinities for the lower reaches of the two creeks are similar to those reported for the adjacent portions of the Neuse River estuary. In August of 1976, salinity levels of 7‰ were measured in the lower reaches

of both creeks and in the Neuse River estuary between the two creeks. These measurements indicate that, during periods of high wind tides on the south side of the Neuse River estuary, a pressure head is created at the mouths of the creeks and considerable turbid water flows into Slocum and Hancock creeks from the Neuse River estuary. Turbid conditions also exist when storms re-suspend some of the fine fraction of the bottom sediments. These processes will be discussed in more detail later.

Water depths in the two creeks range up to a maximum of 3.3 m (10.8 ft) (near the mouths of the creeks) and average 1.6 m (5.2 ft). Water level fluctuations during normal flow periods range 0.3 m (1 ft) above and below mean water level and are attributable to wind tides. Notations on navigation chart No. 11552 (1975) of the National Ocean Survey show that the lunar tidal fluctuation in the adjacent Neuse River estuary is less than 15 cm (6 in).

P R E V I O U S C L A Y
M I N E R A L O G I C
I N V E S T I G A T I O N S

The clay mineralogy of the organic-rich mud in Slocum and Hancock creeks has never been studied. Berryhill, Swanson, and Love (1972) report that organic-rich bottom sediments in the genetically similar, although more saline (12 to 20%.) South River (Figure 2) contain, in order of decreasing abundance, kaolinite, illite, and aluminum-vermiculite. They believe that the poorly sorted, muddy bottom sediments in the South River are mainly derived from the complex metamorphic rocks of the Piedmont and sedimentary Tertiary formations in the central and eastern Coastal Plain. Hartness (1977) reports that the organic-rich mud in the embayed lateral tributaries of the Pamlico River estuary contains kaolinite and dioctohedral vermiculite, with relatively lesser amounts of smectite and illite.

Other relevant clay mineralogic investigations include: 1) those which deal with exposed rocks and sediments within the Neuse River drainage basin; and 2) those which consider bottom sediments of the Neuse River, its estuary, and of Pamlico Sound.

NEUSE RIVER DRAINAGE BASIN

Soils resulting from residual weathering of the Piedmont crystalline rocks contain high concentrations of kaolinite and dioctohedral vermiculite and lesser amounts of illite (Rich and Cook, 1963; Leith and Craig, 1965; Neiheiseland and Weaver, 1967; Leo, Pavich, and Obermeier, 1977). Illite and Smectite are the dominant clay minerals in the sediments of the Durham Basin, with kaolinite being of secondary

importance (Brown and Ingram, 1954).

Smectite and varying amounts of illite, kaolinite, and chlorite comprise the great majority of the clay minerals in the Coastal Plain (Reves, 1956; Dubar and Solliday, 1963; Heron and others, 1964; Heiheisel and Weaver, 1967; Dubar, 1971). In the immediate vicinity of the Slocum-Hancock drainage basin, Dubar and others (1974) report that clay minerals within exposed sediments along the south bank of the Neuse River estuary consist predominately of smectite with minor amounts of illite, kaolinite, and chlorite.

NEUSE RIVER-ESTUARY AND PAMLICO SOUND

Brown and Ingram (1954) studied the clay minerals in the Neuse River bottom sediments west of New Bern. They found that kaolinite was by far the most abundant but decreased in abundance downstream. Varying but lesser amounts of illite and smectite, and even smaller concentrations of chlorite also occur. Hathaway (1972), however, found no chlorite in the Neuse River. A chlorite-like clay mineral was also reported by Brown and Ingram (1954) and was later identified as vermiculite (Brown, 1959). Hathaway (1972) similarly indicates the presence of vermiculite in the Neuse River.

Clay minerals in the bottom sediments of the Neuse River estuary include kaolinite, dioctohedral vermiculite, smectite and minor amounts of illite. Kaolinite is the dominant clay and decreases in abundance downstream, while smectite and illite show an increase in abundance downstream. (Griffin and Ingram, 1955; Hathaway, 1972). Similar distribution trends have been reported for the Pamlico River estuary (Figure 1) (Allen, 1964; Hartness, 1977; Park, 1971; Pevear, 1972). Griffin and

Ingram (1955) attribute these trends to diagenetic changes in response to increasing salinity downstream, but Weaver (1958) suggests that different sources of detrital clay could explain the distribution of clays in the Neuse River estuary.

Clay minerals in the bottom sediments of the Pamlico Sound (Figure 1) are mainly dioctohedral vermiculite and illite, with lesser amounts of smectite, kaolinite, and minor amounts of chlorite (Dobbins, Ragland, and Johnson, 1970; Edzwald, 1972; Hathaway, 1972).

B O T T O M S E D I M E N T S I N
S L O C U M A N D H A N C O C K
C R E E K S

DISTRIBUTION

Methods used to map the distribution and thickness of the bottom sediments in Slocum and Hancock creeks are in Appendix A. Data obtained by this simple probing technique are accurate and demand little interpretation for use in the production of isopach and structural contour maps. The locations of probing traverses made in the two creeks are shown in Figures 4 and 5. In addition to the primary traverses made, minor tributaries in both creeks were routinely probed as far upstream as they were navigable. The boat used during the field phase of the study was restricted by the Marine Corps from entering the upper reaches of Slocum Creek because of "treacherous shoaling" resulting from the effluence of a water treatment plant; consequently, the upper 3 km (1.9 mi) of Slocum Creek are not included in this study.

The mud in both creeks is underlain by a relatively hard, sandy substrate which represents the surface that existed in both creeks prior to the deposition of the mud. The topography of the pre-mud surface in Slocum and Hancock creeks is shown in Figures 6 and 7 (in pocket), respectively. This topography is primarily a subsurface extension of the present drainage.

Except in portions of the upper reaches of Hancock and Cahoogue creeks, the mud rarely occurs immediately offshore. There is almost always a narrow (1 to 15 m) strip of fine to medium, slightly silty sand between the shoreline and the mud. This strip of sand results from the erosion of adjacent Pleistocene bank strata. The sand remains in

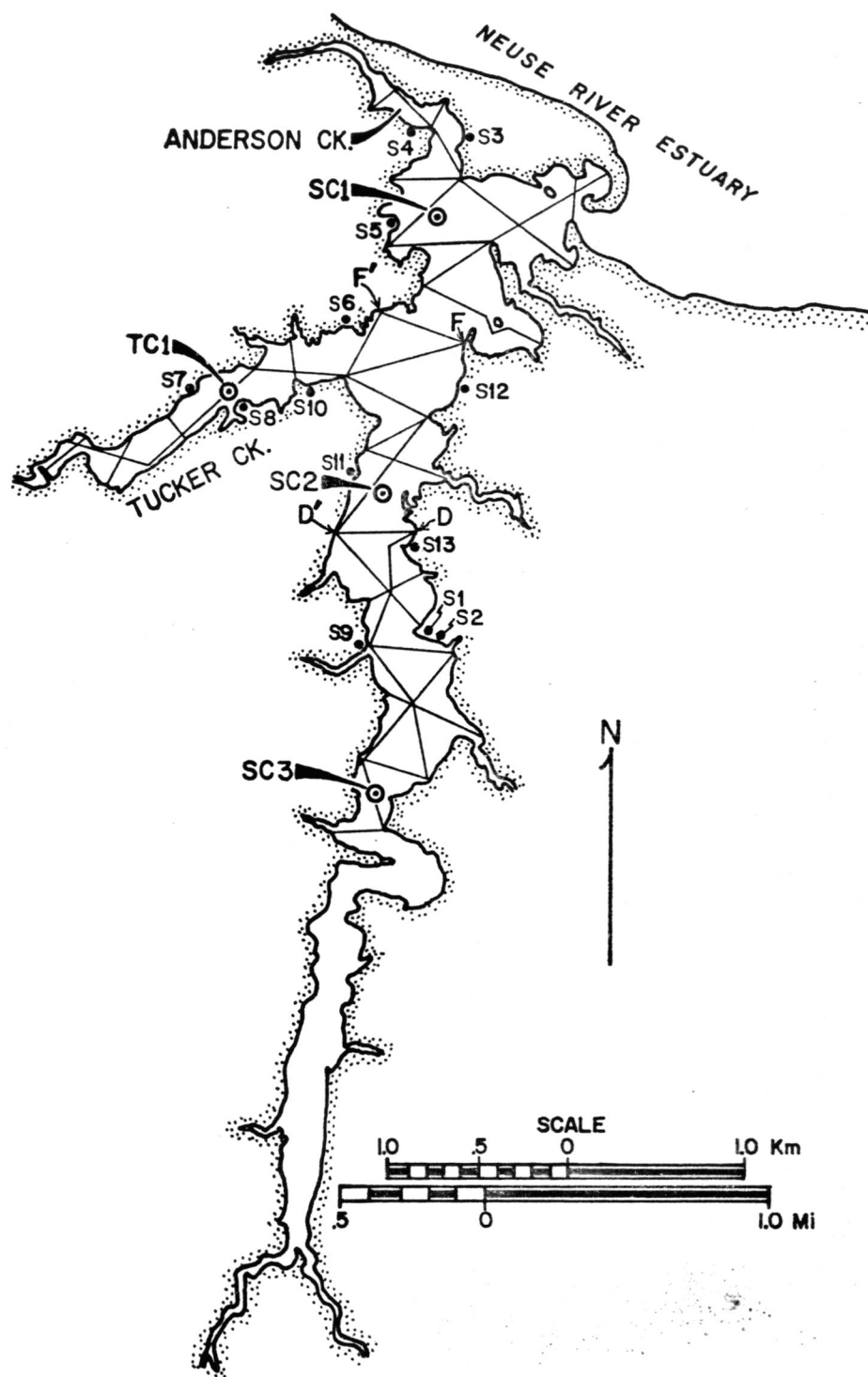


Figure 4. Slocum Creek location map. SC1, SC2, SC3 and TC1 are core samples. S1 through S13 are bank channel samples. D'-D and F'-F are traverses shown in Figure 10.

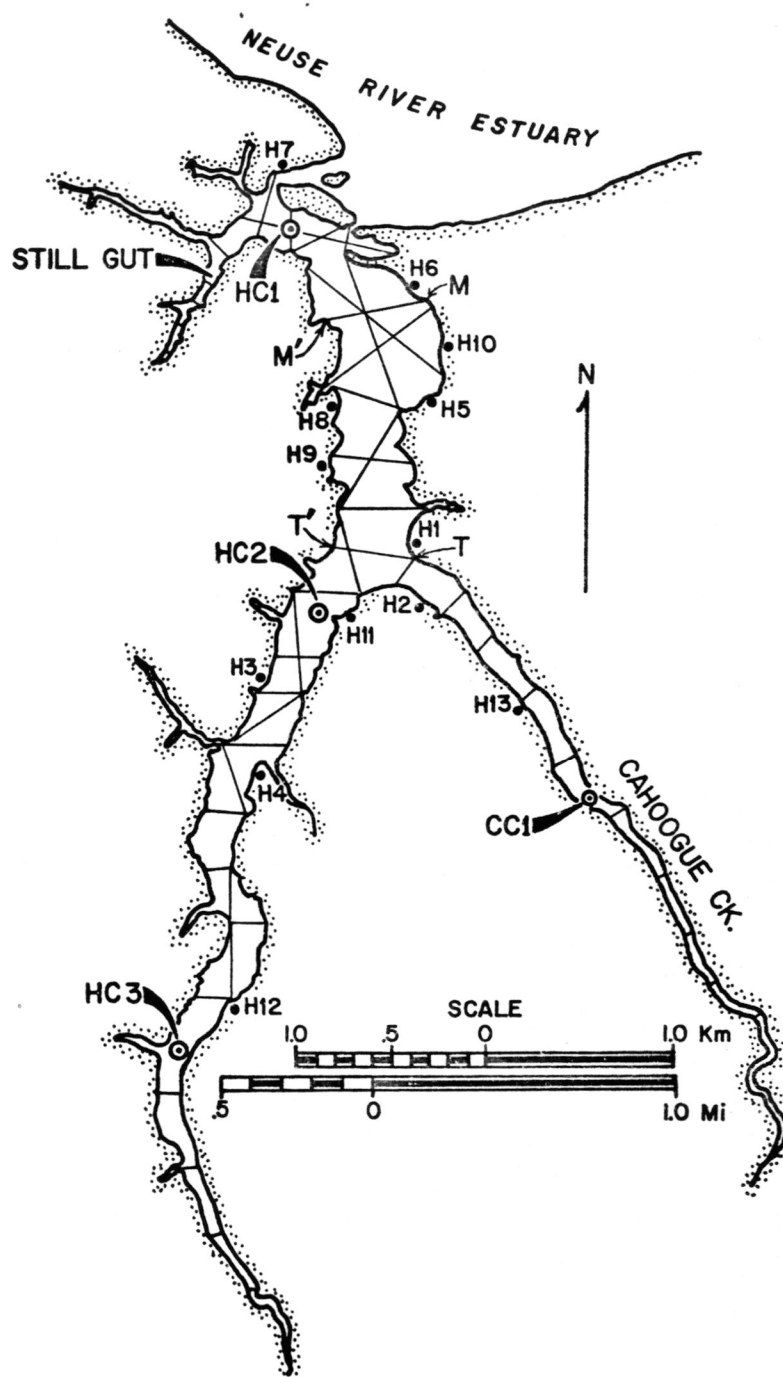


Figure 5. Hancock Creek location map. HC1, HC2, HC3 and CC1 are core samples. H1 through H13 are bank channel samples. M-M' and T-T' are traverses shown in Figure 10.

