Geology of the Betterton Quadrangle, Kent County, Maryland, and a Discussion of the Regional Stratigraphy

GEOLOGICAL SURVEY PROFESSIONAL PAPER 816

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By JAMES P. MINARD

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A description of Coastal Plain formations and a regional correlation with equivalent units to the northeast in Delaware and New Jersey

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GEOLOGY OF THE BETTERTON QUADRANGLE, KENT COUNTY, MARYLAND, AND A DISCUSSION OF THE REGIONAL STRATIGRAPHY

By JAMES P. MINARD

ABSTRACT

Eight Coastal Plain formations crop out in the Betterton quadrangle near the inner edge of the Atlantic Coastal Plain physiographic province. The quadrangle is in Kent County on the Eastern Shore of Chesapeake Bay, east of Baltimore, Md. The eight stratigraphic units constitute a total section of about 300 feet. In ascending order, the units are: The upper part of the Potomac Group, the Magothy, Merchantville, Englishtown, and Marshalltown Formations, and the Mount Laurel Sand, all of Cretaceous age; and the Hornerstown Sand and Vincentown Formation of Early Tertiary (Paleocene) age.

Quaternary deposits are separated into five map units. The most extensive and thickest (as much as 145 ft) is the upland alluvium which blankets nearly all the surface area of the quadrangle except where incised by stream valleys. The other Quaternary units are small in areal extent and reach a maximum thickness of possibly 30 feet. They are mapped as bog, beach sand, marsh deposits, and Holocene alluvium.

The generally unconsolidated Cretaceous and lower Tertiary formations consist chiefly of quartz, clays, muscovite, chlorite, lignite, feldspar, and pyrite. Quaternary sediments are largely sand and gravel with lesser amounts of silt, clay, muck, and peat.

The Cretaceous and Tertiary units strike generally northeast in the region, but trends in the quadrangle range from nearly east-west to north-south. The units appear to be gently warped.

Resources include ground water, peat, and vast quantities of sand and gravel. Appreciable concentrations of ilmenite are locally present, but no ore bodies are known.

The Betterton and adjoining quadrangles contain outcrops of most of the Cretaceous and Tertiary formations of the Coastal Plain. It is the farthest southwest, on the Eastern Shore of Chesapeake Bay, that so many formations are exposed. Some units have been eroded, overlapped, or undergone facies changes along the strike from northeast to southwest, but the remaining units can be traced to or correlated with sections in Delaware, and throughout New Jersey.

INTRODUCTION

LOCATION AND EXTENT OF AREA

The Betterton quadrangle encompasses nearly 58 square miles on the Eastern Shore of Chesapeake Bay, at the confluence of the Sassafras River with the bay, due east of Baltimore (fig. 1). About 4–5 square miles of the area of the quadrangle is water, mostly across the northern part. The quadrangle is entirely within Kent County, Md.

PURPOSE AND HISTORY OF INVESTIGATION

Geologic study of the Betterton quadrangle was undertaken as a projection of detailed quadrangle mapping by the author and J. P. Owens along the inner edge of the Coastal Plain in New Jersey. The Betterton quadrangle is on a southwest extension of a straight line through four of these quadrangles (fig. 1). The mapping in New Jersey was the first modern detailed mapping of a large area at a large scale in that State. Geologic mapping has been completed in twelve 7½-minute quadrangles (1:24,000 scale); maps or reports on 11 of these quadrangles have been published (Minard, 1969, fig. 2). This mapping allowed for accurate correlation along the entire 100-mile strike of the Coastal Plain formations in New Jersey.

Concurrent reconnaissance mapping and investigations were conducted in Delaware in an attempt to correlate the Coastal Plain section of that State (made prior to 1969) with the section in New Jersey. As can be seen on table 1, the Coastal Plain stratigraphy recognized by the Delaware Geological Survey (prior to 1969) could be only partly correlated with the Coastal Plain stratigraphy in New Jersey. In 1967, the section as mapped in the Woodstown quadrangle, New Jersey (Minard, 1965), was tentatively established for Delaware by publication of a special map by the U.S. Geological Survey (1967) (actually nearly the same section Carter attempted to establish in 1937). This was followed 2 and 3 years later by acceptance of the U.S. Geological Survey section by the Delaware Geological Survey (Pickett, 1969, 1970a).

In 1970, Owens and others (1970) correlated the post-Magothy formations of New Jersey, Delaware, and eastern Maryland. The report was based on the New Jersey work from 1957 to 1965, and on reconnaissance field geology in Delaware (particularly in 1963) and in eastern Maryland during this same period.

In 1965, a mapping program, the Upper Chesa-

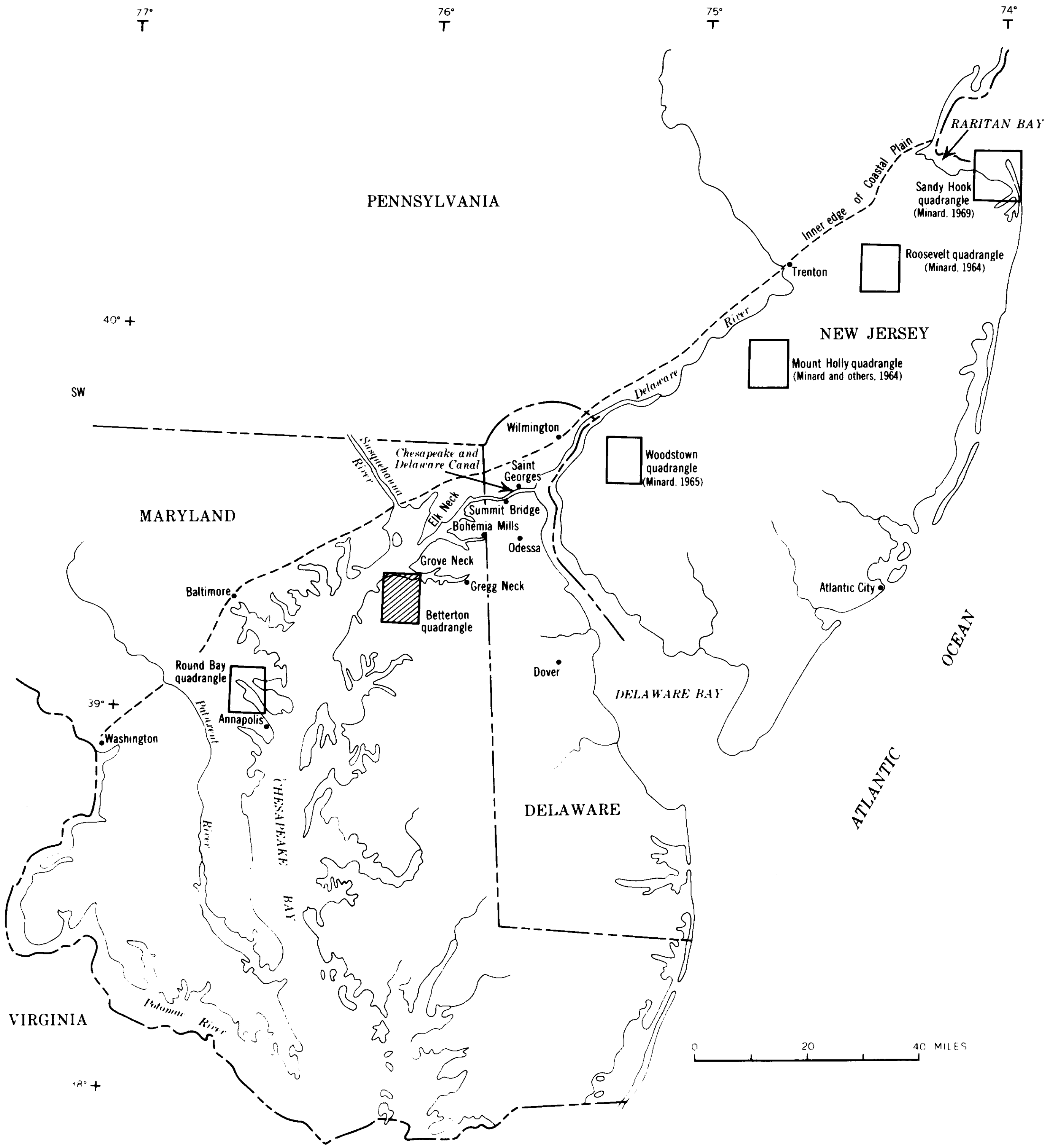


FIGURE 1.—Index map of the Coastal Plain from the Potomac River northeastward to Raritan Bay.

