Stratigraphy of the Tertiary Sediments in a 945-Foot-Deep Corehole near Mays Landing in the Southeastern New Jersey Coastal Plain

By JAMES P. OWENS, LAUREL M. BYBELL, GARY PAULACHOK, THOMAS A. AGER, *and* VIRGINIA M. GONZALEZ, U.S. GEOLOGICAL SURVEY, *and* PETER J. SUGARMAN, NEW JERSEY GEOLOGICAL SURVEY

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Prepared in collaboration with the New Jersey Geological Survey under the Federal and State Cooperative Geologic Mapping (COGEOMAP) component of the National Geologic Mapping Program

A description of the core, which included sediments of late Eocene and early Oligocene age not found before in New Jersey

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METRIC CONVERSION FACTORS

The core was measured in feet, and U.S. customary units are used throughout this report. To convert to metric units, use the table below.

Multiply	by	to obtain
miles	1.609	kilometers
feet	.3048	meters
inches	25.4	millimeters

SEA LEVEL

In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada.

STRATIGRAPHY OF THE TERTIARY SEDIMENTS IN A 945-FOOT-DEEP COREHOLE NEAR MAYS LANDING IN THE SOUTHEASTERN NEW JERSEY COASTAL PLAIN

By JAMES P. OWENS,[1] LAUREL M. BYBELL,[1] GARY PAULACHOK,[2] THOMAS A. AGER,[1] VIRGINIA M. GONZALEZ,[1] and PETER J. SUGARMAN[3]

ABSTRACT

As part of a joint U.S. Geological Survey-New Jersey Geological Survey project, the ACGS-4 corehole was cored to a depth of 945 ft in the southern New Jersey Coastal Plain near Mays Landing in Atlantic County. The hole, which penetrated both lower and upper Tertiary sediments, contains seven recognizable formations: the Manasquan Formation (early Eocene, calcareous nannofossil Zones NP 12–NP 14), Shark River Formation (middle and late Eocene, Zones NP 14–NP 18), ACGS Alpha unit (late Eocene and early Oligocene, Zones NP 18–NP 21), Mays Landing unit (early Oligocene, Zone NP 21), ACGS Beta unit (probable late Oligocene), Kirkwood Formation (early to early middle Miocene), and Cohansey Sand (probable middle Miocene).

The section from the early Eocene (Zone NP 12) through the early Oligocene (Zone NP 21) is nearly complete at this locality; in fact, it is one of the most complete sections through this part of the geologic column found anywhere to date in the U.S. Atlantic Coastal Plain. The presence of upper Eocene and lower Oligocene sediments in the New Jersey Coastal Plain was heretofore unknown. Thus, informal names are used for some units.

All the Paleogene formations recovered in the core were deposited in a shelf environment and are cyclic in character. Each reflects deeper water deposition in its lower part and contains shallower water sediments in its upper part. All the formations are separated by unconformities.

The Kirkwood Formation, which overlies the ACGS Beta unit unconformably, is the thickest unit in the hole. This unit ranges in age from early Miocene (early Burdigalian) to perhaps early middle Miocene (Langhian). The late Miocene (Tortonian) age proposed for the Kirkwood in the southern New Jersey Coastal Plain by some was not substantiated in this hole or in the array of holes surrounding it. Diatoms obtained from the upper Kirkwood indicate that this part of the unit is correlative with the lower Calvert Formation of the Chesapeake Group in Virginia, Delaware, and Maryland. The lower part of the Kirkwood is older than any unit known from the Chesapeake Group to the south, suggesting that what is now New Jersey was the earliest area of downwarping in the northern U.S. Atlantic Coastal Plain during Miocene time. The Kirkwood is largely a marine deltaic unit consisting of interbedded shallow shelf and prodelta deposits.

The precise relationship of the Kirkwood to the overlying Cohansey Sand was not determined in this corehole, largely because of poor recovery of the very loose sandy Cohansey near the contact and the lack of fossil invertebrates within the Cohansey. Pollen collected from both the Kirkwood and Cohansey suggests that the two units are close in age. These pollen assemblages indicate that the Cohansey is middle Miocene (Serravallian). Therefore, we do not accept the Pliocene age for the Cohansey shown in the "Atlantic Coastal Plain Correlation Chart" (American Association of Petroleum Geologists, 1983). The Cohansey in this corehole is largely a marginal marine sand interbedded with thick, dark, carbonaceous beds indicating some deltaic (nonmarine) influence.

After deposition of the Cohansey, the New Jersey Coastal Plain emerged. The sea has not invaded the central Coastal Plain uplands since Cohansey time.

INTRODUCTION

Neogene deposits of the southern New Jersey Coastal Plain have traditionally been divided into the Kirkwood Formation (older) and the Cohansey Sand (Lewis and Kümmel, 1912). The Cohansey is generally very sandy and typically is coarser grained than the Kirkwood (Minard and Owens, 1963). The Kirkwood consists of thick clayey and silty beds at the surface, as well as in the shallow subsurface (Isphording, 1970). Although these units are widespread (fig. 1), their precise lithologies, ages, and paleoenvironments are poorly known.

The Kirkwood Formation in the southwestern part of the State yielded a macrofaunal assemblage to which Richards and Harbison (1942) assigned a middle Miocene age. Melillo and Olsson (1981) subsequently indicated that, in its downdip area, the upper Kirkwood was as young as late Miocene. It has commonly been thought that this formation was deposited during a long time (~19 m.y.), and on that basis, the American Association of Petroleum Geologists (AAPG, 1983) proposed that the

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[1]U.S. Geological Survey, Reston, VA 22092.
[2]U.S. Geological Survey, Dover, DE 19901.
[3]New Jersey Geological Survey, Trenton, NJ 08625.

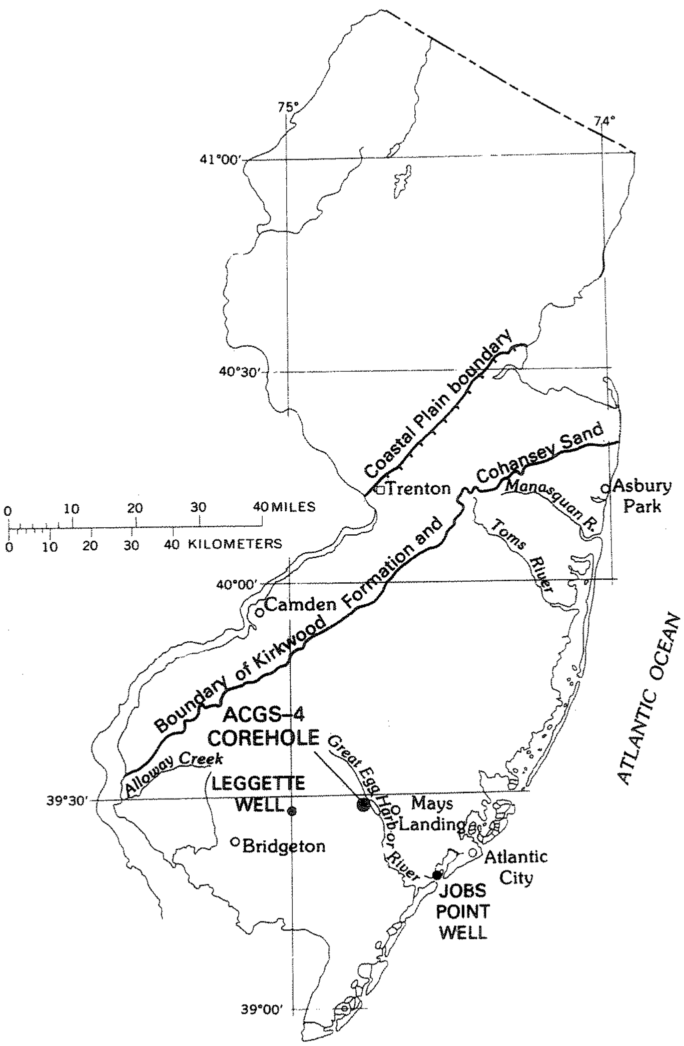


FIGURE 1.—Location of the ACGS–4 corehole in the southern New Jersey Coastal Plain. Hole is 3.7 mi northwest of Mays Landing, N.J., at the Atlantic County Girl Scout Council Camp 4 on the banks overlooking the Great Egg Harbor River.

downdip Kirkwood be divided into two units, one early Miocene and the other late Miocene in age. The younger unit was presumed to have been deposited after a long hiatus encompassing the middle Miocene.

The age of the Cohansey Sand has been even more enigmatic than that of the Kirkwood. The Cohansey has been assigned ages ranging from middle Miocene (Owens and Minard, 1979) to late Miocene–early Pliocene (AAPG, 1983). The scarcity of fossil invertebrates has precluded precise dating of the Cohansey. Greller and Rachele (1983), in a study of the microflora (palynomorphs), favored a middle Miocene age for a peat bed (termed the "Legler lignite") in the Cohansey. They, thus, revised Rachele's 1976 proposal of a Pliocene age.

The Kirkwood and Cohansey lie at the northern end of a large late Tertiary basin. More thoroughly studied sediments that were deposited farther south in the same basin make up the Chesapeake Group (fig. 2) in Delaware, Maryland, and Virginia. Gibson (1983) considered the Kirkwood to be equivalent to most of the Miocene formations in the Chesapeake Group, including the Eastover Formation, and the Cohansey to be equivalent to the Pliocene Yorktown Formation. In the AAPG (1983) chart, on the other hand, the Kirkwood was equated with the Calvert and Eastover Formations, but not with the Choptank and St. Marys Formations, and the Cohansey was again correlated with the Yorktown.

The Paleogene units that crop out in New Jersey include the Hornerstown Sand and Vincentown Formation of Paleocene age and the Manasquan Formation of early Eocene age (Lewis and Kümmel, 1912). In addition, a middle and upper Eocene unit, the Shark River Formation, has been reported in the northern New Jersey Coastal Plain, but its areal distribution is poorly known (Enright, 1969). Olsson and others (1980) reported the presence of lower and middle Eocene units in New Jersey, as well as an upper Oligocene unit (their Piney Point Formation).

The Paleogene beds exposed in outcrops in New Jersey are largely shelf deposits, and these marine units, along with those of Late Cretaceous age, represent cyclic deposition (Owens and Sohl, 1969; Owens and Gohn, 1985). A typical New Jersey sedimentary cycle has a basal transgressive bed (commonly a glauconite sand), a middle regressive clayey or silty unit, and an upper regressive quartz sandy unit. These cycles are interpreted to represent a transition from deep to shallowing conditions; hence, they can be used to interpret basin responses to tectonic crustal movements or eustatic sea-level changes.

In an effort to obtain lithologic and age data on Paleogene and Neogene units in southeastern New Jersey, the ACGS–4 hole was cored to 945 ft near Mays Landing, N.J. (fig. 1). The designation "ACGS–4" is derived from the Atlantic County Girl Scout Council Camp 4, where the corehole was drilled between October 1 and November 15, 1984. This site was selected because detailed geologic and hydrologic information had never been collected from the area and because the upper Tertiary units were expected to be thicker and less weathered there than in the updip sections to the northeast. We planned to compare data from the ACGS–4 hole with data from elsewhere in New Jersey and with data on the better studied formations of the Chesapeake Group (fig. 2) to the south in Delaware, Maryland, and Virginia. A prime objective in drilling this hole was to define the Kirkwood Formation. Also, we hoped to date and describe all units in the core, to resolve inconsistent correlations, and to determine if cyclic sedimentation could be recognized in the Paleogene units.

The hole extended through Miocene and Oligocene beds and bottomed in the lower Eocene Manasquan Formation. The section from the early Eocene through the early Oligocene is nearly complete at this locality; in fact, it is one of the most complete sections through this part of the geologic column found anywhere to date in the U.S. Atlantic Coastal Plain. The presence of upper Eocene and lower Oligocene sediments in the New Jersey Coastal Plain was heretofore unknown. Thus, informal names are used for some units.

The stratigraphy and depositional environments of the sediments found in the ACGS–4 corehole are the subject of this report. Brief sections on the tectonic setting and style of sedimentation are followed by descriptions of each unit found in the core, from the bottom up. The core log is the appendix.

ACKNOWLEDGMENTS

Many people were involved in this project. Two organizations participated in drilling the ACGS–4 hole and analyzing various parts of the recovered core. The hole was drilled as a cooperative effort by the New Jersey Geological Survey and the U.S. Geological Survey (USGS). This report is a product of the Federal and State Cooperative Geologic Mapping (COGEOMAP) component of the National Geologic Mapping Program. Special thanks are extended to the Atlantic County Girl Scout Council for allowing us to drill on their property near Mays Landing, N.J.

We thank Dennis W. Duty and Donald G. Queen of the USGS, whose efforts in drilling the corehole made this paper possible. We also thank the following people in the USGS: George W. Andrews for providing diatom data, Richard Z. Poore and Wylie C. Poag for examining planktic foraminifers, and Lauck W. Ward for providing molluscan data.

Among the authors, Laurel M. Bybell provided the nannofossil data, and Thomas A. Ager provided the palynological data. The rock stratigraphy was provided by James P. Owens, Peter J. Sugarman, Gary Paulachok, and Virginia M. Gonzalez. The mineralogic data were provided by Owens and Gonzalez.

TECTONIC SETTING

The New Jersey Coastal Plain is largely a siliciclastic province, in which sediments are as much as 6,400 ft thick in southernmost New Jersey. These sediments accumulated in parts of two large basins: the Salisbury to the south and the Raritan to the north (fig. 3). Basins or depocenters along the U.S. Atlantic continental margin have migrated through time. The Salisbury and Raritan embayments illustrate such basin mobility. The southern part of the Salisbury embayment, for example, was downwarped in the Berriasian Age of the Early Cretaceous (Owens and Gohn, 1985). The northern part of this basin downwarped later, during the Aptian to Albian Ages. The Raritan embayment, on the other hand, began forming much later, in the late Cenomanian of the Late Cretaceous (Owens and others, 1968).

EPOCH		AGE	FORMATIONS IN MARYLAND, VIRGINIA, AND DELAWARE	
PLEISTOCENE			Omar Formation Accomack Member	
PLIOCENE	Late	Piacenzian	Chowan River(?)	Chesapeake Group
	Early	Zanclean	Yorktown-Brandywine	
MIOCENE	Late	Messinian		
		Tortonian	Eastover	
	Middle	Serravallian	St. Marys	
			Choptank	
		Langhian	Calvert	
	Early	Burdigalian		
		Aquitanian		
OLIGOCENE	Late	Chattian	Old Church	

FIGURE 2.—Ages of formations of the Chesapeake Group in Maryland, Virginia, and Delaware at the southern end of the large Miocene and Pliocene basin that underlies the Coastal Plain from Virginia to New Jersey.

The late Paleogene and Neogene depocenters, which are of prime interest in this report, indicate very different basin histories. The upper Paleogene sediments are thicker in the Raritan embayment than in the Salisbury embayment; this difference in thickness suggests greater downwarping for the Raritan embayment. Neogene sediment thicknesses in this region suggest a reverse motion from that noted in the Cretaceous-Paleogene basins. The Miocene beds are thicker in the Salisbury embayment, and the oldest Miocene sediments are present only in New Jersey and eastern Delaware. The Pliocene depositional basin, however, was centered in the southeastern Virginia Coastal Plain. No Pliocene marine beds are present in New Jersey; hence, this region is believed to have been an arch or at least a positive area at this time. Thus, the basin movements in the Miocene and Pliocene were from north to south.

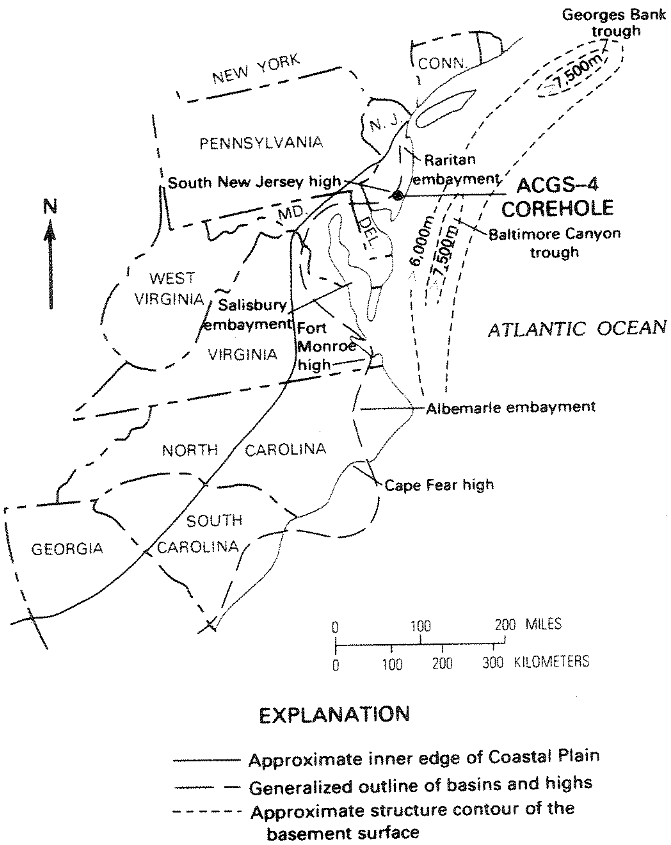


FIGURE 3.—The tectonic setting of the ACGS–4 corehole in the east-central United States (modified from Owens and others, 1968). Of particular interest are the Salisbury and Raritan embayments, whose evolution has controlled the formation of the New Jersey Coastal Plain. The ACGS–4 hole lies athwart the South New Jersey high.

The basin development described above suggests that the basement below the present middle U.S. Atlantic continental margin was mildly deformed. Although this margin is commonly characterized as passive (Bally, 1981), the regional pattern of migrating basins and faulted coastal-plain margins (Mixon and Newell, 1977) indicates a more active margin having a history of long-term crustal motion beneath the present Coastal Plain.

STYLE OF SEDIMENTATION

The sediments of the New Jersey Coastal Plain formations accumulated along the continental margin in an area that was affected by mild tectonic deformation and eustatic sea-level changes. These sediments are a complex wedge of basin-edge deposits in which a terrestrial component (mainly deltaic deposits) interfingers with a marine (shelf) component. A theoretical model illustrating this relationship is given in figure 4, which shows some of the more common facies found in deltaic and marine-shelf environments.

Facies changes are more rapid in the thicker, more sedimentologically inhomogeneous, deltaic deposits than in the thinner, more homogeneous, shelf deposits. However, the shelf deposits commonly exhibit a strong cyclic character in which finer grained sediments (interpreted to mean deposition farther from the source or in deeper water) occur at the bottom and coarser grained sediments (interpreted to mean deposition closer to the source or in shallower water) occur at the top. These cycles are believed to have been controlled primarily by eustatic changes in sea level. The transgressive (deeper water) deposits represent the initial rise in relative sea level and the shoreward movement of deeper water deposits. The regressive (shallower water) deposits record a fall in relative sea level and the movement of the shallow-water deposits away from the emerging land mass. Traditionally, the lithofacies composing a cycle have been mapped as individual formations. In actuality, a cycle could just as easily be defined as a single

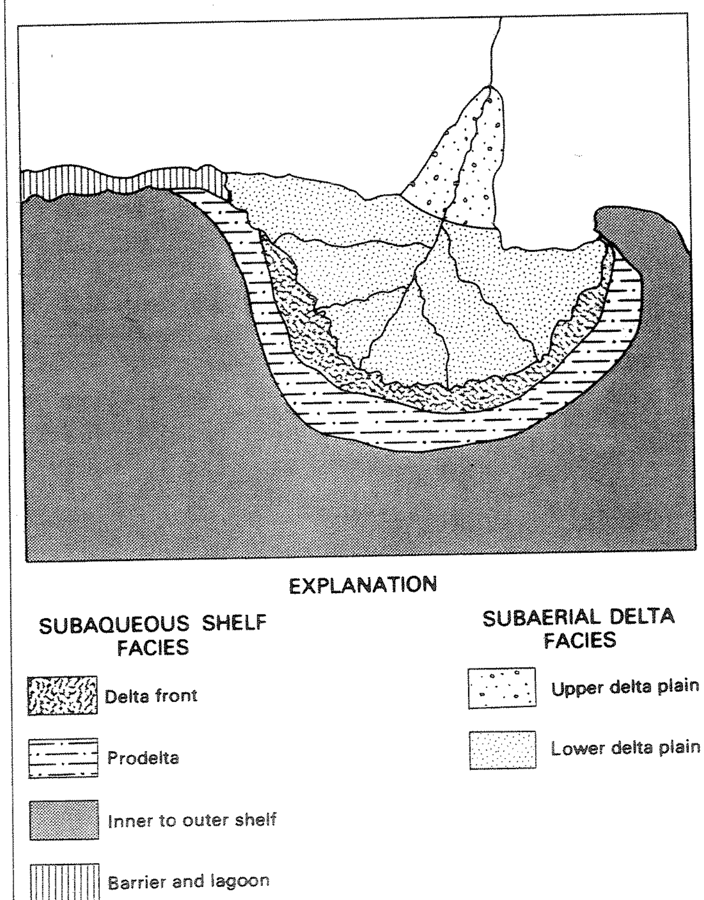


FIGURE 4.—Generalized theoretical depositional model of a delta-shelf association that generally applies to the New Jersey Coastal Plain. The complex interfingering of the facies associated with these depositional environments has resulted in the present clastic sequences of the New Jersey Coastal Plain.

formation. Both interpretations are acceptable according to the "North American Stratigraphic Code" (North American Commission on Stratigraphic Nomenclature, 1983).

