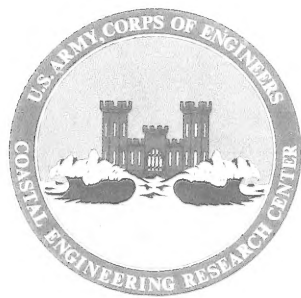


Reconnaissance Geology of the Inner Continental Shelf, Cape Fear Region, North Carolina

by
Edward P. Meisburger

TECHNICAL PAPER NO. 79-3
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More than half of the area surveyed is underlain by two thick sections of Coastal Plain sediments characterized by seaward-dipping progradational internal beds which generate a characteristic acoustic pattern on seismic reflection records. These beds are exposed on the shelf floor in places and elsewhere are covered by a thin sediment blanket. Samples of these extensive units indicate that one is of Cretaceous age and the other of Oligocene age. Both units consist predominantly of fine quartz sand.

Other sediment units closely underlying the shelf floor consist of planar- to complex-bedded sheet and channel-fill deposits of predominantly quartz sand or biogenic calcium carbonate. These deposits range in age from Eocene to Holocene.

Modern sediment accretion on the inner shelf appears to be largely restricted to the shoal fields off Cape Lookout and Cape Fear, and to inlet shoals along the coast. Elsewhere on the inner shelf floor, modern sediments are thin and discontinuous, and modern shelf processes appear to be largely confined to reworking, winnowing, and redepositing older deposits.

PREFACE

This report is one of a continuing series which describe results of the Inner Continental Shelf Sediment and Structure (ICONS) study. One objective of the ICONS study is to provide geological information of the Inner Continental Shelf pertinent to the planning and design of engineering works and to a better understanding of geological aspects of the coastal zone as an engineering environment. Another objective of the ICONS study is to locate and describe offshore sand deposits suitable for beach nourishment and restoration (see Meisburger, 1977).

The report was prepared by Edward P. Meisburger, a geologist in the Geotechnical Engineering Branch of CERC, under the general supervision of R.L. Rector and S.J. Williams, who served successively as Acting Chief of the Branch, and Dr. C.H. Everts, the present Chief. As part of the research program of the Engineering Development Division, the ICONS study was under the general supervision of G.M. Watts, former Chief of the Division.

Preliminary study of the data collected was made by Dr. M.E. Field, formerly with CERC and presently with the U.S. Geological Survey. The fieldwork involving coring and continuous seismic reflection profiling was accomplished under contract by Alpine Geophysical Associates, Inc.

Microfilm of all seismic data is stored at the National Solar and Terrestrial Geophysical Data Center (NSTGDC), Rockville, Maryland 20852. Cores collected during the field survey program are in a repository at the University of Texas, Arlington, Texas 76010, under agreement with CERC. Requests for information relative to these items should be directed to NSTGDC or the University of Texas.

Comments on this publication are invited.

Approved for publication in accordance with Public Law 166, 79th Congress, approved 31 July 1945, as supplemented by Public Law 172, 88th Congress, approved 7 November 1963.



TED E. BISHOP

Colonel, Corps of Engineers
Commander and Director

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CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

| Multiply | by | To obtain |
|--------------------|-------------------------|---|
| inches | 25.4 | millimeters |
| | 2.54 | centimeters |
| square inches | 6.452 | square centimeters |
| cubic inches | 16.39 | cubic centimeters |
| feet | 30.48 | centimeters |
| | 0.3048 | meters |
| square feet | 0.0929 | square meters |
| cubic feet | 0.0283 | cubic meters |
| yards | 0.9144 | meters |
| square yards | 0.836 | square meters |
| cubic yards | 0.7646 | cubic meters |
| miles | 1.6093 | kilometers |
| square miles | 259.0 | hectares |
| knots | 1.852 | kilometers per hour |
| acres | 0.4047 | hectares |
| foot-pounds | 1.3558 | newton meters |
| millibars | 1.0197×10^{-3} | kilograms per square centimeter |
| ounces | 28.35 | grams |
| pounds | 453.6 | grams |
| | 0.4536 | kilograms |
| ton, long | 1.0160 | metric tons |
| ton, short | 0.9072 | metric tons |
| degrees (angle) | 0.01745 | radians |
| Fahrenheit degrees | 5/9 | Celsius degrees or Kelvins ¹ |

¹To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: $C = (5/9) (F - 32)$.

To obtain Kelvin (K) readings, use formula: $K = (5/9) (F - 32) + 273.15$.

RECONNAISSANCE GEOLOGY OF THE INNER CONTINENTAL SHELF,
CAPE FEAR REGION, NORTH CAROLINA

by
Edward P. Meisburger

I. INTRODUCTION

1. Background and Purpose.

The construction, improvement, and periodic maintenance of beaches and dunes by placement (nourishment) of suitable sand along the shoreline is an important means of counteracting coastal erosion and enhancing recreational facilities. Both initial beach restoration and periodic renourishment usually involve large volumes of sandfill. However, it has become increasingly difficult in recent years to obtain suitable sand from traditional sources (i.e., lagoons and inland sources) because of economic and ecological factors.

The problems of locating suitable and economical sand deposits led the U.S. Army Coastal Engineering Research Center (CERC) to initiate a search for offshore deposits of sand. Exploratory efforts to locate and inventory deposits suitable for future fill requirements began in 1964 with a survey off the New Jersey coast (Duane, 1969). Subsequent data collection surveys have included the Inner Continental Shelf areas off New England, Long Island, Delaware, Maryland, Virginia, Florida, the Cape Fear region of North Carolina, south shore of Lake Erie, eastern Lake Michigan, and southern California. This program, initially known as the Sand Inventory Program, is now referred to as the Inner Continental Shelf Sediment and Structure (ICONS) program.

The type of data collected for ICONS studies is not only useful in locating potential borrow areas but is of further value in providing geological information for the planning, design, and environmental impact evaluation of other coastal engineering works. Moreover, knowledge of the regional framework, history, and processes characterizing this little known part of the coastal zone is necessary for planning and conducting investigations in many areas of coastal zone research. For these reasons, ICONS reports have not been limited solely to an evaluation of sand resources but have included information on the geology of the inner shelf as revealed by the basic data sources. Under recently revised procedures, the results of ICONS regional studies will be presented in two separate but complimentary reports--one covering the geological aspects of the inner shelf region, and a companion report covering sand resources in the same region. The Cape Fear ICONS studies are the first to be produced under the revised procedures.

2. Location and Data Coverage.

The study area, a part of the North Carolina Atlantic Continental Shelf, lies within about 26 kilometers (14 nautical miles) of the coast

and extends from the South Carolina border through Long Bay, Frying Pan shoals, and Onslow Bay to Cape Lookout (Fig. 1). Based on survey density, the study area is divided into two segments: the main survey area, which extends about 13 kilometers (7 nautical miles) offshore and lies between the South Carolina border and New River Inlet in Onslow Bay (Figs. 2 and 3), and the reconnaissance area (Fig. 4). The main survey area contains the most detailed data coverage; the reconnaissance area is covered by widely spaced seismic reflection profiles and cores. Data obtained by the ICONS survey in the Cape Fear region consist of 824 kilometers (445 nautical miles) of seismic reflection profiles and 124 cores ranging from 0.6 to 6.1 meters (2 to 20 feet) in length. These data are supplemented by pertinent scientific and technical literature and National Ocean Survey (NOS) hydrographic data.

3. Geologic Setting.

The Atlantic Continental Shelf bordering North Carolina is a submerged extension of the southeast Atlantic Coastal Plain Province. Both the coastal plain and shelf in the study area are topographically subdued and slope gently southeastward. The mainland shore is fringed by barrier islands sheltering a belt of coastal lagoons and marshes. Seaward of the beach a relatively steep shoreface slopes to depths of -9 to -18 meters (-30 to -60 feet) mean low water (MLW) where the gradient flattens into the characteristic gentle seaward dip of the shelf floor. The shelf floor is a wide submarine plain extending 102 kilometers (55 nautical miles) offshore where at a depth of about -45.7 meters (-150 feet) MLW the shelf edge begins.

Coastal plain rock units that crop out on the emerged coastal plain adjacent to the study area consist primarily of marine quartzose and biogenic carbonate sediments and rocks of Cretaceous, Paleocene, Eocene, Miocene, Plio-Pleistocene, and Quaternary age. Preliminary analyses of lithology and fauna in the cores collected from the study area indicate that the inner part of the shelf is closely underlain by sediments of Cretaceous, Paleocene, Eocene, Oligocene, Miocene, and Plio-Pleistocene age. These units crop out on the sea floor in many places; elsewhere they are usually within 4.6 meters (15 feet) of the surface. Quaternary sediments are thus thin and discontinuous throughout much of the study area.

The stratigraphic framework of Atlantic Coastal Plain rocks from North Carolina to New York was discussed in Brown, Miller, and Swain (1972). Instead of using traditional stratigraphic subdivisions applied to Atlantic Coastal Plain rocks, they proposed a modified framework based on 17 chronostratigraphic units. For the Cenozoic section, these units were based on an extension of current gulf region chronostratigraphic boundaries and nomenclature into the Atlantic region. For Mesozoic rocks, informal chronostratigraphic units were designated by the letters A to I. Seven of the units proposed by Brown, Miller, and Swain occur at or near enough below the inner shelf of the Cape Fear region to be within range of cores or seismic reflection data used in this report. These seven units and the formations generally recognized in the coastal plain rocks

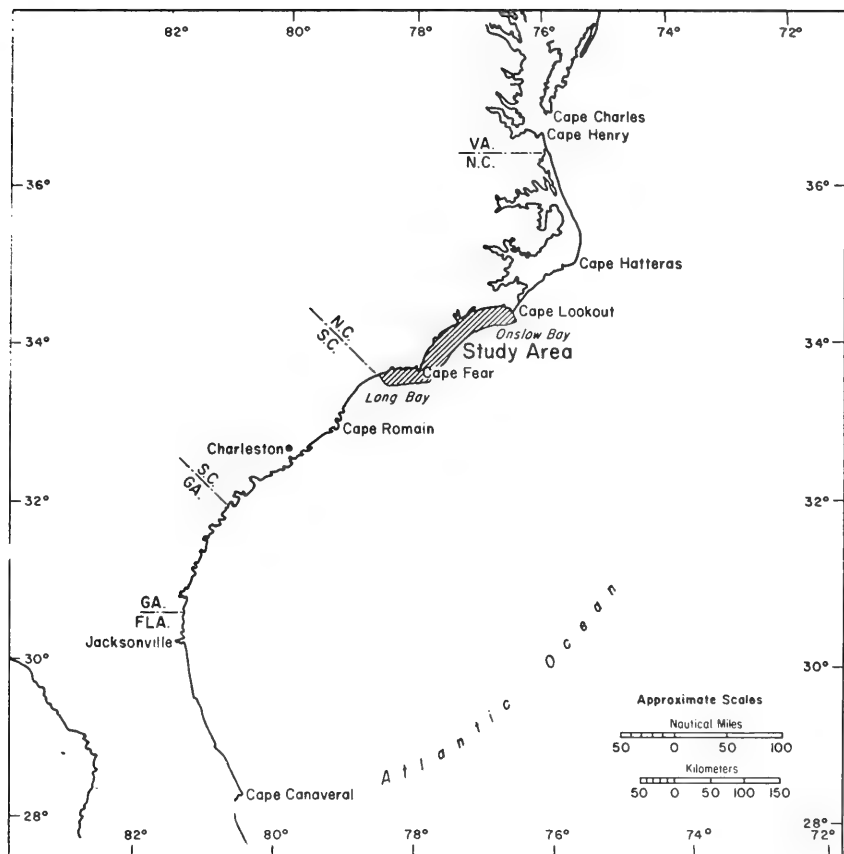


Figure 1. Location of the study region and boundaries of the ICONS survey area.

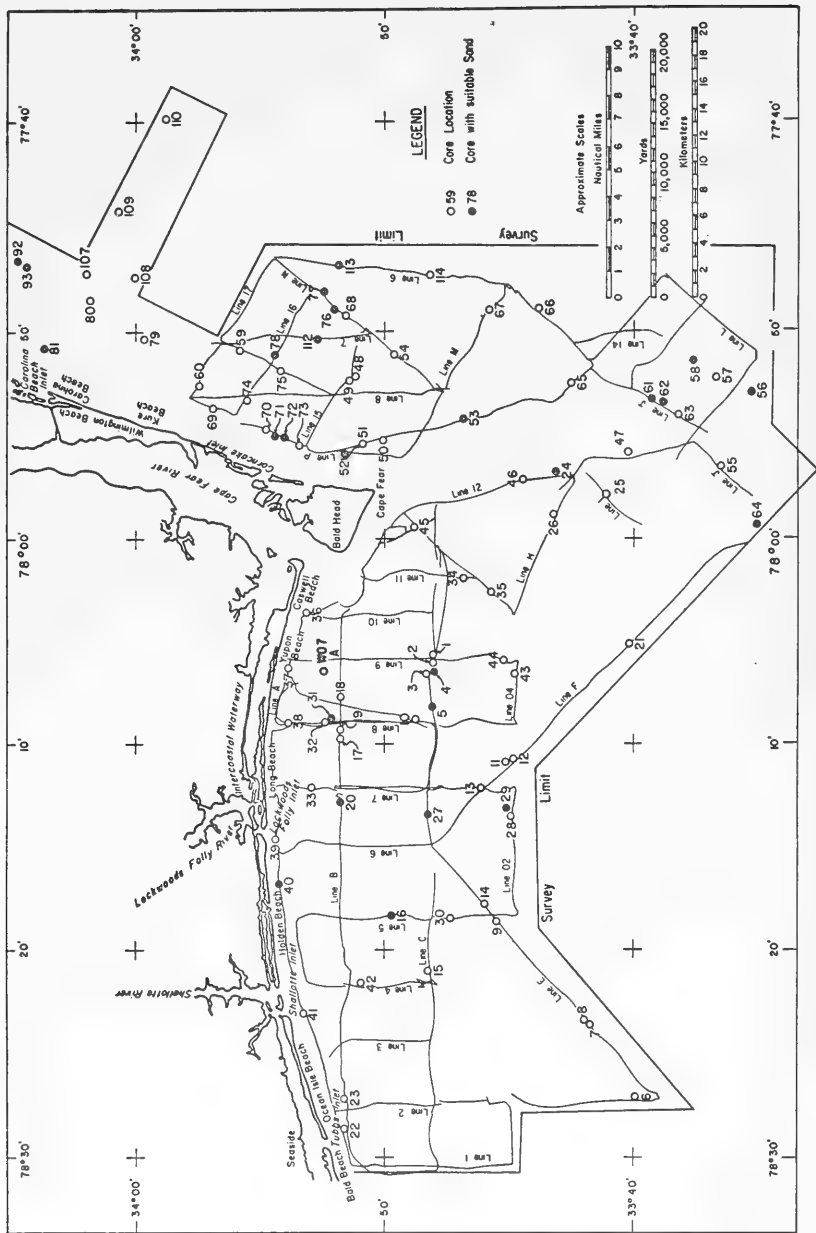


Figure 2. General map of the western part of the study area showing survey coverage.

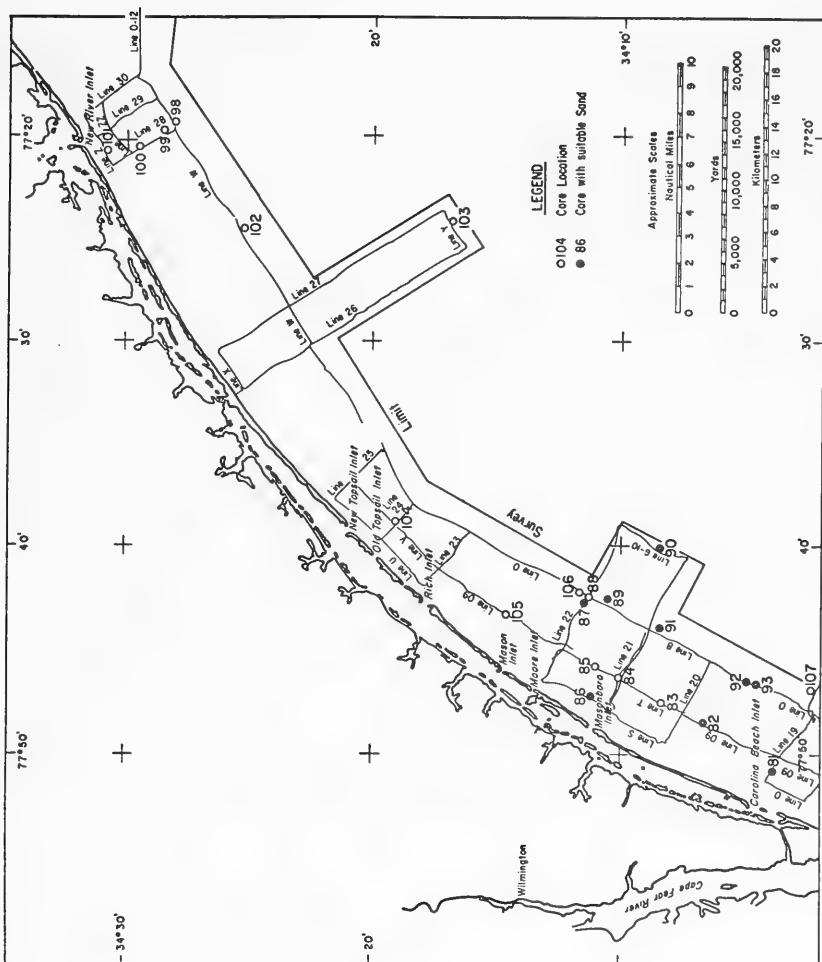


Figure 3. Map of the northeastern part of the main survey area showing seismic reflection survey lines and core sites.

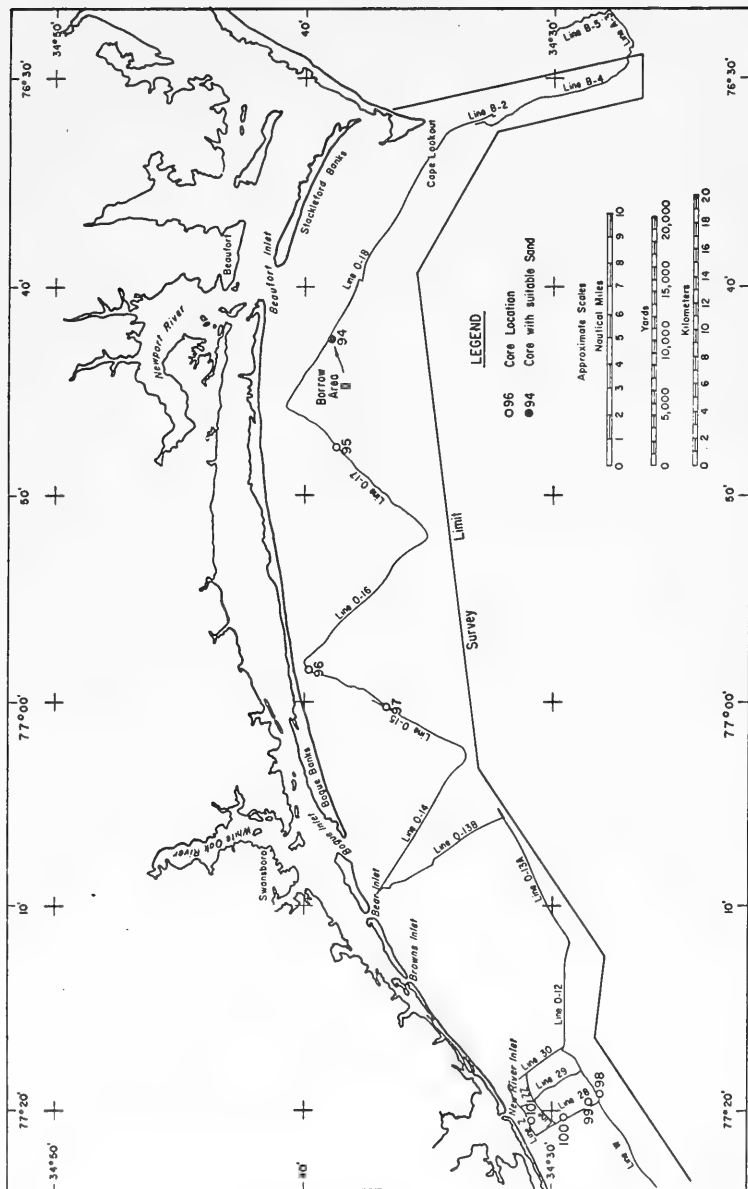


Figure 4. Map of the reconnaissance area showing seismic reflection and core coverage.

of southern North Carolina are listed in Table 1. The formations are shown in probable age relationships to the chronostratigraphic units of Brown, Miller, and Swain. These relationships do not imply precise equivalence; the implication is that the age of the part of the formation which was accessible for study probably falls within the chronological boundaries of the designated unit.

4. Field and Laboratory Procedures.

The field exploration phase of the ICONS program uses continuous seismic reflection profiling supplemented by cores of the bottom sediment. Support data are obtained from NOS hydrographic smooth sheets, engineering logs from boreholes, and from published literature.

a. Data Collection Planning. Geophysical survey tracklines for the study area are laid out in two basic patterns: grid and reconnaissance lines. A grid pattern with variable line spacing depending on regional geology, is used where a relatively detailed picture of sea floor and subbottom geologic conditions is needed. Reconnaissance lines, which are more widely spaced, are used for minimal coverage of the areas between grids. Reconnaissance lines reveal the general morphologic and geologic aspects of the area and identify sea floor areas where more detailed data collection may be advisable. Selection of individual core sites is based on a continuous study of the seismic records as they become available during the survey.

b. Seismic Reflection Profiling. Seismic reflection profiling is a technique widely used for delineating subbottom geologic structures and bedding surfaces in sea floor sediments and rocks. Continuous reflections are obtained by generating repetitive, high-energy sound pulses near the water surface and recording "echoes" reflected from the sea floor-water interface and subbottom interfaces between acoustically dissimilar materials. The compositional and physical properties (e.g., porosity, water content, relative density), which commonly differentiate sediments and rocks, also produce acoustic contrasts (indicated by dark lines on the geophysical records). Thus, an acoustic profile is roughly comparable to a geologic cross section.

Seismic reflection surveys of marine areas are made by towing variable energy and frequency sound-generating sources and receiving instruments behind a survey vessel which follows the predetermined survey tracklines. The energy source used for this survey was a 50- to 200-joule sparker. For continuous profiling, the sound source is fired at a rapid rate (usually four pulses per second) and returning echo signals from sea floor and subbottom interfaces are received by an array of towed hydrophones. Returning signals are amplified and fed to a recorder which graphically plots the two-way signal traveltime. Assuming in this study a constant velocity for sound in water at 1,463 meters (4,800 feet) per second and for typical shelf sediments of 1,658 meters (5,440 feet) per second, a vertical depth scale was constructed to fit the geophysical record. Geographic position of the survey vessel is obtained by frequent navigational fixes keyed to the record by an event marker.

Table 1. Upper Cretaceous to Holocene stratigraphic units of southern North Carolina.

| Period | Epoch | Formation ¹ | Chronostratigraphic units (Brown, Miller, and Swain, 1972) |
|------------|--------------|------------------------|--|
| Quaternary | Holocene | Ocean Forest Peat | Undifferentiated rocks of post-Miocene age |
| | Pleistocene | Princess Ann | |
| Talbot | | | |
| Wicomico | | | |
| | Okefenokee | | |
| Tertiary | Pliocene | Waccamaw | |
| | | Duplin-Yorktown | |
| | Miocene | Pungo River | Rocks of late Miocene age |
| | | | Rocks of middle Miocene age |
| | Oligocene | Unnamed | Rocks of Oligocene age |
| Eocene | Castle Hayne | Rocks of Claiborne age | |
| | | Rocks of Sabine age | |
| Paleocene | Beaufort | Rocks of Midway age | |
| Cretaceous | | Pee Dee | Cretaceous unit A |

¹Based on North Carolina Department of Conservation and Development (1958), Stuckey and Conrad (1958), Richards (1967), and Campbell, et al. (1975).

Detailed discussions of seismic profiling techniques are found in Ewing (1963), Hersey (1963), Van Reenan (1963), Miller, Tirey, and Mecarini (1967), Moore and Palmer (1968), Barnes, et al. (1972), and Ling (1972).

c. Coring Techniques. The sea floor coring device used is a pneumatic, vibrating piston-type coring assembly designed to obtain core samples of 6-meter (20 feet) maximum length and 10-centimeter (4 inches) diameter. The apparatus consists of a standard steel core barrel with a pneumatic driving head attached to the upper end of the barrel, a plastic inner liner, a shoe, and a core catcher. These elements are enclosed in a tripodlike frame with articulated legs which rest on the sea floor during the coring operation. The separation of the coring device from the surface vessel allows limited motion of the vessel during the actual coring process. Power is supplied to the pneumatic vibrator head by a flexible hose line connected to a large capacity, deck-mounted air compressor. After the coring is completed, the assembly is winched on board the vessel where the liner containing the core is removed, capped at both ends, and marked and stored. The historical development of vibratory coring equipment is discussed by Tirey (1972).

d. Processing of Data. Seismic records are visually examined to establish the principal acoustic features in the subbottom strata. Record data are then reduced to detailed cross-sectional profiles showing the primary reflective interfaces within the subbottom (see App. A for seismic profile data for this study). Selected acoustic reflectors are mapped to provide areal continuity of significant reflective horizons. Where possible, the reflectors are correlated with core data to provide a measure of continuity between cores and to establish the lithologic character of reflection units.

Cores are visually inspected and described aboard the vessel, then delivered to CERC where the cores are sampled at close intervals by drilling through the liners and removing parts of material. After preliminary analysis, a number of cores are split longitudinally to show details of the bedding and changes in stratigraphy.

Core samples are examined under a binocular microscope and described in terms of gross lithology, color, mineralogy, and the type and abundance of skeletal fragments of marine organisms (see App. B for core descriptions in this study). Granulometric parameters (e.g., mean size, sorting) for many samples are obtained by using the CERC Rapid Sand Analyzer (RSA) which is analogous to that described by Zeigler, Whitney, and Hays (1960) and Schlee (1966). Appendix C lists the granulometric data for selected samples from the North Carolina cores. A constituent analysis of sediments from the study area is in Appendix D.

Foraminifera from selected ICONS core samples were mounted on micro-paleontology slides for identification. The identification of all the types present was beyond the scope of this study. However, the compiled species list (App. E) is considered detailed enough for the purposes

discussed in this section and for future identification and correlation of sediment bodies discussed in Section IV.

II. SEISMIC REFLECTION RESULTS

1. General.

Seismic reflection records of the study area show acoustic reflectors to depths ranging from a few meters to as much as 122 meters (400 feet) below the shelf floor. Penetration of 30 meters (100 feet) or more was obtained on most records. Selected line profiles reduced from the seismic reflection records are contained in Appendix A.

All reflectors on seismic reflection profiles are assumed to have some geological significance. In this study reflecting horizons which persist over a large area are called *primary reflectors* (Fig. 5); such reflectors delineate a laterally extensive acoustic contrast between bounding units related to one or more sediment properties. Between primary reflectors there may be numerous localized reflectors called *secondary reflectors*. Most secondary reflectors are associated with internal bedding surfaces, local erosional discontinuities such as stream channels, or relatively small sediment bodies of short, lateral extent. The term *reflection unit* denotes extensive bodies of sediment or rock which can be identified and traced on profiles by their bounding primary reflectors and distinctive internal secondary reflector patterns.

Most of the main survey area is underlain by four extensive reflection units (I, II, III, and IV) which are bounded by primary reflectors and can be identified by distinctive internal reflector patterns. The approximate areas of outcrop or shallow subcrop (generally less than 3 meters or 10 feet) are shown in Figure 6. No reflection units were defined north of New Topsail Inlet (reconnaissance area in Fig. 6) because of sparse data coverage. However, available cores and profiles indicate that this area is probably closely underlain by more than one distinctive sediment or rock unit.

2. Primary Reflectors.

The two most extensive primary reflectors in the study area are called *blue* and *green* reflectors. The *blue reflector* marks the top of reflection units I, II, III, and IV. The thickness of sediment above the blue reflector, where it overlies units I, II, and III, is shown on an isopach map in Figures 7 and 8. To show the location and configuration of channels containing unit IV, the isopach base for areas underlain by this unit was shifted from the blue reflector to the channel walls; thus, the isopach interval includes unit IV. The thickness of sediment above the blue reflector overlying unit IV generally does not exceed 3 meters; however, in Frying Pan shoals off Cape Fear the shoal sands overlying the blue reflector exceed 15.2 meters (50 feet) in places.

The blue reflector marks an erosional unconformity because it truncates internal reflectors in underlying units and it transgresses the

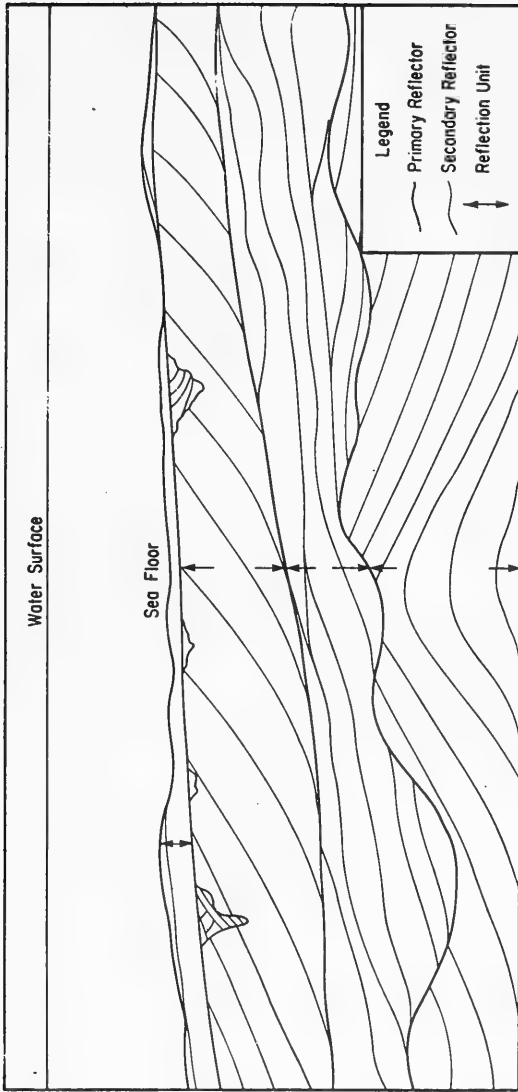


Figure 5. Idealized seismic reflection profile showing primary and secondary reflectors and a reflection unit.

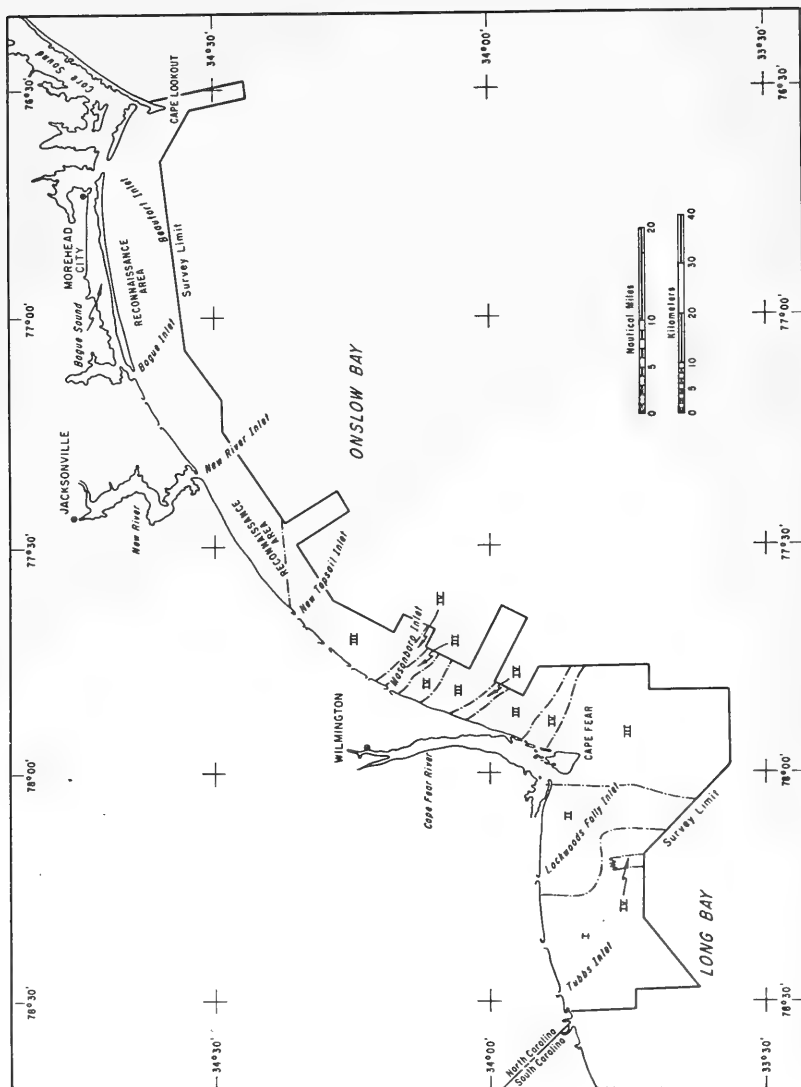


Figure 6. Map of the study area showing outcrop or shallow subcrop areas (generally less than 3 meters) of the various reflection units.

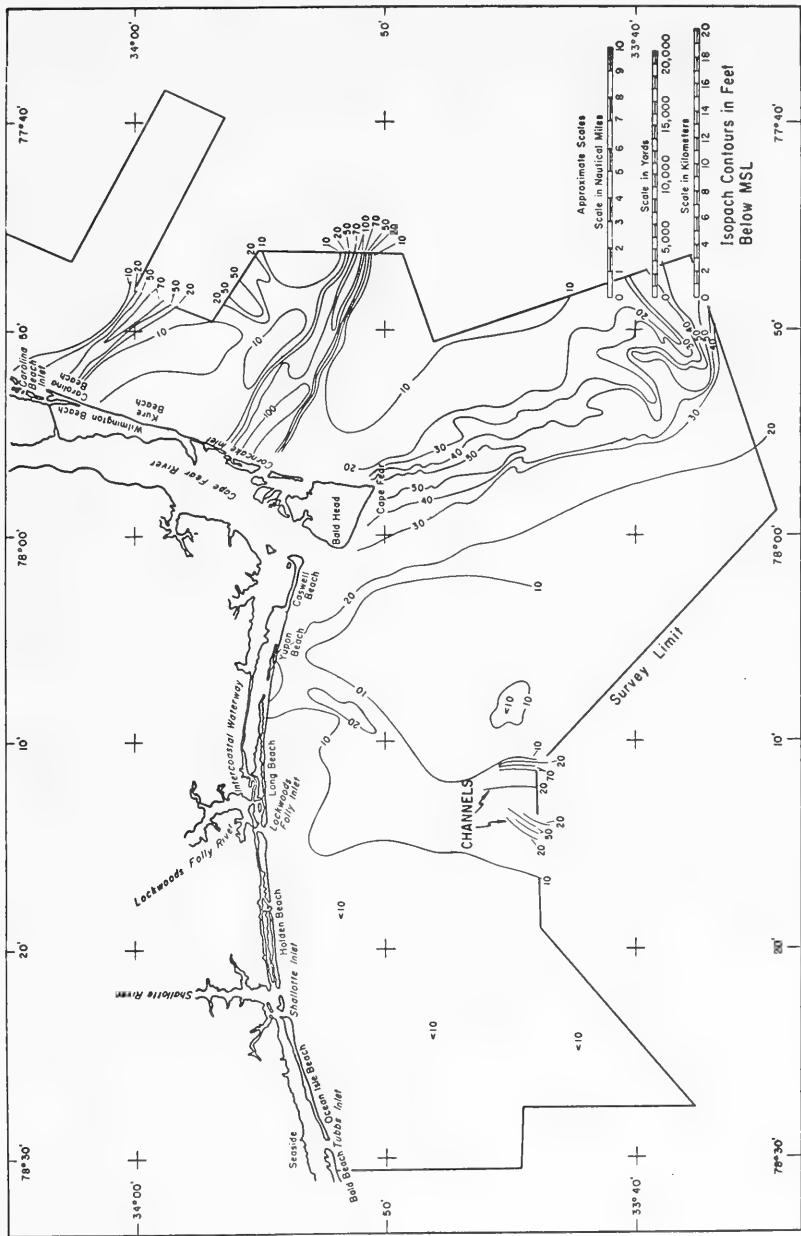


Figure 7. Isopach map showing the surfaces of reflection units I, II, and III, the base of unit IV, and the western part of the main survey area.

