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Reconnaissance Geology of the Submerged and Emerged Coastal Plain Province, Cape Lookout Area, North Carolina

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Reconnaissance Geology of the Submerged and Emerged Coastal Plain Province, Cape Lookout Area, North Carolina

By ROBERT B. MIXON *and* ORRIN H. PILKEY

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Description of the geomorphology, lithology, stratigraphy, sedimentary facies, fossils, and depositional environments of the latest Tertiary and the Quaternary deposits of the Cape Lookout area

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RECONNAISSANCE GEOLOGY OF THE SUBMERGED AND EMERGED COASTAL PLAIN PROVINCE, CAPE LOOKOUT AREA, NORTH CAROLINA

By Robert B. Mixon and Orrin H. Pilkey [1]

ABSTRACT

Surficial deposits of the submerged and emerged parts of the Coastal Plain province in the Cape Lookout area, North Carolina, consist mainly of terrigenous sand, silt, and clay of Quaternary age which almost completely mantle more consolidated Pliocene strata of the Yorktown Formation. Calcareous deposits composed largely of skeletal calcirudites and calcarenites and oolitic calcarenites, probably late Pleistocene to Holocene in age, are present on the shelf southwest of Cape Lookout. A narrow band of algal limestone and calcareous quartz sandstone is exposed along the shelf break. Abundant ooliths and a displaced fossil faunal assemblage, which includes intertidal, inlet, and inner-shelf species, indicate that the Quaternary Continental Shelf sediments are of shallow-water origin. Sediments underlying the emerged Coastal Plain were deposited mainly in barrier, backbarrier, and very nearshore marine environments.

Trends of sand ridges on the Onslow and Raleigh Bay shelf segments suggest that these ridges are constructional features formed subaqueously on the shelf floor during the latter part of the Holocene transgression by storm-generated waves and currents. The ridges are almost certainly being modified today. Shelf-edge features such as the terrace and the paired ridge and trough in the southeastern part of the map area were probably formed by a combination of erosion and biohermal accumulation during a lower stand of the sea. The most prominent landforms on the mainland are Pleistocene barriers (with associated relict beach ridges and Carolina Bays) and backbarrier flats.

The down-to the-coast steplike topography of the subaerial barriers and backbarrier flats in the Cape Lookout area represents partially preserved depositional surfaces and indicates an episodic progradation of the coast toward the south, east, and northeast. The trends of late Pleistocene shorelines in this area and in the Pamlico Sound region to the north suggest that the ancestral Cape Lookout, formed by the seaward-projecting Newport and Arapahoe barriers, extended farther southeast across the Continental Shelf at that time than did contemporary capes to the north or south. The outermost Continental Shelf and upper Continental Slope in this area have formed by a process of upbuilding and outbuilding throughout the late Tertiary and Quaternary, as evidenced by beds of fairly uniform thickness deposited essentially parallel to the present sea floor. Sparker profiles indicate that Cape Lookout and its associated shoals are not related to structural arching of the underlying beds.

A contour map on the base of the Quaternary deposits shows a shallow linear depression in the youngest Tertiary strata which diverges from the present course of the Neuse River near Flanner Beach and trends south-southeast between the Pleistocene Newport and Arapahoe barriers toward the present-day Cape Lookout. The filled depression appears to be a Pleistocene course of the Neuse River; the association of the ancestral Neuse River with an ancestral Cape Lookout supports Hoyt and Henry's hypothesis that capes along the southeastern coast of the United States coincide with river mouths and result from the reworking, by transgressing seas, of deltas deposited on the shallow inner shelf during low stands of the sea.

INTRODUCTION

The geologic map (pl. 1) resulting from this study combines and synthesizes geologic information across the shoreline separating the submerged Atlantic Continental Shelf and the emerged Coastal Plain to the west. To accomplish this, a morphostratigraphic mapping technique similar to that described by Frye and Willman (1962) was used where possible. Different aspects of this technique are emphasized in the submerged and emerged parts of the map area, but nonetheless some degree of continuity across the shoreline has been achieved. Although the emerged areas clearly have a somewhat more complex pattern of map units, this difference appears to be real rather than a reflection of different mapping techniques. That is, present-day estuarine and oceanic conditions, including wave, tide, and storm-induced currents, tend to homogenize topographic forms and disperse sediments, resulting in broader and simpler patterns of sediment distribution on the submerged shelf.

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LOCATION AND GEOGRAPHY

The area of investigation is essentially the 1° square around Cape Lookout, N.C., bounded by long 76°–77° W. and lat 34°–35° N. (fig. 1). A strip 2½ minutes in width has been added to the north border of the 1° square in order to include the entirety of morphostratigraphic units necessary for the development of a more complete geological picture.

The land part of the study area consists mainly of a low-lying peninsula bounded on the north by Pamlico Sound and the Neuse River estuary and on the south and east by Bogue and Core Sounds. Barrier islands, known as Bogue, Shackleford, and Core Banks separate the sounds from the Atlantic Ocean.

The submerged part of the study area includes the southwestern part of Raleigh Bay, which is the Continental Shelf embayment between Cape Hatteras and Cape Lookout, and the northeastern part of Onslow Bay, which is that part of the shelf bounded by Cape Lookout and Cape Fear. The term "bay" in local usage and on navigation and bathymetric charts refers to open shelf waters.

SCOPE

Although raw data for the Continental Shelf part of the map were accumulated over a period of several years, the time allotted for this investigation, including a field reconnaissance of the emerged Coastal Plain, compilation of data, and preparation of the initial report was limited to a 7-month period in 1970–71. Hence, the report is summary in nature, and detailed sedimentologic, paleontologic, and stratigraphic studies, although appropriate, were not conducted.

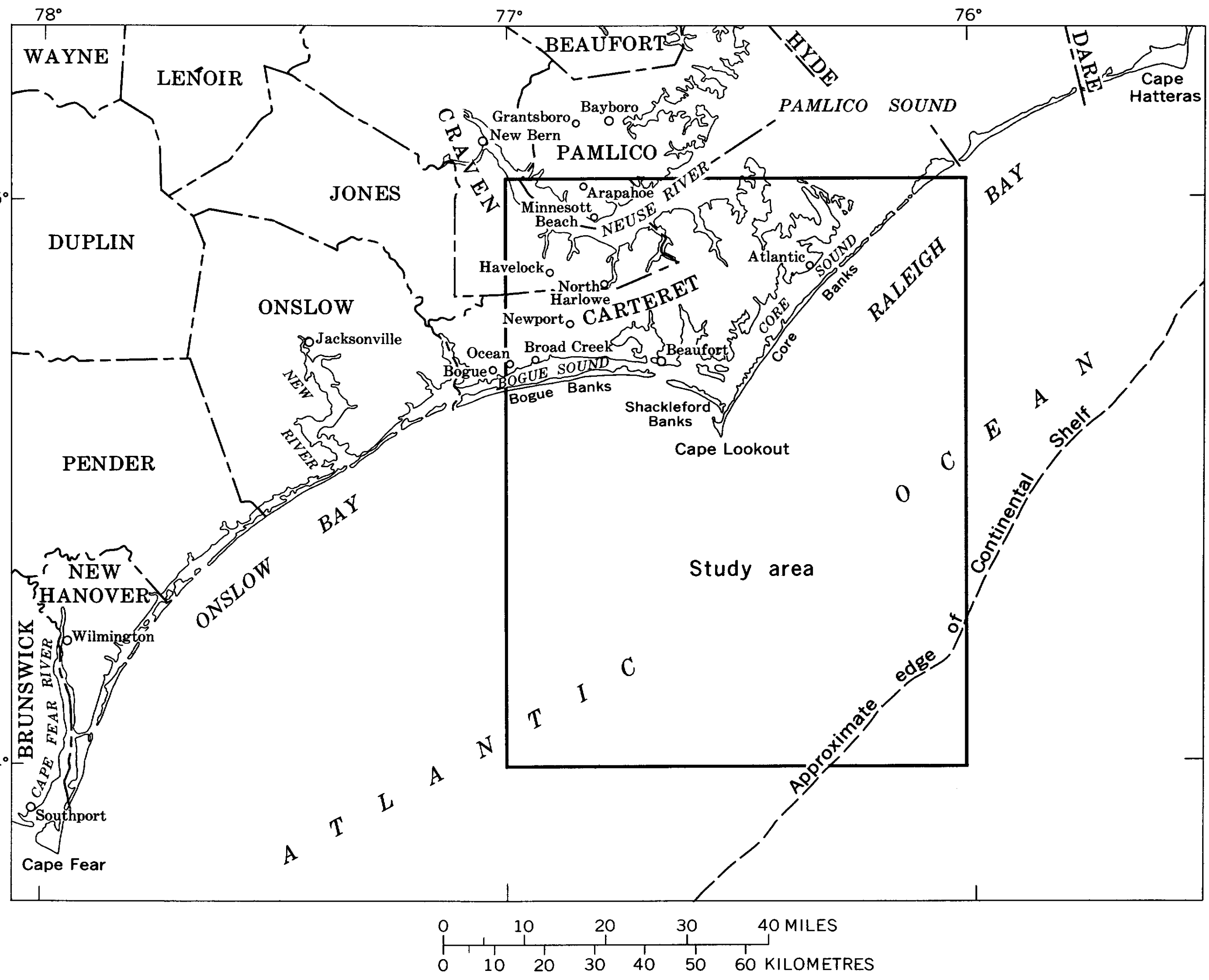

FIGURE 1.—Location of study area in southeastern North Carolina and its relationship to Pamlico Sound and the Onslow and Raleigh Bay shelf segments.

FIELD METHODS

The Continental Shelf part of the map is based on dredge samples accumulated intermittently over a period of several years during cruises of the research vessel *Eastward* of the Duke University Marine Laboratory. Unconsolidated sediments were sampled by means of a Pierce[2] box dredge which samples the upper few centimeters of loose material on the sea floor. Outcrops of consolidated material were sampled by the Cerame-Vivas-McIntyre rock dredge which consists of a rectangular steel frame with a bulldozer-blade cutting edge mounted at one end and a chain bag at the other end. A rock dredge samples indiscriminately over the distance it is dragged, usually 300–2,000 feet (90–600 m), and as a consequence as many as three distinct rock types have been obtained in a single haul. Contacts between map units are sometimes based on samples that represent two different map units and that were obtained in a single dredge haul. Care was taken to distinguish between loose rock material and samples of rock outcrops, the latter being characterized by freshly broken surfaces.

It is important to note that, at the same station, a rock dredge and a box dredge might come up with entirely different samples. For example, where thin unconsolidated sediments overlie well-indurated rocks, the heavy rock dredge will "bite" into and sample the indurated strata; the unconsolidated material will sift out through the chain bag. A box dredge would sample only the unconsolidated sediment. In a situation where both a rock sample and an unconsolidated sediment sample were obtained from one station, the surficial sediment was considered too thin to map, and the consolidated rock unit is shown on the geologic map.

Subbottom profiles in the study area were carried out during the fall of 1969 and 1970 from the *Eastward* using a 500–800-joule sparker with a 0.5-second repetition rate as a sound source. Signals were received in a hydrophone streamer array with a Teledyne preamplifier. Signals received were amplified by a Geo-space dual channel amplifier and recorded on a Gifft I.C. recorder.

The geology of the emerged Coastal Plain is based on compilation of drill-hole data and previously published geologic work plus reconnaissance mapping and aerial-photograph interpretation conducted by the authors in the early part of 1971. In addition, a truck-mounted drill was used to auger a few holes in critical areas. The drill program obtained both stratigraphic information and material for carbon-14 dating, which assisted in setting up a time frame for late Quaternary sedimentation in this area.

[2] The use of trade names is for descriptive purposes only and does not constitute an endorsement of the products by the U.S. Geological Survey.

ACKNOWLEDGMENTS

We wish to thank the Duke University oceanographic program for use of the research vessel *Eastward* in rock-dredging and bottom-sampling work. Ian G. Macintyre, Division of Sedimentology, Smithsonian Institution, participated in and led some cruises and also described many of the rock samples. Blake W. Blackwelder, U.S. Geological Survey, identified the macrofauna in most of the rock samples from the Continental Shelf. Druid Wilson, U.S. Geological Survey, studied the macrofauna from mainland fossil localities and auger holes and provided the data for table 1. Joseph E. Hazel U.S. Geological Survey, made identifications and environmental interpretations of the ostracode assemblages of the emerged Coastal Plain and Continental Shelf sediments. James A. Miller, U.S. Geological Survey, provided the data for the cross section accompanying the geologic map. Meyer Rubin, U.S. Geological Survey, dated the shell and peat samples from both the mainland and the barrier islands. Much data concerning sediment-type distribution in sounds and estuaries came from unpublished studies by Roy Ingram and graduate students at the University of North Carolina. Jack Lee supervised sparker profiling operations on the Continental Shelf. J. W. Pierce, Smithsonian Institution; E. O. Floyd and M. D. Winner, U.S. Geological Survey; and E. T. Grushinski, Chief Ranger, Croatan National Forest, generously provided data which aided construction of the maps.

GENERAL GEOLOGY

PRE-QUATERNARY DEPOSITS

The Cape Lookout area is on the northeast flank of the Cape Fear arch, one of the major positive structural features of the central Atlantic Coastal Plain. The Mesozoic and Cenozoic sedimentary rocks underlying the area form a prism-shaped sequence which thickens generally to the northeast and east (Maher, 1965, 1971). Depth to basement ranges from about 2,300 feet (690 m) in the northwestern part of the map area to an estimated 7,000 feet (2,100 m) in the northeastern corner (Bonini and Woolard, 1960, fig. 4). The deepest oil test well in the area, Bay Land Corporation No. 1 near the town of Atlantic in northeastern Carteret County, penetrated a Pleistocene to Lower Cretaceous sequence 5,570 feet (1,671 m) thick. A generalized cross section (see pl. 2) extending from near New Bern to Cape Lookout is included to show the thickness and distribution of major post-Lower Cretaceous time-stratigraphic units in the subsurface.

The Yorktown Formation, a marine sublittoral deposit, is the only pre-Quaternary rock unit extensively exposed at the surface within the map area. (See pl. 1.) Traditionally, the Yorktown has been considered to be of late Miocene age and correlative with the Duplin Marl of southern North Carolina and South Carolina and the Jackson Bluff Formation of local usage in Florida. Hazel (1971a), however, placed the upper part of the Yorktown (his *Puriana mesacostalis* Zone) in the Pliocene and suggested (Hazel, 1971a, p. 8) that even more of the classic upper Miocene of the Atlantic Coastal Plain may be Pliocene in age. Akers (1972) indicated, on the basis of planktonic foraminifers, that the middle part of the Yorktown (Hazel's *Orionina vaughani* Zone) is also Pliocene in age. Gibson (1971, p. 10) stated that the lower beds of the Yorktown Formation in North Carolina (at the Texas Gulf Sulphur mine near Aurora) are late Miocene in age.

Regionally, the Yorktown consists of clayey sands and sandy clays, generally very fossiliferous, which crop out discontinuously over a wide area in eastern North Carolina and Virginia. Thicknesses of the Yorktown and correlative strata range from a few feet along the western margin of outcrop, as shown on the geologic maps of North Carolina and Virginia (Stuckey, 1958; Milici and others, 1963), to more than 120 feet (36 m) in southeastern Virginia. Gibson (1970, p. 1819) indicated that in the subsurface off the mouth of Chesapeake Bay the Yorktown is more than 500 feet (150 m) thick; however, this thickness includes what is commonly known as the St. Marys Formation in Virginia (Gibson and Buzas, 1973, p. 231). In North Carolina, the Yorktown lies unconformably on subjacent Tertiary rocks and does not appear to have been deformed by tectonic movements such as those that have periodically affected the underlying rocks (James A. Miller, oral commun., 1971; Brown and others, 1972).

Sparker profiles on the submerged shelf perpendicular and parallel to the Cape Lookout shoals show very gently seaward-dipping Tertiary and Quaternary strata to a depth of more than 1,000 feet (300 m) and indicate that the present-day Cape Lookout is not structurally controlled. Northeast-dipping strata near the western margin of the map area represent regional upwarp related to the Cape Fear arch.

QUATERNARY DEPOSITS

In most parts of the map area, the Yorktown Formation is mantled by largely unconsolidated sandy, silty, clayey, and shelly Quaternary sediments, ranging in thickness from a thin veneer to more than 100 feet (30 m) in the vicinity of Cape Lookout. Sediments underlying the emerged part of the Coastal Plain in the Cape Lookout area, along with similar deposits throughout the emerged North Carolina Coastal Plain, have been the subject of reconnaissance-type investigations since the early 1900's. On the other hand, the North Carolina shelf sediments were little studied prior to the work of Stetson (1938), partly because of their relative inaccessibility.

EMERGED COASTAL PLAIN

The earliest investigations of Quaternary landforms and sediments of the emerged part of the North Carolina Coastal Plain were by Johnson (1907) and Stephenson (1912). These workers recognized five terraces roughly paralleling the present coastline and decreasing in altitude eastward. Stephenson divided the terrace sediments, inferred to be of Pleistocene age, into five formations which he correlated with similar deposits known as the Columbia Group in Maryland, Delaware, and Virginia (McGee, 1888; Darton, 1894; and Shattuck, 1906). In accordance with the terrace formation concept as conceived by Shattuck, Stephenson believed each terrace plain and its corresponding formation to be separated from the adjacent lower terrace plain and its deposits by a scarp cut when the sea stood at a lower level. According to Stephenson (1912, p. 272):

> the formation of this group [Columbia Group] in North Carolina consist of a series of terrace deposits the oldest of which occupies the highest position and the younger resting at successively lower levels. These originated in part as shallow marine deposits along sea margins, in part as shallow offshore deposits along the borders of estuaries, and in part as flood-plain deposits along the river valleys at the heads of estuaries. While in Maryland three sets of terrace deposits only have been heretofore recognized, in North Carolina five such sets have been differentiated.

Stephenson's correlation (1912, p. 272) and the range in altitude of the surface of each of the North Carolina formations is as follows:

Terrace formation			Altitude (ft) of terrace, Carolina Coastal Plain	
Maryland and Delaware	Virgina	North Carolina	Eastern part	Western part
Talbot	Talbot	Pamlico	Sea level	25
		Chowan	25–40	50
Wicomico	Wicomico	Wicomico	50	90–100
Sunderland	Sunderland	Sunderland	110	140–150
		Coharie	160–170	230–235

The distribution of these terrace formations is shown on a small-scale geologic map by Stephenson (1912 pl. 13), part of which is modified as figure 2 of this report. Inherent in the terrace formation concept of most workers is the idea of general and uniform uplift of much of the Atlantic Coastal Plain during the Pleistocene, progradation of the Coastal Plain by fluvial and coastal sedimentation processes, and modification of sedimentologic and morphologic features by major fluctuations of sea level caused by periodic warming and cooling.

Later investigators of the Atlantic Coastal Plain Quaternary deposits (Wentworth, 1930; Cooke, 1931, 1936; Doering, 1960; Colquhoun, 1965) further developed and modified the terrace formation concept. Hoyt and Hails (1967) and Colquhoun (1969) retained the classic terrace terminology but demonstrated that the "terrace formations" in Georgia and South Carolina may be divided into barrier-island, lagoon-marsh, and deltaic facies.

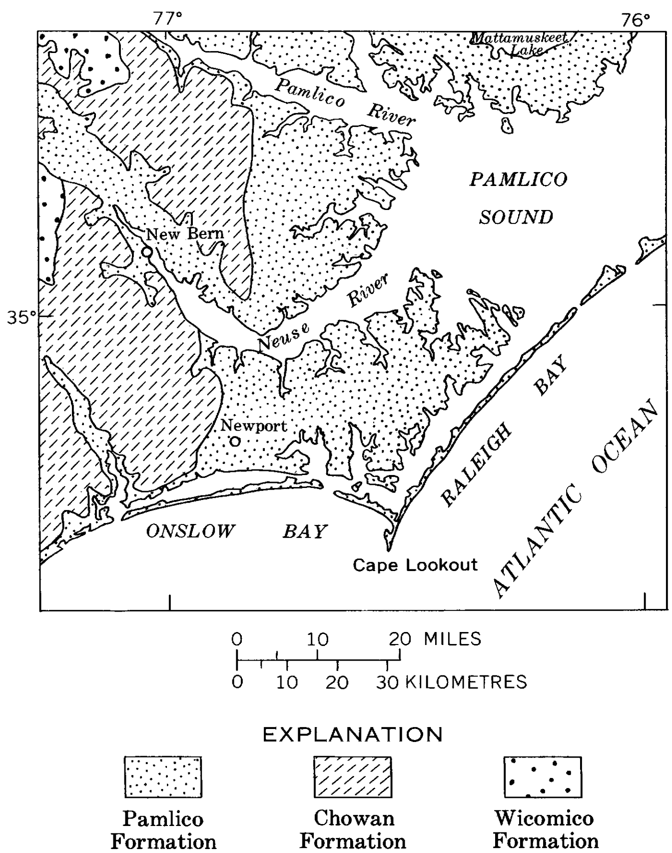

FIGURE 2.—Sketch map showing distribution of Stephenson's terrace formations in east-central North Carolina (modified from Stephenson, 1912, pl. 13).