In summary, the present New Jersey Coastal Plain consists of a complex interleaving of deltaic and shelf deposits. The sediments found in the ACGS–4 corehole are discussed below in this light.

COREHOLE STRATIGRAPHY

The ACGS–4 hole was cored to a depth of 945 ft; the sediments recovered are all Tertiary in age. A generalized stratigraphic column is shown in figure 5, along with the total thickness of the units and the approximate amount of their recovery. The seven formations penetrated in this corehole range in age from early Eocene to middle Miocene; from oldest to youngest, they are the Manasquan Formation, Shark River Formation, ACGS Alpha unit, Mays Landing unit, ACGS Beta unit, Kirkwood Formation, and Cohansey Sand. These units are discussed below, and the appendix describes gross lithologies and shows the recovery intervals for the entire core.

PALEOGENE FORMATIONS

The five Paleogene formations in the ACGS–4 core are herein assigned ages as follows: Manasquan Formation, early Eocene; Shark River Formation, middle and late Eocene; ACGS Alpha unit, late Eocene and early Oligocene; Mays Landing unit, early Oligocene; and ACGS Beta unit, probable late Oligocene. The ACGS Beta unit may be younger than late Oligocene and, hence, may be a Neogene unit. Nonetheless, this unit is discussed with the Paleogene formations. The total thickness of the Paleogene is about 460 ft.

MANASQUAN FORMATION

The oldest unit penetrated in the ACGS–4 corehole is the Manasquan Formation, of early Eocene age. The hole bottomed within this formation, which extends from 945 to 893.5 ft in the corehole; all 51.5 ft of sediment were recovered.

In the ACGS–4 hole, the Manasquan is a crudely bedded to finely laminated, pale-olive, clayey silt (see appendix and figs. 6*A*, *B*). Burrows are common, and fine glauconite sand is dispersed throughout the dominantly clayey matrix. Near the top of the formation (fig. 6*C*), the glauconite grains increase in size to medium sand and occur in small stringers. The uppermost 6 in. of the formation are intensely burrowed, and the burrows are filled with glauconite derived from the overlying formation.

The Manasquan contains abundant calcareous microfossils, but macrofossils are rare. Washed samples from the Manasquan reveal that small, translucent, brown fragments of phosphatic vertebrate fossils are also common constituents in the upper part of the formation.

Petrology

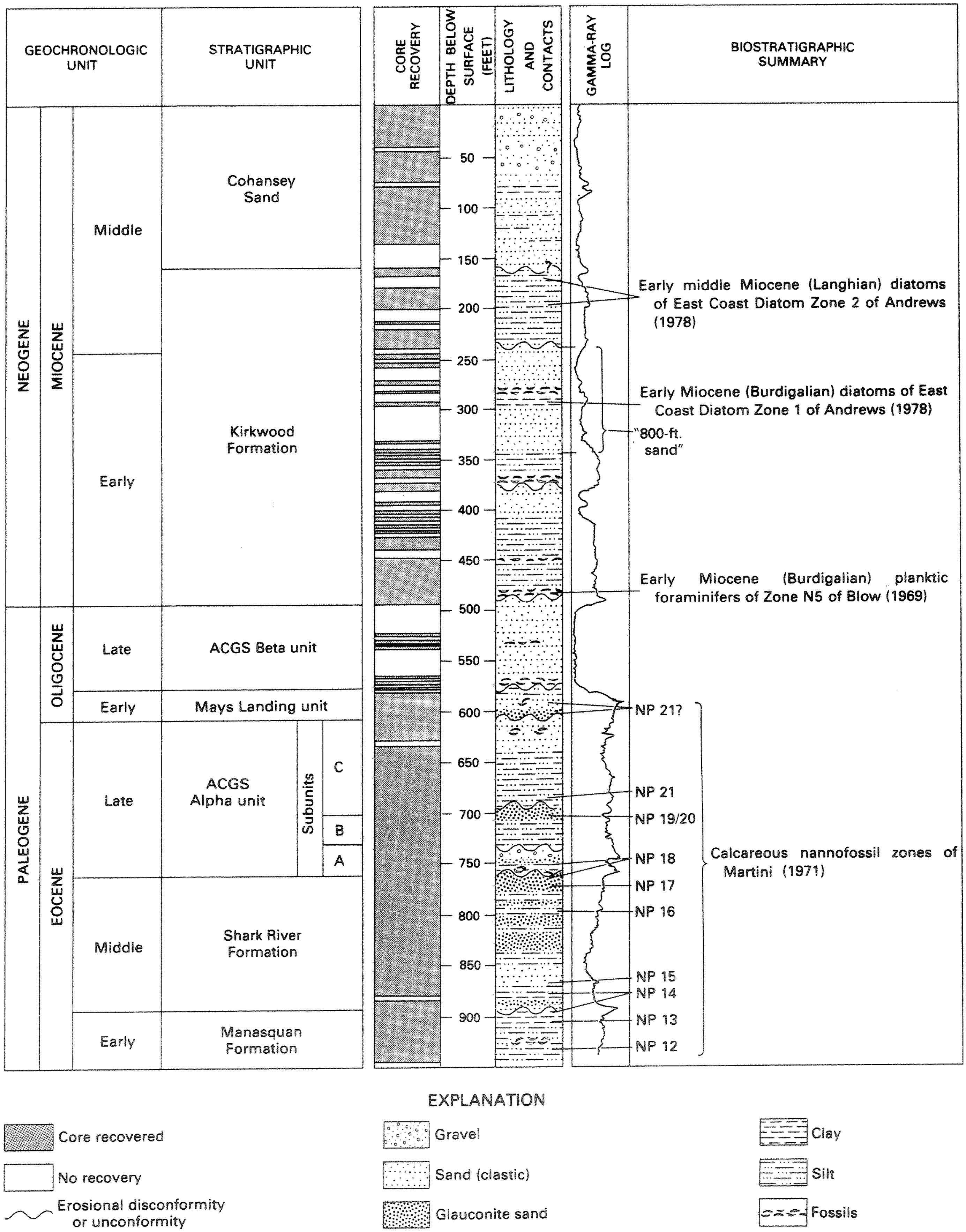
No sand-sized detrital mineral grains were recovered from the Manasquan in the core. X-ray diffractograms of the clay fraction reveal that illite-smectite is the major mineral present (fig. 7), although smaller amounts of illite are also present.

Environment of Deposition

The fossiliferous, fine-grained sediments of the Manasquan in this corehole are marine shelf deposits. The fine texture and abundant microfossils suggest deposition some distance from the shoreline, probably on the middle to outer shelf. The thinly laminated and extensively bioturbated, clayey silt, the few, thin, low-angle cross strata, and the common phosphatic vertebrate remains are all characteristic of relatively deep water deposition. The composition of the clay fraction, which contains no kaolinite, a little illite, and abundant illite-smectite, is also compatible with a middle to outer shelf depositional environment. Kaolinite and illite form larger crystals than illite-smectite; thus, kaolinite and, to a lesser degree, illite tend to concentrate in nearshore environments.

Age

Calcareous nannofossils in the ACGS–4 core from 945 to 893.5 ft indicate that the Manasquan is represented by calcareous nannofossil Zones NP 12, NP 13, and NP 14 of Martini (1971) (fig. 5). *Discoaster lodoensis*, which first appears at the base of Zone NP 12, and *Tribrachiatus orthostylus*, which has its last-appearance datum (LAD) at the top of Zone NP 12, are both present at the base of the core at 945 ft. Above 920.5 ft in the core, *T. orthostylus* is absent, and this part of the Manasquan is placed in Zone NP 13. A sample at 902 ft contains *Discoaster sublodoensis*, which has its first-appearance datum (FAD) at the base of Zone NP 14. According to the geochronology of Berggren and others (1985), these zone assignments indicate that the Manasquan in the core was deposited in the early Eocene (late Ypresian Age) between 55.3 and 52 Ma. The zone assignments also indicate that the Manasquan in the core is equivalent to most of the Tallahatta Formation in the Gulf of Mexico Coastal Plain (Bybell and Gibson, 1985) and to beds in the upper part of the Nanjemoy Formation in Maryland and Virginia that correlate with Zones NP 12 and 13.



GEOCHRONOLOGIC UNIT
STRATIGRAPHIC UNIT
CORE RECOVERY
DEPTH BELOW SURFACE (FEET)
LITHOLOGY AND CONTACTS
GAMMA-RAY LOG
BIOSTRATIGRAPHIC SUMMARY
NEOGENE
MIOCENE
Middle
Early
PALEOGENE
OLIGOCENE
Late
Early
EOCENE
Late
Middle
Early
Cohansey Sand
Kirkwood Formation
ACGS Beta unit
Mays Landing unit
ACGS Alpha unit
Subunits
C
B
A
Shark River Formation
Manasquan Formation
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
Early middle Miocene (Langhian) diatoms of East Coast Diatom Zone 2 of Andrews (1978)
Early Miocene (Burdigalian) diatoms of East Coast Diatom Zone 1 of Andrews (1978)
"800-ft. sand"
Early Miocene (Burdigalian) planktic foraminifers of Zone N5 of Blow (1969)
NP 21?
NP 21
NP 19/20
NP 18
NP 17
NP 16
NP 15
NP 14
NP 13
NP 12
Calcareous nannofossil zones of Martini (1971)
EXPLANATION
Core recovered
No recovery
Erosional disconformity or unconformity
Gravel
Sand (clastic)
Glauconite sand
Clay
Silt
Fossils

Formation Name and Distribution

Sediment in the core from 945 to 893.5 ft was placed in the Manasquan Formation because (1) it unconformably underlies the Shark River Formation, (2) its fossils indicate an early Eocene age of 55.3–52 Ma, and (3) its petrology, lithology, and environment of deposition are similar to those of the upper clayey silt of the Manasquan Formation in outcrops east and southeast of Trenton and along the Manasquan River in New Jersey. In those outcrops, the Manasquan consists of two informal members: a lower quartz glauconite sand and an upper light-colored clayey silt called the ash marl by Clark (1893). The Manasquan Formation appears to be coeval with and similar lithologically to the Nanjemoy Formation of Maryland and Virginia. These formations may have been deposited in a large basin that occupied much of what is now New Jersey and extended south to the Maryland-Virginia area during the early Eocene.

SHARK RIVER FORMATION

The Shark River Formation in the ACGS–4 corehole unconformably overlies the Manasquan Formation above a sharp contact and is approximately 132 ft thick, ranging from 893.5 to 761 ft. Approximately 90 percent of the formation was recovered during coring.

In the basal 4.5 ft, fine to medium, authigenic glauconite sand is abundant in thin beds. This interval is intensely burrowed (fig. 8*A*) and contains abundant phosphatic debris (fish parts) and occasional small shark teeth.

The lower half of the formation in the corehole is normally a light-colored, yellowish-green to light-olive-gray clayey silt and silty, very fine sand containing varying amounts of glauconite sand. The number of burrows decreases upward above the basal 4.5 ft even though the overlying beds are intensely burrowed. The formation is crudely bedded from 885 to 849 ft (fig. 8*B*). Fine to very fine glauconite sand dominates the sand fraction in the lower half of the formation. These grains are scattered randomly throughout the dominantly clay-silt matrix. The lower half of the formation also contains abundant calcareous microfossils. Small, thin-walled mollusks are common between 833 and 825 ft. At 844 ft (fig. 8*C*), a burrowed zone (hard ground) contains flattened shells and calcite-filled toredo burrows.

The upper half of the formation is a darker green (typically dusky yellow-green) than the lower half. The basal part of the upper half (825–815 ft) has abundant small macrofossils and glauconite sand (fig. 8*D*.) Overlying this interval are thick beds of shelly, clayey silt and shelly, clayey, glauconite sand in which the sandy beds are intensely bioturbated. Glauconite sands in this interval are medium to less commonly coarse sand size; the coarser grains are most abundant in the upper 35 ft of the formation. Large shells are associated with the coarse glauconite sands in the upper 35 ft (fig. 8*E*). The bedding characteristics of both the clayey and sandy strata indicate that some current activity was associated with deposition. The clayey silts are finely laminated, but the laminae are irregular, and very small crossbeds are present in places.

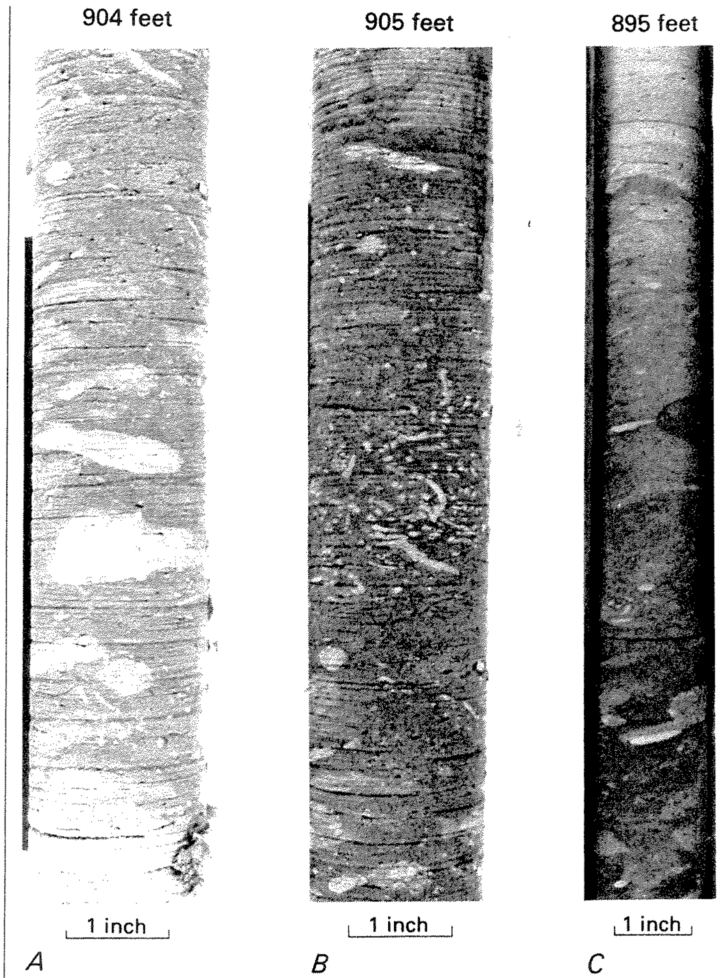


Figure 6.—Segments of the ACGS–4 core from the upper part of the Manasquan Formation. *A*, Core from 904 ft; *B*, Core from 905 ft; *C*, Core from 895 ft.

◀ Figure 5.—Stratigraphic column and gamma-ray log of the ACGS–4 corehole. Core recovery and lithology shown for the top 121 ft are composites of data from the main corehole and an adjacent hole (see appendix). The gamma-ray trace for sand is deflected to the left (toward lower readings), and that for clay (and silt) is deflected to the right (toward higher readings). For example, the ACGS Beta unit is mostly sand; hence, in this diagram, its trace is strongly deflected to the left.

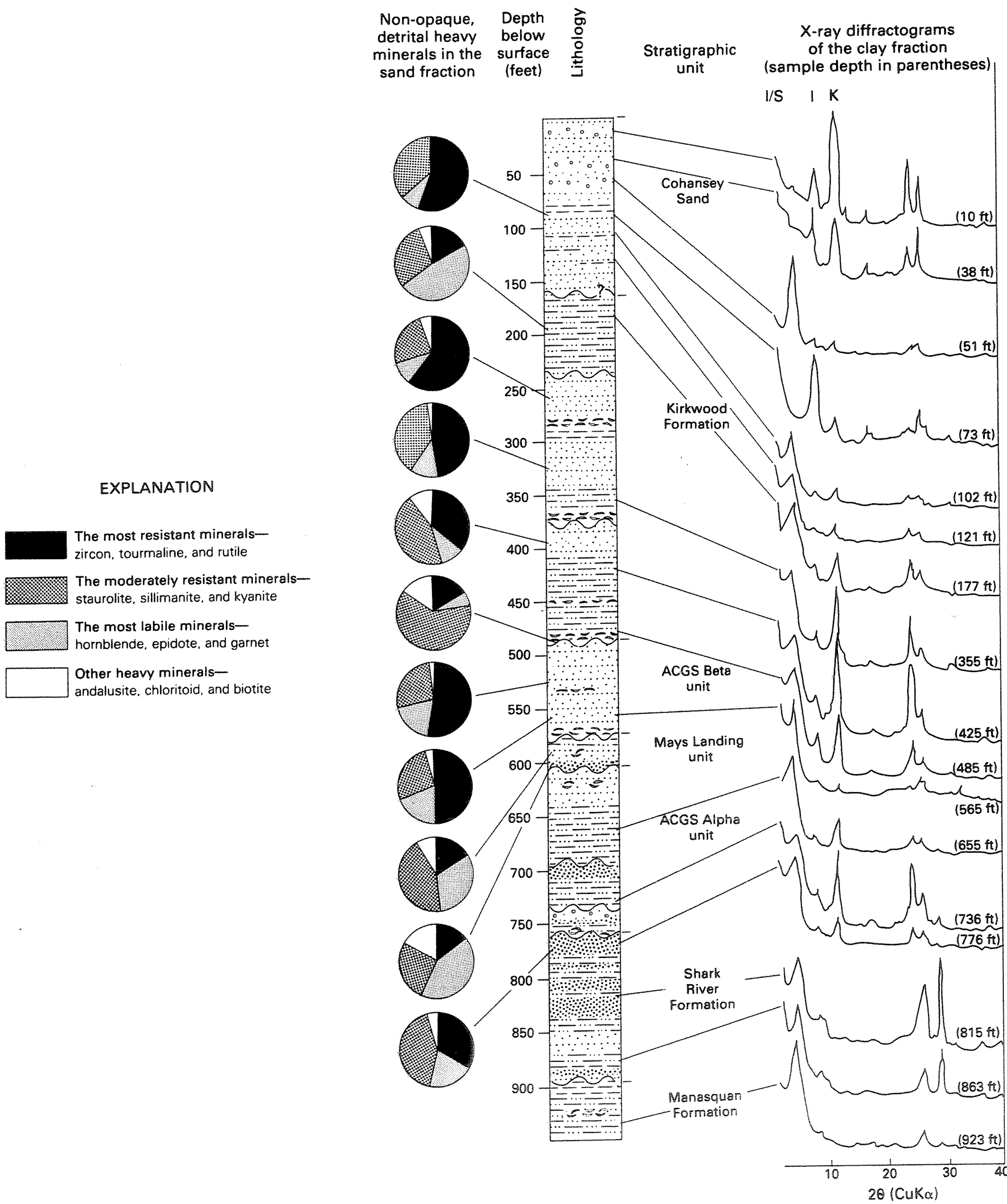
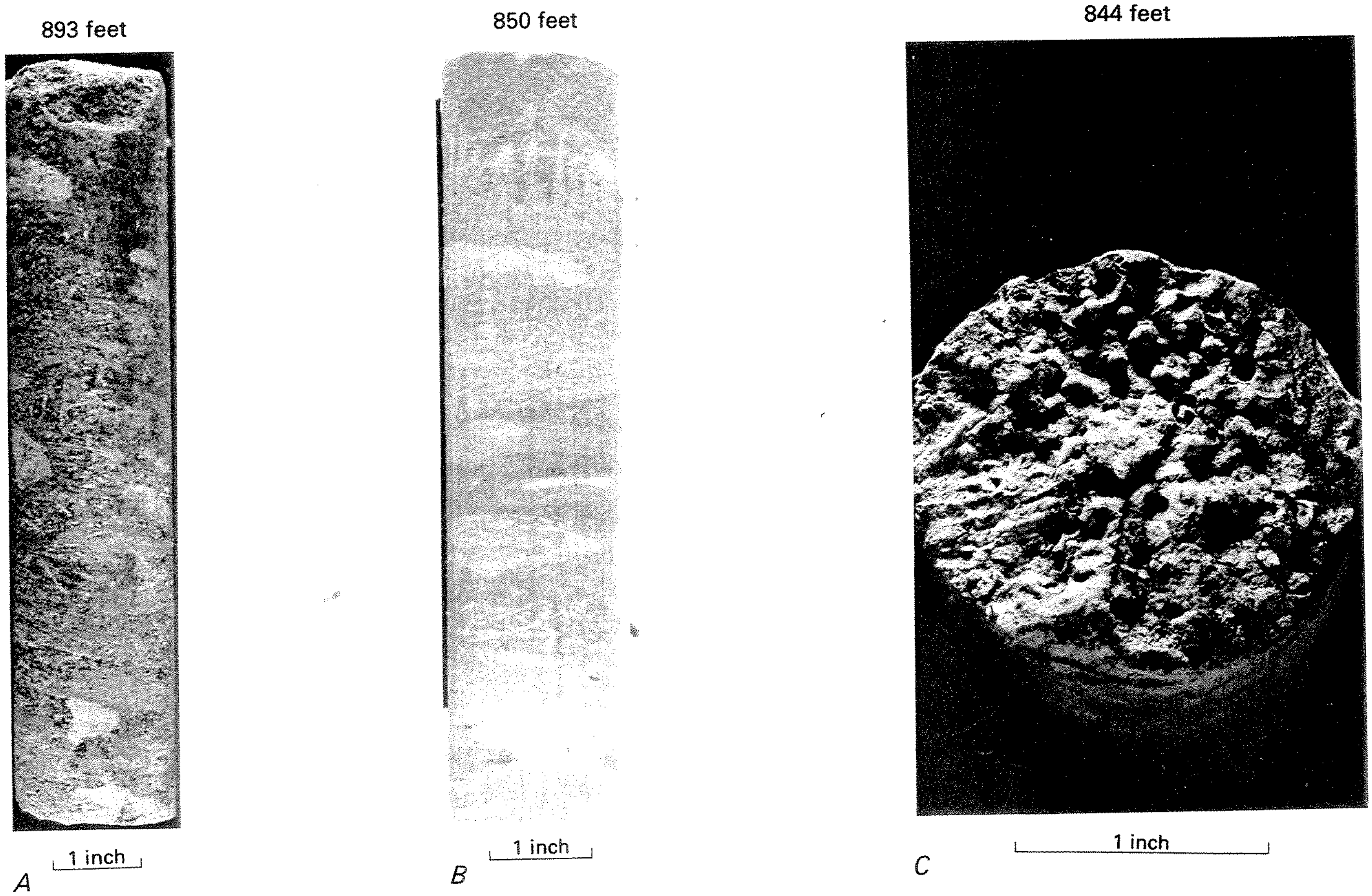