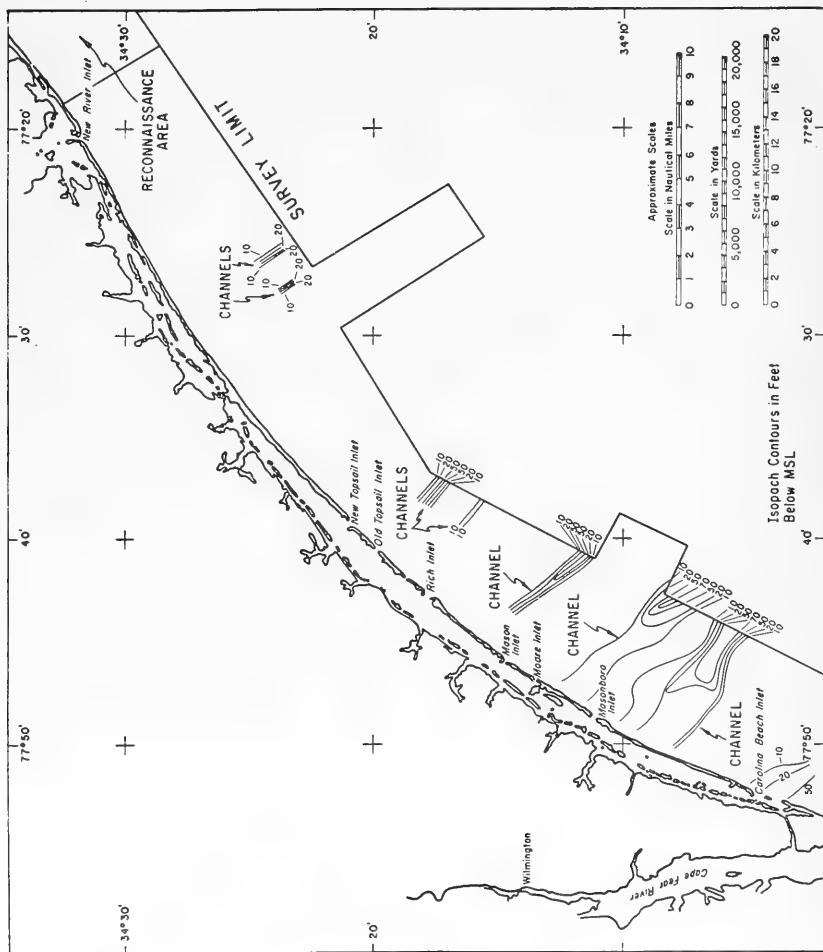


Figure 8. Isopach map showing the surfaces of reflection unit III and base of unit IV in the western part of the main survey area.

tops of units with different geological ages. None of the structural and erosional features in underlying units affect the configuration of the blue reflector surface which is relatively level and featureless. Most of the development of the blue surface probably occurred during marine transgressions and regressions associated with worldwide Plio-Pleistocene sea level fluctuations. The slope and surface morphology of the inner shelf floor are largely controlled by the blue reflector surface which has little or no sediment cover in most places.

Figures 9 and 10 show contours on the surface of a second mapped primary reflector, the *green reflector*, which lies well below the blue reflector. This reflector is the strongest and most persistent found on the profiles. The reflections indicate that the green reflector is a relatively smooth surface dipping in an east-southeast to southeast direction. A projected terrestrial outcrop line trends north-south along the coast of southern Onslow Bay and extends southward into eastern Long Bay. It is believed from evidence, which will be discussed later, that the green reflector marks the top of the Eocene-age rocks in this region.

3. Reflection Units.

Reflection unit I, which underlies the southwest part of the study area, extends offshore to the seaward survey limits and probably westward, beyond study limits, into the South Carolina shelf region. Profiles 21, 22, and 23 (App. A) and Figure 11 show reflection features of unit I seen in shore-normal profiles. The distinctive internal reflectors suggest forset-type bedding and growth of the deposit by southward progradation. The upper surface lies very close to the shelf floor and there appear to be extensive areas of outcrop. The top of the unit has been beveled by erosion truncating the distinctive internal reflectors and forming an even surface dipping very gently southward. This surface essentially determines the gradient of the inner shelf floor within the area where unit I comprises the uppermost subbottom unit as shown in Figure 6.

At the base of unit I a strong reflector (profiles E and 21, App. A) extends only a short distance seaward before being lost due to the relatively shallow penetration of seismic records in the area. Where the base reflector is visible, the thickness of unit I ranges from nearly 0 to 37 meters (120 feet) and continually increases southeastward. The thickness is probably much more than 37 meters in most of the study area.

The dip of the base reflector where it can be seen is toward the southeast. The dip of the internal forset-type reflectors within the unit is predominantly toward the south at about 20 feet per mile (1:264).

Unit II appears to horizontally separate units I and III; however, it may actually overlie one of these units. The top of unit II produces a strong reflection (blue reflector) marking its slightly uneven surface. Coherent reflectors below this surface are rare (Fig. 12; App. A profiles D, E, and 20); thus, the thickness of the unit, with its bedding characteristics and relationship to other units, is obscure.

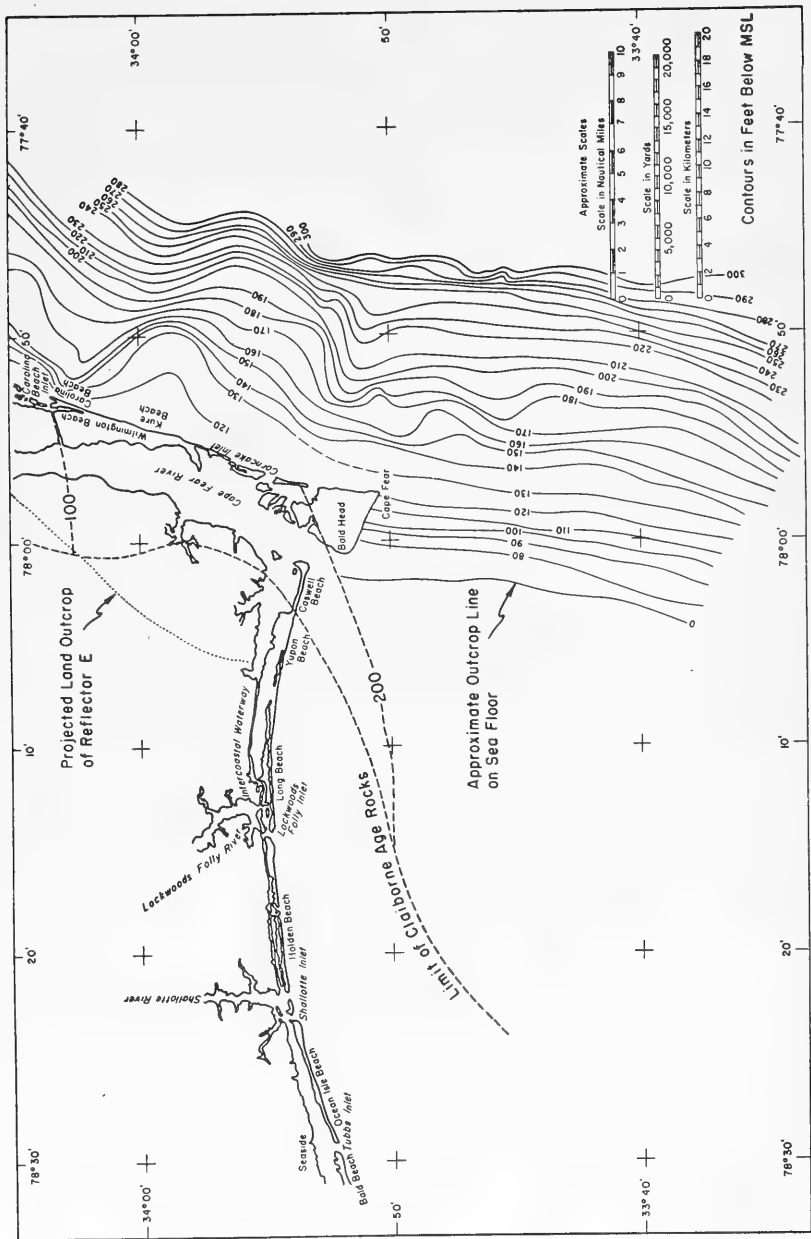


Figure 9. Contours on the surface of the green reflector in the southern part of Onslow Bay.

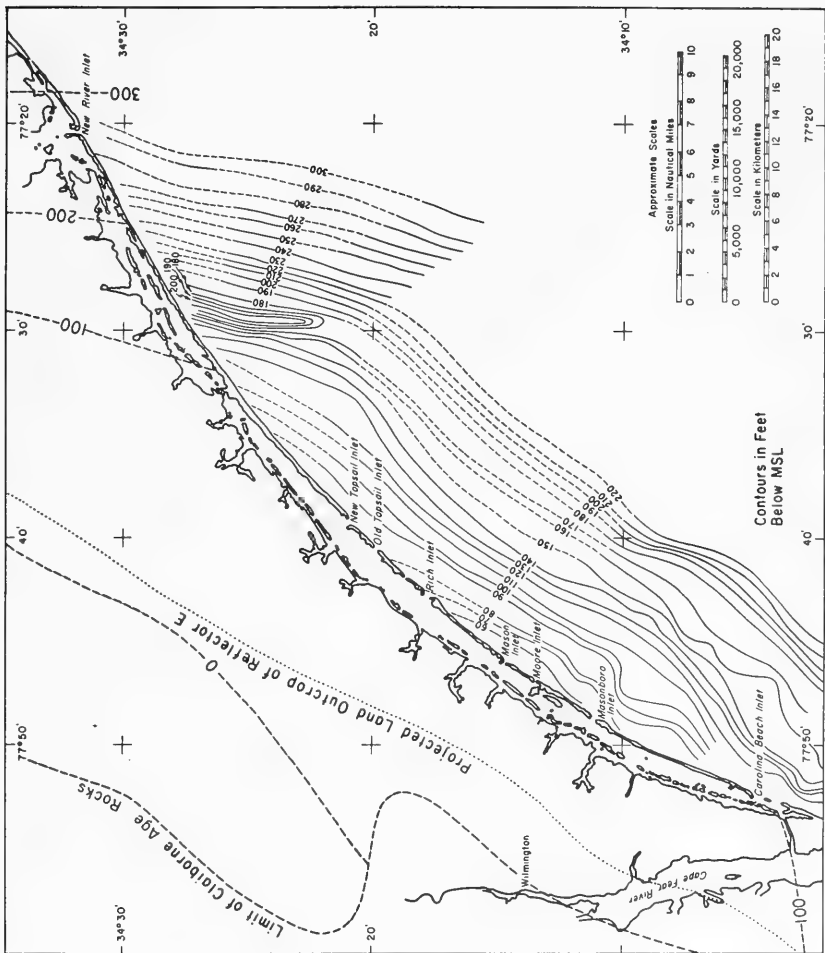


Figure 10. Contours on the surface of the green reflector in the central part of Onslow Bay.

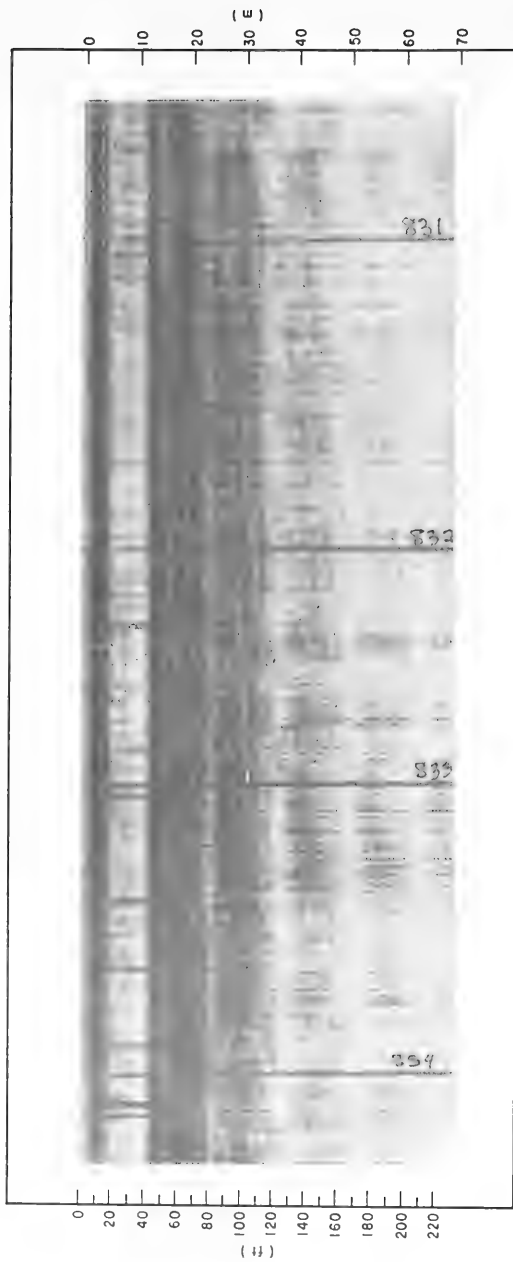


Figure 11. Seismic reflection profile showing the typical pattern of internal reflectors in reflection unit I.

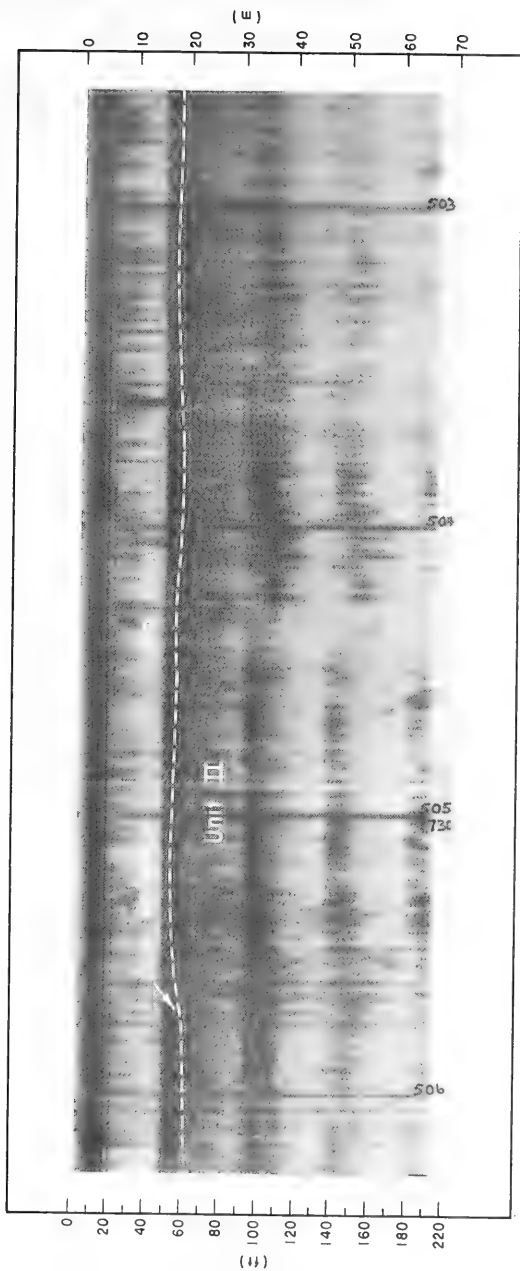


Figure 12. Seismic reflection profile showing the typical near-surface reflector and lack of internal reflectors in reflection unit II.

The lack of penetration below the subbottom reflector over unit II appears to be due to the impenetrability of the unit's surface and not to malfunction of the seismic reflection system or poor sea conditions. Profiles of this area were made over a time period when sea conditions varied and the profiles that were run continuously from the area underlain by unit II into units I and III showed good penetration in segments underlain by the latter units.

Reflection unit III extends from eastern Long Bay to Frying Pan shoals, where it is deeply buried by shoal sands, through Onslow Bay to as far north as New Topsail Inlet (Fig. 6). Internal secondary reflectors in unit III dip southeast to south at 20 to 40 feet per mile (1:264 to 1:132). The pattern is distinctive and suggests that the deposit consists of forset-type beds which were added in a progradational series extending the deposit in a south and southeast direction across the present inner shelf area.

Figure 13 is a photo reproduction of a unit III seismic reflection profile showing these distinctive beds. Profiles A, B, and C in Appendix A provide a general illustration of the configuration and internal bedding patterns of the unit as viewed on a shore-parallel course. Most shore-normal profiles in Onslow Bay also show unit III; however, typical characteristics are best shown by the longer profiles.

The base of unit III appears to rest throughout the area on the prominent green reflector. The dip of the green reflector is generally southeast, while the more variable internal secondary reflectors in the overlying unit III dip from east to southeast. The top of unit III, like unit I, is beveled by an erosional surface (blue reflector) which truncates the internal reflectors. This surface slopes very gently in an east-southeast to southeast direction. Unit III is thickest (more than 61 meters or 200 feet) in the southeast part of the main grid area and thins toward shore and to the north. Off Wrightsville Beach unit III is little more than 6.1 to 15.2 meters (20 to 50 feet) thick.

Filled channels, reaching a depth of more than 46 meters (150 feet) in places, cut into units I and III. Fill in these channels often produces characteristic complex internal reflector patterns on seismic reflection records typified by great variability in reflector length, dip, and grouping. Figure 14 is a typical example of one of these channels (see also App. A, profiles B and C). These complex-bedded channel-fill deposits are collectively called reflection unit IV. Their location and configuration are shown in Figures 6, 7, and 8.

Most of the large channels of unit IV are located in Onslow Bay. Two large channels were detected in Long Bay but reflection coverage and insufficient penetration provided only fragmentary information.

Seismic reflection profiles are too sparse north of New Topsail Inlet to define the reflection characteristics of subbottom strata in that area. However, changes are indicated in seismic reflector patterns and sediment

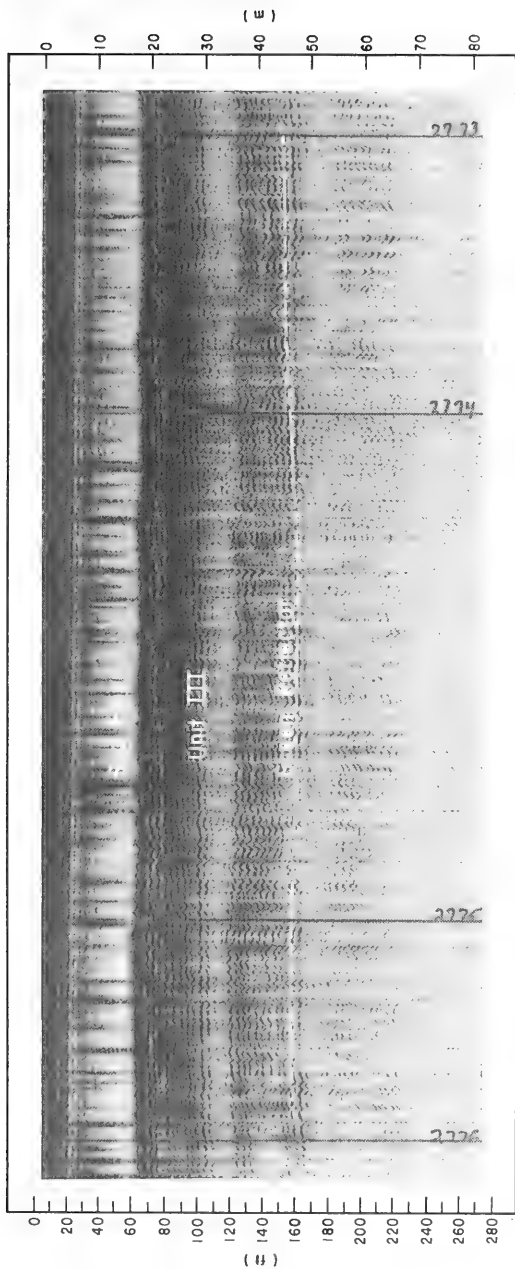


Figure 13. Seismic reflection profile showing the typical pattern of internal reflectors in reflection unit III.

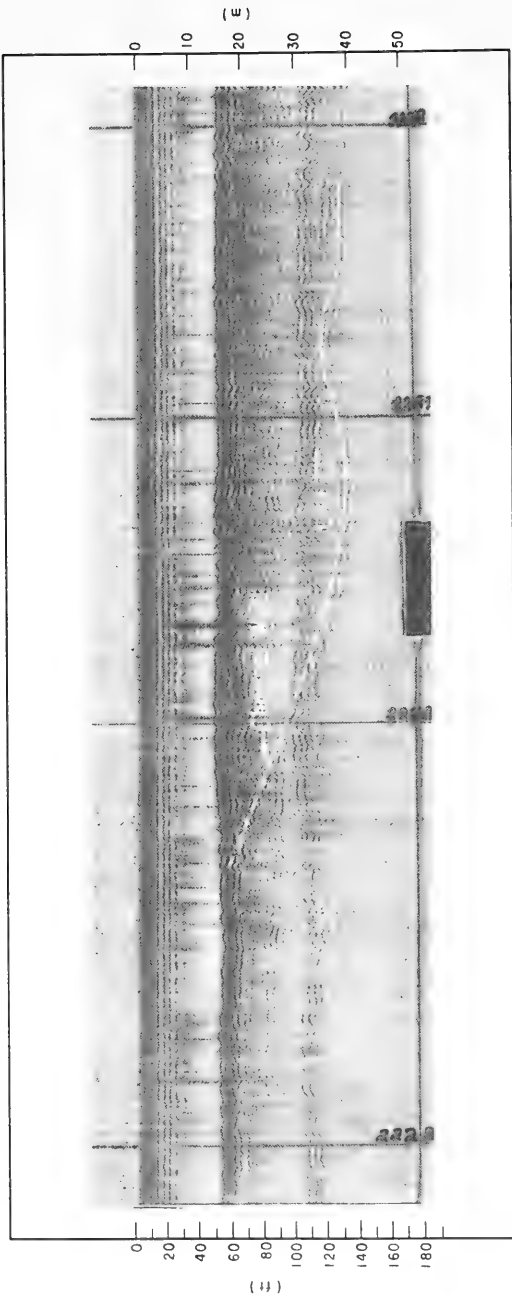


Figure 14. Seismic reflection profile showing typical internal reflection patterns in reflection unit IV.

(H)

lithology in the upper subbottom units between New River Inlet and Cape Lookout. Northeast of the unit III limit (Fig. 6) the characteristic forset-type internal reflectors immediately underlying the first subbottom reflector are no longer apparent and the reflectors in this interval are nearly horizontal. However, few profile lines are available for this area and they could be nearly on strike with these reflectors. Core data suggest that unit III may persist farther eastward to near Bogue Inlet. At that location, reflector patterns change to a more complex arrangement showing that the segment to as far as core 95 contains erosional intervals and sections of complex fill (App. A, profiles 2, 3, 4, and 5). Unit III probably continues below this complex section as suggested by the deeper reflector patterns in profile 3. From just west of core 95 to Cape Lookout, secondary reflectors in the section below the first subbottom reflector (App. A, profiles 1 and 2) become more regular and lie in a semiparallel pattern.

III. SEDIMENT CHARACTERISTICS

1. General.

Most of the sediments and rocks recovered in the ICONS cores were categorized into several broadly defined sediment types, based on lithology and mode of occurrence. General characteristics of these types are summarized in Table 2. Although particular sediments have certain common characteristics, the use of classes is primarily for descriptive purposes and does not necessarily reflect stratigraphic relationships. However, some classes encompass sediments which are apparently part of a single chronostratigraphic unit. These relationships are discussed later in Section IV. The type class of all classifiable sediments in the core logs is indicated in Appendix B; size-frequency data for selected samples are in Appendix C; and a constituent analysis of sediments representative of the various types is in Appendix D (Tables D-1 and D-2). The particle-size terminology in this study follows the Wentworth classification (Table 3).

2. Sediment Composition.

Representative samples from the various sediment types and from several unclassified sediments were examined to find the frequency of occurrence of their principal constituents. The constituents were primarily identified by examining the particles under a light microscope and digesting the acid soluble components; heavy mineral separations on a small number of samples were made using bromoform (specific gravity of 2.87). Tabulated results of the constituent analysis and acid digestion, together with notes on the procedures used and category definition, are in Appendix D. Photos of various constituents are shown in Figure 15 (a to k).

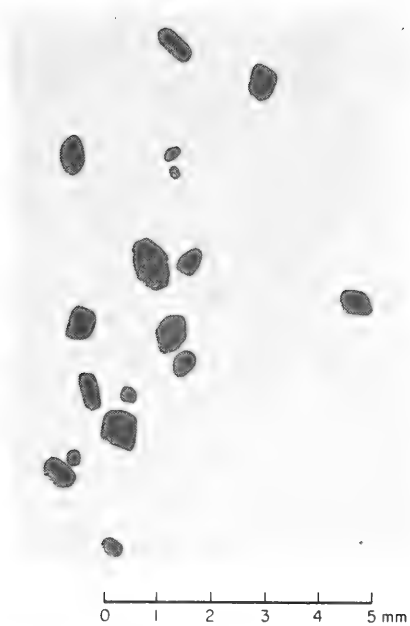
Several general observations on sediment composition were made from the constituent analysis of selected samples during the core logging process. The sediments in the study area consist of two main elements: quartz and biogenic calcium carbonate. The most common accessories are feldspar, phosphorite, and glauconite; opaque and translucent heavy mineral grains and mica are present in very small quantities.

Table 2. Summary of main sediment types.

| Type | Lithology | Description |
|------|--|---|
| A | Fine quartz sand | Widely distributed surficial fine sand; brown to gray; uniform, well sorted; biogenic calcium carbonate 5 to 10 percent; phosphorite up to 2 percent. |
| B | Very fine to fine quartz sand | Extensive deposits mainly in Onslow Bay; uniform, well sorted, angular; light brownish gray; biogenic calcium carbonate 2 to 35 percent; abundant foraminifera in places, phosphorite up to 2 percent. |
| C | Very fine to fine muddy quartz sand | Extensive deposits in Long Bay; well to poorly sorted, angular; dark grayish brown; biogenic calcium carbonate, mostly foraminifera, more than 50 percent in places, phosphorite up to 3 percent, glauconite 2 to 30 percent. |
| D | Medium to coarse quartz sand | Patchy distribution throughout study area; heterogeneous usually poorly sorted light gray to light grayish brown; shell fragments constitute up to 30 percent; phosphorite up to 2 percent. |
| E | Shelly quartz sand, shell sand, and shell hash | Patchy distribution throughout study area; heterogeneous, usually poorly sorted; variegated or uniform brownish; shells and shell fragments constitute 30 percent or more. |
| F | Dark-gray clay | Patchy distribution, mostly in Long Bay; typically soft, highly plastic; dark gray with yellow mottling; usually contains very little sand-size material. |
| G | Calcareous biogenic sand, gravel, and rock | Occurs mostly in ancient channels; heterogeneous, poorly sorted, in various states of consolidation; light gray to gray, occasionally pale brown; usually 80 percent or more biogenic calcium carbonate; occasional granules or pebbles of phosphorite. |

Table 3. Grain-size scales--soil classification (modified from U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1977).

| Unified Soils Classification | | ASTM Mesh | mm Size | Phi Value | Wentworth Classification | | | |
|------------------------------|--------|-----------|---------|-----------|--------------------------|-------------|------|--|
| COBBLE | | | 256.0 | -8.0 | BOULDER | | | |
| | | | 76.0 | -6.25 | COBBLE | | | |
| COARSE GRAVEL | | | 64.0 | -6.0 | PEBBLE | | | |
| | | | 19.0 | -4.25 | PEBBLE | | | |
| FINE GRAVEL | | 4 | 4.76 | -2.25 | PEBBLE | | | |
| SAND | coarse | | 5 | 4.0 | -2.0 | GRAVEL | | |
| | | | 10 | 2.0 | -1.0 | very coarse | SAND | |
| | medium | | 18 | 1.0 | 0.0 | coarse | | |
| | | | 25 | 0.5 | 1.0 | medium | | |
| | | | 40 | 0.42 | 1.25 | medium | | |
| | fine | | 60 | 0.25 | 2.0 | fine | | |
| | | | 120 | 0.125 | 3.0 | fine | | |
| | | | 200 | 0.074 | 3.75 | very fine | | |
| | SILT | | 230 | 0.062 | 4.0 | SILT | | |
| | | | | 0.0039 | 8.0 | CLAY | | |
| CLAY | | | 0.0024 | 12.0 | COLLOID | | | |



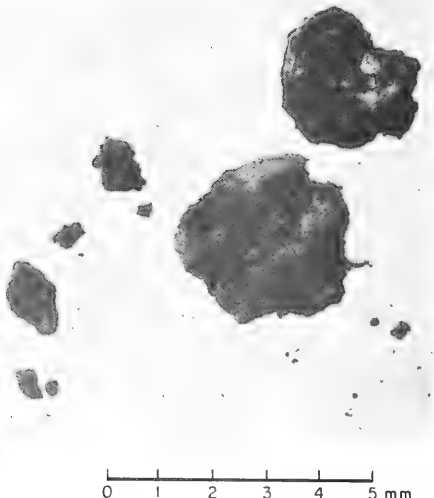
a. Small phosphorite pellets.



b. Large phosphorite granules with embedded quartz grains.



c. Phosphatized teeth and bones.

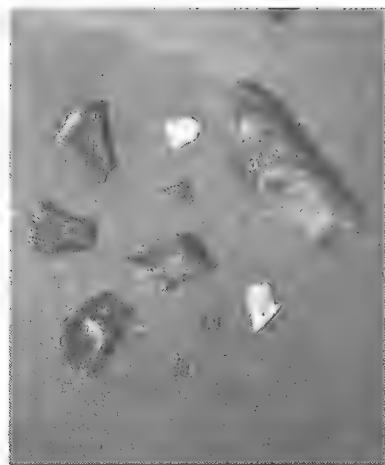


d. Large, irregular glauconite grains.

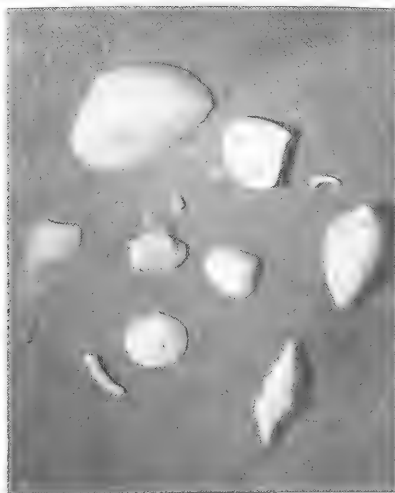
Figure 15. Typical constituents of inner shelf sediments.



e. Echinoid spines and test fragments.



f. Barnacle plates and opercular valves.



g. Mollusk shells.

Figure 15. Typical constituents of inner shelf sediments.--Continued



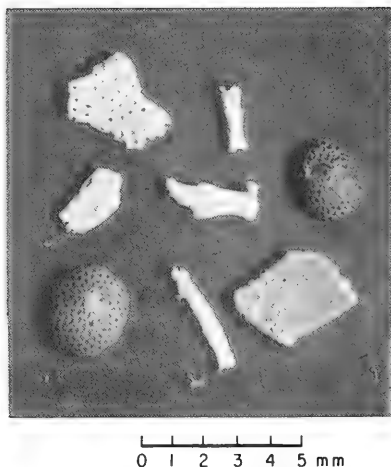
h. Foraminiferal tests.



i. Ostracod carapaces.



j. Various types of bryozoa zooaria.



k. Various types of bryozoa zooaria.

Figure 15. Typical constituents of inner shelf sediments.--Continued

Quartz occurs typically as fine, sand-size, clear, colorless particles of irregular shape with angular to subangular edges. The surface of most grains is smooth and glassy without pitting or frosting. Medium to coarse grains are usually more spherical in form and have rounded edges. Surface pitting, frosting, and iron stains are frequently found.

Feldspar content in the ICONS samples has not been determined; however, available studies of feldspar content in surficial sediments, such as in the study area, indicate that it is one of the more common accessories of the dominant quartz-carbonate lithology. These studies provide frequency data in terms of the feldspar percentage of the quartz-plus-feldspar component of the fine sand or fine and medium sand-size fractions. Cleary (1968) and Pratt (1970), who wrote specifically on the Onslow and Long Bay areas, respectively, both showed feldspar content as generally less than 5 percent. Field and Pilkey's (1969) study of the southeastern shelf reported an average feldspar content of 2.6 percent for the North Carolina shelf. Later studies of Atlantic shelf sediments (Milliman, 1972; Milliman, Pilkey, and Ross, 1972) show considerably higher values for Long Bay and Onslow Bay with 5 to 10 percent for about half the area and 10 to 25 percent for large segments south of Cape Lookout and near Cape Fear.

Phosphorite is distributed widely in small quantities (less than 1 to 3 percent) in most of the deposits sampled by the ICONS cores. It is abundant only in the Miocene deposit in core 95 (Fig. 4) where it comprises almost 25 percent of the sand-size material. Phosphorite grains in the study area are highly variable in character, are pale brown to dark brown and black, and range from subspherical, discoidal, and pelletoid forms to irregular blocky masses; a small percentage are biomorphic forms of phosphatized shells, teeth and bone fragments of marine animals or casts of some animal part (Fig. 15,c). Although occasionally pitted, most phosphorite particle surfaces have a smooth to highly polished surface with a glossy to near vitreous surface. Most phosphorite grains are opaque; however, many of the biomorphic forms and much of the material in core 95 have a waxy translucent cast.

Glaucconite occurs throughout the study area but is usually in very small amounts and in the fine to very fine sand-size fraction. Abundant glauconite (10 to 28 percent) occurs only in cores 9, 14, and 32 where it is in the fine to medium sand-size range. The glauconite grains are light to dark green and usually irregular with rounded edges or with a botryoidal form (Fig. 15,d).

Colored translucent mineral grains are found in small quantities most frequently in the surficial and near-surface deposits. Heavy mineral separation in bromoform (specific gravity of 2.87) of a few selected samples indicates that most of the colored grains are heavier than quartz. Most of the particles are pink to red, pale yellow, or pale yellowish green. From mineralogical studies of the shelf surficial sediments in the general region of the study area (Gorseline, 1963; Pilkey, 1963; Cleary, 1968; Pratt, 1970; Milliman, Pilkey, and Ross, 1972), it seems likely that most are particles of garnet, staurolite, and epidote.

Mica occurs only rarely and is common in only a few places where cores contain micaceous silty clays unrelated to any of the principal sediment types. Doyle, Cleary, and Pilkey (1968) showed that in surficial shelf sediments of the region mica is most common in nearshore sediments at less than 15-meter (49 feet) water depth. They inferred from the frequency distribution that the shelf floor sediments deeper than 15 meters are probably being winnowed of mica which is carried either shoreward to enrich the nearshore sediments or seaward to the continental slope.

Biogenic calcareous particles in sediments are dominated by mollusk shells and shell fragments, echinoid spines, and test fragments (Fig. 15, e and g); foraminifera are also widely distributed, but are abundant only in fine sand and silt facies (Fig. 15,h). Calcareous algae, bryozoa, ostracods, and barnacles are important in certain sediment bodies but rare or missing elsewhere (Fig. 15,f,i,j,k). A substantial number of small calcium carbonate particles seen in the grain counts were too small to classify. Most of the particles are presumed to be small fragments of the more abundant skeletal remains in the deposit. Siliceous skeletal materials such as diatoms, radiolarians, and sponge spicules were rarely found and do not constitute any significant part of the sediment deposits.