Others (Moore, 1956; Oaks and Coch, 1963; Oaks, 1964; Coch, 1965, 1968; Bick and Coch, 1969), who worked mainly in the Norfolk area of southeastern Virginia and based many of their conclusions on extensive subsurface sampling (augering and plastic-tube borings), do not believe that each "terrace plain" is underlain by a single formation deposited during a high stand of the sea. Coch (1968 p. 2) stated that in the Norfolk area "Each of these morphologic features [plains, scarps, and flats] is underlain by several distinct stratigraphic units that can be subdivided into mappable facies; each of these stratigraphic units is evidence of a different Pleistocene sea level."

Thom (1967, figs. 3, 5), who used an approach similar to the morphostratigraphic technique described by Frye and Willman (1962), divided the surficial sediments in Horry and Marion Counties, S.C., into barrier sands and backbarrier-flat clays underlain by, and commonly interfingering with, fossiliferous nearshore sands and estuarine silts. Fluvial terrace deposits were delineated along the major stream valleys. Thom used local names for the landforms and morphostratigraphic units in his area of study, believing that correlations over long distances implied by the classic terrace formation terminology should be dependent on the completion of more widespread detailed studies.

A morphostratigraphic unit, as defined by Frye and Willman (1962, p. 112) is "a body of rock that is identified primarily from the surface it displays: it may or may not be distinctive lithologically from contiguous units; it may or may not transgress time throughout its extent." The morphostratigraphic technique is particularly suited for Pleistocene and Holocene deposits which commonly preserve all or part of the original depositional surface of landforms produced by the emplacement of the deposits. This technique has been used for many years by Frye and others in mapping glacial deposits in the midwestern and northeastern parts of the United States.

On the geologic map of the Cape Lookout area (pl. 1), the Quaternary sediments of the emerged part of the Coastal Plain are divided into coastal (barrier and backbarrier) and fluvial morphostratigraphic units in a manner similar to that used by Thom in

South Carolina. A barrier is a ridge or a complex of ridges and swales composed largely of beach, dune, and washover fan material and separated from the mainland by a lagoon or marsh. One or more of the barriers or barrier systems mapped in the Cape Lookout area probably extended from the mainland as barrier spits. The term "backbarrier" refers to tidal flat, salt marsh, lagoonal, and estuarine areas landward from a barrier. These areas constitute a brackish, relatively protected, shallow-water environment which is generally distinguished from that of barriers by distinctive faunas, sediments, and sedimentary structures (Kraft, 1971).

Barriers within the map area may be divided into two types: (1) barriers built by surf, winds, and longshore currents of the open ocean; and (2) barriers which formed by the same or similar processes but along the margin of a large estuary. The ocean-facing barriers or barrier chains are much more extensive than are the estuary barriers, and the individual sets of beach ridges and back-dune flats on the ocean-facing barriers are commonly larger in both horizontal and vertical dimension. The estuary barriers are limited in extent, being confined to sites where a combination of moderate- to high-velocity prevailing winds and long fetch lengths generate waves of sufficient amplitude to construct beach ridges. Water depths, bottom configuration, and sediment supply are also important factors.

The barrier deposits are largely moderately well-sorted sand; they interfinger in a landward direction with finer clayey backbarrier sediments and in a seaward direction with fossiliferous nearshore-shelf sands or, in the case of estuary barriers, with estuarine sands and silts. The upper surface of the barrier deposits, as in many other coastal regions, commonly has ridge-and-runnel topography representing individual beach ridges and intervening swales. This relict beach-ridge topography is exemplified by parts of the Newport, Atlantic, and Cedar Island barriers (figs. 3, 9, and 10). Commonly, the beach ridges are in part obliterated by Carolina Bays which are postdepositional landforms consisting of depressions with sand rims, generally elongated in a northwest direction. The parts of these barriers that have ridge-and-runnel topography tend to have rectangular drainage networks. (See Thom, 1967.)

The backbarrier deposits are clayey silts and sands interbedded with clays; they were deposited in estuaries, lagoons, tidal flats, and marshes. Surfaces of backbarrier deposits are relatively flat and featureless, and broad areas are commonly very poorly drained. In marked contrast to several of the barriers, backbarrier depositional surfaces within the map area have no Carolina Bays.

Fluvial deposits are mainly sand and silt; they form only a very small part of the surficial sediments within the map area.

SUBMERGED COASTAL PLAIN

Quaternary deposits on the Continental Shelf off Cape Lookout are a complex mixture of both recent and relict sediments derived from terrigenous and biogenic sources (Stetson, 1938; Gorsline, 1963; Emery, 1965; Uchupi, 1968; Pilkey and others, 1969, 1971; Milliman and others, 1972, and many others). Residual sediments derived from reworking of rock outcrops on the shelf are also present. Deposition on the submerged shelf in latest Pleistocene and Holocene time was strongly influenced by construction of Cape Lookout and its associated shoals which extend more than halfway across the shelf (pl. 1; fig. 13). These shoals have effectively blocked extensive lateral exchange of sediments between the Onslow and Raleigh Bay shelf segments (Luternauer and Pilkey, 1967).

The Onslow Bay shelf segment (fig. 1) has no major rivers emptying into it. As a consequence, the rate of terrigenous sedimentation has been low, the unconsolidated sediment cover is thin, rock outcrops are abundant, and residual sediments are relatively important. Because of limited dilution by terrigenous sediment, the Onslow Bay shelf contains a higher proportion of calcareous material than any other part of the Atlantic shelf north of Florida. Calcium carbonate averages about 25 percent by weight of the total sediment in Onslow Bay compared with 5–10 percent of the total sediment in Raleigh Bay (Milliman and others, 1972).

On the other hand, several rivers discharge large sediment loads into Pamlico Sound, and some of this sediment is washed through the tidal inlets of the outer barrier islands into Raleigh Bay. Similar high sedimentation rates undoubtedly existed throughout the Pleistocene in this area. As a result, Raleigh Bay is floored by relatively thick surficial sediments, rock dredging is generally unproductive because of the paucity of consolidated rock outcrops, and the proportion of calcium carbonate in Raleigh Bay sediment is considerably lower than in that of Onslow Bay.

Much of the Pleistocene sediment in the Raleigh and Onslow Bay shelf areas underwent extensive reworking during several transgressions and regressions. No shoreline depositional landforms constructed during low sea levels are recognized on the shelf in this area. The present-day topographic features, ranging from small bars to the larger scale sand ridges or "swells" shown on the geologic map (pl. 1), appear to have been formed and maintained by Holocene currents and waves.

As on the emerged part of the Coastal Plain, a modified morphostratigraphic technique was used in mapping the Quaternary deposits. However, in contrast with the emerged Coastal Plain, lithology rather than surface form has been emphasized. Thus, although the distributions of the Cape Lookout sand (unit Ql, pl. 1), the foraminiferal mud (Qm), the algal limestone and calcareous sandstone (Qa), and the shelf sands and muds (Qsb, Qsg, Qss, and Qsc) are clearly related to the past or present configuration of the shelf and slope and commonly have a characteristic surface expression, they are primarily lithic units. Lithic characteristics such as color, texture, and mineralogy are the sole basis of subdivision of gross mapping units such as the shelf sands and muds.

STRATIGRAPHY AND GEOMORPHOLOGY

YORKTOWN FORMATION

In the Beaufort area, the clayey sands and clays of the Yorktown Formation (included in unit Tpm, pl. 2) lie unconformably on the Pungo River Formation (middle Miocene) and, to the west and northwest, lap over middle Miocene strata onto older rocks. Thicknesses range from a few feet near the limit of outcrop just west of the map area to more than 100 feet (30 m) in the subsurface in the eastern part of the map area. Outcrops occur mainly on the Onslow Bay sea floor and in the bluffs along the south bank of the Neuse River. Very narrow outcrops also occur in the stream valleys of the Newport River and its tributaries and Brices Creek (just west of the map area), which cut through the Quaternary deposits into the uppermost Tertiary strata. Flood-plain deposits and colluvium, however, cover most of the Yorktown Formation in these valleys, and the outcrop area shown on the mainland part of the accompanying map (pl. 1) is exaggerated.

Lithology.—In the Cape Lookout area, the Yorktown beds underlying the emerged part of the Coastal Plain consist mainly of bluish- to greenish-gray clayey quartz sand and interbedded clay and sandy clay beds. The strata are generally more compacted than the overlying Quaternary sediments and consequently contain considerably less interstitial water. Except for the upper 1 or 2 feet (30 or 60 cm), which are commonly leached, the Yorktown beds contain an abundant fossil fauna. Some beds exposed along the Neuse River consist mainly of clay packed with shells of the gastropod *Crepidula fornicata,* many of which are still stacked in living position.

Drill data indicate that the predominantly arenaceous-argillaceous Yorktown beds in Carteret, Craven, and Pamlico Counties become more calcareous northeastward, and in the Pamlico Sound and Outer Banks areas of southeastern Hyde and Dare Counties, they consist of 25–75 percent sandy limestone (Brown and others, 1972, pl. 21). The calcareous sediments are apparently associated with a structural high extending northeastward from Carteret County to Dare County (Brown and others, 1972, p. 52 and pl. 30, 50).

Previous investigations.—The upper Tertiary strata exposed in the Neuse River bluffs between New Bern (fig. 1) and Johnson Point in Craven County, at the northwest corner of the map area, have been considered to be of probable Pliocene age and have been variously called the Croatan beds, Croatan Sand, or Croatan Formation (Dall, 1892; Mansfield, 1928, 1936; McNeil, 1938; Fallaw and Wheeler, 1969) or the James City Formation (Du Bar and Solliday, 1963). These same strata and equivalent beds in the subsurface in this vicinity have been included in the Yorktown Formation by Brown (1958), Brown, Miller, and Swain (1972), Floyd (1969), and Floyd and Long (1970), although these authors consider them to be upper Miocene. The field investigations which defined the "Croatan Sand" and the "James City Formation" were reconnaissance biostratigraphic and, to a lesser extent, lithostratigraphic studies of outcrops along the Neuse River estuary. Stratigraphic and biostratigraphic relationships of these beds with updip facies of the Yorktown Formation in Beaufort and Pamlico Counties adjacent to the north and east, or with the Waccamaw Formation and Duplin Marl farther to the southwest, have not been clearly established. Until detailed field mapping and regional biostratigraphic studies determine that these strata form a mappable lithic unit separable from the Yorktown beds in nearby areas, both in the subsurface and exposed at the surface (for example, Lee Creek phosphate mine in Beaufort County), it appears more logical to include them in the Yorktown Formation.

Outcrops on the sea floor in Onslow Bay, which consist mainly of calcareous sandstone, are well lithified in comparison with mainland outcrops and sequences penetrated in drill holes in western Carteret County. Outcrop surfaces are extensively bored and are similar in general appearance to the exposed rocks in Scripps Canyon described by Warme, Scanland, and Marshall (1971). The cementing matrix material, which forms 5–50 percent of rock volume, is dense microcrystalline calcite, commonly slightly argillaceous. X-ray diffraction studies indicate trace amounts of dolomite in some of these rocks. The difference in degree of lithification between the Onslow Bay outcrops and the drill-hole sequences in western Carteret County is probably due to initial differences in lithology and, possibly, to some sort of cementation that has taken place after exposure of the beds on the sea floor or subaerially during low stands of the sea.

Fauna.—Much of the shell material in dredge samples from the Yorktown strata cropping out in Onslow Bay has been removed by solution, and age determinations have been based principally on abundant well-preserved casts of mollusks. The molluscan fauna includes *Discinisca lugubris* (Conrad), *Mytilus* cf. *Mytilus conradinus* d'Orbigny, *Ecphora quadricostata* (Say), *Amusium mortoni* (Ravenel), and *Eucrassatella* sp. The ostracode assemblage in the dredge samples is also very poorly preserved, apparently because of pronounced leaching of the shelf outcrops, and only nondiagnostic species such as *Cytherura forulata* Edwards and *Paradoxostoma delicata* Puri were identified from samples within the map area.

Shell material in the Pliocene beds cropping out along the Neuse River and in artificial exposures such as marl pits and spoil piles, in marked contrast with that of the shelf outcrops, is generally well preserved. The faunal assemblage, which includes characteristic late Tertiary mollusks such as *Anadara aequicostata, Noetia limula, Ostrea sculpturata, Carditamera arata, Aequipecten eboreus,* and *Mercenaria rileyi,* has been discussed in several publications (Mansfield, 1928, 1936; DuBar, 1959; Richards, 1950; Fallaw and Wheeler, 1969).

Paleoenvironment.—The rather meager molluscan fauna obtained from the outcrops in Onslow Bay suggests a shallow-shelf depositional environment for these beds (B. W. Blackwelder, oral commun., 1971). On the basis of the much larger molluscan assemblage preserved in the Pliocene strata exposed along the Neuse River, DuBar and Solliday (1963, p. 232) suggested that this sequence (=James City Formation of DuBar and Solliday) "was deposited in a very slightly restricted embayment of the sea at a depth of 40 to 50 feet." A preliminary study of the ostracode assemblage obtained from the Neuse River outcrops (J. E. Hazel, written commun., 1971) supports DuBar and Solliday's interpretation. According to Hazel, this assemblage, totaling 57 species, indicates deposition in "very shallow water, perhaps an embayed area that was open to the sea. Bottom temperature in the coldest month probably averaged between 12.5° and 20°C, perhaps around 17.5°C. Bottom temperature in the warmest month probably averaged more than 25°C."

FLANNER BEACH FORMATION OF DuBAR AND SOLLIDAY (1963) (RESTRICTED)

The land north of the Bogue scarp and west of the Grantsboro scarp and shoreline (fig. 5 and pl. 1) has a considerably higher average altitude, 25–40 feet (7.5–12 m) above mean sea level, than the rest of the Cape Lookout map area and corresponds, in large part, to the outcrop of the Chowan Formation as defined and mapped by Stephenson (fig. 2). The correspondence would be even closer except that accurate and detailed topographic maps of this area were not available to Stephenson. For example, 5-foot-contour-interval topographic maps published in 1951 show that much of the wide reentrant in the Chowan terrace formation in the area of the Newport and Neuse Rivers which Stephenson mapped as the Pamlico Formation (fig. 2), underlies depositional surfaces (including relict beach-ridge topography) ranging from 25 to 40 feet (7.5 to 12 m) in altitude. In other areas, especially adjacent to the Neuse River, surfaces corresponding to Stephenson's Chowan terrace plain have been considerably dissected, and much of the present land surface is commonly less than 25 feet (7.5 m) in altitude.

DuBar and Solliday (1963) studied the Pleistocene exposures along the Neuse River estuary and presented arguments against usage of the terms Pamlico and Chowan in a stratigraphic sense. Instead they proposed (1963, p. 215) that the "late Pleistocene deposits of the lower Neuse Estuary which unconformably overlie the James City beds [Pliocene?]" be referred to the "Flanner Beach Formation" and designated the exposures at Flanner Beach (pl. 1) as the type section. They divided these deposits into transgressive and regressive sequences on the basis of faunal assemblages and limited lithostratigraphic studies of outcrops along the Neuse River. However, the lateral limits of the "Flanner Beach Formation" and its relationships to younger Pleistocene deposits were not defined.

More recently, the surficial Coastal Plain deposits in southeastern North Carolina have been studied by Daniels, Gamble, Wheeler, and Holzhey (1972) in connection with soil-survey investigations. These workers have divided the Pleistocene deposits of the outer Coastal Plain in Beaufort, Pamlico, and Craven Counties and adjacent areas into three stratigraphic units, as follows: (1) the Talbot morphostratigraphic unit, consisting of sand, silt, and clay underlying the plain between the Suffolk scarp and the Walterboro scarp to the west; (2) the Minnesott Ridge sand composed of sand and "loamy sand" underlying the ridge paralleling the Suffolk scarp and overlying the Talbot deposits; and (3) the Pamlico morphostratigraphic unit, consisting mainly of sand and silty clay underlying the plain east of the Suffolk scarp. Thus, their Talbot and Pamlico morphostratigraphic units correspond in the main to Stephenson's Chowan and Pamlico Formations. Their classification differs from Stephenson's in that they differentiate the Minnesott Ridge sand from the Talbot (=Chowan) and recognize that it may be correlative with the Pamlico deposits to the east. They also differ from Stephenson in recognizing that in some areas the Talbot deposits may extend east of the Suffolk scarp in the subsurface (Daniels and others, 1972, fig. 9). Except for the Minnesott Ridge sand, the surficial stratigraphic units defined by these workers do not seem to be true morphostratigraphic units as conceived by Frye and Willman (1962), but instead are very similar to the coastwise terrace formations as used by Stephenson (1912), Cooke (1931), Colquhoun (1965, 1969), and others. Pleistocene and older beds underlying the Talbot and Pamlico deposits were assigned to the "Small sequence" which was defined as "a complex of interbedded clays to sands with one or more organic horizons" (Daniels and others, 1972, p. 3 and fig. 2). Their "Small sequence" includes "all stratigraphic units between the Castle Hayne or Yorktown and the overlying surficial sediments [their Talbot and Pamlico morphostratigraphic units]." It would seem that the "Small sequence" is not a valid geologic unit, in either a lithostratigraphic or biostratigraphic sense, inasmuch as it lumps dissimilar stratigraphic units such as the marine James City Formation of DuBar and Solliday (1963) (Pliocene?), the cypress stump bed at Flanner Beach and other swamp deposits (Pleistocene), and fossiliferous marine beds in the area of the Texas Gulf Sulphur phosphate mine which appear to have been assigned to the Yorktown Formation (Miocene and Pliocene) by other workers (Gibson, 1967; Hazel, 1971a).

This report tentatively adopts the Flanner Beach Formation of DuBar and Solliday (1963) (restricted) as a stratigraphic unit including the older Pleistocene marine and brackish-water deposits in the northwestern part of the Cape Lookout map area (pl. 1) which form a progradational sequence deposited during a single transgressive-regressive cycle. Pleistocene beds east of the Grantsboro scarp, interpreted to have been deposited in a separate and later transgressive-regressive cycle or cycles, are excluded. The Minnesott Ridge sand (Minnesott sand of this report), composed of beach and dune deposits along and adjacent to the Grantsboro scarp on the west, is also excluded from the Flanner Beach Formation.

On the geologic map accompanying this report, the Flanner Beach Formation is informally divided into three members. Two of these members, the Newport and Arapahoe sands, consist mainly of well-sorted sands believed to constitute barrier deposits emplaced on each side of an ancestral Neuse River estuary. The other member, the Beard Creek, consists of fossiliferous silty and clayey sands interbedded with lesser amounts of silt and clay; it appears to have been deposited largely in lagoonal and estuarine environments.