TABLE 1.—*Modern correlations of Coastal Plain formations in Maryland, Delaware, and New Jersey*

Maryland				Delaware			New Jersey		Betterton quadrangle
Cleaves and others, 1968				Jordan, 1962	U.S. Geol. Survey, 1967	Pickett, 1970b	Owens and Minard, 1960, and Minard, 1964, 1969		This report
Tertiary	Miocene		Chesapeake Group	Chesapeake Group	Chesapeake Group		Miocene-Pliocene(?)	Cohansey Sand Kirkwood Formation	
	Eocene	Sub-surface	Piney Point Formation	Piney Point Formation			Rancocas Group	Manasquan Formation	
		Pamunkey Group	Nanjemoy Formation	Rancocas Formation					
	Paleocene		Aquia Formation		Vincentown Formation			Vincentown Formation	Vincentown Formation
			Brightseat Formation		Hornerstown Sand			Hornerstown Sand	Hornerstown Sand
Cretaceous	Upper Cretaceous		Monmouth Formation	Redbank Formation			Monmouth Group	Tinton Sand	
								Red Bank Sand	
				Mount Laurel-Navesink Formation				Navesink Formation	
					Mount Laurel Sand	Mount Laurel Formation		Mount Laurel Sand	Mount Laurel Sand
			Matawan Formation	Wenonah Formation			Matawan Group	Wenonah Formation	
					Marshalltown Formation	Marshalltown Formation		Marshalltown Formation	Marshalltown Formation
					Englishtown Formation	Englishtown Formation		Englishtown Formation	Englishtown Formation
								Woodbury Clay	
				Merchantville Formation	Merchantville Formation	Merchantville Formation		Merchantville Formation	Merchantville Formation
			Magothy Formation	Magothy Formation	Magothy Formation	Magothy Formation		Magothy Formation	Magothy Formation
	? Lower Cretaceous		Potomac Group	Potomac Formation	Potomac Group	Potomac Formation		Raritan Formation	Potomac Group

peake Bay Project, was begun because of the need for detailed mapping along strike towards the southwest, primarily to correlate the formations that persist and to recognize areas of facies changes, overlaps, and pinchouts. Included in this project was the Betterton quadrangle on the east shore of Chesapeake Bay and the Round Bay quadrangle on the west shore near Annapolis (fig. 1).

Other quadrangles to the southwest, such as Lanham and Anacostia, between Annapolis and Washington, were to have been included as mapping progressed in that direction. One of the major goals of the plan was to continue mapping along strike across Maryland and Virginia into North Carolina as far as the Cape Fear arch. This would be accomplished by mapping at intervals spaced so as to move appreciable distances but not so far that important facies changes and pinchouts would be overlooked. This type of program and desired goals necessitated considerable reconnaissance in areas between and beyond mapped quadrangles. Because much geologic data have been obtained in these areas and these data are important in the long-range correlation, they are included in this report under the section on regional stratigraphy. Most of the discussion in this section is limited to the area between the Betterton quadrangle, Maryland, and Raritan Bay, N.J. The formations usually will be discussed along strike between these two locations from either direction. The continuity of formations to the southwest is at present being investigated by geologic mapping of the Round Bay quadrangle near Annapolis, Md. (fig. 1).

ACKNOWLEDGMENTS

Appreciation is expressed to L. C. Conant, J. P. Owens, N. F. Sohl, Ruth Todd, Jack Wolfe, G W Hayes, and H. W. Ritzman, all of the U.S. Geological Survey, and to J. A. Doyle, formerly U.S. National Museum.

Conant assisted the author with fieldwork in October and November, 1965. Owens assisted in stratigraphic correlations through discussions and visits to strategic outcrops, Sohl identified megafossils, and Todd identified microfossils. Wolfe and Doyle identified pollen and spores from the Cretaceous units, which aided in age determinations. Ritzman and Hayes assisted with the power auger in 1966 and 1969, respectively.

Appreciation also is expressed to K. N. Weaver, Director of the Maryland Geological Survey, and his staff for their interest and encouragement. Thanks are due my sons Jamie and Brent for much assistance in augering and fossil collecting and to the many property owners who generously granted permission to cross their land.

Fieldwork began in October 1965 and was largely completed in June 1966 when work was halted to begin a special priority study. Fieldwork was completed during several short periods in 1967–69.

PREVIOUS INVESTIGATIONS

Previous investigations in the Betterton quadrangle and adjacent areas were parts of studies designed to obtain a broad regional concept of the geology. As can be seen from table 1, there was no subdivision of the Matawan or Monmouth in Maryland as recently as 1968. The nomenclature remained unchanged from Clark's classification for the New Jersey–Maryland region in 1898 (p. 174–186). The Matawan classification actually was based on even earlier work by Clark (1894, p. 163).

In the present report, the Matawan is divided into three formations (Merchantville, Englishtown, and Marshalltown, in ascending order) in the Betterton area, and the Monmouth interval is designated the Mount Laurel Sand. The Tertiary sediments are divided into two units, the Hornerstown Sand (lower unit) and Vincentown Formation, all from the New Jersey stratigraphic nomenclature and as shown in Owens and others (1970, fig. 5). Detailed descriptions of the history of geologic investigations in the Maryland, Delaware, and New Jersey Coastal Plain region have been given by Clark (1916, p. 34–50) and Greacen (1941, p. 8–19).

PHYSIOGRAPHY

The quadrangle consists largely of a dissected sandy plain, typical of the Atlantic Coastal Plain. Altitudes range from sea level to slightly more than 100 feet. Broad flat interfluves, between altitudes of 60 and 100 feet, constitute much of the land surface. The small areas of land below 60 feet are mostly slopes into stream valleys and drainageways. Wavecut cliffs as high as 80 feet border the Sassafras River in the northern part of the quadrangle and Chesapeake Bay in the northwest (pl. 1).

Streams flowing north into Sassafras River, west into Chesapeake Bay, and south into Chester River have dissected the plain to a considerable extent. Several streams flow into inlets which extend as far as several miles inland from the bay and from the Sassafras River. Tidal marshes are present along these inlets and along Morgan Creek in the southeast part of the quadrangle.

Big Marsh, in the northwest part of the quadrangle, is a swampy area 2 miles long and as much as half a mile wide.

The highest altitudes are in the northwest part of the quadrangle; the dissected plain slopes gently toward the southeast, for a total decrease in altitude of about 30 feet in 8 miles.

Streams in the quadrangle are mostly short and have small volumes of flow. Because of this and the sandy unconsolidated nature of the formations, most exposures along the streams are poor and slumped; very few fresh outcrops are present except along the beaches.

STRATIGRAPHY OF THE BETTERTON QUADRANGLE

The stratigraphic units exposed in the quadrangle consist of a succession of eight sedimentary formations of Cretaceous and early Tertiary age, which range in thickness from 12 to 130 feet and aggregate as much as 308 feet, and several units of Quaternary age, which range in individual thickness from a few feet to 145 feet.