Authogenic calcium carbonate grains in the form of oolites have been reported in the surficial sediments of the Atlantic shelf and off both Long and Onslow Bays (Terlecky, 1967; Milliman, Pilkey, and Blackwelder, 1968; Pilkey, et al., 1969; Milliman, 1972; Mixon and Pilkey, 1976). The main concentrations with frequencies of more than 25 percent are in mid and outer shelf locales where dated oolites indicate deposition during the last recession of the sea (late Wisconsin). No oolites were identified in the ICONS samples; however, only a few cores were obtained from the northern third of Onslow Bay where the oolite-bearing sediments extend farthest shoreward.

3. Sediment Categories.

a. Fine Quartz Sand. Well-sorted, fine-grained quartz sand is the most common sediment of the Cape Fear inner shelf region. Extensive areas of the shoreface and inner shelf floor are mantled by this sand and large deposits of similar material underlie much of the shelf floor.

Most of the fine sands of the study area appear to be part of three large deposits, each of a different age. As a result of varied history and origin, these deposits are different in minor compositional elements, fauna, and bulk properties. Though subtle in some respects, the differences are significant in terms of engineering properties and are of considerable importance in the development of regional stratigraphic relationships. For convenience in notation, the three fine sand facies will be referred to as sediment types A, B, and C.

(1) Type A. Type A sand comprises the fine Holocene surficial deposits which mantle large areas of the shoreface and inner shelf and

make up much of the material in Frying Pan shoals. It is especially prominent in Long Bay and in Frying Pan shoals; in Onslow Bay, it is interspersed with large patches of coarser surficial deposits, reworked substrate material, and exposures of pre-Holocene strata.

Type A sand characteristically contains more than 90 percent quartz grains; most grains are of angular form and subspherical shape (Fig. 16). Silt is present in most places but normally in very small quantities. Calcium carbonate skeletal material, such as small-sized echinoid fragments, foraminiferal tests, bryozoa, ostracod carapaces, and mollusk shells, comprises the bulk of the remaining particles. The mollusks are mostly minute larval and immature forms or representatives of small species; large mollusk shells and shell fragments are uncommon. Type A sand is typically light brownish gray, close to Munsell Soil Color Code 10 yr 6/2 (Munsell Soil Color Charts, 1954 ed., Munsell Color Co., Inc., Baltimore, Md.). In bulk samples the color is usually uniform, but on close inspection dark specks can be discerned in the matrix. These are mostly particles of black and brown phosphorite and blackened shell material.

Type A sand cannot be readily differentiated from the other fine sand types without reference to faunal content (discussed in Sec. IV). Slight differences in color, carbonate content, and mode of occurrence are of some value in gross comparison but are not definitive.

(2) Type B. Very fine to fine, well-sorted sand occurs in all cores that penetrated seismic reflection unit III (Fig. 6) and is apparently characteristic of the upper sampled parts of this extensive deposit underlying southern Onslow Bay and the eastern Long Bay area. Type B sand (Fig. 17) is generally very uniform in size and character from place to place and in depth. Calcium carbonate is a common to abundant constituent of type B sediment in many places, reaching a frequency of over 25 percent locally. Most, if not all, of this calcareous material is biogenic, consisting mostly of ostracod carapaces, echinoid spines, foraminiferal tests, and finely broken mollusk shells. A number of cores containing type B sediment, however, have very little, if any, calcium carbonate and no calcareous fossils but do contain sparse phosphatized teeth and bone fragments. All but two of these cores are closely grouped together in the area between Moores Inlet and Carolina Beach Inlet. Phosphorite in type B sand is usually rounded, brown to black opaque grains, often with a high polish and in the form of phosphatized teeth and bone fragments. Sizes of the grains are near that of the sand matrix (Table 3) though the bone fragments are often larger. Glauconite is also present in small quantities and generally of a size near that of the finer half of the sand matrix.

Type B sand is grayish brown (2.5 yr 5/2) to light brownish gray (2.5 yr 6/2) and uniform. Dried samples show a slight cohesion and often form friable lumps.

(3) Type C. Type C sand occurs in many cores between Lockwoods Folly Inlet and the South Carolina border. This area is underlain by

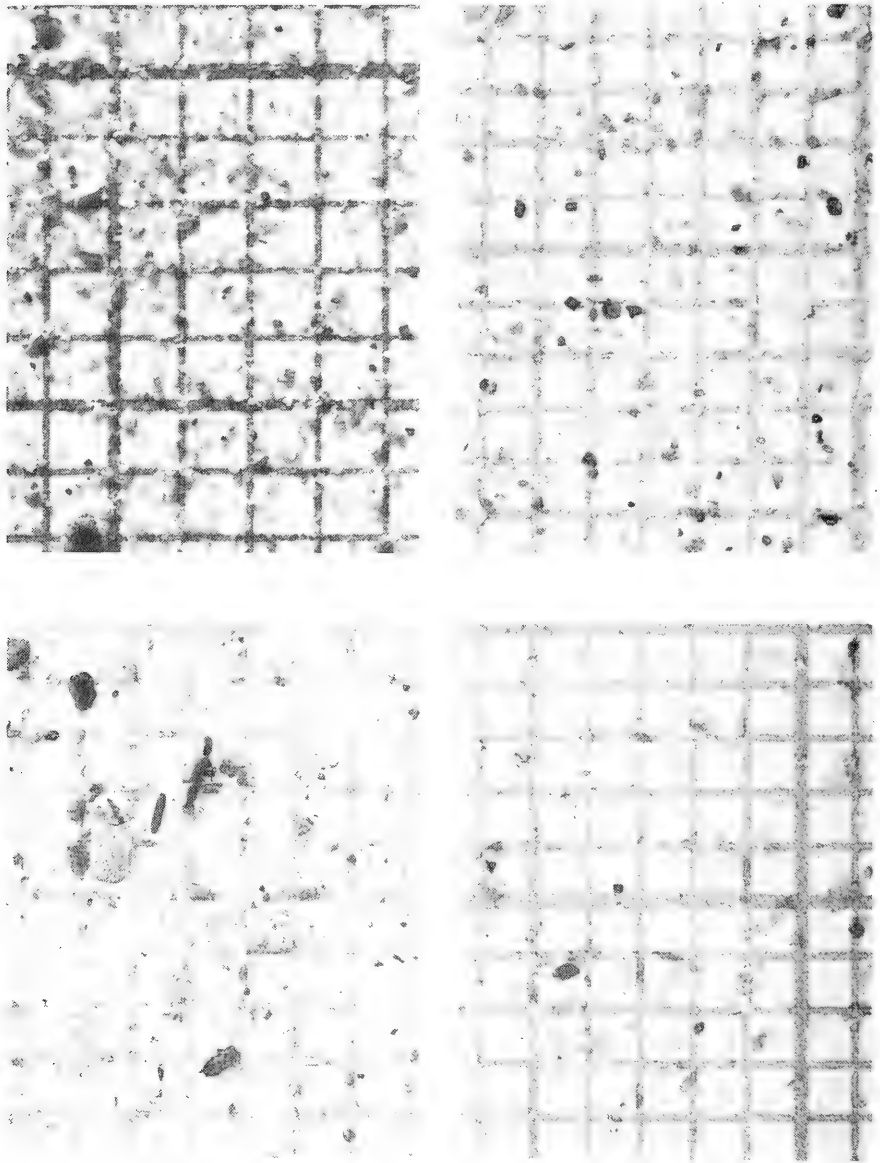


Figure 16. Photos of typical type A, shelf facies sand (grid interval, 1 millimeter).

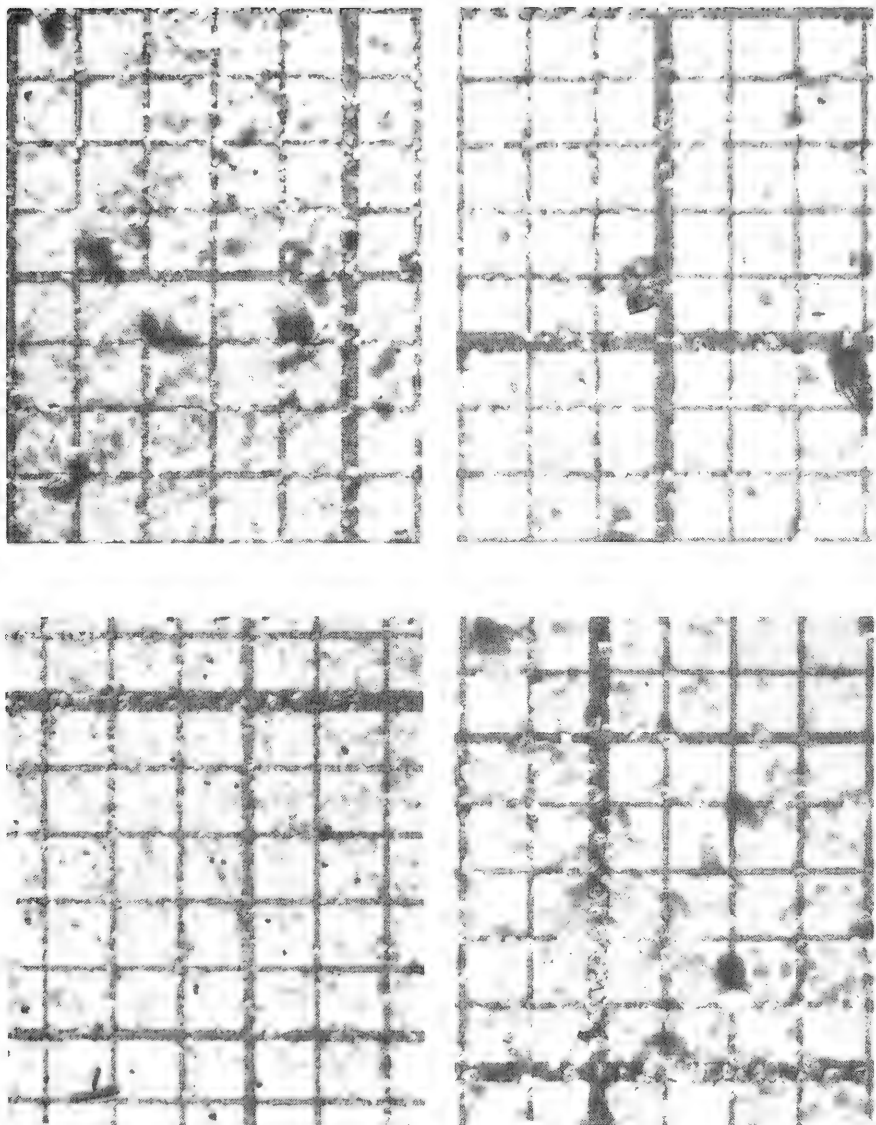


Figure 17. Photos of typical samples of type B, fine angular sand (grid interval, 1 millimeter).

seismic reflection unit I (Fig. 6) and type C sand is characteristic of the upper (sampled) part of this unit. It is not known if the unit below the part sampled by cores is of similar lithology. Seismic reflection profiles show unit I to be within 1.5 meters (5 feet) of the shelf floor in most places and to crop out locally. Cores also indicate a thin overburden and in the locale of core 42 (Fig. 2) the unit crops out on the shelf floor.

Type C sand is composed mostly of very fine to fine quartz particles of angular shape and low sphericity (Fig. 18). Phosphorite and glauconite are common accessory minerals; glauconite is more abundant in some type C samples than in any other inner shelf deposit but is very rare in other samples. Calcium carbonate elements consist mostly of foraminiferal tests, which in some samples comprise about half the particles. Mollusk shell fragments, echinoid spines, and ostracod carapaces are also present in relatively small amounts.

Type C sand, usually darker than type A or B, is typically dark grayish brown (10 yr 4/2) and uniform. The material tends to be silty, partly due to very small foraminiferal tests, and dry samples develop a slight coherence.

b. Coarse-Grained Sediments. The coarse-grained sediments found in the study area comprise a heterogeneous group of quartz sands, shelly sands, and shell gravels which usually occur in thin and discontinuous patches on the shelf floor or beneath a thin surficial layer. Deposits of this group are generally too thin to be resolved on available seismic reflection records and their distribution and extent are poorly known.

Most coarse-grained deposits can be classified into two broadly defined types (D and E), depending on the amount of shell present. It is probable that the material represents a number of discrete deposits which are not closely related in origin and may have formed at different times, although most appear to have been placed under marginal marine environmental conditions.

(1) Type D. Medium to coarse quartz sand and shelly sand (less than 30 percent shells) are grouped as type D sediment. These sands are heterogeneous in character (Fig. 19) and occur in a patchy distribution throughout the study area in both surficial and shallow subsurface deposits. In some cases, medium surficial sands appear to be localized coarser facies of type A sand. Where this is probable, the core log description includes the modifier "shelf facies." Other deposits of this type may be related to some of the type E shelly sand deposits, differing only in shell content.

In general, type D sediment consists predominantly of quartz sand which is less angular and more spherical than types A, B, and C. This is due to the better rounding of the large grains which comprise a substantial part of the material. The finer grain-size fraction is more angular. Locally, the sand contains silt, usually in small amounts, but

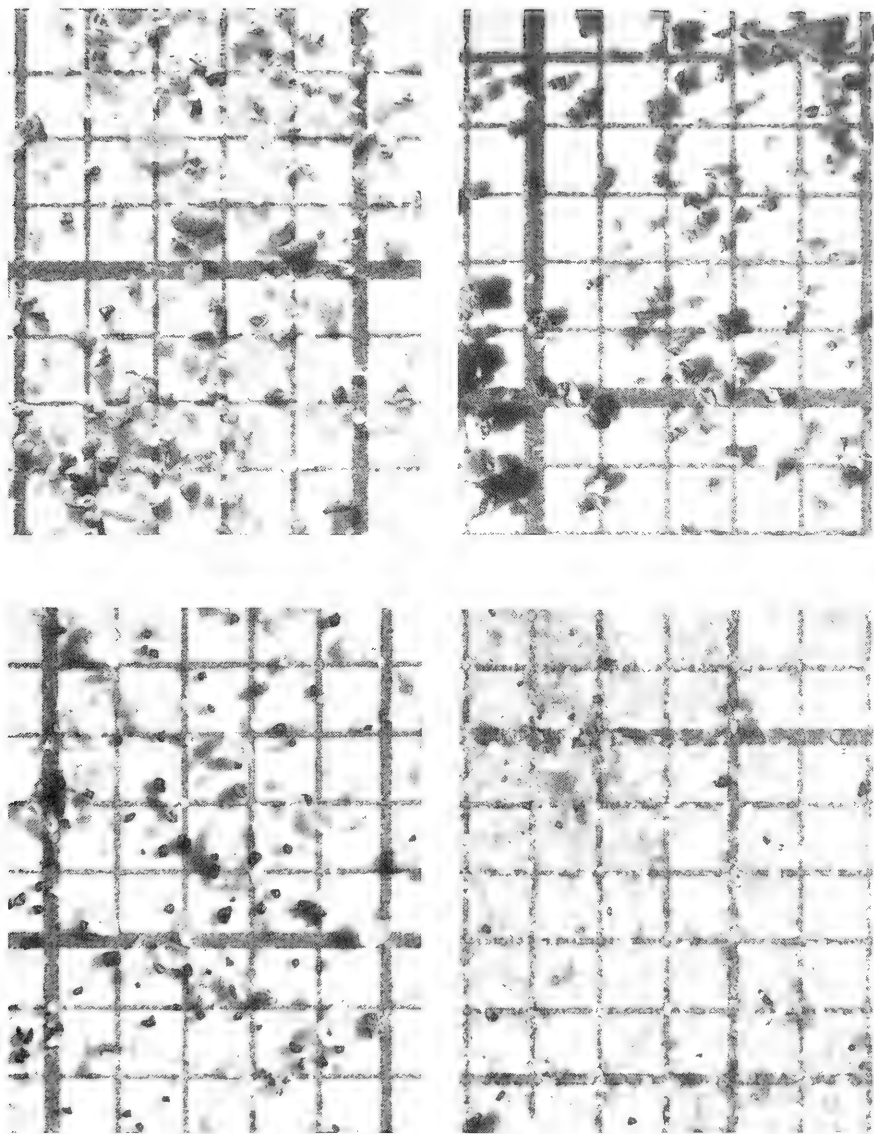


Figure 18. Photos of typical samples of type C, muddy sand (grid interval, 1 millimeter).

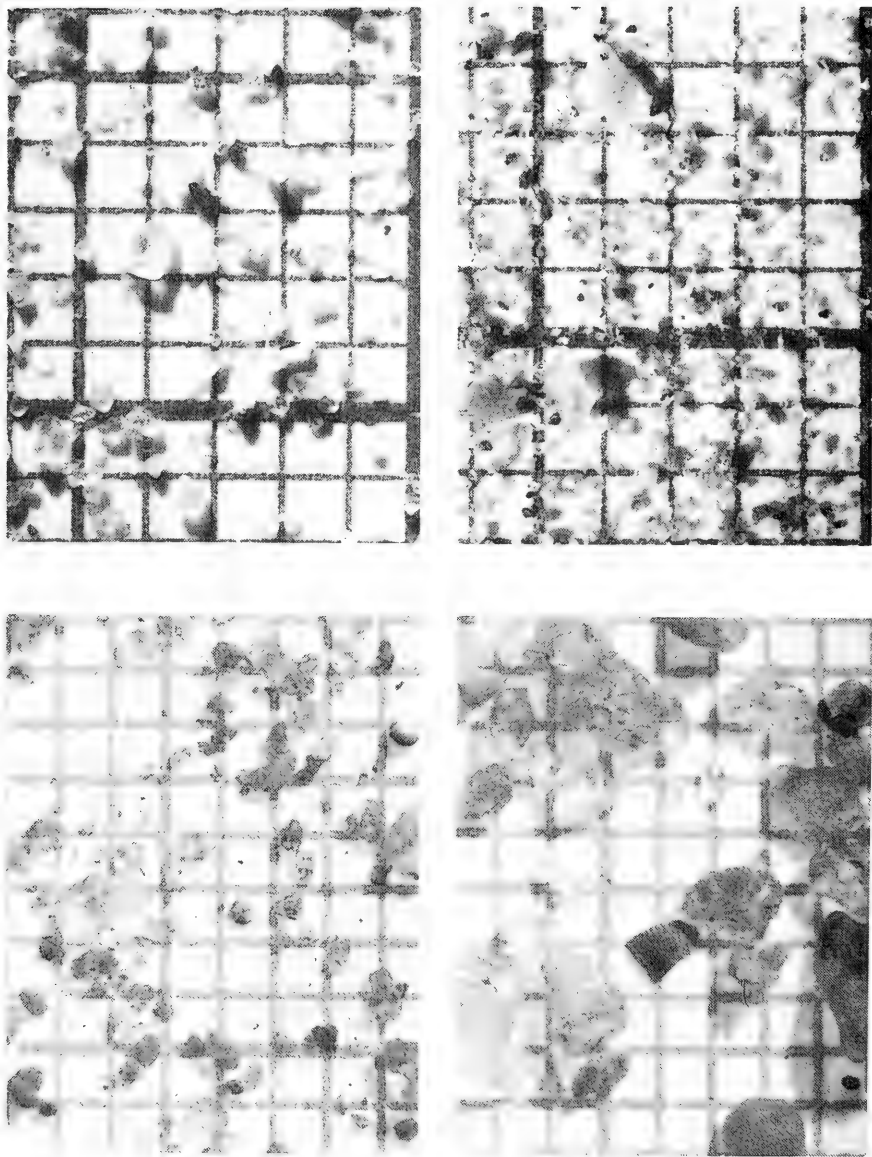


Figure 19. Typical examples of type D sediment (grid interval, 1 millimeter).

more often it is relatively free of fines. Phosphorite is a common accessory and mollusk shell material is usually present. Foraminifera, echinoids, and other small skeletal debris that commonly occur in finer sediments are rare.

Type D sand is light gray (10 yr 7/1) to light brownish gray (10 yr 6/2) and usually uniform: In some samples there is a speckling of darker grains which consist mostly of colored shell fragments and phosphorite.

(2) Type E. Type E sediment includes all coarse deposits in which shells and shell fragments make up about 30 percent or more of the material, thus giving it a distinct texture and composition. It is a broadly defined category with lithologies ranging from shell sand to shell gravel (Fig. 20). These sediments occur throughout the study area, usually in thin discontinuous patches on the shelf floor or in shallow subfloor deposits. Subsurface deposits are commonly silty with a detrital fraction of poorly sorted, fine to coarse quartz sand. Surficial exposures and deposits are not as silty and tend to have a coarser detrital fraction, probably because of reworking.

The shell material in type E is predominantly derived from mollusks, barnacles, bryozoa, serpulid worms, and echinoids; foraminifera are common to abundant, and small pieces of coral and calcareous algae occasionally occur. In most places the shells are a mixture of old shells that are highly worn, pitted and encrusted, and fresh unaltered shell material. The worn shells are often blackened or iron-stained. Fragments with broken edges are smoothed by wear. In many cases, these shells are detrital or reworked elements derived from older deposits; the fresh shells are locally produced.

Most of the type E material is gray to grayish brown or brown and rarely uniform, consisting of a varicolored pattern of cream, gray, black, and brown individual shell fragments and gray or brown matrix material. Several of the shell sands and gravels occurring on the shelf floor are heavily iron-stained which gives them a more uniform reddish-brown color.

c. Silt and Clay. Deposits of silt and clay size particles occur throughout the study area but are particularly common in Long Bay. These deposits are neither as extensive nor numerous as the sand deposits and usually occur in the thin and discontinuous layer overlying the major reflection units. In general, they cannot be identified or traced on available seismic reflection units.

The most common fine-grained deposits consist of highly plastic, dark to very dark gray clay (type F). Other fine-grained deposits are heterogeneous and are mostly mixtures of various amounts of sand, silt, and clay. The deposits appear to be unrelated and probably represent a variety of depositional situations. Their characteristics are individually noted in the core logs (App. B).

Type F, a distinctive dark-gray clay with yellow mottling, occurs in many cores from Long Bay and in a few cores from Onslow Bay. The

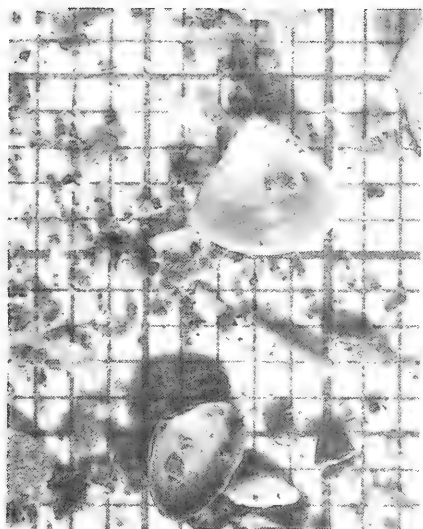


Figure 20. Typical examples of type E, shelly sand and shell hash (grid interval, 1 millimeter).

distribution of known occurrences indicates that these clay deposits are discontinuous; however, their similar character and consistent relationship to underlying and overlying units suggest that they are genetically related. Where present, type F deposits occur either in outcrop on the sea floor or under shelf facies sand. The surface of the deposit is level and creates no topographic expression in the sea floor, whether exposed or within a few feet of the bottom. Thickness varies from about 1 to 5 meters (2 to 15 feet); maximum thickness within the study limits is unknown since many cores bottomed within the deposit.

The chief characteristics of type F clay are the dark-gray color (Munsell Color Code N3), the typical yellow mottling, and the high plasticity when wet. Residues from washing representative samples through a fine mesh (0.105 millimeter) screen were volumetrically very small and usually consisted of quartz grains and partly decomposed vegetation (Fig. 21). In some samples the residue contained abundant selenite crystals, possibly precipitated by partial drying during storage. Similarly, the yellow mottling which appears to be due to accumulations of microscopic iron sulfide particles could have formed during storage; if so, the mottling may not characterize fresh samples.

d. Carbonate Sediments and Rocks. A diverse group of carbonate sediments and rocks occurs in the study area. They range in lithology from calcareous silt to calcareous sandstone but the majority are biogenic calcarenite and calcirudite in various degrees of consolidation. This material, which is classified as type G, appears to be part of a single deposit.

Other carbonate lithologies occur frequently, especially in easternmost Long Bay and off New River Inlet, but no single lithology of this group is frequent enough to be treated as a specific type. These deposits include calcareous sandstone, limestone, calcareous silt, and bryozoan hash. Brief descriptions are given in the core logs (App. B).

Type G material consists of biogenic calcareous sand, gravel, and rock and commonly occurs as fill in the large channels underlying parts of Long Bay and southern Onslow Bay, south of Moore Inlet (Figs. 7 and 8). However, there are a few occurrences that do not appear to lie in ancient channels, suggesting that the deposit may once have been more widespread but had subsequently eroded from the interfluvial areas. If type G material completely fills the channels, it probably exceeds the 45-meter thickness in places, but core data are only available for the upper 6 meters. Numerous and extensive outcrops of type G material occur on the inner shelf floor and the large area of rock outcrops extending through the mid-shelf region east of Cape Fear (Cleary, 1968) are likely exposures of this material.

Type G sediment and rock particles consist largely of barnacle plates, bryozoa, and highly fragmented mollusk shells which range from silt to small pebble size (Fig. 22). Calcium carbonate often comprises over 90 percent of type G material and detrital quartz particles are apparently

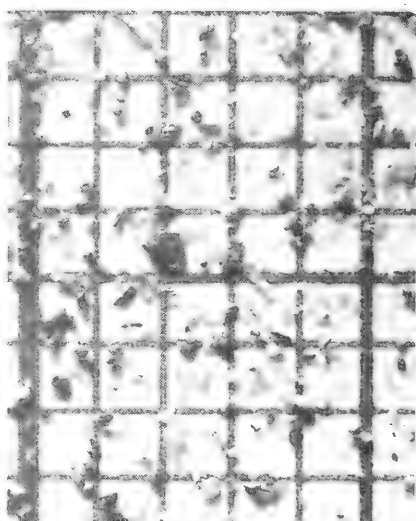
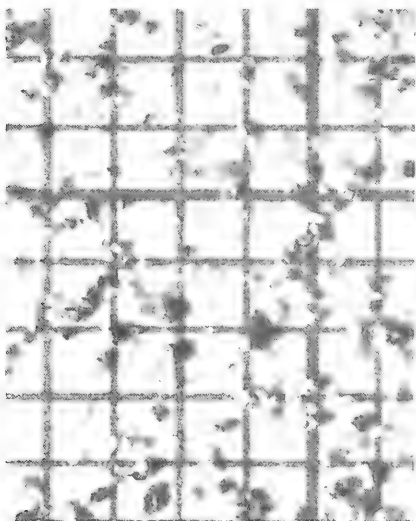
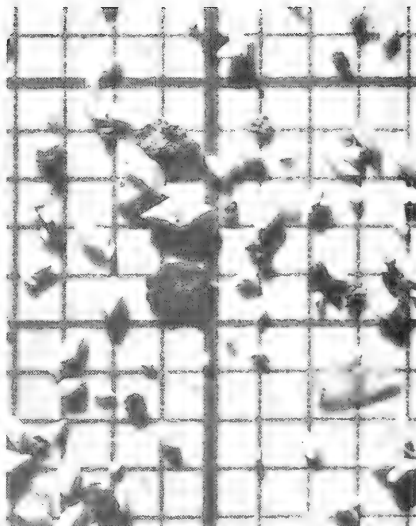
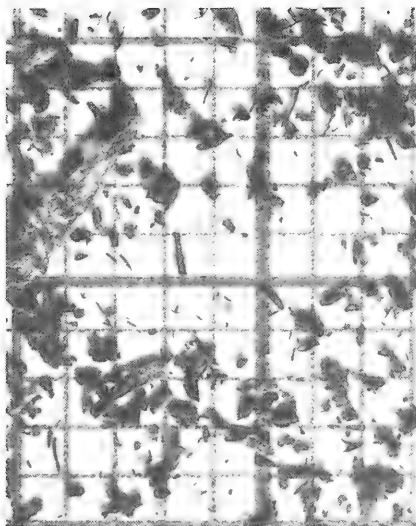


Figure 21. Typical examples of type F, gray clay, and residue from washing clay through a sieve (grid interval, 1 millimeter).

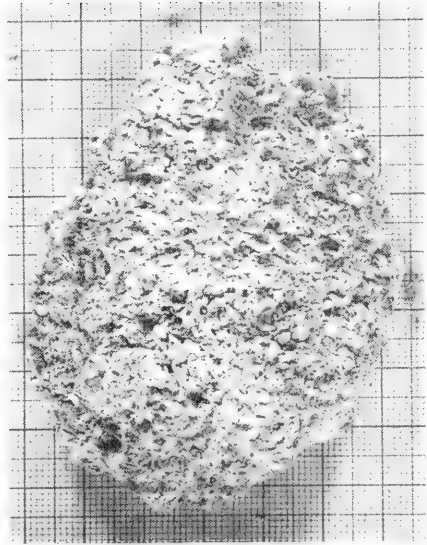
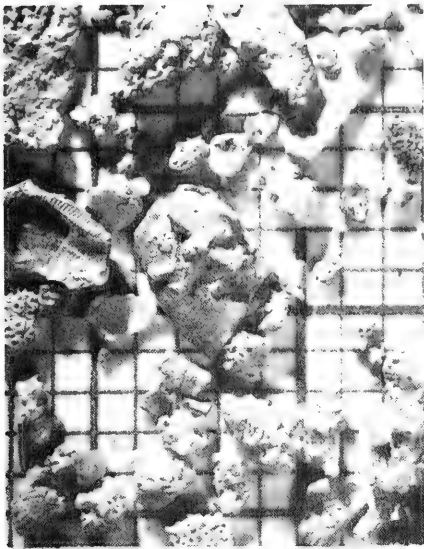


Figure 22. Typical examples of type G, calcareous sediment and rocks (grid interval, 1 millimeter).

not supplied to the depositional site in any substantial amounts. Higher quartz content occurs in places but these are usually near a sandy substrate; thus, the quartz is probably a reworked rather than detrital element. Phosphorite occurs in modest amounts with grains reaching granule or small pebble size. Foraminifera, ostracods, and echinoid spines are usually plentiful in the finer fraction of the better preserved material.

Typically, type G material is light gray (N7) to gray (N6) but locally the upper part of the deposit may be pale brown (10 yr 6/3). Recrystallization of the individual carbonate particles has occurred to a greater or lesser degree throughout and this gives the particles a frosty or glazed look under magnification. Type G material appears to be partly consolidated in most places; however, it was recovered in a well-consolidated state in some cores. Material recovered in a loose, granular state may have been disaggregated during the vibratory coring process. However, there is little evidence of cementation in some samples except that small, pebble-size aggregates of cemented grains are distributed throughout the matrix. Where the material was recovered in a consolidated state the grains are usually cemented at grain contact points only and the interstices are open.

IV. DISCUSSION

1. Age and Correlation of Sediment Bodies.

a. General. An analysis of faunal assemblages (chiefly foraminifera) in core samples indicates that sediments on or close beneath the shelf floor range in age from Late Cretaceous to Holocene. Most of the fossiliferous core samples were grouped geologically into the following age categories: Late Cretaceous, Paleocene, Eocene, Oligocene, Miocene, Pliocene, and Quaternary. Partial correspondence was established between these age categories and the lithologic types and seismic reflection units described earlier.

Sufficient data were not obtained on the inner shelf to synthesize the various elements of lithology, age, and seismic reflection patterns into a formal chronostratigraphic framework. However, a comparison of these elements suggests the possible outline of such a framework and indicates that the inner shelf geology generally accords with a projection of the onshore geological framework.

Figures 23, 24, and 25 show the probable age of pre-Quaternary sediments that occur in cores of the study area. Sediments of more than one age, which occur in a few cores, are indicated by multiple symbols. Age of the sediments was determined in most cases by fauna; however, in a few cases barren sediments were age-classified on the basis of continuity with or lithologic similarity to fossiliferous material. The figures also show the areas underlain by the different seismic reflection units where the tops are predominantly within 3 meters of the shelf floor.

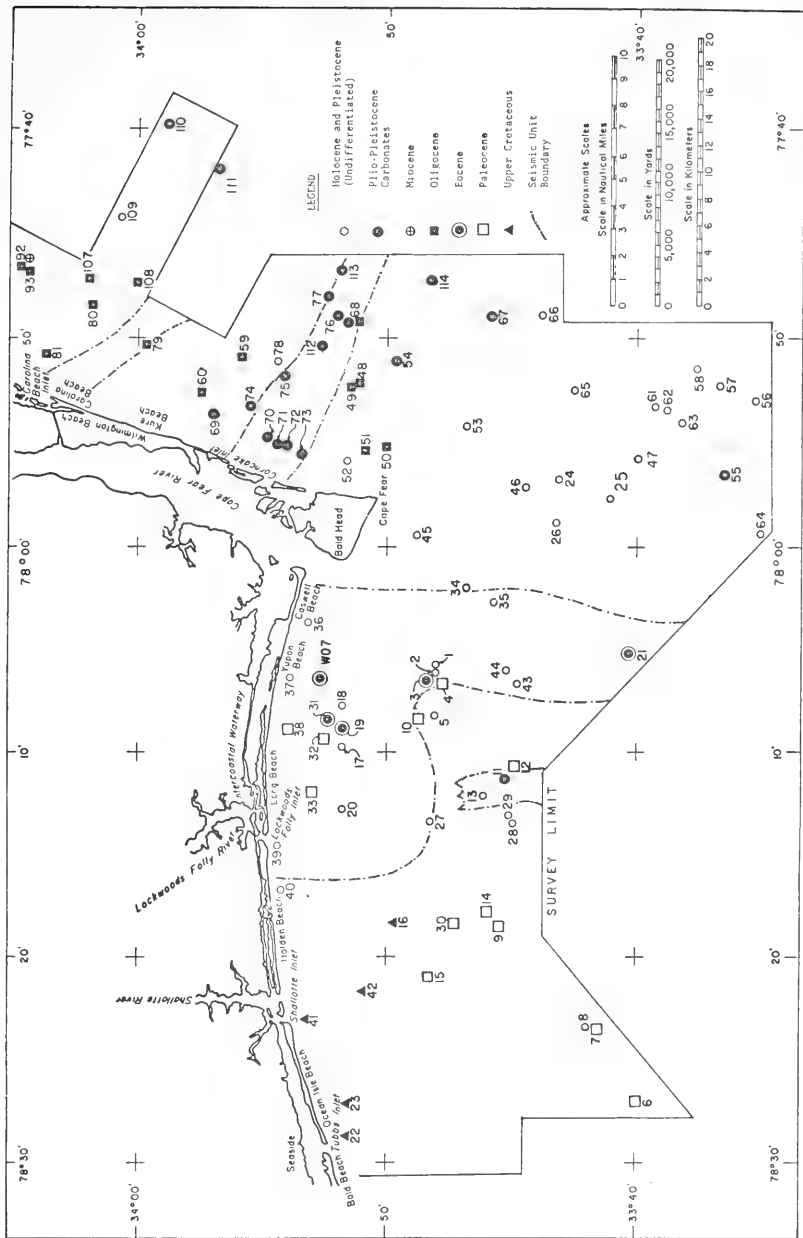


Figure 23. Probable age of sediments in the western part of the main survey area.