FIGURE 7.—X-ray diffractograms and pie diagrams showing clay and sand mineralogy of samples from the ACGS–4 core. The lithologic log is from figure 5. In the X-ray diffractograms, only the major reflection of each clay mineral is labeled: I/S, illite-smectite; I, illite; and K, kaolinite.



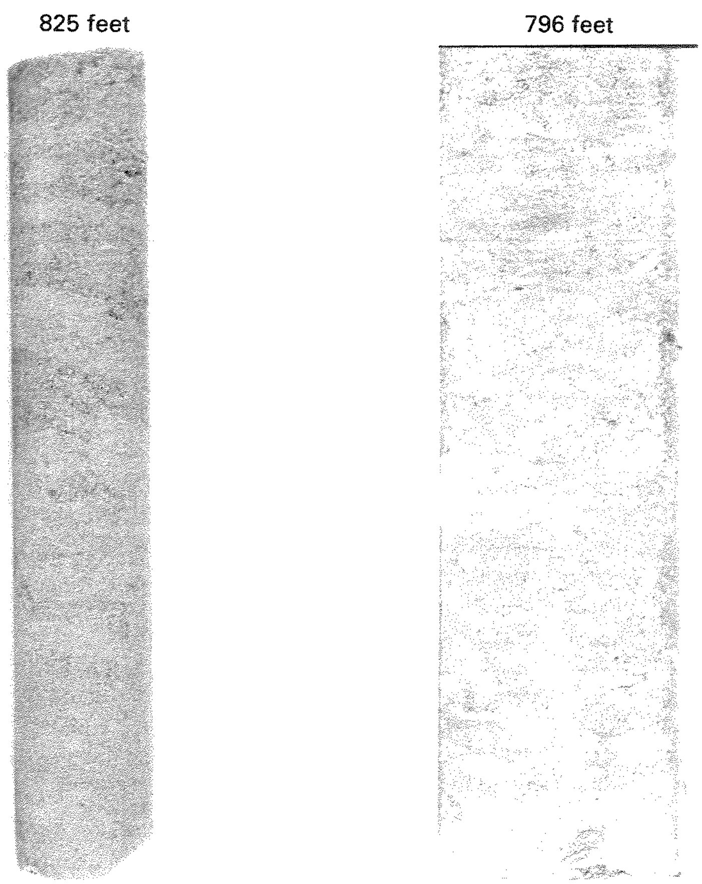


Figure 8.—Segments of the ACGS-4 core from the Shark River Formation. *A*, Core from 893 ft showing abundantly burrowed, silty, very fine sand. Most burrows are small, although some larger burrows are present. *B*, Core from 850 ft showing crude bedding. *C*, A broken surface along a thin layer of pyrite at 844 ft. The surface seems to be one of omission and is characterized by extensively burrowed pyritized wood; burrows are filled with calcite. Flattened large shells are also present here. Several other thin layers of pyrite are present within the formation. *D*, Core from 825 ft, which contains abundant fine glauconite sand. *E*, Core from 796 ft, which contains many shells (white irregular masses in photograph) and is extensively bioturbated.

Petrology

In the sand fraction of a sample from the Shark River Formation, the heavy-mineral assemblage is relatively immature (table 1), as evidenced by the presence of the labile minerals hornblende and chloritoid. The light minerals include large amounts of quartz and minor amounts of potassium feldspar. The Shark River, therefore, is an orthoquartzite (Pettijohn, 1975).

X-ray diffractograms of samples from the lower half of the Shark River in the core show that illite-smectite and, to a lesser degree, illite are the major clay minerals present (fig. 7). Clay-sized quartz is also common in this interval. In the upper part of the formation, kaolinite is present in moderate amounts associated with illite-smectite and illite.

Environment of Deposition

The Shark River Formation in the ACGS–4 corehole, like the underlying Manasquan Formation, is a marine shelf deposit. The burrowed authigenic glauconite sand and phosphatic debris of the basal 4.5 ft make this interval similar to the basal beds of transgressive units in Upper Cretaceous shelf deposits in New Jersey (Owens and Gohn, 1985). The scarcity of sand-sized quartz and feldspar suggests that this unit is a middle-to-outer-shelf deposit. The upper and lower facies within this unit, however, suggest changes in water depth; the deeper water facies in the lower half of the formation is succeeded by the somewhat shallower water facies in the upper half. The deeper water sediments of the lower half of the formation are characterized by extensive bioturbation, abundant calcareous microfossils, and little sand-sized material. The upper, shallower facies is characterized by an abundance of medium to coarse glauconite sand, local concentrations of calcareous macrofossils, small cut-and-fill structures, and some sand-sized quartz grains.

Age

Calcareous nannofossils in the ACGS–4 core from 893.5 to 761 ft indicate that the Shark River includes the upper part of Zone NP 14 of Martini (1971), Zones NP 15, NP 16, and NP 17, and the lower part of Zone NP 18. *Nannotetrina fulgens*, which has its FAD at the base of Zone NP 15, is present at 860 ft. A sample from 796 ft is presumed to fall within Zone NP 16 because it contains no specimens of the genus *Nannotetrina*, which is believed to extend no higher than Zone NP 15, but it does still contain *Chiasmolithus solitus*, whose LAD marks the top of Zone NP 16. *Chiasmolithus solitus* is absent at 786 ft, as is *Chiasmolithus oamaruensis*, which first appears at the base of Zone NP 18, and this sample is therefore placed in Zone NP 17. *Chiasmolithus oamaruensis* first appears in a sample at 767 ft; this FAD indicates that the upper part of this unit is in the lower part of Zone NP 18.

According to the geochronology of Berggren and others (1985), these zone assignments indicate that the Shark River in the core was deposited in the middle and late Eocene (late Lutetian, Bartonian, and early Priabonian Ages) between approximately 51 and 39.5 Ma. These zone assignments also indicate that the Shark River in the core is equivalent to the uppermost Tallahatta Formation, the Lisbon Formation, the Gosport Sand, and probably the Moodys Branch Formation in the Gulf of Mexico Coastal Plain. The Piney Point Formation at its reference locality in Virginia is middle Eocene in age (Ward, 1984), is placed in Zone NP 16 and possibly Zone NP 17, and is equivalent to the middle part of the Shark River.

Formation Name and Distribution

The Shark River Formation was named the Shark River marl by Conrad (1865) for scattered small outcrops along the Shark River near Asbury Park, N.J.; it was later better defined by Clark (1893, p. 208–210). This formation crops out only in the northern New Jersey Coastal Plain area. Because of its poor exposure and small areal outcrop distribution, the Shark River is the least studied of all the outcropping formations in the New Jersey Coastal Plain.

Enright (1969) best studied this formation and noted that the Shark River in outcrop is principally a clayey quartz glauconite sand; it is similar to some of the lithologies in the Shark River Formation in the ACGS–4 corehole. Additionally, he examined the middle Eocene sediments in the subsurface as far south as Toms River, N.J., and proposed a two-member zonation: a lower, glauconite-dominated member and an upper, more quartzose member.

Gohn and others (1983) considered the outcropping Shark River Formation in northern New Jersey in reference to their study of Eocene deposits in South Carolina. They concluded that the Shark River was middle Eocene in age, and this name has been adopted herein for the sediments from 893.5 to 761 ft in this corehole.

The only other place where middle Eocene beds crop out in the northern U.S. Atlantic Coastal Plain is in Virginia. Here these sediments are mapped as the Piney Point Formation. The Piney Point is primarily a massive, clayey, coarse quartz sand containing abundant finely dispersed carbonate matter (Ward, 1984). This unit was deposited in much shallower water than the Shark River Formation. Nonetheless, the Piney Point and the Shark River indicate a possible widespread onlap of the sea in a

TABLE 1.—*Detrital heavy and light minerals in the sand fractions of samples from the ACGS–4 corehole*

[Detrital heavy minerals were separated in bromoform and have specific gravities higher than 2.85. The sand fraction studied under the petrographic microscope consisted of grains having diameters ranging from 0.003 to 0.007 in. Opaque and non-opaque heavy-mineral fractions have been averaged to 100 percent. Sample designations under the formation names are depths below the surface in feet. Authigenic pyrite is designated C, common; A, abundant; VA, very abundant; ?, may be present. Authigenic glauconite is not reported here. Dot leaders (...) mean component was not found]

	Cohansey Sand							Kirkwood Formation						ACGS Beta unit		Mays Landing unit		ACGS Alpha unit	Shark River Formation
	10	26	47	81	101	120	155	165	197	253	325	395	485	525	565	594	613	729	774
Opaque heavy minerals																			
Ilmenite	21	27	49	69	86	81	79	75	52	68	72	52	31	67	76	47	47	86	80
Pseudorutile	36	57	41	25	8	11	15	24	14	20	21	23	24	27	20	16	11	3	2
Leucoxene	43	16	10	6	6	9	6	1	34	12	6	26	45	6	4	37	42	11	18
Pyrite	...	...	...	C	...	?	?	?	...	C	A	C	A	A	A	A	A	VA	A
Non-opaque heavy minerals																			
Zircon	62	26	25	37	54	38	63	47	4	32	35	22	4	39	39	7	3	21	12
Tourmaline	9	20	17	9	7	10	4	4	8	17	8	9	12	8	9	10	9	4	20
Rutile	5	12	9	10	2	4	4	4	5	12	2	4	3	9	3	...	2	8	...
Hornblende	1(?)	2	2	2	2	...	1	4	31	...	3	1	...	1	...	...	4	...	8
Epidote	...	...	...	...	...	...	...	...	10	...	4	5	1	...	...	14	27	18	...
Garnet	...	3	2	7	9	8	9	15	8	10	8	4	2	18	19	21	15	25	15
Staurolite	10	10	12	14	11	20	4	17	8	13	7	12	32	13	9	9	3	2	28
Sillimanite	10	18	26	19	9	16	10	4	21	11	28	28	17	8	17	29	19	6	1
Kyanite	3	8	7	2	3	4	3	2	...	...	2	5	13	5	1	3	1	16	12
Andalusite	...	...	...	...	...	...	...	...	...	...	...	...	2	...	...	...	...	2	...
Chloritoid	1	1	...	...	3	...	2	3	6	4	2	8	14	1	3	8	16	...	3
Biotite	...	...	...	...	...	...	...	...	...	...	...	2	...	...	...	...	...	...	...
Percentage of heavy minerals that are opaque																			
	84	82	75	71	82	83	80	78	72	74	82	81	61	61	76	64	75	81	75
Light minerals and rock fragments [Polycrystalline quartz was absent from all samples]																			
Common quartz	74	100	98	98	99	97	97	88	76	90	95	84	72	90	89	76	77	90	97
Potassium feldspar	...	...	1	...	...	2	3	7	9	5	4	7	23	6	9	17	17	10	3
Plagioclase	...	...	...	1	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...
Rock fragments	26*	...	1	2	1	...	...	5	15	5	...	9	5	4	2	7	6	...	...

*Rock fragments in the sample from 10 ft include 1 percent clay galls.

basin extending from what is now northern New Jersey to Virginia during the middle Eocene.

Some investigators have used the name "Piney Point" for coarse-grained subsurface sediments of the northern U.S. Atlantic Coastal Plain that are similar to the Piney Point Formation of Virginia; for example, Olsson and others (1980) used it for subsurface sediments in New Jersey. As discussed below in the "Formation Name and Distribution" section for the ACGS Beta unit, these sediments are late Oligocene in age, not middle Eocene, and the use of the name "Piney Point" for these sediments is not tenable and should be discontinued.

ACGS ALPHA UNIT

Upper Eocene and lower Oligocene sediments in the ACGS–4 corehole between 761 and 615 ft are bounded by unconformities. Core recovery was 97 percent in this interval. In this report, these sediments are informally called the ACGS Alpha unit because no other unit of this age has been reported in the Raritan embayment.

The ACGS Alpha unit, which unconformably overlies the Shark River Formation, is 146 ft thick and is divisible into three subunits separated by disconformities (see appendix). The regional extent of these disconformities is unknown at this time. The lowest subunit, A, occurs from 761 to 735 ft; the middle subunit, B, from 735 to 695 ft; and the uppermost and thickest subunit, C, from 695 to 615 ft.

Subunit A, which is approximately 26 ft thick, overlies the Shark River along a sharp contact. The basal beds are a brownish-gray, silty clay. This subunit is very fossiliferous and has abundant, small shells in the lower 5 ft; it then grades upward into a fine, glauconite sand, which is extensively burrowed and has scattered, worn, calcareous shells. At 748 ft, the subunit is generally a medium to coarse glauconite sand containing abundant broken shells. From 745 to 735 ft, the subunit consists of interbedded, medium to coarse glauconite sand containing scattered pebbles and clayey, fine to medium glauconite sand. Glauconite occurs in moderately sized burrows in this interval (fig. 9*A*).

Subunit B disconformably overlies subunit A along a sharp contact and is approximately 40 ft thick. The basal 10 ft of this subunit are an olive-black, clayey silt interbedded with slightly to moderately glauconitic, fine sand. Small shells are scattered throughout this interval (fig. 9*B*). The overlying 10 ft are mainly a silty fine sand, which is intensely burrowed. Between 719 and 717 ft, the sand consists of medium to coarse quartz and glauconite. The upper 20 ft are mainly fine to medium glauconite quartz sand containing interbeds of nonglauconitic silt. Moderately sized macrofossils are scattered throughout this interval.

Subunit C, which disconformably overlies subunit B, is 80 ft thick. The lower 60 ft (695–635 ft) of this subunit are a brownish-black, laminated, very clayey silt (fig. 9*C*). The lower 40 ft have small, thin-walled macrofossils scattered throughout and have small pieces of wood at some levels. The upper 20 ft (635–615 ft) are a massive to laminated, micaceous, fine sand (fig. 9*D*). Small, thin-walled shells are scattered throughout this interval also.

PETROLOGY

The non-opaque heavy minerals in the sand fraction of a sample from subunit B of the ACGS Alpha unit are mostly epidote, garnet, kyanite, and zircon (table 1). In the opaque-heavy-mineral fraction, ilmenite is very abundant. The light-mineral fraction is somewhat feldspathic, and subunit B is a subarkose (Pettijohn, 1975).

X-ray diffraction studies (fig. 7) indicate that illite-smectite and kaolinite are the major clay minerals; illite is present in only minor amounts in samples from both subunits A and C. The presence of large amounts of kaolinite distinguishes the ACGS Alpha from the underlying Manasquan and Shark River Formations.

ENVIRONMENT OF DEPOSITION

Subunits A, B, and C of the ACGS Alpha unit are separated by disconformities, and each of the three subunits has the same textural distribution; the lower beds are finer grained than the upper beds. The lower, finer grained beds are considered to be the deeper water (transgressive) phase, and the coarser grained beds represent the shallower water (regressive) phase. These deposits are, therefore, asymmetrically cyclic.

The clay minerals are dominated by kaolinite and support a relatively nearshore depositional site for the subunits in the ACGS Alpha. The presence of fine gravel and wood and the abundance of mica plates in the ACGS Alpha as a whole all indicate that the ACGS Alpha was deposited somewhat nearer the shoreline than the underlying Shark River Formation. Nonetheless, all the subunits of the ACGS Alpha unit are shelf deposits, and their lithologic characteristics suggest that they represent middle shelf deposition at its deepest and inner shelf deposition at its shallowest.

AGE

Calcareous nannofossils in the ACGS–4 core from 761 to 615 ft indicate that the ACGS Alpha unit includes the upper part of Zone NP 18, Zone NP 19/20, and the lower part of Zone NP 21 of Martini (1971). Zone NP 18 and Zone NP 19/20 define a late Eocene age, and Zone NP 21 straddles the Eocene-Oligocene boundary. The presence of *Chiasmolithus oamaruensis* and the absence of

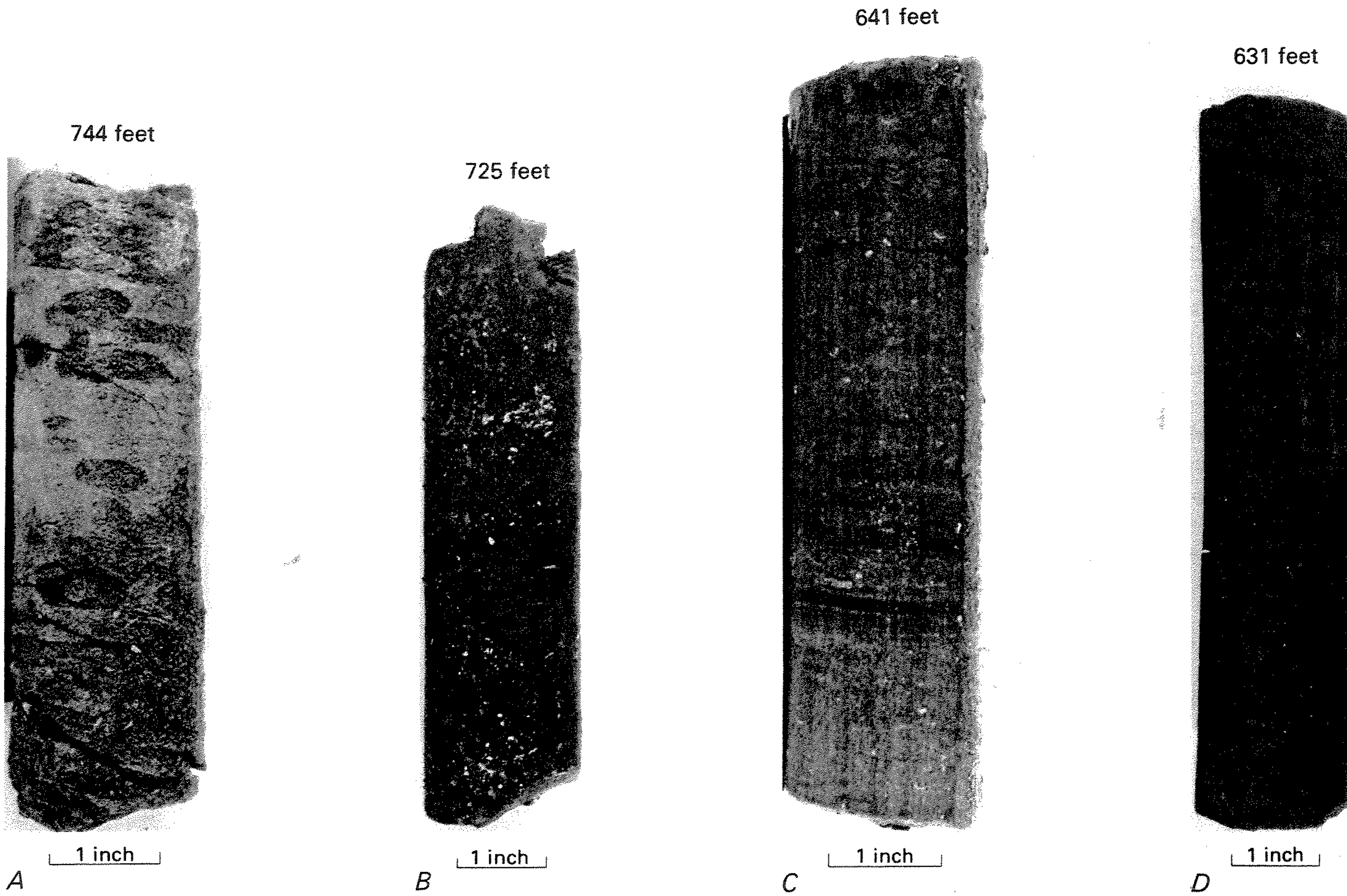


FIGURE 9.—Segments of the ACGS–4 core from the ACGS Alpha unit. *A*, Core from 744 ft showing light-colored matrix penetrated by numerous burrows filled with glauconite. This lithology is typical of subunit A. *B*, Core from 725 ft showing dark-colored aspect of subunit B. Small fossils are scattered throughout the interval shown, which is massive. *C*, Core from 641 ft; this segment is dark colored. The fine laminations characteristic of most of subunit C are evident. *D*, Core from 631 ft showing the massive character of the top part of subunit C. The dark lines are cracks formed after the core dried.