Most of the pre-Quaternary sediments consist of unconsolidated marine clay, silt, sand, and gravelly sand; some continental deposits are at the base of the section in the quadrangle. Beds within the formations locally are cemented by iron oxide and iron carbonate into resistant layers. The Quaternary deposits range in grain size from clay to boulders; these deposits are largely of alluvial origin.

The exposed Cretaceous formations are, in ascending order, the upper part of the Potomac Group, the Magothy, Merchantville, Englishtown, and Marshalltown Formations, and the Mount Laurel Sand. These formations are overlain by the Hornerstown Sand and Vincentown Formation of Paleocene age (pl. 1). The Quaternary deposits include alluvium of Pleistocene age, and peat, beach sand, marsh deposits, and alluvium of Holocene age.

The Cretaceous and Tertiary formations are composed chiefly of quartz, glauconite, montmorillonite, mixed-layer clay, kaolinite, muscovite, chlorite, lignite, feldspar, and pyrite. Sediments of the Quaternary deposits were derived from older formations both within and outside the quadrangle.

LOWER AND UPPER CRETACEOUS SEDIMENTS

POTOMAC GROUP

The Potomac Group consists of continental deposits of gravel, sand, silt, and clay. The name Potomac apparently was first used when McGee (1886) assigned the name Potomac Formation to the sequence of unconsolidated nonmarine sediments along the inner edge of the Coastal Plain in Maryland and Virginia. Several years later, Clark and Bibbins (1897, p. 481) established the Potomac Group and divided it into four formations—Patuxent, Arundel, Patapsco, and Raritan (oldest to youngest). As studies evolved, ages were assigned by Berry (1910; 1911), Clark and others (1911, p. 80–98), Dorf (1952, p. 2169), and Brenner (1963, p. 33). Recently accepted ages seem to be Early Cretaceous for the Patuxent, Arundel, and Patapsco stratigraphic units, and Late Cretaceous for the Raritan or equivalent(?) in the Maryland area (Owens, 1969, p. 86–91; Hansen, 1969, p. 1923–1924).

However, Doyle (1969a, p. 13) suggested a younger age for the Patuxent and Arundel, possibly middle Cretaceous. Wolfe and Pakiser (1971, p. B37) agreed with this age, at least for all except possibly the lower part of the Patuxent. Doyle stated (p. 12, 13) that the Patapsco is almost certainly no older than lower Albian, and may in fact be younger. Wolfe and Pakiser (1971, p. B37) considered the lower part of the Patapsco to be somewhere in the later half of the Albian. The Raritan has been dated as middle or upper Cenomanian (Doyle, 1969a, p. 14), which is significantly younger than the typical Patapsco of Maryland. "Older beds [than the Raritan] which promise to close the gap [from lower Albian to middle Cenomanian] between the Patapsco and Raritan, are becoming known to the south of Raritan Bay and in the subsurface, as are younger beds of presumed Turonian age (South Amboy Fire Clay Member) in the Raritan Bay area" (Doyle, 1969a, p. 14). This interval between the Potomac and Raritan is known informally as zone III (Doyle, oral commun., Aug. 4, 1971), which places it above Brenner's zone II (Patapsco, Doyle, 1969a, p. 3; 1969b). Wolfe and Pakiser (1971, p. B38) suggested that the "so-called Raritan of Maryland probably represents the uppermost part of the Patapsco Formation."

The Potomac Group crops out only in a small area in the northwestern part of the quadrangle; probably only about the upper 25 feet of the unit is exposed within the quadrangle. The upper 6–10 feet is exposed in the bank back of the narrow beach between 0.4 and 0.5 mile east of Howell Point. It is white to light-gray, pinkish-yellow, and brown clay, silt, and very fine sand. About 25 feet of the unit is well exposed in the bluff at Worton Point, 5 miles to the southwest in the Hanesville quadrangle; it is nearly the next 25 feet stratigraphically below the section exposed at Howell Point.

Most of the section exposed at Worton Point is similar to that near Howell Point, that is, white to light-gray, yellow, and brown clay, silt, and sand. At the base of the bluff, however, is a dark-gray very lignitic clay, which contains flattened lignitized logs as much as 6 inches thick, 10–18 inches wide, and 6–10 feet long. Locally, white and red clay is under and interbedded with the dark clay (fig. 2*A*). Most of the dark-gray clay is under the beach and can be seen best at low tide. Light-gray to yellow-brown siderite concretions are present in the light-colored clay. The sand fraction is largely quartz, and the clays are kaolinite and illite.

The author collected a sample of the dark-gray clay at Worton Point. It was examined by Doyle, who stated (oral commun., Aug. 4, 1971) that the pollen from the clay correlates with that from his informal zone III, which places the dark clay in the time position between the Patapsco and Raritan.

Because only a few feet of the upper part of the section is exposed in the Betterton quadrangle, a detailed description of the entire group is not appropriate here. Such descriptions are found in Miller (1906, p. 3), Bascom and Miller (1920, p. 8–10), Owens (1969, p. 79–91), and Hansen (1969, p. 1927).

UPPER CRETACEOUS SEDIMENTS

MAGOTHY FORMATION

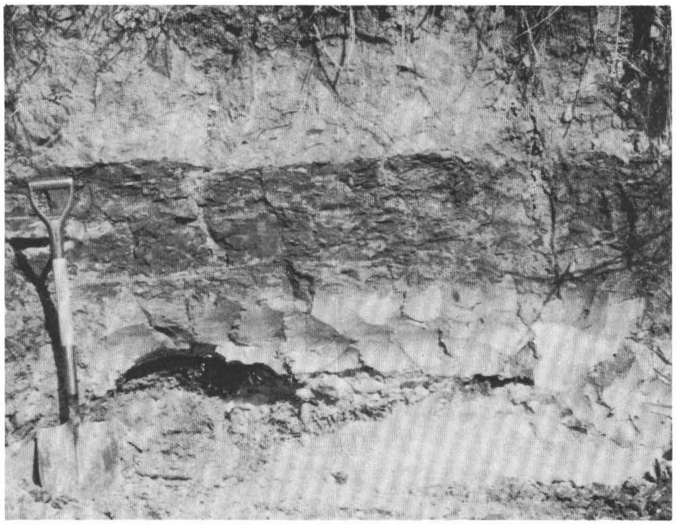
The Magothy Formation is predominantly well-stratified quartz sand, but contains an abundance of discontinuous layers of clay-silt. The formation is about 30–35 feet thick in the quadrangle. A 30-foot-thick section is exposed 0.2 mile east of the Magothy-Potomac contact, or 0.7 mile east of Howell Point at the mouth of the Sassafras River. The base of the outcrop, at beach level, consists of several feet of unctuous dark-gray carbonaceous clay (about 500 ft to the west, several feet of light-gray to yellow-brown fine to medium sand underlies the clay). Above the clay is about 5 feet of interbedded gray clay and fine to very fine light-gray quartz sand. Above this is about 20 feet of both horizontally and cross stratified light-gray to yellow-brown fine to coarse quartz sand. The formation is exposed in the bluff for a distance of nearly half a mile both east and west of the 30-foot-high outcrop.

The basal contact with the Potomac Group is distinct. The clean sands of the Magothy unconformably overlie light-gray to pinkish, yellow, and brown clay silt of the Potomac Group. The Magothy is earliest Campanian in age.

The formation also is well exposed in the adjacent Hanesville quadrangle. Almost continuous exposures are present in the bluff from a short distance west of Camp Tockwogh for more than 1 mile around Stillpond Neck to Codjus Cove.