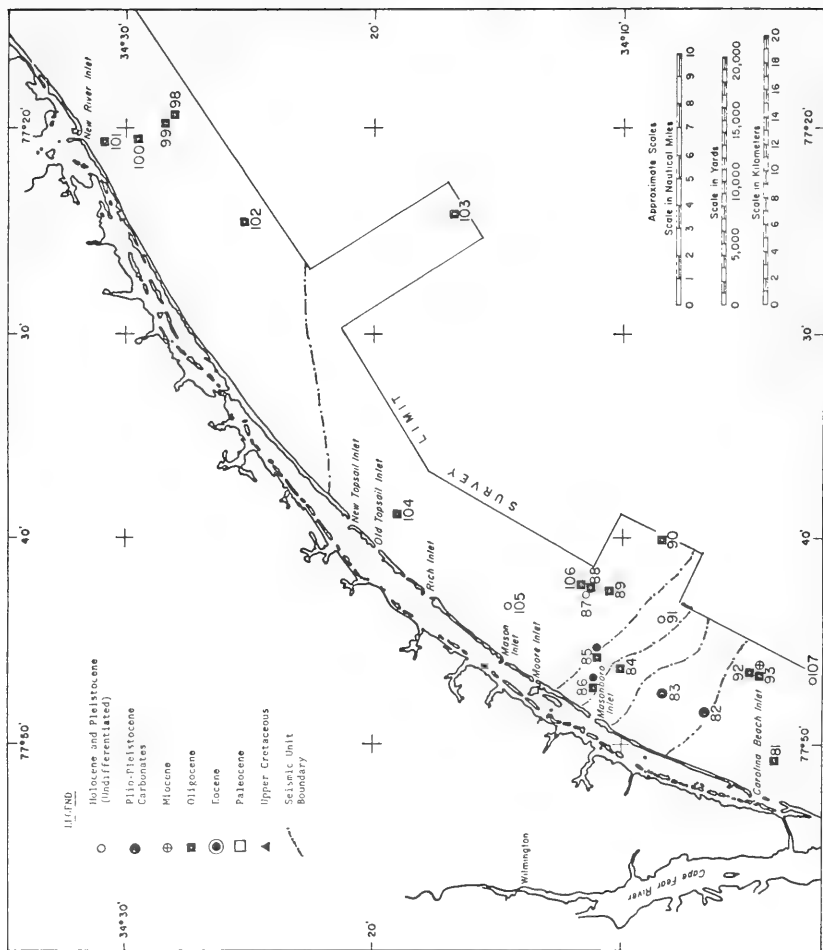


Figure 24. Probable age of sediments in the northeastern part of the main survey area.

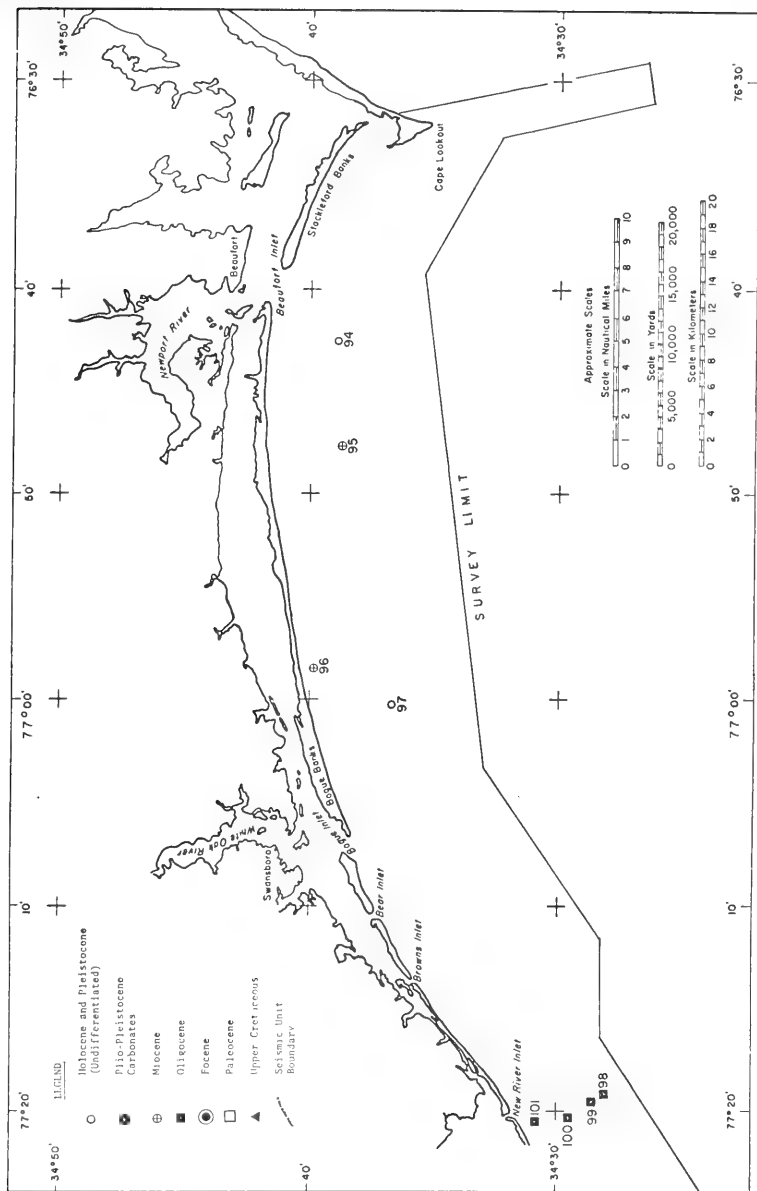


Figure 25. Probable age of sediments in the reconnaissance area.

b. Cretaceous Deposits. Fine to very fine muddy sand (lithologic type C) containing Upper Cretaceous fauna was found in outcrop or beneath thin overburden in cores 16, 22, 23, 41, and 42. These cores are grouped in the area between the South Carolina border and Lockwoods Folly Inlet, and are within 10.2 kilometers (5.5 nautical miles) of the shore (Fig. 23). The location of the cores and the depth to the Cretaceous contact indicate that the Cretaceous material corresponds with seismic reflection unit I.

Only a few macrofossil fragments were recovered from the cores, probably because of the small area sampled. The Cretaceous mollusk shells that often wash up on nearby beaches (Cooke, 1936) probably come from sea floor exposures of this deposit. Microfossils are abundant in the Cretaceous sediments and consist chiefly of well-preserved foraminiferal tests (comprising as much as 20 percent of the sediment particles), ostracod carapaces, and echinoid parts.

The foraminiferal assemblage, which contains a large number of both benthonic and planktonic species, is dominated by *Cibicides harperi* Sandidge and *Anamalinoides carolinensis* Curran. Together, these species account for more than half the population. Other common species are *Dorothea bulleta* (Carsey), *Loxistomum platium* (Carsey), *Guembelitria cretacea* Cushman, and *Heterohelix globulosa* (Ehrenberg) (see App. E for more details). The foraminiferal assemblage as a whole indicates a Late Cretaceous age and deposition probably at mid or outer shelf depths. Seismic reflection records of the deposit show southward-dipping secondary reflectors which indicate that the Cretaceous sediments accumulated by southward progradation. Truncation of these reflectors at the top of the deposit also indicates that, subsequent to deposition, the unit underwent one or more erosional episodes.

Lithologically, the Cretaceous sediments are relatively homogeneous and typically in the fine to very fine quartz sand size. The dominant constituent is quartz, followed by biogenic calcium carbonate. Other constituents are sparse.

Samples from core 16 are lithologically different from other Cretaceous samples. The material is coarser and contains more phosphorite and glauconite. The phosphorite, though sparse in the core sample, is conspicuous because many grains are coarse or very coarse sand size. These large grains are typically almost black, irregular in outline, and often incorporate quartz grains (Fig. 15,a).

The Upper Cretaceous deposits underlying the inner shelf are probably related to Cretaceous unit A (Brown, Miller, and Swain, 1972) and to the Pee Dee Formation (part of unit A). The nearest borehole information logged by Brown, Miller, and Swain is OT-15 near Kure Beach where the upper part of unit A is classified as fine sand with calcareous accessories. Swift and Heron (1967) describe the typical Pee Dee lithology from outcrop as a "medium dark-gray (N3), muddy (15 to 50 percent silt and clay) sand." Curran (1968), Brown, Miller, and Swain (1972), and

Wheeler and Curran (1974) have described the foraminifera in the Upper Cretaceous deposits of the Carolina Coastal Plain. Many of the foraminiferal species listed by these authors as abundant or characteristic are well represented in the inner shelf cores.

c. Paleocene Deposits. Two apparently separate Paleocene deposits occur in Long Bay. One was sampled by cores 6, 7, 10, 12, 15, 29, and 30 and the other by cores 4, 9, 14, 32, 33, and 38. Although available seismic profiles do not provide conclusive evidence because of low resolution, it is reasonably certain that Paleocene sands in cores 6, 7, 10, 12, 15, 29, and 30 are from seismic reflection unit I and not from the thin overlying deposits. Therefore, all of unit I south of a shore-parallel line somewhere between cores 16 and 30 is likely of Paleocene age. Shore-normal seismic profiles extending from the inshore part of unit I, where Cretaceous material occurs, to the Paleocene section show no break in the regular seaward-dipping internal reflectors of unit I between these areas (see App. A, profiles 21, 22, and 23). Therefore, the deposition of unit I possibly proceeded in an unbroken succession from Late Cretaceous to Paleocene time. Colquhoun, et al. (1969) found no evidence of a major hiatus between Upper Cretaceous and Lower Tertiary deposits in the Coastal Plain of South Carolina.

The Paleocene sediments from unit I consist of very fine to fine quartz sand of typical type C lithology with little apparent difference from the Cretaceous material. However, faunal remains, which consist almost entirely of foraminifera, are significantly less abundant. The foraminiferal assemblages are varied in diversity and composition but all are dominated by *Anamalinoidea newmana* Cushman and *Cibicides howelli* Toulmin.

The benthonic fauna, as a whole, suggests that the deposit is of early Paleocene age. The planktonic fauna, which contains, among other species, *Globigerina pseudobulloides* Plummer, *Globorotalia compressa* Plummer, and *Globoconusa daubjergensis* (Bronniman), indicates correlation with the Cenozoic planktonic foraminiferal zone P1, as classified by Berggren (1972). Though barren of any fossils, seismic reflection data and sediment lithology suggest that the type C sand in cores 12 and 29 also belongs to this Paleocene deposit.

The second deposit (cores 4, 9, 14, 32, 33, and 38) consists of material that is heterogeneous and not similar to the material found in unit I. Cores 9 and 14 contain fine to medium sand with more glauconite (25 percent) than any other sediments recovered from the study area. Cores 4, 32, 33, and 38 contain poorly to well-consolidated calcareous sandstone with shell casts and molds. Core 33 also contains abundant sand-size glauconite which is incorporated in the rock. Of this group, core 14 recovered the only material with well-preserved faunal remains; these consist chiefly of foraminifera dominated by two species *Anamalinoidea umbonifera* and *Gyroidinoides* cf. *G. octacamerata* (Cushman and Hanna). Planktonic foraminifera are rare in core 14 and most are of one species, *Globigerina pseudobulloides* Plummer. Very sparse and often poorly preserved foraminiferal tests in the rock recovered in cores 4,

32, and 33 indicate that they are probably of similar age. Glauconitic sand in core 9 and calcareous sandstone in core 38, though barren of fossil remains, are lithologically similar and probably related to the fossiliferous material.

The sparse evidence indicates that the two Paleocene deposits are part of a sediment and rock deposit overlying unit I at cores 9 and 14 and extending into the area of unit II where the material, at least locally, is lithified and seems to be part of the acoustically impenetrable layer encountered in that area.

Rocks of middle Paleocene age occur extensively in the subsurface of eastern North Carolina and extend southwestward as far as New Topsail Inlet (Brown, Miller, and Swain, 1972). The predominant lithology in this area is sand with varying amounts of silt and clay and localized deposits of sandy glauconitic limestone, shale, and dolomite. Brown, Miller, and Swain also found that high percentages of glauconite (10 to 90 percent) were characteristic of the middle strata in the Atlantic Coastal Plain Province.

Brown (1958) proposed the name Beaufort Formation for Paleocene-age deposits (known only at that time from well data) in the North Carolina Coastal Plain. Subsequently, outcrops were discovered in Lenoir and Craven Counties, North Carolina. Recently, Harris and Baum (1977) described microfauna from the outcrop locales and determined an average rubidium-strontium age from included glauconite of 56.8 million years. The foraminiferal fauna indicated a correlation with zone P4 of Berggren (1972). Lithology and fauna suggest a possible relationship between the outcropping Paleocene deposits described by Harris and Baum (1977) and the glauconitic sand and calcareous sandstone deposits found in cores 9, 14, 32, 33, and 38 in Long Bay. The Paleocene deposits associated with unit I, however, appear to be of earlier age, probably correlating with zone P1. Their location seaward of the Cretaceous deposits in the truncated, prograding deposit beds of unit I suggests that they may not occur in the emerged coastal plain area.

d. Eocene Calcareous Sediments. Sediments of probable Eocene age occur in ICONS cores 3, 19, 21, and 31 and in a core obtained from U.S. Army Engineer District, Wilmington (identified as W07). All are from the Long Bay area. Lithologically, these sediments do not fit into any of the types previously described. They consist of poorly sorted calcareous silt, sand, and granule-size particles with the identifiable material almost entirely composed of bryzoa and foraminifera. Because of a high calcium carbonate content (>90 percent) and white to light-gray color, these sediments resemble type G sediment. A major difference is their lack of barnacle plates, a principle constituent of type G sediment.

The base of the Eocene strata and any internal features cannot be discerned on available seismic reflection profiles because the area of occurrence lies within reflection unit II where no signal penetration

was obtained below the first subbottom reflector. The top of the Eocene strata is believed to coincide with the green primary reflector which dips eastward from its outcrop in Long Bay under Frying Pan shoals and into Onslow Bay where it can be traced as far north as New River Inlet (Figs. 9 and 10). The green reflector is believed to lie at or very near the Eocene-Oligocene contact for the following reasons. First, the projected outcrop of the green reflector on the adjacent emerged coastal plain accords well enough with the outcrop of the Eocene Castle Hayne Formation (North Carolina Department of Conservation and Development, 1958; Stuckey and Conrad, 1958) to suggest that discrepancies are within the range expected from projection error and from horizontal variations in the outcrop line due to topographic relief. Second, Eocene bryozoa hash occurs in several ICONS cores near the sea floor outcrop of the green reflector in Long Bay. Third, elevations to the top of the Eocene in several wells on the coastal plain (described in Brown, Miller, and Swain, 1972), are close to the projected elevation of the green reflector at the well location.

Only three cores (C21, C31, and W07) contained foraminifera in sufficient quantity and state of preservation to characterize the Eocene assemblage. In these cores planktonic types are sparse, the benthonic fauna are abundant and diverse; common and characteristic benthonic species are *Eponides cocoaensis* Cushman and *Cibicides subspirata* Nuttall.

The Eocene calcareous deposits under the inner shelf probably correlate with the rocks of Clarborne age identified in the Cape Fear region (Brown, Miller, and Swain, 1972) and the Castle Hayne Formation of the Carolina Coastal Plain. Brown, Miller, and Swain describe the Clarborne unit in nearby wells onshore as a molluskan limestone grading laterally into bryozoan limestone. Castle Hayne deposits are usually characterized as calcareous sediment or rock.

e. Oligocene Sand and Calcareous Rock. Extensive and thick deposits of Oligocene age closely underlie the inner shelf of much of Onslow Bay and probably extend under Frying Pan shoals into eastern Long Bay. All of reflection unit III is believed to be made up of Oligocene sediment. Core data indicate that Oligocene strata also lie near the surface in the southern part of the reconnaissance area as far north as New River Inlet and possibly beyond.

Typically, the Oligocene sediments consist of very fine or fine, well-sorted quartz sand, with biogenic calcium carbonate ranging from a few percent to more than 35 percent by weight. Near New River Inlet, consolidated calcareous rock of Oligocene age occurs in cores 98 and 99; Crowson and Riggs (1976) report that calcareous rocks in this general area are exposed on approximately 50 percent of the sea floor inside the 15-meter isobath.

Some of the Oligocene sediments are devoid of recognizable fossils except for occasional phosphatized bones and teeth from marine vertebrates (Fig. 15,a). Most of the samples, however, contain calcareous skeletal

fragments which are locally abundant. Of these, few are recognizable macrofossils and the majority are microfossils. Remains of the larger organisms consist mostly of small mollusk fragments, barnacle plates, and echinoid parts, particularly spines. The calcareous rock in cores 98 and 99 contains abundant casts and molds of mollusks. Outcrops (presumably of this same rock) found off New River Inlet are reported by Lawrence (1975) and Crowson and Riggs (1976) to contain shells of the large Tertiary oyster, *Crassostrea gigantissima* Finch.

The more numerous microfauna consist chiefly of foraminifera, by far the most abundant element, ostracods, and bryozoa. The foraminiferal fauna is varied from place to place in species composition and in non-specific characteristics. However, a few elements are near ubiquitous and are useful for identifying the deposit. The most important species of this group are *Nonion advenum* Cushman and *Discorbis assulata* Cushman. A comprehensive study of the Oligocene foraminifera in the ICONS cores and from onshore samples is planned for publication by the U.S. Geological Survey.

The distribution and thickness of Oligocene rocks in the North Carolina Coastal Plain are illustrated and discussed in Brown, Miller, and Swain (1972). They found the characteristic lithology from borehole data to consist chiefly of algal and shell limestone with the original shell material leached out. Locally, there were deposits of sand and calcareous sand. Except for the calcareous sandstone in the cores from New River Inlet, there was little lithologic similarity between the material beneath the inner shelf and the Oligocene unit onshore. However, they note an east-west facies progression and the facies found offshore apparently does not extend much inland of the shoreline of Onslow Bay.

Coastal plain deposits containing the large Tertiary oyster, *Crassostrea gigantissima* Finch, have been recognized at several locales on the North Carolina Coastal Plain; these deposits have been variously correlated to the Eocene Castle Hayne Formation or to the Trent Marl Formation of Oligocene or lower Miocene age. In a general study of the oyster communities, Lawrence (1975) reviewed prior work, and added new data on outcrops of these deposits. He found that the localities of oyster-bearing strata form an arcuate belt from Pollocksville through Belgrade to Jacksonville, and shoreward along the westward margin of New River, with deposits extending also along the sublittoral southward of New River Inlet for 5 to 10 kilometers. He concluded that the oyster-bearing deposits which rested on unnamed, well-indurated late Oligocene "shell rock" were also of late Oligocene age and were formed along the northeastern margin of a late Oligocene delta. In this connection, he points out that the areal distribution and unit geometries of sand-rich lithofacies in the unnamed rocks of Oligocene age mapped in this area strongly suggest a prograding delta complex. The inner shelf ICONS data support this conclusion. The internal reflectors in unit III which extends generally south and southeast of Lawrence's study area indicate that the deposit is probably a deltalike progradational sediment body. The consolidated carbonate rock in cores 98 and 99 off New River Inlet

may be part of the late Oligocene carbonate rock underlying the oyster-bearing deposits.

f. *Miocene Deposits.* Sediments of probable Miocene age occur in cores 95 and 96 from northeastern Onslow Bay. In addition, cores 91 and 93 contain an anomalous mixture of shallow marginal marine and planktonic foraminifera (possibly detrital or reworked), which appear to be of Miocene age. Cores 91 and 93 have not been studied in any detail because the older fauna appears to be displaced.

The Miocene sediments in core 95 consist of silty sand and shells with a phosphorite content of around 25 percent, the highest found in any of the ICONS cores. Nearly all of the phosphorite consists of pelletoid grains that are well rounded and typically have a dull waxy amber to dark-brown color. Glauconite is also present and in greater frequency than in any other material in the Onslow Bay cores. Foraminifera in core 95 are sparse but well preserved. The assemblage is dominated by two species--*Hanzawaia concentrica* (Cushman) and *Bolivina paula* (Cushman). Planktonic species are rare relative to the nearby core 96.

Miocene sediment in core 96 is a silty, sandy barnacle plate hash containing abundant foraminifera. The abundance of barnacle plates is a distinctive feature of this sediment, though abundant barnacle plates also occur in type G sediment. The two deposits, however, can be readily separated by differences in color, degree of recrystallization, and faunal content. The foraminiferal assemblage of core 96 is diverse but dominated by abundant specimens of large *Cibicides floridanus* (Cushman). This species has been widely reported as showing considerable diversity in form. The specimens in core 96 are similar to those illustrated by Figure 1 in Todd and Low (1976). Other common benthonic types in core 96 are *Cibicides lobatulus* (Walker and Jacob), *Cibicides pseudoungerianus* (Cushman), and *Bolivina paula* (Cushman and Cahill). Planktonic species are well represented in this deposit. The most common species are *Globorotalia obesa* Bolli and *Globigerinoides trilobus*. Core 97, which lies seaward of core 96, contains many reworked foraminifera of this assemblage and may either closely overlie the same deposit or the fauna may be detrital elements.

Cores 95 and 96 probably correlate with either the middle or late Miocene rocks described by Brown, Miller, and Swain (1972) from well and outcrop data on the adjacent coastal plain. They describe the middle Miocene beds as predominantly composed of clay (partly diatomaceous), limestone, dolomite, shells, sand, and phosphatic sand. Late Miocene deposits are characterized as highly shelly gray clay, fine to medium clayey and shelly sand, shell hash, and limestone.

Kimrey (1965) described interbedded phosphatic sands, silts, clays, diatomaceous clays, and phosphatic limestone in the North Carolina Coastal Plain for which he proposed the name Pungo River Formation. This unit has been correlated with the middle Miocene Calvert Formation of Maryland and Virginia (Brown, 1958; Gibson, 1967). The stratigraphy of the Pungo River Formation was mapped and further described by Miller (1971). Late

Miocene rocks in the North Carolina Coastal Plain are usually ascribed to the Yorktown or Duplin Formations which are probable near-time equivalents. Various investigators have correlated these formations to either late Miocene or Pliocene age (see Campbell, 1975).

Fauna in cores 95 and 96 do not correlate closely in terms of dominant species with any of the described fauna from either the middle to late Miocene or Pliocene strata on the adjacent coast; however, in general they appear to be most consistent with a middle Miocene age.

g. Plio-Pleistocene Bioclastic Calcareous Sediments and Rocks. Distinctive bioclastic carbonate sediments and rocks comprising sediment type G, and correlating with the ancient channel-fill deposits of reflection unit IV, are judged to be largely the product of a single depositional event. The lithologic character of these deposits and included fauna suggests that deposition occurred in a warm, shallow sea during late Tertiary or Pleistocene time.

The Plio-Pleistocene material is found in shallow subcrops and outcrops in both Long and Onslow Bays; however, it is far more extensive in the latter area. Since no cores taken north of Moores Inlet in Onslow Bay contained this material, the northern limit of the deposit may be in that locale. The extensive rock outcrops reported in the inner and mid shelf area of southwestern Onslow Bay (Cleary, 1968; Cleary and Pilkey, 1968) are likely exposures of Plio-Pleistocene rocks possibly mixed with consolidated facies of Oligocene material.

Large numbers of individual particles in the deposits are not identifiable because of fragmentation and recrystallization. However, a substantial amount of the material is skeletal parts of various marine invertebrates; the unidentified particles are probably similar material. Of the larger particles, the most abundant are acorn barnacle plates and fragmented zoaria of bryozoans. Smaller recognizable particles consist mostly of foraminifera and echinoid spines. Mollusk shells are commonly present but in such a highly fragmented state that few are identifiable.

The Plio-Pleistocene deposits can be readily differentiated from other deposits in the study area by their distinctive white to light-gray color, the abundance of barnacles and bryozoa in the constituent particles, and by foraminiferal fauna. The only similar material found in the study area is the Eocene bryozoan hash which occurs in eastern Long Bay. The Eocene deposits have no barnacle plates and they differ in foraminiferal fauna. Foraminifera in the Plio-Pleistocene rocks and sediments have been partially recrystallized and coated with various amounts of calcareous material. The identified fauna are long ranging and do not clearly indicate the time of deposition. On the basis of available faunal data, however, the most probable age appears to be Pliocene.

Characteristics and ubiquitous benthonic foraminifera found in the Pliocene deposits are *Planulina depressa* (d'Orbigny), *Cibicides lobatulus* (Walker and Jacob), and *Textularia gramen* d'Orbigny. Among the sparse planktonic species, *Globigerinoides ruber* (d'Orbigny) is most common.

Brown, Miller, and Swain (1972) did not differentiate rocks of post-middle Miocene age in their study of Atlantic Coastal Plain geology. Onshore geologic formations that have generally been ascribed a late Miocene or Pliocene age in the southern North Carolina Coastal Plain are the Duplin Formations of probable early to middle Pliocene age and the Waccamaw of probable late Pliocene age (Campbell, 1975).

h. Quaternary Deposits. Most of type A, D, E, and F deposits are sediments of apparent Quaternary age, but possibly contain late Tertiary elements. Except in shoal areas, the Quaternary deposits are rarely thick enough to be identified or traced on available seismic reflection records and their distribution and character are known only from the core data.

Type E shelly sands and shell gravels are believed to be the oldest of the Quaternary deposits. They are heterogeneous and probably not all the product of a single depositional episode; however, most seem to have been deposited in a shallow, marginal marine environment probably near the leading edge of the transgressing Holocene sea or during the mid-Wisconsin recession. The shell content of type E sediments consists of a mixture of skeletal fragments derived mostly from mollusks but also containing bryozoa, echinoids, and barnacles; calcareous algae and coral occur locally in small quantities. The disparate nature of the fauna and the wide variation in the condition of shell particles indicate that the sediment contains reworked and detrital biogenic elements as well as those resulting from in situ production. Some mollusk shell fragments appear to be from Tertiary species. In most cases, these shells are badly worn and their presence with modern, well-preserved shells suggests detrital origin. The Tertiary material is dominant in a few places; these deposits may be of late Tertiary age.

The most common and ubiquitous mollusk found in type E sediment is the coot clam, *Mulinia lateralis* Say, an abundant inhabitant of marginal marine waters. Other locally common species are *Anadara transversa* (Say), *Crassinella lunulata* Conrad, *Gemma gemma* (Totten), *Crassostrea virginica* Gmelin, *Nucula proxima* Say, and *Nuculana acuta* (Conrad).

Foraminifera are usually abundant in type E deposits. Species of *Elphidium*, *Ammonia*, and *quinqueloculina* typically dominate the assemblages. In some places, there are numerous *Hanzawaia concentrica* Cushman, suggesting deposition in somewhat deeper waters than now exist over the inner shelf. However, for the most part the assemblage indicates deposition in marginal marine conditions. A distinctive assemblage of abundant *Elphidium gunteri* Cole occurs in several cores from southern Onslow Bay and these may be from a single extensive deposit. Elsewhere, the deposits appear to be more localized.

The type F clay and sandy clay deposit is also believed to be Quaternary in age on the evidence of its position relative to other units. Except for plant fragments, samples of this deposit contain little or no in situ fossils. It is apparently a shallow estuarine, marsh, or

lagoon deposit which accumulated under environmental conditions that were unfavorable for most marine animals.

Coarse quartz sand of type D sediment probably represents deposition at different times during the Quaternary. Part of these sediments seem to be closely related to type E material, differing mostly in a smaller shell content. This difference may be due only to minor differences in depositional environment from place to place, or to episodes of post-depositional leaching or preferential sorting which locally altered the original character of the deposit. A second group of quartz sands (classified as type D material) is judged to be closely related to type A sand because it also forms part of the modern surficial sediment deposits and contains similar fauna. This aspect of type D material is identified on the core logs (App. B) as a "shelf facies" deposit.

The shelf facies sands also include all type A sediments. They are judged to be the most recent of the Quaternary sediments and are, for the most part, wholly modern because they represent the ongoing nearshore and shelf sedimentation processes. Locally, however, the deposits may have been initiated during the last stages of the transgression at a sea level somewhat lower than present. Shelf facies deposits overlie large areas of the inner shelf floor and shoreface zone, and probably comprise the bulk of the material in the shoal complex off Cape Fear and lesser shoal features elsewhere.

Faunal elements in the shelf facies sands are mostly compatible with the inner shelf and existing nearshore environments. Reworked or detrital faunal components occur frequently but can usually be discriminated from the more modern elements. The modern fauna consist primarily of mollusks, echinoids, and foraminifera. Many of the mollusks are larval or juvenile forms; large mollusk shells are rare. Common mollusks found in adult form are small species with shells generally less than 25 millimeters (1 inch) long. Of these, *Caecum pulchellum* Stimpson and *Ervillea concentrica* (Holmes) are most common; others occurring frequently are *Parvilucina multilinea* (Tuomey and Holmes), *Crassinella lunulata* Conrad, and *Tellina* cf. *T. sybaritica* Dall.

Foraminifera in shelf facies sediments vary in frequency from rare to abundant. The assemblages in many instances contain reworked and detrital tests derived from substrate deposits. Where they are clearly exotic, such as the Oligocene fauna which are common detrital and reworked elements in surface sediments, the assemblages can be readily differentiated from the more modern types. Those derived from late Tertiary and Quaternary substrate deposits are not usually separable. Although it is probable that such displaced material is present in substantial amounts locally, the general consistency from place to place in the more common species suggests they are representative of the modern shelf floor assemblage.

Studies of southeastern Atlantic shelf foraminifera have shown the existence of distinct inner, mid, and outer shelf assemblages (Wilcoxon,

1964; Kilbourne, 1970; Schnitker, 1971; Sen Gupta, 1972; Meisburger and Field, 1976). The inner shelf zone generally lies between the shore and water depths of 15 meters (49 feet) and is dominated by the species of *Elphidium*, *Quinqueloculina*, and *Ammonia*.

Foraminifera in most of the surficial deposits of the study are typical of the dominance of species in the inner shelf assemblage. A few cores from near the seaward limits of the study area contain fauna with some characteristic midshelf types, particularly *Peneroplis proteus* d'Orbigny. A few cores from the shorewardmost locales contained assemblages strongly dominated by species of *Ammonia* and *Elphidium*. Meisburger and Field (1976) found a similar fauna to be characteristic of a nearshore subzone, roughly coincident with the shoreface; Kilbourne (1970) reported that off Georgia these two genera were dominant throughout the entire inner shelf zone.

2. Evolution of the Inner Shelf Zone.

a. General. The topography and sediments on the inner shelf of the Cape Fear Region, as with most of the Atlantic shelf province, reflect both modern and relict events. For example, some of the events which have shaped the gross morphology of the Cape Fear shelf region are clearly related to structural, erosional, and depositional processes that occurred during or before the Tertiary period. The present morphology of the shelf surface with its characteristic low relief was probably established by planation of the Tertiary substrate during the repeated recession-transgression cycles consequent to Plio-Pleistocene glacial events. This pre-Holocene surface probably corresponds in most places to the blue reflector which was used as the isopach datum in Figures 7 and 8. It seems unlikely that the relatively rapid Holocene transgression materially affected the existing gross morphology of the shelf floor in most places. However, the prominent Frying Pan and Lookout shoals are exceptions and may have been established during the transgression (Swift, et al., 1972).

Shelf sediment distribution patterns were significantly affected by glacioeustatic sea level fluctuations, particularly by the mid-Wisconsin eustatic fall of sea level and its subsequent rise during the early and middle Holocene. The minimum sea level stage reached during the mid-Wisconsin low was about 122 meters below present level; thus, the entire shelf off Cape Fear was exposed to subaerial processes. During the subsequent Holocene transgression each part of the shelf came, in turn, under the influence of shallow marine processes and environmental conditions followed by gradually deepening water as sea level rose to its present worldwide stand.

It is generally believed that eustatic sea level reached its lowest stand some 15,000 to 19,000 years ago and the present stand about 3,000 years ago (Curry, 1965; Milliman and Emery, 1972). In most places, sea level today seems to be rising slowly (see Lisitzin, 1974). This rise is, however, considerably less than that which existed before about 3,000 years ago.

From Curray's (1965) eustatic sea level data, the rate of sea level rise was about 0.83 meter (2.7 feet) per century during the first 12,000 years of this period, then slowed to about 0.27 meter (0.9 foot) per century from 7,000 to 3,000 years Before Present (B.P.) when the present sea level was reached. Subsequent fluctuations at that level or continued slow rise may have occurred but most evidence is on a local or regional scale.

Dated marine peats from two ICONS cores (56 and 57) off Cape Fear provide local control for the transgression of the inner shelf in the study region because they lie very near its seaward limits. These cores are close together and probably penetrated the same peat deposit. The peat in core 56, which lies 1.5 meters (4.9 feet) below the shelf floor and 24.5 meters (80 feet) below present MLW, has a radiocarbon age of $10,000 \pm 300$ years B.P.; the peat in core 57, which lies 4.9 meters (16.1 feet) below the shelf floor and 22.9 meters (75 feet) below present MLW, has a radiocarbon age of $10,200 \pm 140$ years B.P. Thus, the transgression of the inner shelf from the depth of the peats in cores 56 and 57 took about 7,000 years. These samples plot considerably above the eustatic sea level curves reported by several authors; however, they show relatively good agreement with Kraft's (1976) curve based on samples from the Delaware shelf and coast, and with the trend of other peat samples obtained in ICONS cores of the Atlantic inner shelf (Field, et al., in preparation, 1979).

The present character and distribution of the shelf surficial sediments are probably largely a product of processes in the shallow marine environment near the leading edge of the encroaching Holocene sea with subsequent additions and local modification by modern shelf and nearshore processes.

b. Inner Shelf Topography. The main topographic elements of the inner shelf are the shelf floor, the adjacent shoreface slope (defined here as a submarine topographic feature which extends from the shore seaward to where there is a perceptible flattening of the slope to the more gentle gradient of the shelf floor), and the cape-associated shoal complexes off Capes Lookout and Fear. None of these features appear to be wholly modern although all are probably undergoing some modification as a result of present shelf processes. The most pronounced effects are on the upper shoreface and the cape-associated shoals. Little modification of the shelf floor topography is apparent as a result of modern processes.

The most prominent positive elements of the shelf topography are the massive shoal complexes extending seaward from Capes Lookout and Fear. Swift, et al. (1972) believe these shoal complexes initially formed during the Holocene transgression as cape-associated shoals which were sequentially created and abandoned as the cape retreated across the shelf floor, and that subsequently these shoals were and continue to be maintained and locally modified by waves and currents, especially during storms (see also Hunt, Swift, and Palmer, 1977).

The few ICONS samples available from the shoal area also suggest existing processes are actively reworking the surficial layers of shoals and that local erosion and redeposition probably occur. For example, the sediment in core 62, obtained 22.2 kilometers (12 nautical miles) offshore on the shallow crest of a shoal in the Cape Fear complex, contains the highly polished mollusk fragments and clean, well-sorted sand typical of high-energy beach sediments, which suggests vigorous periodic reworking of the shoal crest sediments.

Little is known of the substructure of the shoreface in the study area. It may be either a relict or essentially a modern feature. In its simplest form, the shoreface slope comprises the ramplike seaward face of a barrier spit or island which is composed entirely of sand, and which formed initially during the late phases of the transgression. In many places, however, barriers seem to have a more complex structure. For example, barrier sands may comprise a relatively thin surficial veneer covering a slope carved into lagoonal, washover, and possibly relict sediments which are progressively exposed on the shoreface as a result of erosional retreat of the coastline. In addition, some barriers are underlain by preexisting topographic features which form a core to the modern beach and shoreface superstructure (Tanner, 1960; Pierce and Colquhoun, 1970). In such cases, the shoreface is essentially an ancient feature although the veneer of modern sand may modify the slope characteristics through closer equilibrium with the prevailing wave and current regimens.

There is evidence that an ancient relict substructure may exist beneath the shoreface near New River Inlet where outcrops of Oligocene carbonate rock occurring inshore (Lawrence, 1975; Crowson and Riggs, 1976) are apparently contiguous with carbonate rocks of the same age found at about -12.2 meters (-40 feet) MLW in ICONS cores 98, 99, and 100 near the toe of the shoreface. This evidence indicates the rock surface probably underlies the entire shoreface slope.

Secondary topographic features on the relatively level inner shelf surface are sparse and of low relief. Some features may be erosional remnants of Pleistocene sediment accretions which survived late Wisconsin subaerial exposure of the shelf and subsequent transgression. Other highs have developed by differential erosion around resistant rock outcrops. A notable example of this topography occurs off New River Inlet where Crowson and Riggs (1976) report scarps up to 5 meters (16 feet) high surmounted in places by worm reefs. These features are formed by outcropping Tertiary carbonate rocks. Another example was reported by Mixon and Pilkey (1976) who found knobs and ledges of Pleistocene coquina on the shelf floor south of Cape Lookout shoals. Elsewhere in the study area rocky ledges and knobs occur in the areas underlain by the Pliocene calcarenites and where scattered patches of shell coquina of probable Pleistocene age crop out on the shelf floor. Most of the inner shelf secondary topography, however, was probably molded by marine processes operating in the shallow waters near the leading edge of the transgressing Holocene sea, or by present shelf and nearshore processes subsequent

to the transgression; e.g., subtle hills, ridges, and depressions. These processes are not detailed enough on available bathymetric charts to be outlined but can be detected on fathometer and seismic reflection records.

c. Surficial Sediment Distribution and Origin.