NEWPORT SAND MEMBER

A complex of northeast-trending sand ridges 2–3 miles (3.2–4.8 km) wide extends from the town of Newport in western Carteret County to the vicinity of Bogue just west of the Cape Lookout map boundary (fig. 1). Ridges in the southeastern part of the complex flare oceanward and trend east-northeast forming slightly curving arcs which are convex landward. Individual ridges, numbering 40 or more, can be traced for distances of as much as 3 miles (4.8 km). The sand ridges, fairly well drained at the surface and vegetated in part by longleaf pine and oak, show on aerial photographs as long, narrow discontinuous light-gray bands or stripes (fig. 3). The swales between the ridges are relatively poorly drained and are commonly characterized by soils rich in organic matter (muck) and thick scrubby vegetation; they appear as dark-gray stripes on the air photos. Relief from the ridge crests to the bottom of adjacent swales is generally about 5 feet (1.5 m) or less. Ridge spacing ranges from 6 to 12 ridges per mile. The sand ridges are truncated in many places by shallow depressions with low sand rims; these depressions range in size and shape from small rounded forms to larger ellipsoidal ones whose long axes are consistently oriented in a northwest direction. The depressions are similar to features known as Carolina Bays, which occur on Pleistocene depositional surfaces of the Coastal Plain from New Jersey to the Carolinas (Thom, 1970; Price, 1968). The surface of the sand-ridge complex, which is generally 30–40 feet (9–12 m) in altitude, merges northwestward with featureless sand flats and swamps. To the south it is bounded by a highly dissected scarp (Bogue scarp of this report, fig. 5) which

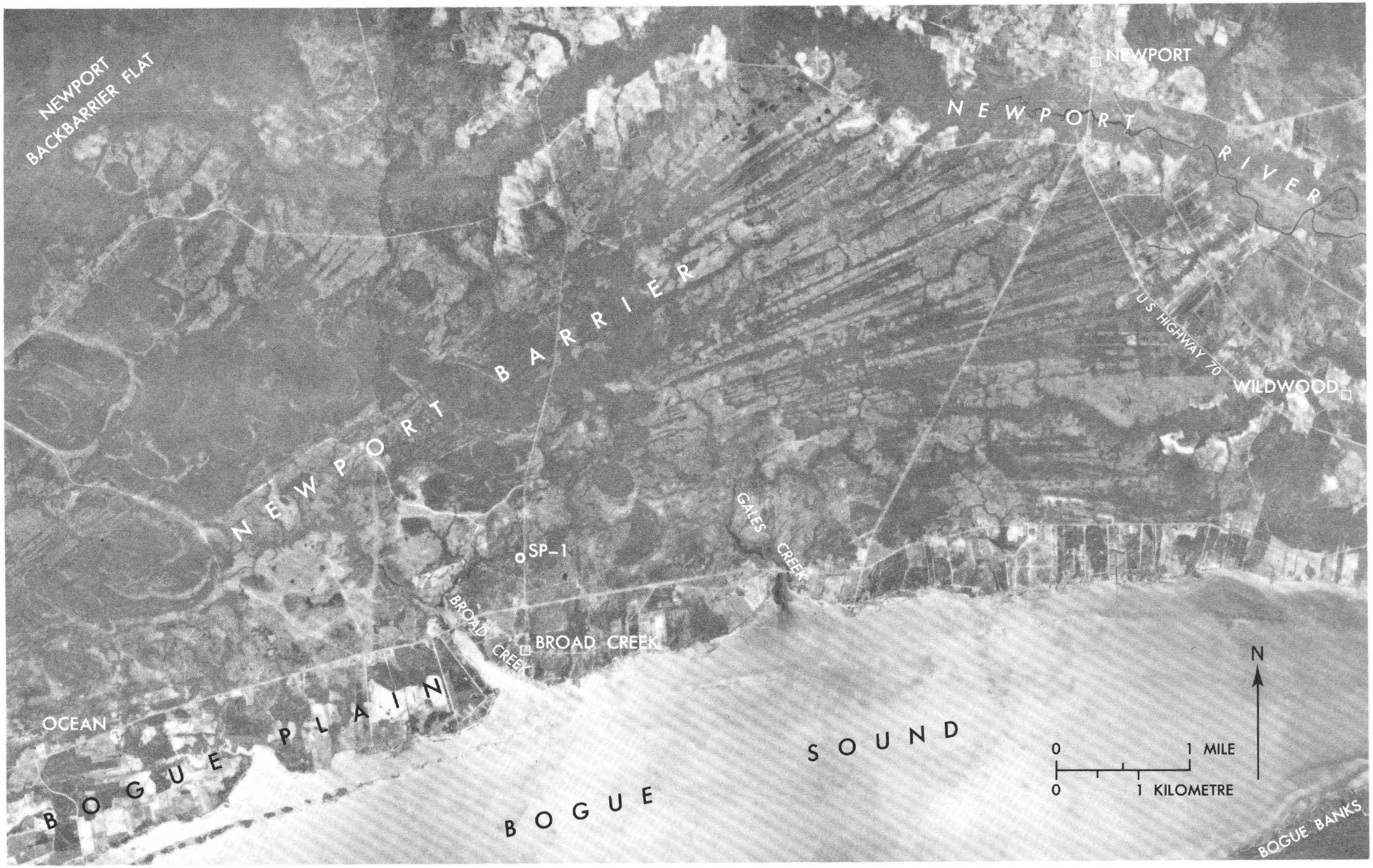

FIGURE 3.—Surface features of Newport barrier, Carteret County, N.C. Light-gray northeast-trending stripes are beach ridges; intervening swales are dark gray. Northwest-trending elliptical areas (dark-gray) with sand rims (light-gray) are relict lakes known as Carolina Bays (Thom, 1970). Small subsidiary rims within the larger ellipses result from shrinkage of original larger lakes. Data from fossil locality SP–1 are given in table 1. Photograph by U.S. Geological Survey, 1964.

separates the sand ridges from a lower sand plain, and by the present-day Bogue Sound shoreline.

The sand-ridge complex and the sand flats adjacent to the northwest are underlain by pale-yellowish-gray, fine to coarse, moderately well sorted to well-sorted quartz sand locally containing fine to very fine quartz and chert pebbles. A vertical section generally includes one or more zones impregnated with the black organic colloids called humate (Swanson and Palacas, 1965; Thom, 1967, 1970). The very few outcrops generally show some crossbedding. No fossils were observed. The sand ranges in thickness from 10 feet (3 m) or less on the northwest to about 40 feet (12 m) near the communities of Ocean and Broad Creek at the southern edge of the sand-ridge complex. The sand deposits described above are here informally named the Newport sand member of the Flanner Beach Formation.

The well-sorted Newport sand member appears to interfinger to the northwest and east with silty and clayey sands and clays which underlie the flat, swampy terrain southwest of Havelock Station and the dissected lowland east of Newport (pl. 1, section *A–A′*). In the vicinity of Holly Springs, spoil piles from dredging operations along the Newport River contain Pliocene fossils and sediments probably correlative with the James City Formation of DuBar and Solliday (1963) (equals upper Yorktown of this report), suggesting that the Newport sand member directly overlies the Yorktown in this area. To the south, along the southern edge of the sand-ridge complex, the Newport sand member overlies bluish-gray clayey sand and clay containing an abundant molluscan and ostracode fauna indicative of a Pleistocene age (Druid Wilson and J. E. Hazel, written commun., 1971). (See pl. 1, sec. *A–A′*, unit Qcs.) These fossil beds and the basal part of the overlying Newport sand are well-exposed in a canal bank 1 mile (1.6 km) north of the community of Broad Creek. The fossil assemblage obtained from the shelly sand at this locality (table 1, loc. SP–1) is dominated by *Mulinia* but includes species such as *Donax roemeri protracta* and *Spisula solidissima* which are characteristic of nearshore normal marine environments. Mollusks representative of restricted environments, such as *Crassostrea* and *Rangia*, are very few and badly worn.

The sand ridges and the underlying well-sorted sand deposits of the Newport area are comparable to landforms and associated sedimentary deposits of other coastal regions which have been interpreted as beach-ridge complexes (Colquhoun, 1969; Psuty, 1966; Thom, 1967; Zenkovich, 1967) and are inferred to have a similar origin. The Newport area beach ridges appear to have formed on the downdrift side of the mouth of an ancestral Neuse River (fig. 4). They may have prograded seaward from the mainland or from fringing swamps to form strand or chenier plains (Byrne and others, 1959; Hoyt, 1969; Otvos, 1970), or they may have formed as a barrier or barrier spit separated from the mainland by a lagoon.

TABLE 1.—*Fauna of Pleistocene fossil localities, Cape Lookout area, North Carolina*

[Data provided by Druid Wilson, U.S. Geol. Survey]

	Flanner Beach (HL–1)	Beard Creek (UB—1A)	Smith Gut (CP–4)	Broad Creek (SP–1)	Core Creek Canal (CC–1)	Mansfield (1928) "Open lands," USGS 10892
Gastropoda:						
Polinices duplicatus (Say)	×	×	×	×	--	×
Tectonatica pusila (Say)	--	--	×	--	--	--
Crepidula fornicata (Linné)	--	--	×	--	--	×
"*Nassa*" *trivittata* (Say)	×	×	×	×	×	×
"*N.*" *acuta* (Say)	×	×	×	×	--	--
Ilyanassa obsoleta (Say)	×	×	--	×	×	--
Busycon carica (Gmelin)	×	×	--	×	--	×
B. canaliculatum (Linné)	×	×	--	--	--	×
Oliva sayana Ravenel	--	--	--	×	--	×
Eupleura caudata (Say)	×	--	--	×	×	--
Retusa canaliculata (Say)	×	×	×	--	--	--
Pelecypoda:						
Nucula proxima Say	×	×	×	--	×	--
Nuculana acuta (Conrad)	×	×	×	--	×	--
Yoldia limatula Say	×	×	×	--	--	--
Anadara transversa (Say)	×	×	×	×	×	×
Cunearca incongrua (Say)	--	--	--	--	--	×
Lunarca ovalis (Bruguiere)	×	×	--	×	×	×
Noetia ponderosa (Say)	×	×	--	--	×	×
Argopecten irradians (Lamarck)	×	×	--	×	×	×
Crassostrea virginica (Gmelin)	×	--	--	×	--	×
Anomia simplex (d'Orbigny)	×	×	×	×	--	×
Carditamera floridana (Conrad)	×	--	--	--	--	×
Venericardia tridentata	--	×	--	×	×	×
Cyclocardia borealis (Conrad)	--	--	--	×	--	--
Chama macerophyla Gmelin	--	--	--	--	--	×
Dinocardium robustum (Solander)	×	×	×	×	--	--
Mercenaria mercenaria (Linné)	×	×	--	×	×	×
Chione cancellata (Linné)	--	--	--	×	×	×
Gouldia cerina Adams	--	--	×	--	--	--
Gemma gemma (Totten)	--	--	--	--	×	×
Transenella cubaniana (d'Orbigny)[1]	--	--	×	--	--	--
Anatina (*Raeta*) *plicatella* (*Lamarck*) (= *Labiosa canaliculata*)	×	×	×	×	--	--
Mulinia lateralis (Say)	×	×	×	×	×	×
Spisula solidissima (Dillwyn)	--	--	×	×	×	×
Rangia cuneata (Gray)	×	--	--	×	×	×
Tellina alternata Say	×	×	--	--	--	--
T. (*Angulus*) *agilis* Stimpson	×	×	×	--	--	×
Donax roemeri protracta (Conrad)	--	--	--	×	×	×
Abra aequalis (Say)	×	×	×	--	--	--
Ensis directus Conrad	×	×	×	--	×	×
Tagelus plebeius (Solander)	--	--	--	×	×	--
Corbula contracta (Say)	--	×	×	×	×	×
Cyrtopleura costata (Linné)	--	×	--	×	--	--
Pandora trilineata Say	×	×	×	--	--	--

[1] Reported as living today only from the Florida Keys to the West Indies.

ARAPAHOE SAND MEMBER AND MINNESOTT SAND

A broad sand ridge extends from the community of Minnesott Beach on the Neuse estuary northward beyond the map area to the Pamlico River. This feature is the Minnesott Ridge of Daniels, Gamble, Wheeler, and Holzhey (1972). Altitudes along the ridge crest range from about 35 feet (10.5 m) near

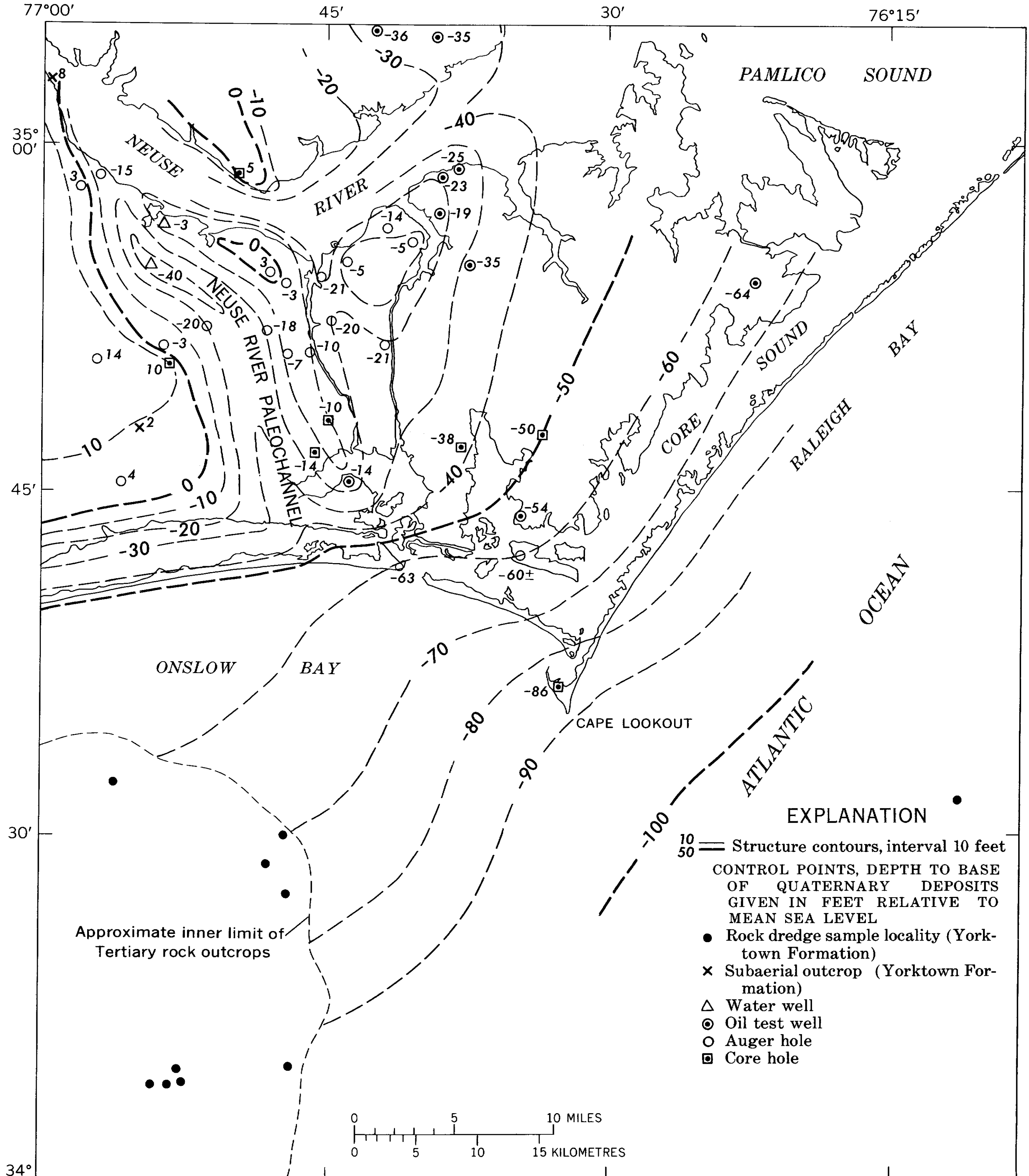

FIGURE 4.—Generalized contour map showing configuration of base of Quaternary deposits.

Minnesott Beach to 42 feet (12.8 m) near the town of Arapahoe and as much as 60 feet (18 m) near the Pamlico River (Aurora 7½-minute quadrangle). Westward within the Cape Lookout map area, the sand ridge merges with a dissected lowland with flat interfluves at about 30 feet (9 m). To the east, the ridge is bounded by a prominent linear break-in-slope or scarp which separates the ridge from a low-lying, gently undulating plain. The toe of the scarp ranges from 15 to 20 feet (4.5 to 6 m) in altitude but is commonly 17 or 18 feet (5.1 or 5.4 m). This scarp has been correlated with the Suffolk scarp of Virginia and is inferred to represent a Pleistocene shoreline (Flint, 1940; Oaks, 1964; Daniels and others, 1972). As the scarp between the Neuse and Pamlico Rivers appears to be, at least in part, a much younger feature than the Suffolk scarp in its type area (Suffolk, Va.), it is herein called the Grantsboro scarp after the town of Grantsboro in Pamlico County (fig. 5). (See section on formation of this scarp for a more detailed discussion.)

Along the projection of the Minnesott Ridge south of the Neuse estuary, a similar but much less pronounced sand ridge or "rise" extends from the Neuse estuary to the vicinity of North Harlowe (pl. 1) where it merges southward and westward with a flat lowland. Crestal altitudes range from about 25 to 30 feet (7.5 to 9 m), decreasing gradually southward. This ridge is not bordered on the east by a well-defined scarp, as is the ridge north of the Neuse, but the trend of the inferred Grantsboro shoreline is traceable as a steeper-than-average slope indicated by the close spacing and parallelism of the 15- and 20-foot contours.

The two north-trending ridges described above are underlain by fine to coarse, well-sorted quartz sand 30–40 feet (9–12 m) thick. A cross section of the Pleistocene deposits near Arapahoe (Daniels and others, 1972, fig. 9; this report, fig. 6) suggests that the well-sorted quartz sand is divisible into two lithic units: (1) an older. sheetlike sand beneath and west of the ridges which forms the upper part of the Talbot of Daniels and others in this area; and (2) a younger linear sand body forming the surficial deposits of the Minnesott Ridge and Grantsboro scarp.

The upper sand, informally named the Minnesott sand, following the example of Daniels and others, is not assigned to the Flanner Beach Formation but is discussed here for convenience. The outcrop belt, as much as 1 mile (1.6 km) wide, coincides in part with the strip of Norfolk and Leon fine sand soils along the Minnesott Ridge as shown on the soil map of Pamlico County (Miller and Taylor, 1937). The well-sorted quartz sand composing the unit attains a maximum thickness of 15–20 feet (4.5–6 m). Humate commonly impregnates one or more zones. The base of the Minnesott sand is delimited in some areas by a buried peat or soil zone at the top of the Talbot (Daniels and others, 1972, p. 13 and fig. 8), suggesting that the sand is unconformable on the underlying deposits. At the toe of the Grantsboro scarp, the well-sorted Minnesott sand grades into the silty and clayey sands composing the upper Pamlico deposits (Daniels and others, 1972, p. 16 and fig. 9). To the west, the sand thins to a featheredge. South of the Neuse River, the seaward edge of the Flanner Beach Formation is probably overlapped by thin sands correlative with the Minnesott sand, but these deposits are not differentiated on plate 1.

Moderately to well-sorted nonfossiliferous sand deposits in southern Pamlico and Craven Counties, which unconformably underlie the Minnesott sand and conformably overlie fossiliferous clayey sands of Pleistocene age, are herein informally named the Arapahoe sand member and mapped as a unit of the Flanner Beach Formation (fig. 6 and pl. 1). This sand, as much as 25 feet (7.5 m) or more thick in the eastern part of its outcrop area, thins westward and overlaps or intertongues with clayey sands and silt of the Beard Creek member of the Flanner Beach Formation. The extent and relationships of the Arapahoe sand member with lithic units to the east has not been firmly established, but the cross section near Arapahoe (fig. 6) suggests that it may be truncated along the Grantsboro scarp by the younger Pamlico deposits (Core Creek sand of this report). The uppermost part of the deposits mapped as the Arapahoe sand member south of the Neuse estuary probably includes sandy sediments correlative with the Minnesott sand.

The Arapahoe sand member is especially well exposed in freshly eroding bluffs at three localities along the Neuse River estuary; (1) near Smith Gut, a small tributary on the north side of the estuary about 2 miles (3.2 km) northwest of Minnesott Beach; (2) west of the mouth of Beard Creek, also on the north side of the estuary; and (3) in the vicinity of the Pine Cliff recreation area on the south side of the estuary. At Smith Gut, the Arapahoe sand member is conformably underlain at beach level by fossiliferous bluish-gray clayey sand very similar to that exposed below the Newport sand member at the Broad Creek locality. Here the molluscan assemblage (table 1, loc. CP–4) is also dominated by *Mulinia lateralis* but includes abundant *Tellina* (*Angulus*) *agilis* and *Ensis directus* and less abundant *Spisula solidissima*. The ostracode assemblage, dominated by *"Haplocytheridea" setipunctata*, suggests a bay or lagoonal depositional environment. However, the presence of the surf clam *Spisula solidissima*, a common form in nearshore shelf en-

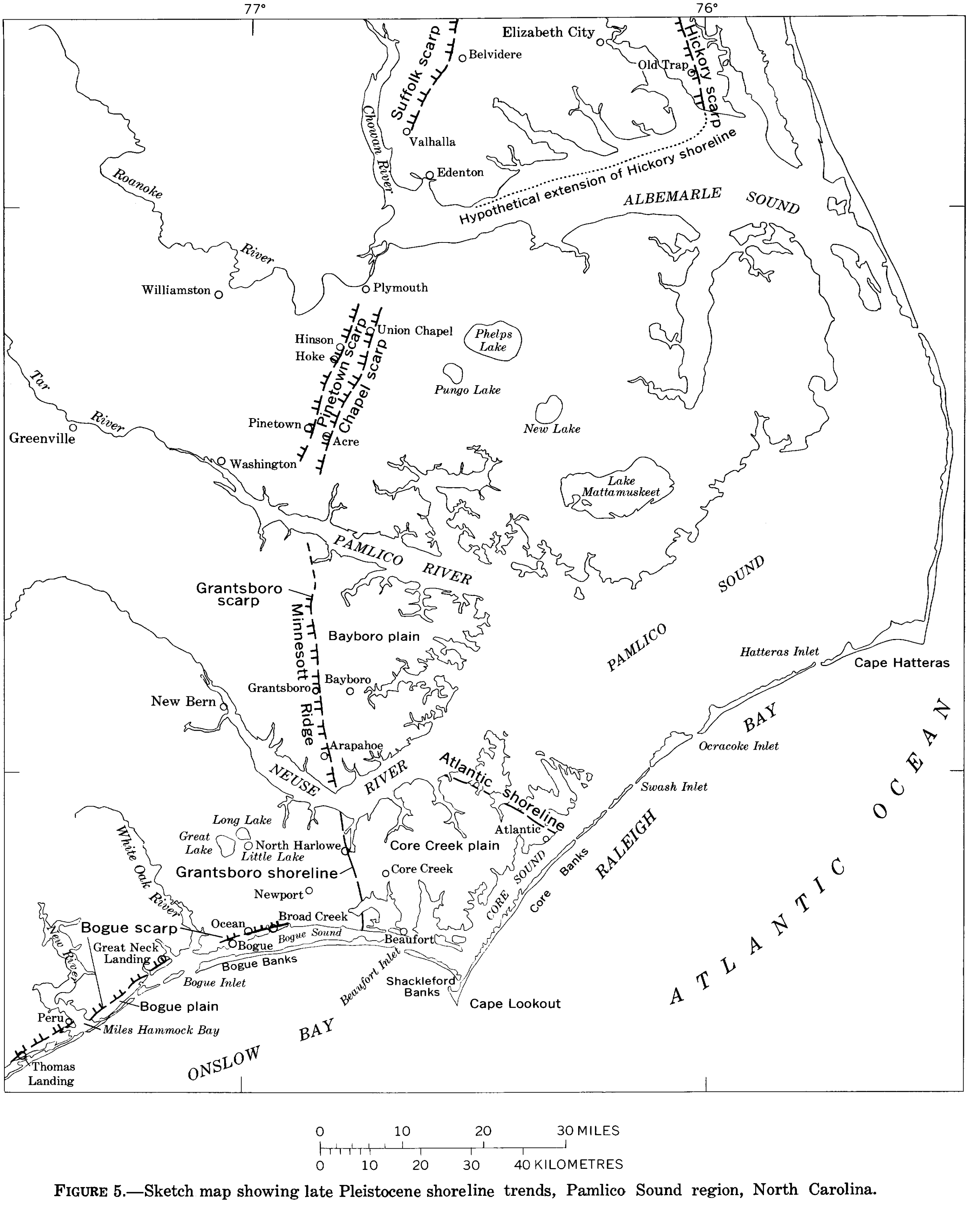

FIGURE 5.—Sketch map showing late Pleistocene shoreline trends, Pamlico Sound region, North Carolina.