Most of the section here consists of light-gray to yellow-brown quartz sand, ranging in grain size from very fine through very coarse. Granules and pebbles (as much as 1½ inches in diameter) are present in beds in the lower half of the formation. Conspicuous cross-stratified layers characteristically interfinger with thin horizontal layers. Lenticular clay-silt bodies are present in the section here. One such body can be traced for more than 1,000 feet along the northern part of Stillpond Neck, where it increases in thickness from a few inches in the southwest to 15 feet in the northeast. The clay-silt is dark gray and contains abundant carbonaceous matter. Within the body, layers of clay-silt are typically separated by laminae of fine to very fine white quartz sand, so that thick blocks part easily along these quartz-sand laminae. The clay-silt is overlain and underlain by clean cross-stratified light-gray very fine to medium quartz sand, partly stained by iron oxide (fig. 2*B*). Some sand beds locally are indurated by iron oxide and are yellow brown.

FIGURE 2.—Cretaceous and Tertiary formations, Betterton quadrangle and nearby areas. *A*, Potomac Group sand and clay beds at Worton Point. Dark-gray clay bed yielded pollen correlated by Doyle (oral commun., Aug. 4, 1971) with his zone III (1969a, p. 17). Leaching of the dark color may be a function of ground water in the clean loose sand at the base. Beneath the basal sand is more oxidized clay underlain by dark-gray clay which contains lignitized logs. *B*, Dark-gray clay layer in the Magothy at Meeks Point on Stillpond Neck in the Hanesville quadrangle just west of the Betterton quadrangle. The clean, loose, finely cross stratified, fine sand below is also Magothy. *C*, Ten-foot-thick section of the Englishtown Formation exposed beneath 15–18 feet of Quaternary alluvium in the bank along the Sassafras River about 200 feet east of the pier at Betterton. The base of the Quaternary alluvium is iron oxide cemented gravel. The Englishtown is well bedded; crossbedding is visible in the light-gray sand. The exposure is chiefly a clean, loose, fine sand with thin clay layers. Near the base it is less weathered and contains abundant organic matter, including pieces of wood. About 5 more feet of section is present at the base above tide level. *D*, Hornerstown Sand (basal Tertiary) overlying the Mount Laurel Sand (Upper Cretaceous) at Gregg Neck, Md. (see fig. 1). The Hornerstown here contains an appreciable amount of quartz sand but is still predominantly glauconite, whereas the Mount Laurel is predominantly quartz sand. ▶



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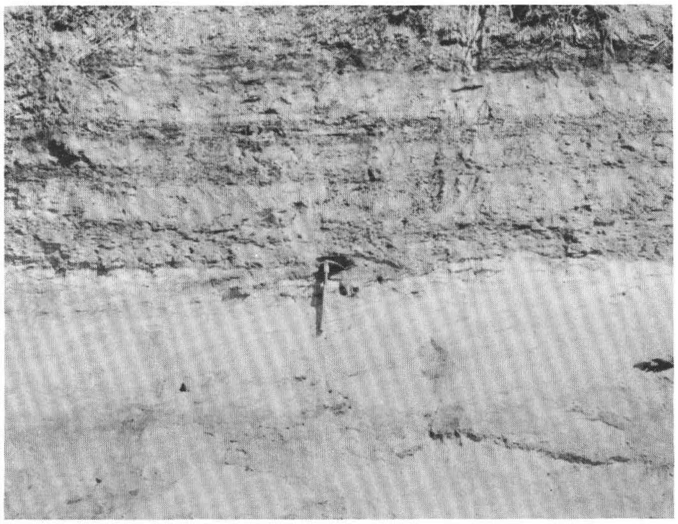

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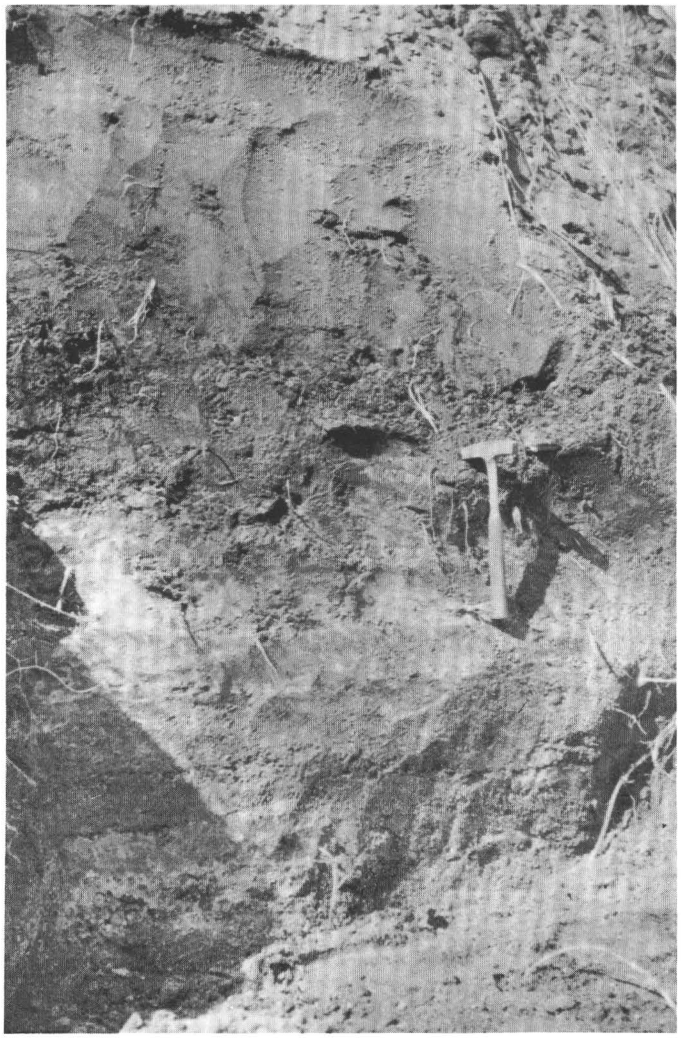


D

Where the formation is unweathered, the sand is light gray and contains dark-gray to black carbonaceous matter. Where weathered, the sand is yellow brown and locally cemented by iron oxide; the organic matter is leached where weathered. Where the clay is unweathered it is dark gray to black; where weathered, it is medium gray to very light gray, again a function of leaching of the organic matter.

MERCHANTVILLE FORMATION

The Merchantville Formation is mostly thick-bedded to massive dark-gray to grayish-black clayey silt to fine and very fine sand. Quartz, glauconite, feldspar, chlorite, and muscovite are major sand-sized minerals. Pyrite and siderite are important diagenetic minerals. Carbonaceous matter is abundant throughout, chiefly as small particles (less than 1 in.), although larger pieces are common in the basal 1 foot. Pyrite occurs as small (sand-sized) crystals and clusters of crystals, or as coatings on carbonaceous matter; siderite is in irregular concretionary masses as much as several inches across. The concretions are typically iron oxide stained on the surface but are light gray to tan inside. Locally near the base, the formation contains a layer of very coarse sand and granules in fine silty clayey sand. Similar thin layers also are present locally in the upper few feet.

The formation is 20–40 feet thick in the quadrangle. It is thinner in outcrop at the western edge of the quadrangle than in the north along the Sassafras River.

Characteristic detrital heavy minerals include chloritoid, rutile, tourmaline, staurolite, and garnet. Mica is abundant as fine flakes of colorless muscovite (and some green chloritized mica) scattered throughout the unit. Glauconite also is present as fine to very fine dark- and light-green botryoidal and accordian (Galliher, 1935, p. 1587) grains. Quartz is the most abundant mineral and occurs as silt and fine to very fine sand grains. Illite, kaolinite, and montmorillonite are the dominant clay minerals.

The contact with the underlying Magothy is sharp and unconformable. Typically, dark-gray thick-bedded micaceous, glauconitic fine to very fine silty and clayey sand of the Merchantville overlies thin, horizontally and cross-stratified clean light-gray to yellow-gray and yellow-brown quartz sand of the Magothy. The contact can be seen at several places in the bluffs east of Howell Point.