(1) Previous Studies. Surficial sediment characteristics of the south Atlantic shelf have been covered in regional studies by Gorsline (1963), Pilkey (1963, 1964), Goodell (1967), Terlecky (1967), Doyle, Cleary, and Pilkey (1968), Pilkey, et al. (1969), Field and Pilkey (1969), and Judd, Smith, and Pilkey (1970). These studies, though general in nature, provide valuable information on the inner shelf between Cape Lookout and the South Carolina border. More localized studies concerning the North Carolina shelf have been made by Roberts and Pierce (1967), Laternauer and Pilkey (1967), Cleary and Pilkey (1967), Cleary (1968), Milliman, Pilkey, and Blackwelder (1968), Pratt (1970), and Milliman, Pilkey, and Ross (1972).

Within the Cape Fear ICONS study boundaries, the most common surface sediment has been described as pale-olive or yellowish-gray, fine quartz sand. Calcium carbonate content is commonly less than 20 percent but may be larger locally. Heavy minerals usually constitute less than 1.3 percent of the total. Pratt (1970) found that on the inner shelf of Long Bay, opaques comprised 30 to 45 percent of the heavy mineral fraction and that nonopaque heavy minerals are dominated by staurolite (comprising 15 to more than 32 percent of the total heavy mineral fraction), followed by epidote (5 to 14 percent), and the pyroxene-amphibole group (0 to 10 percent). Garnet, zircon, rutile, sillimanite, kyanite, and tourmaline were also present but comprised less than 5 percent of the heavy fraction.

On the inner shelf of Onslow Bay, Cleary (1968) found that heavy minerals increase in abundance from a low of 0 to 0.5 percent near Cape Fear to more than 2 percent near Cape Lookout. Opaques comprise more than 40 percent of the heavies in this region (Gorsline, 1963; Goodell, 1967). Pilkey (1963) reported significantly higher percentages of zircon and garnet north of Cape Fear than to the south (Long Bay); epidote was higher to the south of Cape Fear. Staurolite was the dominant heavy mineral species with a frequency ranging from 5 to more than 15 percent of the heavy mineral fraction. Other heavy minerals found by Pilkey (1963) in Onslow Bay include kyanite, pyroxenes and amphiboles, rutile, and tourmaline, all apparently with a frequency of less than 10 percent. Gorsline (1963) found that staurolite comprised 10 to as high as 60 percent of the heavy mineral fraction in Onslow Bay inner shelf sediments, with an average frequency of 40 percent or more south of about Bogue Inlet. In Long Bay staurolite was less than 32 percent (Pratt, 1970), suggesting a further mineralogical division between the two bay areas.

Doyle, Cleary, and Pilkey (1968) reported that sand-size detrital mica on the southeastern Atlantic shelf is deficient in the central and

outer shelf areas, which they believe are areas of winnowing. They found that mica was concentrated in a narrow nearshore zone and on the upper continental slope which they interpret as areas of deposition. The nearshore deposits in Long and Onslow Bays contain 20 to 40 grains of mica per 10,000 grains and mostly less than 10 grains per 10,000 elsewhere on the North Carolina shelf.

Laternauer and Pilkey (1967) studied phosphorite grains in North Carolina shelf sediments and found that Onslow Bay surface sediments contained significantly more phosphorite (3 to more than 14 percent) than the adjacent Long and Raleigh Bays. They believe that the higher frequency of phosphorite in Onslow Bay sediments probably indicates derivation from local shelf outcrops of phosphatic strata.

In a general study by Milliman, Pilkey, and Ross (1972), glauconite is shown to be less than 5 percent in the North Carolina shelf region. Farther seaward on the Florida Hatteras slope, frequencies as high as 95 percent glauconite occur in the noncarbonate fraction.

(2) ICONS Data. Surface sediments found in the ICONS cores are shown in Figures 26, 27, and 28. Not enough samples were collected to delineate the extent and limits of the various sediments occurring on the surface of the inner shelf; however, some of the deposits appear to be very extensive. Core data provide evidence that shows many places where materials of radically different lithologic properties lie in close proximity. This is partly due to the thin bedded and discontinuous nature of the Quaternary and modern sediments which produce a pattern of modern sediment patches alternating with outcrops of older Quaternary, Tertiary, and Late Cretaceous sediments. Consequently, many of the surface sediments are relict and not consistent with the hydraulic process now dominating the inner shelf.

The most striking feature of surficial sediment distribution in the study area is the predominance of a fine sand facies in Long Bay and Frying Pan shoals. This is in contrast to coarser sediments and pre-Holocene outcrops which dominate the Onslow Bay inner shelf and suggests that the sedimentation history as well as present inner shelf processes in the two areas may be substantially different. Many of the coarser sediments which occur on the shelf floor are probably relict deposits of the last transgression or have been reworked from such deposits. Because of the lower sea level at that time, streams likely delivered coarser detrital sediments to the shelf than are presently available. Other coarse surface deposits were also probably generated at this time by reworking of substrate material as the shoreline advanced across the present shelf floor. Evidence of this derivation is indicated by invertebrate remains in surficial deposits that are clearly exotic in the existing inner shelf environment but are contained in situ in the underlying relict substrate. The mineralogy also suggests reworking in many places where calcareous particles, phosphorite, or glauconite from substrate deposits appear in abundance in the overlying sediments. Reworked substrate deposits have been described as a common mode of origin of shelf

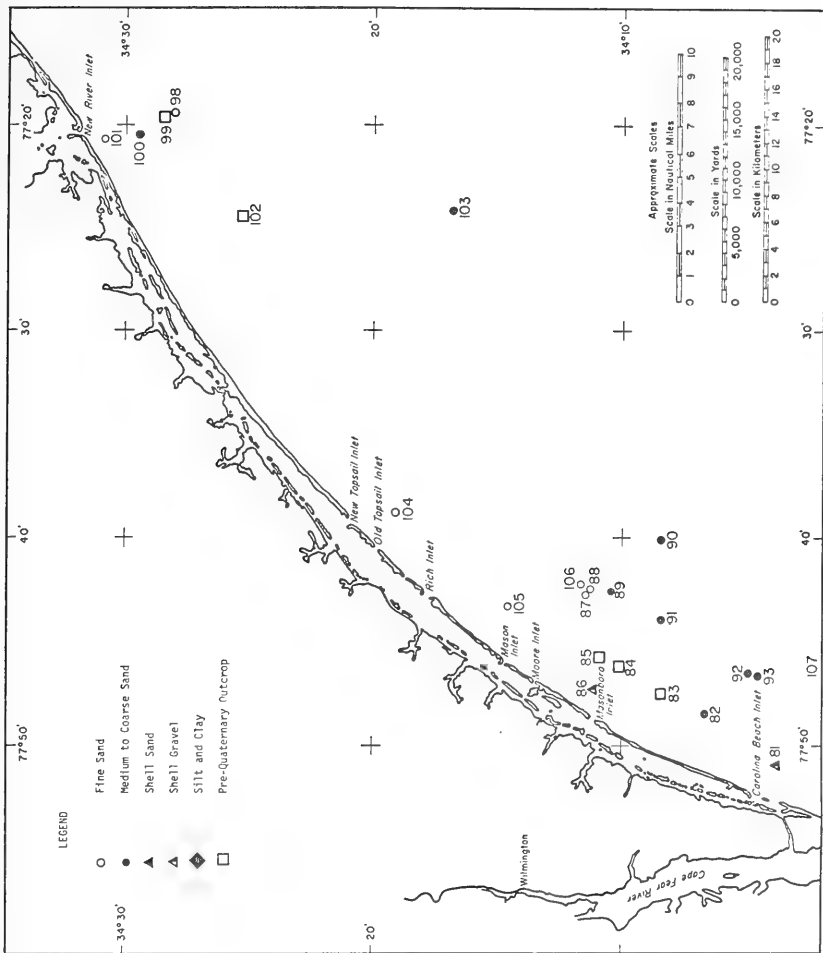


Figure 27. Map of the northeastern part of the main survey area showing surface sediment characteristics.

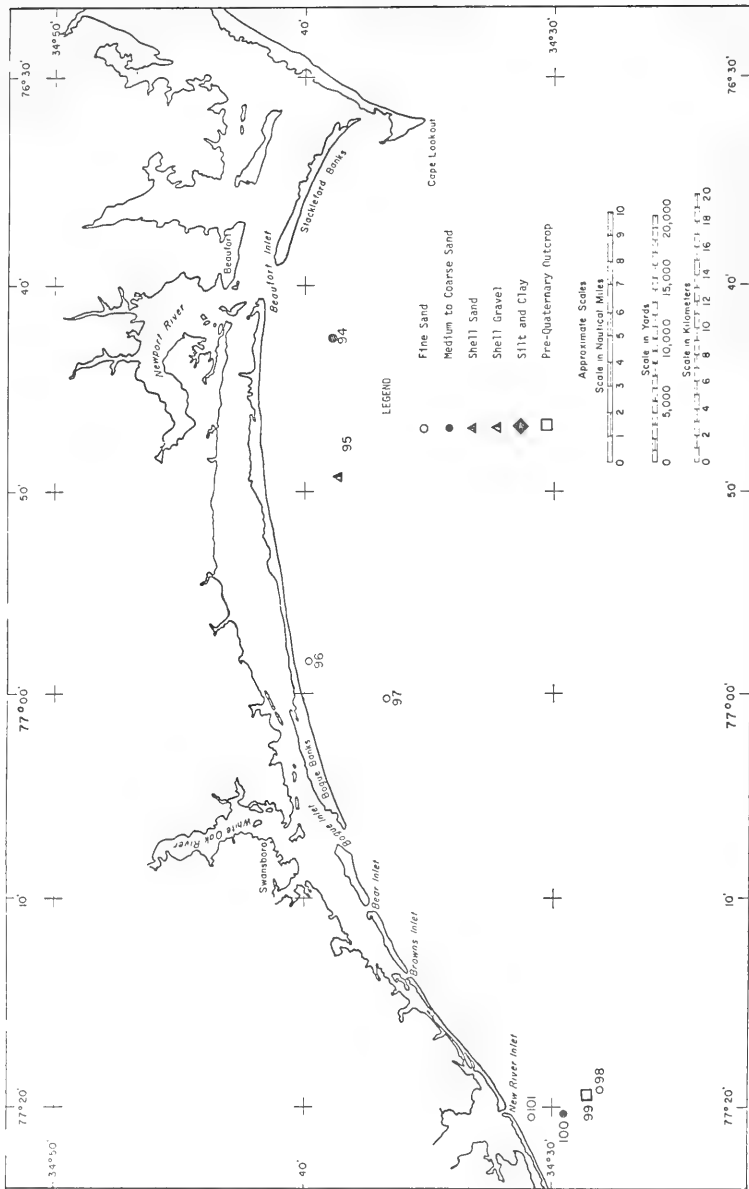


Figure 28. Map of the reconnaissance area showing surface sediment characteristics.

floor sediments by Swift, Stanley, and Curray (1971) who called the sediments "palimpsest" deposits.

In general, the medium to coarse sand and shelly sand of the inner shelf floor surficial deposits are probably the result of either sediment transport or reworking of substrate deposits in waters much shallower than now exist over the area. Present shelf processes in most of these areas, however, are probably effective in removing the finer detrital and biogenic sediment particles which accumulate during periods of fair weather. Evidence of the latter process is the usual scarcity of foraminifera in the medium and coarse sand areas as compared to nearby areas of fine sand and also that many of the tests that occur in the coarser deposits are of large size. Since both fine and coarse surface sands occur in close proximity and at about the same depths in many places, the modern benthonic foraminifera can reasonably be expected to be near equivalent in both abundance and kind unless substrate character is of decisive importance, but this seems unlikely. The probable reason is that coarser sands are located in areas where strong wave and current flow either prevents establishment of smaller foraminifera or periodically winnows out their discarded tests.

In contrast, many of the finer shelf facies sand deposits probably occupy areas where deposition is the dominant process under existing conditions. The foraminifera in these sand deposits, unlike the nearby coarser sands, have a higher abundance, greater species variability, and a predominance of small tests. In addition, the fine deposits contain large numbers of other small biogenic particles, such as echinoid spines and mollusk larvae, which are rare in the coarser facies.

Not all the fine shelf facies sand deposits, however, are located in modern depositional environments. Some deposits consist of locally reworked fine sands of type B or C sediment which may have originated during the transgression.

In a few cases, fine sand on the surface consists of exposures of type B or C sediments which are probably being actively eroded, at least on a periodic basis. For example, at core 80 the surface is an exposed type B deposit containing abundant Oligocene foraminifera but practically no modern types. This indicates fresh surfaces had recently been or are continually being exposed by erosion. Therefore, it is judged that while many shelf facies, fine sand deposits occupy areas of probably active deposition, some occur where there is little or no deposition now taking place and a few occupy areas of active erosion.

The major source of the fine shelf facies sand apparently lies in the extensive Cretaceous and Oligocene fine sand and muddy sand deposits underlying large parts of the inner shelf. Most of the sand was probably originally eroded from these deposits during the transgression, but quantities of fine sand are now being derived by winnowing of coarser shelf facies sand and by active erosion of exposures of Cretaceous and Oligocene strata.

V. ENVIRONMENTAL AND ENGINEERING FACTORS

1. General.

The planning and design of most coastal and inner shelf engineering works require an assessment of a number of factors related to the geological environment. Such factors as geologic hazards in the project area, shelf floor and subfloor soil characteristics, and the mobility of the surficial sediment layer are important considerations in most construction, dredging, and disposal operations. In addition, many inner shelf sediment and rock deposits are potential sources of sand for restoration and nourishment of nearby beaches, construction aggregate, fill material, and riprap.

As a result of the analysis of the ICONS survey data, some general observations can be made on a number of these factors in the Cape Fear inner shelf region. Quantitative data cannot be provided in most cases because of the general nature of the survey and the unsuitability of vibracore samples for many engineering soil tests. Available samples are, however, suitable for classification under the Unified Soils Classification System (see U.S. Department of Interior, 1963).

2. Geological Hazards.

Of the many geological hazards affecting engineering works (Bolt, et al., 1975), the following were most pertinent to the study area: ground rupture, ground shaking, soil liquefaction, rapid settlement, slope instability, and tsunami waves. All of these hazards are apt to occur in association with earthquakes but most can also be initiated by other causes. Earthquakes appear to be the principal geological hazard for large-scale or widespread damage, and the assessment of earthquake risk and the predisposition of soils for failure under earthquake loading are important planning factors for engineering works. Local and State planning agencies, the U.S. Geological Survey, and the National Oceanic and Atmospheric Administration compile and publish data on earthquake potential and characteristics in the United States (e.g., Algermissen, 1969; Coffman and Von Hake, 1973).

Earthquakes are most commonly caused by massive movement of earth segments along fault zones. The relative displacement itself may cause severe damage to structures which span the fault and associated phenomena, such as tsunamis and soil failures due to ground shaking, can affect an area extending many miles from the actual epicenter. For that reason, the presence or absence of faults which could be potential areas of massive earth movements is an important consideration in locating and designing offshore and coastal zone structures.

Faults can be detected on seismic reflection profiles provided three conditions are met. First, there must be sufficient penetration of sub-bottom strata to reach the faulted strata; second, there must be one or preferably more reflective interfaces within the faulted strata to serve

as key beds; and third, the displacement component must be large enough to be apparent at the resolution level of the seismic reflection system in use. Absence of faulting on seismic reflection records which do not meet these criteria is, therefore, not conclusive evidence of nonexistence.

The reflection profiles taken during the ICONS survey provided penetration in most places to 61.0 meters or more below the shelf floor. However, in substantial areas over unit II and elsewhere (particularly over unit III), there was little or no penetration below the first sub-bottom reflector which lies usually at less than 4.6 meters below the sea floor. Where good penetration was achieved there were many closely spaced subbottom reflectors so it is likely that faulting with vertical displacement would be apparent. In areas where both penetration and subbottom reflectors were adequate enough to show shallow subs shelf faults, only a few possible faults were detected (see App. A, profiles B and C). On the basis of probability it seems reasonable to conclude that the scarcity of evidence of faulting in areas suitable for their detection would also apply to those areas where penetration was deficient, unless lack of penetration itself was occasioned by fault displacement of acoustically impenetrable strata into a laterally contiguous relationship with more penetrable strata. It is improbable, however, that such a consistent pattern of displacement would occur in so many places throughout the area; it appears more likely that large faults within the upper 61.0 meters of the subs shelf strata are rare.

Fine, well-sorted type A sand of the Holocene shelf deposits and the similar types B and C sand have textural properties making them more susceptible to liquefaction than other sediment bodies in the study area. Plots of the size-frequency distribution of 34 representative samples from these deposits were compared to a size distribution curve (Fig. 29) showing the envelope of values for a number of sands which have liquefied under cyclic loading in nature and in laboratory experiments (Seed, Arango, and Chan, 1976). A significant part of the curves for all 34 samples, varying from 50 to 100 percent, fell within the envelope of greatest susceptibility.

Since sand types A, B, and C cover or underlie more than half the survey area and extend in depth to 61.0 meters or more below the shelf floor, their potential for liquefaction is an important aspect of the inner shelf engineering environment. However, liquefaction potential is also affected by other factors--in situ density (the most important single factor), geological and seismic history, grain structure, cementation, and characteristics of the cyclic load. Available samples are not suitable for measurement of grain structure or density. For factors related to geological history, it seems reasonable to expect that considerable differences exist between deposits of types B and C sediments which have been in place for several millions of years and type A sediment which, at most, is a few thousand years old. For example, types B and C sand may be considerably denser than type A sand because of longer exposure to overburden stresses. The eroded upper surface of these deposits, as indicated by truncation of secondary reflectors, suggests

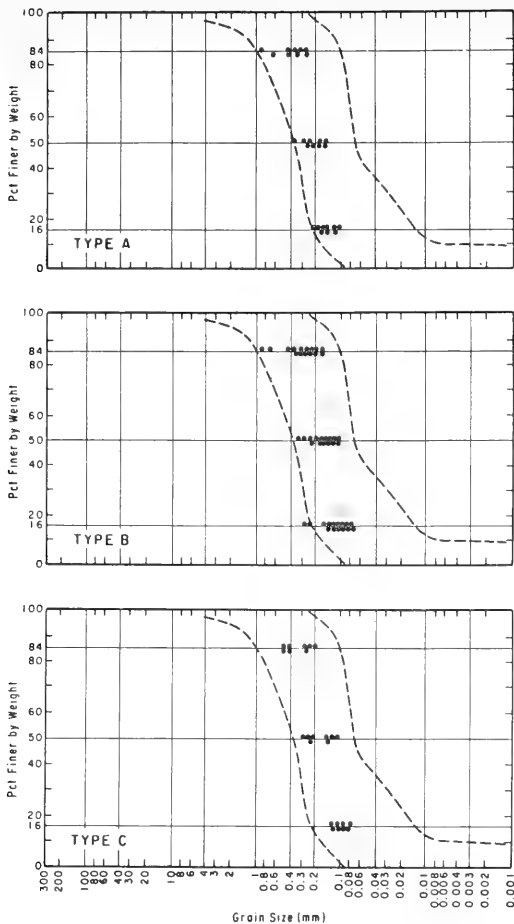


Figure 29. Comparison of fine sand from the study area with sands known to have liquefied under cyclic loading.

also that they may have been much thicker in the past. In addition the age of types B and C sediments indicates they were more likely subjected to cyclic loading in the past, due to seismic events, than type A sediments. There is evidence that a past history of cyclic loading reduces liquefaction potential which tends to increase the density (Seed, Arango, and Chan, 1976). Finally, a very rudimentary cementation was noted in several samples of types B and C sediment, particularly type B, due to partial leeching and redeposition of calcium carbonate particles. Although these sediments are not consolidated, the slight cementing in many places may lessen liquefaction potential. Though fine type A and types B and C sands are almost identical in size characteristics, they can be readily identified by their distinctive microfauna, even where one overlies the other (Sec. IV, 1) or by the absence of microfauna as in barren types B or C.

Slope failure by downslope sliding, slumping, and creeping of soil masses often occurs in the submarine environment as a result of gravitational forces or cyclic loading by waves and seismic events. In general, the bottom slope, the thickness of the unconsolidated sediment blanket, the soil strength, and the nature of the load applied dictate the type and magnitude of displacement. Evidence of prior downslope soil displacement may be indicated in bathymetric and high-resolution seismic reflection data, but the absence of such evidence does not preclude the existence of displaced soil masses or the potential for such occurrences.

Most of the study area is occupied by a shelf floor with an extremely gentle gradient of about 1:3000. Although gravitational downslope forces are small on the gentle slopes, soil displacements occur under highly favorable conditions, such as liquefaction of the soil mass or of an unstable sublayer.

Considerably steeper slopes occur in the shoreface zone, with gradients as steep as 1:60, and in the large shoal fields where slopes of 1:20 occur locally. Because of the steeper gradients in these areas and because some are areas of active deposition where soil density is probably low, they are considered more prone to slides and slumps than shelf floor deposits.

Landward-facing rock scarps up to 5 meters (16 feet) high occur in extensive carbonate rock outcrops inshore of the 15-meter depth off New River Inlet (Crowson and Riggs, 1976). While these scarps are probably relatively stable, the highly irregular topography would affect engineering activities such as pipeline construction and dredging.

3. Soil Properties.

Knowledge of the engineering properties of submarine sediments and rock deposits is needed to determine bearing capacity for various types of foundations, side-slope stability in dredged channels, and the uplift resistance of embedded footings and anchors. Because of the unsuitability of available vibrocore samples for standard engineering soil tests,

precise data regarding engineering properties of the various sediment types in the study area are not obtainable. However, certain general observations can be made regarding the engineering properties of possible value in the preliminary planning of engineering works in the coastal and inner shelf environment and in devising sampling plans for specific project sites.

Clay deposits in the Holocene shelf sediments are most likely to pose foundation problems. Most of these clays are classed as type F lithology. When recovered from cores, they are soft, unconsolidated, highly plastic clays with little apparent strength. Under the Unified Soil Classification, this material is classified as a fat clay (CH) and is rated a poor foundation medium. The clay layer in some places is too thin to cause special problems but elsewhere the deposit is much more than 3 meters thick. Clay deposits occur throughout the study area but are particularly frequent in Long Bay. Though clay often fills small channels, the usual occurrence is in areas showing flat-lying reflectors; thus, there is no pattern by which clay can be identified on seismic reflection profiles. Clay deposits rarely crop out and no known distribution pattern or relationship with shelf morphology is present that could be used to predict the presence of clay in specific areas.

Fine quartz sands (types A, B, and C sediments) comprise the dominant lithology of inner shelf surficial and shallow subsurface deposits. Size gradation data of material from these deposits are included in Appendix B.

Under the Unified Soils Classification System, most types A, B, and C sediments fit the criteria of poorly graded sand (SP), which has fair to good foundation properties. Other than liquefaction potential previously discussed, the inner shelf, fine sand deposits are probably similar to typical SP class sediments in their response to foundation stresses and slope stability. Two factors, however, in the character of these inner shelf deposits may be of significance. One is the large number of foraminiferal tests (external skeleton) in the carbonate fraction of some types B and C sediments. These tests are hollow and easily broken so some volume change may occur during the initial loading of a mass of the soil. A second factor which may affect the properties of types B and C sediments is the slight cementation which occurs locally due to dissolution and redeposition of some calcium carbonate grains. These cementation bonds probably increase the in situ strength of the soils but they are easily broken by disturbance. The occurrence of partly cemented sections seems to be spotty both laterally and in depth; therefore, high in situ strength characteristics at one locale may not be typical of the material elsewhere and may be modified during construction operations.

The degree of cementation of type G sediment varies from well cemented to essentially uncemented. This, along with variations in size and sorting characteristics, can be expected to create substantial variations in engineering properties from place to place and in depth. Although type G rock facies appear quite competent in places, there is typically considerable void space in the unfilled interstices between

individual particles; cementation is primarily confined to grain contact surfaces.

The void space in type G rock and the low strength of the individual carbonate grains relative to quartz and many other rock-forming minerals suggest that this material may be prone to failure under loading by breaking of cementation bonds and the crushing of the individual carbonate particles. This would be especially likely under high-bearing stress such as occurs in pile foundations. It should be noted that skin friction on such piles may contribute relatively little to the bearing capacity because horizontal earth pressure in a cemented medium would be very small. The essentially unconsolidated facies may, in such cases, provide a better foundation medium than cemented or partly cemented facies.

4. Sand Resources.

The chief requirement for large volumes of sand-size sediment in the study area is for beach restoration and nourishment on the nearby coast. Sand suitable for this purpose should closely match the size distribution of native beach material, be mechanically and chemically stable, and be reasonably free of fines and foreign material (e.g., sharp coral fragments) which might degrade the quality of the beach for recreational purposes. Specific site locations of potential offshore sand resources within the study limits have been reported in U.S. Army Engineer District, Wilmington (1973) and Meisburger (1977).

Previous studies of the Atlantic inner shelf sediments indicate that suitable sand occurs most commonly in offshore shoals, relict-filled stream channels, and outcrops of sandy coastal plain strata on the shelf floor. Except for the shoals, these deposits rarely have topographic expression and can be detected only by seismic reflection and core data.

Frying Pan shoals off Cape Fear and Lookout shoals off Cape Lookout are the main shoal deposits in the study area. Occasional shore-connected linear shoals and shoals off the mouth of inlets are also potential sources but of much smaller size. Relict stream channels can be detected on the seismic reflection records throughout the area, particularly in Onslow Bay. Cores from these channel areas indicate that most of them south of New River Inlet do not contain quartz sand but are either filled with or capped by biogenic calcareous sand, gravel, and rock.

Most of the quartz sand occurring outside shoal areas is located in the thin and discontinuous Holocene surficial layer and in outcropping Coastal Plain strata associated with seismic reflection units I and III. These deposits consist largely of types B and C sediment and together with types A and D sand make up the larger part of accessible sand reserves in the study area. All of these deposits are similar in character, and in terms of distribution, accessibility, uniformity, and freedom from objectionable matter would make excellent beach fill. However, the typical fine size range of most of types A, B, and C material

(125 to 250 millimeters or 3.0 to 2.0 phi) and the well-sorted character indicate these deposits are poorly suited for nourishment of most beaches in the area.

The most suitable sand for beach fill should be in the medium to coarse size range (0.250 to 1.00 millimeter or 2.0 to 0.0 phi) which corresponds to the size of the natural beach sediment. Potentially suitable sand found in cores of the study area has been of the medium to coarse type D facies which typically occurs as a relatively thin discontinuous blanket deposit on the shelf floor. In addition, at least one area of Frying Pan shoals near cores 58, 61, and 62 contains medium to coarse sand.

The bulk of the Frying Pan shoal material appears to be fine sand, but due to the draft of the coring vessel few cores were taken from this area; consequently, there may be other suitable deposits within the shoal complex. It is pertinent to note that the single coarse sand facies in Frying Pan shoals was found near the western end of some linear transverse depressions which may have been created and subsequently maintained by strong tidal or storm-driven currents. The coarser sand deposits in this locale may be the result of winnowing of the finer material by these currents. This suggests that similar topographic features in the shoal area are promising for further exploration.

Type E sediment often contains medium to fine quartz sand and a few usable sand deposits of this material were located. However, the large shell content, which often exceeds 50 percent in volume, and the frequent presence of silt and clay make most of the type E material of marginal quality for beach fill. It is also commonly buried under unsuitable overburden and tends to occur in discontinuous patches which makes recovery difficult.

Type G calcareous rocks and sediment occur widely in southern Onslow Beach and in part of Long Bay. In many places, this deposit is exposed or covered by only a thin overburden, making it readily accessible for dredging. As previously discussed, it is unclear whether the occurrences of unconsolidated type G material represent a naturally unconsolidated material or disaggregation during the coring process. In either event, it is probable that large quantities of granular sediment could be dredged from the area. However, since there are well-consolidated ledges throughout, detailed surveys with a dense net of probe or drill holes would be necessary to delineate the recoverable material.

The suitability of the calcareous granular sediment for beach fill is questionable. Its coarseness and abundance of granule and pebble-size fragments are undesirable for a recreational beach. In addition, being almost entirely composed of calcium carbonate, it is chemically and mechanically less durable than quartz and could degrade rapidly or form cemented crusts when placed in the beach environment. It would, however, probably be suitable for purely protective beaches or as core material for beaches or armored structures.

No cores were taken in Lookout shoals during the ICONS survey. Mixon and Pilkey (1976) report sand in the Cape Lookout shoals to be a "fairly well sorted, light-gray to yellowish-gray, fine to medium sand" with a mica content of 20 to 40 grains per 10,000 and a calcareous fraction of generally less than 5 percent.

5. Relict-Modern Sediment Boundary.

The distribution of relict and modern sediments, along with the areal and vertical location of the boundaries between these sediment bodies, is an important aspect of engineering site investigations of the shelf floor. For example, fixing the vertical boundary between modern, and possibly mobile, surface sediments and underlying relict strata is important in the subsoil analysis of shelf floor foundation properties.

Because many modern surficial sediments of the inner shelf floor are lithologically similar to the underlying substrate, from which in many cases they are derived by reworking (Swift, Stanley, and Curray, 1971), it is often difficult to determine the boundary by gross lithology or mineralogy alone. In such cases, faunal components of the sediment bodies are the most useful in delineating the boundary. In most cases, the relict deposits contain fauna with extinct elements or, if the deposit is of Quaternary age, fauna that originated under different environmental circumstances and is clearly exotic in the present environment. Even where there is considerable mixing across the boundary, the mixed, modern-relict assemblages can usually be discriminated from the wholly relict assemblage of the substrate.

The areal distribution pattern of relict and modern sediments in the Cape Fear region does not conform to the classic onshore-offshore zonal arraignment with modern paralic sediments dominant inshore and relict sediments offshore. The distribution is much more complex. The inner shelf floor contains numerous and extensive areas of relict sediment interspersed with modern marine sediments. Even in the shoreface zone, where modern sediments probably dominate, there are known outcrops of Tertiary carbonate rock near New River Inlet (Lawrence, 1975; Crowson and Riggs, 1976).

The most distinctive relict deposits exposed on the shelf floor are Plio-Pleistocene calcareous sediment and rock (type G). This material contrasts sharply with the quartz sand and shelly sand deposits characteristic of the modern shelf sediments. Other relict outcrops, especially the fine quartz sands (types B and C) of late Cretaceous and Oligocene age, are less distinct lithologically from modern deposits but are identifiable by the included fauna.

More subtle distinctions occur where there are shelf floor outcrops of relict sediments deposited during the Holocene transgression. Although these deposits were placed in water shallower than now prevails over the area, much of the relict faunal content is derived from organisms with a wide enough bathymetric range to have existed at the present water depth.

However, it is believed that a high dominance of typical marginal marine mollusks, such as *Mulinia lateralis* Say or the distinctive foraminifer *Elphidium gunteri* Cole, in shelf floor sediments probably indicates deposition in the shallower transgressing sea. Even though such species may occur at existing depths, they are not likely to be a dominant faunal element in modern shelf floor deposits. More restricted marginal marine species, such as *Crassostrea virginica* Gmelin and *Gemma gemma* Totten, locally provide a more reliable indication of shallow-water origin in shelf surface deposits. Lithologically, these shallow-water transgressive deposits tend to be muddy and much more heterogeneous in composition and size-distribution characteristics than the modern shelf, shoal, and shore-face sediments.

6. Natural Tracers.

Unique constituents of a sediment body are often of value in engineering site investigations and sedimentological studies as indicators of vertical mixing, sediment source, and sediment transport routes. Heavy mineral suites are often used for this purpose; however, many other common elements of sediment bodies can be used. Some of the more easily identified constituents are listed in Table D-1. Many faunal elements are of potential value for natural tracers.

Laternauer and Pilkey (1967) used phosphorite grains in North Carolina shelf to investigate the sediment source for adjacent beaches and to delineate shelf sediment transport patterns. They concluded that the phosphorite grains were of detrital origin and not formed in place as authigenic minerals. They also found that sediments of river and estuary bottoms opening on the shelf are presently devoid of phosphorite; thus, phosphorite grains are not being contributed to shelf sediments from nearby land areas. Their data showed that areas of high phosphorite concentration occurred on the shelf floor, particularly in a locale centered about 31.5 kilometers (17 nautical miles) southeast of Cape Fear which they believed to be an outcrop of Tertiary phosphatic sediment and the likely source of phosphorite grains distributed throughout Onslow Bay. The presence of phosphorite on adjacent beaches led them also to conclude that the shelf was an important source of the beach sediment. From their studies Laternauer and Pilkey found that phosphorite grains were useful in tracing sediment provenance and transport in Onslow Bay and were an indicator of sediment interchange with adjacent Long and Raleigh Bays.

Cores from the study area show that units closely underlying the inner shelf floor of both Onslow and Long Bays contain phosphorite which is contributed to the surficial sediments by reworking and lateral transport from outcrops. None of these deposits are as high in phosphorite grain content as the 40 percent content found by Laternauer and Pilkey (1967). The Miocene deposit at core 95, where the phosphorite content by grain count was nearly 25 percent, is the closest. Substantial amounts of phosphorite also occur locally in the Cretaceous and Oligocene deposits underlying Long Bay and Onslow Bay, and are usually present in more modest amounts elsewhere (Table D-1). This widespread occurrence of phosphorite

grains within Cretaceous and Tertiary deposits underlying the shelf floor makes their worth as tracers questionable because potential sources of phosphorite grains to the modern shelf sediments are nearly ubiquitous. Laternauer and Pilkey (1967) suggested that the value of phosphorite grains might be enhanced by considering grain color which they found to vary from place to place. Variations in predominant color and shape were also noted in localities sampled by the ICONS cores. Thus, a more detailed sampling and study of phosphorite characteristics in potential source beds might show that particular types of phosphorite grains could be usefully used as natural tracers.

Rock fragments from lithified Tertiary and Pleistocene outcrops are also potential large-size tracer elements which indicate erosion and transport conditions on the shelf. Rock fragments from Pleistocene coquina outcrop on the sea floor near Cape Lookout are washed up on the beaches on both sides of the cape (Mixon and Pilkey, 1976); calcareous sandstones and fragments of *Ostrea gigantissima* Finch from nearshore outcrops of probable Oligocene age occur on the beaches around New River Inlet (Lawrence, 1975).

Several faunal elements in the shelf floor and subfloor sediment bodies are nearly unique to the unit and may prove useful as natural tracers. Mollusks are potentially the most useful, especially those derived from the Tertiary and Cretaceous substrate deposits; most are clearly exotic in more recent sediments. For example, the Cretaceous shells found on the shores of Long Bay can be related to sea floor exposures of Cretaceous sediment from which the shells are eroded and subsequently transported to the beach (Cooke, 1936). Probably, there are several molluskan species that can also be used to indicate erosion and movement of material from the Tertiary deposits; however, the available core samples of these units contain too few megafossils to list specific types. Occasional mollusk shells and fragments indicate they exist but are probably not dense enough to be sampled often by the cores. Larger samples from outcrops are needed to characterize the megafauna.

Barnacle plates and opercular valves are abundant constituents of the Pliocene calcareous sediment and rock (type G lithology) and in the Miocene deposit at core 96 but sparse to rare elsewhere. Thus, the presence of large quantities of barnacle parts in the modern sediments may indicate transport or vertical mixing from the older deposits; however, the appearance of barnacle parts alone is not conclusive since these organisms presently contribute to the shelf sediments in small quantities.

Similarly, the presence of large quantities of bryozoa in modern shelf sediments suggests derivation from one of the two bryozoa-rich deposits in the study area--the Plio-Pleistocene calcareous sediment and rock (type G lithology) or the Eocene bryozoa hash outcropping in Long Bay.