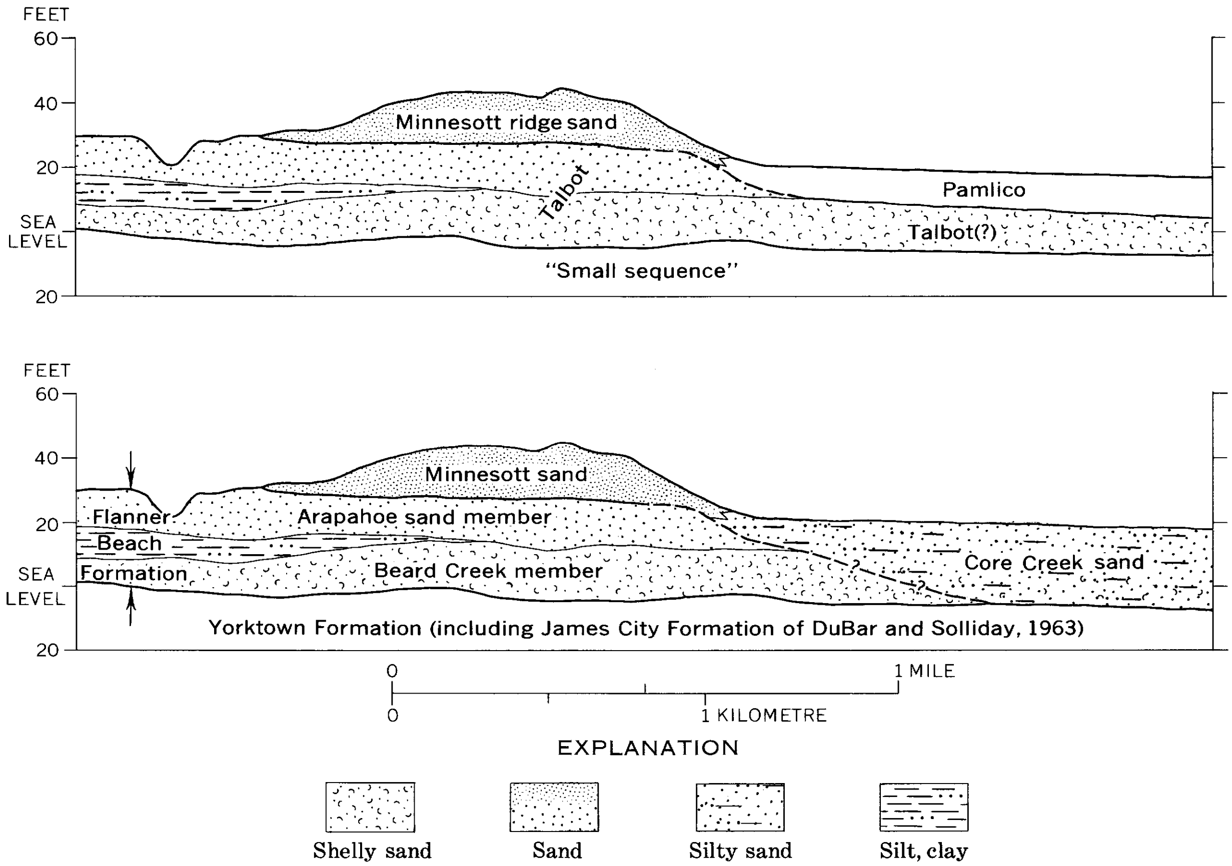

FIGURE 6.—Cross sections of Minnesott Ridge near Arapahoe, N.C. *Upper*, Interpretation modified from Daniels, Gamble, Wheeler, and Holzhey (1972, fig. 9). *Lower*, Alternative interpretation of stratigraphic units and modification of nomenclature as proposed in this report.

vironments, suggests some mechanical mixing of the faunal assemblage such as might have occurred in the outer part of a lagoon near an inlet through a barrier or at the mouth of the ancestral Neuse River estuary.

The thin western edge of the Arapahoe sand member is exposed in the bluffs west of the mouth of Beard Creek (loc. UB–1A, pl. 1). This locality was studied by Fallaw and Wheeler (1969, p. 41, 42), and the following section measured by them constitutes the type section of their Neuse Formation.

Surficials	*Thickness (feet)*
6. Fine-grained quartz sand; well-sorted unfossiliferous, light gray, loose	6.3
Unconformity	
Neuse Formation	
5. Clayey silt; very poorly sorted, very light gray, moderately indurated; shell layers up to 0.5 feet thick in the lower part; *Cyrtopleura* in living position; parting in some places	4.2
4. Fine-grained quartz sand; poorly sorted, yellowish-gray, poorly indurated; molds of fossils accentuated by limonite	1.4
Neuse Formation—Continued	
3. Very fine-grained quartz sand; poorly sorted, light olive-gray, poorly indurated; abundant fossils	1.8
2. Very fine-grained quartz sand; well-sorted, grayish-yellow, moderately indurated; a few fossils	3.2
1. Very fine-grained quartz sand; poorly sorted, light olive-gray, moderately indurated; a few round-quartz pebbles scattered throughout; many fossils; lower contact not visible	3.4
	20.3

The upper 6–8 feet (1.8–2.4 m) of the deposits (equivalent to unit 6 of Fallow and Wheeler) is the Arapahoe sand member of this report. These well-sorted pale-gray sands contain a few discontinuous thin beds and laminae of clay and abundant small branching burrows, indicating deposition in water where there was considerable animal activity. The contact between the Arapahoe sand member and the underlying clay-silt unit (unit 5 of Fallaw and Wheeler) is fairly abrupt but gradational. There is no evidence of an erosional break such as a scoured surface or pebble bed.

The Arapahoe sand member is similar lithically to the Newport sand member of western Carteret County. Like the Newport, it is conformable on highly fossiliferous Pleistocene marginal marine sands and overlaps or intertongues westward with clayey sands or clayey silts which appear to have been deposited mainly in brackish-water environments. It is tentatively interpreted as a complex of sands deposited in shoreface, beach, dune, back-dune flat, and tidal-delta environments of a barrier-island system north of an ancestral Neuse River estuary (fig. 4). The overlying Minnesott sand appears to comprise later beach and dune deposits, probably separated in time from the Arapahoe sand member by a regression and transgression of the sea; these deposits were plastered on the (eroded?) front and upper part of the old barrier complex.

BEARD CREEK MEMBER

The land area west and northwest of the Newport and Arapahoe sand members for a distance of several miles is a rather featureless flat plain ranging from 30 to 40 feet (9 to 12 m) in altitude. Within and west of the map area, this plain is segmented into broad poorly drained interfluves characterized by swamps and shallow lakes. The eastern part of the plain is continuous with a more dissected lowland extending southeastward from the Neuse River between the Newport and Arapahoe sand members to the Grantsboro shoreline (pl. 1 and fig. 5). Relatively undissected interfluves of this lowland, which coincides with the inferred course of the ancestral Neuse River (fig. 4), range from about 20 to 30 feet (6 to 9 m) in altitude.

The plain and dissected lowland described above are underlain by clayey and silty sand commonly interbedded with lesser amounts of clay and silt. These deposits, characterized by brackish or mixed brackish and normal marine faunal assemblages, interfinger laterally with the generally coarser grained, better sorted Arapahoe and Newport sand members. Thus, the fauna, lithology, and stratigraphic relationships of these deposits suggest that they constitute a backbarrier facies (deposited mainly in estuarine and lagoonal environments) which is correlative with the Newport and Arapahoe sand members. This facies of the Flanner Beach Formation, consisting mainly of poorly sorted sand, silt, and clay, is herein informally named the Beard Creek member after the excellent exposures in the bluffs on the Neuse River estuary just west of the mouth of Beard Creek in southernmost Pamlico County (locality UB–1A, pl. 1; see also Upper Broad Creek and Arapahoe 7½-minute topographic quadrangles).

The fossiliferous beds at the Beard Creek locality (units 1 through 5 of Fallaw and Wheeler) also constitute the type section of the Neuse Formation of Fallaw and Wheeler (1969) and Fallaw (1973). The "Neuse Formation" is not used in this report because as defined it would appear to include all the fossiliferous Pleistocene beds of the North Carolina Coastal Plain irrespective of their different lithologies and the possibility that these strata were deposited during several separate transgressive-regressive cycles.

The Beard Creek member comprises the lower 15–20 feet (4.5–6 m) of the section exposed in the bluffs west of the mouth of Beard Creek. The two main lithologies are: (1) medium- to thick-bedded clayey and silty sand containing abundant well-preserved mollusks (unit 1 through 4 of Fallaw and Wheeler, 1969), and (2) light- to medium-gray clayey silt and clay (unit 5 of Fallaw and Wheeler, 1969). The overall aspect of the molluscan assemblage (table 1) and an ostracode assemblage, dominated by *"Haplocytheridae" setipunctata* (Brady) and *"H." bradyi* Stephenson, suggests a restricted depositional environment perhaps similar to the outer part of Pamlico Sound and Core Sound today. However, the pelecypod *Anatina plicatella* Lamarck, known today only from open shelf waters, suggests that the beds containing this species may have been deposited in a more normal marine environment, perhaps an embayment open to the ocean.

Silty sands, clays, and silts of the Beard Creek member are also well-exposed in bluffs along the south side of the Neuse River estuary between Johnson Point and Slocum Creek. The classic exposures at and near Flanner Beach are among the most accessible outcrops and have been described in some detail by Berry (1926), Mansfield (1928), DuBar and Solliday (1963), and others. The sequence at this locality, penetrated by power-auger hole HL–1 (fig. 7 and pl. 1), consists from top to bottom of (1) 20–25 feet (6–7.5 m) of interbedded sand and clay with molds and casts of mollusks: (2) about 9 feet (2.7 m) of dark-gray sandy clay containing upright cypress stumps and fresh-water diatoms; (3) 11 feet (3.3 m) of unfossiliferous light- to medium-gray sand, (4) 9 feet (2.7 m) of bluish-gray clay containing abundant Pliocene mollusks and ostracodes, and (5) greenish-gray fine sand which appears to be typical of the Yorktown Formation in this area.

The bluish-gray clay (unit 4 above) is probably

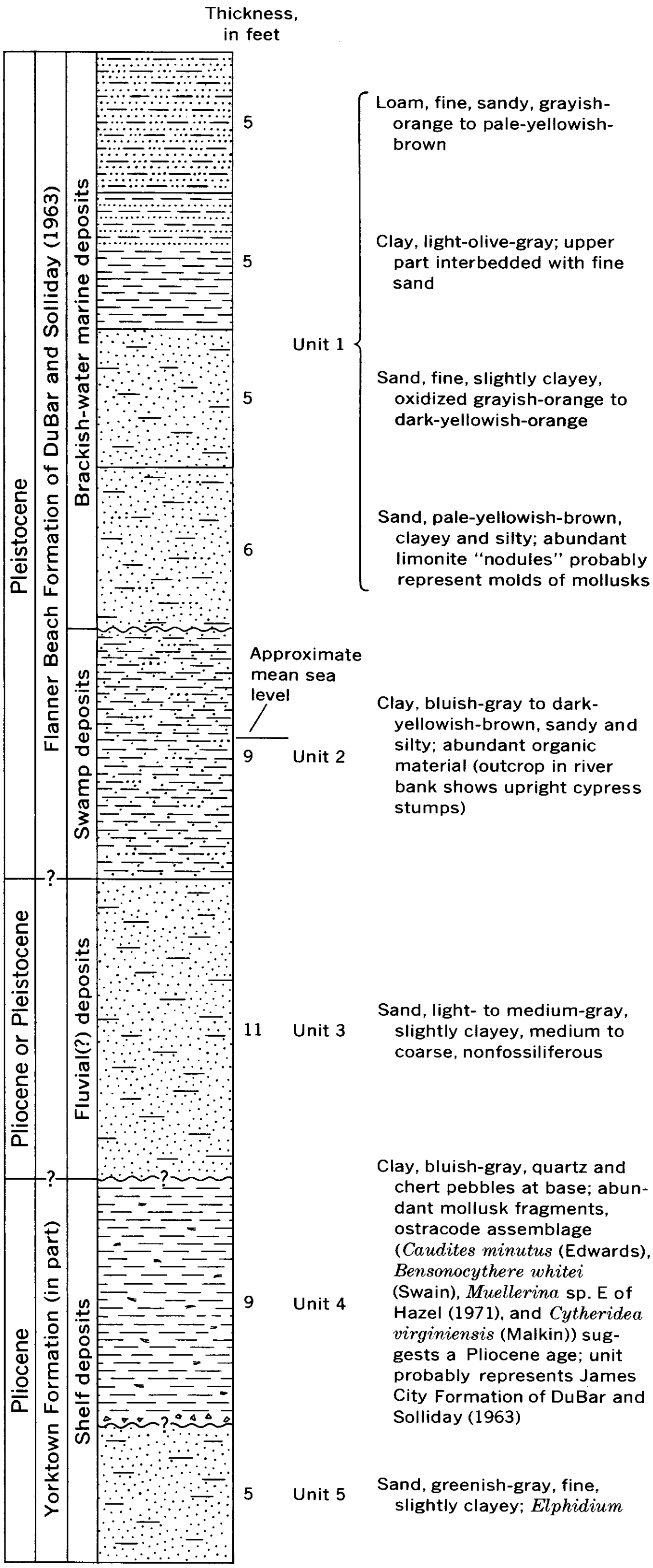

FIGURE 7.—Section of Flanner Beach Formation of DuBar and Solliday (1963) and underlying deposits in auger hole (site HL–1 on pl. 1) at Flanner Beach, Craven County, N.C.

correlative with the James City Formation of DuBar and Solliday (1963). Although the clay is included in the Yorktown Formation in this report, the pebble bed at its base suggests that it may be unconformable on the greenish-gray sand (unit 5). Hence, additional drilling in Craven and Carteret Counties may demonstrate that the James City beds are indeed separable from the Yorktown Formation and constitute a mappable rock-stratigraphic unit.

The upper 3 feet (90 cm) of the cypress stump bed (unit 2 above) crops out just above beach level; it is probably the oldest Pleistocene unit exposed within the map area. The cypress stump bed and the underlying barren sand (unit 3) appear to pinch out a short distance southeast of Flanner Beach where, according to Fallaw and Wheeler (1969, p. 51), the marine Pleistocene beds directly overlie the "Croatan Formation" [uppermost Yorktown Formation of this report]. Thus, the cypress stump bed and the underlying sand may be confined to a low in the pre-Pleistocene topography (fig. 4) which is interpreted to represent a Neuse River paleochannel. Such a relationship, in conjunction with the contained flora, would suggest that these strata represent swamp and fluvial deposits bordering an ancestral Neuse River. The swamp represented by the cypress stump bed probably existed early in the same interglacial period during which the overlying marine strata (unit 1 above) were deposited. Although DuBar and Solliday included the cypress stump bed in the Flanner Beach Formation, it and the underlying nonfossiliferous sand (unit 3) could be treated as a separate rock-stratigraphic unit.

The Pleistocene marine beds at this locality (unit 1 above) are well exposed in the Neuse River bluffs. At the base of the sequence is a thin bed of clayey sand containing abundant *Rangia cuneata,* a brackish-water bivalve. The overlying shell bed, characterized by *Dinocardium robustum,* is indicative of markedly higher salinities. Interbedded clayey sands and sandy clays above the *Rangia* and *Dinocardium* beds contain an abundant macrofauna (table 1) very similar to that of the shelly sands of the Beard Creek locality. It is notable that the fossil assemblages from the Flanner Beach and Beard Creek localities do not contain specimens of *Donax roemeri protracta* or *Spisula solidissima* which are characteristic of nearshore open-marine depositional environments.

The thickness of the Beard Creek member varies from about 15 feet (4.5 m) or less near the western edge of the map area to 50 feet (15 m) or more along the axis of a broad low in the pre-Quaternary surface, as shown by a contour map constructed on the base of the Quaternary deposits (fig. 4). A maximum thickness of about 65 feet (19.5 m) is indicated by the log of a water well on the Cherry Point Marine Corps Air Station, but this may be excessive and should be verified by other drilling. The low extends southeastward from the vicinity of Flanner Beach to a point east of Havelock where it curves southward toward Mansfield and Morehead City. The trend is toward Cape Lookout, but control is too sparse to delineate its exact course in that area. The dimensions of this feature, the divergence of its northern end from the present course of the Neuse River, and its position between the Newport and Arapahoe barrier sands strongly suggest that it represents a channel occupied by the ancestral Neuse River.

SANGAMON(?) TO WISCONSINAN COASTAL AND FLUVIAL DEPOSITS

A broad Coastal Plain lowland, bordered on the west by the Suffolk scarp and by equivalent or younger scarps along the same trend to the south (fig. 5), extends from the vicinity of Cape Lookout northward into Virginia as far as Chesapeake Bay. This lowland is nearly 60 miles (96 km) wide at its widest point in northeastern North Carolina. Surface altitudes range from sea level to a maximum of 25 feet (7.5 m) at the toe of the Suffolk scarp. Three major easterly drainage systems, Albemarle Sound and the Pamlico and Neuse River estuaries, divide the lowland into four segments. The segment south of the Neuse River and a small part of the segment between the Neuse and Pamlico estuaries are included in the Cape Lookout map area. For convenience these two segments are referred to in this report as the Bayboro and Core Creek plains.

Surficial Pleistocene deposits underlying the extensive lowland described above correspond to the marine part of Stephenson's Pamlico Formation (Stephenson, 1912, p. 286). The higher "terrace plain" and deposits to the west constitute Stephenson's Chowan terrace plain and Chowan Formation. Stephenson's map of the terrace formations in North Carolina (1912, pl. 13; this report, fig. 2) shows reentrants of the Pamlico Formation, consisting of fluvial and estuarine deposits, extending into the Chowan Formation outcrop area for long distances along the principal river valleys.

Later, Wentworth (1930), in a study of the Quaternary deposits of the Virginia Coastal Plain, subdivided Stephenson's Pamlico Formation into the Princess Anne and Dismal Swamp Formations. Surface altitudes of the corresponding terrace plains which defined these formations range from sea level to about 15 feet (4.5 m) and from 10 to 25 feet (3 to 7.5 m), respectively (Wentworth, 1930, fig. 24). Hence, most of the surficial deposits in the Cape Lookout map area east of the Grantsboro scarp, if mapped according to Wentworth's concepts, would be assignable to the Princess Anne Formation. However, recent workers in Virginia have objected to use of the name "Princess Anne" in either a stratigraphic or geomorphologic sense as defined by Wentworth, proposing instead map units based strictly on lithology (Oaks, 1964; Coch, 1968, 1971).

CORE CREEK SAND

The Core Creek plain is a gently undulating surface, ranging in altitude from sea level to about 18 feet (5.4 m), which extends northeastward from the Grantsboro shoreline to a complex of sand ridges in the vicinity of Atlantic (pl. 1). The outer parts of the plain are dissected by minor streams that deposit sediment loads directly into adjacent estuaries, bays, and sounds. Several large areas in the central part of the plain are undissected and are characterized by swamps and poorly drained soils rich in organic matter. The Bayboro plain, north of the Neuse River, is similar but merges eastward almost imperceptibly with salt marshes bordering Pamlico Sound. No Carolina Bays occur on these surfaces.

Exposures of the sediments underlying the Core Creek and Bayboro plains are very limited but show a variety of lithologies and sedimentary structures. Coarse crossbedded well-sorted sand cropping out at the base of low bluffs along the Neuse estuary near Pierson Point, about 2 miles (3.2 km) east-northeast of Minnesott Beach, is suggestive of high-energy depositional environments such as tidal deltas or the surf zone. Abundant fine to very fine quartz and chert pebbles on the present beach bordering these exposures are probably eroded from a coarser stratum just below sea level. About 2 miles (3.2 km) northeastward, between Dawson Creek and Daniels Point (see Merrimon 7½-minute quadrangle), low wave-cut cliffs expose thin horizontally bedded sands and pebbly sands interbedded with very thin clays. These sediments were deposited in quieter water, possibly on tidal flats or on the shelf farther offshore than the coarse sands at Pierson Point. Low banks along the Adams Creek Canal of the Intercoastal Waterway, north of the community of Core Creek, expose well-sorted fine to medium sand interbedded with thin clays; much of the sand above the water table appears to have been leached white. Crossbedded sand units as much as 8 inches (20 cm) thick, which include clay laminae as crossbeds, are suggested of tidal-flat deposits.