In some outcrops the Merchantville may be weathered to light gray, moderate pink, and light olive gray or brown. The lighter colors are partly due to oxidation and lixiviation by ground water as it moves along permeable sandy beds, either at the base of the overlying Quarternary alluvium or beneath in the clean sands of the Magothy.

Although no identifiable fossils were found, they are abundant in the formation along the Chesapeake and Delaware Canal, about 23 miles to the northeast (Owens and others, 1970, p. 35–39). The important fossil for stratigraphic correlation of the Merchantville is the ammonite *Scaphites hippocrepis,* which suggests an early (but not earliest) Campanian age (Sohl and Mello, in Owens and others, 1970, p. 39).

ENGLISHTOWN FORMATION

The Englishtown Formation is chiefly a fine to very fine micaceous quartz sand that contains thin intercalated clay layers. The unit is characterized by distinctive thin horizontal and cross stratification. Quartz, feldspar, and mica are the primary constituents. Glauconite is present, particularly in the unweathered darker material, as fine to very fine rounded green grains. Characteristic heavy minerals include ilmenite, rutile, tourmaline, staurolite, and chloritoid. Dominant clay minerals are kaolinite and montmorillonite. Where weathered, the formation is light gray to yellowish gray, and yellowish brown.

Where the formation is not weathered to the light color typical of it in outcrop above the water table, it is dark gray and contains layers of grayish-black clay which is characterized by abundant lignitic material and laminae of angular to subangular fine to very fine light-gray quartz sand. Thin layers of very micaceous lignitic materials are common in the unweathered sand. Small pyrite crystals and clusters of crystals and coatings of pyrite on lignitic material are abundant in these layers and common throughout the entire unweathered section. Thin layers of clay in the oxidized sand are light gray to yellowish brown. Where penetrated below the water table by the auger, the entire section is dark gray, except that the sand is light gray when the lignitic material is removed by washing. The formation is about 15–18 feet thick in the quadrangle. The formation is quite similar to the Magothy in lithology and internal structures.

The thickest outcrop of the formation is in the bank 200–500 feet east of the boat pier at Betterton. The total exposure is about 30 feet; the upper 15–18 feet is sand and gravel alluvium of Quaternary age, which contains ironstone layers. Beneath the alluvium is about 15 feet of Englishtown Formation, nearly the entire thickness present in the quadrangle. The upper 8 feet of the Englishtown is clean loose yellowish-brown and gray to white fine quartz sand (fig. 2*C*). The sand is both horizontally and cross stratified and contains thin layers of oxidized clay. The lower 7 feet of the exposure consists of dark-gray silty, clayey layers containing much carbonaceous matter and abundant mica interbedded with sand and "sooty" black clay layers about 1–2 inches thick; the sand is thin bedded to laminated. Pieces of lignitized logs as much as several inches in diameter are present in these basal beds. This is probably the best exposure southwest of the outcrop along the north side of the abandoned channel of the Chesapeake and Delaware Canal, 23 miles to the northeast.

Six-tenths of a mile west of the above exposure, the basal contact of the Englishtown with the underlying Merchantville Formation is well exposed 10–12 feet above beach level. Five feet of the Englishtown basal thin intercalated silt, sand, and clay overlies the massive Merchantville. Three thin (1–3 in.) layers of coarse to very coarse sand, granules, and small (1/8- to 3/8-in.) pebbles are in the basal Englishtown. At this exposure, as at a few others, the formations appear to interfinger at the contact. A coarse sand and granule layer in the base of the Englishtown grades laterally into the upper massive Merchantville, which in turn thins and pinches out laterally in the opposite direction within the basal bedded Englishtown.

Locally, brown to light-gray siderite concretions are present in the lower part of the formation. No fossils were found in the Betterton quadrangle, but they are abundant in the unit in outcrop along the Chesapeake and Delaware Canal (Owens and others, 1970, p. 39–41, 51) and have been reported previously in New Jersey (Minard, 1969, p. 7). Animal borings, typically 1/2–1 inch in diameter and several inches long, are in the upper 1–2 feet. These are filled by glauconite-rich quartz sand from the overlying Marshalltown Formation. The fauna, abundant lignite, and internal structures (thin horizontal and cross stratification) suggest a shallow-water to beach-complex depositional environment.

MARSHALLTOWN FORMATION

The Marshalltown Formation is typically thick-bedded to massive, mottled, medium-greenish-gray to medium-dark-greenish-gray, fine to medium, silty, glauconitic quartz sand. The unit is 15–18 feet thick in the quadrangle. The lower 6–7 feet contains many coarse to very coarse quartz grains and a few scattered quartz pebbles as much as three-quarters of an inch in diameter. Animal borings, as much as 1 inch in diameter and several inches long, are present in the lower part of this section. The borings are conspicuous in the dark-greenish-gray background because they are chiefly filled by white quartz sand. The basal 1 foot contains a "trash" layer, several inches thick, of granules, small pebbles, and pieces of lignite. Major minerals are quartz, glauconite, and feldspar. The glauconite grains are both rounded and accordian shaped (Galliher, 1935, p. 1587). Fine plates of colorless mica are present throughout much of the unit. Glauconite content of most of the section is 5–10 percent, but a glauconite-rich (40–50 percent) layer, about 1 foot thick, locally occurs at the top. Much of the glauconite is concentrated in small-animal borings similar to the quartz-sand-filled borings in the lower part. Characteristic heavy minerals include ilmenite, staurolite, zircon, tourmaline, rutile, epidote, garnet, and andalusite. Dominant clay minerals are kaolinite, montmorillonite, and illite.

The contact with the underlying Englishtown Formation is sharp. Thick-bedded to massive dark-greenish-gray silty glauconite-quartz sand of the Marshalltown directly overlies thin-bedded medium-dark-gray quartz sand of the Englishtown.

The only exposures of the formation are in the south banks of the Sassafras River east of Betterton, largely between Gut Marsh and Yapp Marsh. The entire thickness crops out, and the contacts with the underlying Englishtown Formation and overlying Mount Laurel Sand can be seen. The subcrop of the formation beneath the Quaternary alluvium was traced across the quadrangle by augering.

Fossils are sparse and poorly preserved in the quadrangle. They are abundant and well preserved along the Chesapeake and Delaware Canal to the northeast (Owens and others, 1970, p. 41, 42, 52). The diagnostic stratigraphic marker fossil is *Exogyra ponderosa* Roemer, which suggests Campanian age. A greater diversity of fauna and the general lithic character suggest that the Marshalltown was deposited in deeper water than the Englishtown Formation.

MOUNT LAUREL SAND

There has been considerable disagreement among previous workers as to what part of the northern Atlantic Coastal Plain stratigraphic column actually is Mount Laurel. Consequently, what is mapped as Mount Laurel in the Betterton quadrangle is specifically stated here. The Mount Laurel is that thick unit of glauconitic quartz sand at the top of the Cretaceous column, between the Marshalltown Formation below and the basal Tertiary Hornerstown Sand and Vincentown Formation above. A more thorough discussion of the regional distribution and correlation and the thickness variations is given in the section on regional stratigraphy.

The Mount Laurel Sand is massive to thick-bedded glauconitic quartz sand. It ranges from yellowish gray and yellowish brown to moderate brown and reddish brown where weathered, and from medium gray to dark greenish gray and grayish black where not weathered. Grain size ranges from fine to very coarse sand, granules, and small pebbles (generally less than 1 in. in diameter). Some silt and clay are present as coatings on sand grains or in small lenses. Glauconite occurs throughout most of the section in amounts ranging from scattered grains to about 50 percent.