Microfaunal elements, particularly the foraminifera, are usually abundant in marine sediments and many are potentially usable for natural

tracers (Grabert, 1971; Colbourn and Resign, 1975). Several species of foraminifera in the study area are unique to specific sediment units. Their occurrence elsewhere indicates either vertical mixing or the erosion and transport of material from the parent unit. Those species with relatively large and robust tests are best adapted to use as natural tracers because they are more likely to survive long transport than smaller and more delicate types. In addition, small species and those with easily transported tests (e.g., the planktonic types) are apt to be winnowed and widely dispersed by a weak flow which may not transport the matrix material.

The lists of common species of foraminifera in Appendix E indicate the abundant and unique types which might be best suited for natural tracers, provided test size and durability are satisfactory. Such species as the large and distinctive *Cibicides floridana* Cushman in the Miocene deposits at core 96 and *Nonion advenum* Cushman occurring in abundance in the Oligocene deposits underlying the inner shelf are examples of species which may provide useful information on shelf sediment movement and sources. Both have been found in more recent deposits of the shelf floor where they have been incorporated after erosion and transportation from the parent unit.

Some general indications of regional transport patterns and the depth of vertical mixing of substrate elements into modern shelf sediments could be obtained by a more detailed study of the occurrence of displaced foraminiferal fauna in the ICONS core samples. However, a more comprehensive sediment sampling program would be needed to obtain detailed knowledge of shelf transport patterns by this method. Such sampling might prove worthwhile for a future need for information on sediment movement in specific locales.

VI. SUMMARY

The inner shelf off southern North Carolina was surveyed to obtain data on sand resources and engineering geology. A total of 824 kilometers (512 statute miles) of seismic reflection survey and 134 cores ranging from 0.6 to 6.1 meters (2 to 20 feet) in length were obtained.

The inner shelf floor is topographically subdued except for prominent shoals off Cape Fear and Cape Lookout. The shoreface is well developed in most places and distinctly steeper in slope than the shelf floor. The inner shelf is underlain over much of the study area by distinctive seismic units which can be recognized by their characteristic internal reflectors and mode of occurrence. Correlation of these reflection units with core data indicates that the most extensive are of Cretaceous and Oligocene age.

Surficial and shallow-subbottom sediments consist mostly of quartz sand, biogenic calcareous sand, clay, silt, biogenic calcareous rock, limestone, and sandstone. Most of these sediments are of Late Cretaceous, Tertiary, and Pleistocene age. Holocene sediments are, in general, thin

and discontinuous except in the shoal areas where accumulations of more than 12 meters (40 feet) occur. Elsewhere, the sea floor is thinly veneered by Holocene sediments interspersed with outcrops of older sediments.

The gross morphology of the shelf was probably established by planation during late Tertiary and Pleistocene time. Minor shelf floor features and surficial sediment distribution have been created during the Holocene transgression which began about 15,000 to 20,000 years ago, and by modern shelf processes which have affected the area since the sea level reached its present stand about 3,000 years ago.

Engineering properties of the shelf floor sediments and subfloor sedimentary units vary considerably from place to place due to differences in lithology and postdepositional history. Foundation problems are most apt to occur in the silt and clay deposits and in deposits of weakly lithified calcareous rock.

Sand suitable for restoration and nourishment of beaches is scarce; most occurs in Holocene sand deposits. The sandy Cretaceous and Tertiary Coastal Plain sediments underlying the shelf are, for the most part, poorly suited for beach fill; however, suitable material occurs in a few places.

The boundary between modern and ancient sediment can be perceived in some places by sharp contrasts in lithology which reflect differences in environments of deposition and postdepositional history. However, in many areas lithologic differences are not apparent and the best means of establishing the boundary are by faunal analysis.

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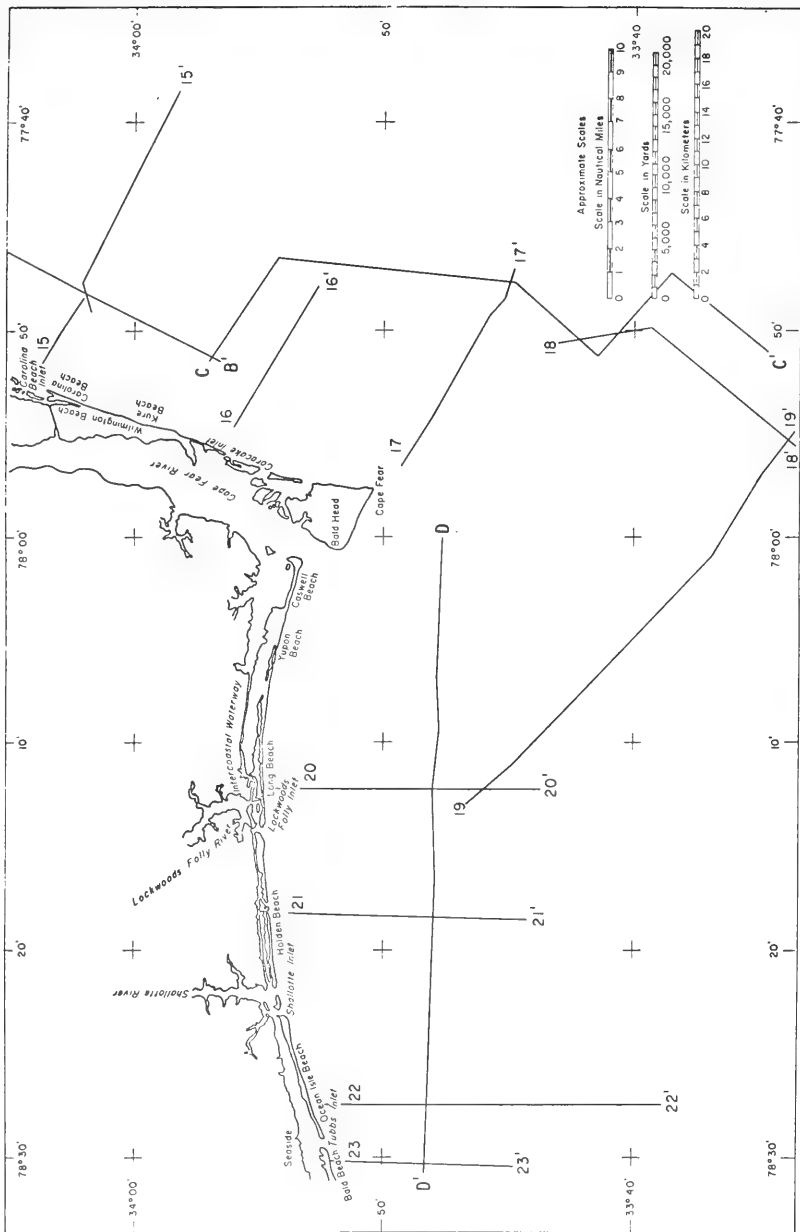
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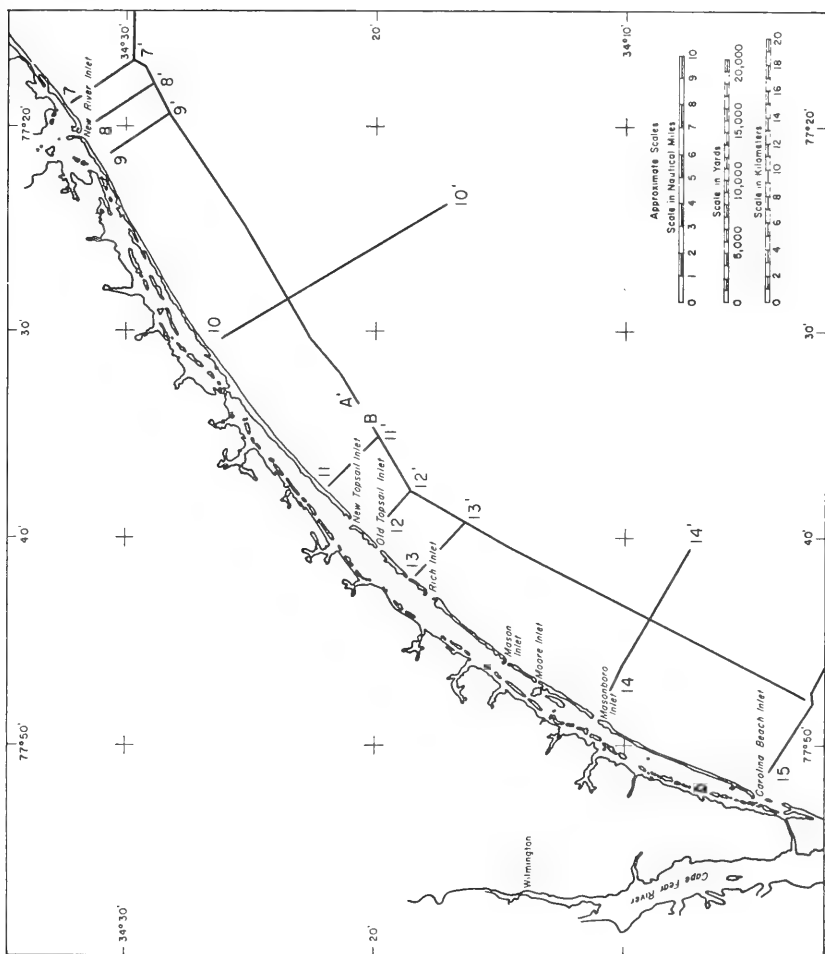
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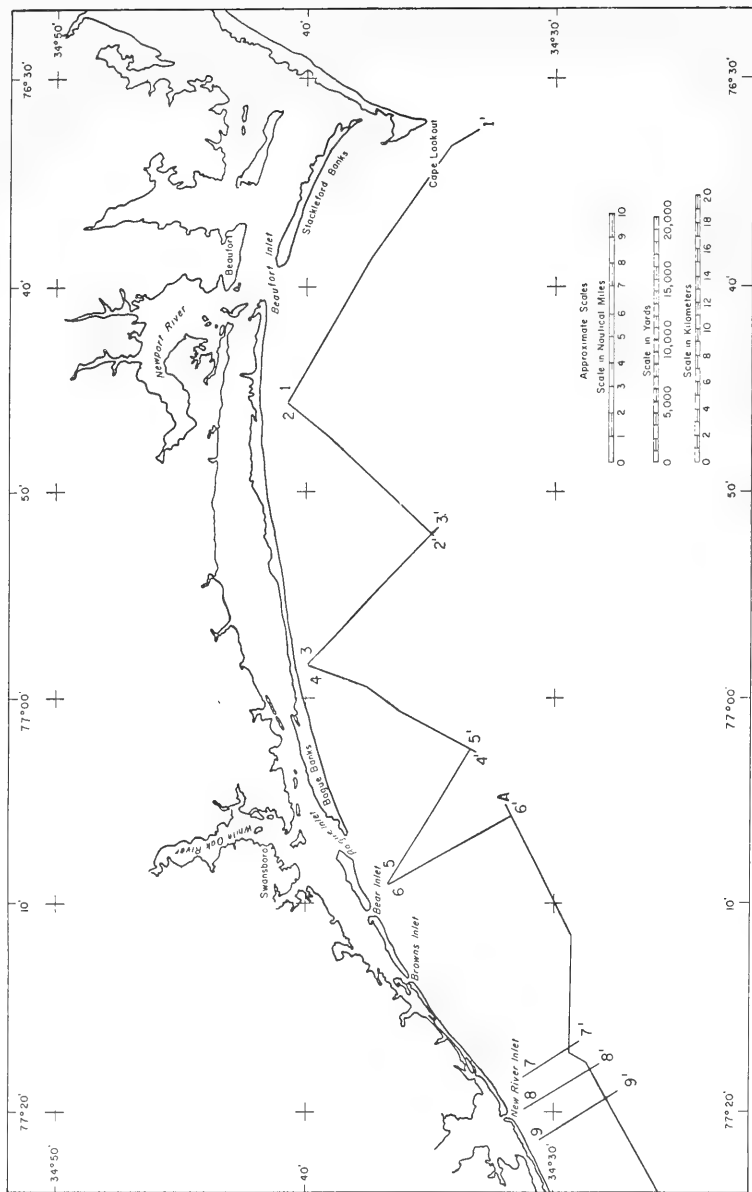
APPENDIX A
SEISMIC PROFILE DATA

This appendix contains profile locations for the study area and line profiles of bottom and subbottom reflectors on selected seismic reflection records. Identification of the green reflectors is noted where present. The blue reflector is also identified where it appears in the subbottom section but not where it is coincident with the sea floor. Because of the small scale of the profiles and location maps, intermediate fix points cannot be represented. Large-scale navigation plots and profile lines containing fix marks are on file at CERC and are available for more detailed definition of the location of features shown on the profiles.

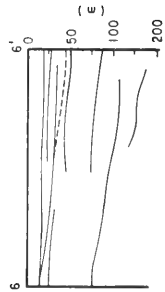
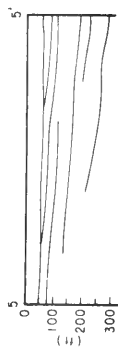
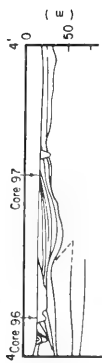
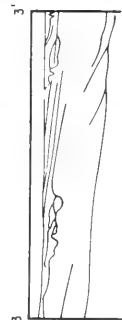
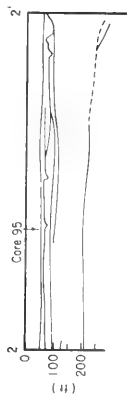
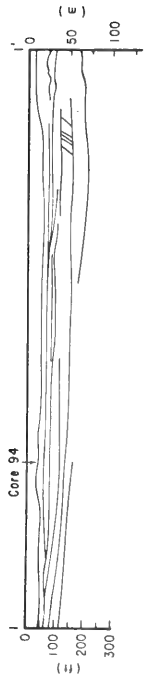
The vertical scale of line profiles in this appendix is based on an assumed sound velocity of 1,463 meters (4,800 feet) per second in water and 1,658 meters (5,440 feet) per second in the subbottom deposits.

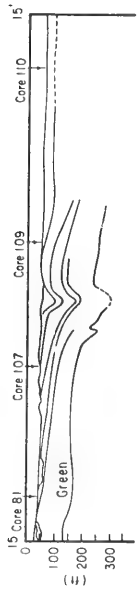
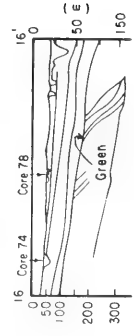
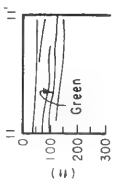
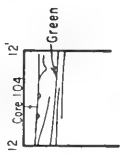
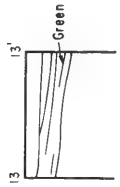
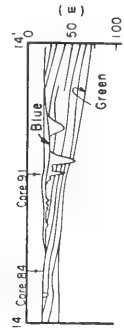
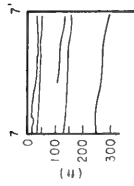
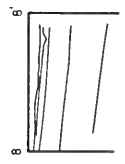
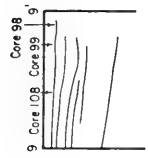
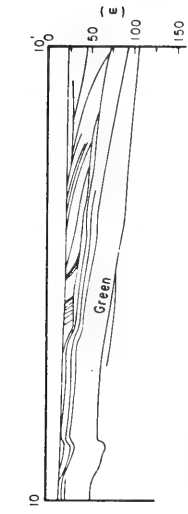


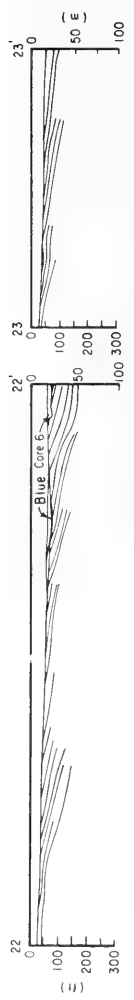
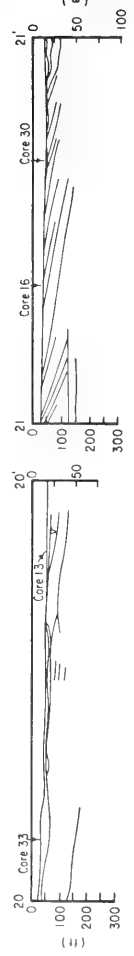
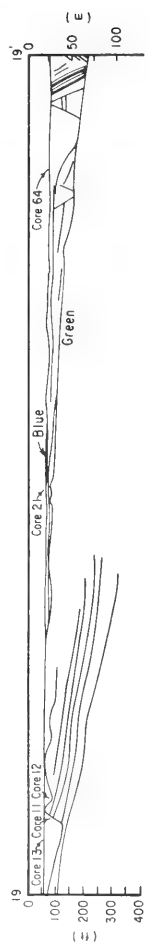
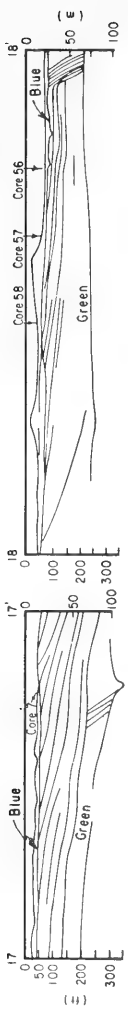






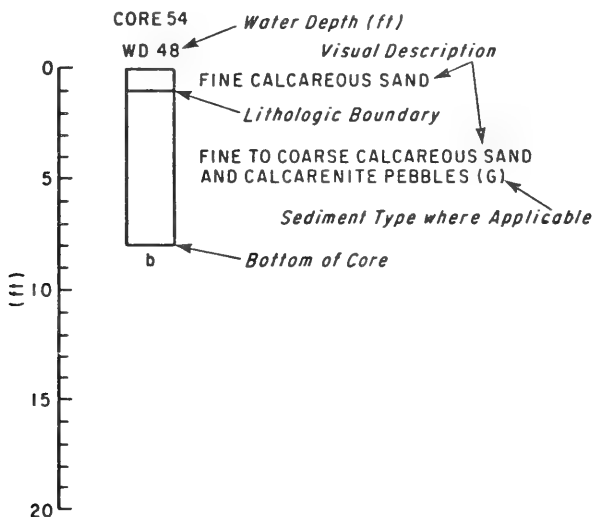


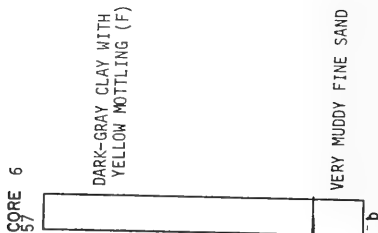
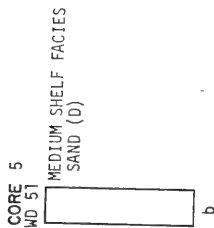
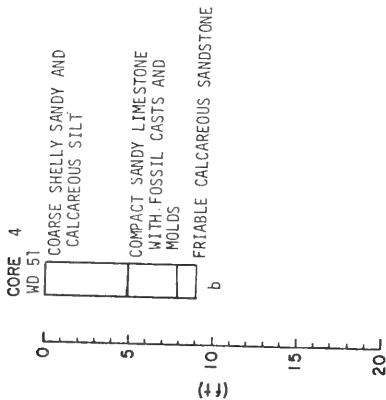
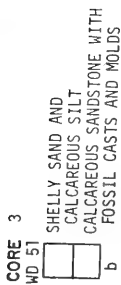
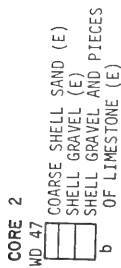
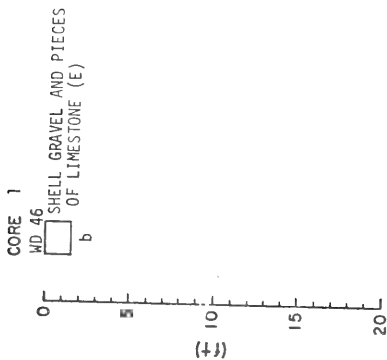


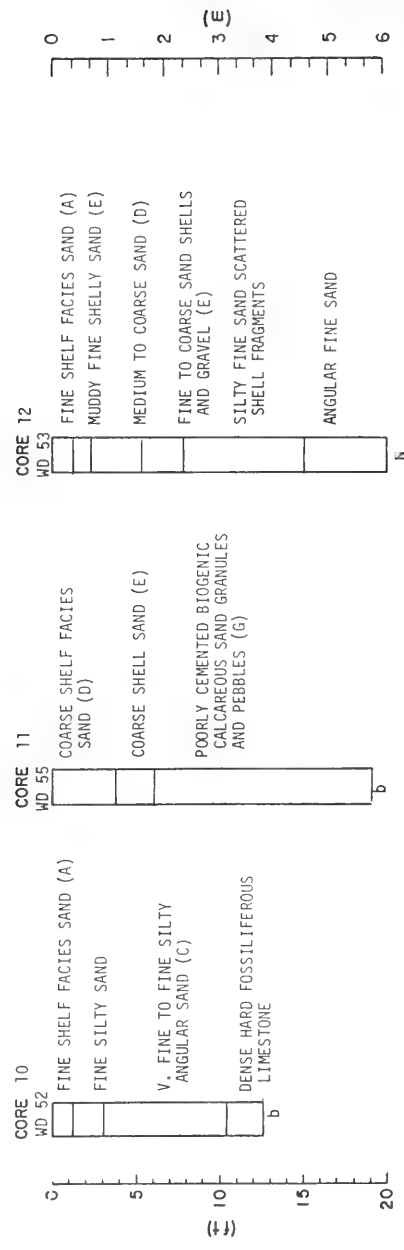
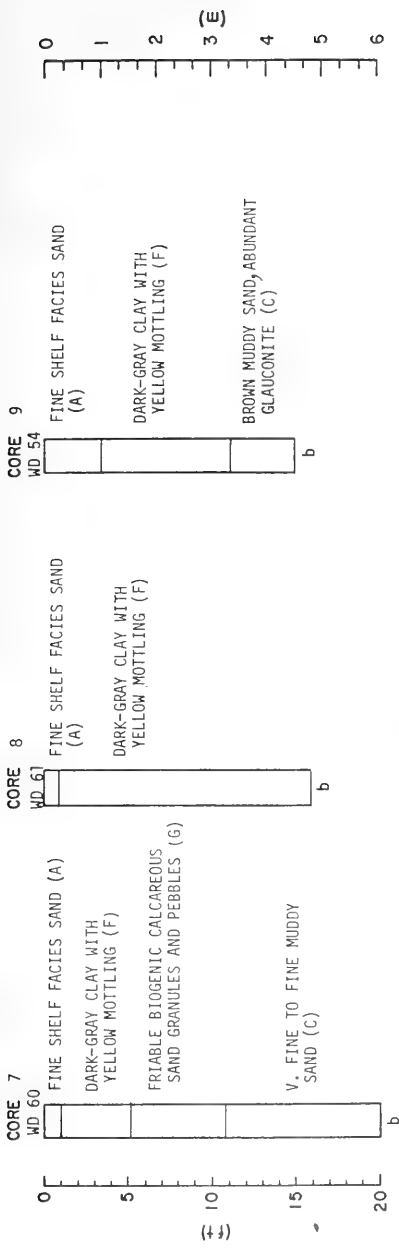


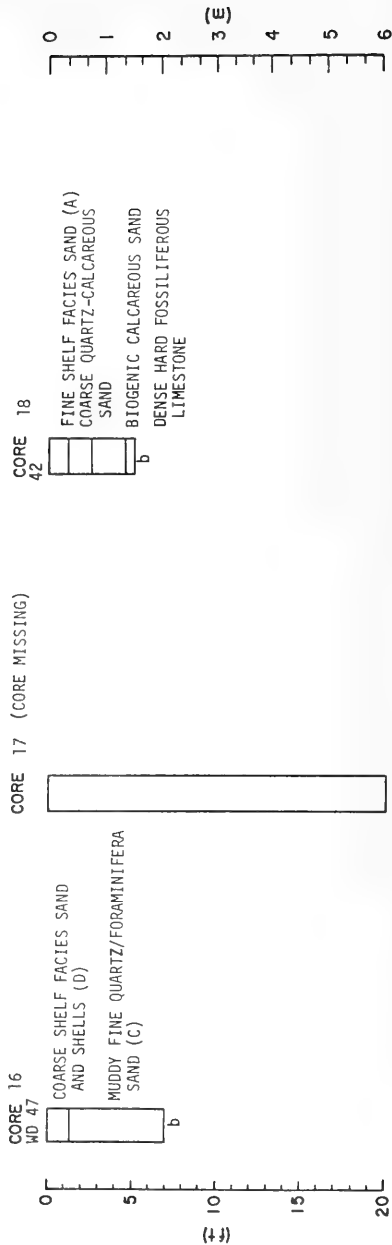
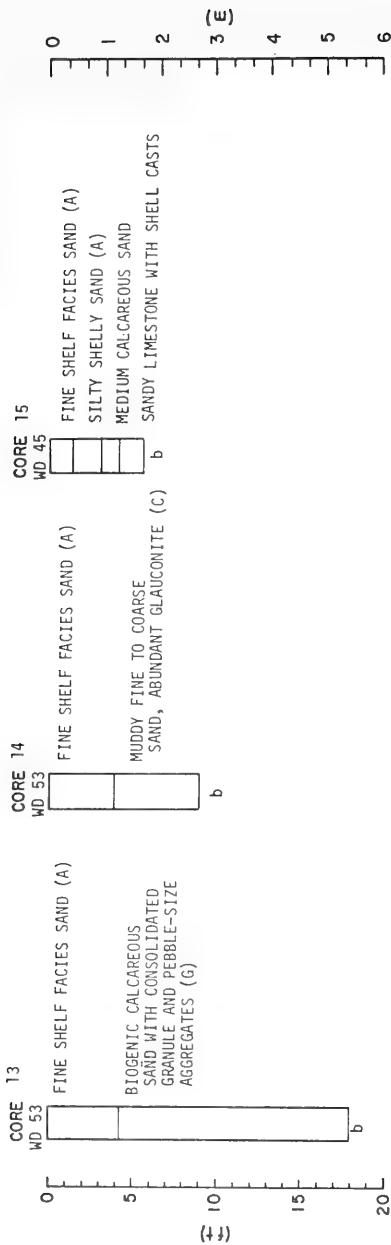
APPENDIX B
CORE DESCRIPTIONS

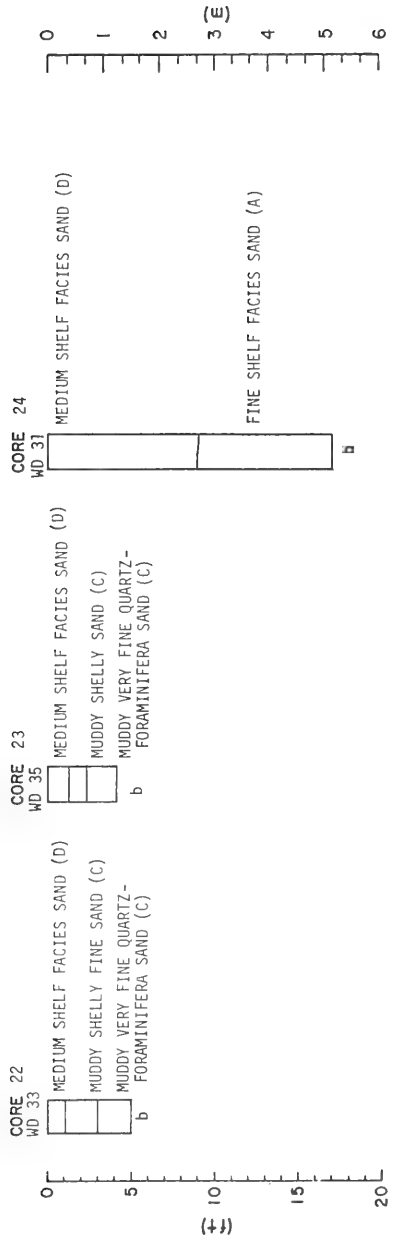
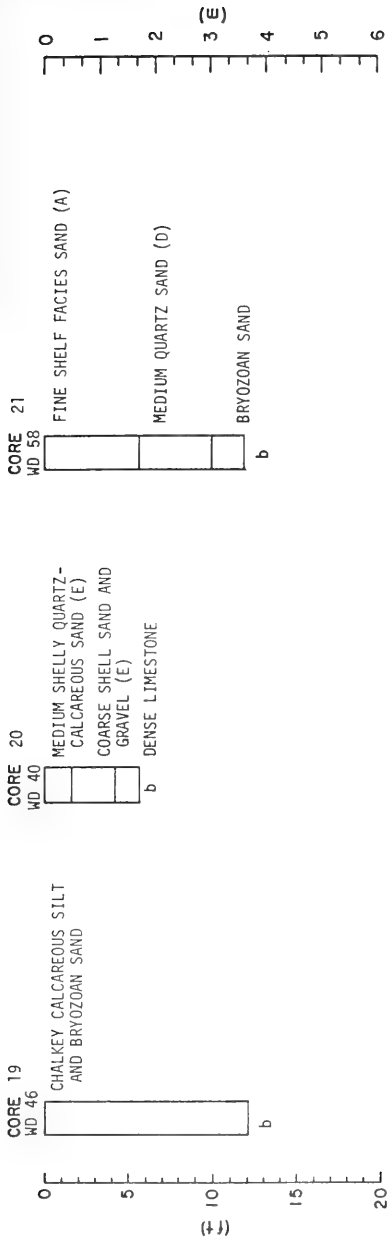
This appendix contains logs of the CERC ICONS cores from North Carolina. Locations of the cores are shown in Figures 2, 3, and 4. Descriptions of core lithologies are based on visual examinations of samples and examinations made under a binocular light microscope. Lithologies that correspond to one of the sediment types discussed in Section III are noted. An annotated example of a log is shown below.

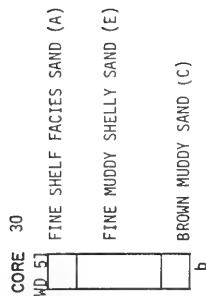
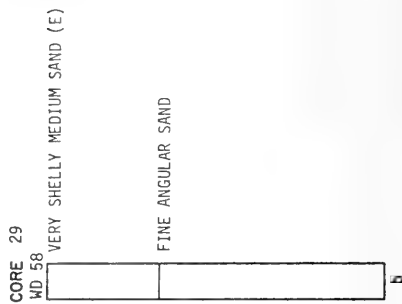
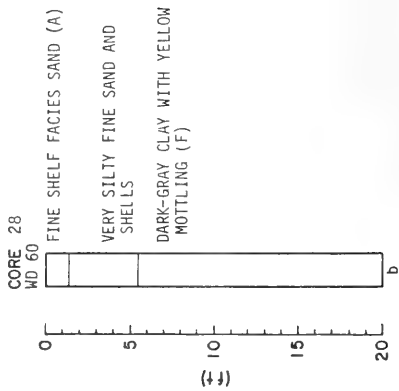
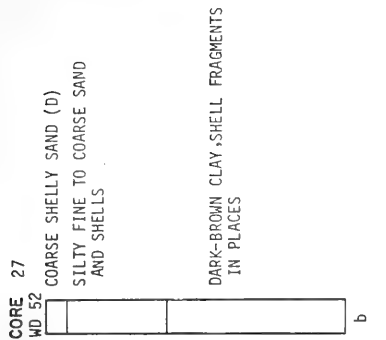
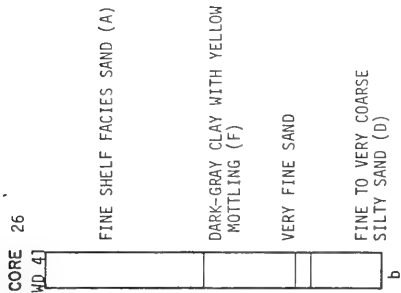
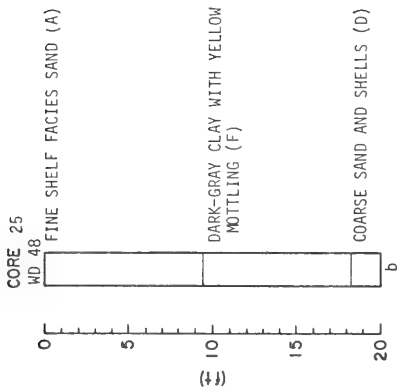


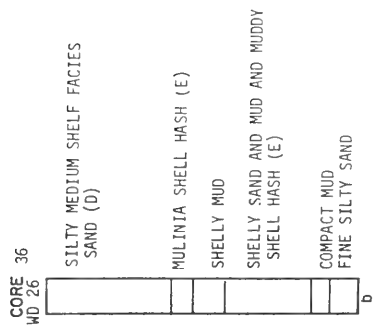
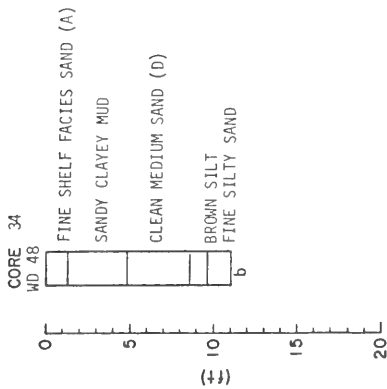
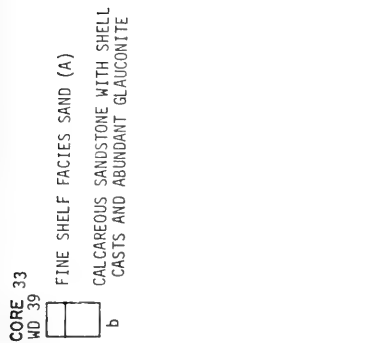
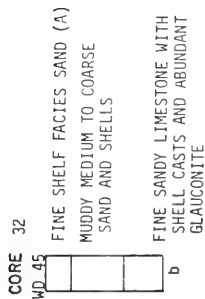
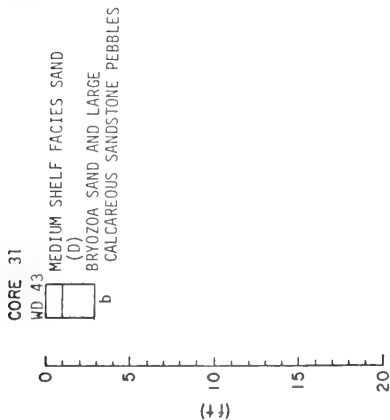


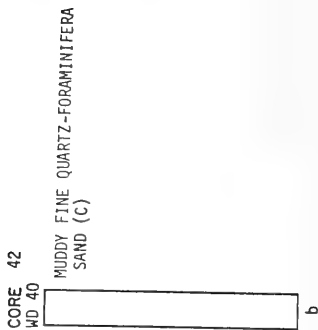
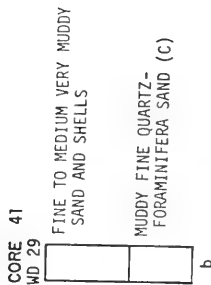
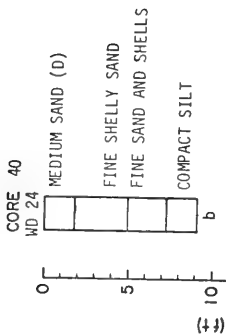
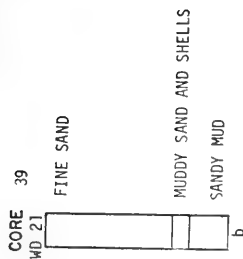
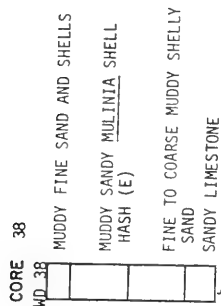
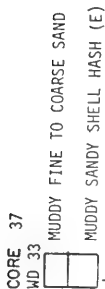