the relatively higher energy near shore zone, while most of the silt and clay fractions are winnowed out by wave action and presumably deposited as part of the mud in the deeper, lower energy areas of the creek. The relationships among the bank strata, the sand strip, and the mud are depicted in Figure 8. This strip of sand is deposited over

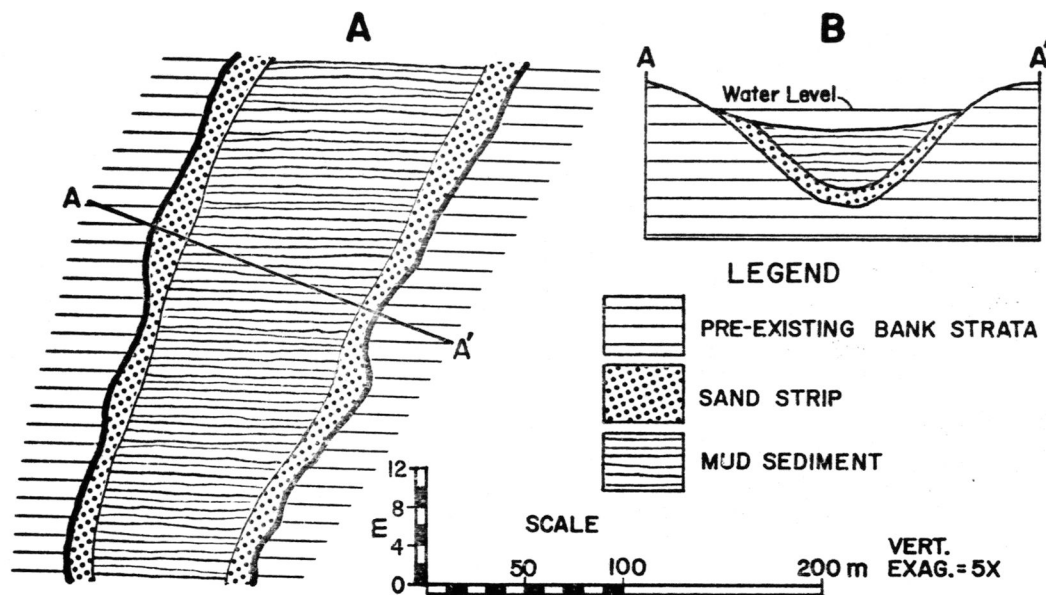


Figure 8. Schematic representation of relationships among pre-existing bank strata, sand strip, and mud. A is the plan view; B is the cross sectional view along A-A'.

the pre-depositional creek channels and in turn is buried by the transgressing mud. Thus, during the process of flooding, the creek channels experience simultaneous deposition of reworked sands along their margins and mud in the deeper areas. Figure 9 represents an idealized cross-sectional view of the progressive infilling of the creeks.

The thickness of the mud in Slocum and Hancock creeks is shown in Figures 10 and 11 (in pocket). The distribution and thickness of the organic-rich mud in the two creeks is controlled by the topography of the pre-mud surface in each creek. The deposition of mud in the two

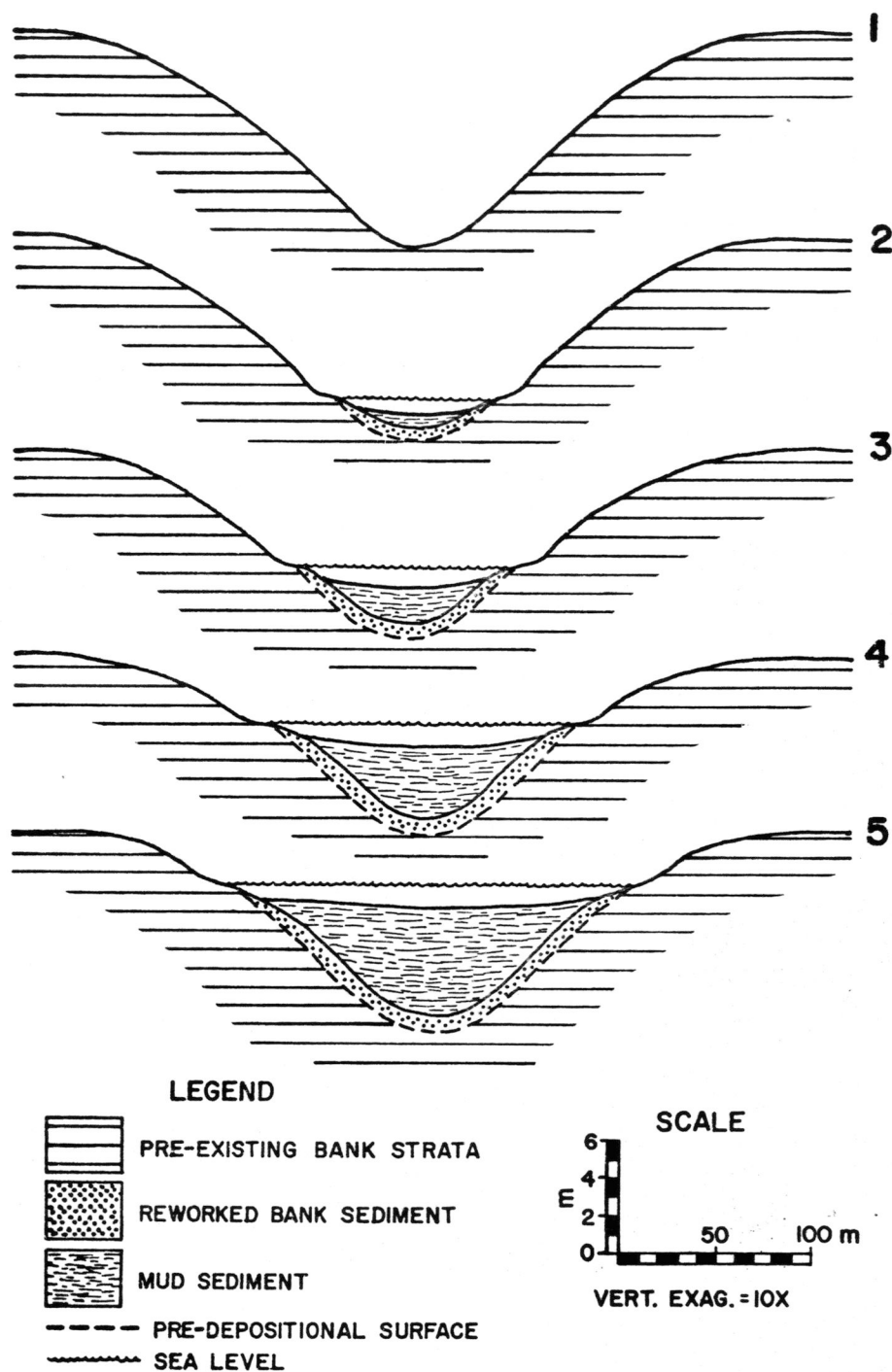


Figure 9. Sequential cross sections along the same hypothetical traverse showing progressive infilling with a rising sea level. 1 = low stand of sea; 5 = present sea level.

creeks is the direct result of the progressive flooding of their drainage systems as depicted in Figure 9.

Methods used to measure the thickness of the mud were not capable of measuring accumulations greater than about 6.1 m (20 ft). Therefore, the maximum thickness of the mud is not known for either of the creeks. Extrapolation of data along several probing traverses in each creek (Figure 12) indicates, however, that accumulations of mud in excess of 7 m (23 ft) are not uncommon. An increase in thickness of the mud toward the Neuse River estuary can be seen in the upper reaches of Hancock and Cahogue creeks (Figure 11). This northward-thickening

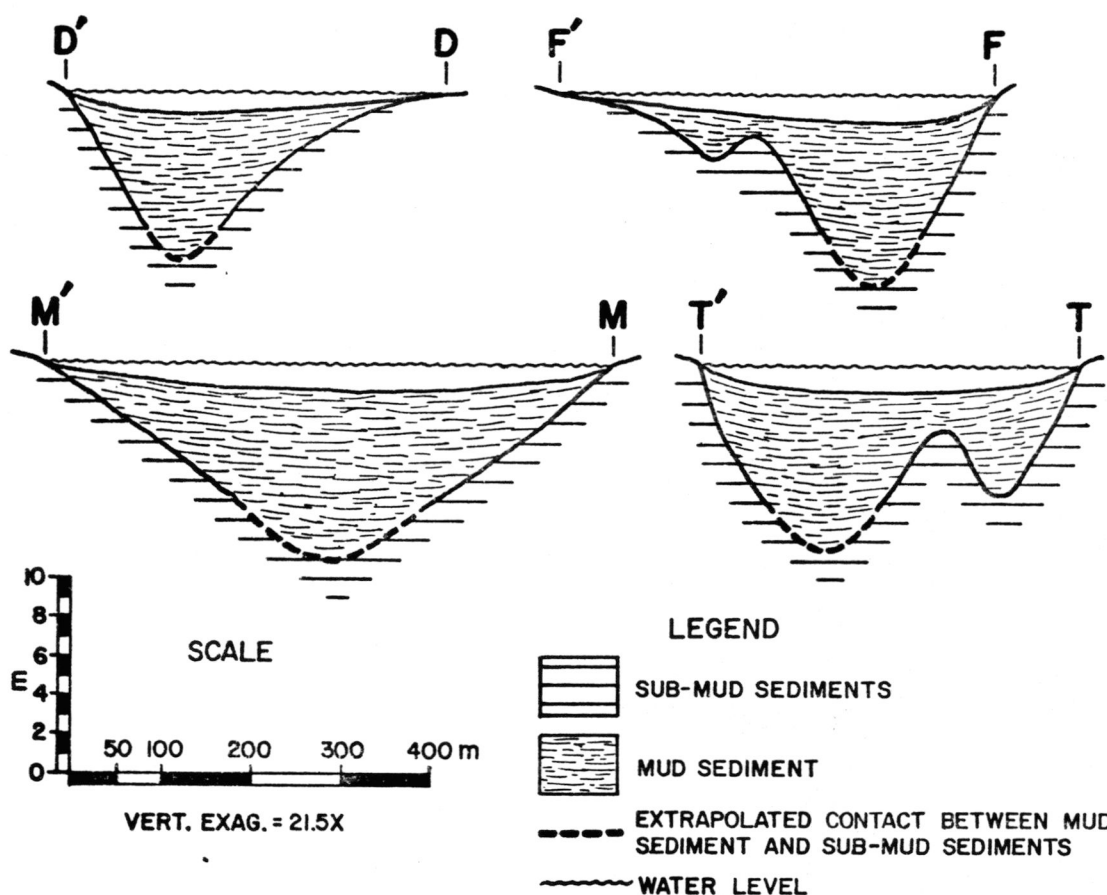


Figure 12. Typical cross sections in Slocum (D'-D and F'-F) and Hancock (M'-M and T'-T) creeks (See Figures 4 and 5 for traverse locations).

trend reflects the general stream gradient of the pre-mud channels, and implies that the process of infilling systematically progressed up the creeks through time as flooding proceeded into the upper reaches of the creeks. It is very probable that a similar northward-thickening trend exists in the upper reaches of Slocum Creek not included in this study, since a rising sea level would first flood the lower portions of both drainage basins.