The major minerals are quartz, glauconite, and feldspar; mica and apatite are important minor constituents. Heavy minerals present include ilmenite, zircon, tourmaline, rutile, epidote, staurolite, sillimanite, and kyanite. Lignite is present mostly as small pieces (less than 1 in. in maximum dimension), but some as clay- to sand-sized particles. Siderite concretions are present, particularly in the lower third of the section. These concretions are unusual when compared with the siderite concretions in the other formations. They are much larger; some roughly cylindrical forms measure 2 feet across and 6 feet long. They are light gray to reddish brown, depending on the degree of oxidation. These large concretions are present at the base of the 70-foot bluff at the mouth of Lloyd Creek.

Typically, the unweathered formation is massive dark-greenish-gray to grayish-black glauconitic quartz sand in the lower 30–40 feet. The middle 40–50 feet is characterized by thick (6- to 15-ft) beds; cross-stratified layers are locally present in this interval. A typical section of this middle sequence consists of a basal bed, 6–10 feet thick, of medium glauconitic (5–10 percent) feldspathic quartz sand, overlain by a 9- to 10-foot-thick bed of coarse to very coarse quartz-glauconite sand containing granules and small pebbles. Glauconite constitutes as much as half of this bed. Both microfossils and megafossils are abundant in this bed. The coarse bed is about at the stratigraphic middle of the formation as mapped in the quadrangle and is a distinctive horizon marker, both in outcrop and, particularly, in auger holes.

Above the coarse bed is a thick (20-ft) bed of medium glauconitic quartz sand. The basal 4 feet of this bed contains considerable clay and black heavy minerals, mostly ilmenite. Above this thick bed is about 10 feet of medium to coarse glauconitic quartz sand that contains a fair amount of ilmenite.

Quartz is clear to milky to greenish and mostly subrounded to rounded. Glauconite is dark-green to greenish-black and grayish-olive-green (except where weathered to shades of brown) mostly smooth to irregular botryoidal grains and aggregations of botryoidal grains and some accordian (Galliher, 1935, p. 1587) or tabular (Light, 1952, p. 73) forms. Feldspar is mostly weathered sand-sized grains. Mica is chiefly colorless muscovite and is most abundant in thin layers containing carbonaceous matter. Apatite is present as small ovoid sand-sized pellets with glossy exteriors; they resemble fecal pellets.

The Mount Laurel Sand is the thickest unit whose entire thickness crops out within the quadrangle. It is about 130 feet thick in the northeast part and thins to about 60 feet at the western edge of the quadrangle. The basal contact with the Marshalltown is not as distinctive as the contacts between some of the underlying formations. At the base of the massive lower part is a glauconite-rich layer about 1 foot thick. This layer contains about 50 percent glauconite and is chiefly fine to medium but contains some very coarse sand grains, granules, and a few small pebbles. This layer overlies a mottled greenish-black silty, glauconitic quartz sand which is extensively bored. The borings are in the upper Marshalltown and contain quartz-glauconite sand derived from the basal Mount Laurel bed.

Excellent exposures are present in the quadrangle; in fact, probably the best exposures in the northern Atlantic Coastal Plain are along the Sassafras River. A 60- to 70-foot-thick section is exposed in the bluffs northeast of the mouth of Lloyd Creek. Many exposures are present along the irregular shoreline of Lloyd Creek inlet. The basal contact with the Marshalltown is exposed in the bluffs along the Sassafras River between Yapp Marsh and Gut Marsh. Many other outcrops are in the upper drainageways of Lloyd, Stillpond, and Churn Creeks. Typical exposures near the surface are reddish-brown, iron oxide crusted and cemented, medium to coarse glauconitic quartz sand.

The Mount Laurel Sand is largely late Campanian in age. It is fairly fossiliferous, but many of the fossils have been leached, leaving molds coated by iron oxide. Diagnostic fossils found in this unit to the northeast are *Exogyra cancellata* Stephenson, *Belemnitella americana* (Morton), and *Anomia tellinoides* (Morton) (Owens and others, 1970, p. 45). The formation is regionally overlain unconformably by beds of Paleocene age, leaving a time gap represented by part or all of the Maestrichtian. However, locally at the top of the formation, particularly in the northeast part of the quadrangle where it is thickest, are fossiliferous beds of Maestrichtian age. These beds may be nearly time equivalent to the Red Bank Sand of New Jersey and are discussed in more detail in the Mount Laurel section in the discussion on regional stratigraphy.

TERTIARY SEDIMENTS

HORNERSTOWN SAND

The Hornerstown Sand is a dusky-green fine to medium quartz-glauconite sand; glauconite content ranges from 50 to 90 percent of the sand fraction. The clay-sized fraction is unusual in that it is green and chiefly glauconite. The unit is one of the most easily recognizable in the northern Atlantic Coastal Plain.

The glauconite, which is distinctive from that in all the other formations, including the younger Vincentown Formation, is chiefly fine to medium, dusky green, smooth surfaced, and botryoidal. Quartz ranges from fine to very coarse and is mostly milky. Detrital heavy minerals are sparse; they include hornblende, staurolite, tourmaline, and zircon. Because of the high percentage of glauconite, specimens of the formation have a soft nonabrasive feel when crumbled in the hand.

The basal contact with the underlying Mount Laurel is sharp and unconformable (fig. 2*D*) ; the green, very glauconitic Hornerstown lies directly on the brown to gray, sparingly glauconitic quartz sand of the Mount Laurel. In some outcrops, glauconite-filled borings extend downward from the basal Hornerstown into the Mount Laurel.

The formation ranges in thickness from 0 to 12 feet in the quadrangle. It is absent beneath the Quaternary alluvium and Vincentown Formation in the eastern part of the quadrangle because it was locally eroded before deposition of the Vincentown. About 8 feet of the formation is exposed in a cut along the west side of the road 0.45 mile north-northeast of Smithville, near the west-central part of the quadrangle. The basal contact with the Mount Laurel can be seen several feet above the road surface. The upper part of the formation, just beneath the veneer of gravel, is mostly blocky green glauconite clay, a weathering product of the glauconite sand. Oxidized sand and clay of the formation crops out along the north side of Route 297, 0.15 mile east of the west edge of the quadrangle, but locally is buried by slope wash in the ditch. It is better exposed in a cut along the south side of the same road just over the hill in the Hanesville quadrangle to the west. The color of the formation here is chiefly dusky red with some dusky green. In a washed sample, the sand fraction is 80–90 percent glauconite. Several other small outcrops are present along creeks near Smithville. Another exposure is on the south slope of a hillside 1 mile southeast of Worton. The presence or absence of the formation beneath the alluvium and Vincentown Formation elsewhere in the quadrangle was determined by augering.

The Hornerstown is Paleocene in age and is the basal unit of the Tertiary System in New Jersey, Delaware, and eastern Maryland. No fossils were found in the formation in the Betterton quadrangle. The underlying Mount Laurel Sand is largely Campanian in age; much of the uppermost Cretaceous Maestrichtian is absent. In New Jersey the Upper Cretaceous Navesink Formation, Red Bank Sand, and Tinton Sand occupy the interval between the Mount Laurel and the Hornerstown (table 1).

VINCENTOWN FORMATION

The Vincentown Formation is thick-bedded fine to medium glauconitic quartz sand; coarse to very coarse grains of sand are common throughout. The unit is predominantly greenish gray to grayish green, but ranges from greenish black (where unweathered) to yellowish brown and moderate to pale red where weathered. Glauconite generally constitutes 1 or 2 percent to 15 percent of the unit. Some beds, however, contain as much as 30–50 percent glauconite; one such bed is common at the base of the formation. The clay-silt fraction typically constitutes about 15 percent. As a result of deep weathering and comminution of glauconite grains, the clay-silt fraction may constitute nearly half the very glauconitic beds. Some fine mica, both colorless muscovite and some green chloritized mica, is locally present. The formation contains beds of clean loose sand and sticky clay-coated sand grains. Locally, iron encrustation is common in the more glauconitic beds. About 25 feet of the lower part of the formation is present in the quadrangle, this being about one-third to one-half the total thickness in the region.