Isthmolithus recurvus between 760 and 755 ft indicate that the basal sediments of the ACGS Alpha are in the upper part of Zone NP 18. *Isthmolithus recurvus*, which has its FAD at the base of Zone NP 19/20, is present in a sample from 754.5 ft (subunit A), as is *Discoaster saipanensis*, which does not range above the top of Zone NP 19/20. A subunit C sample from 688 ft does not contain *Discoaster saipanensis*, *D. barbadiensis*, or *Cribrocentrum reticulatum*. These three species all last appear at or near the very top of Zone NP 19/20. The lack of these species and the presence of *Cyclococcolithus formosus*, which has its LAD at the top of Zone NP 21, indicate a zone NP 21 age for this sample. Representatives of *Turboroatalia cerroazulensis* s.l. (planktonic foraminifers) do not occur above 630 ft in the corehole; subunit C sediments above this depth are, therefore, placed in the lower Oligocene.

Pollen and spore samples collected from 680 to 620 ft include such taxa as *Momipites*, *Castanea* type, *Nyssa*, *Ilex*, *Carya*, *Ulmus*, *Tilia*, Sapotaceae, Ericales, *Pinus*, Taxodiaceae type, and *Podocarpus*. *Quercus* and quercoid pollen grains are present in small amounts. Rare specimens of *Aglaoreidia pristina* were observed at depths of 680 and 620 ft. All of the above-mentioned taxa have been found previously in the upper Eocene to lower Oligocene of the Gulf of Mexico Coast (Frederiksen, 1980).

According to the geochronology of Berggren and others (1985), the calcareous nannofossil and foraminifer zone assignments indicate that the ACGS Alpha was probably deposited between 39.5 and 36.5 Ma. This unit is approximately equivalent in age to the lower part of the Cooper Formation in South Carolina.

FORMATION NAME AND DISTRIBUTION

Sediments of late Eocene or early Oligocene age have not previously been reported from the New Jersey Coastal Plain; therefore, sediments of this age in the ACGS–4 corehole between 761 and 615 ft are informally called the ACGS Alpha unit. Upper Eocene beds in the northern U.S. Atlantic Coastal Plain were first described in the subsurface of southeastern Virginia by Cushman and Cederstrom (1945). They described this unit (the Chickahominy Formation) as primarily a glauconitic sandy clay. The ACGS Alpha unit in New Jersey is lithically much more heterogeneous than the unit in southeastern Virginia. Richards (1948) reported late Eocene macrofossils from beds beneath the lower Delmarva Peninsula. Benson and others (1985) did not find any upper Eocene sediments in a core near Dover, Del., in the middle of the Delmarva Peninsula, indicating that the upper Eocene sediments are restricted to the lower part of that peninsula. In New Jersey, upper Eocene sediments do not reach the outcrop belt and, therefore, are only a subsurface unit in this State. The late Eocene basin in the Salisbury and Raritan embayments is widespread but appears to lie well seaward of the present outcrop belt of the Coastal Plain formations.

MAYS LANDING UNIT

The Mays Landing unit, recognized for the first time in this report, unconformably overlies the ACGS Alpha unit in the ACGS–4 corehole and is early Oligocene in age. The unit is 40 ft thick in this corehole and extends from 615 to 575 ft. Core recovery was 95 percent.

The basal 9 ft of the Mays Landing unit (615–606 ft) are massive to laminated, fine, micaceous sand containing small shells and scattered pieces of lignitized wood. The upper 20 ft (595–575 ft) are thin interbeds of dark-greenish-gray, micaceous, silty clay and light-gray, micaceous, fine to medium, glauconite quartz sand. Small shells are scattered throughout this interval. In the upper part of the formation, small, disarticulated shells are concentrated between 595 and 585 ft. Woody fragments are common throughout the upper 20 ft.

PETROLOGY

In the sand fractions of the two analyzed samples of the Mays Landing unit, epidote, garnet, sillimanite, and chloritoid are the major non-opaque heavy minerals (table 1). In the opaque-heavy-mineral fraction, ilmenite, pseudorutile, and leucoxene are major detrital components. Pyrite is an abundant authigenic opaque mineral. In the light-mineral fraction, quartz is the most abundant mineral, and potassium feldspar and rock fragments are less common constituents. The feldspar content indicates that the Mays Landing is a subarkose (Pettijohn, 1975).

X-ray diffractograms (not shown in fig. 7) show that the clay-mineral assemblages in the Mays Landing unit are similar to those in the underlying ACGS Alpha unit.

ENVIRONMENT OF DEPOSITION

The Mays Landing unit is a marine deposit; its lithic character suggests deposition of the lower half of the formation in waters of moderate to shallow depth and deposition of the upper half of the formation in nearer shore, shallower depths.

The wood fragments and abundant mica associated with the interbedded sands and clays at the top of the formation indicate that this part of the formation probably was deposited in a prodelta. The lower part of the formation, because of its finer grained character and laminations, suggests either a distal prodelta or an inner shelf environment. Overall, the sedimentologic characteristics suggest a much shallower depositional site for this unit than that associated with the ACGS Alpha unit.

As seen in many of the older formations in this corehole, the upward coarsening and inferred shallowing environment of the Mays Landing indicate that a transgressive-regressive cycle is contained within this unit. The basal fine-grained beds are the deeper water, transgressive beds. The medium-grained, sandy beds at the top represent a regression.

AGE

Calcareous nannofossils in the ACGS–4 core from 615 to 575 ft indicate that the Mays Landing unit is most probably in the lower Oligocene part of Zone NP 21 of Martini (1971). According to the geochronology of Berggren and others (1985), this zone assignment indicates that the Mays Landing was deposited between approximately 36 and 35 Ma. Samples from this unit are placed in Zone NP 21 because *Cyclococcolithus formosus* is still sporadically present. The sporadic occurrence of *C. formosus* in the Mays Landing unit could indicate reworking of this species from below. However, reworking seems unlikely as *C. formosus* in the Gulf of Mexico Coastal Plain also has a decreased abundance in the upper part of its range.

Microfloras collected from the core at and above 610 ft show a dramatic increase in the *Quercus* and quercoid pollen where they are the dominant taxa. A similar abrupt shift in the amount of *Quercus* pollen was observed in Gulf of Mexico Coastal Plain deposits by Frederiksen (1980) at about the position of the boundary between the Jackson Group (upper Eocene) and the Vicksburg Group (lower Oligocene). This major vegetation change is also seen in plant microfossil and macrofossil records from North America and elsewhere in the world (Wolfe, 1985). Recent interpretations suggest that this shift was caused by climate change, apparently a global-scale cooling event during the late Eocene and early Oligocene (Wolfe, 1985; Wolfe and Poore, 1982). Apparently, few plant genera were eliminated from the

Gulf of Mexico and U.S. Atlantic Coastal Plains as a result of the cooling event(s), but a major restructuring of regional vegetation occurred. In the U.S. Atlantic Coastal Plain, this vegetation change appears to have involved a shift from predominantly tropical and subtropical, broad-leaved evergreen forests to subtropical and warm-temperate, broad-leaved deciduous forests adapted to a broader range of annual temperatures, as well as a lower mean annual temperature (Wolfe and Poore, 1982).

Formation Name and Distribution

The Mays Landing unit is recognized for the first time in this report. It has no known equivalents in the U.S. Atlantic Coastal Plain. It is equivalent in age to the Red Bluff and Bumpnose Formations in the Gulf of Mexico Coastal Plain.

ACGS BETA UNIT

Sediments in the ACGS–4 corehole between 575 and 485 ft are bounded by unconformities and are informally called the ACGS Beta unit because this is the only known occurrence of this unit in the Raritan embayment. Because the sediment is very loose and sandy, core recovery was very poor; less than 10 percent of the 90-ft-thick unit was recovered. However, the vertical extent of the unit in the corehole is well documented by a distinctive gamma-ray signature (fig. 5).

Short cores were recovered from the base and upper half of the unit. They show that the unit is typically dark-grayish-green to olive-gray, slightly clayey, poorly sorted, fine to medium sand (fig. 10). Locally, thin beds of coarse sand are interlayered with beds of medium to fine sand. Most of the sand is quartz, containing about 5–10 percent glauconite sand. Most of the glauconite is light to dark green and is botryoidal. Pale-tan, worn shell fragments are present and locally abundant throughout, as shown by drilling mud washings. In the base of the unit, thin beds of cemented, finely comminuted shells are present. The shells in this interval (575–563 ft) are small, thin walled, and most commonly a mactrid type.

Figure 10.—Segment of the ACGS–4 core from the ACGS Beta unit (515 ft) showing massive sand.

Petrology

Minerals in the sand fractions of two samples of the ACGS Beta unit are listed in table 1. Relative to all the underlying units, the ACGS Beta has the highest zircon content, and it also includes large concentrations of garnet. In the opaque-heavy-mineral fraction, ilmenite is the major mineral.

Most of the light-mineral fraction is quartz. Potassium feldspar is present in amounts of less than 10 percent, and plagioclase is absent. The ACGS Beta, therefore, is a subarkose to orthoquartzite (Pettijohn, 1975).

Clay minerals in the ACGS Beta, which are found only as matrix in the sand, are mainly illite-smectite and small amounts of kaolinite and illite (fig. 7).

Environment of Deposition

The very sandy, clastic nature of the ACGS Beta unit, which has an abundance of worn shell fragments throughout, indicates deposition on a very shallow marine shelf. The shells present (mactrid type) also indicate shallow-water deposition. The ACGS Beta was deposited in much shallower water than any of the underlying Paleogene deposits, as evidenced by the size and concentration of the clasts in this unit.

The nearshore sand of the ACGS Beta has a clay-silt matrix dominated by illite-smectite. This finding is puzzling, as in the underlying units, kaolinite, which forms relatively large crystals, dominates nearshore deposits, and illite-smectite dominates deep-water deposits.

The sediments in the ACGS Beta are relatively mature (largely a subarkose or orthoquartzite) and have a mature heavy-mineral content (high zircon). The maturity of the sand fraction indicates either reworking of sand from older units or derivation of resistant sand minerals from a deeply weathered provenance. The first hypothesis seems more likely. However, if the sand were derived from older units, it must have come from updip, more shoreward units west of the corehole because the underlying unit in the corehole (the 40-ft-thick Mays Landing unit) does not contain enough sand of the right grain size to have been the source of the 90-ft-thick ACGS Beta unit. However, older units updip from the corehole site do contain sufficient sand. For example, the presence of an abundant, Late Cretaceous microfauna supports possible reworking of such updip formations as the Maestrichtian Red Bank Formation. This interpretation is favored here and suggests that the ACGS Beta, because of its position relative to the Cretaceous outcrop belt, was deposited during a net regression, presumably following an earlier transgression in the late Oligocene or early Miocene.

Age

The ACGS Beta unit cannot be precisely dated. Foraminifers from the limestone layers at the base of the ACGS Beta in the corehole were examined by Wylie Poag; the dominant assemblage is a group of reworked Late Cretaceous planktic foraminifers, and two minor assemblages are present: (1) a few broken acarinids and a *Subbotina* of Eocene age and one specimen of *Globigerinita unicava* of Eocene or Oligocene age and (2) single specimens of *Bolivina multicostata* and "*Nonion*" cf. *calvertensis*, which are typical of the Miocene but do not rule out a late Oligocene age. The foraminifers in this interval, therefore, are clearly a mixed assemblage from several different ages; such mixtures are not uncommon in the basal parts of some transgressive coastal plain units.

Only one sample has been examined for fossil pollen and spores from the ACGS Beta unit in the core. The sand composing most of the unit is poorly suited for preservation of palynomorphs. The sample from 514 ft contains pollen of *Quercus*, *Carya*, *Fagus*, *Nyssa*, *Momipites*, *Liquidambar*, *Ilex*, *Alnus*, *Betula*, *Pinus*, *Tsuga*, *Podocarpus*, and Taxodiaceae-Cupressaceae type. *Alangium barghoornianum* is rare in the sample.

The lithology and stratigraphic position of the ACGS Beta unit are similar to those of the Old Church Formation at its type locality along the Pamunkey River in Hanover County, Va. (Ward, 1985). The only studies of the palynomorph assemblages in the Old Church Formation were reported by Frederiksen (1984a) and Edwards (1984) from deposits exposed along the Pamunkey River of Virginia. The fossil pollen assemblage reported by Frederiksen (1984a) contains many, but not all, of the taxa observed in the ACGS–4 core sample, and some of the taxa seen in the ACGS–4 sample have not been observed in the sample from Virginia. These differences in taxa may simply reflect local differences in vegetation at these two sites. Edwards (1984) studied the dinoflagellate assemblage in the Old Church Formation. Dinoflagellates are present in the sample from the ACGS–4 core but have not yet been studied.

Ward (1984, 1985) evaluated the various faunal studies of the Old Church Formation, which could not be more precisely dated than late Oligocene or early Miocene. Ward noted that a common problem in the Old Church is the presence of microfossil contaminants from older strata, a situation also found in the New Jersey strata.

At 570.5 ft in the ACGS–4 hole, the calcareous nannofossil species *Helicosphaera carterae* is present; this species does not appear to range earlier than the late Oligocene. However, it does not preclude a Miocene age. Therefore, the presence of upper Oligocene sediments in the ACGS Beta unit currently can be neither proven or disproven, but we favor the late Oligocene age.

Formation Name and Distribution

The name "Piney Point Formation" has been used widely for subsurface sediments of late Oligocene age (Olsson and others, 1980; Zapecza, 1984). Because the Piney Point was dated as middle Eocene at its reference section along the Pamunkey River in Virginia (DiMarzio, 1984; Ward, 1984, 1985), the use of this name for sediments in New Jersey has been discontinued in this report.

Sediments between unconformities at 575 and 485 ft in the ACGS–4 corehole are informally called the ACGS Beta unit because this is the only known occurrence of this unit in the Raritan embayment. Olsson and others (1980) dated sediments similar to the ACGS Beta unit from the Leggette well (fig. 1) near Vineland, N.J., as late Oligocene.

Sediments of late Oligocene(?) age have been found in the subsurface at Dover, Del. (Benson and others, 1985), and in outcrops of the Old Church Formation in southeastern Virginia (Ward, 1985). The upper Oligocene sediments, therefore, appear to be widespread in the Salisbury embayment, cropping out, however, only in Virginia.

NEOGENE FORMATIONS

The Neogene deposits of marine origin in the New Jersey Coastal Plain include the Kirkwood Formation (lower to middle Miocene) and the Cohansey Sand (middle Miocene). Both occur in the ACGS–4 corehole, where they total about 485 ft in thickness.

KIRKWOOD FORMATION

The ACGS Beta unit is overlain unconformably along a sharp contact by the lower to middle Miocene Kirkwood Formation. As stated in the Introduction, definition of the Kirkwood was one of the prime objectives for drilling the ACGS–4 corehole. The Kirkwood in this corehole is 323 ft thick; core recovery was 47 percent. Although the Kirkwood in the corehole contains a wide range of lithologies from fine, gravelly sand to silty sand, it can be divided into three lithic sequences separated by disconformities. Each sequence consists of a lower, fine-grained section and an upper, coarse-grained section. The three sequences occur from 485 to 385 ft, from 385 to 245 ft, and from 245 to 162 ft in the corehole.

In the first and lowest lithic sequence, the basal 5 ft between 485 and 480 ft consist of highly bioturbated, olive-green to grayish-olive-green, clayey, micaceous, very glauconitic, fine sand. Scattered quartz granules and sand-sized pieces of lignitized wood are common in this interval. Washed samples of this sand reveal that both planktic and benthic foraminifers are common. Glauconite decreases rapidly upward, and above the basal 5 ft, this mineral is very rare. The overlying 20 ft (480–460 ft) are laminated to very thinly bedded, brownish-gray to moderate-brown, micaceous, clayey silt (fig. 11*A*). Microfossils are common to abundant in the lower 10 ft of this interval (480–470 ft) but are rare above.

Sediments in the succeeding 48 ft (460–412 ft) change in bedding style and become laminated clayey silt and more massive beds of silty fine sand (figs. 11*B–E*). These beds are the same dark gray and brown as those below. Small, calcareous shell fragments are scattered throughout this interval. From 410 to 385 ft, the sediment is a coarse sand at the base and a fine gravel (maximum size 0.25 in.) near the top. These beds are olive gray and dusky yellowish brown. Fine wood fragments and peaty fibers are associated with abundant pyrite throughout this interval.

In the second sequence (385–245 ft), a 3-ft-thick, medium to coarse sand at the base contains sparse, small pebbles; broken, thin-walled mollusk shells; finely dispersed organic matter; and abundant pyrite masses. Between 382 and 335 ft (figs. 12*A–D*), the sediment consists of laminated to very thinly intercalated silt and very fine sand. These beds have abundant fine mica and finely dispersed carbonaceous matter. Locally, the beds are extensively bioturbated and have scattered and broken, thin-walled shells. The upper part of this lithic sequence between 335 and 245 ft is generally a loose, olive-gray, medium to coarse, quartz sand. Thick shell beds (as much as 1 ft thick) are interstratified with the sands (fig. 12*E*). The shells in this interval are usually broken and oriented roughly parallel to bedding.

The base of the third sequence between 245 and 241 ft consists of a silty fine sand containing scattered quartz and black, shiny, phosphate granules. This interval is overlain by approximately 40 ft of dusky-yellowish-brown, massive to less commonly laminated, diatomaceous, clayey silt and fine sand (figs. 12*F–H*). At 200 ft, there is a change from the fine sand below to a slightly clayey, very fine sand. Diatoms, small flakes of mica, and finely dispersed lignitized wood are common constituents in the interval from 200 to 185 ft. The top 13 ft of this lithic sequence (175–162 ft) consist of intercalated, thin beds of olive-gray silt and light-yellow, micaceous, medium sand.

Petrology

The sand fractions of samples from the Kirkwood Formation exhibit some range in heavy-mineral assemblages (table 1). For the most part, assemblages of non-opaque heavy minerals are dominated by the most resistant minerals, zircon, tourmaline, and rutile, and the moderately resistant minerals, staurolite, sillimanite, and kyanite. Hornblende and epidote are also typically present in small amounts, although in one sample from 197 ft, these minerals are major constituents. The presence of hornblende, epidote, and garnet suggests a relatively immature assemblage.