Drill samples and spoil from deep drainage ditches and canals indicate that the surficial beds are underlain by fossiliferous silty and clayey sand. Macrofossil collections from spoil at two localities on the Core Creek plain are tabulated in table 1 (see pl. 1 for locations). Locality CC–1 is a spoil bank on the east side of the Adams Creek Canal. The Mansfield station 10892 (Mansfield, 1928, p. 135) is described as spoil from drainage ditches at an "Open land project about 10 miles northwest of Beaufort." However, the locality card with the collection in the U.S. National Museum lists the location as 10 miles (16 km) *northeast* of Beaufort. The latter location, which coincides with a network of drainage canals in the Open Grounds (a local term applied to extensive reedland) shown in detail on the Williston 7½-minute quadrangle, fits the locality data best. The plot on the geologic map should be considered as an approximate location. For purposes of this report, Mansfield's collection was reexamined so that current taxonomic nomenclature might be used in table 1. Very abundant *Donax roemeri protracta* along with some *Spisula solidissima* in the collections from these localities suggest that much of the fossiliferous clayey sand in the shallow subsurface in this area was deposited nearshore in shallow water of normal salinity (see also, Fallaw, 1973, p. 261). On the other hand, north of the map area near Bayboro (fig. 1), abundant brackish-water oysters (*Crassostrea virginica*) are reported. Their presence suggests that backbarrier deposits, as well as very nearshore marine and barrier deposits, may compose an appreciable part of the sediments underlying the Core Creek and Bayboro plains.

The dominantly silty and clayey fossiliferous sands described above are herein informally called the Core Creek sand. This unit, approximately 30 feet (9 m) thick near the community of Core Creek (auger hole CC–2, see fig. 8 and pl. 1) appears to thin westward toward the Grantsboro shoreline and is inferred to be correlative, at least in part, with the Minnesott sand. The unit appears to thicken to the east and southeast and may be 50–60 feet thick (15–18 m) in southeastern Carteret County. At Core Creek, the Core Creek sand is unconformable on green clayey sand of Pliocene age (J. E. Hazel, written commun., 1971) which is here included in the Yorktown Formation. Elsewhere the base of the unit has not been defined.

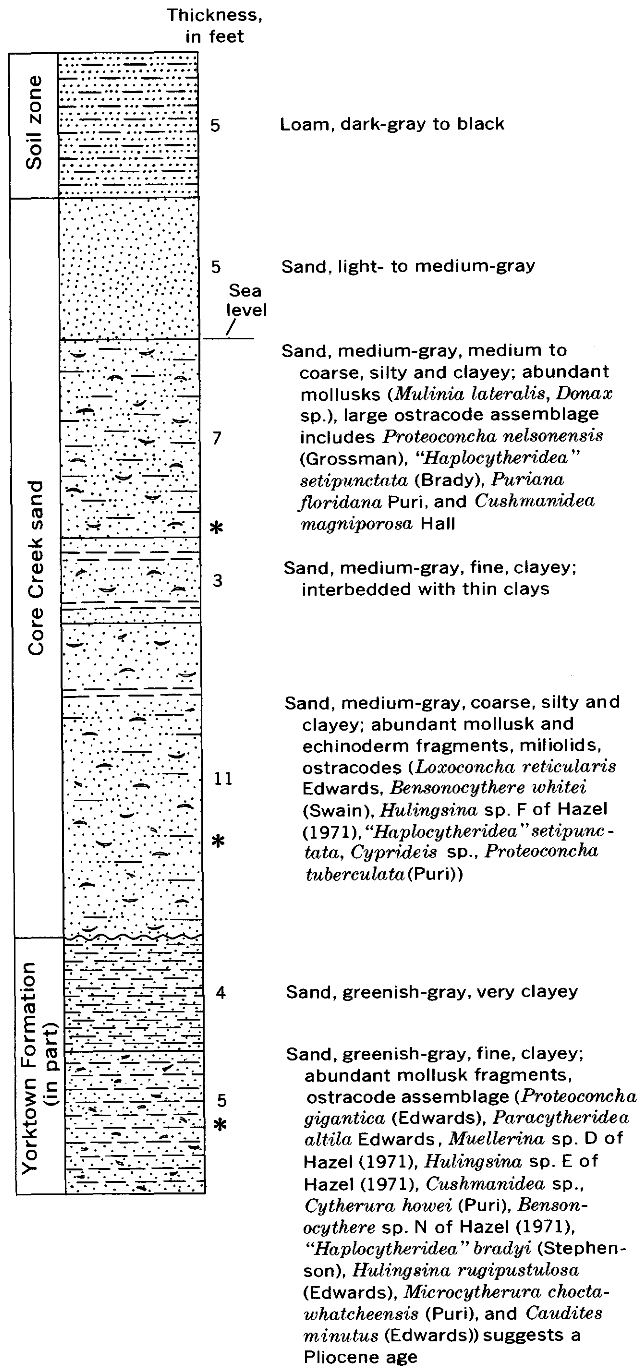

FIGURE 8.—Section of Core Creek sand and uppermost part of Yorktown Formation in auger hole (site CC–2 on pl. 1) 2.1 miles north of the community of Core Creek, Carteret County, N.C. Asterisk shows location of fossil identication sample.

The Core Creek sand seems to be at least partly correlative with the Sand Bridge Formation of the Norfolk, Va., area which was defined by Oaks and Coch (1963) and later mapped in considerable detail by Coch (1968, 1971). According to Shideler, Swift, Johnson, and Holliday (1972, p. 1796) "tentative thorium-ionium dates indicate an age of 50,000 to 75,000 years B.P. (N. K. Coch, 1970, personal commun.)" for the Sand Bridge Formation. Thus, if these dates are accurate, the Sand Bridge Formation and apparently correlative sediments such as the Core Creek sand must have been deposited during early Wisconsin and, possibly, late Sangamon time.

ATLANTIC, CEDAR ISLAND, AND NORTH BAY SANDS

Between the Core Creek plain and Pamlico Sound are two roughly triangular sandy land areas characterized by northwest-trending sand ridges and rounded or elliptical shallow depressions (figs. 9 and 10). Both areas are about 4 by 7 miles (6.4 by 11.2 km) in maximum dimension and both are elongate to the northwest. The southwestern ridge complex, which is adjacent to a low-lying, swampy part of the Core Creek plain, is separated from the other ridge complex by a 5-mile-wide (8 km) belt of salt marsh, shallow bays, and low sand flats. The surface of the southwestern ridge complex averages 10–15 feet (3–4.5 m) in altitude but ranges from sea level to a maximum of 20 feet (6 m) along the ridge crests. The northeastern ridge complex is lower, averaging only 5–10 feet (1.5–3 m) in altitude.

The sediment underlying the two ridge complexes, to a depth of 10–15 feet (3–4.5 m) below sea level, is very pale gray to light-greenish-gray, fine to medium quartz sand which is generally well sorted and nonfossiliferous. Much of the sand at and just above the water table is stained brown by organic colloids (humate of Swanson and Palacas, 1965). Both rounded and elliptical depressions at the surface of the sand are commonly filled with thin peat or silt rich in organic matter. In the subsurface the well-sorted sands overlie silty and clayey sands containing an abundant macrofauna dominated by *Mulinia lateralis* and, at least locally, *Crassostrea virginica*. Laterally they appear to interfinger with finer sediments which underlie the adjacent flats. These stratigraphic relationships, together with the lithology and surface topography, suggest that the well-sorted nonfossiliferous sands represent barrier deposits (probably, at least in part, of estuarine origin, see also p. 6) and that the surficial sand ridges are beach ridges.

The southwestern beach ridge complex described above, which was probably formed during the late Pleistocene, is herein called the Atlantic barrier after the small town of Atlantic at its southeastern edge. The underlying clean quartz sands are informally named the Atlantic sand. (See pl. 1, unit Qas.) The northeastern beach ridge complex may be divided into two parts: (1) an older (probably latest Pleistocene) part to the southwest, herein called the Cedar Island barrier; and (2) a Holocene beach and dune ridge to the northeast, referred to as the North Bay barrier. The sands underlying the northeastern ridge complex are mapped as the Cedar Island sand (well-sorted sand facies, unit Qci_1) and the North Bay sand (units Qns and Qnb).

Silty sands and muds directly underlying the salt marsh and sand flats between the Cedar Island and Atlantic sand ridge complexes are mapped as the silty sand facies of the Cedar Island sand (unit Qci_2, pl. 1). This sequence is known only from a few bore holes and spoil piles; hence, several interpretations of its age and stratigraphic relationships are possible (see Fisher, 1967, p. 209–216; Pierce and Colquhoun, 1970b, p. 3704–3705). We believe that the lower and middle parts of this sequence are of late Pleistocene age and are correlative, in part, with the clean well-sorted sand facies of the Cedar Island sand to the northeast (pl. 1, sec. *B–B′*). The uppermost part of the sequence is a thin veneer of Holocene marsh deposits mapped elsewhere as Qbm but here lumped for convenience with the Cedar Island silty sand facies.

The North Bay barrier is a present-day estuarine barrier at the southwestern extremity of Pamlico Sound (fig. 10). The barrier includes a beach and dune ridge, small but distinct tidal inlets and deltas, and washover fans. At one or more points the barrier impinges against remnants of the Pleistocene Cedar Island barrier; elsewhere these features are separated by shallow "backbarrier" bays or marsh. The North Bay barrier trends west-northwest, perpendicular to prevailing winds blowing from the north and northeast across the widest expanse of Pamlico Sound (fig. 11). The sandy barrier deposits are probably derived in part from Holocene Pamlico Sound bottom sediments and in part from sediment reworked from the northeastern edge of the Pleistocene Cedar Island barrier. Southward hooked ends of several sandy shoals which project eastward from the southwestern margin of Cedar Island Bay (fig. 10) suggest intermittent movement of strong tidal currents or storm-driven "surges" from Pamlico Sound southward through inlets in the North Bay barrier into Cedar Island Bay and Core Sound. Thus, Cedar Island Bay may be largely an erosional feature carved from the Cedar Island barrier in the Holocene by storm waves and currents.

The sand ridges forming the Cedar Island ridge complex are very similar in dimensions and trend to the modern North Bay barrier. Therefore, they may also have formed as estuarine beach ridges that fronted an ancestral "Pamlico Sound" or similar body of water which existed during the last high stand of the sea in the Pleistocene. According to this interpretation, the wide expanse of salt marsh southwest of Cedar Island would represent a latest Pleistocene backbarrier flat which formed at the same time as the Cedar Island beach ridges. Re-

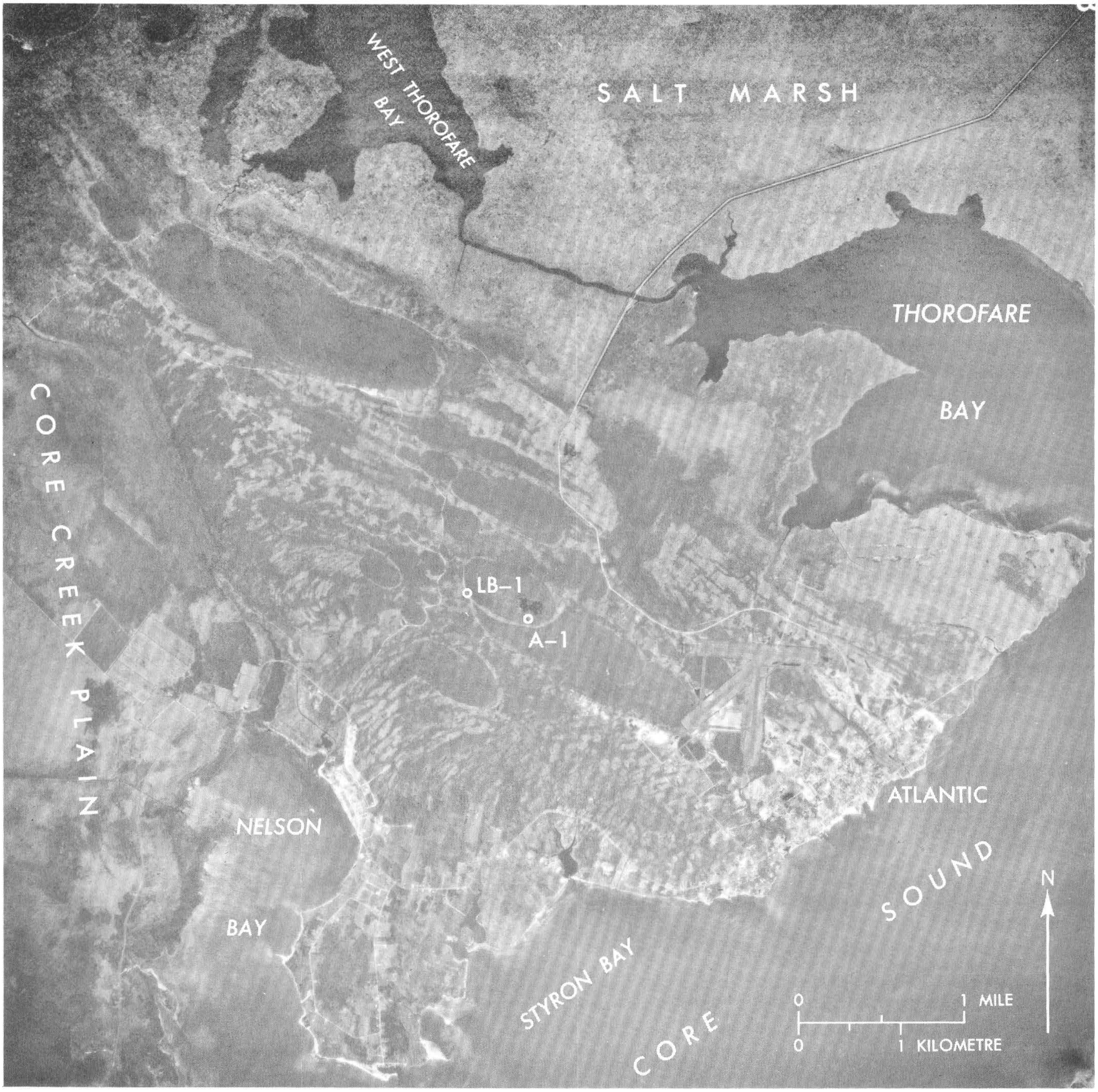

FIGURE 9.—Triangular ridge complex underlain by well-sorted quartz sand northwest of Atlantic, Carteret County, N.C. The ridge complex is inferred to represent a Pleistocene estuarine barrier (the Atlantic barrier) at the southwestern extremity of an ancestral Pamlico Sound or similar body of water. Light-gray stripes trending northwest through central part of the photograph are beach ridges 10–15 feet (3–4.5 m) higher than sea level salt marsh and sand flats adjacent to the northeast. Arcuate northeast-trending ridges constitute southwestern part of ridge complex. Dark-gray elliptical areas with light-gray sand rims (central part of photograph) are Carolina Bays. Northeastern part of Core Creek plain (west of ridge complex) is a flat 4–8 feet (1.2–2.4 m) above sea level. Localities A–1 and LB–1 are sites of auger holes from which peat and shell yielding radiocarbon ages were obtained (table 2). Photograph by U.S. Geological Survey, 1964.

FIGURE 10.—North Bay and Cedar Island barriers, Carteret County, N.C. North Bay barrier is a present-day estuarine barrier at southern end of Pamlico Sound; note small-scale barrier inlets, tidal deltas, and washover fans. Cedar Island barrier is a latest Pleistocene beach-ridge complex; note northwest-trending light-gray sand ridges and dark-gray elliptical depressions. Circles show sites of auger holes from which radiocarbon ages (table 2) were obtained. Photograph by U.S. Geological Survey, 1964.

flooding of the Pleistocene surface by the present Holocene transgression has resulted in deposition of a thin veneer of Holocene marsh deposits on top of the older Pleistocene backbarrier sediments.

Elliptical depressions on the Cedar Island barrier surface tend to be alined in rows parallel or subparallel to the grain of the beach-ridge topography; long axes of the ellipses also parallel the beach ridges (fig. 10). It is not clear whether the depressions originated as oriented lakes on a subaerially exposed surface or as narrow segmented lagoons (Zenkovich, 1967). A carbon-14 date of 24,750 ± 700 years B.P. obtained from material at the base of a peat bed in a small depression on the central part of the Cedar Island barrier (locality A–4, table 2) indicates that the barrier is a Pleistocene feature. Because of the possibility that the material is contaminated by ground water containing younger organic colloids, the 24,750 date is considered to provide a minimum age for the lower part of the peat bed. A carbon-14 date of greater than 40,000 years B.P. was obtained from shell material from a fossiliferous bed directly underlying the well-sorted sand facies of the Cedar Island sand (locality A–3, table 2).

Both the triangular outline of the Cedar Island-North Bay ridge complex and the northwest trend of the beach ridges appear to be directly related to the position of the ridge complex respective to adjacent water bodies and the erosional and constructional processes resulting from waves and tidal currents generated by winds acting on these bodies of water. Present-day winds in this region, as shown by a wind rose for the Cherry Point area (fig. 11), blow principally from the southwest and from the north and northeast. In the following discussion it is tentatively assumed that in this region wind directions during the last high stand of the Pleistocene sea were similar to present-day wind directions.

The configuration of the northeastern side of the Cedar Island–North Bay ridge complex appears to be due mainly to constructional processes in latest Pleistocene and Holocene time which have resulted in accretion of beach ridges essentially perpendicular to prevailing winds from the north and northeast blowing across a wide expanse of water. Erosive processes on the northeast side, except in the Cedar Island Bay area, have been subordinate. The irregular southwestern edge of the ridge complex, bordered by a wide sand beach (fig. 10), appears to be a regressing shoreline reflecting wave erosion in the Holocene perpendicular to southwesterly prevailing winds blowing across West Bay. The southeastern side of the triangular-shaped barrier complex bordering Core Sound also appears to have been subjected to wave erosion in the Holocene but to a lesser degree than the southwestern side and that part of the northeastern side fronting Cedar Island Bay.

The triangular configuration of the Atlantic ridge complex and the northwest alinement of its most prominent surface features are strikingly similar to the arrangement of these features on the Cedar Island and North Bay ridge complex to the northeast. Probably during its development this land area was similarly situated with regard to extensive bodies of water and probably prevailing wind directions were essentially the same as those that shaped the Cedar Island and North Bay barriers. Very low arcuate sand ridges in the southwestern part of the Atlantic ridge complex (or barrier, fig. 9) trend northeast; arcs are convex to the northwest. These ridges differ markedly in trend from the more conspicuous ridges to the north and northeast. The ridge pattern and the relationship of the ridges to adjacent land areas are somewhat similar to those of beach ridges formed near and at the mouths of small bays bordering the Bering Sea (Zenkovich, 1967, fig. 230) and in river embayments in New South Wales, Australia (Thom, 1965, fig. 2 and pl. 3). The low relief of the arcuate ridge set and its northwestward convexity would be consistent with formation by relatively weak winds and waves acting from the southeast (fig. 11) across a restricted body of water—perhaps a lagoon similar to the present-day Core Sound. Carbon-14 dates of 18,460 ± 400 years B.P. from the peat fill of the large Carolina Bay near the center of the Atlantic barrier and greater than 38,000 years B.P. from a shell bed directly underlying the Atlantic sand (localities A–1 and LB–1, table 2) indicate that the sand-ridge complex was constructed before the last major transgression of the sea, which began about 18,000 to 15,000 years ago.

According to Pierce and Colquhoun (1970b, figs. 4 and 5), the upper 10 feet (3 m) of section penetrated by a borehole at the southwestern edge of the Atlantic barrier consists of lagoonal sediments. This section suggests to us that the flat featureless surface of a 4-to-5 mile (6.4–8 km)-wide strip of the Core Creek plain adjacent to the southwest, averaging 4–8 feet (1.2–2.4 m) above sea level, may be a backbarrier flat associated with the Atlantic beach-ridge complex (fig. 9). Because of lack of subsurface control, these deposits were not differentiated on the geologic map accompanying this report but are included with the Core Creek sand.