Very little to no mud accumulated in and around the mouths of the two creeks (Figures 10 and 11). This is due primarily to the constricted creek mouths which produce a venturi effect whereby waters moving in or out of the creek mouths travel at a velocity high enough to either inhibit the deposition of silts and clays, or winnow out most fines deposited during quiescent periods. Slocum and Hancock creeks can, therefore, be considered as restricted, elongate basins characterized by the deposition of organic-rich mud.

COMPOSITION

The locations of eight cores of organic-rich mud taken in Slocum and Hancock creeks are shown in Figures 4 and 5 and the coring method used is in Appendix A. Two 25 cm (10 in) samples were taken from the top and bottom of each of the 8 cores which ranged from 1.5 to 2.2 m (5 to 7 ft) in depth. Portions of each sample were analyzed for sand, organic content, and clay mineral composition.

Sand Content

The method used to determine the sand content is explained in Appendix B. Samples SC1, SC2, and SC3 were taken from Slocum Creek, and samples HC1, HC2, and HC3 were taken from Hancock Creek (Figures 4

and 5). Three 50 g portions of each surficial and subsurface split wet sieved and the weight percentage of sand determined (Figure 13). The values for each split are given in Appendix D, Table 4. Each sand portion was subjected to microscopic examination to determine the gross textural characteristics.

An increase in sand content upstream in Slocum Creek, and a decrease in sand upstream in Hancock Creek are noted. However, approximately 75% of the sand fraction of samples SC2 and SC3 consists of poorly to moderately sorted, medium to fine sand, while the sand fraction of all other samples in both creeks consists predominantly of moderately well to well sorted, fine to very fine sand. Since samples SC2 and SC3 are located 2 and 4 km, respectively, from the creek mouth (Figure 4) the relatively high sand content in these samples (Figure 13) cannot be attributed to a Neuse River source. When compared to samples HC2 and HC3, the textural characteristics and relative abundance of the sand fraction of samples SC2 and SC3 further imply a source other than Neuse River. The high percentage of sand in these samples is the result of high erosion taking place within the well entrenched tributaries immediately downstream of SC2 and upstream of SC3 (Figure 4).

With the exception of samples SC2 and SC3, 80 to 90% of the sand fraction of the mud sediment falls within the size range (.07 to .25 mm) capable of being transported in suspension (Custer and Ingram, 1974). Circulation of Neuse River estuarine waters in the lowermost reaches of Hancock Creek is enhanced by the existence of two creek mouths (Figure 5). The relatively high sand content in sample HC1 (Figure 13) is the result of this unrestricted circulation, where the turbid waters

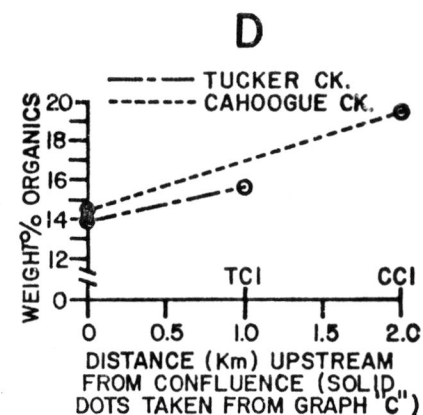
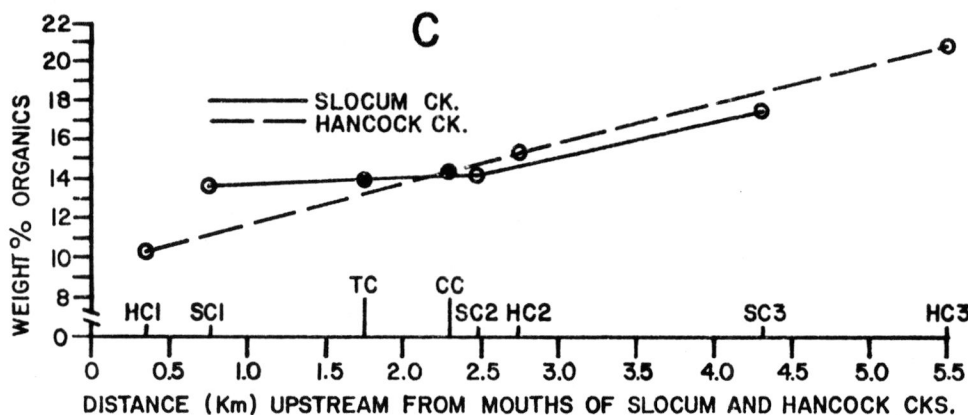
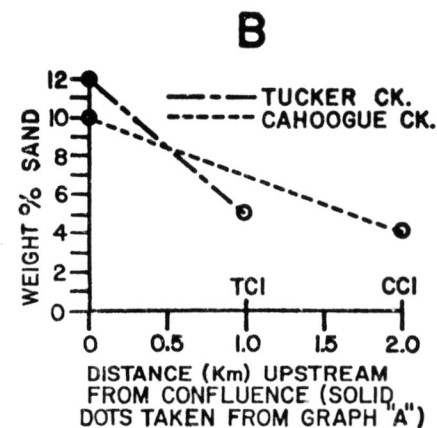
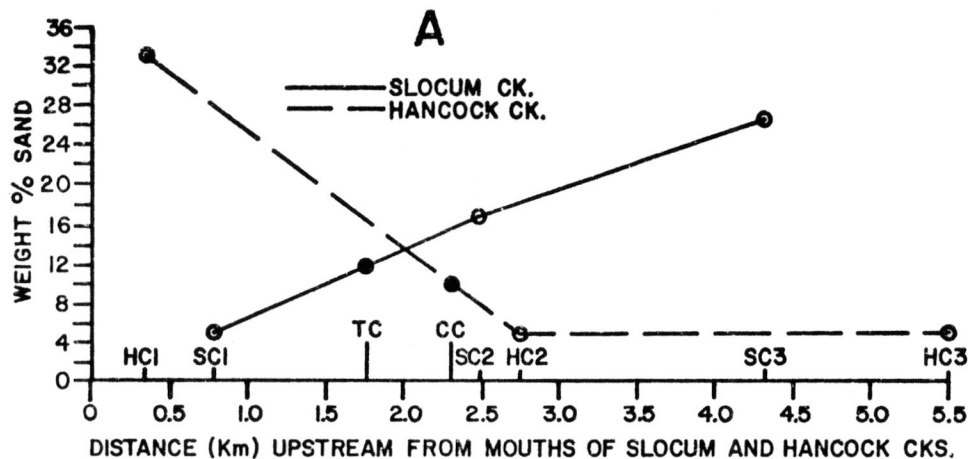


Figure 13. Average weight % sand (A and B) and organics (C and D) for mud in Slocum, Tucker, Hancock, and Cahoon creeks. See Figures 4 and 5 for locations of core samples, SC1-SC3, TC1, HC1-HC3, and CC1. TC is the location of the confluence of Slocum and Tucker creeks, and CC is the location of the confluence of Hancock and Cahoon creeks.

resulting from intense wave activity in the near shore area of the Neuse River estuary are easily moved in and out of the mouths of Hancock Creek, depositing the sand fraction of their suspended load in the relatively protected and quiescent region immediately inside the creek mouths. The mouth of Slocum Creek is more restrictive with respect to the inflow of suspended sand (Figure 4) and the sand content of sample SC1 reflects this condition. The sand content in the other samples results from the re-suspension of the finer sands being deposited in the narrow strips along the margins of the creeks, or from saltation of coarser sands during storms.

More extensive sampling may indicate that sand content in the Slocum Creek bottom sediments is generally higher than that of Hancock Creek due to greater relief and consequently more extensive erosion in the Slocum Creek drainage basin. However, in light of the present data, if samples SC2, SC3, and HC1 are assumed to contain anomalously high percentages of sand, the average sand content of the mud in both creeks is approximately 5% by weight.

Organic Content

In estuarine sediments, there is an inverse relationship between the concentration of organic material and the grain size of the sediments (Berryhill et al., 1972, and Folger, 1972). With the exception of near shore sand deposits, estuarine bottom sediments consist predominantly of silts and clays; hence, it is predictable that these bottom sediments would be typically organic-rich. In Pamlico Sound (Figure 1), where bottom sediments are primarily sandy, the concentrations of organic detritus are limited by intense wave action and rarely exceed 4% (Pickett, 1965). Bottom sediments in the Pamlico River

estuary are composed predominantly of silts and clays and contain an average of 13% organic materials (Hartness, 1977), and the sediments in the South River (Figure 2) contain up to 13% organic detritus (Berryhill et al., 1972).

Since the organic constituent of estuarine sediments is typically high in alkaline-soluble humic substances and low in bitumen content (Berryhill et al., 1972) and since primary productivity far exceeds secondary productivity in and around the estuarine environment (Darnell, 1967) it is not surprising that the great bulk of organic materials in the estuaries is derived from vegetation. Autochthonous sources of vegetation (derived from within the estuarine waters) include: 1) phytoplankton, 2) submerged vegetation, 3) diatoms and algae, and 4) periphyton. Allochthonous sources (derived from outside the estuarine waters and transported into the estuaries) include: 1) marsh vegetation, 2) swamp and forest vegetation, 3) phytoplankton and organic detritus from rivers, 4) beach and shore material washed in during storms or other periods of high water, 5) windblown material (leaves and pollen grains), and 6) phytoplankton and other material originating within the adjacent marine environments (Darnell, 1967).

Organic materials are important constituents of the bottom sediments in Slocum and Hancock creeks. Bacterial breakdown of the organics imparts a very strong hydrogen sulfide odor to the sediment that persists throughout most stages of laboratory analysis. Three portions of both the surface and subsurface splits of each core were analyzed for weight percentage of organics (Figure 13; see Appendix B for procedures). The average percentage for each split is given in Appendix

D. Since the amount of organic materials in any given sample is the result of complex chemical, biologic, sedimentologic, and hydrologic processes, an accurate interpretation of variations from the data is very difficult. However, the data do indicate that the concentration of organic material increases with distance upstream. This trend is particularly evident in Hancock Creek where samples taken represent the actual lower, middle, and upper reaches. Table 4 (Appendix D) indicates that subsurface samples generally contain a higher concentration of organic materials than surficial samples. A similar trend is noted by Hartness (1977) in the lateral tributaries of the Pamlico River and in the Pamlico River itself.

Bottom sediments in Slocum and Hancock creeks contain an average of 15.8% organic materials. However, in the deeper parts of both creeks there are discontinuous layers of soupy, flocculated materials ranging from 5 to 40 cm (2 to 15 in) thick and grading downward into the firm bottom sediment. These layers contains as much as 85% organic materials and form an indefinite water-sediment interface. Similar deposits were noted by Berryhill and others (1972) in the South River, and by Riggs (pers. comm., 1978) in the upper reaches of the Pamlico River.

Clay Minerals

In the two preceding sections it has been shown that bottom sediments in Slocum and Hancock creeks contain an average 5% of sand and approximately 16% organics. The remaining 79% of the average sample is composed of inorganic silt-and clay-sized particles. A size analysis of this fraction would yield data with respect to the relative abundance

of silt versus clay. However, perhaps the most valuable criteria for characterizing a sediment comprised of nearly 80% silt and clay, and only 5% sand are the types and relative abundance of the clay minerals in the sediment. Procedures utilized for the analysis of the clay minerals are outlined in Appendix B, and the X-ray identification of clay minerals is discussed in Appendix C.