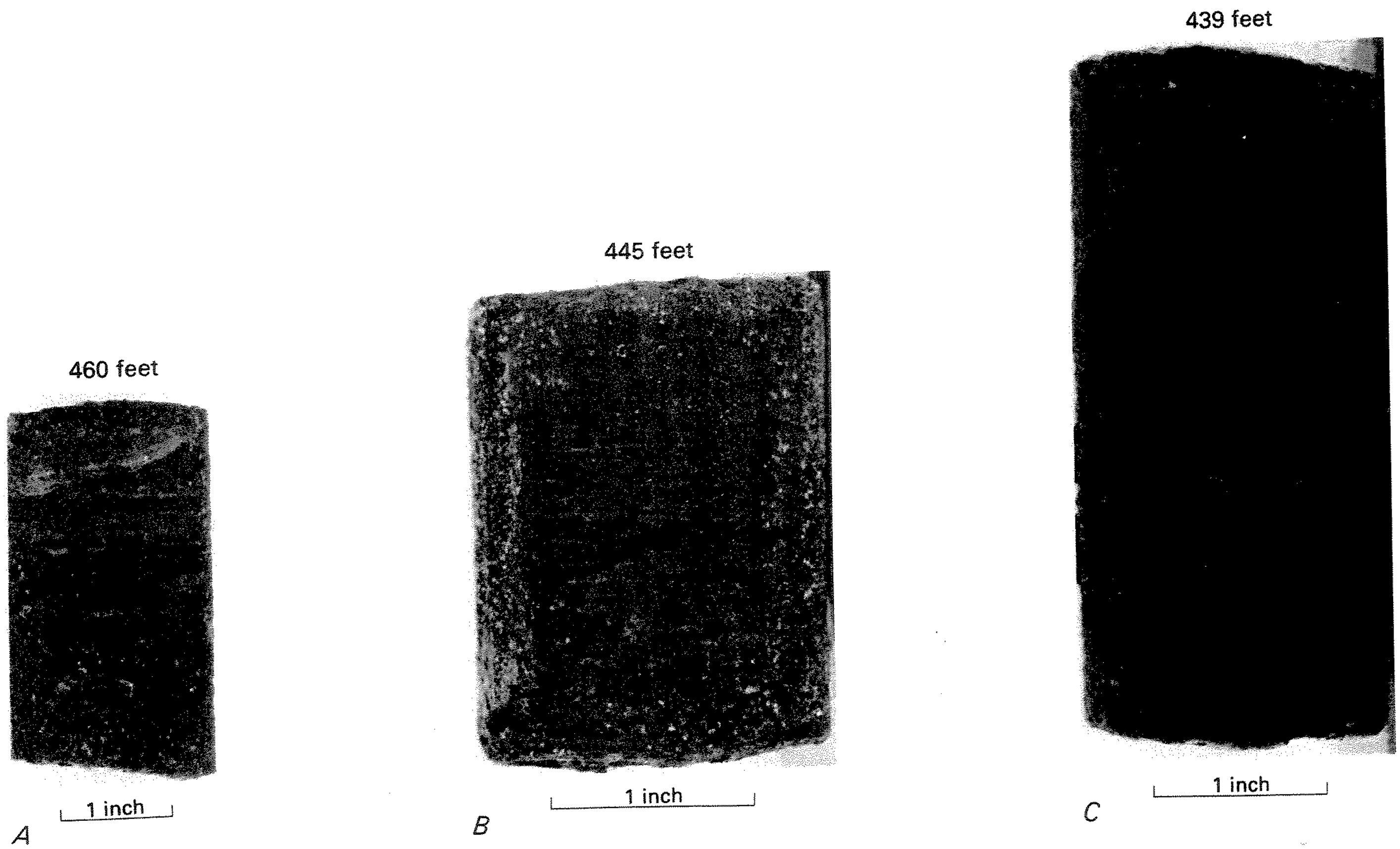
Ilmenite is the principal opaque heavy mineral, although its weathering products (pseudorutile and leucoxene) are present in major amounts.

The feldspar content in the Kirkwood ranges from 23 percent at the base to 7 percent at the top. Most of the feldspar is the potassium variety, although small amounts of plagioclase are present. The Kirkwood, therefore, is an orthoquartzite to subarkose (Pettijohn, 1975).

X-ray diffraction studies show that illite-smectite, illite, and kaolinite are the major clay minerals in the lower part of the Kirkwood (fig. 7). Both kaolinite and illite decrease upward through the formation, and near the top, illite-smectite is by far the major clay mineral present.

Environment of Deposition

In recent times, two investigators have presented differing models for deposition of the Kirkwood, which is recognized only in New Jersey. Isphording (1970) distinguished three members in outcrops of the Kirkwood and noted that downdip the members could not be identified in deep wells. The members are the Alloway Clay



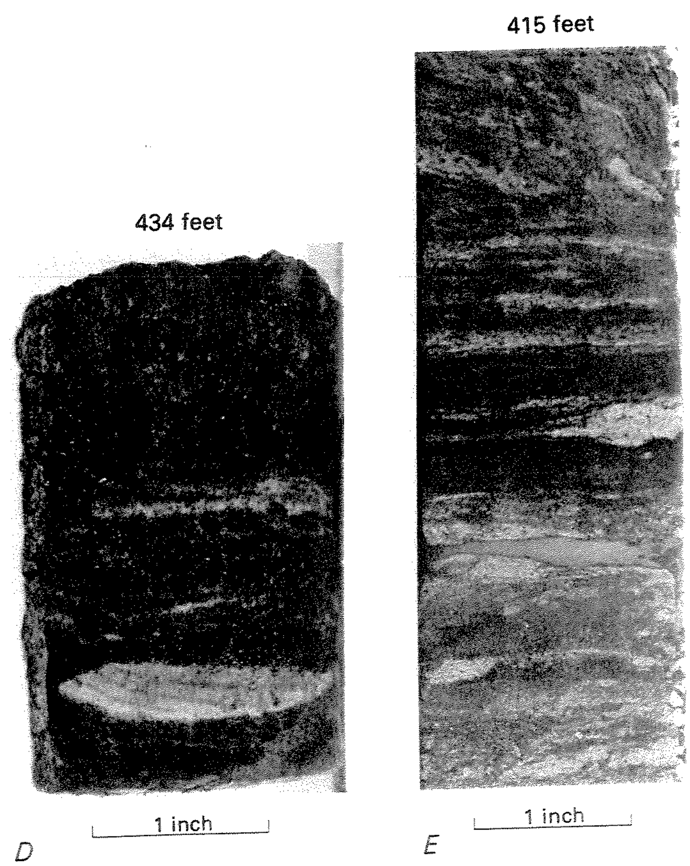
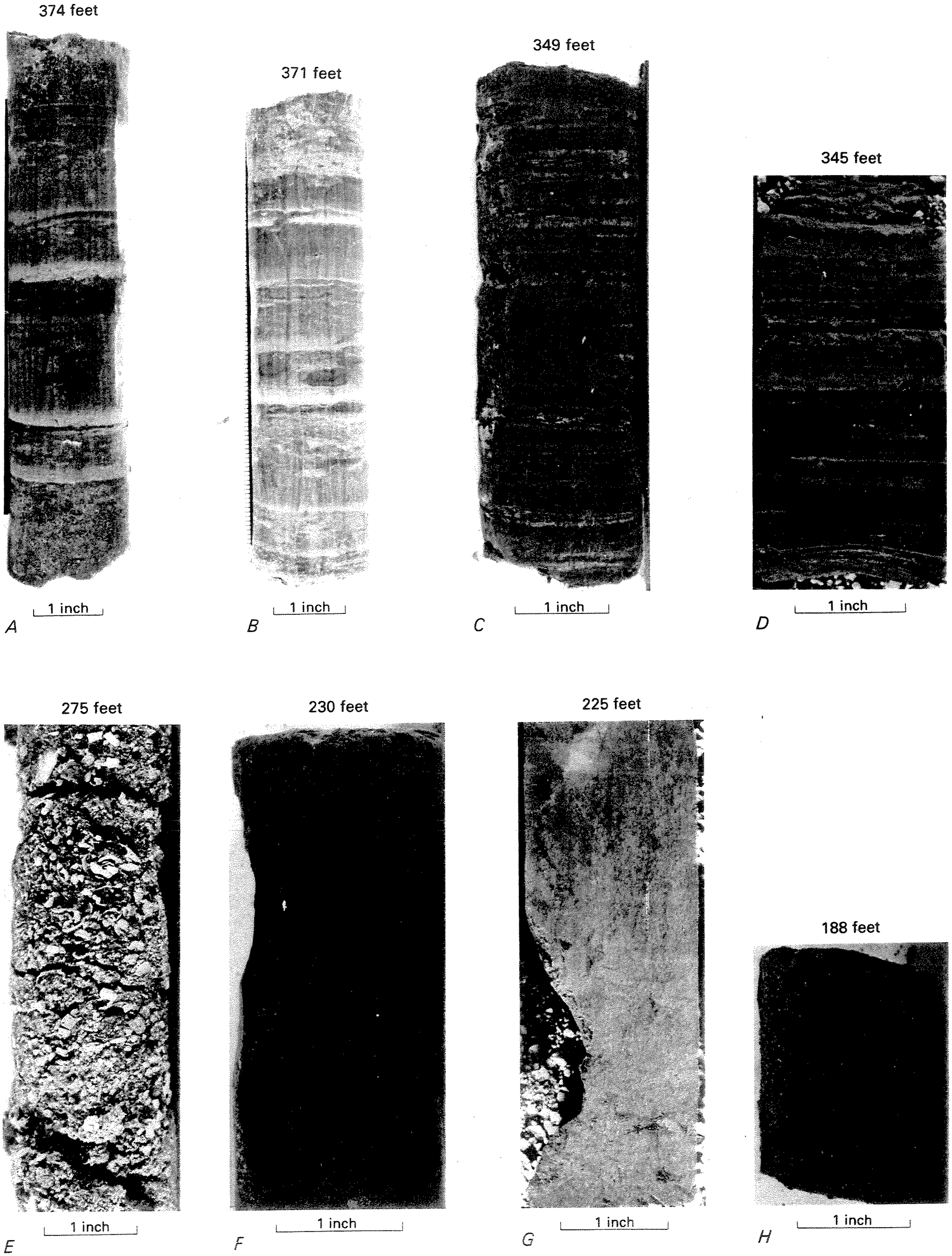


FIGURE 11.—Segments of the ACGS–4 core from the lower part of the Kirkwood Formation. *A* and *B*, Core from 460 and 445 ft showing faintly laminated silt and darker silty clay. *C–E*, Core from 439, 434, and 415 ft showing well-defined, lenticular to horizontal beds of silt and sand.

FIGURE 12.—Segments of the ACGS–4 core from the upper part of the Kirkwood Formation. *A–D*, Core from 374, 371, 349, and 345 ft showing interbedded dark silt and light-colored sand typical of delta-front to prodelta depositional environments. *E*, Core from 275 ft consisting of shell hash, which may have accumulated in a delta-front environment. *F–H*, Core from 230, 225, and 188 ft showing massiveness and faint bedding characteristic of the diatomaceous shelf facies. ▶


374 feet
1 inch
A
371 feet
1 inch
B
349 feet
1 inch
C
345 feet
1 inch
D
275 feet
1 inch
E
230 feet
1 inch
F
225 feet
1 inch
G
188 feet
1 inch
H

Member, Grenloch Sand Member, and Asbury Park Member. The Alloway Clay Member and Grenloch Sand Member were considered by Isphording (1970) to be the major facies and were described as inner shelf marine deposits. The Asbury Park Member was considered to be a minor facies restricted to the northern part of the Kirkwood outcrop belt and was thought to have been deposited in lagoons, swamps, and estuaries open to the sea. In Isphording's view, therefore, the Kirkwood is dominantly a shelf deposit.

Gibson (1983) studied the Miocene in a much broader context, including most of the northern U.S. Atlantic Coastal Plain. In his view, the Kirkwood deposition was deltaically influenced. He based this interpretation on the bedding characteristics he found in the Kirkwood in the southwestern part of the New Jersey Coastal Plain (mainly thin interbeds of clay and sand, which he thought were deposited at the delta front or prodelta).

Isphording's three members cannot be identified in the Kirkwood in the ACGS–4 hole, and the unit seems to fit Gibson's model better than that of Isphording. The dominance of thin-bedded to laminated sequences that typically contain abundant carbonaceous matter and concentrations of fine to coarse mica suggests a prodeltaic depositional environment. Concentrations of coarse shells and fine gravel are consistent with a river-influenced depositional system. Although the fauna is mostly marine, nonmarine forms such as *Navicula* aff. *N. gastrum* and *Eunatia* are present in the Kirkwood from the corehole. The Kirkwood is certainly characterized by a wide variety of bedding forms and lithologies, a situation commonly found in deltaically influenced depositional systems. Nevertheless, the unit appears to be mainly marine.

Age

The Kirkwood in the ACGS–4 corehole in the downdip southern New Jersey area is older than any other investigators in this area have reported. Johnson and Richards (1952) thought that the Kirkwood was equivalent to the Calvert, Choptank, and St. Marys Formations of Maryland. Melillo and Olsson (1981) and the AAPG (1983) thought that the Kirkwood in this area was actually two formations separated by a large time interval; the lower Kirkwood (if the ACGS Beta unit is included) being late Oligocene to early Miocene in age and the upper Kirkwood being late Miocene in age. The Kirkwood in the ACGS–4 corehole is early to early middle Miocene in age and is separated from the underlying ACGS Beta unit by an unconformity. The microfossils indicate that the Kirkwood could be as old as 22 Ma and as young as 15 Ma.

A sample from 473 ft was examined by Richard Z. Poore and yielded the following assemblage of planktic foraminifers: *Globigerina praebulloides*, *Globigerinoides trilobus* (s.l.), *G. altiaperturus*, and *Globorotalia siakensis*. These forms indicate an early Miocene (early Burdigalian) age (Zone N5 of Blow, 1969).

Diatoms are abundant in the upper part of the formation. Samples collected from 199, 179, and 175 ft by George W. Andrews (1987) contained the following stratigraphically significant diatoms: *Delphineis ovata*, *Rhaphoneis fusiformis*, *Rhaphoneis margaritata*, *Rhaphoneis scalaris*, *Sceptroneis grandis*, and *Sceptroneis caduceus*. These diatoms provisionally correlate with East Coast Diatom Zone 2 of Andrews (1978), which is equivalent in part to zones 6–8 of the Calvert Formation (Shattuck, 1904). This correlation would indicate that the Kirkwood Formation above 199 ft is early middle Miocene (Langhian) in age.

Diatoms from 293 ft in the corehole include the form *Actinoptychus heliopelta*. This diatom is found only in the very base of the Calvert Formation in East Coast Diatom Zone 1 (Burdigalian Age) of Andrews (1978). Thus, the Kirkwood is partially equivalent to the lower Calvert, but the lower 192 ft of the Kirkwood (485–293 ft) are older than any Calvert-equivalent section known in the Chesapeake Bay region. Benson and others (1985) found a similar relationship in a core through the Chesapeake Group in the Delmarva Peninsula at Dover, Del.; there the *Actinoptychus heliopelta* Zone is present well above the base of their Chesapeake Group. Although they reported no fauna from the pre-*heliopelta* beds, these beds probably are similar to the lower part of the Kirkwood.

Samples of the Kirkwood Formation taken at irregular intervals from the ACGS–4 core were examined by Thomas A. Ager for pollen content. Preliminary analysis suggests that the Kirkwood may be divided into at least three pollen assemblage zones. Exotic flora in the three zones support the early to middle Miocene age determined from microfossils.

The lowermost zone is represented by samples from core depths of 455 and 415 ft. This zone is characterized by a predominance of pollen of *Quercus*, *Carya*, and *Pinus* and by smaller amounts of *Fagus*, *Nyssa*, *Alnus*, *Betula*, Sapotaceae, *Ulmus*, *Tilia*, *Momipites*, *Liquidambar*, *Podocarpus*, and Taxodiaceae-Cupressaceae-Taxaceae type, as well as other taxa. This assemblage appears to be floristically quite similar to that observed in the underlying ACGS Beta unit.

The overlying middle pollen assemblage zone is represented by samples from core depths of 375, 354, and 335 ft. These samples contain unusually high percentages of *Fagus* pollen, along with smaller amounts of *Quercus*, *Carya*, *Pinus*, *Ulmus*, and other taxa observed in the underlying assemblage zone. The relative abundance of *Fagus* pollen suggests an interval of time during which at least local forests contained a great abundance of beech trees. *Fagus* is a common element of several forest types in eastern North America, but it is usually a minor component of modern pollen assemblages (Delcourt and Delcourt, 1984). Modern forests of New Jersey have been greatly disturbed by human activity. Only a few stands in which *Fagus* and *Quercus* are dominant occur in several limited areas within the Inner Coastal Plain (Robichaud and Buell, 1973). Additional cores from the Kirkwood Formation will have to be examined in order to determine whether or not the *Fagus-Quercus* assemblage zone observed in the ACGS–4 core has more than local significance. Previous palynological research on the Kirkwood (Goldstein, 1974) found no evidence of a *Fagus-Quercus*-rich zone in other areas of New Jersey.

The upper pollen assemblage zone of the Kirkwood Formation (200–162 ft) contains *Quercus*, *Carya*, *Pinus*, *Fagus*, *Ulmus*, *Pterocarya*, *Tilia*, *Liquidambar*, *Ilex*, *Betula*, *Alnus*, *Podocarpus*, Sapotaceae, and rare representatives of herbaceous taxa including Gramineae (Poaceae), Cyperaceae, Compositae (Asteraceae), and Chenopodiaceae-Amaranthaceae type. Kirkwood samples from some New Jersey localities reported by Goldstein (1974) contained relatively abundant herb pollen, apparently reflecting relatively open vegetation.

Formation Name and Distribution

The Kirkwood Formation was first named by G.N. Knapp (1904, p. 81–82). It is recognized only in New Jersey. Because of poor exposures, the definition and age determinations of this unit were derived largely from the subsurface. The definition of the Kirkwood has been revised many times since 1904. Several investigators presented age correlations of the Kirkwood with the better exposed and studied Chesapeake Group to the south in Maryland, Delaware, and Virginia, but as shown in figure 13*A*, a great degree of uncertainty about the age still existed as late as 1983. Our correlation of the Kirkwood and other Tertiary units with formations to the south is shown in figure 13*B*. In our interpretation, the Kirkwood contains the oldest beds of a large Neogene basin that extended from what is now New Jersey to Virginia. The only correlation the Kirkwood has with the Chesapeake Group is that the upper Kirkwood is the same age as the lower Calvert Formation.

Figure 1 shows the inland limit of the Kirkwood Formation and Cohansey Sand; near this limit, these formations appear in outcrop. As mentioned above, Isphording (1970) recognized three members in outcrops of the Kirkwood; these members are not distinguishable downdip of the outcrops in several wells including the ACGS–4 corehole. The Alloway Clay Member and Grenloch Sand Member of the Kirkwood are lithofacies of major extent, whereas the Asbury Park Member is a minor facies found only in the northeastern end of the Kirkwood outcrop belt.

Minard and Owens (1963) mapped the Kirkwood in detail near Trenton, N.J., in a part of Isphording's (1970) study area. They noted that the Kirkwood is primarily a light-colored sand (here the Grenloch Sand Member) in most of the area, but that eastward, or downdip, the light-colored sand overlies a black, clayey silt (Isphording's Alloway Clay Member?). Continuing eastward into the subsurface, the light-colored sand disappears, and the Kirkwood is mainly a dark-colored clayey silt to the coast.

COHANSEY SAND

The Kirkwood Formation is overlain in the ACGS–4 corehole by the Cohansey Sand. The nature of the contact between the two units could not be determined in this corehole because of the poor core recovery for the Cohansey. To compensate in part for this core loss, a split-spoon hole was driven adjacent to the main corehole to a depth of 121 ft. The Cohansey, however, is approximately 162 ft thick at Mays Landing. The lithology of the lower 41 ft is known only from cuttings and a few short cores. Approximately 139 ft (85 percent) of the formation were recovered in the two holes bored into this unit (fig. 5).

The Cohansey is dominantly a loose sand, which from 136 to 79 ft contains beds of dark-gray to gray-brown, carbonaceous sand and silty sand. The overall sandy nature of the unit can be seen in the gamma-ray log of the main corehole (fig. 5) and is described in the appendix.

The Cohansey near Mays Landing is dominantly a medium sand, but it varies considerably, ranging from very fine sand to gravelly, coarse sand. The sand is typically crossbedded, although some massive intervals are present. Flaser bedding is common in the massive beds, and the crossbeds are extensively burrowed. In a few beds, dark-colored heavy minerals are abundant.