The Vincentown overlies the Hornerstown Sand in most of the quadrangle. In the eastern part, however, the Hornerstown is absent, and the Vincentown directly overlies the Mount Laurel Sand. Because of similar lithologies, the basal contact with the underlying Hornerstown appears nearly gradational. The basal Vincentown is primarily a glauconite sand with several percent quartz. Reworking of some Hornerstown glauconite sand into the basal Vincentown is indicated by the high glauconite content. Although the glauconite in the basal Vincentown is partly reworked from the Hornerstown, it differs from the typical Hornerstown glauconite in grain morphology and size. Grains range from fine to very coarse, whereas the typical Hornerstown glauconite is fine to medium sand. Glauconite grains in the Vincentown also include irregular aggregates of smaller grains, whereas the grains of glauconite in the Hornerstown are smooth surfaced and botryoidal. Glauconite grains in the Hornerstown typically are dusky green, whereas the grains in the Vincentown include many black ones with polished crusted outer shells, possibly a result of rolling around on the bottom. Typically, the clay throughout most of the Vincentown is dark gray to black, whereas in the Hornerstown it generally is green.

The basal contact with the Mount Laurel Sand in the eastern part of the quadrangle is clearly unconformable because the Hornerstown is truncated and wedges out towards the east beneath the Vincentown. Most of the contact is buried beneath the Quaternary capping material; the pinchout was determined by use of the truck-mounted power auger.

The basal layer of the Vincentown contains nearly as much glauconite where it directly overlies the Mount Laurel Sand as where it overlies the Hornerstown Sand. This may be a result of some of the Hornerstown being incorporated into the basal Vincentown during marine planation and reworking of the remnants of the Hornerstown. Several exposures of this high-glauconite-content basal Vincentown are present in the southeast part of the quadrangle. The area extends from the railroad between Hepbron and the east edge of the quadrangle southward for 2 miles. One outcrop is in the south bank of Route 292, 1 mile south-southeast of Hepbron. Another outcrop is in the east bank of the creek 0.1 mile south of Route 213, 0.8 mile southeast of Fountain Church. A third outcrop is in a cutbank of the road that crosses Morgan Creek, 1.3 miles east of Fountain Church. The outcrop is in the bank on the northeast side of the road at its junction with the unimproved dirt road branching off to the northeast, just south of Morgan Creek. At this last exposure, the glauconite content is more than half the sand fraction and strongly resembles the glauconite in the Hornerstown. The section is only 1–3 feet thick and is somewhat layered. It may represent the former basal few feet of the Hornerstown which was reworked during Vincentown deposition.

The only fossils found in the formation were from an outcrop in the bottom of a pit about 0.1 mile west of the extreme southwest corner of the quadrangle (west of Flatland Road). The fossils occur in a shell bed found in the basal few feet of the formation in many places from Sandy Hook (Minard, 1969, p. 24, 25) to the Woodstown quadrangle in the southwest part of New Jersey (fig. 1). The fossils, which are fragmental or badly altered, are in a basal glauconite sand bed 3–6 feet thick. Most of the shells are *Oleneothyris harlani*, a brachiopod, or *Gryphaea dissimilaris*, a pelecypod. Taken in conjunction with the microfauna, they indicate the Paleocene age of the formation (Loeblich and Tappan, 1957, p. 1113, 1114, 1128–1132).

QUATERNARY DEPOSITS

PLEISTOCENE UPLAND ALLUVIUM

Most of the quadrangle is blanketed by a sheet of Pleistocene alluvial sand and gravel, which, except where incised by streams, constitutes a relatively flat plain. The upper surface is remarkably uniform in altitude, mostly 80–90 feet above sea level. Small areas in the northwest part of the quadrangle are slightly more than 100 feet in altitude. Altitudes are somewhat less in the southeast part, averaging about 70–80 feet. Streams have incised this plain from all sides, so that, except for flat interfluves, much of the surface of the plain slopes gently into the stream valleys. The thickness of the blanket of alluvium mapped varies from several feet to about 145 feet.

In most of the quadrangle, the base of the alluvium is above sea level, much of it between 30 and 60 feet. Channels are locally below sea level; several such narrow channels are exposed in the bluffs along the Sassafras River. A broad channel enters Chesapeake Bay in the northwest part of the quadrangle. This channel may have been an outlet, via Big Marsh, for the deep channel (60 ft below sea level) about 1 mile north of the tidal flats on Stillpond Creek (pl. 1).

Although the base of the alluvium locally is below sea level, the name "upland alluvium" is used because the upper surface is mostly 70–100 feet above sea level.

The alluvium is chiefly sand, with gravel, silt, and clay in lesser amounts. The sand typically is yellowish brown or gray and is strongly cross stratified (fig. 3). Gravel is mostly concentrated in layers and is more abundant at and near the base. The gravel chiefly consists of pebbles with some cobbles, but locally boulders are present, some of which are as

FIGURE 3.—Twenty-foot exposure of Quaternary sand in the upland alluvium in a pit 1 mile north of the tidal flats on Stillpond Creek (pl. 1). An auger hole penetrated 83 feet of alluvium here, from 20 feet above sea level to 63 feet below. A total thickness of 55 feet was exposed in another part of the pit, but slumping covered the fresh face. If the vertical distance to the top of the hill is considered, the total thickness of the alluvium here is 145 feet. Strong cross stratification is evident.

much as 6 feet in maximum dimension. Boulders litter the beaches, particularly along Stillpond Neck and Worton Point in the Hanesville quadrangle adjacent to the west. Thin clay-silt layers are present in some outcrops. The thickest such layers are in the upper part of the bluff at Stillpond Neck where five separate clay-silt beds, each about 2 feet thick, are in the 43-foot-thick alluvial deposit above the Magothy Formation. The only appreciable gravel in this deposit is a layer at the base which is locally cemented by iron oxide, a feature common in the Betterton quadrangle.

Most of the gravel is hard quartz, but some is weathered and crumbly, particularly shaly and feldspathic material. Many rock types are present and include shale, sandstone, quartzite, conglomerate, schist, gneiss, gabbro, and diabase. Rocks can tentatively be identified from formations such as the Tuscarora, Newark Group, Baltimore Gneiss, and Wissahickon Schist.

In lithology, internal structures, altitudes, and areal distribution, the upland alluvial deposits resemble the Pensauken Formation of New Jersey and probably are a southward extension of this formation. They likely were deposited by either the ancestral Susquehanna River or the ancestral Delaware River or both. The deposits formerly were assigned the name Columbia Group by McGee (1886, p. 473; 1888a, p. 367; 1888b, pl. 58) and Darton (1893, p. 409). Jordan (1962, p. 36–44) gave a comprehensive review of the history of the origin of the term Columbia Group which he used for similar-appearing deposits in Delaware.

HOLOCENE DEPOSITS

BOG

Big Marsh in the northwest part of the quadrangle is the only area mapped as bog. To outward appearances it is a swamp covered by a thick growth of mostly small trees and brush, but actually it is a peat bog presently operated by the Maryland Peat Co. The author sampled the bog near its center, where the peat was 12 feet thick beneath the shallow root mat. It is underlain by firm medium-gray silt and sand. A sample of peat was obtained from a dragline bucket from material taken at a depth of 12 feet. The material was dated, by the radiocarbon method, at 1,435±250 years B.P. (Before Present) (Meyer Rubin, written commun., May 20, 1966, U.S. Geol. Survey Radiocarbon Lab. sample W–1789). The dragline operator reported that the thickness of the peat is generally 10–15 feet but locally as much as 30 feet.