Quantification. Numerous methods have been employed in an attempt to quantify the clay mineral constituent in sediments. The inherent difficulties in quantification of clay minerals have been reviewed by Carrol (1974), Gibbs (1965), and Pierce and Siegel (1969). Factors that influence and often bias results obtained from X-ray diffractograms include: 1) sample preparation techniques, 2) sample treatment, 3) equipment conditions (particularly calibration), 4) the methods used to determine the relative abundance of individual minerals in a sample, and 5) variations in crystallinity, hydration, and in chemical composition and structure between groups of minerals and within the same mineral group. The last factor is perhaps paramount with respect to the quantification of clay minerals. Regardless of the method employed, attempts to determine the actual percentage of a specific clay mineral in a sample are inherently complicated and made even more difficult by any one or a combination of the above factors.

The relative abundance of clay minerals in a sample can be determined by the relative intensities of their basal (001) reflections in oriented mounts, assuming sampling techniques and laboratory procedures are carefully chosen and remain consistent. Any change in relative intensities of basal reflections reflects the relative change

in abundance of the clay mineral in the samples.

For the present study, the method used to determine the relative abundance of clay minerals is adopted from Hartness (1977), and is based on the minimum manipulation of raw data. The intensity of the first order basal reflection (001) of each clay mineral was compared to the intensity of the (100) reflection of a quartz standard analyzed prior to and after each sample run. If the intensities of the quartz reflections varied more than 3%, the run was discarded and the sample was reanalyzed. The intensities of the (001) basal reflection of the clay mineral and quartz standard were formulated according to the ratio, $\text{Intensity}_{(\text{clay})} / \text{Intensity}_{(\text{standard})}$. Thus, changes in the ratio for a given clay mineral between samples would indicate relative changes in the abundance of that mineral. It should be pointed out that the intensity of the standard relative to that of the clay mineral remains constant even though equipment settings are changed.

Distribution. Clay minerals identified in the bottom sediments of Slocum and Hancock creeks include, in order of decreasing relative abundance, kaolinite, dioctohedral vermiculite, smectite, and illite. Relative intensity ratio values were calculated for surface and subsurface splits of each core (Appendix D). Since values obtained for surface splits were closely parallel to those for subsurface splits, the average of surface and subsurface values was taken for each core. The average values obtained were then plotted versus distance upstream from the mouths of the two creeks, and from the confluence of Slocum and Hancock creeks and their tributaries, Tucker and Cahogue creeks.

The distribution of average relative intensity values for Slocum, Hancock creeks (Figure 14) indicates that kaolinite and dioctohedral

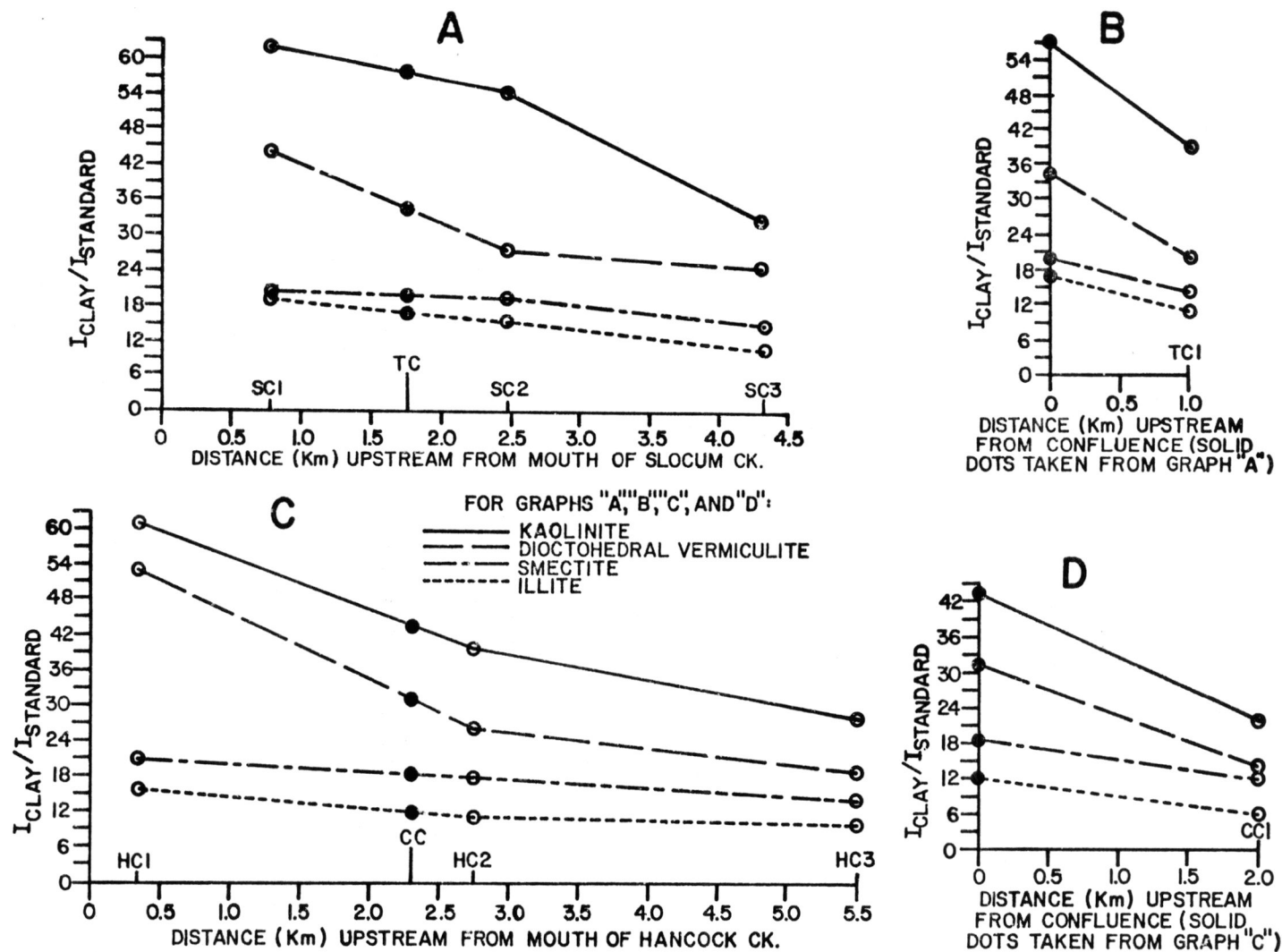


Figure 14. Mid-creek distribution of relative clay mineral peak intensities in Slocum (A), Tucker (B), Hancock (C), and Cahogue (D) creeks. See Figures 4 and 5 for locations of core samples. TC is the location of the confluence of Slocum and Tucker creeks, and CC is the location of the confluence of Hancock and Cahogue creeks.

vermiculite are the dominant clay minerals in all four creeks. This is particularly evident in the lower reaches of Slocum and Hancock creeks, however, their relative abundance decreases with distance upstream. In Slocum Creek, kaolinite decreases slowly at first and then more rapidly upstream. Kaolinite in Hancock Creek and dioctohedral vermiculite in Slocum and Hancock creeks decrease at faster rates in the lower reaches than in the upper reaches. The change in relative abundance of these clays from lower to upper reaches is similar in both creeks. Smectite and illite are present in relatively minor amounts in Slocum and Hancock creeks. These minerals also decrease in relative abundance upstream, but at slower and nearly linear rates.

Tucker and Cahoon creeks are the major tributaries of Slocum and Hancock creeks (Figures 4 and 5). Average relative intensity values for samples in these tributaries, plotted from their approximate confluence with the major creeks versus distance upstream, also indicate a dominance of kaolinite and dioctohedral vermiculite with lesser amounts of smectite and illite. All four minerals decrease in relative abundance upstream.

D I S C U S S I O N

Studies dealing with the sediment infilling of estuaries (Meade, 1969; Pevear, 1968; Potsma, 1967) have cited the following primary source areas for the sediment: 1) sediments derived from inflowing rivers and creeks; 2) landward transport of bottom sediments by currents and astronomical tidal action; and 3) influx of eroded estuarine shoreline strata. An evaluation of these source areas as they relate to the lateral estuaries may serve to better delineate the sources of sediment infilling Slocum and Hancock creeks.

The trunk estuaries of eastern North Carolina, such as the Neuse and Pamlico River estuaries, are the result of continued drowning of river systems that originate in the Piedmont and commonly carry large suspended loads. Sediment infilling of these estuaries is, therefore, greatly affected by the flow regime and suspended loads of these major, Piedmont-born rivers. In contrast, tributaries to the trunk estuaries, such as Slocum and Hancock creeks, rise and flow entirely within the low-lying Coastal Plain, drain relatively small areas, and contain relatively little suspended sediments as evidenced by their clear waters, during normal flow conditions (Heron et al., 1964). Thus, except during periods of extremely high discharge, the flow regime of the tributary creeks probably has little effect on the sediment infilling process operating within the embayed portions of these creeks.

The distribution of clay minerals in the estuaries is also significant with respect to the source of the infilling sediment in Slocum and Hancock creeks. Allen (1964) found that the clay minerals in the suspended sediments in the Tar River consist predominantly of kaolinite

and dioctohedral vermiculite with lesser amounts of illite and smectite, thus reflecting the clay mineral assemblage of the soils within the Tar River drainage basin. Numerous investigators (Allen, 1964; Griffin and Ingram, 1955; Hartness, 1977; Hathaway, 1972; Park, 1971; Pevear, 1972) have shown that kaolinite and dioctohedral vermiculite are the dominant clay minerals in the upper reaches of the Neuse and Pamlico estuaries and that they decrease in abundance downstream, relative to illite and smectite. Illite and smectite are present in minor amounts in the upper reaches of both estuaries and increase in relative abundance downstream. It is important to note that kaolinite and dioctohedral vermiculite decrease in abundance away from their source. These trends have been attributed to the relative stabilities of clay minerals in saline solutions, where stability retards coagulation and flocculation. According to Edzwald (1972), kaolinite and vermiculite are unstable relative to illite; therefore, upon encountering saline waters in the upper reaches of the estuaries, kaolinite and vermiculite coagulate and flocculate prior to illite and are deposited before illite. The present study shows that, although they are dominant in the upper and lower reaches of both Slocum and Hancock creeks, the relative abundance of kaolinite and vermiculite increases downstream. This trend is the reverse of the trend noted in the Neuse and Pamlico estuaries and may indicate that the kaolinite and dioctohedral vermiculite present in the two creeks are not derived from the inflowing waters of their drainage basins and subsequently deposited in response to increasing salinity downstream. Thus, even though illite increases in abundance downstream as expected on the basis of its relative stability, source areas other

than the drainage basins of Slocum and Hancock creeks must be considered in order to explain the distribution of clay minerals in the two creeks.

Since astronomical tidal fluctuations within North Carolina's estuarine systems are greatly reduced by the barrier islands, it is doubtful that landward bottom transport of sediment by these forces could be of any direct significance with respect to the infilling of Slocum and Hancock creeks. However, Meade (1962) and Pevear (1964) have suggested that the dominance of illite in the sediments of Pamlico Sound may be attributable to landward transport of marine clays by current activity through the inlets that breach the barrier islands. Although the present number and size of inlets would seem to greatly limit the amount of sediments being flushed into Pamlico Sound by tidal surges either on a day-to-day basis or due to seasonal storms, such tidal transport may have been possible in the past when inlets were more numerous (O'Connor and others, 1972). Subsequent vertical mixing caused by winds could re-suspend clays in Pamlico Sound, and the tides and currents produced by these winds would be capable of transporting these suspended clays into virtually all parts of the estuaries, including the embayed laterals. Thus, there may be an indirect relationship between astronomical tides and the infilling of Slocum and Hancock creeks. However, in the absence of tangible evidence, such a relationship is at best speculative.

The progressive inundation of North Carolina's coastal system by the continuing Holocene transgression results in almost ubiquitous estuarine shoreline erosion. The nature and extent of this erosion has been studied by Bellis and others (1975). The rate of shoreline erosion

is a direct function of fetch, bottom characteristics, bank topography and composition, shoreline vegetation, and other more subtle variables. Unpublished data from a recent follow-up study by Bellis, O'Connor, and Riggs (pers. comm., 1978) indicate that shoreline erosion may be occurring at faster rates than initially estimated (Table 2).