Petrology

The Cohansey Sand is dominantly a quartz sand, although very small amounts of feldspar and even less common rock fragments are locally present (table 1). Some beds of the Cohansey are, therefore, orthoquartzites or quartz arenites (Pettijohn, 1975).

Suites of non-opaque heavy minerals in the Cohansey have high concentrations of zircon, tourmaline, and rutile; zircon is typically dominant. Staurolite, sillimanite, and kyanite are also major constituents in this unit, and staurolite and sillimanite occur in nearly equal

EPOCH	AGE	FORMATIONS: MARYLAND, VIRGINIA, AND DELAWARE	FORMATIONS: SOUTHERN DELMARVA	FORMATIONS: NEW JERSEY
PLEISTOCENE		Columbia	Omar Beaverdam	Cape May Pensauken Bridgeton
PLIOCENE	Piacenzian	Chowan		Beacon Hill — ? —
	Zanclean	Yorktown	— ? —	Cohansey
MIOCENE	Messinian		Pocomoke Aquifer	— ? —
	Tortonian	Eastover	Manokin Aquifer St. Marys	Kirkwood — ? —
	Serravallian	St. Marys	Chesapeake Group undifferentiated	
	Langhian	Choptank		— ? —
	Burdigalian	Calvert		Kirkwood
	Aquitanian			
OLIGOCENE	Chattian			Piney Point

A

EPOCH	AGE	FORMATIONS: MARYLAND, VIRGINIA, AND DELAWARE	FORMATIONS: SOUTHERN DELMARVA	FORMATIONS: NEW JERSEY
PLEISTOCENE		Omar Formation Accomack Member	Omar	Cape May
PLIOCENE	Piacenzian	Chowan River(?)	Beaverdam	
	Zanclean	Yorktown-Brandywine	Yorktown (Virginia only)	
MIOCENE	Messinian			
	Tortonian	Eastover	Pocomoke Aquifer	Bridgeton
	Serravallian	St. Marys Choptank	Manokin Aquifer Choptank	Pensauken Cohansey — ? —
	Langhian	Calvert	Calvert	Kirkwood
	Burdigalian			
	Aquitanian	— ? —	— ? —	— ? —
OLIGOCENE	Chattian	Old Church	Unnamed	ACGS Beta unit

B

FIGURE 13.—Correlation charts of the Neogene and middle Pleistocene formations in the northern U.S. Atlantic Coastal Plain. *A*, Correlations from the American Association of Petroleum Geologists (1983). *B*, Correlations proposed in this report for the Kirkwood Formation and Cohansey Sand.

amounts. Garnet, hornblende, and lesser amounts of chloritoid are minor components (table 1).

The opaque minerals are much more abundant than the non-opaque minerals in this formation (about a 4:1 ratio). The opaque minerals are ilmenite and its weathering products, pseudorutile and leucoxene. In the lower part of the formation, ilmenite is the major opaque mineral, but in the upper beds, pseudorutile and leucoxene are the major minerals. This relationship suggests substantial postdepositional alteration or deep weathering of the Cohansey beds (at least to 80 ft).

X-ray diffractograms of the clayey strata and the clay matrix of the sand in the upper part of the formation are shown in figure 7. The samples from 121 to 73 ft have assemblages similar to those in the underlying Kirkwood Formation; illite-smectite is dominant, and lesser amounts of illite and kaolinite are present. At 73 ft, the clay assemblage is different from the assemblage in the lower beds and is marked by a sharp increase in kaolinite and illite and a decrease in illite-smectite content. Probably, this transition is related to postdepositional weathering. In a zone of strong oxidation, illite-smectite is unstable and breaks down to kaolinite and illite.

The assemblages of sand-sized minerals and clay minerals in the Cohansey resemble those from the underlying Kirkwood, although some variations occur. The Cohansey, in general, has less feldspar than the Kirkwood and generally has no epidote. Whether these differences reflect normal minor variations in sediment-dispersal patterns or are regionally specific to each of the formations is beyond the scope of this study. Isphording (1970, 1976) considered the differences in the heavy-mineral assemblages to be minor and, therefore, concluded that the ages of the two units were nearly the same.

The provenance of the Cohansey is similar to that of the Kirkwood; that is, a low-feldspar terrane that provided an abundance of the metamorphic minerals staurolite, sillimanite, kyanite, garnet, and ilmenite. The most likely source would be the rocks of the Reading Prong; if so, the sediments supplied to the Cohansey must have been deeply weathered in the sourcelands so that the feldspar decomposed before the sediments were stripped.

Environment of Deposition

Carter (1972, 1978) examined the Cohansey over its whole outcrop belt in New Jersey, and he interpreted this unit to have formed mainly in a regressing sea some time during the Miocene or Pliocene. Carter (1978) proposed that the Cohansey Sand consisted of two major lithofacies sequences: one deposited in a barrier island and one deposited behind the barrier. He identified the barrier deposits by the wide distribution of *Ophiomorpha* burrows in crossbedded sand. Markewicz (1969) presented an alternate view of the depositional system for this unit and favored a fluvial system that had minor estuarine influence.

Collecting intact cores from the loose Cohansey sediments in the aqueous environment at Mays Landing proved to be very difficult. Reconstruction of paleoenvironments without good bedding-form information is, therefore, very speculative.

What is evident is that the upper 79 ft of the formation are generally loose, fine to very coarse sand and that the interval between 136 and 79 ft is dominated by dark-colored sand, silt, and clay, commonly containing fine pieces of wood. No samples were collected from 155 to 136 ft.

The Cohansey at Mays Landing may be a barrier-dominated facies in the upper part of the formation and a back-barrier sequence in the lower part. Alternatively, the whole sequence could represent a deltaic sequence. Lithologic studies of the dark, clayey sequence and the lack of marine macrofaunas and microfaunas suggest deposition in a freshwater delta, apparently formed behind a barrier system or perhaps in a lower delta plain. Certainly, however, a large part of the Cohansey is a barrier-dominated system. Equally large parts of the formation have a decided fluvial aspect. Probably, the Cohansey was deposited in a barrier-delta system that prograded from northeast to southwest.

Age

The age of the Cohansey is controversial. Previously, a late Miocene to early Pliocene age was assigned to this unit (Melillo and Olsson, 1981; AAPG, 1983), apparently on the basis of microfossils obtained from the Jobs Point well, approximately 19 mi southeast of the ACGS–4 well (fig. 1). In the Jobs Point well, the upper Kirkwood Formation (as used by Melillo and Olsson, oral commun., 1981) at depths of 390 ft contained foraminifers representing the *Globorotalia acostaensis* Zone of late Tortonian Age (late Miocene).

Sidewall cores were obtained by us from a well south of Atlantic City (fig. 1), 6 mi east of the Jobs Point well. Diatoms collected from approximately 390 ft at the apparent top of the Kirkwood indicate that this unit may be provisionally correlated with lithologic zone 15 of Shattuck (1904) in the Chesapeake Group of Maryland. Zone 15 is the uppermost zone of the Calvert Formation and is no younger than the early middle Miocene (Andrews, 1978). The late Miocene age reported for the Kirkwood by Melillo and Olsson (1981) could not be confirmed in the area between the ACGS–4 hole and Atlantic City, or essentially the same area in which they reported the *Globorotalia acostaensis* Zone. If the Kirkwood is no younger than middle Miocene, then the overlying Cohansey could be older than reported by Melillo and Olsson (1981).

Palynomorphs were studied to help in dating the Cohansey as this unit at Mays Landing lacks other stratigraphically significant fossils. The most detailed earlier floristic study of the Cohansey was by Rachele (1976). She examined a peat bed, termed the "Legler lignite," from a pit near Lakehurst, N.J. The Legler contains abundant representatives of many exotic types of flora that no longer grow in New Jersey. These exotic genera include *Podocarpus*, *Engelhardtia*, *Pterocarya*, *Cyrilla*, *Gordonia*, and *Cyathea*. On the basis of stratigraphy proposed by Owens and Minard (1979), Greller and Rachele (1985) assigned a middle Miocene age of 11 Ma to this unit.

The close similarity between the pollen assemblages of the upper Kirkwood Formation and the Cohansey Sand suggests that the regional floras and climates were similar during deposition of these units. Common taxa in the Cohansey in the ACGS–4 core include *Quercus*, *Carya*, *Fagus*, *Ulmus*, *Pinus*, *Nyssa*, *Momipites*, *Tilia*, *Betula*, *Alnus*, Ericales, Sapotaceae, *Myrica*, *Podocarpus*, and *Tsuga*. Occasional specimens of *Alangium barghoornianum* were observed in samples from core depths of 109 to 88.5 ft. *Alangium barghoornianum* was previously reported in the upper Kirkwood (Wolfe and Tanai, 1980) but not in the Cohansey (Rachele, 1976). The Cohansey is unlikely to be younger than about 11 Ma because many exotic taxa present in the Cohansey pollen and spores disappeared from eastern North America during late Miocene time. Climatic cooling events that began about 13 Ma probably caused the disappearance of these exotic taxa (Wolfe and Poore, 1982). By Pliocene time, floras of the Atlantic and Gulf of Mexico Coastal Plains were becoming quite modern, and very few exotic taxa remained (Elsik, 1969; Frederiksen, 1984b; T.A. Ager, unpub. data). The pollen, therefore, indicates that the Cohansey is unlikely to be late Miocene–early Pliocene in age as suggested by Melillo and Olsson (1981) and the AAPG (1983); it probably is middle Miocene (Serravallian) in age.

Formation Name and Distribution

The Cohansey Sand was named by Kümmel and Knapp (1904) for exposures in southern New Jersey along Cohansey Creek. Correlation of the Cohansey with units south of New Jersey is highly speculative because of (1) the lack of a good invertebrate fauna in the Cohansey, (2) the removal of much of the Cohansey equivalents from the Delmarva Peninsula during the emplacement of younger units, primarily the Pensauken Formation, and (3) possible facies changes southward.

Our interpretation of the age of the Cohansey is based on the microflora. Because of the large number of exotics in the microfloral assemblage of the Cohansey and the similarity of the microflora of the Cohansey to that of the underlying Kirkwood, we estimate that the Cohansey is middle Miocene (Serravallian) in age. We propose that the Cohansey is equivalent to the Choptank Formation of the Chesapeake Group (fig. 13*B*).

SUMMARY AND CONCLUSIONS

In this section, we summarize the descriptions of the seven formations penetrated in the ACGS–4 corehole and then draw a few conclusions about the depositional history of the Raritan embayment since the early Eocene.

Manasquan Formation.—The Manasquan Formation is the oldest unit penetrated in this hole. About 51.5 ft of the upper part of the formation were recovered from 945 to 893.5 ft. Fine glauconite sand is scattered throughout the clay-silt matrix. The unit is thinly laminated to crudely bedded, and burrows are common. The formation has an abundant calcareous microfauna throughout. The Manasquan is interpreted to be an outer to middle shelf deposit. The nannofossils recovered from this hole indicate that the part of the formation cored encompasses Zones NP 12 and 13 and the lower part of Zone NP 14; it, therefore, is of late Ypresian age.

Poag (1980) suggested that Zone NP 13 is absent from the northern U.S. Atlantic Coastal Plain, and he believed its absence confirmed a 2-m.y. regression on the sea-level curve shown by Vail and Hardenbol (1979). Data from the ACGS–4 corehole do not support this conclusion.

Shark River Formation.—The Shark River Formation unconformably overlies the Manasquan in the corehole from 893.5 to 761 ft and is characterized by an abundance of clay and silt and the absence of clastic sand. The basal 4.5 ft of the Shark River contain abundant fine to medium, authigenic glauconite sand. This interval is intensely burrowed and contains abundant phosphatic debris (fish parts) and occasional small shark teeth. Beds of this type commonly make up the transgressive units found at the bases of many Upper Cretaceous shelf deposits in New Jersey (Owens and Gohn, 1985).

The glauconite sand content decreases rapidly in the overlying 64 ft, which are characterized by laminations or extensive burrowing and abundant calcareous microfossils. At least one hard ground, or zone of nondeposition, is present in the 64-ft interval. The lithologic characteristics of this part of the formation suggest an outer shelf depositional environment.

The upper half of the formation is characterized by a marked increase in the size and concentration of glauconite sand and the presence of scattered, thin beds of macrofossils. The bedding in this interval typically indicates some current activity. These characteristics suggest that the upper half of the Shark River was deposited in shallower water than the base, possibly on the middle shelf.

The Shark River thus represents a transition upsection from deep- to shallow-water deposits. The nannofossils in the Shark River are within Zones NP 14–NP 18, which include the late Lutetian, Bartonian, and early Priabonian Ages.

The name "Piney Point Formation" has been used widely for subsurface sediments of late Oligocene age in New Jersey and to the south (Olsson and others, 1980; Zapecza, 1984). Because the Piney Point was dated as middle Eocene at its reference section along the Pamunkey River in Virginia (DiMarzio, 1984; Ward, 1984, 1985), the use of this name for sediments in New Jersey has been discontinued in this report. The Piney Point Formation at its reference section is placed in Zone NP 16 and possibly Zone NP 17 and is equivalent to the middle part of the Shark River.

ACGS Alpha unit.—The Shark River in the corehole is overlain unconformably by the ACGS Alpha unit from 761 to 615 ft. The unit is 146 ft thick and consists of three upward-coarsening subunits separated by sharp disconformities at 735 and 695 ft. Each subunit is a clay or silt overlain by a sand, either glauconite or quartz. Each subunit is interpreted to represent a transgression at the base and a regression at the top. The ACGS Alpha was deposited on a middle to inner shelf during the late Eocene and early Oligocene. The nannofossils represent the upper part of Zone NP 18, all of Zone NP 19/20, and the lower part of Zone NP 21. Sediments of late Eocene and early Oligocene age have not previously been reported from the New Jersey Coastal Plain.

Mays Landing unit.—The ACGS Alpha unit in the corehole is overlain unconformably by the Mays Landing unit, which is recognized for the first time in this report. The Mays Landing is 40 ft thick and extends from 615 to 575 ft. It is another upward-coarsening unit; a clayey fine sand is overlain by interbedded clay and medium sand. The Mays Landing unit is the thinnest unit in the corehole, and it is interpreted to have been deposited during a single transgressive-regressive event. The lower beds may have been deposited in an inner shelf or distal prodelta, and the upper beds, in a prodelta.

Nannofossils in this unit fall within the early Oligocene part of Zone NP 21. Deposits of this age have not been reported heretofore from the U.S. Atlantic Coastal Plain. The presence of the Mays Landing beneath the New Jersey Coastal Plain shows that the early Oligocene was not a time of offlap in this area; offlap was suggested by Olsson (1980) and Poag (1980, p. 63–65) because of the lack of lower Oligocene sediments in the Baltimore Canyon wells off New Jersey.

ACGS Beta unit.—The Mays Landing unit is overlain unconformably by the ACGS Beta unit, which is 90 ft thick and extends from 575 to 485 ft. The ACGS Beta is a fine to medium glauconite quartz sand containing abundant worn shells indicating a marine origin. Most of this unit is loose sand except that the lowest 12 ft contain thin layers of indurated, very shelly, glauconite quartz sand. The abundance of fine to medium quartz sand suggests deposition on an inner shelf nearer shore than the Mays Landing unit and all other underlying units.

In spite of the fossiliferous nature of the ACGS Beta unit, its age is equivocal. It is either late Oligocene (Chattian) or early Miocene (Aquitanian). We favor a late Oligocene age for the unit.

Kirkwood Formation.—The ACGS Beta unit is overlain unconformably by the Kirkwood Formation, the thickest unit (323 ft) penetrated in the ACGS–4 corehole. The Kirkwood, like some of the underlying formations, is a composite consisting of more than one subunit or sequence. The Kirkwood consists of three sequences separated by sharp disconformities at 385 and 245 ft. Each sequence has a thin zone of reworked sediment at the base. Like most of the transgressive-regressive units, each of the three Kirkwood sequences coarsens upward.

All the sequences of the Kirkwood contain marine organisms. The abundance of clastic and carbonaceous matter indicates that these sediments were deposited on the inner shelf (prodelta). The age of the Kirkwood ranges from early Miocene (early Burdigalian) to early middle Miocene (Langhian).

Cohansey Sand.—The Kirkwood Formation is overlain by the Cohansey Sand, which occupied the top 162 ft of the ACGS–4 corehole. Because of poor recovery, the nature of the contact between the Kirkwood and Cohansey could not be determined precisely in this corehole, but we think that the contact is an unconformity. The Cohansey is dominantly a loose sand and has interbeds of more compact carbonaceous and silty sand.

Also because of poor recovery of intact core from the Cohansey, the depositional environments for this unit could not be determined. Observations nearby suggest that the upper part of the Cohansey may have been deposited in a barrier environment, and the lower part, in a back-barrier (lower delta plain) environment.

The age of the Cohansey can only be inferred from its pollen content. No other animal or plant groups were found in the samples from this unit to help date it. Because the pollen in the Cohansey is similar to that in the upper Kirkwood, the two units are probably close in

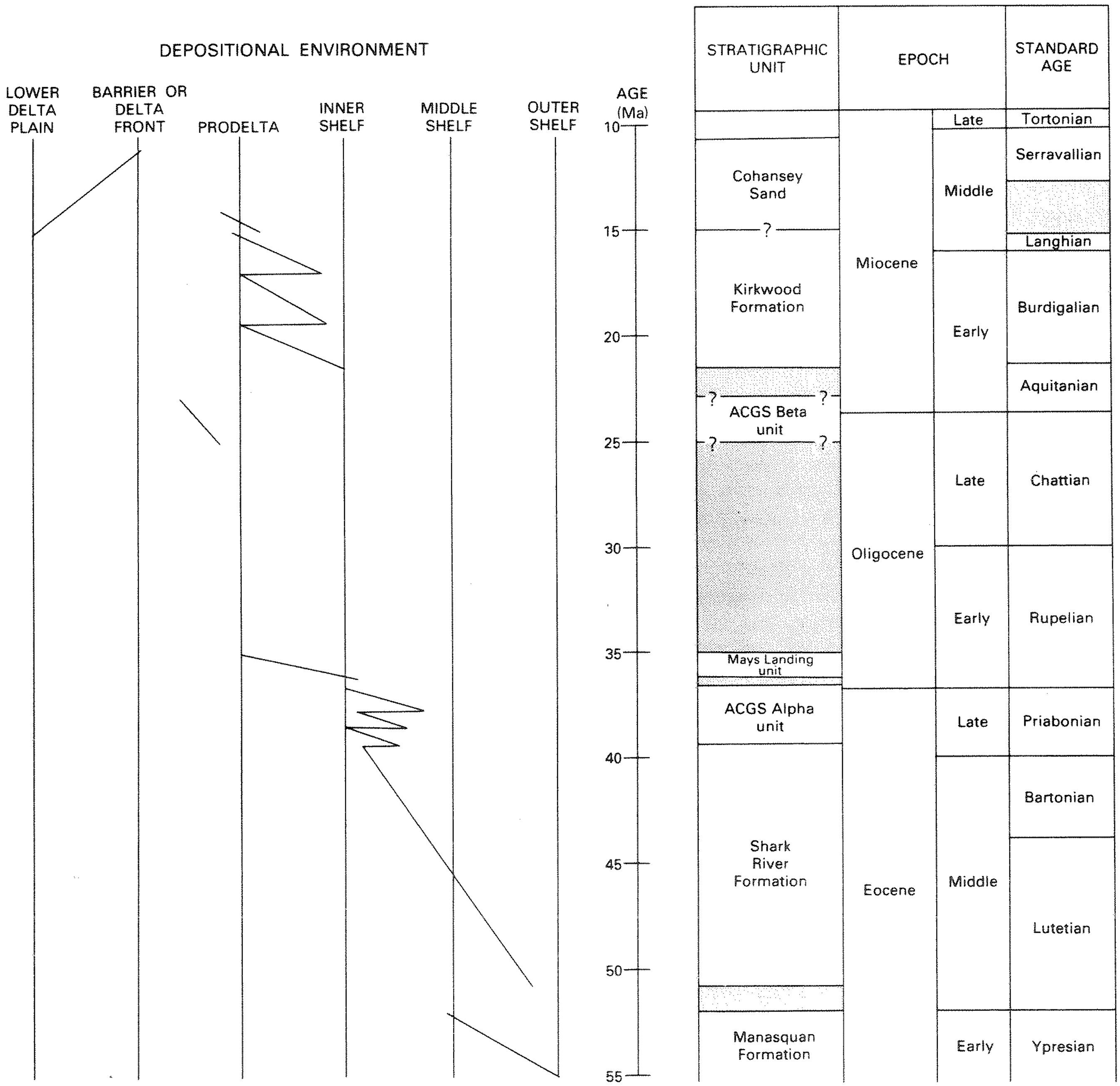


FIGURE 14.—Depositional environments inferred for units in the ACGS–4 corehole. In general, the trend is from deep- to shallow-water deposits from the bottom of the core up. These data suggest an initial drop in the basin (Raritan embayment) during the Eocene followed by a gradual shoaling through time, culminating in the final emergence of the modern Coastal Plain after Cohansey deposition. Superimposed on this general tectonic movement is a deep-to-shallow pattern within many of the units. This pattern suggests that the units were influenced by transgressions and regressions, which probably were caused by eustatic sea-level changes. Ages from Berggren and others (1985).

age. The Cohansey, therefore, is considered to be middle Miocene (Serravallian) in age.