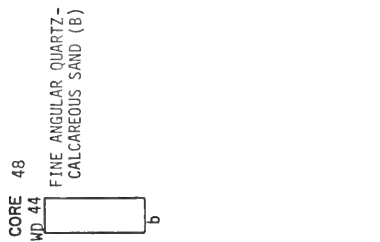
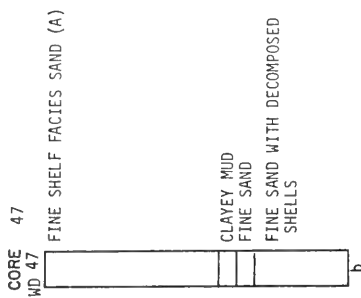
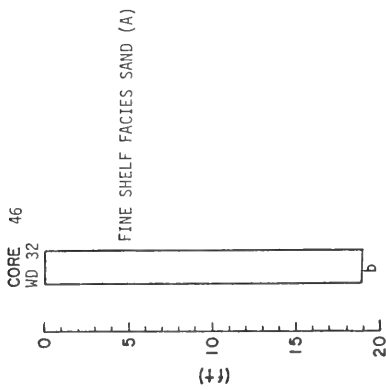
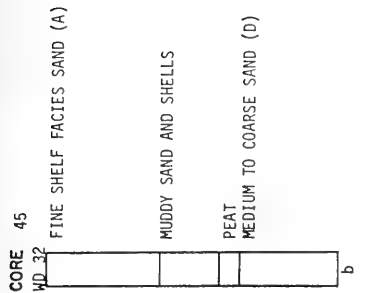
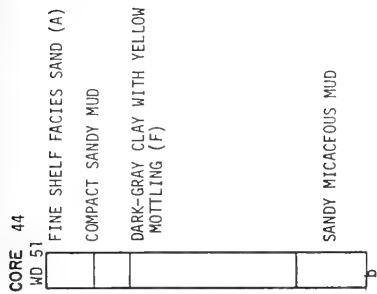
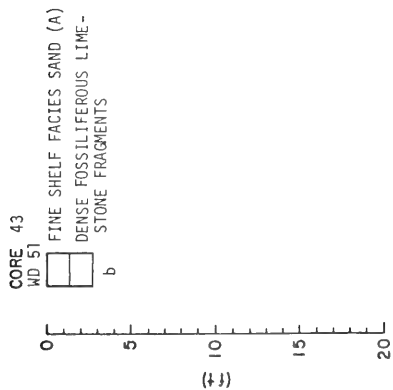


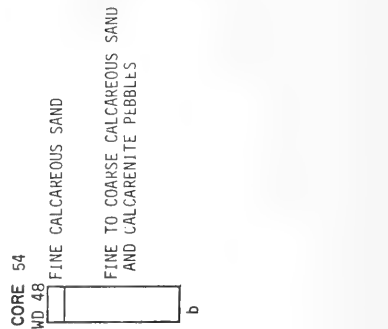
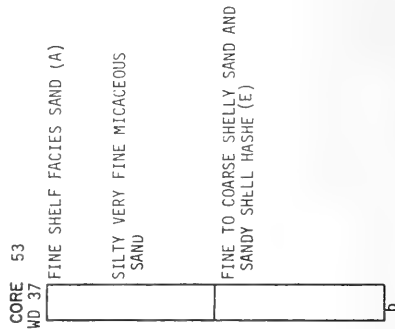
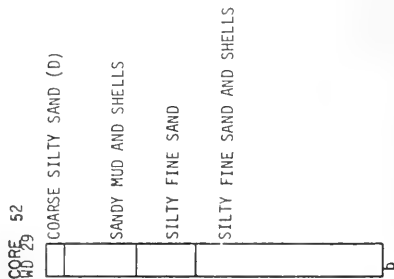
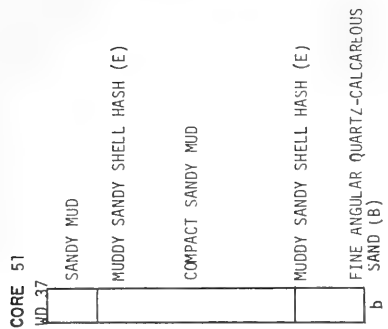
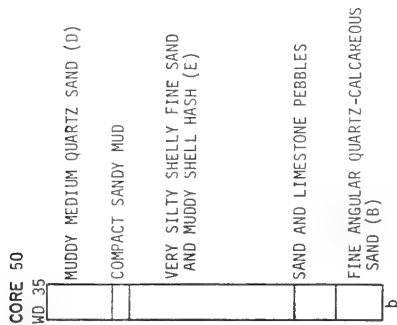
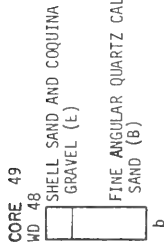


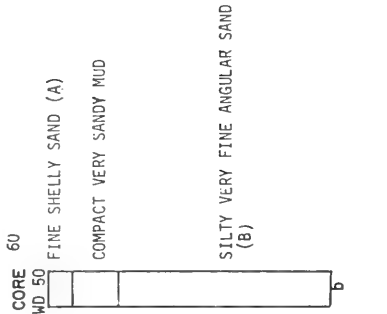
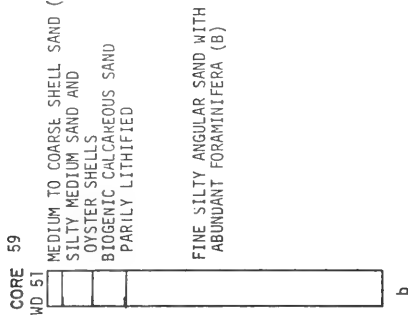
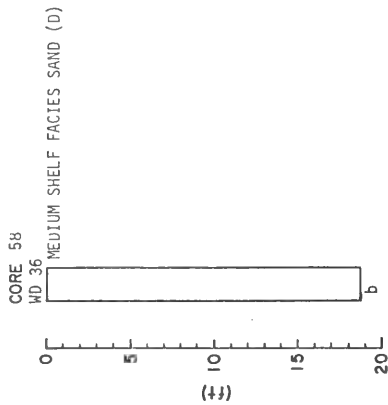
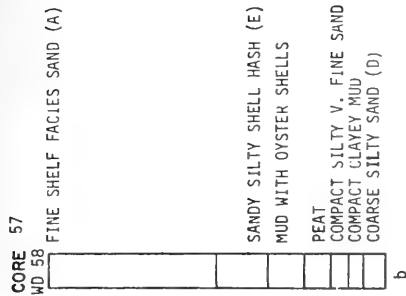
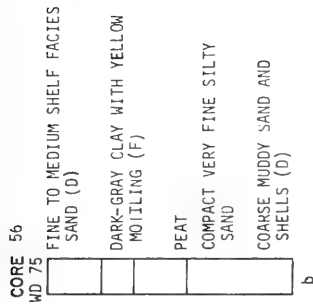
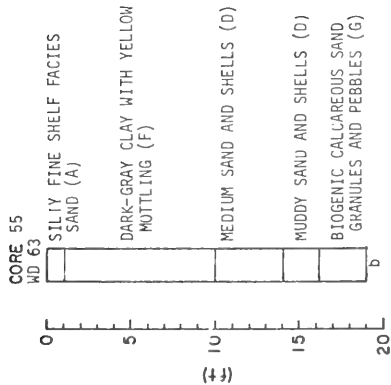


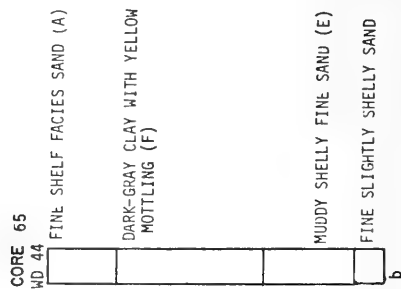
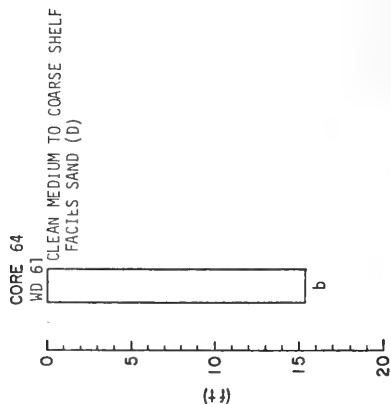
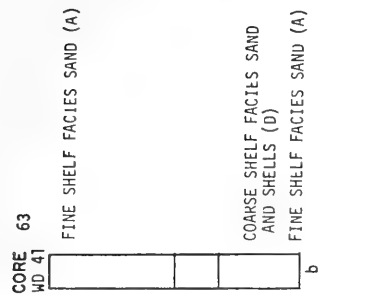
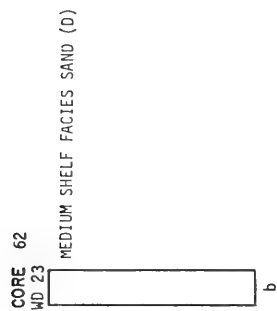
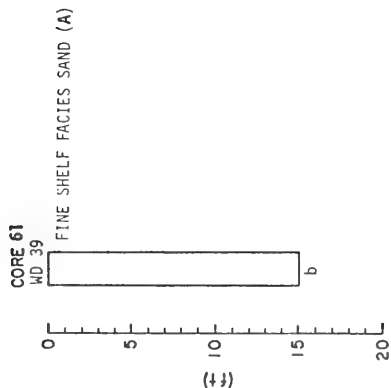


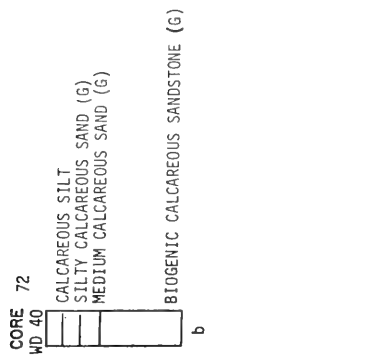
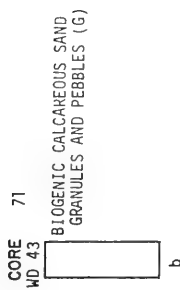
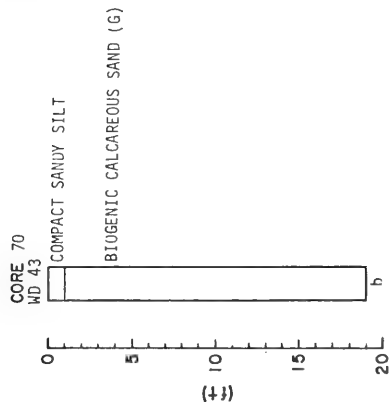
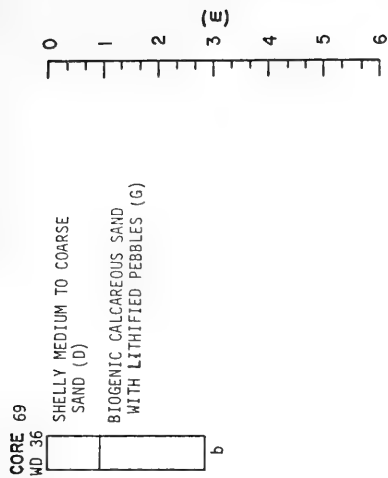
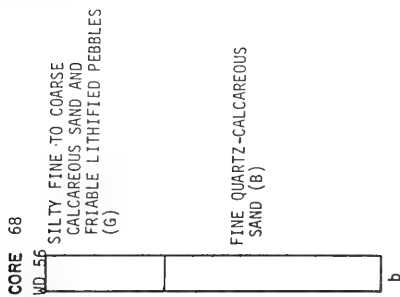
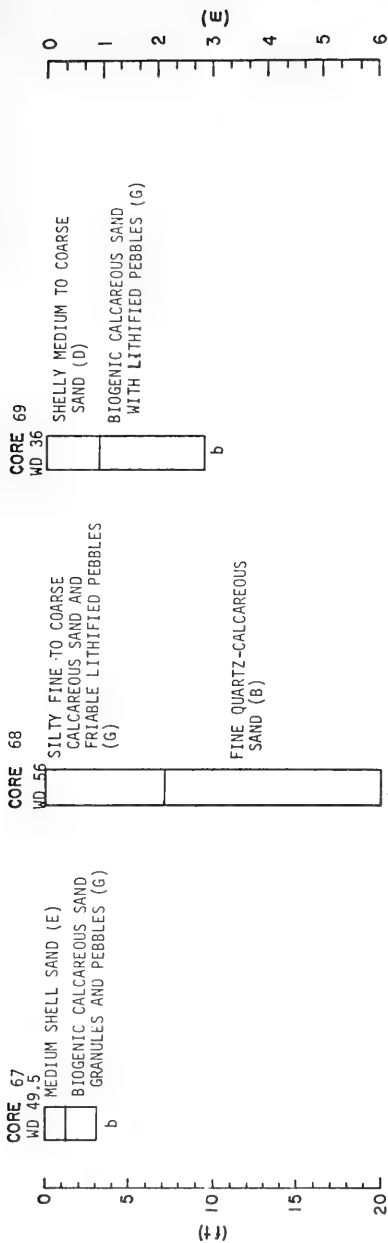


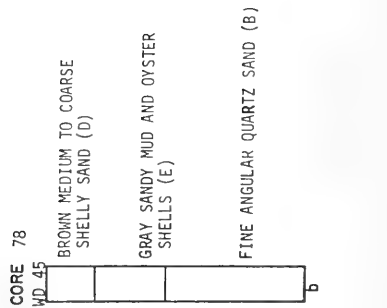
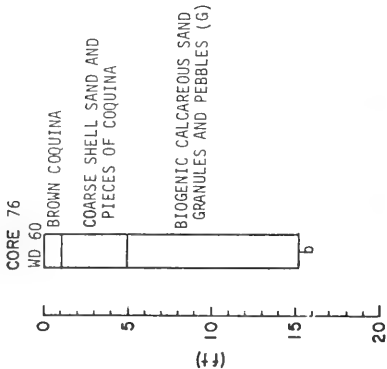
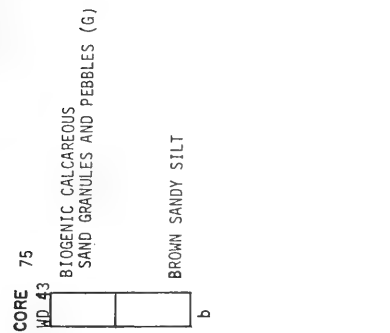
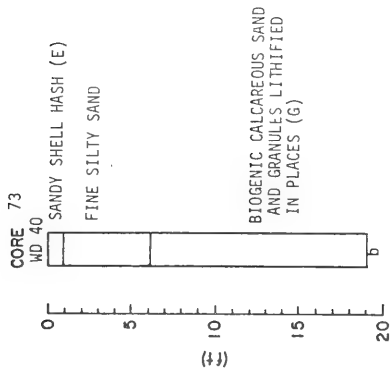


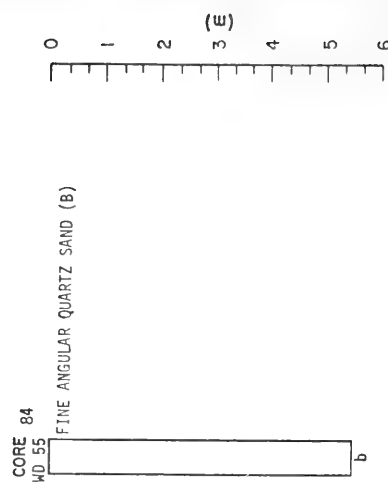
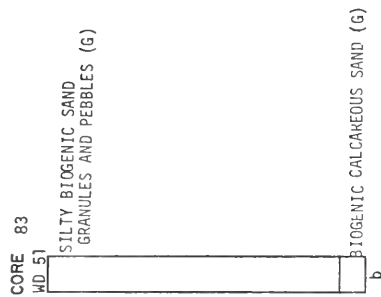
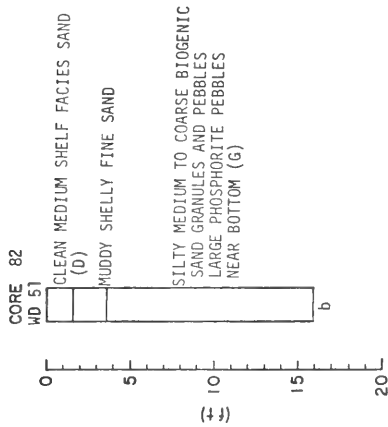
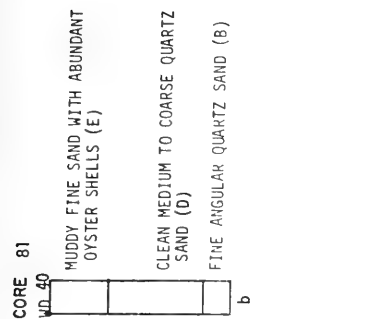
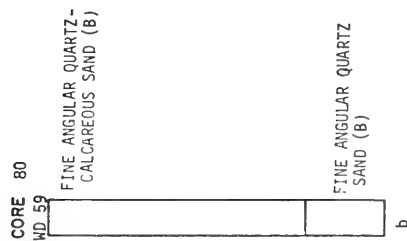
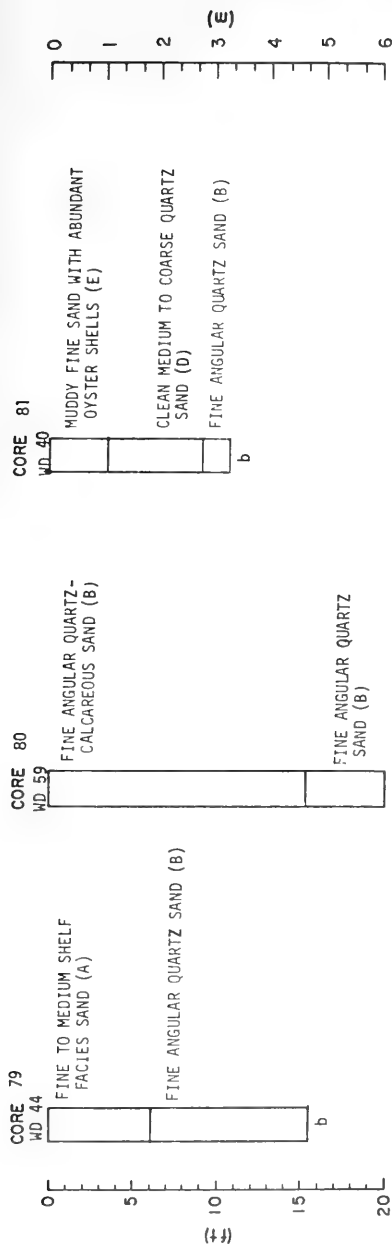


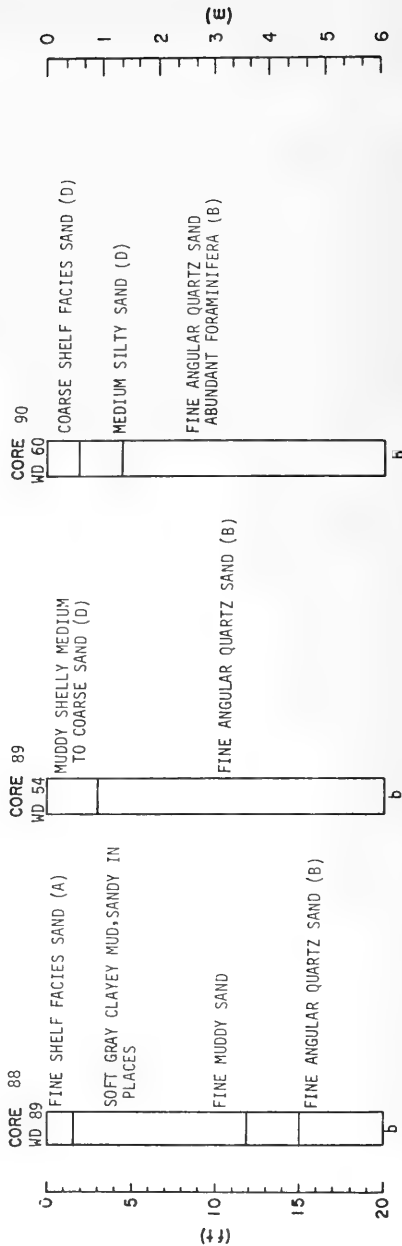
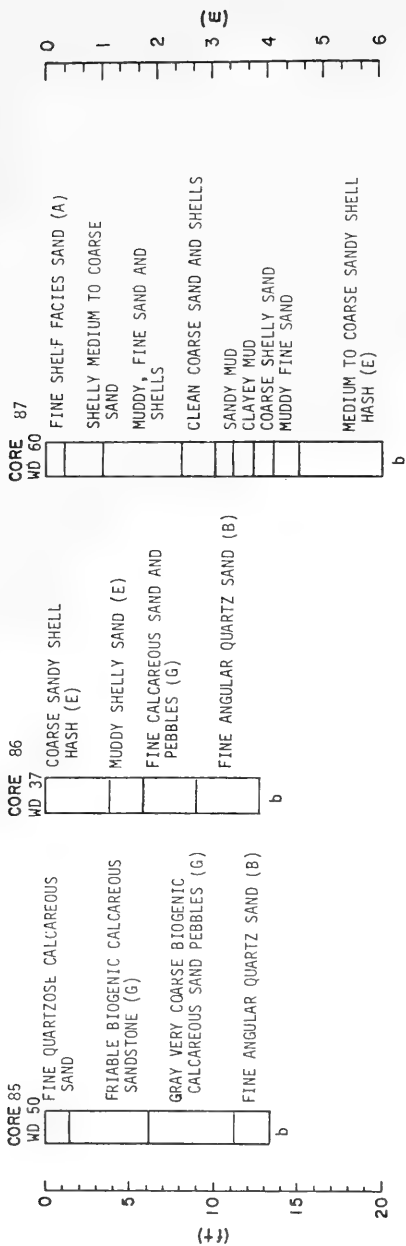


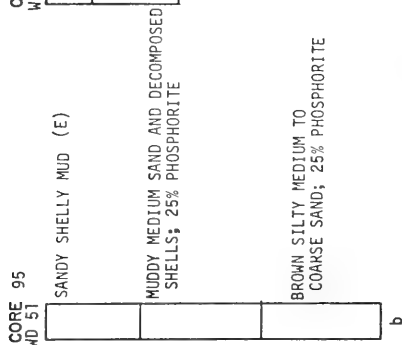
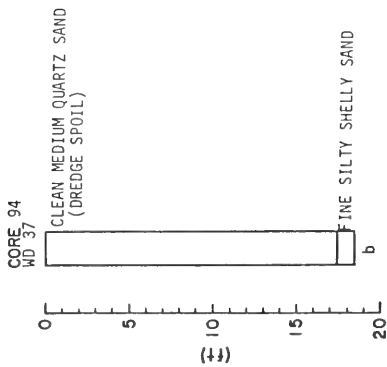
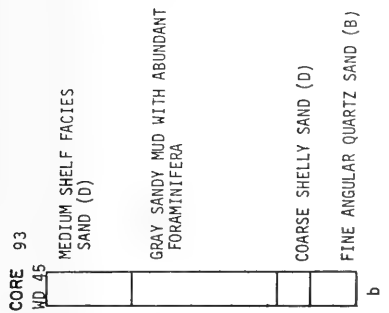
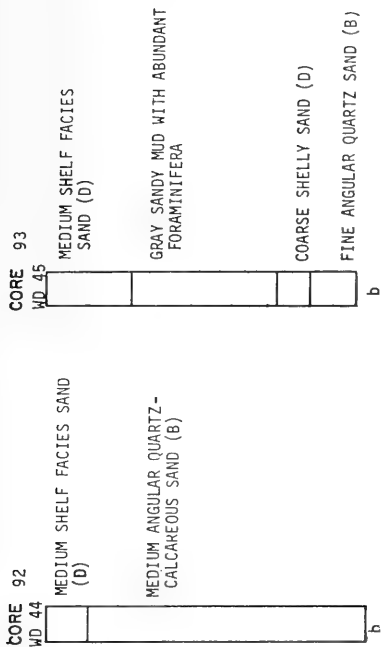
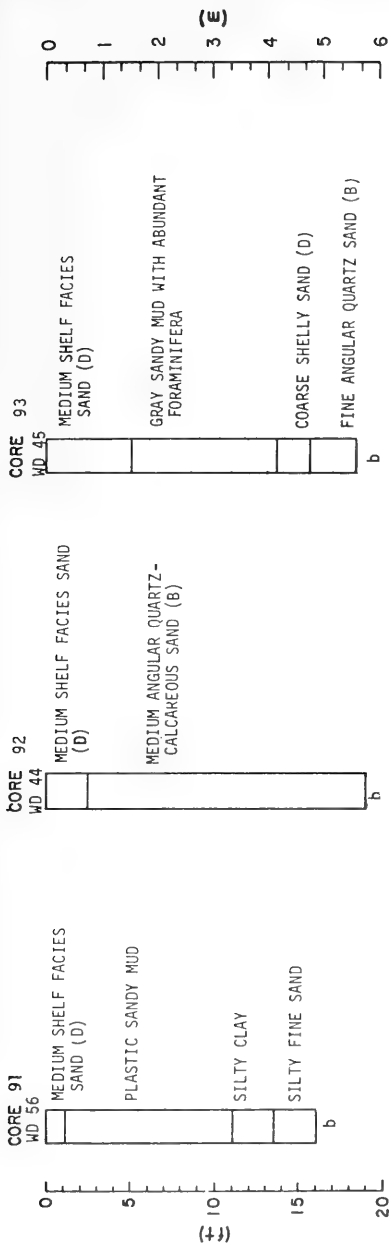


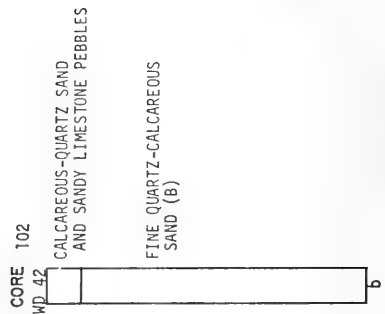
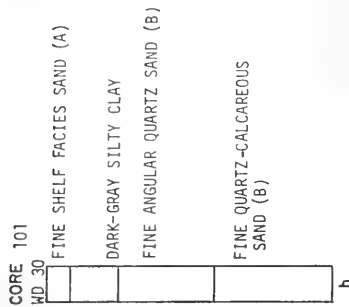
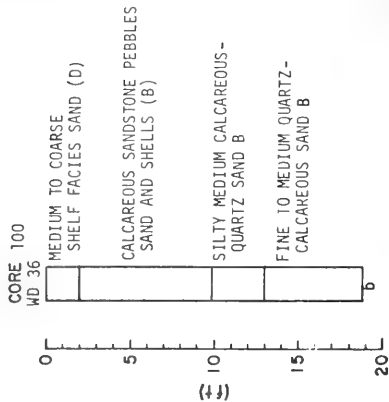
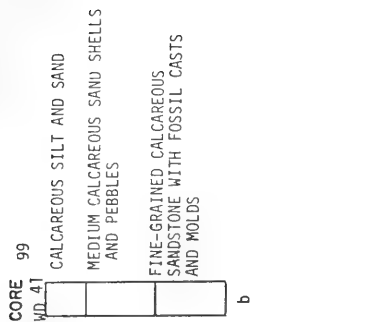
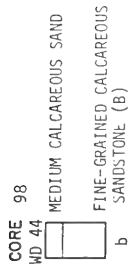
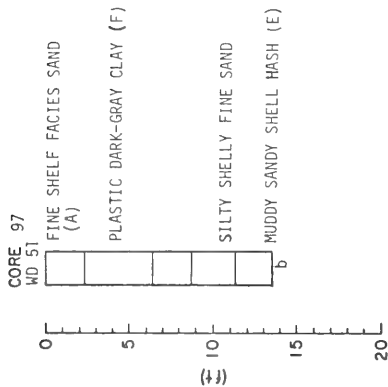


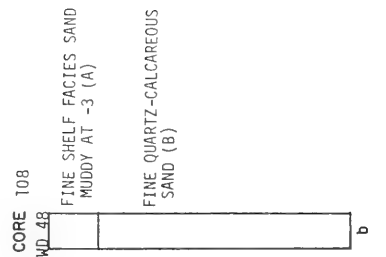
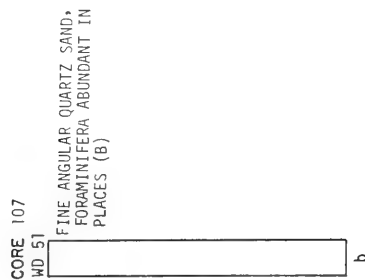
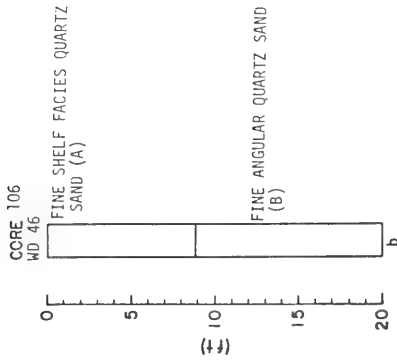
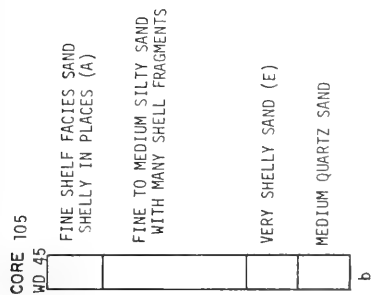
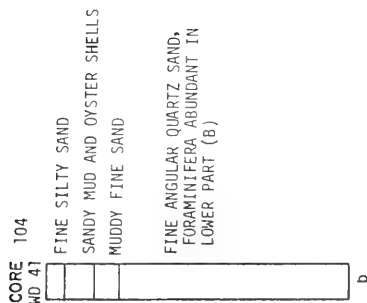
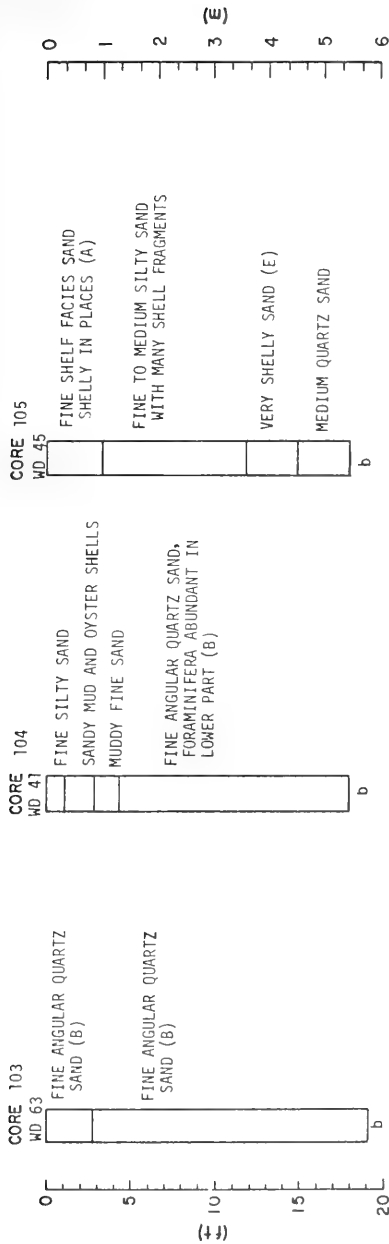










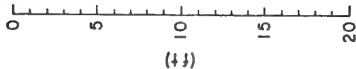


CORE 109

WD 51

FINE TO MEDIUM SHELF FACIES SAND (D)

b



CORE 110

WD 60

FINE SHELL SAND BIOGENIC CALCAREOUS SANDSTONE (G)

MEDIUM TO COARSE BIOGENIC SAND (G)

b



CORE 111

WD 62

MEDIUM CALCAREOUS SAND AND GRANULES

SANDY LIMESTONE WITH FOSSIL MOLDS

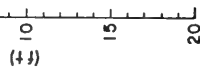
b

CORE 112

WD 50

BROWN CALCAREOUS SANDSTONE
COARSE BIOGENIC CALCAREOUS SAND AND BIOGENIC CALCAREOUS PEBBLES (G)
BIOGENIC CALCAREOUS SANDSTONE (G)

b



CORE 113

WD 51

COARSE SHELL SAND (E)
VERY COARSE BIOGENIC CALCAREOUS SAND GRANULES AND PEBBLES (G)

b



CORE 114

WD 60

BIOGENIC CALCAREOUS SANDSTONE (G)

b

APPENDIX C

GRANULOMETRIC DATA

This appendix lists the mean diameter, the median diameter, and the standard deviation of selected samples from the North Carolina cores (see App. B for core logs and Figs. 2, 3, and 4 for core locations). Samples are identified by core number and the sample depth (in feet) below the top of the core, i.e., the sea floor. All samples were analyzed using the fall velocity method in the CERC rapid sediment analyzer.

DISTRIBUTION OF SIZE CLASSES BY FREQUENCY PERCENTAGES

| REFERENCE | SIZE CLASS | | | | | | | | | | PAN | PAN | PAN | STATISTICAL PARAMETERS | | | | | |
|-----------|------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|-------|------------------------|-------|------|------|------|--------|
| | -1.00 | -.50 | 0.00 | .50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 | 3.50 | | | | 4.00 | MEAN | MM. | MM. | MM. | MM. |
| 103 | 0.00 | 1.414 | 1.000 | 7.07 | 5.00 | 3.54 | 2.50 | 1.77 | 1.25 | 0.98 | 0.62 | 0.00 | 0.00 | 2.09 | 2.34 | 1.91 | 2.55 | 1.0 | 2.109 |
| 105 | 0.00 | 1.91 | 5.84 | 7.640 | 5.15 | 6.56 | 19.94 | 19.63 | 19.54 | 8.16 | 5.61 | 0.00 | 0.00 | 1.849 | 1.55 | 1.64 | .558 | 9.0 | 1.916 |
| 105 | -9 | 0.00 | .51 | 7.27 | 11.50 | 16.11 | 16.73 | 15.78 | 10.73 | 6.59 | 0.00 | 0.00 | 0.00 | 1.879 | 1.20 | 1.69 | .313 | 83.1 | 1.708 |
| 105 | -11 | 0.00 | .73 | 3.00 | 6.41 | 9.5 | 4.80 | 27.91 | 21.09 | 8.15 | 4.90 | 0.00 | 0.00 | 2.55 | 1.94 | 2.69 | .205 | 84.1 | 1.530 |
| 106 | -1 | 0.00 | 0.00 | 0.00 | 0.00 | .75 | 4.87 | 18.15 | 4.52 | 13.17 | 4.12 | 0.00 | 0.00 | 2.55 | 1.90 | 2.31 | .602 | 47 | 1.385 |
| 106 | -9 | 0.00 | 0.00 | 0.00 | 0.00 | .32 | 2.62 | 24.13 | 35.17 | 32.88 | 5.29 | 0.00 | 0.00 | 2.55 | 1.71 | 2.48 | .174 | 47 | 1.385 |
| 104 | -0 | 0.00 | .73 | 3.12 | 2.78 | 3.65 | 4.70 | 6.70 | 17.13 | 20.85 | 11.50 | 0.00 | 0.00 | 2.65 | 1.59 | 2.34 | .149 | 30 | 1.8232 |
| 104 | -15 | 0.00 | 0.00 | 0.00 | 0.00 | 2.04 | 2.11 | 2.04 | 0.00 | 21.04 | 39.16 | 18.421 | 0.00 | 2.74 | 1.49 | 2.75 | .149 | 30 | 1.8232 |
| 106 | -1 | 0.00 | 0.00 | 0.00 | 0.00 | 2.88 | 3.18 | 28.60 | 35.66 | 26.72 | 2.74 | 0.00 | 0.00 | 2.62 | 2.06 | 2.17 | .223 | 57 | 1.462 |
| 108 | -3 | 0.00 | 0.00 | 0.00 | 0.00 | 2.24 | 2.98 | 18.60 | 41.11 | 32.62 | 2.422 | 0.00 | 0.00 | 2.54 | 1.97 | 2.28 | .207 | 46 | 1.377 |
| 108 | -5 | 0.00 | 0.00 | 0.00 | 0.00 | .23 | 4.63 | 5.93 | 18.07 | 36.14 | 19.19 | 12.39 | 2.45 | 2.60 | 1.43 | 2.68 | .156 | 77 | 1.716 |
| 108 | -6 | 0.00 | 0.00 | 0.00 | 0.00 | .07 | 2.65 | 5.30 | 7.37 | 15.07 | 31.75 | 17.67 | 12.32 | 2.74 | 1.50 | 2.49 | .178 | 94 | 1.941 |
| 108 | -12 | 0.00 | 0.00 | 0.00 | 0.00 | .31 | 5.30 | 9.00 | 11.65 | 16.77 | 36.59 | 14.68 | 4.91 | 2.60 | 1.65 | 2.41 | .189 | 77 | 1.703 |
| 103 | -2 | 0.00 | .13 | 4.11 | 15.41 | 16.77 | 15.62 | 21.75 | 16.04 | 4.76 | 0.00 | 0.00 | 0.00 | 1.58 | 1.365 | 1.69 | .100 | 60 | 1.673 |
| 113 | -5 | 0.00 | 7.09 | 11.69 | 21.52 | 23.84 | 14.10 | 8.57 | 4.63 | 3.41 | 2.19 | 3.01 | 0.00 | .68 | .622 | .66 | .551 | 1.04 | 2.401 |

APPENDIX D

CONSTITUENT ANALYSIS

This appendix contains data concerning the mineralogical character of sediments from the study area. Table D-1 lists the frequency of occurrence of the more readily identifiable constituents from selected samples of the main lithologic types described in Section III. The samples were examined by obtaining a small split which was then dispersed on a gridded paper for analysis. Frequency was determined by placing the paper under a light microscope and counting the various constituents (1,000 particles) in randomly selected grid squares. Large fragments such as whole shells were removed from the splits before counting so the frequency data pertain to sample material smaller than 2-millimeter sieve diameter.