Shoreline Type	Erosion Rate m/yr (ft/yr)
low bank 0.3 - 1.5 m (1-5 ft)	0.8 (2.6)
high bank 1.5 - 6.1 m (5-20 ft)	0.6 (1.9)
bluff 6.1 m (20 ft)	0.6 (1.9)
Swamp forest	0.6 (1.9)
Grass Marsh	0.9 (3.1)

Table 2. Susceptibility of estuarine shoreline to erosion (from Riggs, O'Connor, and Bellis, unpublished data, 1978).

Although short segments of the shoreline in the embayed portions of Slocum and Hancock creeks do exhibit substantial erosion, conditions in the two creeks generally do not favor extensive shoreline erosion. In order to identify the clay mineral assemblage of the bank strata in Slocum and Hancock creeks, channel samples were taken from 26 obviously eroding bank locations along both creeks. X-ray analysis (Table 5, Appendix D) indicates that all of the clay minerals identified in the

bottom sediments of the creeks are also represented in the bank strata. Although shoreline erosion is not rapid or readily obvious in most places along Slocum and Hancock creeks, local erosion of the bank strata probably does contribute some, but an unknown amount to the bottom sediments in both creeks.

The turbid conditions observed in the lower reaches of both creeks and the salinity data strongly indicate that waters from the Neuse River estuary periodically flow into Slocum and Hancock creeks. Wind tides produced in the Neuse River create a pressure head at the mouths of both creeks. Since wind tides are capable of raising the water level in the river more than a meter, it is not difficult to envision the water level in the creeks a meter below that of the river. Under such conditions, river water containing resuspended silt and clay would easily flow into and up both creeks. Salinity data supports the occurrence of such back flow in the creeks.

All of the clay minerals in the bottom sediments of Slocum and Hancock creeks are present in the bottom sediments of the Neuse River estuary. In both creeks and in the Neuse River estuary, kaolinite and dioctohedral vermiculite are the dominant clays, while smectite and illite are present in smaller quantities. In light of these facts, the proposed mechanism for sediment infilling of the two creeks can be considered in the following stages: 1. The Neuse River estuary becomes turbid with high suspended load as a result of either resuspension of the bottom sediments containing silt, organic detritus, and relatively fixed proportions of clay minerals by vertical mixing due to intense wave action or during periods of high trunk river discharge. 2. These

turbid waters are carried into Slocum and Hancock creeks during periods of high wind tides. 3. Upon reaching the protected and relatively quiescent waters of the creeks, the suspended materials eventually settle out on the creek bottoms. A small amount of this newly deposited organic-rich mud is no doubt re-suspended and carried out into the river and deposited there. However, the mechanism described above is seen largely as a one-way transport of sediment from the river into the creeks since the capacity for the development of turbid conditions is far greater in the open waters of the river than in the restricted reaches of the creeks. The distribution of clay minerals in Slocum and Hancock creeks and their tributaries is also explained by this mechanism. River water flowing up the creeks becomes progressively diluted by creek water upstream. This diluting effect also reduces the amount of suspended sediment carried upstream. The decrease in the abundance of clays upstream is clearly seen in Figures 13 and 14. Since illite and smectite decrease in relative abundance at slower rates than kaolinite and dioctohedral vermiculite, it is assumed that they remain in suspension for a longer period of time and are therefore transported further upstream before settling out. It should be noted that the decrease in the abundance of clay minerals upstream is countered by an increase in organic content (Figure 13). Apparently the organic materials are primarily derived from within the Slocum-Hancock drainage basin, while only a small amount flows into the creeks with waters from the Neuse River estuary.

S U M M A R Y A N D C O N C L U S I O N S

The deposition of the organic-rich mud in Slocum and Hancock creeks results from the progressive flooding of their drainage systems. The distribution of the mud in the two creeks is controlled by the topography of the pre-mud surface in each creek. The thickness of the mud ranges up to a known 6.1 m (20 ft) and is estimated to exceed 7 m (23 ft) in the central portions of both creeks.

Clay minerals in the two creeks include, in order of decreasing relative abundance: kaolinite, dioctohedral vermiculite, smectite, and illite, all of which decrease in abundance upstream. There appear to be two sources for these clays. First, and probably the most important, is bottom sediments in the Neuse River estuary, which are re-suspended by wave action, flushed into the creeks during periods of high wind tides, and deposited in the creeks. Second, erosion of bank strata contribute some, but an unknown amount of clay constituents to the bottom sediments.

Sand content of the mud averages 5% by weight but is considerably higher near the creek mouths. Most of the sand is fine to very fine and is within the size range (0.07 to 0.25 mm) capable of being transported in suspension. Sand content generally decreases upstream.

Organic content of the mud averages 15.8% by weight and shows a general increase upstream and with depth.

SUGGESTIONS FOR FURTHER RESEARCH

Many questions were generated by this investigation. Suggestions for further study that may answer these questions include:

1) Dye-tracing of water flow in and out of the creek mouths would establish a better understanding of the amount and extent of mixing of river water in the creeks.

2) Salinity monitoring in the creeks and in the river between the creeks would provide a better understanding of the nature and extent of upstream flow in the two creeks.

3) Regular water sampling and analysis for suspended load in the creeks and in the river would yield valuable information with respect to the relationship of the clay minerals in the river waters to those in the creeks.

4) Bottom sediments in the Neuse River estuary adjacent to the creeks could be cored to determine the distribution of clay minerals in the river sediments, allowing for direct comparisons with those in the creek bottom sediments.

5) Radiocarbon dating of organic detritus in the mud would yield important data with respect to the rates of sediment infilling in the creeks.

6) An investigation of the effects of chemical controls (Eh, pH, salinity, etc.) on the flocculation of clay minerals in Slocum and Hancock creeks would better define the sedimentological regime operating in the two creeks.

R E F E R E N C E S

- Allen, D. W., 1964, Clay minerals of the Tar-Pamlico River sediments: M.S. Thesis, University of North Carolina, Chapel Hill, 25p.
- Bellis, V. J., O'Connor, M. P. and Riggs, S. R., 1975, Estuarine shoreline erosion in the Albemarle-Pamlico Region of North Carolina: University North Carolina Sea Grant Program Pub. UNC-SG-75-29, Raleigh, North Carolina, 67p.
- Berryhill, H. L., Swanson, V. E. and Love, A. H., 1972, Organic and Trace element content of Holocene sediments in two estuarine bays, Pamlico Sound area, North Carolina: U.S. Geol. Survey, Bull. no. 1314-E, p. 1-32.
- Brown, C. Q., 1959, Clay mineral relations in two tributary basins within the York River tributary basin: Southeastern Geol., v. 1, p. 95-104.
- _____, and Ingram, R. L., 1954, The clay minerals of the Neuse River sediments N.C.: Jour. Sed. Petrology, v. 24, p. 196-199.
- Carroll, D., 1974, Clay Minerals: a guide to their X-ray identification: Geol. Soc. America. Spec. Paper 126, 79p.
- Custer, E. S., Jr., and Ingram, R. L., 1974, Influence of sedimentary processes on grain size distribution curves of bottom sediments in the sounds and estuaries of North Carolina: Univ. North Carolina Sea Grant Pub. UNC-SG-74-13, Raleigh, North Carolina, 88p.
- Darnell, R. M., 1967, Organic detritus in relation to the estuarine ecosystem, in Lauff, G. H., ed., Estuaries: Am. Assoc. Adv. Sci. Pup. 83, p. 376-382.
- Dobbins, D. A., Ragland, P. C., and Johnson, D. J., 1970, Water-clay interactions in North Carolina's Pamlico estuary: Environmental Sci. & Tech., v. 4, p. 743-748.
- DuBar, J. R., 1971, Neogene stratigraphy of the lower Coastal Plain of the Carolina: Atlantic Coastal Plain Geol. Assoc., 12th Ann. Field Conf., 128p.
- _____, and Solliday, J. R., 1963, Stratigraphy of the Neogene deposits, lower Neuse estuary, N. C.: Southeastern Geol., v. 4, p. 213-233.
- DuBar, J. R., Solliday, J. R., and Howard, J. F., 1974, Stratigraphy and morphology of Neogene deposits, Neuse River Estuary, in Oaks, R. Q., Jr., and DuBar, J. R., eds., Post-Miocene stratigraphy central and southern Coastal Plain: Utah State Univ. Press, p. 102-122.

- Edzwald, J. K., 1972, Coagulation in estuaries: Univ. North Carolina Sea Grant Pub., no. UNC-72-06, 217p.
- Fallow, W. C., and Wheeler, W. H., 1969, Marine fossiliferous Pleistocene deposits in southeastern North Carolina: Southeastern Geol., v. 10, p. 35-54.
- Folger, D. W., 1972, Characteristics of estuarine sediments in the United States: U. S. Geol. Survey Prof. Paper 742.
- Gibbs, R. J., 1965, Error due to segregation in quantitative clay mineral X-ray diffraction mounting techniques: Am. Mineral., v. 50, p. 741-751.
- Griffin, G. M., and Ingram, R. L., 1955, Clay minerals of the Neuse River Estuary, N. C.: Journal Sed. Petrology, v. 25, p. 194-200.
- Hartness, T. S., 1977, Distribution and clay mineralogy of organic-rich mud sediments in the Pamlico River estuary, North Carolina: (un-publ.) M. S. Thesis, East Carolina University, Greenville, North Carolina, 45p.
- Hathaway, J. C., 1972, Regional clay mineral facies in estuaries and continental margin of the United States, in Nelson, B. W., ed., Environmental Framework of Coastal Plain Estuaries: Geol. Soc. America, Mem. 133, p. 293-316.
- Heron, D., Jr., Johnson, H., Jr., Wilson, P. G., and Michael, G. E., 1964, Clay mineral assemblages in a South Carolina lake-river-estuary complex: Southeastern Geol., v. 6, p. 1-11.
- Hobbie, J. E., and Smith, N. W., 1975, Nutrients in the Neuse River estuary: Univ. North Carolina Sea Grant Program Pub. UNC-SG-75-21, Raleigh, North Carolina, 183p.
- Knowles, C. E., 1975, Flow dynamics of the Neuse River Estuary, North Carolina: Univ. North Carolina Sea Grant Program Pub. UNC-SG-75-16, Raleigh, North Carolina, 147p.
- Leith, C. J., and Craig, R. M., 1965, Mineralogic trends induced by deep residual weathering: Am. Mineral., v. 50, p. 1959-1971.
- _____, and Welby, C. W., 1967, An application of the high resolution boomer seismic technique in groundwater problems in the Pamlico Sound area, in Symposium on Hydrology of the Coastal Waters of North Carolina: Water Resour. Res. Inst., North Carolina State Univ., Raleigh, North Carolina, Rept. no. 5, p. 39-48.
- Leo, G. W., Pavich, M. J., and Obermeier, S. F., 1977, Mineralogical, chemical, and physical properties of saprolite overlying crystalline rocks, Fairfax County, Virginia (abs.): Geol. Soc. America, Abst. with Programs, 1977, vol. 9, p. 157.