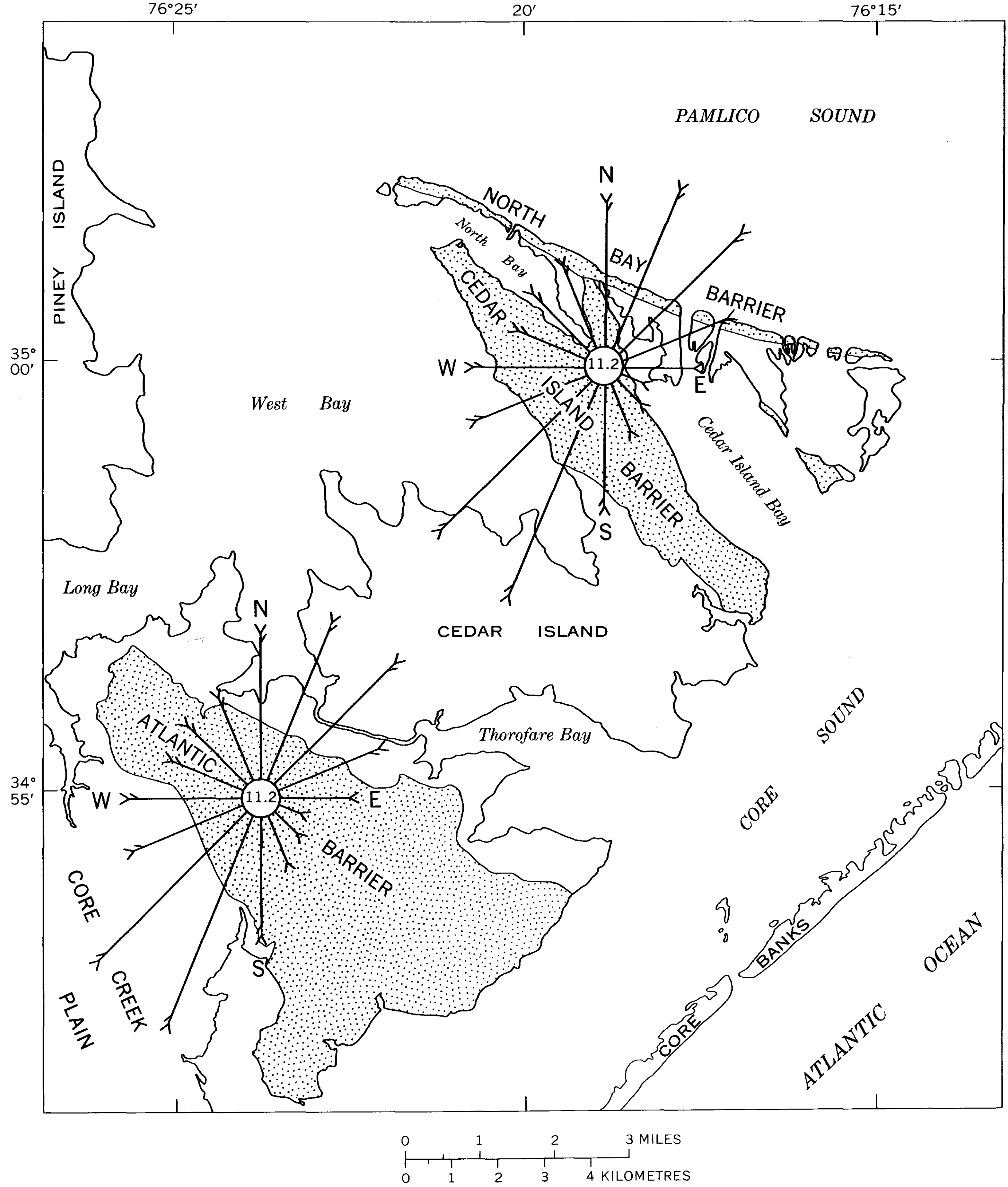

FIGURE 11.—Sketch map showing the relationship between principal wind directions and triangular configuration of the Atlantic and Cedar Island–North Bay barriers. The wind rose was constructed from data compiled for the Cherry Point Marine Corps Air Station (southern Craven County) by the U.S. Naval Weather Service Command. Line length is proportional to percentage frequency of wind direction. Figure in circle is percentage frequency of calm. Feathers show mean wind speed in increments of 3 knots.

TABLE 2.—*Radiocarbon ages, Continental Shelf and outer Coastal Plain, Cape Lookout area, North Carolina*

Lithic unit	Location	Locality No.	Altitude or depth of sample (ft)	Material	Age (years B.P.)	Source (Numbers prefaced by "W" refer to U.S. Geol. Survey Radiocarbon Laboratory
Shell bed below the Atlantic sand (Qas).	2.6 miles WNW of Atlantic.	LB–1	–7 to –9	Shell	>38,000	W–2600
Carolina Bay fill on Atlantic barrier complex.	2.1 miles WNW of Atlantic.	A–1	11.0 to 12.5	Peat	18,460±400	W–2601
Shell bed below well-sorted sand facies of Cedar Island sand (Qci) in unit Qci_2.	0.45 miles S. of Roe School.	A–3	–9 to –10	Shell	>40,000	W–2611
Base of peat fill in depression on Cedar Island barrier.	Road junction 0.4 miles SW. of Roe School site.	A–4	3 to 4	Peat	24,750±700	W–2629
Shell bed between Cedar Island and North Bay barriers in unit Qci_2.	0.25 miles SW. of Cedar Island Ferry Landing.	NB–1	–6 to –11	Shell	>38,000	W–2628
Shell bed below well-sorted sand facies of Beaufort sand (Qbf_1) in unit Qbf_2.	Approximately 0.5 miles S. of highway bridge over the straits.	H–1	–10 to –15	Shell	>45,000	W–2612
Shell bed below Outer Banks sand (Qob) in unit Qb.	Fort Macon State Park on Boque Banks.	B–1	MSL to –2	Shell	7,070±250	W–2627
Qa	Continental shelf edge 34°06.5′N. 76°15.5′W.	7845	–245	Calcareous sandstone	13,500±230	Macintyre and Milliman, 1970.
Qa	Continental shelf edge 33°58.58.4′N. 76°22.4′W.	8200	–320 to –360	Calcareous sandstone	15,180±280	Do.
				Algal limestone	12,270±190	Do.
Qoc	Central shelf 34°12.4′N. 76°42.3′W.	L–40	–92	Ooliths	29,100 $^{+1,400}_{-1,750}$	Terlecky, 1967.
Qoc	Central shelf 34°09.1′N. 76°44.0′W.	WHOI–1847	–110	Total oolith	25,450±850	Milliman, Pilkey, and Blackwelder 1968.
				Outer part of oolith	27,650 $^{+1,050}_{-950}$	Do.

BOGUE SAND

The Newport sand member is bounded on the south by a highly dissected scarp and plain, herein named the Bogue scarp and Bogue plain after the community of Bogue which is just west of the Cape Lookout map area (figs. 1, 5). The scarp can be easily traced on 5-foot-contour-interval maps from its northeastern terminus at Broad Creek southwestward through Ocean, Bogue, Great Neck Landing, and from just east of Peru to just west of Thomas Landing (shown as Tar Landing on the Spicer Bay 7½-minute quadrangle), a distance of approximately 40 miles (64 km). It probably extends farther southwest, but suitable topographic maps of that area are not available, and time limitations did not permit a field check.

The scarp is broken and offset at major drainages such as the White Oak and New Rivers; the Great Neck Landing-Miles Hammock Bay and Peru-Thomas Landing segments are much more distinct (that is, less dissected) than the segment east of the White Oak River. Relief on the scarp averages 15–20 feet (4.5–6 m). The toe altitude is slightly less than 20 feet in the Thomas Landing-Peru segment and slightly more than 20 feet to the northeast.

Between the Bogue scarp on the northwest and the Holocene lagoon-barrier complex on the southeast are narrow highly dissected remnants, as much as 1½ miles (2.4 km) wide, of the Bogue plain. Surface altitudes range from sea level to more than 25 feet (7.5 m) but probably average about 15–20 feet (4.5–6 m). A narrow sliver of this plain, as much as 1 mile (1.6 km) wide at Ocean, extends into the map area to the vicinity of Broad Creek, where it is truncated by a younger scarp which is the present mainland shoreline of Bogue Sound. Although sediments underlying the Bogue plain are very poorly exposed, soil types shown on the Carteret County soils map suggest that the dominant lithology is sand. The Newport barrier and the bordering Bogue scarp and plain may represent: (1) a natural profile, including barrier, shoreface, and shelf plain; or (2) two features, barrier and shelf plain, of different ages, separated by an erosional scarp.

BEAUFORT SAND

A broad discontinuous sand ridge (see pl. 1), ½-mile to ¾-mile (0.8–1.2 km) wide, arcs east-southeastward for 13 miles (20.8 km) from the projected juncture, near Morehead City, of two prominent older Pleistocene shorelines (Grantsboro and Bogue). This feature, herein called the Beaufort ridge, probably extended farther southeast but has been "chopped off" by later marine erosion. Altitudes along the ridge crest average 10–15 feet (3–4.5 m) above mean sea level but reach a maximum of 20–25 feet (6–7.5 m). Although the ridge is interpreted to represent a relict barrier island, no ridge-and-runnel topography suggestive of beach ridges is preserved, perhaps in part because of the relatively intense urbanization of the area. (Beaufort and Morehead City and the communities of Lenoxville and Harkers Island are population centers along the ridge.) Elliptical surface features on the northernmost part of Harkers Island and nearby Browns Island are reminiscent of segmented lagoons (Zenkovich, 1967, p. 516–522). These features may represent remnants of a backbarrier flat which was associated with the formation of the inferred Beaufort barrier and which was subsequently partly submerged during the Holocene marine transgression.

The Beaufort ridge is underlain by well-sorted nonfossiliferous light-gray to yellowish-gray quartz sand 20–30 feet (6–9 m) thick. This sand appears to be continuous with similar sands extending westward from Morehead City as a thin discontinuous blanket overlapping the seaward edge of the Flanner Beach Formation outcrop. These well-sorted sandy sediments and associated silty and clayey sands described below are informally named the Beaufort sand (see pl. 1, units Qbf_1 and Qbf_2). As exposures are very poor, the distribution of this unit on the geologic map is based in large part on topography and the soils map of Carteret County (Perkins and others, 1938).

The nature of the sediments underlying the well-sorted quartz sand facies of the Beaufort sand is poorly known except at the northwest end of Harkers Island. Here a power-auger hole penetrated about 20 feet (6 m) of the well-sorted unfossiliferous Beaufort sand apparently conformable on very shelly sand at a depth of 10 feet (3 m) below mean sea level. The upper 5 feet (1.5 m) of the shelly sand, at 10–15 feet (3–4.5 m) below sea level, contained a molluscan fauna dominated by *Mulinia lateralis* (Say). The samples contained no *Spisula* and only one *Donax*. The foraminiferal and ostracode assemblages (*Elphidium clavatum, Ammonia beccarii, "Haplocytheridea" setipunctata, "Haplocytheridea" bradyi, Hulingsina americana* of Valentine (1971)) are more suggestive of a backbarrier than an offshore marine environment. The next samples studied, at about 25 feet (7.5 m) below sea level and deeper, contained more diverse foraminiferal and ostracode assemblages, suggesting a very shallow offshore marine environment, possibly close to a barrier inlet. Thus, at this locality, the section appears to consist, from the bottom up, of a conformable sequence of offshore marine, backbarrier, and barrier deposits.

A carbon-14 date of >45,000 years B.P. (see table 2, locality H–1) indicates that the uppermost part of the shelly sand described above is Pleistocene rather than Holocene as proposed by Pierce and Colquhoun (1970b, p. 3705, fig. 5). If the shelly sand and the overlying well-sorted quartz sand represent a conformable sequence, as appears to be the case, then the entire unit is Pleistocene.

NEUSE RIVER TERRACE DEPOSITS

Adjacent to the Cape Lookout map area, to the north, a low plain extends northeastward from the upper Neuse River estuary for 4 or 5 miles (6.4 or 8 km). The average altitude is 5–10 feet (1.5–3 m) above mean sea level; the range is sea level to a maximum of 15–20 feet (4.5–6 m) along crests of ridges and other irregular topographic highs. The most prominent surface features are Carolina Bays. The northeastern edge of the plain is commonly bounded by a scarp 15–20 feet (4.5–6 m) high; the toe of the scarp is about 10 feet (3 m) in altitude. Along much of its southwestern edge, the plain merges imperceptibly with brackish-water marshland bordering the Neuse River estuary. Soil types shown on the Craven County and Pamlico County soil maps (Jurney and others, 1929; Miller and Taylor, 1937) suggest that at least the uppermost sediments underlying the plain are mainly sand. The narrow southeasternmost part of the plain and its bordering scarp are included in the Cape Lookout map area.

UPPER WISCONSINAN AND HOLOCENE(?) CALCAREOUS SHELF DEPOSITS

Well-indurated calcareous deposits, in part covered by thin terrigenous sand and silt, form the surficial and near-surface deposits of a considerable part of the submerged shelf. Oolitic calcarenite and coquina, which are restricted to the Onslow Bay shelf area, probably reflect a much lower rate of terrigenous sedimentation in this area than in the Raleigh Bay shelf area. Algal limestone and calcareous sandstone crop out in a distinct band along the shelf break on both the Onslow Bay and Raleigh Bay shelf segments. All these sediments appear to have been deposited in shallow water during the late Pleistocene and, possibly, early Holocene.

OOLITIC CALCARENITE

Light-brown, yellowish-brown, and brownish-gray oolitic calcarenite is exposed in the central and outer parts of the Onslow Bay shelf (Qoc on pl. 1). Dredge hauls containing samples of this rock type also commonly include fragments of rock from the Yorktown Formation, suggesting that the calcarenite is a thin veneer overlying the Yorktown. Before the discovery of the calcarenite, abundant ooids had been observed in the unconsolidated sediments of the Onslow Bay floor (Terlecky, 1967; Milliman and others, 1968; Pilkey and others, 1969). The calcarenite and the associated unconsolidated sediments appear to constitute the most oolitic deposits on the Atlantic shelf north of Cape Kennedy.

The calcarenite consists mainly of ooids cemented in a dense chalky microcrystalline matrix. Coarse calcareous skeletal fragments are present but generally constitute less than 5 percent of the rock volume. Ooid nuclei are dominantly quartz grains but include Foraminifera tests, small gastropods, unidentifiable calcareous fragmental material, and fecal pellets. The rock matrix is high-magnesium calcite, indicating subaqueous cementation. No evidence of ooid recrystallization was observed in the calcarenites or the unconsolidated oolitic sediments.

Six radiocarbon dates, ranging from 29,000 to 22,630 years B.P. have been obtained from ooids from the unconsolidated surficial sediments on the North Carolina shelf. Three of the dated samples are from within the bounds of the Cape Lookout map area and are listed in table 2. Assuming that these ooids were derived from weathering and (or) erosion of the oolitic calcarenite, we infer that the calcarenite was deposited during the latest Pleistocene regression of the sea. However, such an origin might imply subaerial weathering of the calcarenite for several thousands of years on the exposed shelf and raise the question of lack of alteration of the unstable aragonitic ooids and very unstable high-magnesium calcite matrix material. Perhaps the thin calcarenite was protected by fine-grained relatively impermeable lagoonal or salt-marsh deposits which were removed by erosion during the last marine transgression. Also, cementation of the calcarenite by the unstable calcite may not have occurred until some time during the last transgression.

According to Milliman, Pilkey, and Blackwelder (1968), oxygen-isotope ratios from ooids separated from the unconsolidated sediment in Onslow Bay suggest that the ooids formed in a restricted hypersaline environment similar to that indicated for Laguna Madre ooids (Rusnak, 1960).

ALGAL LIMESTONE AND CALCAREOUS SANDSTONE

Sediments along the shelf edge in the Cape Lookout area and adjacent parts of the Carolina shelf have been studied in considerable detail by Macintyre and Milliman (1970). Their investigation, which included extensive sparker profiling, rock dredging, and bottom photography, showed that algal limestone and calcareous sandstone are the two main consolidated rocks. Although these rock types appear to be rather uniformly distributed along the ridges, troughs, terraces, and slopes adjacent to the shelf edge, they are covered in many places by a thin mantle of shelly sand.

The algal limestone consists of a mixture of encrusting coralline algae and lesser amounts of skeletal material from a wide variety of other calcareous organisms. The cementing material is submicrocrystalline to blocky high-magnesium calcite. The rock is extensively bored, and several stages of infilling and lithification are evident. A small amount of quartz sand and silt is commonly present in the infillings and cementing matrix. Some of the limestone occurs as concentrically banded balls as large as 150 mm in diameter. According to Macintyre and Milliman, high-magnesium calcite constitutes 75–90 percent of the total carbonate material in the rock. Of the remaining carbonate fraction, aragonite predominates over low-magnesium calcite.

The sandstones range from calcareous quartz arenites to quartz-rich calcarenites (Macintyre and Milliman, 1970, p. 2582). The component calcareous grains are mainly fragments of mollusks and coralline algae but include varying amounts of bryozoans, foraminifers, barnacles, serpulid worm tubes, and ooids. The rock is commonly cemented by high-magnesium calcite with a "pelletoid or pseudopelletoid" (p. 2582) texture. The carbonate fraction of the bulk rock averages 66 percent high-magnesium calcite and 27 percent aragonite. Like the algal limestone, the sandstone has been highly bored by marine organisms.

Three radiocarbon dates of samples of the algal limestone and calcareous sandstone from localities within the map area range from 12,270 ± 190 years to 15,180 ± 280 years B.P. (Macintyre and Milliman, 1970, p. 2583, table 1; this report, table 2). Comparison of these ages with those used to construct the sea-level curve of Milliman and Emery (1968) suggest that the rocks may have formed in shallow water during the early stages of the last transgression of the sea.

COQUINA

Light-brown skeletal calcirudite and calcarenite crop out as irregular patches on the shelf floor south of the Cape Lookout shoals. In many areas, knobs and ledges of coquina project through a thin cover of quartz sand (Qsg and Qss, pl. 1). Numerous pebble- to boulder-sized coquina fragments on the beaches and in storm overwash channels between dunes on Bogue, Shackleford, and Core Banks suggest that the actual areal distribution of the coquina may be much more extensive than that shown on the geologic map.

The rock consists mainly of well-rounded coarse sand- to pebble-sized fragments of pelecypods cemented by coarsely crystalline low-magnesium calcite. Quartz grains average about 20 percent of the rock volume; locally the percentage is much higher. Sorting is poor. The shell material includes both chalky white and iron-stained fragments and material retaining its original coloration. Commonly, most or all of the calcareous material in the chunks of coquina washed up on the beaches has been removed by solution or subaerial weathering, leaving only coarse sand- to granule-sized quartz and feldspar grains and molds of mollusks.

The faunal composition (especially *Donax*), coarse grain size, and high degree of rounding of shell fragments suggest that the coquina was deposited in a beach or near-beach environment. The low-magnesium calcite composing the cementing material suggests that cementation occurred subaerially.

UPPER PLEISTOCENE TO HOLOCENE SHELF SAND AND MUD

Over most of the shelf in the Cape Lookout area, a sheet of unconsolidated terrigenous material (map units Qsb, Qsg, Qss, Qsc), consisting mainly of sand but including lesser amounts of silt and clay, mantles the Yorktown Formation and younger Quaternary calcareous deposits. Known thicknesses range from a maximum of about 90 feet (27 m) near Cape Lookout to zero in the vicinity of consolidated rock outcrops in Raleigh and Onslow Bays. The surface of these deposits is characterized by ridge-and-swale topography similar to that found over much of the Atlantic Continental Shelf. Low-relief ridges delineated by bathymetric contours within the Cape Lookout map area range in length from 3 miles (5 km) or less to more than 12 miles (20 km); the relief from trough to crest is generally 3–16 feet (1–5 m), widths vary from less than three-quarters of a mile (1 km) to about 3 miles (5 km). The maximum trough to crest relief shown by several of the large arcuate sand ridges southeast of the Cape Lookout shoals, is as great as 53 feet (16 m). The relatively poor development of the ridge-and-swale topography in the western half of the Cape Lookout map area, compared with that of the eastern half, may be due at least in part to the much thinner cover of unconsolidated sediment.

The north-northwest grain of the ridge-and-swale topography nearshore in Onslow Bay (see fig. 12 and pl. 1) is nearly perpendicular to the shoreline. On the outer shelf, especially seaward from the Cape Lookout shoals, the trend of the ridges changes gradually to east and, in the southwesternmost part of Raleigh Bay, to northeast. In effect, the ridges appear to "wrap around" the present cape. Farther northeast, in the central part of Raleigh Bay, the trend of the ridges changes again to east or northwest, at fairly high angles to the Holocene barrier-island shoreline. As noted by Uchupi (1968, p. C17), the high angles between shelf ridge systems and the present shoreline in many areas of the continental shelf, especially south of Cape Hatteras, suggest that the ridges are not drowned barriers, as tentatively proposed by Sanders (1962) and Shepard (1963, p. 214), but features that have formed as a result of the present current and wave regime. The main mechanism of sediment transport, especially in the Raleigh Bay shelf segment, is probably bottom currents created by strong winter storms from the northeast and east or long-period swells generated far at sea. The Gulf Stream, which sometimes migrates northwestward across the shelf almost to the tip of the Cape Lookout shoals (R. S. Menzies, oral commun., 1967) may also play an important part in sediment transport on the central and outer shelf.

The sand fraction of the terrigenous sediments is mostly quartz, but feldspar may constitute 1–15 percent; the average is about 5 percent. Orthoclase is more common than plagioclase. The nonopaque heavy-mineral suite, which is dominated by staurolite, hornblende, and epidote, reflects an ultimate derivation from the Piedmont province. Phosphorite grains, constituting 0–2 percent of the sand fraction, are probably derived by reworking of older Coastal Plain sediments on the continental shelf.