Roundness and sphericity were determined for 300 quartz grains in randomly selected squares by comparison with a roundness and sphericity chart in Krumbein and Sloss (1963, p. 111).

Table D-2 presents the results of acid digestion of carbonate elements in selected samples using dilute hydrochloric acid. The table shows the percent by weight of material dissolved by the acid. A visual analysis of sediment constituents indicates that the acid soluble elements consist almost entirely of biogenic calcium carbonate.

Table D-1. Results of constituent analysis.

| SAMPLE I.D. | | AGE | FREQUENCY (Grains per thousand) | | | | | | | | | | | PARTIAL SHAPE (3) (Pct Frequency) | | | | | | | | |
|-------------|----------------------|------------------|------------------------------------|------------------------------|--------------------------------|------|------------|-------------|---------------------|--------------------|--------------------------------|----------------|-----------------|--------------------------------------|-----------|-----|-----|-----|-----|------------|-----|-----|
| Core Number | Ft Below Top of Core | | Lithologic Type | Clear Translucent Grains (1) | Colored Translucent Grains (2) | Mica | Glauconite | Phosphorite | Foraminiferal Tests | Ostracod Carapaces | Echinoid Spines and Test Parts | Bryozoa Zoaria | Sponge Spicules | Unidentified Calcareous Fragments | ROUNDNESS | | | | | SPHERICITY | | |
| | | 0.1 | | | | | | | | | | | | | 0.3 | 0.5 | 0.7 | 0.9 | 0.3 | 0.5 | 0.7 | 0.9 |
| 8 | Top A | Holocene, PT (4) | 941 | 4 | | 2 | 26 | 2 | | | | | 19 | 59 | 30 | 10 | 1 | 1 | 24 | 63 | 11 | 2 |
| 9 | Top A | Holocene, PT | 919 | 16 | | | 10 | 2 | 2 | 3 | | | 44 | 70 | 25 | 4 | 1 | | 28 | 62 | 10 | |
| 10 | Top A | Holocene, PT | 886 | 57 | | | 3 | 9 | 3 | | | | 41 | 71 | 18 | 8 | 2 | | 21 | 70 | 9 | |
| 47 | Top A | Holocene, PT | 948 | 6 | | | 11 | 3 | 6 | | | | 27 | 73 | 25 | 2 | | | 42 | 44 | 13 | 1 |
| 57 | -3 A | Holocene, PT | 937 | 18 | | 1 | 16 | 3 | | | | | 23 | 62 | 35 | 2 | 1 | | 42 | 45 | 12 | 1 |
| 60 | Top A | Holocene, PT | 877 | 10 | | 9 | 12 | 7 | 2 | | | | 83 | 67 | 30 | 3 | | | 44 | 51 | 5 | |
| 65 | Top A | Holocene, PT | 951 | | | | 13 | | 2 | | | | 33 | | | | | | | | | |
| 96 | -1 A | Holocene, PT | 894 | 45 | | | 21 | 2 | 3 | | | | 28 | 30 | 58 | 9 | 4 | | 19 | 71 | 8 | 3 |
| 16 | Top D | Holocene, PT | 932 | 11 | | | 29 | 1 | 1 | | 1 | | 25 | 32 | 56 | 9 | 3 | | 24 | 69 | 7 | |
| 22 | Top D | Holocene, PT | 945 | 10 | | | 25 | 3 | | | | | 13 | 47 | 39 | 11 | 2 | 2 | 19 | 66 | 13 | 2 |
| 24 | Top B | Holocene, PT | 977 | 10 | | | 2 | | | | | | 9 | 27 | 59 | 13 | 2 | 1 | 16 | 66 | 16 | 1 |
| 36 | Top D | Holocene, PT | 962 | 8 | 9 | | 9 | | | | | | 11 | 43 | 44 | 8 | 1 | | 18 | 73 | 8 | 1 |
| 40 | Top D | Holocene, PT | 950 | 10 | | | 23 | 2 | | | | | 16 | 75 | 21 | 2 | 1 | | 56 | 39 | 5 | |
| 50 | Top D | Holocene, PT | 976 | 2 | | | 3 | 1 | | | | | 18 | 46 | 42 | 10 | 2 | | 25 | 47 | 24 | 3 |
| 52 | Top B | Holocene, PT | 965 | 10 | | 1 | 12 | 3 | 1 | | | | 9 | 56 | 35 | 7 | 1 | | 27 | 62 | 10 | 1 |
| 62 | Top B | Holocene, PT | 887 | 26 | | | 8 | | | | | | 80 | 35 | 47 | 17 | 1 | | 15 | 74 | 10 | 1 |
| 89 | Top D | Holocene, PT | 940 | 3 | | | 3 | 7 | 2 | | | | 45 | 59 | 33 | 7 | 3 | | 30 | 58 | 12 | |
| 90 | Top D | Holocene, PT | 947 | 17 | 1 | 2 | 6 | 17 | 1 | 1 | | | 24 | 28 | 55 | 14 | 2 | 1 | 19 | 65 | 16 | 1 |
| 110 | Top B | Holocene, PT | 930 | 15 | 1 | | 14 | 1 | | | | | 39 | 33 | 46 | 17 | 17 | 17 | 13 | 62 | 20 | 5 |
| 29 | -3 E | Quaternary (5) | 883 | 17 | 1 | 1 | 15 | 28 | 2 | 3 | | | 51 | 38 | 54 | 5 | 3 | | 10 | 81 | 9 | |
| 51 | -19 E | Quaternary | 857 | 2 | 7 | 2 | 9 | 43 | | | | 2 | 28 | | | | | | | | | |
| 81 | Top E | Quaternary | 930 | 9 | 2 | 1 | 22 | 7 | | | | | 28 | 68 | 26 | 5 | 1 | | 19 | 68 | 12 | 1 |
| 86 | Top E | Quaternary | 845 | 18 | 1 | | 7 | 2 | | 5 | | | 122 | 52 | 40 | 7 | 2 | | 29 | 63 | 6 | 2 |
| 87 | -10 E | Quaternary | 890 | 5 | | | 11 | 3 | 1 | 27 | | | 54 | 24 | 49 | 21 | 6 | | 13 | 65 | 17 | 5 |
| 95 | Top E | Quaternary | 894 | 1 | 6 | | 14 | 10 | 1 | 5 | | | 69 | 21 | 56 | 18 | 5 | | 12 | 70 | 17 | 1 |
| 11 | -12 G | Plio-Pleistocene | 94 | 2 | 1 | | 1 | 26 | | 7 | | | 868 | 53 | 42 | 3 | 1 | 1 | 38 | 55 | 5 | 2 |
| 54 | -2 G | Plio-Pleistocene | 543 | | | | 9 | 8 | | | | | 442 | 60 | 30 | 9 | 1 | | 50 | 43 | 8 | 1 |
| 74 | -7 G | Plio-Pleistocene | 141 | | | | 6 | 12 | | | | | 841 | 42 | 52 | 6 | | | 30 | 64 | 5 | 1 |
| 83 | -12 G | Plio-Pleistocene | 526 | 2 | | | 4 | 30 | 4 | 6 | | | 426 | 65 | 22 | 10 | 3 | | 49 | 41 | 7 | 2 |
| 110 | -4 G | Plio-Pleistocene | 771 | | | | | 3 | | | | | 227 | 71 | 23 | 6 | | | 59 | 36 | 4 | 1 |
| 95 | -15 | Miocene | 753 | | | 9 | 248 | 1 | 1 | | | | 2 | 69 | 54 | 10 | | | | | | |
| 96 | -6 | Miocene | 305 | | | | 6 | 139 | 1 | 1 | | | 791 | 72 | 27 | 2 | | | | | | |
| 59 | -19 B | Oligocene | 828 | | | | 6 | 61 | 3 | 4 | | | 160 | 92 | 7 | 1 | | | | | | |
| 68 | -19 B | Oligocene | 887 | 1 | | 1 | 3 | 41 | 3 | | | | 95 | 90 | 13 | 1 | | | 33 | 56 | 10 | 1 |
| 78 | -14 B | Oligocene | 960 | 2 | | 17 | 21 | | | | | | | | | | | | | | | |

(1) Nearly all quartz particles

(2) Mostly heavy minerals.

(3) Based on visual comparison with chart in Krumbein and Sloss (1953, p. 81).

(4) PT: Post transgressive Holocene (i.e. essentially modern).

(5) Shallow water relict deposits of probable transgressive Holocene or Pleistocene age.

Table D-1. Results of constituent analysis.--Continued

| SAMPLE I. D. | | | AGE | FREQUENCY (Grains per thousand) | | | | | | | | | | PARTIAL SHAPE (3) (Pct Frequency) | | | | | | | | | | | | | | | | | | |
|--------------|-----------------------|-----------------|------------|------------------------------------|--------------------------------|------|------------|-------------|------------------|--------------------|--------------------------------|----------------|-----------------|---------------------------------------|-----------|----|---|---|---|------------|---|---|---|---|----|----|----|---|---|---|---|--|
| Core Number | Fl. Below Top of Core | Lithologic Type | | Clear Translucent Grains (1) | Colored Translucent Grains (2) | Mico | Glaucanite | Phosphorite | Foramiferal Test | Ostracod Carapaces | Echinoid Spines and Test Parts | Bryozoa Zoecia | Sponge Spicules | Undifferentiated Calcareous Fragments | ROUNDNESS | | | | | SPHERICITY | | | | | | | | | | | | |
| | | | | | | | | | | | | | | 0 | 1 | 0 | 3 | 0 | 5 | 0 | 7 | 0 | 9 | 0 | 3 | 0 | 5 | 0 | 7 | 0 | 9 | |
| 80 | -14 | B | Oligocene | 852 | 5 | 1 | 1 | 19 | 12 | | 2 | | 111 | 62 | 33 | 17 | | | | | | | | | 42 | 54 | 2 | | | | | |
| 88 | -17 | B | Oligocene | 938 | 8 | | 34 | 16 | | | | | 4 | 79 | 16 | 4 | 1 | | | | | | | | 48 | 47 | 5 | 1 | | | | |
| 92 | -18 | B | Oligocene | 980 | 3 | | 1 | 16 | 16 | | 1 | | 72 | 30 | 52 | 12 | 6 | | | | | | | | 27 | 52 | 21 | 1 | | | | |
| 100 | -15 | B | Oligocene | 946 | 1 | | | 3 | 1 | | | | 17 | | | | | | | | | | | | | | | | | | | |
| 106 | -16 | B | Oligocene | 961 | 5 | 1 | 2 | 8 | 5 | | 1 | | 18 | | | | | | | | | | | | | | | | | | | |
| W07 | btm | | Eocene | 5 | | | | | 45 | | 2 | 7 | 881 | | | | | | | | | | | | | | | | | | | |
| 21 | -12 | | Eocene | 3 | | | | 1 | 26 | 1 | | 1 | 947 | | | | | | | | | | | | | | | | | | | |
| 7 | -14 | C | Paleocene | 981 | 3 | | | 4 | 2 | | | | 3 | | | | | | | | | | | | | | | | | | | |
| 10 | -10 | C | Paleocene | 967 | 2 | | | 8 | | | | | 16 | 85 | 10 | 4 | 1 | 1 | | | | | | | 56 | 40 | 9 | 1 | | | | |
| 14 | btm | C | Paleocene | 801 | 3 | 2 | 136 | 15 | 14 | | | | 26 | 79 | 17 | 4 | | | | | | | | | 46 | 45 | 9 | 1 | | | | |
| 30 | btm | C | Paleocene | 931 | 3 | | 2 | 10 | 30 | 1 | | | 24 | | | | | | | | | | | | | | | | | | | |
| 16 | btm | | Cretaceous | 663 | 5 | | 60 | 32 | 174 | | | | 65 | 46 | 40 | 10 | 3 | 1 | | | | | | | 25 | 58 | 14 | 2 | | | | |
| 22 | btm | | Cretaceous | 267 | 4 | 1 | 14 | 14 | 224 | 9 | 17 | 1 | 448 | 85 | 14 | 1 | | | | | | | | | | | | | | | | |
| 41 | -9 | | Cretaceous | 304 | 7 | | 2 | 2 | 137 | 8 | | | 510 | | | | | | | | | | | | | | | | | | | |

(1) Nearly all quartz particles.

(2) Mostly heavy minerals

(3) Based on visual comparison with chart in Krumbein and Sloss (1953, p. 81)

(4) PT - Post Transgressive Holocene (i.e. essentially modern)

(5) Shallow water relict deposits of probable transgressive Holocene or Pleistocene age

Table D-2. Acid soluble percentages of selected sediment samples.

| Core No. | Interval (ft) | Lithology ¹ | Pct soluble |
|----------|---------------|-------------------------|-------------|
| 10 | btm | limestone | 70.65 |
| 14 | -8 | C (glaucopitic) | 14.50 |
| 16 | -4 | C (glaucopitic) | 16.57 |
| 18 | -4 | | 84.76 |
| 21 | btm | bryozoan hash | 97.01 |
| 22 | btm | C | 57.58 |
| 32 | -6 | sandy limestone | 63.93 |
| 33 | btm | calcareous sandstone | 48.34 |
| 42 | -12 | C | 52.86 |
| 59 | 13 | B | 36.91 |
| 67 | -3 | G | 59.98 |
| 68 | btm | B | 19.69 |
| 73 | -8 | G | 95.60 |
| 74 | -4 | G | 90.49 |
| 84 | -9 | B (barren) | 6.51 |
| 88 | -19 | B (barren) | 2.21 |
| 99 | -8 | calcareous sandstone | 51.93 |
| 100 | -10 | calcareous sandstone | 60.81 |
| 102 | -9 | B | 22.46 |
| 104 | -14 | B | 18.24 |
| 113 | -9 | G | 82.48 |

¹See Table 2 for a summary of sediment types.

APPENDIX E
FAUNAL LISTS

This appendix contains lists of the foraminifera (Tables E-1 to E-5) from samples of the deposits of Late Cretaceous and Tertiary age occurring in the study area. Specimens were picked from small splits of representative samples and mounted on micropaleontology slides for identification. In a few cases where the fauna were sparse, the foraminifera were concentrated by flotation in a mixture of bromoform and acetone which had a specific gravity of about 2.2.

Identification of species was made from available literature. In addition, the most frequently occurring species were checked with specimens in the Cushman Collection at the U.S. National Museum, Washington, D.C.

Faunal lists show the frequency of occurrence of each listed species from representative samples of the pertinent age. Each list also includes several nonspecific measures which are useful in assessing the assemblage as a whole. The percent frequency of planktonic and agglutinated specimens includes percent of these types in the unidentified part insofar as they can be determined.

Table E-1. Foraminifera in selected Upper Cretaceous samples.

| Species | Pct frequency by core and interval (ft) | | |
|--|---|---------|---------|
| | C16 (7) | C22 (6) | C41 (8) |
| <i>Anomalinooides carolinensis</i> Curran | 19.2 | 33.0 | 34.7 |
| <i>Anomalinooides pseudopapillosa</i> (Carsey) | 0.2 | 0.7 | 2.0 |
| <i>Anomalinooides</i> cf. <i>A. taylorensis</i> (Carsey) | | 0.2 | 1.3 |
| <i>Bulimina prolixa</i> Cushman and Parker | | | 1.5 |
| <i>Bulimina referata</i> Jennings | | 2.9 | |
| <i>Cibicides coonensis</i> (Berry) | | 1.2 | 4.4 |
| <i>Cibicides harperi</i> (Sandidge) | 63.8 | 30.1 | 29.4 |
| <i>Cibicides</i> cf. <i>C. harperi</i> (Sandidge) | | 2.6 | 1.5 |
| <i>Cibicides</i> sp. A. | | 0.2 | |
| <i>Cibicides</i> sp. B. | | 0.5 | |
| <i>Dentalina basiplanata</i> Cushman | | | 0.4 |
| <i>Dorothia bulletta</i> (Carsey) | 0.2 | 6.9 | 1.8 |
| <i>Discorbis</i> sp. | | | 0.2 |
| <i>Gaudryina bulloides</i> Olsson | | 1.2 | 0.2 |
| <i>Gaudryina rudita</i> Sandidge | | 0.5 | 0.4 |
| <i>Globigerinelloides prairiehillensis</i> Pessagno | 1.1 | | |
| <i>Globotruncana monmouthensis</i> Olsson | | 0.2 | |
| <i>Globotruncana</i> sp. | 0.2 | | 0.2 |
| <i>Globulina lacrima</i> (Reuss) | | 0.2 | 0.2 |
| <i>Guenbelitria cretacea</i> Cushman | | 1.7 | 5.0 |
| <i>Guttulina adhaerens</i> (Olszewski) | | | 0.4 |
| <i>Gyroidinooides imitata</i> Olsson | 0.2 | 3.8 | |
| <i>Heterohelix carinata</i> (Cushman) | 0.2 | 0.2 | |
| <i>Heterohelix globulosa</i> (Ehrenberg) | 2.6 | 1.9 | 2.4 |
| <i>Heterohelix pseudotessera</i> (Cushman) | | | 0.2 |
| <i>Heterohelix striata</i> (Ehrenberg) | 1.7 | 1.4 | |
| <i>Heterohelix</i> sp. | 3.0 | 1.4 | |
| <i>Lenticulina navarroensis</i> (Plummer) | 0.2 | 0.5 | |
| <i>Lenticulina</i> cf. <i>L. stephensoni</i> Cushman | | 0.2 | 4.2 |
| <i>Lenticulina</i> sp. | 0.2 | 0.5 | 0.4 |
| <i>Loxostomum platium</i> (Carsey) | 3.8 | 2.2 | |
| <i>Pseudoguenbelina excolata</i> Cushman | 0.4 | | |
| <i>Pseudotextularia elegans</i> (Rzehak) | | 0.7 | |
| <i>Pseudovigierina seligi</i> (Cushman) | | 0.1 | |
| <i>Pyrulina</i> sp. | | | 0.2 |
| <i>Rugoglobigerina macrocephala</i> Bronnimann | 1.3 | 0.7 | |
| <i>Rugoglobigerina rugosa</i> (Plummer) | | 1.0 | 0.2 |
| <i>Rugoglobigerina</i> sp. | | 0.5 | 0.2 |
| <i>Siphogenerinoides plummeri</i> (Cushman) | 0.4 | | |
| <i>Spiroplectammina</i> sp. | | | 0.2 |
| <i>Tappanina selmensis</i> Cushman | | 0.7 | 1.3 |
| <i>Textularia</i> cf. <i>T. subconica</i> Franke | | 0.2 | 0.2 |
| Unidentified | | 2.6 | 7.9 |
| Number of specimens counted | 470 | 418 | 456 |
| Number of species | 17 | 31 | 26 |
| Percent planktonic specimens | 10.1 | 9.7 | 8.2 |
| Percent agglutinated specimens | 0.0 | 1.9 | 1.0 |

Table E-2. Foraminifera in selected Paleocene samples.

| Species | Pct frequency by core and interval (ft) | | |
|---|---|---------|---------|
| | C6 (19) | C14 (9) | C30 (8) |
| <i>Alabamina wilcoxensis</i> Toulmin | 0.3 | 0.2 | 0.6 |
| <i>Anamolina</i> sp. | 0.3 | 0.2 | 0.3 |
| <i>Anomalinoidea midwayensis</i> (Plummer) | | | 1.5 |
| <i>Anomalinoidea newmana</i> Cushman | 51.7 | | 48.5 |
| <i>Anomalinoidea unboniferous</i> (Schwager) | | 40.8 | |
| <i>Bulimina</i> sp. | | | 0.9 |
| <i>Cibicides</i> cf. <i>C. alleni</i> | 0.6 | | |
| <i>Cibicides</i> cf. <i>C. howelli</i> Toulmin | 16.2 | 8.5 | 14.1 |
| <i>Cibicides</i> sp. | 0.3 | 0.2 | 0.9 |
| <i>Dentalina basiplanata</i> Cushman | | 1.4 | |
| <i>Dentalina</i> sp. | | 0.2 | |
| <i>Eponides pygmeus</i> Page | | | 6.0 |
| <i>Ephides lotus</i> (Schwager) | | 0.7 | |
| <i>Fursenkoina</i> cf. <i>F. wilcoxensis</i> (Cushman and Ponton) | | 1.7 | 3.0 |
| <i>Globiconusa daubjergensis</i> (Bronnimann) | 0.6 | | 0.6 |
| <i>Globorotalia compressa</i> (Plummer) | 1.1 | | |
| <i>Globorotalia pseudobulloides</i> (Plummer) | | 2.1 | 1.2 |
| <i>Globorotalia</i> sp. | | 0.2 | 0.9 |
| <i>Globulina</i> sp. | 1.1 | 1.6 | |
| <i>Guttulina</i> sp. | | 0.2 | |
| <i>Gyroldinoidea octocamerata</i> (Cushman and Hanna) | 25.3 | 23.6 | 3.3 |
| <i>Lenticulina midwayensis</i> (Plummer) | 0.3 | 10.6 | 3.3 |
| <i>Lenticulina</i> sp. | 0.3 | | 0.6 |
| <i>Loxostoma</i> sp. | | 0.2 | |
| <i>Nonion</i> sp. | | 0.2 | |
| <i>Pseudowuigerina triangularis</i> Jennings | 0.3 | 4.5 | 0.6 |
| <i>Sigmomorphina</i> sp. | 0.3 | 0.5 | |
| <i>Siphogenerina eleganta</i> (Plummer) | | 0.2 | 2.7 |
| <i>Spiroplectammina</i> cf. <i>S. plummerae</i> Cushman | 0.3 | | 1.2 |
| <i>Spiroplectammina</i> sp. | | | 0.3 |
| Unidentified | 1.4 | | 6.4 |
| Number of specimens counted | 352 | 424 | 334 |
| Number of species | 15 | 20 | 19 |
| Percent planktonic specimens | 1.7 | 2.3 | 2.7 |
| Percent agglutinated specimens | 0.3 | 0 | 1.5 |

Table E-3. Foraminifera in selected Eocene sediments.

| Species | Pct frequency by core and interval (ft) | | |
|---|---|----------|---------|
| | W07 | C21 (12) | C31 (2) |
| <i>Alabamina</i> sp. | 0.5 | 0.3 | |
| <i>Angulogerina ocalana</i> Cushman | 0.3 | | |
| <i>Angulogerina</i> sp. | | 0.3 | 1.0 |
| <i>Anomalina</i> sp. | | | 0.5 |
| <i>Bolivina striatella</i> Cushman and Applin | 0.3 | | |
| <i>Bolivina</i> sp. | | | 1.3 |
| <i>Bulimina</i> cf. <i>B. cacumenata</i> Cushman and Parker | | | 5.4 |
| <i>Bulimina</i> cf. <i>B. longicamerata</i> (Bandy) | | | 0.5 |
| <i>Bulimina</i> sp. A. | 0.5 | | |
| <i>Bulimina</i> sp. B. | 0.3 | | |
| <i>Buliminella robertsi</i> Howe and Ellis | | | 5.6 |
| <i>Cassidulina</i> sp. | | | 1.5 |
| <i>Catapsydrax</i> cf. <i>C. unicus</i> Bolli, Loeblich, and Tappan | | | 0.5 |
| <i>Chiloguembelina</i> sp. | | | 1.0 |
| <i>Cibicides</i> cf. <i>C. praecipuus</i> Copeland | 0.3 | | 0.3 |
| <i>Cibicides subspirata</i> Nuttall | 38.5 | 37.8 | |
| <i>Cibicides westi</i> Howe | | | 18.9 |
| <i>Cibicides</i> sp. A. | 5.7 | 4.3 | |
| <i>Cibicides</i> sp. B. | | | 0.3 |
| <i>Cibicidina minuta</i> Copeland | 0.3 | | |
| <i>Coelites reticulosus</i> (Plummer) | 0.3 | 1.2 | |
| <i>Dentalina</i> sp. | | 0.6 | |
| <i>Discorbis assulata</i> Cushman | 0.5 | | |
| <i>Discorbis</i> cf. <i>D. jacksonensis</i> Cushman | | | 0.5 |
| <i>Discorbis</i> sp. | | 0.3 | |
| <i>Eponides cocoaensis</i> Cushman | 27.9 | 19.1 | 7.7 |
| <i>Eponides ellisorae</i> Garrett | | | 0.3 |
| <i>Eponides jacksonensis</i> (Cushman and Applin) | | 2.1 | |
| <i>Eponides</i> sp. | | 1.2 | 0.3 |
| <i>Fissurina</i> sp. | | 0.3 | 0.5 |
| <i>Globigerina</i> cf. <i>G. angustumbilicata</i> Bolli | | | 5.6 |
| <i>Gaudryina gardnerae</i> Cushman | | 0.3 | |
| <i>Globigerina danvillensis</i> Howe and Wallace | | | 3.8 |
| <i>Globigerina linaperta</i> Finlay | | | 1.0 |
| <i>Globigerina</i> sp. A. | 1.5 | 2.1 | |
| <i>Globigerina</i> sp. B. | | | 0.3 |
| <i>Globigerina</i> sp. C. | | | 0.5 |
| <i>Globorotalia broedermanni</i> Cushman and Bermudez | | | 3.8 |
| <i>Globorotalia crassata</i> (Cushman) | | | 2.6 |
| <i>Globorotalia</i> sp. A. | | | 0.3 |
| <i>Globorotalia</i> sp. B. | | | 0.3 |

Table E-3. Foraminifera in selected Eocene sediments.--Continued

| Species | Pct frequency by core and interval (ft) | | |
|--|---|----------|---------|
| | W07 | C21 (12) | C31 (2) |
| <i>Globulina inaequalis</i> Reuss | | 0.3 | |
| <i>Globulina</i> sp. | 0.3 | | 0.7 |
| <i>Guttulina</i> sp. | 0.3 | | 0.5 |
| <i>Gyroidinoides danvillensis</i> (Howe and Wallace) | | | 8.4 |
| <i>Gyroidinoides octocamerata</i> (Cushman and Hanna) | 1.0 | 4.3 | |
| <i>Hanzawaia</i> cf. <i>H. danvillensis</i> (Howe and Wallace) | 0.7 | | 0.3 |
| <i>Lagena acuticosta</i> Reuss | | 0.3 | |
| <i>Lagena costata</i> (Williamson) | | | 0.5 |
| <i>Marginulina</i> sp. A. | | 0.6 | |
| <i>Marginulina</i> sp. B. | | | 0.3 |
| <i>Meloides planatus</i> Cushman and Thomas | 0.7 | | 2.0 |
| <i>Nonion advenum</i> (Cushman) | | | 0.3 |
| <i>Nonion</i> sp. | 1.0 | | 0.3 |
| <i>Planularia georgiana</i> Cushman and Herrick | 0.6 | | |
| <i>Pseudohastigerina wilcoxensis</i> (Cushman and Ponton) | | | 3.1 |
| <i>Quinqueloculina</i> sp. | 0.3 | | |
| <i>Sigmomorphina semitecta</i> (Reuss) | | | 0.5 |
| <i>Siphonina tenuicarinata</i> Cushman | 4.9 | 6.8 | |
| <i>Spiroplectammina alabamensis</i> Cushman | 2.0 | 0.6 | |
| <i>Textularia dibollensis</i> Cushman and Applin | 4.9 | 0.9 | 0.8 |
| <i>Textularia</i> sp. | 0.5 | 0.3 | |
| <i>Valvulineria texana</i> (Cushman and Ellisor) | | | 0.3 |
| <i>Valvulineria</i> sp. | | 1.2 | |
| Unidentified | 3.7 | 11.7 | 14.6 |
| Number of specimens counted | 405 | 325 | 391 |
| Number of species | 26 | 24 | 39 |
| Percent planktonic specimens | 1.5 | 2.1 | 21.3 |
| Percent agglutinated specimens | 7.4 | 2.1 | 0.8 |

Table E-4. Foraminifera in selected Miocene samples.

| Species | Pct frequency by core and interval (ft) | |
|--|---|---------|
| | C95 (15) | C96 (6) |
| <i>Angulogerina occidentalis</i> (Cushman) | | 0.9 |
| <i>Bolivina marginata</i> Cushman | | 3.4 |
| <i>Bolivina paula</i> Cushman and Cahill | 27.8 | 20.2 |
| <i>Bolivina</i> sp. | | 0.6 |
| <i>Buccella mansfieldi</i> (Cushman) | 4.2 | |
| <i>Bulimina ovata</i> d'Orbigny | 0.7 | |
| <i>Bulimina</i> sp. | | 0.3 |
| <i>Buliminella</i> cf. <i>B. bassendorffensis</i> Cushman and Parker | 0.3 | |
| <i>Buliminella elegantissima</i> (d'Orbigny) | 1.8 | |
| <i>Cassidulina laevigata</i> d'Orbigny | 5.3 | |
| <i>Cibicides floridanus</i> (Cushman) | | 34.7 |
| <i>Cibicides lobatulus</i> (Walker and Jacob) | 0.4 | 14.1 |
| <i>Cibicides</i> sp. | 0.4 | 1.2 |
| <i>Discorbis floridana</i> Cushman | | |
| <i>Discorbis assulata</i> Cushman | | 2.8 |
| <i>Elphidium</i> sp. | 0.4 | |
| <i>Fissurina</i> sp. A. | | 0.3 |
| <i>Fissurina</i> sp. B. | | 0.3 |
| <i>Florilus pisarrense</i> (Berry) | 4.6 | |
| <i>Florilus mediocostatus</i> (Cushman) | 2.5 | |
| <i>Globigerina bulloides</i> d'Orbigny | | 2.1 |
| <i>Globigerina</i> cf. <i>G. apertura</i> Cushman | | 0.4 |
| <i>Globigerina</i> sp. | 0.7 | 0.3 |
| <i>Globigerinoides conglobatus</i> (Brady) | | 0.3 |
| <i>Globigerinoides ruber</i> (d'Orbigny) | | 1.5 |
| <i>Globigerinoides trilobus immaturus</i> LeRoy | | 2.1 |
| <i>Globigerinoides trilobus trilobus</i> (Reuss) | | 0.3 |
| <i>Globigerinoides</i> sp. | 0.4 | 4.3 |
| <i>Globorotalia siakensis</i> (LeRoy) | | 2.1 |
| <i>Globorotalia obesa</i> Bolli | 0.4 | 0.6 |
| <i>Guttulina</i> sp. | 0.4 | |
| <i>Hanzawaia concentrica</i> (Cushman) | 44.0 | 1.8 |
| <i>Lagena</i> cf. <i>L. sulcata</i> (Walker and Jacob) | | 0.3 |
| <i>Lenticulina convergens</i> (Borjemann) | | 0.9 |
| <i>Marginulina</i> sp. | | 0.3 |
| <i>Marginulina</i> cf. <i>M. vaughani</i> (Cushman) | | 1.5 |
| <i>Nonionella auris</i> (d'Orbigny) | 0.7 | |
| <i>Rotalia bassleri</i> Cushman and Cahill | 0.7 | |
| <i>Spiroplectimmina</i> sp. | 0.4 | |
| <i>Textularia</i> cf. <i>T. conica</i> d'Orbigny | | 0.3 |
| <i>Textularia</i> sp. | 0.3 | 1.2 |
| <i>Uvigerina directa</i> Dorsey | 2.8 | |
| Unidentified | 1.1 | 2.5 |
| Number of specimens counted | 284 | 326 |
| Number of species | 21 | 27 |
| Percent planktonic species | 1.5 | 14.0 |
| Percent agglutinated species | 0.7 | 1.5 |

Table E-5. Foraminifera in selected Plio-Pleistocene samples.

| Species | Pct frequency by core and interval (ft) | | |
|--|--|----------|----------|
| | C11 (12) | C55 (19) | C74 (15) |
| <i>Angulogerina occidentalis</i> (Cushman) | 8.5 | | 5.0 |
| <i>Asterigerina</i> sp. | 2.1 | 0.4 | |
| <i>Amphistegina lessonii</i> d'Orbigny | 0.7 | 3.5 | 0.4 |
| <i>Bolivina</i> sp. | 0.7 | 0.4 | 0.8 |
| <i>Cancris sagra</i> (d'Orbigny) | | 0.4 | 0.4 |
| <i>Cassidulina laevigata</i> d'Orbigny | | | 2.1 |
| <i>Cibicides lobatulus</i> (Walker and Jacob) | 26.0 | 63.0 | 24.8 |
| <i>Discorbis consobrina</i> (d'Orbigny) | 2.8 | 2.0 | |
| <i>Discorbis floridana</i> (Cushman) | | | 1.2 |
| <i>Discorbis orbicularis</i> (Terquem) | 1.4 | 2.4 | 2.9 |
| <i>Discorbis</i> sp. | | | 1.6 |
| <i>Eponides repandus</i> (Fichtel and Moll) | | | 2.1 |
| <i>Fissurina</i> sp. | | 0.8 | |
| <i>Florilus grateloupi</i> (d'Orbigny) | | 0.4 | |
| <i>Globigerinoides ruber</i> (d'Orbigny) | 3.5 | 4.3 | 0.4 |
| <i>Globigerinoides trilobus</i> (Reuss) | 0.7 | 0.8 | |
| <i>Globigerinoides immaturus</i> Bolli | | 0.8 | |
| <i>Globorotalia</i> cf. <i>G. acostaensis</i> Blow | | 1.2 | |
| <i>Globorotalia</i> sp. | | 0.8 | |
| <i>Globulina inaequalis</i> Reuss | 0.7 | | |
| <i>Guttulina</i> sp. | 0.7 | | |
| <i>Hanzawaia concentrica</i> (Cushman) | 1.4 | 5.5 | 0.4 |
| <i>Lenticulina</i> sp. | 0.7 | 0.4 | 0.4 |
| <i>Nonion</i> sp. | 4.2 | | 4.5 |
| <i>Planulina exorna</i> Phleger and Parker | 26.8 | | 19.0 |
| <i>Quinqueloculina seminula</i> (Linne) | | 0.4 | 1.2 |
| <i>Reussia spinulosa</i> (Reuss) | 6.3 | 0.4 | 5.8 |
| <i>Textularia candeiana</i> d'Orbigny | | | 1.7 |
| <i>Textularia conica</i> d'Orbigny | | 0.4 | 0.4 |
| <i>Textularia</i> cf. <i>T. floridana</i> Cushman | 1.4 | 0.8 | 12.0 |
| <i>Textularia gramen</i> d'Orbigny | 7.8 | 2.4 | 7.0 |
| <i>Textularia</i> cf. <i>T. mayori</i> Cushman | | 0.1 | |
| Unidentified | 5.6 | 7.5 | 4.9 |
| Number of specimens counted | 142 | 254 | 242 |
| Number of species | 18 | 23 | 21 |
| Percent planktonic species | 4.2 | 7.9 | 0.4 |
| Percent agglutinated species | 9.2 | 3.7 | 21.1 |

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The Inner Continental Shelf between the South Carolina border and Cape Lookout, North Carolina, was surveyed to obtain information on bottom and subbottom sediment deposits and structures. The location and the extent of deposits of sand suitable for restoration and nourishment of nearby beaches were investigated.

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