- Mead, R. H., 1969, Landward transport of bottom sediments in estuaries of the Atlantic Coastal Plain: Jour. Sed. Petrology, v. 39, p. 222-234.
- Mixon, Robert B., and Pilkey, Orrin H., 1976, Reconnaissance geology of the submerged and emerged Coastal Plain province, Cape Lookout area, North Carolina: U.S. Geol. Survey Prof. Paper 859, 45 p.
- National Ocean Survey, 1975, Neuse River and upper part of Bay River; U. S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Washington, D. C.
- Neiheilsel, J. and Weaver, C. E., 1967, Transportation and deposition of clay minerals, southeastern United States: Journ. Sed. Petrology, v. 37, p. 1084-1116.
- O'Connor, M. P., Riggs, S. R., and Winston, D., 1972, Recent estuarine sediment history of the Roanoke Island area, North Carolina, in Nelson, B. W., ed., Environmental Framework of Coastal Plain Estuaries: Geol. Soc. America Me. 133, p. 453-464.
- Park, B. K., 1971, Mineralogy of recent sediments of North Carolina sounds and estuaries (abs.): Diss. Abstr. Int., v. 32, p. 2800B-2801B.
- Pevear, D. R., 1968, Clay mineral relationships in recent river, near-shore marine, continental shelf, and slope sediments of the southeastern United States: (unpubl.) Ph.D. Thesis, Univ. Montana, 164p.
- _____, D. R., 1972, Source of recent nearshore marine clays, southeastern United States, in Nelson, B. W., ed., Environmental Framework of Coastal Plain Estuaries: Geol. Soc. America, Mem. 133, p. 317-336.
- Pickett, T. E., 1965, The modern sediments of Pamlico Sound, North Carolina: (unpubl.) Ph.D. Thesis, Univ. North Carolina, Chapel Hill, 1950.
- Pierce, J. W., and Siegal, F. R., 1969, Quantification in clay mineral studies of sediments and sedimentary rocks: Jour. Sed. Petrology, v. 39, p. 187-193.
- Potsma, H., 1967, Sediment transport and sedimentation in the estuarine environment, in Lauff, G. H. ed., Estuaries Am. Assoc. Advanced Sci., Washington, D. C.
- Reves, W. D., ⁵⁶1965, The clay minerals of the North Carolina Coastal Plain: (unpubl.) M. S. Thesis, Univ. North Carolina, Chapel Hill, 36 p.

- Rich, C. I., and Cook, M. G., 1963, Formation of dioctohedral vermiculite in Virginia soils: *Clays and Clay Minerals*, v. 10, p. 96-106.
- Richards, H. G., 1950, Geology of the Coastal Plain of North Carolina: *Trans. Am. Phil. Soc.*, v. 40, 83p.
- Riggs, S. R., 1974, Sediment, sediment processes and sediment pollution in the Chicod Creek-Green Mill Run-Tar River drainage system: *Watershed Environmental Statement (Revised)*, U.S. Dept. of Agriculture Soil Cons. Ser., Raleigh, North Carolina, 32p.
- _____, and O'Connor, M. P., 1974, Relict sediment deposits in a major transgressive coastal system: Univ. North Carolina Sea Grant Program Pub. UNC-SG-74-04, Raleigh, North Carolina, 37p.
- Schwartz, F. J., and Chestnut, A. F., 1973, Hydrographic Atlas of North Carolina's estuaries and sound waters: Univ. North Carolina Sea Grant Pub. no. UNC-SG-73-13, Raleigh, North Carolina, 132p.
- Stephenson, L. W., 1912, The Quaternary formations, in Clark, W. B., Miller, B. L., and Parker, H. N., eds., *The Coastal Plain of North Carolina: North Carolina Geol. and Economic Survey*, v. 3, 372p.
- Tien, P. L., 1974, A simple device for smearing clay-on-glass slides for quantitative X-ray diffraction studies: *Clay and Clay Minerals*, v. 22, p. 367-368.
- _____, Leavens, P. B., and Nelen, J. A., 1975, Swinefordite, a dioctahedral-trioctahedral Li-rich member of the smectite group from Kings Mountain, North Carolina: *Am. Mineralogist*, v. 60, p. 540-547.
- U. S. Geol. Survey, 1977, Water resources data for North Carolina water year 1976: U. S. Geol. Survey Water-Data Report NC-71-1, Raleigh, North Carolina, 41lp.
- Weaver, C. F., 1958, Geologic interpretation of argillaceous sediments, Part 1, Origin and significance of clay minerals in sedimentary rocks: *Am. Assoc. Petroleum Geologists Bull.*, v. 42, p. 254-271.
- Woods, W. J., 1969, Current study in the Neuse River and Estuary of North Carolina: *Water Resour. Res. Inst.*, North Carolina State Univ., Raleigh, North Carolina, Rept. no. 13, 35p.

A P P E N D I C E S

APPENDIX A: FIELD METHODS

A Ray-Jefferson model 621 continuous recording fathometer was used in an attempt to obtain continuous bathymetric profiles along specific traverses across both creeks. This technique proved unsuccessful due to extremely high attenuation of the fathometer signal, presumably caused by the poorly defined water-sediment interface, resulting in fathometer signatures that were either very weak or non-existent, and, therefore, unusable. Leith and Welby (1967) reported similar difficulties in interpreting boomer reflection data collected in the Pamlico River estuary, citing attenuation of the soundings by the river bottom as the cause of the problem. Bathymetric data for this study was obtained by the use of a knotted rope with a 6 x 6 inch piece of thin sheet metal attached to the end.

Thickness data was obtained by the use of a half-inch graduated metal probing rod. The rod was pushed through the mud until the relatively hard and impenetrable underlying sand was reached, or until further insertion through the mud became impossible. A minimum of two probes were made at each station, and the average of the probe depths was recorded. Where the total thickness of the mud sediment could not be measured, the data was recorded as greater than the maximum depth reached. The thickness of the mud (T_s) at each station was obtained according to the formula

$$T_s = D_p - D_s,$$

where D_p =the probe depth, and D_s =the sounding depth.

Core samples were taken utilizing hand coring techniques from

aboard a 13½ foot Boston Whaler. A graduated 3" PVC pipe was pushed through the mud until the underlying sand was reached or until further insertion was impossible. Total insertion depth was read off the pipe at water level and recorded. The pipe was then filled with water and sealed to prevent loss of the core upon pipe extraction. A sounding was made at each coring station, and the thickness of the mud cored (T_c) was obtained according to the formula,

$$T_c = D_i - D_s,$$

where D_i =the insertion depth, and D_s =the sounding depth. Coring stations were located and plotted on 7.5 minute U.S. Geologic Survey topographic quadrangles (Havelock and Cherry Point). With the exception of splitting the coring pipe, which was cost-prohibitive, there was no way to avoid considerable compaction of the cored mud upon extrusion from the coring pipe. The percentage of core compaction (%C) was obtained according to the formula,

$$\%C = \frac{L_c}{T_c} \cdot 100,$$

where L_c =the length of the core extruded from the coring pipe, and T_c =the thickness of the mud sediment cored.

Splits were taken at 25 cm intervals and placed in labeled plastic bags and returned to the laboratory for analysis. Due to the compaction encountered, which ranged from 30 to 59 percent and averaged 42 per cent, stratigraphic control was limited to the uppermost and lowermost splits of each core. For this reason, only the top and bottom splits were analyzed in the laboratory.

The channel samples of the creek banks were taken with a hand trowel at various locations depending upon the variation in bank

lithology encountered and the distribution of these lithologies. Field descriptions of each sample were made and recorded, and the samples were placed in labeled plastic bags and returned to the laboratory for analysis. The locations of bank sampling were plotted on the 7.5 minute U. S. Geologic Survey topographic quadrangles.

APPENDIX B: LABORATORY PROCEDURES

Sample Preparation

Figure 15 shows the basic procedures used for sample preparation.

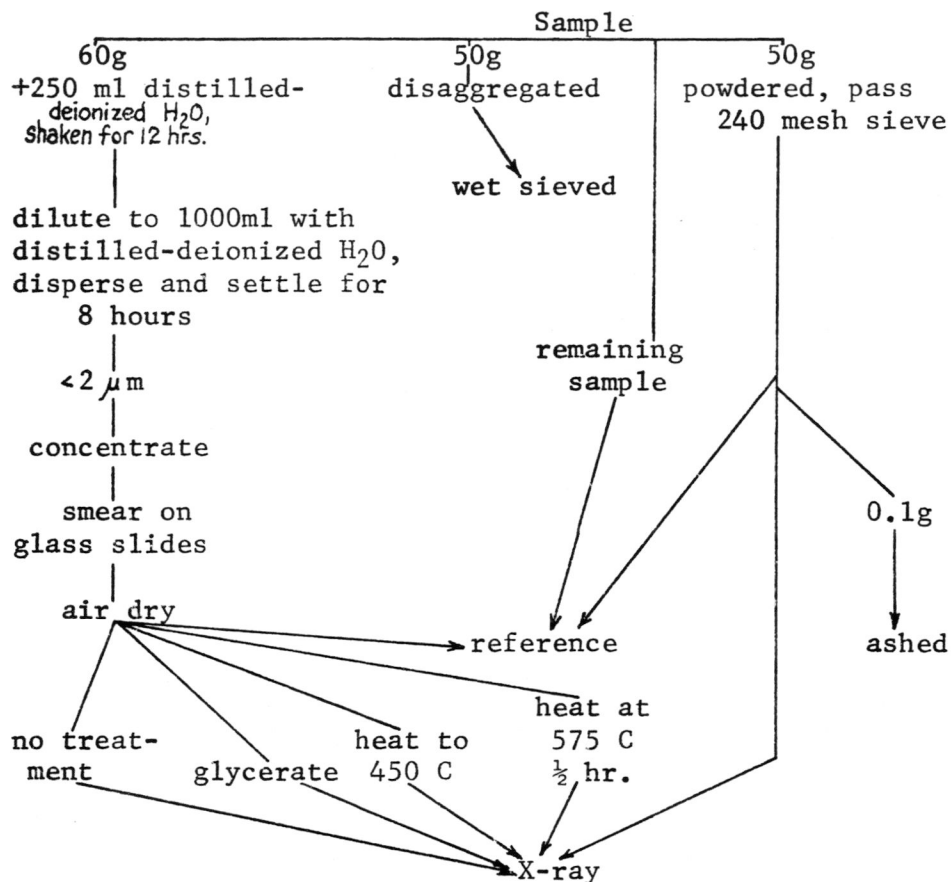


Figure 15. Laboratory flow chart.

The following sections detail the various phases of sample preparation.

Separation of the <2 μ m fraction. Samples were oven-dried at 40°C for 24 hours. Sixty grams of dried sample were placed in a 600 ml flask with 250 ml of distilled-deionized water. This mixture was gently agitated for 12 hours in a wrist-action shaker. The water-sediment mixture was transferred to a 1000 ml beaker and sufficient distilled-

deionized water was added to make a 1000 ml mixture. A blender was used to assure thorough mixing of the water-sediment mixture. To remove any remaining cations, each sample was washed by concentrating the sediment through the use of a porcelian filter until complete dispersion was obtained. As many as five 1000 ml washings were necessary to eliminate flocculation in some samples. Once complete dispersion was attained, a 1000 ml water-sediment suspension was blended again and allowed to settle for 8 hours, at which time the $<2\mu\text{m}$ fraction was obtained by decanting according to Stokes' Law.

Slide preparation of the $<2\mu\text{m}$ fraction for X-ray diffraction analysis. The $<2\mu\text{m}$ fraction of the water-sediment suspension was transferred to a 600 ml beaker and concentrated by use of a porcelain filter. The resulting $<2\mu\text{m}$ concentrate was transferred to a 50 ml beaker and thoroughly blended by use of a grooved rubber stopper attached to a blender. The blended clay paste was uniformly smeared on five glass slides simultaneously utilizing a smearing device described by Tien (1974), and dried under room conditions. One slide was treated with a 1:2 glycerine-water solution sprayed from an atomizer. To ensure complete absorbtion of glycerine by expandable clay minerals in the samples, a slide smeared with swinefordite (Tien, 1975) was included in each group of slides that were glycerated. Only when the swinefordite slide had completely absorbed the glycerine (verified by X-ray analysis) were the other slides in the group considered treated. The second slide was heated to 450°C in a box furnace and allowed to cool in the furnace. The third slide was heated to 575°C , maintained at that temperature for one-half hour, and allowed to cool in the furnace. The fourth slide was not treated. The fifth slide, also untreated, was preserved as a reference or for back-up use in the

event that a problem was encountered with one of the other slides. The excess clay paste was preserved for reference.

Whole rock preparation for X-ray diffraction analysis. Approximately fifty grams of oven-dried sample were crushed and passed through a 240 mesh sieve. Repeated sieving through a 60 mesh sieve ensured thorough mixing of the powder. The powdered sample was then back-packed in an aluminum sample holder. Since different packing techniques applied to the same sample generally result in reflection intensity variations, the method of packing was kept uniform.