Admixed with the terrigenous sediments are varying amounts and types of calcareous materials. Skeletal debris, which is dominant, consists of fragments of infaunal filter-feeding bivalves and lesser amounts of foraminifers, echinoids, barnacles, bryozoans, coralline algae, and serpulid tubes. Ooids and calcareous rock fragments are less common but locally constitute an important part of the carbonate fraction. The tan to black ooids, generally 200-1,000 microns in diameter, are nucleated about quartz grains. Their similarity to ooids forming the Pleisto-

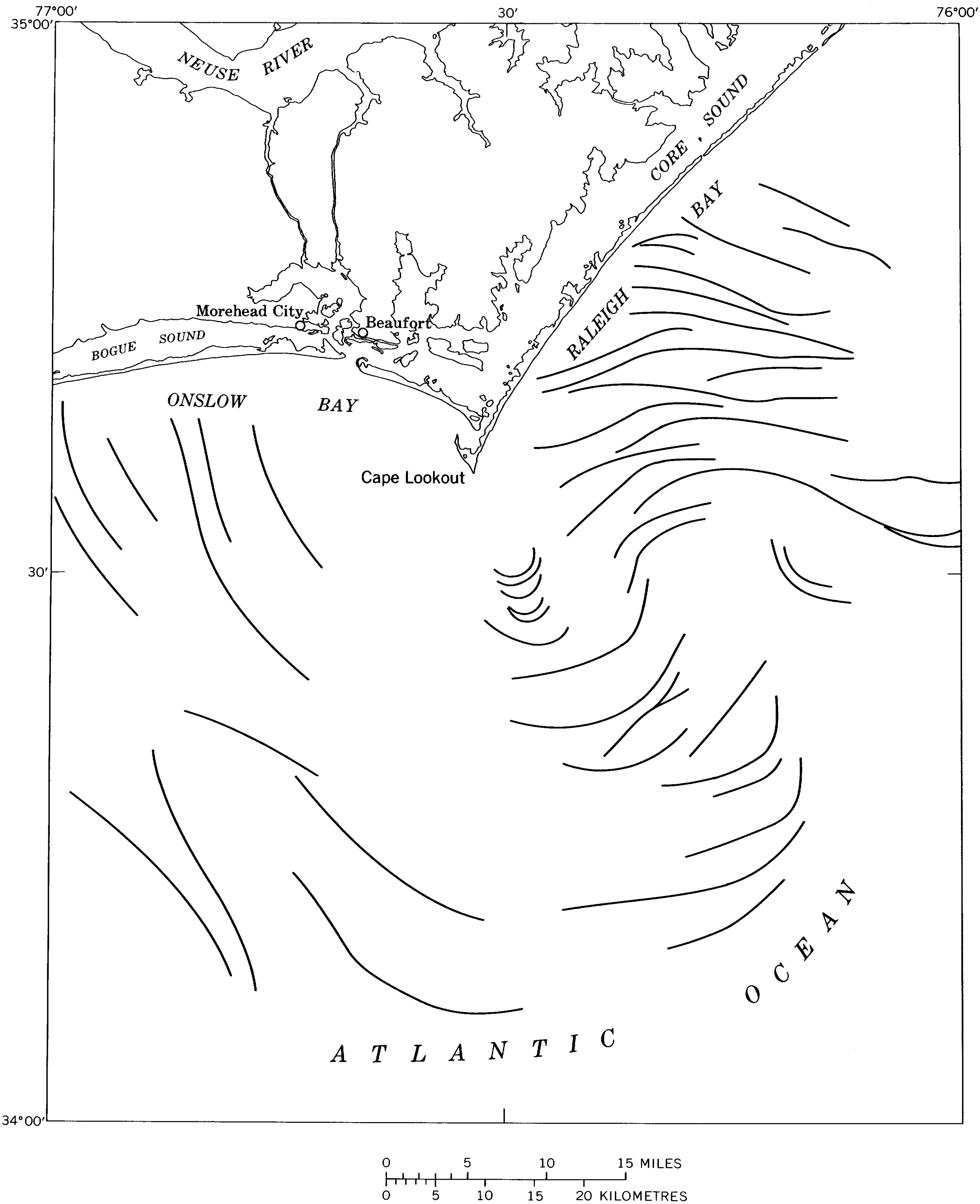

FIGURE 12.—Sketch map showing trends of sand ridges on the submerged shelf, Cape Lookout area, N.C.

cene oolitic calcarenite (unit Qoc, pl. 1) suggests that they may be derived from erosion of the calcarenite.

Two distinct faunal assemblages, both indicative of shallow-water marine environments, have been identified in the terrigenous shelf sediments (Pilkey and others, 1969; this report, see below). One assemblage, characterized by *Donax* and *Spisula solidissima,* is a normal marine inner-shelf fauna indicative of water depths ranging from 0 to 20 m. The other assemblage, which includes *Crassostrea virginica* and *Nassarius obsoletus,* suggests intertidal to inlet environments. The almost ubiquitous presence of these "out-of-place" shallow-water assemblages is an important line of evidence indicating the relict nature of the shelf sediments.

The surficial terrigenous sediments have been divided, principally on the basis of grain size, into two gross mapping units: (1) sandy shelf deposits, generally containing less than 5 percent silt and clay; and (2) muddy shelf deposits, also dominantly sand, but containing appreciable amounts of silt and clay. Each of these map units are in turn divided into two subunits on the basis of overall sediment color and grain size. All four subunits are gradational.

Molluscan species used to define the shallow-water assemblages occurring in the terrigenous sands and muds on the shelf are as follows (Pilkey and others, 1969):

Inlet and intertidal assemblage:
- *Crassostrea virginica* (Gmelin)
- *Gemma gemma* Totten
- *Littorina irrorata* Say
- *Nassarius obsoletus* Say
- *Tagelus plebeius* Solander

Inner-shelf assemblage:
- *Donax variabilis* Say
- *Mercenaria campechiensis* (Gmelin)
- *Mulinia lateralis* (Say)
- *Spisula solidissima* Dillwyn
- *Terebra dislocata* Say

Sandy shelf deposits.—These deposits consist mostly of fine to very coarse quartz sand; the mean size is generally medium sand. On the basis of overall sediment color they have been divided into dark-gray sands, found mainly on the central and outer shelf, and light-yellowish-brown to grayish-brown sands which are largely restricted to the inner shelf in Raleigh Bay and a large irregular outcrop on the central shelf in Onslow Bay. The color of the brown sand is due to brown-stained shell material and iron-stained quartz grains. The dark-gray or "salt and pepper" appearance of the gray sand unit results from a combination of black-stained shells and shell fragments and the lack of any iron staining of quartz grains. As iron-stained sand, particularly brown-stained shell material, is characteristic of North Carolina beach and shoreface sands, the color of the brown sand unit may be a feature inherited from a time of lowered sea level. Black-stained shell, although characteristic of local estuarine sediments, may also result from reducing conditions in other sedimentary environments.

Muddy shelf deposits.—The muddy shelf sediments, consisting of fine to medium silty sands and clayey silts, are found mainly on the inner shelf in Onslow Bay and in a small topographic basin on the outer shelf east of the Cape Lookout shoals. Small patches of this sediment, too small to map, are also found along the shoreface in front of the barrier islands.

Except for the smaller mean grain size, the composition of the sand fraction of these sediments is essentially the same as that of the cleaner, coarser shelf sands. An important difference is the high mica content, probably indicating that some sedimentation is taking place in these areas at present. The location of the Onslow Bay outcrop areas directly in front of Beaufort and Bogue Inlets (see fig. 5 and pl. 1) suggests that much of the silt-clay fraction of this unit may be deposited from turbid waters, initially of fluvial origin, which are discharged from the inlets after periods of rainfall on the emerged part of the Coastal Plain. This hypothesis is substantiated by Apollo photographs of the Cape Lookout area (fig. 13) which clearly show a fan-shaped mass of sediment-laden water emerging from Beaufort Inlet. The muddy water extends continuously from Beaufort Inlet through Back and Core Sounds to Pamlico Sound. The increasing turbidity of the water in this direction, together with the relatively clear water in Bogue Sound and the upper parts of the Newport and North River estuaries, suggest that the suspended sediment entering the shelf through Beaufort Inlet at the time the photographs were taken probably came from rivers draining into Pamlico Sound and was transported to Beaufort Inlet via Core and Back Sounds by tidal and wind-driven currents. In a similar fashion, the silt-clay fraction of the large outcrop of muddy sand and silt east of the Cape Lookout shoals was probably derived, at least in part, from suspended sediment discharged into Raleigh Bay shelf waters mainly through inlets such as Ocracoke and Hatteras (fig. 5). The association of the muddy sediment with a topographically low part of the shelf east of the Cape Lookout shoals suggests that this basinlike feature affords some degree of protection from the winnowing action of shelf currents.

HOLOCENE DEPOSITS

OUTER BANKS BARRIER DEPOSITS

The seaward part of the emerged Coastal Plain in the Cape Lookout map area is a 70-mile-long (112 km) chain of barrier islands known as the Core Banks (northeast of Cape Lookout) and Shackleford and Bogue Banks (west of the cape). Altitudes of the subaerially exposed parts of Shackleford and Bogue Banks average 5–15 (1.5–4.5) and 10–20 feet (3–6 m), respectively, but reach a maximum of 40 feet (12 m). The Core Banks barrier is lower, averaging 5–10 feet (1.5–3 m) above sea level. At depths of about 30 feet (9 m) below sea level the front of the barrier (shoreface) merges with the upper part of the more gently sloping inner shelf.

The Core Banks barrier is a single sand ridge except northeast of Sand Island Inlet, where it consists of two main ridges and an intervening sand flat. In contrast, the northwestern part of Shackleford Banks and the Hoop Pole Landing and Salter Path areas of Bogue Banks show well-developed ridge-and-swale topography, suggesting that in these areas barrier growth was accomplished by accretion of beach ridges. The change from the north-northwest or northwest trends of the landward (older) beach ridges to the west-northwest or west trends of the seaward (younger) ridges—proceeding from east to west in each area—indicates westerly growth of these parts of the islands. Studies of aerial photographs of the Beaufort Inlet area (El-Ashry and Wanless, 1968, fig. 10) demonstrated westward elongation of Shackleford Banks (and the consequent narrowing of Beaufort Inlet) by more than half a mile between 1953 and 1962.

The low elevation of Core Banks, in comparison with Shackleford and Bogue Banks, is due to the relatively poor development of beach-dune ridges. According to Godfrey (oral commun., 1972), the lack of appreciable dune development on Core Banks may result, at least in part, from the parallelism of the long axis of the barrier island and the dominant wind directions (see fig. 11). As a consequence, a lesser amount of sand may be transported from the beach to the dune line than would be the case if the barrier trend was at a greater angle to the prevailing winds. Shackleford and Bogue Banks, which are oriented perpendicular to dominant wind directions, show extensive dune development.

Godfrey (1970) also suggested that the landward migration of the Core Banks barrier islands, caused by a generally rising sea level, takes place by the development of salt marsh on former tidal inlet deltas and the subsequent burial of the marsh by overwash fans. The overwash fans are stabilized by the growth of grasses.

BACKBARRIER DEPOSITS

The salt marshes and sounds, bays, and estuaries behind the outer barrier islands are areas of very active sedimentation and, in some areas, erosion. The net result is sediment accumulation, probably at a rate far exceeding that of other areas of Holocene sedimentation on the Continental Shelf and upper Continental Slope. Sediment sources include both rivers and smaller streams and the adjacent Continental Shelf.

The bays and sounds are generally quite shallow, averaging less than 2 m deep; the central parts are as much as 3 m deep. Tidal channels are commonly 7–10 m deep, particularly near tidal inlets. Much of the central part of the Neuse River estuary and Pamlico Sound is more than 6 m deep. Low-relief intertidal and subtidal sand bars are widely distributed in the shallower, sandier parts of the sounds and bays.

For purposes of mapping at the scale of 1:250,000, the sediments of these relatively low-energy backbarrier depositional environments are divided into sandy and muddy facies in a manner similar to that used in the classification of the terrigenous deposits of the open shelf. The backbarrier sands (Qbs on pl. 1) contrast strongly with the surficial sands of the adjacent barriers in the abundance of black, rather than brown, shell fragments and in the lack of any iron staining of quartz grains. All calcareous skeletal material, unless very fresh, is either gray or black. It has been shown experimentally that in a reducing environment the blackening may occur in a matter of days.

The backbarrier muds are divided into bottom muds, which in large part are not exposed by tidal fluctuations, and marsh deposits, which are subaerially exposed during at least part of each day. Deposition of the bottom muds (unit Qbc, pl. 1) is mainly restricted to the upper parts of estuaries and small sheltered bays, or to depths greater than about 3.5 m in the larger bodies of water such as the Neuse River estuary or West Bay (Ingram, 1968, and oral commun., 1971). The concentration of muddy sediments in the deeper parts of the large water bodies appears to be due to the winnowing of fines from the sediment in shallow-water areas, mainly by wave action, and the movement of this material by tidal currents into deeper water. Bottom muds also accumulate in dredged channels and depressions where

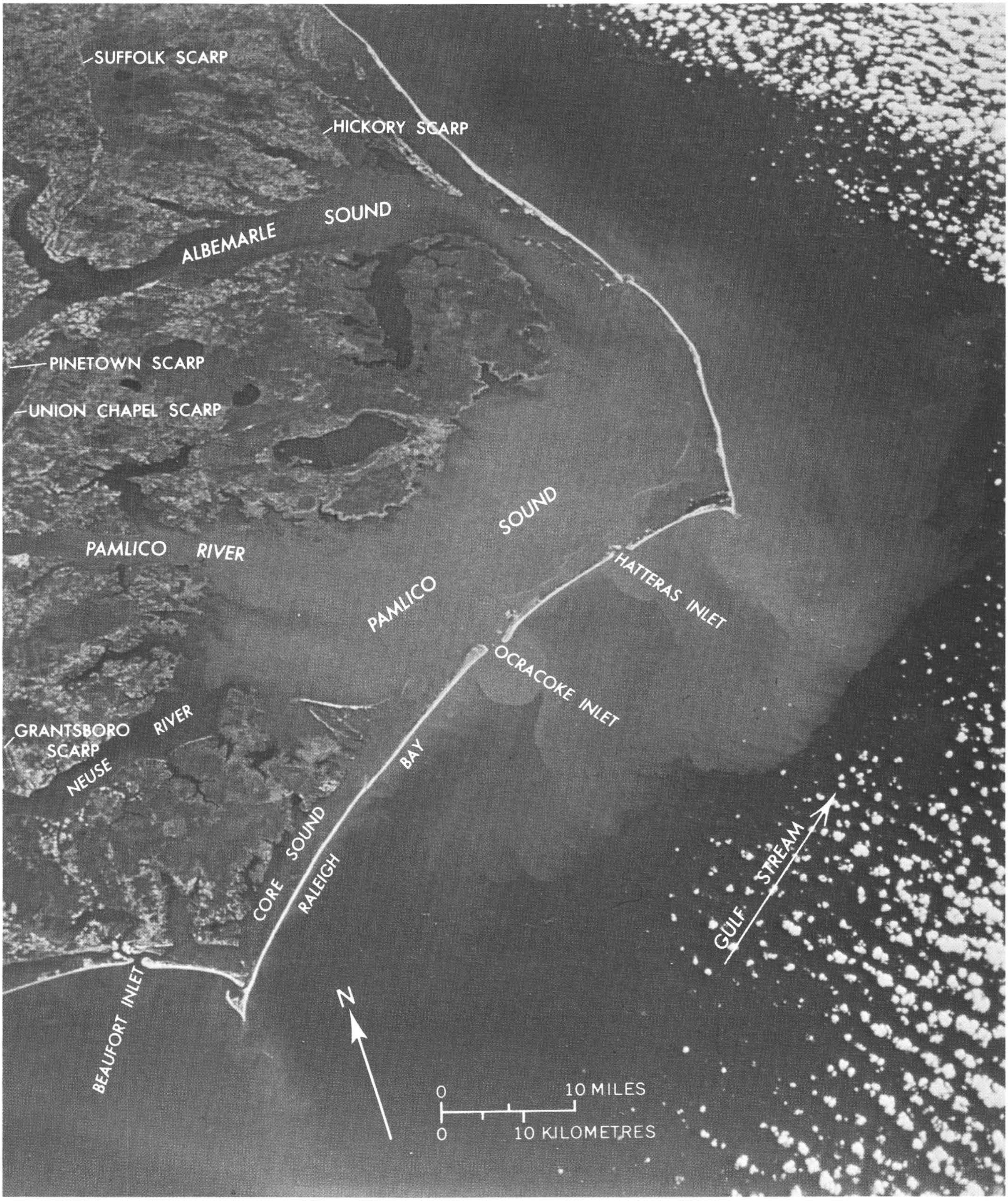

FIGURE 13.—(For explanation see facing page.)

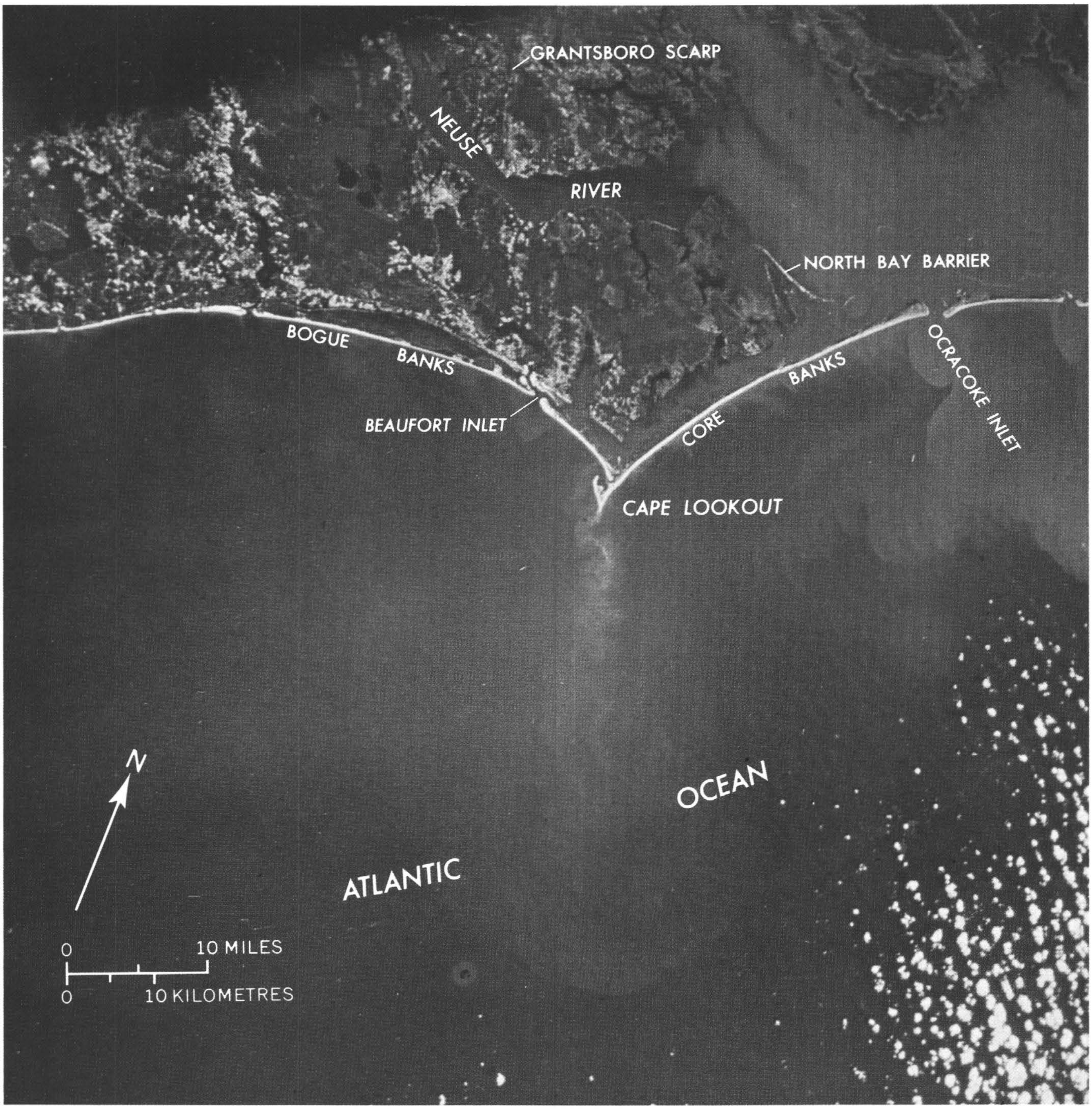

FIGURE 13.—Apollo 9 photographs showing the distribution of suspended sediment in the Cape Lookout region, North Carolina. Photographs by NASA, March 1969. *A* (left), Dispersal patterns of fine fluvial sediment in backbarrier and Continental Shelf areas, Pamlico Sound region. Cape Hatteras is shown in right center and Cape Lookout in the lower left. Pamlico Sound and lower parts of Pamlico and Neuse River estuaries are west and southwest of Cape Hatteras. Albemarle Sound and lower parts of Chowan and Roanoke Rivers are northwest of Pamlico Sound. (See fig. 5.) Main sediment discharge to shelf appears to be through Ocracoke and Hatteras Inlets; a small fan of turbid water at Beaufort Inlet indicates that some sediment is carried southwestward through Core Sound to Onslow Bay shelf area. Sharp break southeast of Cape Hatteras between turbid water to northwest and clear deep-blue water to southeast probably coincides with western edge of northerly flowing Gulf Stream. Suffolk scarp is visible in upper left corner of photograph. *B* (above), Cape Lookout photographed almost directly above the cape. Clear-blue water of Onslow Bay, west of Cape Lookout, contrasts with turbid water of Raleigh Bay, east of cape, and of Pamlico Sound, upper right. Cape Lookout sediment plume, center of photograph, appears to consist mainly of fluvial material discharged from Pamlico Sound through barrier inlets and carried southward by longshore currents. Grantsboro scarp is visible in upper center of photograph.

current velocities are low; the four outcrops of unit Qbc in Bogue Sound are an example. (See pl. 1.)