Movement in the Raritan embayment.—All the units in the corehole are considered to have formed within a shelf-delta depositional system (figs. 4, 14). The Eocene units are all deep shelfal, the Oligocene are shelfal but shallower water deposits, and the Miocene units contain shelf-dominated facies at the base interfingering with more deltaic beds upward through the section. The uppermost unit, the Cohansey, apparently is a barrier and back-barrier sequence, but it may have had some deltaic influence. Thus, from the Eocene to the Miocene, the basin in southern New Jersey gradually continued to become shallow or to rise. In fact, the Cohansey represents the last marine invasion in this part of the Coastal Plain, indicating that the rise of the basin continued into post-Cohansey or late Miocene time.

The structural history of the Raritan embayment suggests that, at least in early Eocene time, the basin was downwarped. Following this initial downwarping, the basin began to gradually emerge, at least through the early Oligocene. The unconformity between the ACGS Beta unit (possible uppermost Oligocene) and the lower Oligocene Mays Landing unit means that we have no record for the middle Oligocene; the unconformity may represent the large sea-level regression proposed by Vail and Hardenbol (1979) for this time. The basin shoaling certainly continued during the early and middle Miocene after ACGS Beta deposition, and the basin ultimately emerged above sea level after deposition of the Cohansey. The later Miocene and Pliocene transgression that was widespread to the south in Delaware, Maryland, and Virginia did not overlap the emerged New Jersey Coastal Plain.

Mineralogy.—All the sediments in the corehole appear to have been derived from essentially the same sources. All units contain a significant amount of metamorphic minerals, especially staurolite, sillimanite, and kyanite. The feldspars are, on the average, more abundant in the older formations than in the younger units. This feldspar distribution may be related to depositional environment or postdepositional weathering rather than to differences in source areas.

The clay minerals suggest that crystal sorting is the major mechanism controlling clay distribution in the formations. Kaolinite, which is coarser than illite-smectite, is more abundant in the shallower water facies in most units.

Significance of the ACGS-4 corehole.—The calcareous nannofossils show that the ACGS-4 core contains a nearly complete record between Zones NP 12 and NP 21. This corehole, therefore, contains one of the most complete sections found anywhere in the U.S. Atlantic Coastal Plain for early Eocene through early Oligocene time.

REFERENCES CITED

American Association of Petroleum Geologists, 1983, Atlantic Coastal Plain [correlation chart]: Tulsa, Okla., 1 folded sheet in jacket. (Correlation of Stratigraphic Units of North America (COSUNA) Project.)

Andrews, G.W., 1978, Marine diatom sequence in Miocene strata of the Chesapeake Bay region, Maryland: Micropaleontology, v. 24, no. 4, p. 371–406.

———1987, Miocene marine diatoms from the Kirkwood Formation, Atlantic County, New Jersey: U.S. Geological Survey Bulletin 1769, 14 p., 3 pls.

Bally, A.W., 1981, Atlantic-type margins, *in* Bally, A.W., and others, Geology of passive continental margins—History, structure and sedimentologic record (with special emphasis on the Atlantic margin): American Association of Petroleum Geologists Continuing Education Course Note Series 19, 48 p. (Each article is separately paged.)

Benson, R.N., Jordan, R.R., and Spoljaric, Nenad, 1985, Geological studies of Cretaceous and Tertiary section, test well Je32–04, central Delaware: Delaware Geological Survey Bulletin 17, 69 p.

Berggren, W.A., Kent, D.V., Flynn, J.J., and Van Couvering, J.A., 1985, Cenozoic geochronology: Geological Society of America Bulletin, v. 96, no. 11, p. 1407–1418.

Blow, W.H., 1969, Late middle Eocene to Recent planktonic foraminiferal biostratigraphy, *in* Brönnimann, P., and Renz, H.H., eds., Proceedings of the First International Conference on Planktonic Microfossils, Geneva, 1967: Leiden, Netherlands, E.J. Brill, v. 1, p. 199–421.

Bybell, L.M., and Gibson, T.G., 1985, The Eocene Tallahatta Formation of Alabama and Georgia—Its lithostratigraphy, biostratigraphy, and bearing on the age of the Claibornian Stage: U.S. Geological Survey Bulletin 1615, 20 p.

Carter, C.H., 1972, Miocene-Pliocene beach and tidal flat sedimentation, southern New Jersey: Baltimore, Md., The Johns Hopkins University, Ph.D. dissertation, 186 p.

———1978, A regressive barrier and barrier-protected deposit—Depositional environments and geographic setting of the late Tertiary Cohansey Sand: Journal of Sedimentary Petrology, v. 48, no. 3, p. 933–950.

Clark, W.B., 1893, A preliminary report on the Cretaceous and Tertiary formations of New Jersey, *in* Annual report of the The State Geologist for the year 1892: Trenton, N.J., New Jersey Geological Survey, p. 167–245.

Conrad, T.A., 1865, Observations on the Eocene lignite formation of the United States: Academy of Natural Sciences of Philadelphia Proceedings, v. 17, p. 70–73.

Cushman, J.A., and Cederstrom, D.J., 1945, An upper Eocene foraminiferal fauna from deep wells in York County, Virginia: Virginia Geological Survey Bulletin 67, 58 p.

Delcourt, P.A., and Delcourt, H.R., 1984, Late Quaternary paleoclimates and biotic responses in eastern North America and the western North Atlantic Ocean: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 48, p. 263–284.

DiMarzio, J.A., 1984, Calcareous nannofossils from the Piney Point Formation, Pamunkey River, Virginia, *in* Ward, L.W., and Krafft, Kathleen, eds., Stratigraphy and paleontology of the outcropping Tertiary beds in the Pamunkey River region, central

Virginia Coastal Plain—Guidebook for Atlantic Coastal Plain Geological Association 1984 field trip: Atlantic Coastal Plain Geological Association, p. 111–116.

Edwards, L.E., 1984, Dinocysts of the Tertiary Piney Point and Old Church Formations, Pamunkey River area, Virginia, *in* Ward, L.W., and Krafft, Kathleen, eds., Stratigraphy and paleontology of the outcropping Tertiary beds in the Pamunkey River region, central Virginia Coastal Plain—Guidebook for Atlantic Coastal Plain Geological Association 1984 field trip: Atlantic Coastal Plain Geological Association, p. 124–134.

Elsik, W.C., 1969, Late Neogene palynomorph diagrams, northern Gulf of Mexico: Gulf Coast Association of Geological Societies Transactions, v. 19, p. 509–528.

Enright, Richard, 1969, The stratigraphy and clay mineralogy of the Eocene sediments of the northern New Jersey Coastal Plain, *in* Subitzky, Seymour, ed., Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook of excursions: New Brunswick, N.J., Rutgers University Press, p. 14–20.

Frederiksen, N.O., 1980, Sporomorphs from the Jackson Group (upper Eocene) and adjacent strata of Mississippi and western Alabama: U.S. Geological Survey Professional Paper 1084, 75 p.

———1984a, Sporomorph correlation and paleoecology, Piney Point and Old Church Formations, Pamunkey River, Virginia, *in* Ward, L.W., and Krafft, Kathleen, eds., Stratigraphy and paleontology of the outcropping Tertiary beds in the Pamunkey River region, central Virginia Coastal Plain—Guidebook for Atlantic Coastal Plain Geological Association 1984 field trip: Atlantic Coastal Plain Geological Association, p. 135–149.

———1984b, Stratigraphic, paleoclimatic, and paleobiogeographic significance of Tertiary sporomorphs from Massachusetts: U.S. Geological Survey Professional Paper 1308, 25 p.

Gibson, T.G., 1983, Stratigraphy of Miocene through lower Pleistocene strata of the United States central Atlantic Coastal Plain, *in* Ray, C.E., ed., Geology and paleontology of the Lee Creek Mine, North Carolina; I: Smithsonian Contributions to Paleobiology, no. 53, p. 35–80.

Goddard, E.N., and others, 1948, Rock-color chart: Washington, D.C., National Research Council, 6 p. (Republished by Geological Society of America, 1951; reprinted 1975.)

Gohn, G.S., Hazel, J.E., Bybell, L.M., and Edwards, L.E., 1983, The Fishburne Formation (lower Eocene) a newly defined subsurface unit in the South Carolina Coastal Plain: U.S. Geological Survey Bulletin 1537–C, p. C1–C16.

Goldstein, F.R., 1974, Paleoenvironmental analyses of the Kirkwood Formation: New Brunswick, N.J., Rutgers University, Ph.D. dissertation, 70 p.

Greller, A.M., and Rachele, L.D., 1983, Climatic limits of exotic genera in the Legler palynoflora, Miocene, New Jersey, U.S.A.: Review of Palaeobotany and Palynology, v. 40, no. 3, p. 149–163.

Isphording, W.C., 1970, Petrology, stratigraphy and re-definition of the Kirkwood Formation (Miocene) of New Jersey: Journal of Sedimentary Petrology, v. 40, no. 3, p. 986–997.

———1976, Multivariate mineral analysis of Miocene-Pliocene coastal plain sediments: Gulf Coast Association of Geological Societies Transactions, v. 26, p. 326–331.

Johnson, M.E., and Richards, H.G., 1952, Stratigraphy of Coastal Plain of New Jersey: American Association of Petroleum Geologists Bulletin, v. 36, no. 11, p. 2150–2160.

Knapp, G.N., 1904, Underground waters of New Jersey ***, Part IV *of* Annual report of the State Geologist for the year 1903: Trenton, N.J., New Jersey Geological Survey, p. 73–93.

Kümmel, H.B., and Knapp, G.N., 1904, The stratigraphy of the New Jersey clays, *in* Ries, Heinrich, and Kümmel, H.B., The clays and clay industry of New Jersey, v. 6 *of* Final report of the State Geologist: Trenton, N.J., New Jersey Geological Survey, p. 117–209.

Lewis, J.V., and Kümmel, H.B., 1912, Geologic map of New Jersey, 1910–12: Trenton, New Jersey Geological Survey, scale 1:250,000. (Revised by H.B. Kümmel in 1931 and by M.E. Johnson in 1950 and issued by New Jersey Department of Conservation and Economic Development as Atlas Sheet 40.)

Markewicz, F.J., 1969, Ilmenite deposits of the New Jersey Coastal Plain, Field Trip 6 *in* Subitzky, Seymour, ed., Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook of excursions: New Brunswick, N.J., Rutgers University Press, p. 363–382.

Martini, Erlend, 1971, Standard Tertiary and Quaternary calcareous nannoplankton zonation, *in* Farinacci, Anna, ed., Proceedings of the II Planktonic Conference, Roma, 1970: Rome, Edizioni Tecnoscienza, v. 2, p. 739–785.

Melillo, A.J., and Olsson, R.K., 1981, Late Miocene (late Tortonian) sea level event of Maryland-New Jersey Coastal Plain [abs.]: Geological Society of America Abstracts with Programs, v. 13, no. 3, p. 166.

Minard, J.P., and Owens, J.P., 1963, Pre-Quaternary geology of the Browns Mills quadrangle, New Jersey: U.S. Geological Survey Geologic Quadrangle Map GQ–264, scale 1:24,000.

Mixon, R.B., and Newell, W.L., 1977, Stafford fault system—Structures documenting Cretaceous and Tertiary deformation along the Fall Line in northeastern Virginia: Geology, v. 5, no. 7, p. 437–440.

Munsell Color Company, 1975, Munsell soil color charts: Baltimore, Md., 18 p.

North American Commission on Stratigraphic Nomenclature, 1983, North American Stratigraphic Code: American Association of Petroleum Geologists Bulletin, v. 67, no. 5, p. 841–875.

Olsson, R.K., 1980, The New Jersey Coastal Plain and its relationship with the Baltimore Canyon trough, *in* Manspeizer, Warren, ed., Field studies of New Jersey geology and guide to field trips—52nd annual meeting of the New York State Geological Association: p. 116–129.

Olsson, R.K., Miller, K.G., and Ungrady, T.E., 1980, Late Oligocene transgression of middle Atlantic Coastal Plain: Geology, v. 8, no. 11, p. 549–554.

Owens, J.P., and Gohn, G.S., 1985, Depositional history of the Cretaceous Series in the U.S. Atlantic Coastal Plain—Stratigraphy, paleoenvironments, and tectonic controls of sedimentation, *in* Poag, C.W., ed., Geologic evolution of the United States Atlantic margin: New York, Van Nostrand Reinhold, p. 25–86.

Owens, J.P., and Minard, J.P., 1979, Upper Cenozoic sediments of the lower Delaware Valley and the northern Delmarva Peninsula, New Jersey, Pennsylvania, Delaware, and Maryland: U.S. Geological Survey Professional Paper 1067–D, 47 p.

Owens, J.P., Minard, J.P., and Sohl, N.F., 1968, Cretaceous deltas in the northern New Jersey Coastal Plain, Trip B *in* Guidebook to field excursions at the 40th annual meeting, 1968, New York State Geological Association, Flushing, N.Y.: Brockport, N.Y., State University College, Department of Geology, p. 33–48.

Owens, J.P., and Sohl, N.F., 1969, Shelf and deltaic paleoenvironments in the Cretaceous-Tertiary formations of the New Jersey Coastal Plain, Field Trip 2 *in* Subitzky, Seymour, ed., Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook of excursions: New Brunswick, N.J., Rutgers University Press, p. 235–278.

Pettijohn, F.J., 1975, Sedimentary rocks (3d ed.): New York, Harper and Row, 628 p.

Poag, C.W., 1980, Foraminiferal stratigraphy, paleoenvironments, and depositional cycles in the outer Baltimore Canyon trough, *in*

Scholle, P.A., ed., Geological studies of the COST No. B-3 well, United States mid-Atlantic continental slope area: U.S. Geological Survey Circular 833, p. 44–66.

Rachele, L.D., 1976, Palynology of the Legler lignite—A deposit in the Tertiary Cohansey Formation of New Jersey, U.S.A.: Review of Palaeobotany and Palynology, v. 22, no. 3, p. 225–252.

Richards, H.G., 1948, Studies on the subsurface geology and paleontology of the Atlantic Coastal Plain: Academy of Natural Sciences of Philadelphia Proceedings, v. 100, p. 39–76.

Richards, H.G., and Harbison, Anne, 1942, Miocene invertebrate fauna of New Jersey: Academy of Natural Sciences of Philadelphia Proceedings, v. 94, p. 167–250.

Robichaud, B., and Buell, M.F., 1973, Vegetation of New Jersey: New Brunswick, N.J., Rutgers University Press, 340 p.

Shattuck, G.B., 1904, Geological and paleontological relations, with a review of earlier investigations: Maryland Geological Survey, Miocene [Volumes], v. 1, p. 33–137.

Vail, P.R., and Hardenbol, Jan, 1979, Sea-level changes during the Tertiary: Oceanus, v. 22, no. 3, p. 71–79.

Ward, L.W., 1984, Stratigraphy of outcropping Tertiary beds along the Pamunkey River—Central Virginia Coastal Plain, *in* Ward, L.W., and Krafft, Kathleen, eds., Stratigraphy and paleontology of the outcropping Tertiary beds in the Pamunkey River region, central Virginia Coastal Plain—Guidebook for Atlantic Coastal Plain Geological Association 1984 field trip: Atlantic Coastal Plain Geological Association, p. 11–77.

———1985, Stratigraphy and characteristic mollusks of the Pamunkey Group (lower Tertiary) and the Old Church Formation of the Chesapeake Group—Virginia Coastal Plain: U.S. Geological Survey Professional Paper 1346, 78 p.

Wolfe, J.A., 1985, Distribution of major vegetational types during the Tertiary, *in* Sundquist, E.T., and Broecker, W.S., eds., The carbon cycle and atmospheric CO_2—Natural variations Archean to present: American Geophysical Union Geophysical Monograph 32, p. 357–375.

Wolfe, J.A., and Poore, R.Z., 1982, Tertiary marine and nonmarine climatic trends, *in* U.S. National Research Council, Geophysics Study Committee, Climate in Earth history: Washington, D.C., National Academy Press, p. 154–158.

Wolfe, J.A., and Tanai, Toshimasa, 1980, The Miocene Seldovia Point flora from the Kenai Group, Alaska: U.S. Geological Survey Professional Paper 1105, 52 p.

Zapecza, O.S., 1984, Hydrogeologic framework of the New Jersey Coastal Plain: U.S. Geological Survey Open-File Report 84–730, 61 p., 24 oversize sheets, scale 1:250,000.

APPENDIX

APPENDIX, DESCRIPTION OF THE ACGS–4 CORE FROM NEAR MAYS LANDING, N.J.

[The hole was spudded in at 50 ft above sea level at lat 39°29′ N., long 74°46′ W. Significant core losses are noted below, but minor losses are omitted for simplicity. The core from 121 to 945 ft was described by J.P. Owens of the USGS; color designations are from the rock-color chart (Goddard and others, 1948). Because of the loose sandy nature of the Cohansey Sand (0–162 ft), recovery of core was very poor when a 10-ft core barrel was used. This loss of core necessitated drilling a second hole adjacent to the main corehole. In the second hole, the sand was split spooned at 2-ft intervals to a depth of 121 ft, and recovery of sample was good. The split-spoon core was described by C.E. Larsen and V.M. Gonzalez of the USGS; color designations are from the Munsell soil color charts (Munsell Color Company, 1975). Descriptions below of sediment from the top 121 ft are of material retrieved from both holes]

	Depth (feet)
Cohansey Sand:	
Light-brownish-gray (10YR6/2), silty, medium sand and brownish-yellow (10YR6/8), silty, fine to medium sand	0–2
Brownish-yellow (10YR6/8), silty, fine to medium sand and very pale brown (10YR7/4), medium to coarse sand containing scattered granules of rounded quartz having diameters as large as 0.25 in	2–4
Very pale brown (10YR7/4), medium to coarse sand containing scattered quartz granules and yellow (10YR7/6), silty, very fine sand containing scattered pebbles	4–6
Very pale brown (10YR7/4), silty, fine sand containing scattered pebbles and cobbles. Ilmenite is abundant	6–8
Very pale brown (10YR7/4), silty, fine sand containing scattered pebbles	8–10
Very pale brown (10YR8/3) silt alternating with silt and fine sand; 2 in. of dark-reddish-brown (2.5YR3/4), limonite-cemented sand are at bottom; reddish-yellow (7.5YR6/8), iron-stained bands are scattered throughout	10–12
Light-gray (10YR7/1), clayey silt overlying reddish-yellow (7.5YR6/8), silty, fine sand at bottom	12–14
Light-gray (10YR7/1), clayey silt grading downward to reddish-yellow (7.5YR6/8), silty, medium sand grading downward to reddish-yellow (7.5YR8/6), well-sorted, fine sand at bottom	14–16
Yellow (10YR7/6), silty, medium to fine sand containing white (10YR8/2) oxidized layers	16–18
Cohansey Sand—Continued	
Light-gray (10YR7/1), silty, medium to coarse sand grading downward to yellow (10YR7/6) and white (10YR8/2), fine to medium sand in alternating layers	18–20
Very pale brown (10YR7/4), silty, medium to coarse sand grading downward to very pale brown (10YR7/4), medium to coarse sand grading downward to very pale brown (10YR7/4), silty, medium to coarse sand at bottom	20–22
Very pale brown (10YR7/4), silty, medium to coarse sand grading downward to light-gray (10YR7/1) silt overlying white (10YR8/2), medium to coarse sand at bottom	22–24
White (10YR8/2), sandy silt overlying very pale brown (10YR8/3), medium to coarse sand that is laminated with more oxidized layers	24–26
Sequence in this interval is like that from 24 to 26 ft except that the bottom 2 in. of this interval are yellow (10YR7/8), medium to coarse sand, which is heavily oxidized	26–28
Yellow (10YR7/8), medium to coarse sand grading downward to white (10YR8/1), very coarse sand grading downward to dark-reddish-brown (2.5YR3/4), very coarse sand grading downward to brownish-yellow (10YR6/6), very coarse sand	28–30
Brownish-yellow (10YR6/8), well-sorted sand containing gravel overlying silty, fine sand	30–32
Brownish-yellow (10YR6/8), clay-silt matrix in a medium to coarse sand. At 33 ft, partings of light-gray silt are 3–4 in. thick	32–34