Sample preparation for low temperature ashing. Approximately 0.1 g of dried, crushed, and sieved sample (see above) was used for low temperature ashing. A known quantity of the described sample was placed in a glass weigh-boat, subjected to the ashing treatment, and re-weighed, thus yielding the per cent weight loss resulting from the ashing treatment. After ashing, each sample was treated with a 5% solution of hydrogen peroxide. Since none of the samples reacted with the solution, the ashing of all samples was complete.

Sample preparation for isolation of sand and silt-clay fractions. A known quantity of oven-dried sample (approximately 50 g) was soaked in water in a sealed jar until complete, unassisted disaggregation of the dried sample was attained. The resulting slurry was wet-sieved through a 250 (Tyler no.) mesh sieve. The remaining sand fraction was air dried and weighed, yielding the percentage of sand and silt-clay fractions in each sample.

Instrument Operation

X-ray diffraction unit. X-ray analyses were performed with a

General Electric XRD-6 diffractometer utilizing LiF monochromatized CuK_α radiation. The unit was operated at 45kv and 20ma. A scanning rate of $4^\circ 2\theta$ per minute was used for all samples. Oriented slides were scanned from 3 to $47^\circ 2\theta$, and whole rock back-packed samples from 3 to $90^\circ 2\theta$. A quartz standard was run immediately before and after each sample to ensure optimum performance of the X-ray unit and as a reference for comparison of reflection intensity.

Low temperature ashing unit. An LFE model 302 low temperature asher was used to obtain the percentage of volatile material in each sample. Samples were ashed for 10 minutes with 300 watts of RF power and with an oxygen flow rate of 200 cc per minute.

APPENDIX C: IDENTIFICATION OF CLAY MINERALS BY X-RAY DIFFRACTOMETRY

Clay minerals are hydrous layer silicates (phyllosilicates), with the exception of palygorskite and sepiolite which are chain or pseudo-layer silicates. The structure of most clay minerals is based on two structural units: an octahedral unit and a tetrahedral unit. There is general agreement that the upper size limit for individual clay particles is $2\mu\text{m}$.

Because of their internal structure and the small size of their individual particles, clay minerals are most easily identified by means of X-ray diffraction techniques on the basis of their basal (001) reflections (in oriented mounts). Basal reflections commonly overlap for some clay minerals; hence, special treatments, principally glyceration and heating, are needed to identify the different clay minerals in a mixture. Absorption of glycerine causes structural expansion along the c-axis of expandable clay minerals such as those of the smectite group. Structural contraction or collapse along this c-axis may be induced by heat treatments of oriented mounts.

The major clay mineral constituents of the bottom sediments in Slocum and Hancock creeks are kaolinite, smectite, dioctohedral vermiculite and illite. The following paragraphs give the characteristics used in their identification.

Kaolinite

Carrol (1974) gives the chemical composition of kaolinite as $2\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$. Each unit cell is composed of a single octohedral layer, typically with no isomorphous replacement in the structure.

Diagnostic basal reflections in oriented mounts occur at $7.15\text{\AA}$ (001) and $3.75\text{\AA}$ (002). Kaolinite is not affected by glyceration. However, heating at 450°C can cause partial collapse of the structure, and heating to 575°C for one-half hour results in the complete collapse of the structure, noted by the disappearance of the basal reflections from the X-ray diffractogram.

Smectites

The unit cells of clay minerals in the smectite group are composed of one octohedral layer between two tetrahedral layers. Unit cells are weakly bonded by exchangeable cations and interlayer water, giving smectites their ability to expand. It is impractical to define species within this group because of the infinite variation of possible isomorphous replacement (Carrol, 1974).

Minerals within the smectite group exhibit a strong first order basal reflection at $13\text{\AA}$ or $15\text{\AA}$. Glyceration results in expansion of the first order basal reflection to $17\text{\AA}$, and heating above 300°C results in collapse of the structure to $9\text{\AA}$ or $10\text{\AA}$ due to the expulsion of interlayer water.

Dioctohedral Vermiculite

The general chemical composition for vermiculite is $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2 \cdot \text{H}_2\text{O}$ (Carrol, 1974). Isomorphous replacement in both the tetrahedral and octohedral layers does not allow for a single composition for all dioctohedral vermiculite. Interlayer water occupies the space between unit cells, as in smectites; however, the bonding is stronger than in the smectites, and expansion is quite restricted and usually undetectable.

Diocetohedral vermiculite gives a basal reflection at $14\text{\AA}$ that is essentially unaffected by glyceration, but that gradually collapses to $9.3\text{-}12\text{\AA}$ upon heating to above 500°C (Brown, 1959; Heron, et al., 1964).

Illite

The chemical composition of illite is similar to that of muscovite, $\text{KAl}_2(\text{AlSi}_3\text{O}_{10})$, but contains less potassium and more silicon and water (Carrol, 1974). Each unit cell is composed of two tetrahedral layers and one octohedral layer. Basal reflections, occurring at $10\text{\AA}$ and $5\text{\AA}$, are unaffected by glyceration or heating.

APPENDIX D: RAW DATA

core no.	water depth (m)	core depth below creek bottom (m)	core compaction (m)	percent compaction
SC1	1.2	1.7	0.6	35
SC2	1.4	1.5	0.7	47
SC3	1.3	1.7	0.7	41
TC1	1.5	1.9	0.9	47
HC1	1.2	2.0	0.6	30
HC2	1.4	2.2	1.0	45
HC3	1.5	1.7	0.6	35
CC1	1.1	1.7	1.0	59

Table 3. Field data.

sample number ¹⁾	SAMPLE LOCATION in extruded core (m from top)	%Sd	%O	I / I ²⁾ clay / standard			
				K	D.V.	S	I
SC1	A 0-0.25	6.3	13.0	0.70	0.47	0.14	0.17
	B 0.85-1.10	3.9	14.3	0.53	0.41	0.26	0.17
SC2	A 0-0.25	11.1	14.5	0.60	0.24	0.23	0.13
	B 0.55-0.80	22.7	13.7	0.47	0.30	0.15	0.16
SC3	A 0-0.25	34.2	17.9	0.40	0.29	0.14	0.11
	B 0.75-1.00	19.8	17.0	0.24	0.19	0.19	0.09
TC1	A 0-0.25	5.1	14.5	0.62	0.22	0.13	0.12
	B 0.75-1.00	5.2	16.7	0.16	0.17	0.15	0.10
HC1	A 0-0.25	30.3	10.0	0.55	0.45	0.20	0.14
	B 1.15-1.40	37.1	10.5	0.67	0.60	0.23	0.17
HC2	A 0-0.25	5.5	15.6	0.52	0.31	0.16	0.14
	B 0.95-1.20	4.3	16.0	0.27	0.21	0.19	0.08
HC3	A 0-0.25	5.3	20.8	0.42	0.21	0.16	0.14
	B 0.85-1.10	4.8	21.0	0.13	0.16	0.12	0.06
CC1	A 0-0.25	2.9	17.2	0.33	0.21	0.13	0.05
	B 0.45-0.70	5.3	21.5	0.11	0.07	0.10	0.05

Table 4. Laboratory data: 1) "A" is uppermost slit of core, and "B" is lowermost split; 2) Intensity of X-ray diffractogram reflection of the sample divided by the intensity of X-ray diffractogram reflection of the quartz standard. Sd=sand, O=organics, K=kaolinite, D.V.=dioctohedral vermiculite, S=smectite, and I= illite.

Sample Number	Kaolinite	Dioctohedral Vermiculite	Smectite	Illite
S1	P	P	P	P
S2	P	P	P	P
S3	P	P	P	P
S4	P	P	?	?
S5	P	P	P	P
S6	P	P	P	P
S7	P	P	?	P
S8	P	P	P	P
S9	P	P	P	A
S10	P	P	P	P
S11	P	P	A	P
S12	P	P	?	?
S13	P	P	P	?
H1	P	P	A	P
H2	P	P	A	P
H3	P	P	?	?
H4	P	P	P	P
H5	P	P	P	P
H6	P	P	P	P
H7	P	P	P	?
H8	P	P	?	?
H9	P	P	P	?
H10	P	P	P	P
H11	P	P	A	P
H12	P	P	P	P
H13	P	P	P	P

Table 5. Clay minerals in the channel samples taken in Slocum and Hancock creeks. P=present, A=absent, ?= possibly present.

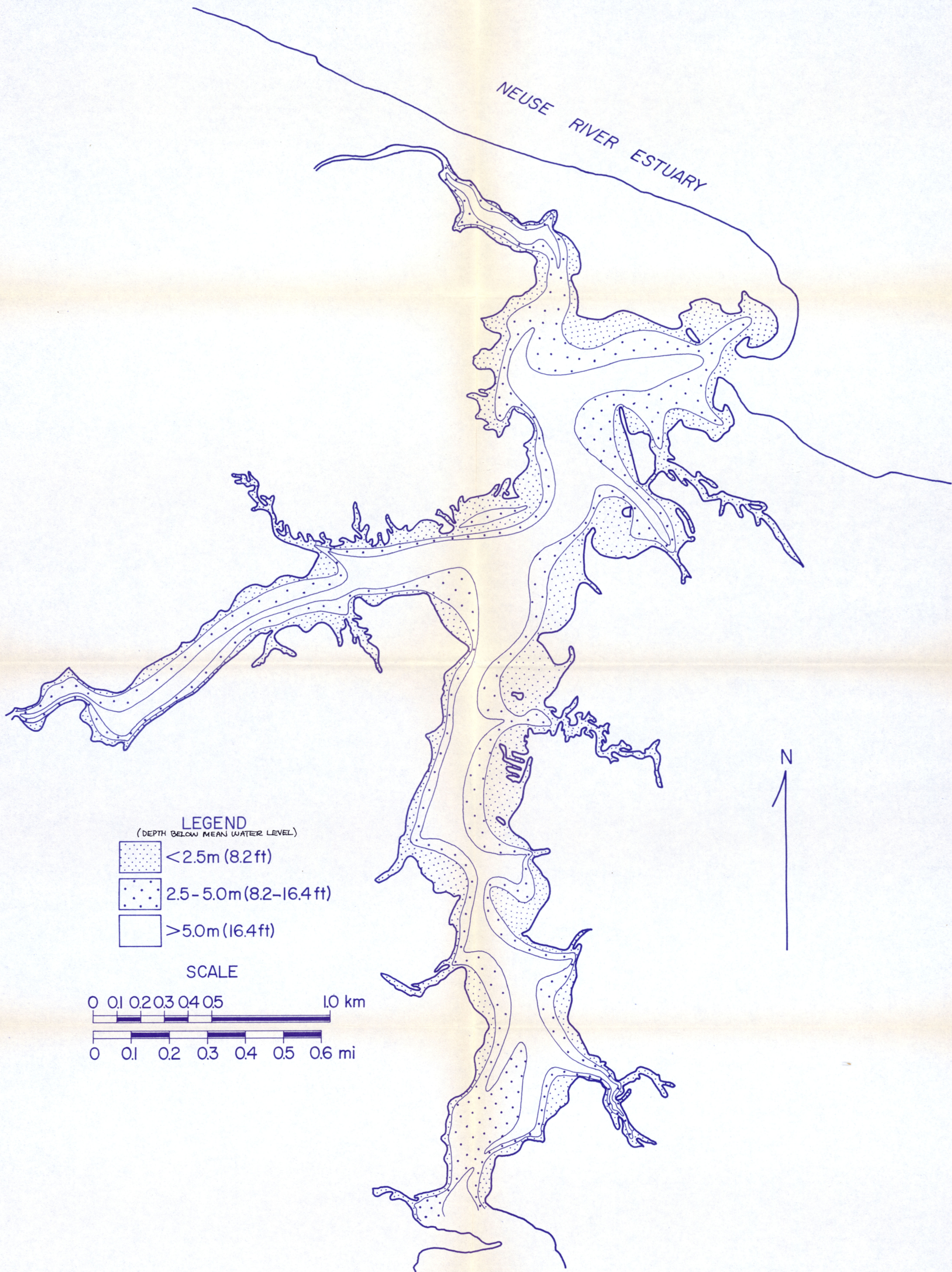


FIGURE 6. STRUCTURE CONTOUR MAP of the PRE-MUD SURFACE in SLOCUM CREEK.