Salt-marsh muds (Qbm, pl. 1) accumulate by a different mechanism—the baffle effect of the salt-marsh grasses, *Spartina alterniflora* and *S. patens*. Although the marsh-mud accumulations are more common along the borders of sheltered bays, they also occur in areas exposed to estuarine waves. According to Godfrey (oral commun., 1972), marsh development on the backsides of barrier islands is related to formation of tidal deltas behind shifting barrier inlets. The marsh is initiated after closure of the barrier inlet at which the delta formed.

The backbarrier muds differ from muddy sediments on the Continental Shelf and Slope in their darker color, considerably higher percentage of clay-sized material, very low percentage of calcium carbonate, abundance of fibrous organic material, and strong odor of hydrogen sulfide.

CAPE LOOKOUT SAND

The Cape Lookout sand is a lobate body, approximately 13 miles (21 km) long and as much as 10 miles (16 km) wide, which extends southeastward across the shelf from Cape Lookout. The uppermost part of this unit forms the Cape Lookout shoals, a series of southeast-trending longitudinal submarine sand ridges or sand waves which are superimposed, in the outer shoals, upon larger arcuate ridges convex to the southeast and delineated by the 10-m depth contour (see pl. 1 and fig. 12). The shallow longitudinal ridges, defined by the 2- to 8-m depth contours, are clearly shown on aerial photographs (Sheppard and Wanless, 1971, p. 115, fig. 5.8).

The unconsolidated sand constituting this map unit is light gray to light yellowish gray, fine to medium grained, and fairly well sorted. The mica content, averaging 20 to 40 grains per 10,000 sediment grains, is high compared with that of adjacent map units and is thought to reflect an environment in which depositional processes, rather than winnowing processes, dominate (Doyle and others, 1968). The calcareous component (largely shell material) generally constitutes less than 5 percent of the sediment—considerably less than the percentage of calcareous material in adjacent map units.

The longitudinal sand ridges forming the Cape Lookout shoals and the presence of a plume of fine sediment (clay- to very fine sand-sized) extending seaward from Cape Lookout (see fig. 13) indicate that the dominant direction of sediment transport and sand accretion is from north-northwest to south-southeast, parallel to the trend of the shoals. The transporting mechanism, at least in part, is undoubtedly the southerly longshore current in Raleigh Bay. This assumption is substantiated by the nonphosphatic character of the Cape Lookout sand which, in combination with the known distribution of phosphate grains in the Onslow and Raleigh Bay shelf areas (phosphate rich and phosphate poor, respectively), suggest that Raleigh Bay is the main source of sediment at present. The direction of longshore drift in Onslow Bay and the amount of sediment derived from that part of the shelf are less clear. The U.S. Army Corps of Engineers (1947) has reported a net eastward movement of sediment in the Beaufort Inlet area, suggesting a dominant eastward longshore current. However, El-Ashry and Wanless (1968) have demonstrated westward accretion of Shackleford Banks in the same area. According to Langfelder, Stafford, and Mein (1968), longshore transport along Shackleford Banks and the easternmost part of Bogue Banks is from east to west; then, in the vicinity of Atlantic Beach, the direction of sediment transport changes, becoming west to east.

CONTINENTAL SLOPE DEPOSITS

An abrupt change in sediment processes and sediment types is associated with the topographic break between the gently sloping Outer Continental Shelf and the much more steeply dipping surface of the Continental Slope. The shelf sediments are predominantly quartz sand and calcareous deposits of shallow-water origin, whereas the slope deposits are foraminiferal muds (unit Qm on pl. 1). These muds consist mainly of brownish-gray silt and very fine silty sand characterized by abundant Foraminifera tests and mica flakes. Mean grain size generally decreases with increasing depth. Sorting ranges from fairly good (foraminiferal oozes) to poor (silty sands).

The high percentage of mica (>80 grains per 10,000 grains of sand-sized sediment) in the Continental Slope mud in this area indicates that deposition rather than winnowing is dominant. Although the Gulf Stream does not appear to be actively scouring the Continental Slope at present, the rate of deposition is probably greatly reduced as a consequence of Gulf Stream currents carrying northward much of the suspended material which crosses the shelf as the Cape Lookout sediment plume. Some of this sediment is probably deposited off Cape Hatteras where the Gulf Stream diverges from the shelf edge. The more rugged topography of the upper slope north of Cape Hatteras, compared with the very smooth slopes in the Cape Lookout map area, may be small-scale slump structures resulting from very rapid sedimentation on the steeper slopes of that area.

LATEST TERTIARY AND QUATERNARY GEOLOGIC HISTORY

YORKTOWN TRANSGRESSIVE-REGRESSIVE SEQUENCE

The basal beds of the Yorktown Formation, which unconformably overlie the Pungo River Formation (middle Miocene) and, west and northwest of the map area, lap onto older Tertiary strata, record one of the major transgressions of the Tertiary sea onto the Atlantic Coastal Plain. At the time of maximum transgression in the early Pliocene, the shoreline in North Carolina was far inland from the present coast, trending northeast from Robeson County in the southwest to Northampton County in the north (Stuckey, 1958). A general regression of the sea during middle and late Yorktown time has been documented by Hazel (1971a, p. 8; 1971b) on the basis of the distribution of brackish-water faunal elements (characterized by the ostracode *Cyprideis* and the pelecypod *Corbicula*). These fossils are common in the upper Yorktown beds in North Carolina and Virginia and indicate nearness to shore during deposition of the enclosing sediment. Hazel (1971a, b) has shown that the first brackish-water fauna found is in progressively younger strata as distance from the inner margin of outcrop increases—thereby demonstrating the regressive nature of the upper Yorktown. According to Hazel (1971a, p. 10) a disconformity within the Yorktown at Yadkin, Va. "indicates that at least locally the sea readvanced over an eroded middle Yorktown surface during early Pliocene time." Hazel (oral commun., 1973) now believes that the middle Yorktown is also of Pliocene age (also see Akers, 1972). The suspected disconformable contact (see p. 17) between the clay (James City Formation of DuBar and Solliday, 1963) and sand units of the Yorktown as used herein could represent this event.

Regional uplift and emergence of the Coastal Plain beginning in the Pliocene initiated development of the unconformity that marks the upper surface of the Yorktown Formation. During this regression and subsequent fluctuations of sea level in the Quaternary, the original depositional surface of the Yorktown (a fairly flat plain dipping east and south at very low angles) was modified by both marine and fluvial erosional and depositional processes. Today, the Yorktown plain is largely covered by a thin blanket of Quaternary sediments resulting from the seaward progradation of coastal deposits and upbuilding of the shelf.

FLANNER BEACH PROGRADATIONAL SEQUENCE

The Flanner Beach Formation consists mainly of sediments deposited in barrier, backbarrier, and open-bay environments along the eastern margin of a coastal lowland composed of older Pleistocene deposits. The basal deposits of this sequence include silty clay rich in organic matter and containing cypress stumps; this clay, which is exposed at Flanner Beach, appears to have formed in fresh-water swamps bordering the Neuse paleochannel. These fluvial sediments are directly overlain by more widespread brackish marine strata which record a transgression of the sea during a middle to late Pleistocene interglacial period. This transgression flooded the Neuse paleochannel and adjacent lowlands, probably creating an estuary similar in size to that of the present-day Neuse River but opening to the open ocean rather than to an extensive lagoon as does the Neuse today. At about this time, the Newport and Arapahoe sand members were deposited as barriers and (or) strand or chenier plains flanking the mouth of the ancestral Neuse estuary.

The seaward-projecting land area at the junction of the Arapahoe and Newport barriers appears to have formed a major cape in the Masontown-North Harlowe area; as the Newport barrier prograded southeastward, the position of the cape (and the mouth of the ancestral Neuse) migrated to the southeast. Late Pleistocene shoreline trends in the Cape Lookout map area, in the coastal area to the south bordering Onslow Bay, and in the Pamlico Sound region to the north (see fig. 5) suggest that this cape extended farther southeast across the Continental Shelf at the time than did contemporary capes to the north or south. The coincidence of the cape with the ancestral Neuse River mouth suggests that the formation of the cape may have closely paralleled the genesis of Carolina capes as proposed by Hoyt and Henry (1971, p. 64–66). These authors theorize that deltas were constructed on the shallow inner shelf during glacial low stands of the sea, as a consequence of increased river gradients near river mouths and higher sedimentation rates along the regressing shoreline. During the subsequent interglacial, the deltas were reworked by transgressing seas to form pronounced capes.

The Newport and Arapahoe sand members and the associated Beard Creek member are inferred to be the oldest surficial Pleistocene units within the map area because of their higher topographic position and location nearer the inner (western) margin of the outer Coastal Plain. Surface altitudes of the Newport-Arapahoe barrier and backbarrier flat are strikingly similar to those of the Jaluco barrier-backbarrier sequence in South Carolina (Thom, 1967, p. 34); barring significant late Quaternary tectonic movements, it seems that these units may be correlative. It should be noted that Colquhoun and Blanchard (1971) have reported a uranium series age of 147,000±13,000 years B.P. for a similar stand of sea at 34 feet above mean sea level in South Carolina.

FORMATION OF THE GRANTSBORO SCARP

The Grantsboro scarp (see p. 13 and fig. 5) may have formed in an early stage of the regressive cycle which followed deposition of the Newport-Arapahoe-Beard Creek complex, or much later during a subsequent transgression. The age of this scarp is better defined by comparing the scarps and associated depositional surfaces of the Cape Lookout area with those of the Norfolk area of southeastern Virginia, where the sedimentary record appears to be more complete. There the outer Coastal Plain has two prominent east-facing scarps separated by a broad plain, as much as 30 miles (48 km) wide, ranging in altitude from 18 to 30 feet (5.4 to 9 m) above sea level. These scarps (Suffolk scarp on the west and Hickory scarp to the east) have toe elevations of about 25 feet (7.5 m) and 15 feet (4.5 m), respectively.

To the south, the segment of the outer Coastal Plain between Albemarle Sound and Pamlico River shows comparable eastward-facing scarps spaced only 3–4 miles (4.8–6.4 km) apart. The older scarp to the west near Pinetown, Hoke, and Hinson is herein called the Pinetown scarp or Pinetown shoreline (fig. 5). The younger, topographically lower scarp on the southeast passes through the communities of Acre and Union Chapel (the Union Chapel shoreline, fig. 5). These features are shown on 5-foot contour-interval topographic maps of the area and, in part, on the Apollo-9 photograph of the Pamlico Sound region (fig. 13). The toe of the Union Chapel scarp is consistently 17–21 feet (5.1–6.3 m), similar to that of the Grantsboro scarp to the south. The area between the two scarps, including most of Van Swamp, appears to consist of ancient beach ridges and back-dune flats; the break in slope between this complex and the Pinetown scarp is 30–35 feet (9–10.5 m) in altitude. The Pinetown shoreline appears to be correlative, at least in part, with the Suffolk scarp in its type area (Suffolk and Beckford, Va., 15-minute quadrangles). The younger Union Chapel shoreline may be approximately correlative with the Hickory and Big Bethel scarps of the Norfolk area, Virginia (Oaks, 1964, p. 33; Johnson, 1969, p. 2, 4). It is suggested that at the time of formation of the Hickory and Union Chapel scarps, the shoreline curved abruptly east-northeast from the vicinity of Union Chapel, essentially parallel to the northern edge of the present-day Albemarle Sound.

Southward convergence of these two sets of shorelines (Suffolk-Pinetown and Hickory-Union Chapel) suggests that the Grantsboro scarp may be a compound feature formed during two separate high stands of the Pleistocene sea. Thus, it may have represented the front of a barrier or barrier spit complex during the time of formation of the Suffolk and Pinetown shorelines. Later, during the development of the Hickory and Union Chapel scarps, the break in slope at the seaward edge of the old barrier complex was probably accentuated by marine erosion along a mainland shoreline characterized by beaches and extensive dune fields (Minnesott sand) or low sea cliffs.

DEPOSITION OF THE CORE CREEK SAND AND MINNESOTT SAND

The Core Creek sand, consisting of nearshore shelf and tidal-flat deposits, appears to interfinger westward with the Minnesott sand, a complex of beach and dune deposits. The emplacement of these beds was contemporaneous, at least in part, with the formation of the Grantsboro scarp. Two alternative interpretations of the stratigraphic relationships between this sequence and the Pleistocene marine complex adjacent to the west are: (1) the Core Creek sand and Minnesott sand form a time-stratigraphic unit deposited during a transgressive-regressive cycle separate and later in time than that during which the Newport-Arapahoe-Beard Creek complex formed, or (2) the two sequences are partly correlative, the Minnesott sand and at least the upper part of the Core Creek sand being deposited during a regressive phase of the same cycle in which the Newport-Arapahoe-Beard Creek complex was emplaced. The latter interpretation would involve a prolonged stillstand of the sea during the regressive phase, allowing deposition of the Minnesott sand and the cutting of the Grantsboro scarp. The first interpretation given above would require that an unconformity separate the Core Creek sand from the Arapahoe sand member and the Beard Creek member of the

Flanner Beach Formation. Although drill data relating to the presence or absence of such an unconformity are equivocal (Daniels and others, 1972, p. 16 and figs. 5, 7, and 9), we agree with Daniels, Gamble, Wheeler, and Holzhey in favoring the first interpretation because of the following factors: (1) the multiple age of the Grantsboro scarp, as suggested by the southward convergence of relict shorelines in the Pamlico Sound area (see section on formation of Grantsboro scarp and figure 5); and (2) regional relationships of the Core Creek sand with sedimentary deposits possibly intermediate in age between it and the Newport-Arapahoe-Beard Creek complex (specifically, deposits underlying depositional surfaces between the Suffolk-Pinetown and Hickory-Union Chapel scarp trends).

CORE CREEK-ATLANTIC-CEDAR ISLAND PROGRADATIONAL SEQUENCE

The gentle seaward slope of the Core Creek plain and the down-to-the-coast steplike character of the Atlantic and Cedar Island barrier-backbarrier complexes at the outer margin of the plain suggest that the uppermost part of the Core Creek sand and the Atlantic and Cedar Island sands were deposited during a regression, punctuated by periodic stillstands or minor fluctuations of the sea, which followed cutting of the Grantsboro scarp. At about the same time, the Beaufort sand appears to have accreted at the southern margin of the newly emerged Core Creek plain. The overall picture is one of eastward and northeastward progradation of the Coastal Plain in the Cape Lookout area in the latest Pleistocene. (See also Fisher, 1967, p. 209–216.)

Alternatively, Pierce and Colquhoun (1970b) have proposed that the Cedar Island, Atlantic, and Beaufort barriers form a sequence, from oldest to youngest, of barriers that formed from northeast to southwest by spit elongation from an "ancestral" Cape Lookout in the vicinity of Cedar Island. They tentatively suggested (1970b, fig. 5, p. 3705) that the surficial sediments of this stretch of the mainland coast were deposited during the Holocene. However, radiocarbon dates (see table 2, this report) obtained from the Cedar Island, Atlantic, and Beaufort barriers indicate that this part of the Coastal Plain is Pleistocene rather than Holocene. The critical dates demonstrating a Pleistocene age for the Atlantic and Cedar Island barriers are from two near-surface peats (localities A–1 and A–4, table 2). Because of the possibility of contamination of the peats by waters containing younger carbon, these dates are considered to provide a *minimum* age for formation of the surface depressions in which the peat beds were deposited. The beach ridges themselves may be considerably older than the surficial peats. Carbon-14 dates from shell material from fossil beds directly underlying the Cedar Island, Atlantic, and Beaufort sands range from greater than 38,000 years B.P. to greater than 45,000 years B.P. (table 2), indicating only that these strata are too old to date reliably by the carbon-14 method.

PLEISTOCENE CONTINENTAL SHELF SEDIMENTATION

The composition and nature of preservation of the relict fauna in the surficial shelf sediments, together with radiocarbon dates from ooids and other calcareous materials in Onslow Bay and along the shelf break, suggest that the bulk of these sediments were emplaced during the regressive-transgressive cycle encompassing the last glacial maximum.

The oldest radiocarbon dates, ranging from about 29,000 to 22,000 years B.P., have been obtained from ooids apparently derived from weathering and(or) erosion of the oolitic calcarenite in the southwestern part of the map area. These ages, together with oxygen-isotope ratios reported by Milliman, Pilkey, and Blackwelder (1968), suggest that the oolitic calcarenite was deposited during the last major regression in a restricted hypersaline environment—possibly in shallow lagoons which formed on the shelf as a result of lowered sea levels.

Much of the coquina, which extends as a broad band of irregular patchy outcrops from just southwest of the present cape southward almost to the shelf edge, may be roughly equivalent in age to the oolitic calcarenite. The faunal composition of this coquina indicates that it, like the oolitic calcarenite, was deposited in very shallow water but in a normal marine (beach or near-beach) rather than hypersaline environment. The coquina's shallow-water origin, probable cementation in a subaerial environment, and fairly wide distribution on the shelf floor (about 30 miles (48 km) roughly perpendicular to the present coastline and at depths ranging from 18 to 40 m), suggests that it may have formed along a retreating strandline—possibly related to a series of capes and(or) shoals which formed on the central and outer shelf during lower stands of the sea. On the other hand, local inclusion of shell material retaining its original coloration argues that at least some of the coquina may have been deposited during the last transgression.

The algal limestones and calcareous sandstones that crop out in a narrow band along the shelf edge appear to have formed in shallow water during the early stages of the general transgression which followed the last glacial maximum (18,000±years B.P.). This is suggested by the similarity of these rocks to shallow-water deposits on the Bermuda Platform (Macintyre and Milliman, 1970, p. 2591) and by radiocarbon dates, ranging from about 15,000 to 12,000 years B.P. (table 2), obtained from rock samples within the Cape Lookout area. The marine terrace at 60 to 70 m depth in the southeastern part of the map area and the ridge along its outer edge, which appears to be underlain by unstratified biohermal material (Macintyre and Milliman, 1970, p. 2594, fig. 8*B*), probably represent both erosional and constructional strandline features, respectively, formed during lower stands of sea level. These features may have formed only a short time before deposition of the algal limestones and calcareous sandstones which appear to mantle them—or may be considerably older.

The quartzose sand sheet which covers most of the submerged part of the shelf probably formed through much of the Pleistocene and Holocene as the result of the extensive redistribution and winnowing of fluvial material deposited on the shelf during low stands of the sea and, to a lesser extent, residual material derived from weathering and erosion of pre-Pleistocene strata exposed on the shelf floor. In the Onslow Bay area, where the sand is thin or absent, it appears to have been largely reworked by the present wave and current regime and is thus considered to be Holocene in age. To the east the sand thickens, and in the vicinity of Cape Lookout and parts of the Raleigh Bay area the lower part of the sequence almost certainly includes much Pleistocene sediment, which was too deeply buried to have undergone reworking during the Holocene transgression. Probably very little sediment is being added to the shelf at present.

HOLOCENE SEDIMENTATION

Most of the sediment being introduced into the map area today is derived directly from the emerged Coastal Plain via the Neuse River and smaller streams or indirectly from the Coastal Plain and Piedmont via the Tar, Roanoke, and Chowan Rivers. Some of the suspended load from the latter rivers, which drain into Pamlico and Albemarle Sounds, is transported southward by tidal or wind-driven currents in Pamlico Sound or by longshore currents on the adjacent shelf. The bulk of the sand and much of the clay-silt fraction is trapped in the backbarrier environment—comprising the bottom deposits of the estuaries and sounds and the surficial deposits, at least, of the adjacent tidal flats and salt marsh. An important additional source of sediment is provided by wave-induced erosion of the shoreline along the more exposed parts of the estuaries and sounds.

The fine sediment which escapes through the outer barrier inlets to mix with the open shelf waters is in large part swept across the shelf and deposited on the Continental Slope and Rise. However, two areas within the vicinity of Cape Lookout are at least partially protected from shelf winnowing processes and consequently appear to be the sites of at least some sedimentation at present. One of these areas, adjacent to the Cape Lookout shoals on the west, is underlain by mica-rich silty sand which very likely incorporates some fine material discharged onto the shelf through Beaufort Inlet. The other area, underlain by silty and clayey sand, is a topographically low part of the outer shelf east of the shoals.

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