Cohansey Sand—Continued	*Depth (feet)*
Yellow (10YR7/6), fine to medium sand is at the top of a downward-coarsening sequence. Below it is a brownish-yellow (10YR6/6), medium to coarse sand, which overlies a very pale brown (10YR7/3), medium to coarse sand. At the base of the interval is yellow (10YR7/6), silty, coarse to very coarse sand containing light-gray (10YR4/1) silt partings	34–36
Brownish-yellow (10YR6/6), coarse to very coarse sand grading downward to yellow (10YR7/6), fine to medium sand	36–39
Yellow (10YR7/6), fine to medium sand interbedded with well-sorted, very coarse sand	39–41
White (10YR8/2), very coarse sand overlying yellow (10YR7/6), fine to medium sand	41–43
No recovery, probably very coarse sand or gravel	43–45
Light-brownish-gray (10YR6/2), very coarse sand grading downward into light-brownish-gray (10YR6/2), medium sand. Next is brownish-yellow (10YR6/8), medium sand overlying brownish-yellow (10YR6/8), medium to fine sand	45–47
Light-brownish-gray (10YR6/2), silty, medium sand grading downward to brownish-yellow (10YR6/6), fine to medium sand containing occasional silt partings in the upper part	47–50
Brownish-yellow (10YR6/6), fine to medium sand in which the heavy-mineral content increases with depth	50–51
Brownish-yellow (10YR6/8), fine to medium sand	51–53
Yellow (10YR7/8), fine to medium sand containing light-gray partings (flasers) of clay 0.08 in. thick	53–55
Brownish-yellow (10YR6/8), silty, fine to medium sand, which is crossbedded and contains concentrations of heavy minerals	55–57
Brownish-yellow (10YR6/8) and very pale brown (10YR7/4), medium to coarse sand containing occasional gravel beds; maximum diameter of gravel is 0.50 in.	57–59
Yellow (10YR7/8), poorly sorted, medium sand, which is oxidized in patches to brownish yellow (7.5YR6/8)	59–61

Cohansey Sand—Continued	*Depth (feet)*
Light-gray (10YR7/2), medium sand containing a trace of very fine ilmenite overlying brownish-yellow (10YR6/8), silty, medium to very coarse sand containing occasional granules and pebbles and also small wood fragments 0.16 in. long	61–63
Brownish-yellow (10YR6/8), poorly sorted, silty, fine to very coarse sand containing occasional pebbles	63–65
Yellow (10YR7/8), silty, fine to very coarse sand containing thin, very pale brown (10YR7/3) silt layers	65–67
Sediment in this interval resembles that from 65 to 67 ft	67–69
Yellow (10YR7/8), poorly sorted, silty, fine to very coarse sand containing granules and pebbles	69–71
Very pale brown (10YR7/4), medium to coarse sand grading downward to very pale brown (10YR7/4) and brownish-yellow (10YR6/8) medium sand interbedded with same-color medium to coarse sand; light-gray silt partings are present near 71.5 ft	71–73
Very pale brown (10YR7/4), medium to coarse sand interbedded with finely layered, very pale brown (10YR7/4), very coarse sand containing quartz granules	73–75
No recovery	75–77
Dark-reddish-brown (2.5YR3/4), medium to coarse sand overlying brownish-yellow (10YR6/8), clayey to sandy silt interbedded with gray (10YR6/1), silty, medium to coarse sand	77–79
Dark-gray (7.5YR4/0), silty, very fine sand containing some dark-yellowish-orange, rust-colored silt overlying dark-gray (7.5YR4/0), silty, fine sand	79–81
Dark-gray (7.5YR4/0), silty, fine to medium sand containing orange streaks and laminae of clayey silt overlying well-sorted, gray (2.5YR5/0), fine to medium sand containing blebs of clayey silt and some coarse sand	81–83
Gray (7.5YR9/0), fine to medium sand containing some coarse sand and traces of silt; grading to gray (7.5YR9/0), silty, fine to medium sand containing some clayey silt laminae	83–85
Gray (7.5YR5/0), silty, fine to medium sand	85–87

	Depth (feet)
Cohansey Sand—Continued	
Very dark gray (10YR3/0), clayey silt containing traces of fine sand and grading to very dark gray (7.5YR3/0), silty, medium to coarse sand	87–89
Very dark gray (7.5YR3/0), sandy silt thinly interbedded with clean, very dark gray (7.5YR3/1), fine to medium sand	89–91
Very dark gray (10YR3/1), micaceous, sandy silt overlying dark-grayish-brown (10YR3/2), sandy silt layered with gray (10YR6/1), fine sand	91–93
Dark-gray (10YR4/1), clayey and sandy silt interbedded with micaceous, dark-gray (10YR4/1), slightly silty, medium to coarse sand	93–95
Dark-gray (10YR4/1), silty, medium to coarse sand overlying well-sorted, medium-gray (10YR5/1) and light-gray (10YR6/1), medium to coarse sand	95–97
Dark-gray (10YR4/1), silty, medium to coarse sand grading downward to well-sorted, gray (10YR5/1), medium to coarse sand grading downward to dark-gray (10YR4/1), silty, medium to coarse sand	97–100
Dark-gray (10YR4/1), silty, medium to very coarse sand overlying well-sorted, gray (10YR5/1), medium to coarse sand overlying dark-gray (10YR4/1), silty, medium to very coarse sand containing some gravel and pebbles having a maximum diameter of 0.2 in.	100–102
Dark-gray (10YR4/1), silty, fine to very coarse sand; coarse sand grains are angular and include many clear quartz shards having a maximum diameter of 0.2 in.	102–104
Sand in this interval is like that from 102 to 104 ft but contains more pebbles	104–106
Gray (10YR5/1), well-sorted, coarse to very coarse sand grading downward to very dark gray (10YR3/1), silty, medium to coarse sand containing black (10YR2/1) streaks (possibly organic fragments) and overlying very dark grayish brown (10YR3/2), slightly silty, fine to medium sand	106–108
Dark-gray (10YR4/1), silty, fine to very coarse sand containing traces of organic material, including rounded wood fragments having diameters as large as 0.8 in.	108–110

	Depth (feet)
Cohansey Sand—Continued	
Dark-gray (10YR4/1), silty, fine to very coarse sand	110–112
Sand in this interval is like that from 110 to 112 ft	112–114
Dark-gray (10YR4/1), silty, fine to coarse sand containing traces of organic material and overlying thinly bedded, dark-gray (10YR4/1) silt and gray (10YR5/1), fine to medium sand; compressed wood is conspicuous in two layers (0.2–0.4 in. thick) near the bottom	114–116
Very dark grayish brown (10YR3/2), silty, fine to very coarse sand containing occasional quartz granules and overlying dark-gray (10YR4/1), fine to very coarse sand containing occasional silt layers 0.08–0.12 in. thick	116–118
Dark-gray (10YR4/1), silty, fine to very coarse sand overlying dark-gray (10YR4/1), slightly silty, fine sand	118–121
Dark-gray (10YR4/1), silty clay; shell fragments are at the bottom of the interval	121–126
Dark-gray (10YR4/1), poorly sorted, medium to fine sand overlying micaceous, silty, fine to medium sand	126–136
No recovery	136–146
No recovery	146–155
Olive-gray (5Y3/2), clayey, medium to fine sand containing scattered pebbles	155–162
Kirkwood Formation:	
Olive-gray (5Y3/2), clayey, fine to medium sand; diatoms are common	162–163
Olive-gray (5Y3/2), very clayey silt containing a few interbeds of light-yellow, medium sand and abundant diatoms; the silt oxidized readily, coating the core with jarosite	163–165
No recovery	165–172
Olive-gray (5Y3/2) to grayish-brown (5YR3/2), clayey and silty, medium sand containing abundant diatoms	172–175
Brownish-gray (5YR4/1), fine, very clayey sand, which is micaceous and faintly bedded; small pieces of wood are abundant at 180 ft	175–185
Olive-gray (5Y3/2), clayey silt to very fine sand, which is micaceous, sparingly diatomaceous, and laminated to massively bedded; occasional small pieces of wood are present	185–195
Sediment in this interval resembles that from 185 to 195 ft	195–200

	Depth (feet)
Kirkwood Formation—Continued	
No recovery	200–211
Dusky-yellowish-brown (10YR2/2) silt, which is slightly clayey, micaceous, and massive and which contains thin seams of very fine sand; diatoms are common at 213 ft	211–215
No recovery	215–220
Dusky-yellowish-brown (10YR2/2), clayey silt and fine sand, which is micaceous and diatomaceous; fine pieces of wood are common	220–225
Sediment in this interval resembles that from 220 to 225 ft	225–235
No recovery	235–241
Olive-gray (5Y3/2), silty, fine sand containing occasional quartz granules and black, shiny, phosphate grains; diatoms are present	241–245
Disconformity.	
No recovery	245–252
Olive-gray (5Y3/2), slightly clayey, medium to coarse sand containing pebbles having a maximum diameter of 0.25 in	252–255
No recovery	255–264
Olive-gray (5Y3/2) thin beds of coarse broken shells in fine sand matrix	264–265
No recovery	265–272
Olive-gray (5Y3/2), coarse shelly layer having a medium sand matrix; shells are oriented parallel to the bedding plane	272–275
No recovery	275–284
Olive-gray (5Y3/2) interbeds of silt and fine sand; finely divided woody fragments are common	284–285
No recovery	285–289
Olive-gray (5Y3/2) clay and silt interbedded with lighter colored, very coarse, pebbly sand; lignitic, woody pieces are dispersed throughout the interval	289–295
No recovery	295–324
Olive-gray (5Y4/1) sand containing coarse, abundant, broken, thick-walled shells	324–325
No recovery	325–334
Olive-gray (5Y3/2), interbedded medium to coarse sand and micaceous silty clay containing scattered lignite fragments	334–335
No recovery	335–344
Olive-gray (5Y3/2), finely laminated interbeds of fine micaceous sand and silty clay	344–345
No recovery	345–348

	Depth (feet)
Kirkwood Formation—Continued	
Olive-gray (5Y4/1), silty clay interbedded with poorly sorted, fine to coarse sands; a few large pieces of lignitic wood are present	348–350
No recovery	350–353
Olive-gray (5Y4/1), laminated clay containing thin interbeds of silty, very fine sand; bioturbation is intensive, and the interval is very carbonaceous	353–355
Sediment in this interval resembles that from 353 to 355 ft	355–361
No recovery	361–363
Olive-gray (5Y3/2), micaceous, silty clay oxidized in part to yellowish gray (5Y7/2)	363–365
Grayish-olive (10Y4/2), locally oxidized to dusky-yellow (5Y6/4), interbedded laminated clay and silty fine sands; finely divided lignitic material is scattered throughout; locally, small shell fragments are also present	365–375
No recovery	375–382
Dark-grayish-green (5GY4/1), clayey, medium to coarse sand containing occasional small pebbles; thin-walled, broken mollusk shells are common; finely dispersed organic matter and pyrite are abundant	382–385
Disconformity.	
No recovery	385–393
Dusky-yellowish-brown (10YR2/2), clayey, medium to coarse sand containing pebbles having a maximum diameter of 0.25 in.; finely dispersed organic matter and pyrite are common	393–395
No recovery	395–403
Olive-gray (5Y3/2), pebbly, very coarse sand, which is slightly clayey	403–405
No recovery	405–409
Olive-gray (5Y3/2), clayey silt	409–410
No recovery	410–412
Grayish-brown (5YR3/2) to moderate-brown (5YR3/4), laminated, clayey and silty, fine sand, which is micaceous; finely dispersed carbonaceous matter is abundant	412–415
No recovery	415–424
Sediment in this interval resembles that from 412 to 415 ft	424–425
No recovery	425–432
Sediment in this interval resembles that from 412 to 415 ft	432–435

	Depth (feet)
Kirkwood Formation—Continued	
Dark-grayish-brown (5YR3/4) to dark-yellowish-brown (10YR4/2), laminated, micaceous, silty clay and clayey silt containing scattered masses of pyrite and abundant finely dispersed carbonaceous matter	435–445
No recovery	445–450
Moderate-brown (5YR3/4), oxidized locally to yellowish-brown (10YR2/2), clayey silt, which is massive to finely laminated; small fossils are present in thin layers as much as 0.40 in. thick	450–455
Brownish-gray (5YR4/1), laminated, clayey silt containing occasional thin layers of very fine sand, scattered small shells, and some foraminifers	455–465
Moderate-brown (5YR3/4), laminated, clayey silt, which is micaceous; interval is locally shelly near 468 ft; microfossils are abundant at 473 ft	465–475
Grayish-olive-green (5GY3/2), clayey, fine sand, which is micaceous and bioturbated; glauconite is present, especially in the lower 5 ft; foraminifers are common near 484 and 476 ft	475–485
Unconformity.	
ACGS Beta unit:	
No recovery	485–513
Olive-gray (5Y4/1) to grayish-olive-green (5GY3/2), slightly clayey, fine quartz sand, which is slightly glauconitic and contains abundant worn shell fragments	513–515
No recovery	515–519
Olive-gray (5Y4/1) to olive-black (5Y3/1), silty, fine to medium quartz sand containing abundant worn shells and glauconite sand	519–520
No recovery	520–525
Olive-gray (5Y4/1), silty, fine to medium quartz sand containing abundant shell fragments and glauconite sand	525–525.5
No recovery	525.5–563
Grayish-green (10G4/2), indurated, laminated, fine to medium, glauconite quartz sand, which is very shelly	563–565
No recovery	565–569
Sediment in this interval resembles that from 563 to 565 ft	569–571
No recovery	571–574
Sediment in this interval resembles that from 563 to 565 ft	574–575
Unconformity.	
Mays Landing unit:	
No recovery	575–577
Dark-greenish-gray (5GY4/1), micaceous, silty clay thinly interbedded with light-gray, fine to medium, micaceous, glauconite quartz sand; fine shells are scattered throughout; woody fragments are common	577–585
Sediment in this interval resembles that from 577 to 585 ft except that it contains more fine shells	585–595
Olive-gray (5Y2/1) to olive-black (5Y4/1), finely laminated, very fine sand, which is micaceous and contains scattered small shells and occasional pieces of lignitic wood	595–605
Dusky-green (5G3/1), loose, slightly clayey, medium, glauconite sand	605–606
Olive-black (5Y2/1), massive to laminated, clayey, fine sand, which is micaceous and contains scattered small shells and some burrows	606–615
Unconformity.	
ACGS Alpha unit:	
Subunit C:	
Sediment in this interval resembles that from 606 to 615 ft except that it is all massively bedded	615–625
No recovery	625–630
Olive-black (5Y2/1), massive to laminated, very clayey, fine sand; scattered, small, fine-walled shells are present	630–635
Dark-greenish-gray (5GY4/1), laminated clayey silt; scattered, small, fine-walled shells are present	635–645
Dark-greenish-gray (5GY4/1) to olive-gray (5Y3/2), laminated clay and silt layers; rip-up microbreccias are common in this interval; masses of pyrite are present	645–655
Olive-gray (5Y3/2), laminated silt and clay; small shells and small wood pieces are scattered throughout	655–665
Sediment in this interval resembles that from 655 to 665 ft except that this interval contains fine to very fine glauconite grains	665–675
Olive-black (5Y2/1) to grayish-olive-green (5GY3/2), laminated, very clayey silt, which is micaceous and contains some glauconite sand and scattered, small, thin-walled shells	675–685
Brownish-black (5YR2/1), laminated, very clayey silt containing scattered, small, thin-walled shells and more glauconite sand than the interval from 675 to 685 ft	685–695
Disconformity.	

	Depth (feet)
ACGS Alpha unit—Continued	
Subunit B:	
Olive-black (5Y2/1), thin-bedded, fine to medium glauconite quartz sand containing interbeds of nonglauconitic silt and scattered, moderate-sized shells; the whole interval is bioturbated	695–705
Sediment in this interval resembles that from 695 to 705 ft except that burrows in this interval seem larger, particularly near 710 ft	705–715
Sediment in this interval is the same color as that from 695 to 715 ft, but it is mainly a clayey silt to fine sand	715–717
Grayish-olive-green (5GY3/2), medium to coarse quartz glauconite sand	717–719
Olive-black (5Y2/1), massive, clayey, fine sand, which is burrowed and contains some clusters of pyrite	719–725
Olive-black (5Y2/1), clayey silt interbedded with fine sand layers containing different amounts of glauconite; scattered, large shells are present, especially near 727 ft	725–735
Disconformity.	
Subunit A:	
Olive-gray (5Y3/2), medium to coarse glauconite sand containing scattered pebbles having a maximum diameter of 0.25 in. is interbedded with clayey, fine to medium, quartz glauconite sand; large shells are concentrated near 743 ft; pyrite clusters are present in some parts of the interval	735–745
Dark-yellowish-gray (5Y7/2), massive, medium to coarse, quartz glauconite sand, which is fossiliferous; the fossils are mostly broken shells (hash); clusters of pyrite are present	745–748
Sediment in this interval resembles that from 745 to 748 ft, but it is laminated, contains less glauconite sand, and is bioturbated intensively; burrows are filled with glauconite sand	748–752
Dark-yellowish-gray (5Y7/2), crudely stratified, clayey, fine glauconite sand containing scattered mica and large, worn, calcareous shells	752–755
Brownish-gray (5YR2/1), silty clay containing many small shells	755–761
Unconformity.	
Shark River Formation:	
Grayish-olive-green (5GY3/2), clayey, medium to coarse glauconite sand interbedded with clayey, silty, fine quartz sand; bioturbation is intensive; scattered fossils are present	761–765
Sediment in this interval resembles that from 761 to 765 ft	765–775
Sediment in this interval resembles that from 761 to 775 ft	775–785
Dusky-green (5G3/2), clayey, medium to coarse, quartz glauconite sand containing scattered, large shells and many burrows	785–792
Pale-olive (10Y6/2), laminated, clayey silt to fine sand	792–795
Dusky-yellow-green (5GY5/2), massive, very clayey, quartz sand containing small amounts of glauconite sand; the interval is intensively burrowed and contains many small shells	795–805
Sediment in this interval resembles that from 795 to 805 ft	805–815
Dusky-yellow-green (5GY5/2), crudely laminated, fine glauconite sand, which is locally thinly bedded, especially near 820 ft; burrows are present	815–825
Sediment in this interval resembles that from 815 to 825 ft except that it contains occasional indurated layers	825–835
Pale-olive (10Y6/2), massive to faintly bedded, clayey silt containing scattered, fine, glauconite grains; occasional large burrows are filled with glauconite sand	835–843
Sediment in this interval resembles that from 835 to 843 ft; at 844 ft, an indurated pyritic layer contains flattened shells and is intensively burrowed; burrows are filled with calcite	843–849
Sediment in this interval resembles that from 835 to 843 ft	849–864
Sediment in this interval resembles that from 835 to 843 ft except that it contains some medium quartz sand, contains more glauconite sand, and is intensively burrowed	864–869
Light-olive-gray (5Y5/2), massive, silty, very fine sand containing fine grains of glauconite scattered throughout; the interval is intensively bioturbated	869–873

	Depth (feet)
Shark River Formation—Continued	
Sediment in this interval resembles that from 869 to 873 ft except that it is crudely stratified	873–885
No recovery	885–889
Light-olive-gray (5Y5/2), silty, very fine sand interbedded with dusky-yellowish-green (10GY3/2), very glauconitic sand; the glauconite sand is thickest from 891 to 893 ft; abundant phosphatic debris (fish parts) and occasional small shark teeth are present; the interval is intensively burrowed; contact with underlying bed is sharp	889–893.5
Unconformity.	
Manasquan Formation (part):	
Pale-olive (10Y6/2), crudely bedded, burrowed, clayey silt containing small amounts of fine glauconite sand; scattered large shells are present, but most fossils are very small	893.5–905
Manasquan Formation—Continued	
Pale-olive (10Y6/2), finely laminated, clayey silt containing numerous small burrows and abundant microfauna	905–913
Sediment in this interval resembles that from 905 to 913 ft	913–923
Pale-olive (10Y6/2), crudely laminated, clayey silt, which is intensively bioturbated and contains some large burrows and abundant microfauna	923–941
Sediment in this interval resembles that from 923 to 941 ft except that it contains more fine glauconite sand	941–945
Base of drilling.	

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