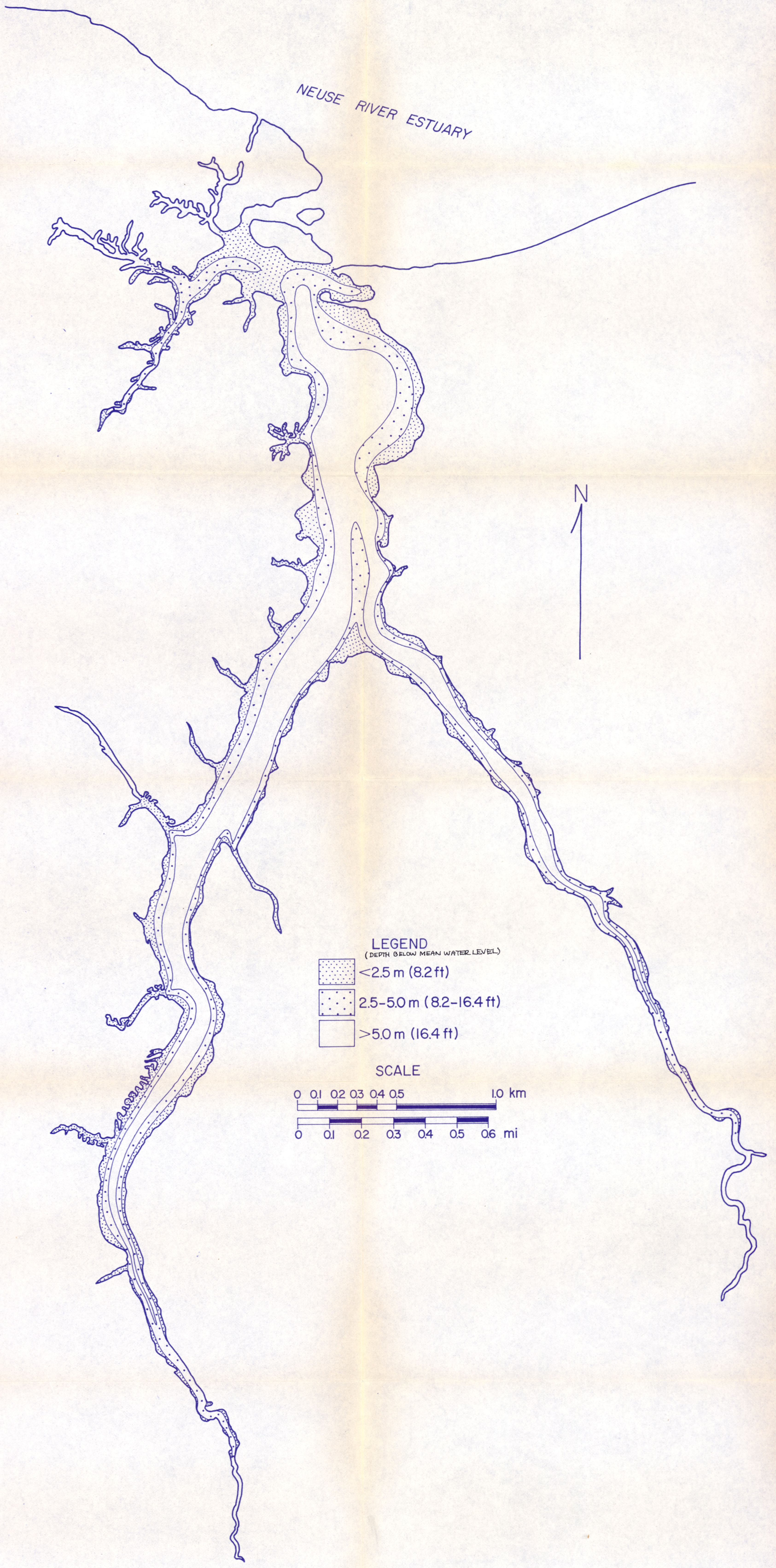


FIGURE 7. STRUCTURE CONTOUR MAP of the PRE-MUD SURFACE in HANCOCK CREEK.

GE
148
SS
Dix
map4

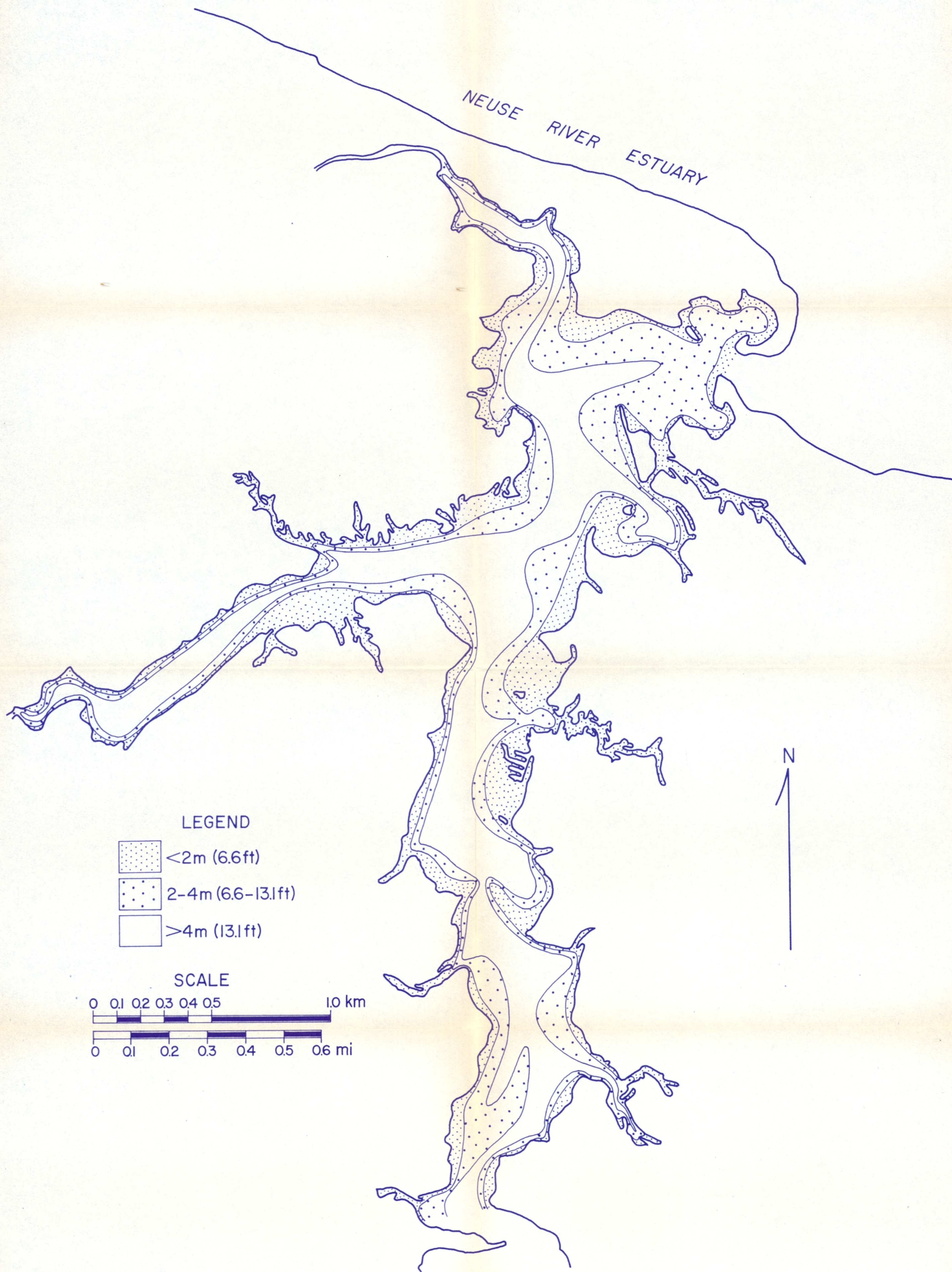


FIGURE 10. ISOPACH MAP of the MUD
in SLOCUM CREEK.

DE
1/88
SS
D8x
map 2

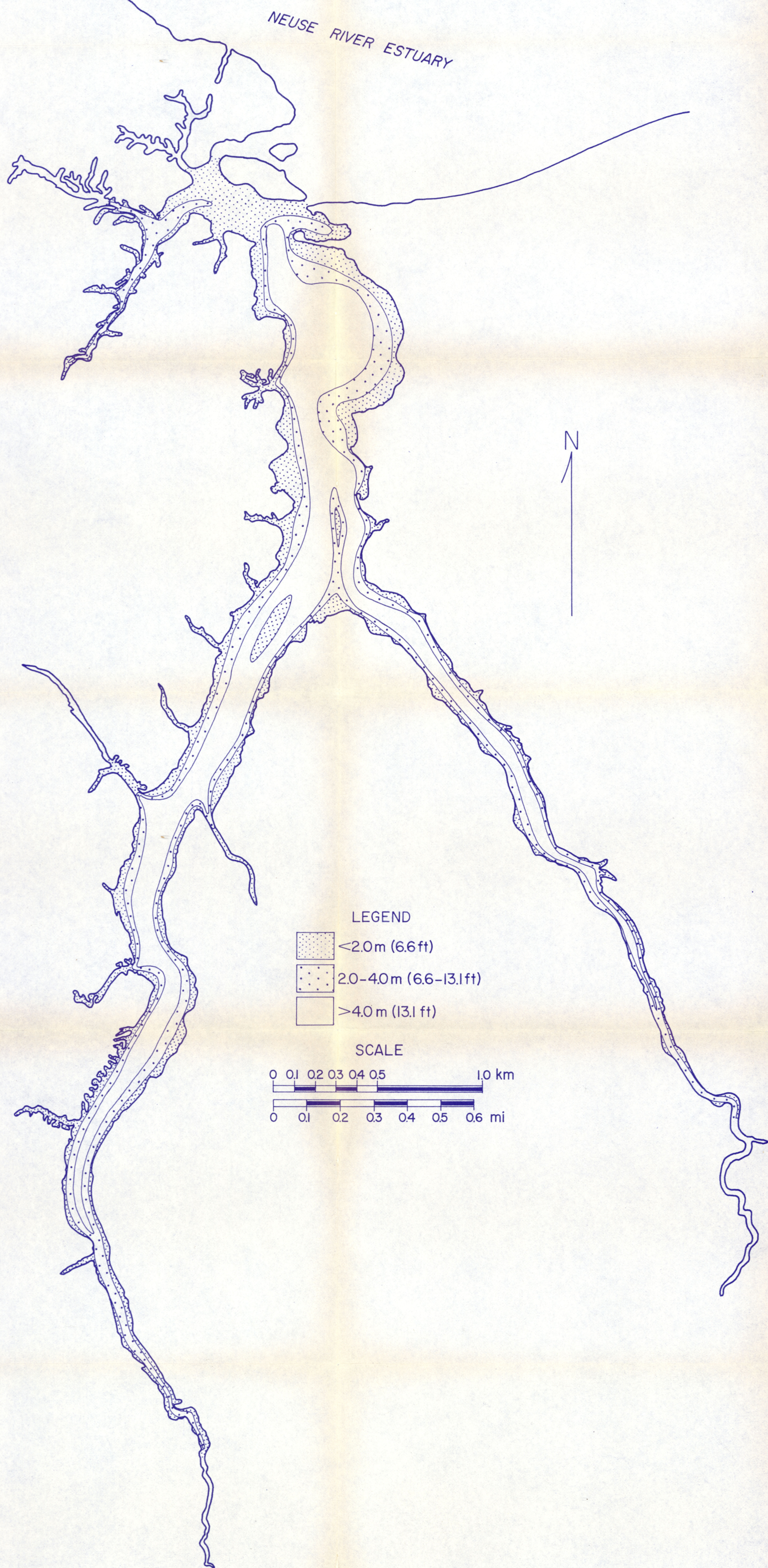


FIGURE II. ISOPACH MAP of the MUD in HANCOCK CREEK.