The surface of Big Marsh is several feet above sea level; at its mouth, the marsh is separated from Chesapeake Bay by a narrow strip of beach sand. The rest of Big Marsh is completely bordered by Quaternary alluvium.

BEACH SAND

Only two small areas are mapped as beach sand, one at Howell Point and one, a long narrow sand spit, across most of the entrance to Lloyd Creek estuary. These deposits are chiefly sand derived from the older formations in the bluffs bordering Chesapeake Bay and Sassafras River and reworked by wave action. A narrow strip of beach sand is present along the entire shore of Chesapeake Bay and Sassafras River in the quadrangle, but the sand is largely exposed only at low tide and is too narrow to show at the map scale. The deposits range in thickness from a few feet to possibly 30 feet.

Locally, considerable concentrations of ilmenite are present on the beach where the ilmenite has been reworked from the older formations, particularly the Mount Laurel Sand, Magothy Formation, and upland alluvium (fig. 4). The highest concentration noted is on Stillpond Neck in the Hanesville quadrangle adjacent to the west where the ilmenite source is the Magothy Formation and upland alluvium.

FIGURE 4.—Concentration of heavy minerals, chiefly ilmenite, on the beach at Meeks Point along Stillpond Neck in the Hanesville quadrangle about 1 mile west of the Betterton quadrangle. The heavy minerals are derived from the Magothy Formation and upland alluvium in the 60-foot-high bluff.

MARSH DEPOSITS

The marsh deposits are chiefly at tide level and lie along streams at their mouths or in their lower reaches and are largely subject to tidal flooding. They are composed chiefly of muds that are rich in organic matter and that contain minor amounts of sand, and they are characterized by thick aquatic plant growths. They range in thickness from a few feet to possibly 20 feet.

ALLUVIUM

Deposits in and along present streams are mapped as Holocene alluvium. These deposits are small in area and volume and are only mapped along a few streams where they are wide enough to show at map scale, and then only upstream from the marsh deposits at and near tide level.

The deposits are derived entirely from formations within the quadrangle and from the Galena quadrangle adjacent to the east. The deposits consist of gravel, sand, silt, and clay, and some organic matter. The deposits are thin and range in thickness from 3 feet to about 15 feet.

STRUCTURE

The general strike of the pre-Quaternary formations in the Betterton region is northeast, and the dip is a gentle 20 to 40 feet per mile towards the southeast. Locally in the Atlantic Coastal Plain, particularly along the inner edge, there are divergences from the general strike and dip, and in some areas, shallow warps or domes are present (Minard and Owens, 1966). In the Betterton quadrangle the formational trend diverges from the usual northeast strike and southeast dip. The general strike of the formations along the Sassafras River east of the town of Betterton is more to the east. Westward across the quadrangle, the formations trend more to the south. This southerly trend is also apparent in the Hanesville quadrangle to the west. South of the Hanesville quadrangle trends are more to the east again. The result is a broad S-shaped swing in the strike through the quadrangle and south and west of it.

If the Vincentown-Hornerstown contact is traced along the west edge of the south half of the quadrangle, the divergence in trend is evident. Northwest of Smithville the contact is at an altitude of about 60 feet; northwest of Butlertown it is about 50 feet. It drops to about 40 feet southwest of Butlertown, but in the far southwest corner of the quadrangle, it is at about 60 feet. The strike here is generally north with a shallow downwarp between the northern and southern points.

The top of the Mount Laurel just south of Stillpond is at an altitude of about 35 feet; 3.3 mile to the south-southeast (along the southeast bank of Morgan Creek) it is at an altitude of about 20 feet, an average dip of less than 5 feet per mile. The general regional dip for this unit is 40 feet per mile.

A contact between the Marshalltown and Englishtown can be seen in the bluff between Betterton and Gut Marsh. The contact dips east about 15°–20°. This steeper dip may be the result of a small warp, but more probably it is the result of slumping into the Pleistocene channel adjacent to the east. The basal foot of the Marshalltown is clayey and somewhat structureless (fig. 5*A*), possible the result of movement along the base of a slump block.

ECONOMIC ASPECTS

Large quantities of ground water are available from the formations that underlie the Betterton quadrangle. Vast quantities of sand and considerable amounts of gravel are present, particularly in the upland alluvial deposits. Appreciable concentrations of ilmenite are present locally in the Mount Laurel Sand, upland alluvium, and on the beaches, but no ore bodies are known. Peat from Big Marsh is presently excavated, dried, and marketed. Some clay is present in the Potomac Group, but any quantity of good quality clay is too deeply buried to be of value.

The sand and gravel are the most attractive economic commodity. These deposits could be moved in large volumes easily and inexpensively by barges. Once much of the peat is excavated from Big Marsh, an access waterway would lead into the heart of the thick deposits surrounding Big Marsh. These deposits would be particularly convenient to water transportation because their base is at and below sea level over much of the area, and they are thicker here than elsewhere in the quadrangle. The deposits are 100 feet and more thick along and near the south side and end of the marsh.

REGIONAL STRATIGRAPHY

LOWER AND UPPER CRETACEOUS SEDIMENTS

POTOMAC GROUP

As noted earlier, only the upper few feet of the Potomac Group crops out in the Betterton quadrangle. By the old terminology (Clark and Bibbins, 1897, p. 481), this would be the Raritan of Late Cretaceous age. Typical Raritan in the type locality at Raritan Bay, N.J. (fig. 1), is a probable deltaic sequence of alternating dark and light sands and clays locally containing marine fossils. This sequence of beds appears to wedge out towards the southwest near Trenton and is replaced by beds resembling the Potomac Group (fig. 6), that is, varicolored sands and clays. These beds in turn appear to be equivalent to or grade into the Potomac Group continental beds in Delaware and Maryland. It is questionable, therefore, whether there are any true type Raritan beds in Delaware and Maryland, or even in New Jersey southwest of Trenton (Owens and Sohl, 1969, p. 238). Rather, they may be in the Patapsco-Raritan transition zone (zone III) of Doyle (1969a, p. 17). Wolfe and Pakiser (1971, p. B40) suggested that the "Raritan" of the Salisbury embayment (which includes southern New Jersey) is the uppermost Patapsco and that the Raritan Formation is not in the Salisbury embayment.

In outcrop, the Raritan Formation at Raritan Bay was divided into seven units of alternating sands and clays by Kümmel and Knapp (1904, pl. 11) and by Barksdale and others (1943, p. 66). Barksdale and others (p. 67–140) gave the formation a maximum thickness of about 440 feet. Owens and Sohl (1969, p. 239–242) placed the upper unit, the Amboy Stoneware clay, in the basal Magothy. Wolfe and Pakiser (1971, fig. 6) also placed the next lower member, the Old Bridge Sand Member, in the Magothy.

In the subsurface, downdip and to the south at Island Beach State Park, the formation was given a thickness of 1,228 feet by Seaber and Vecchioli (1963). Clark and Bibbins (1897, p. 482–493) estimated the Raritan in Maryland to be nearly 500 feet thick and the Potomac beneath to be about 400 feet thick. Miller (*in* Bascom and Miller, 1920, p. 9, 10) estimated the Raritan to be about 400 feet thick and the underlying Potomac to be about 550 feet thick. Owens (1969, p. 80) gave the thickness of the Potomac as 400 feet but suggested that this is only a partial thickness because of erosion and unconformable overlap by younger formations. Hansen (1969, p. 1927) showed the thickness of the Raritan-Potomac combined as 750 feet along the outcrop belt. The thickness of the Potomac Group in the subsurface in eastern Maryland has been shown to range from 3,800 feet near Salisbury to 5,380 feet near Ocean City (Vokes, 1961, p. 47).

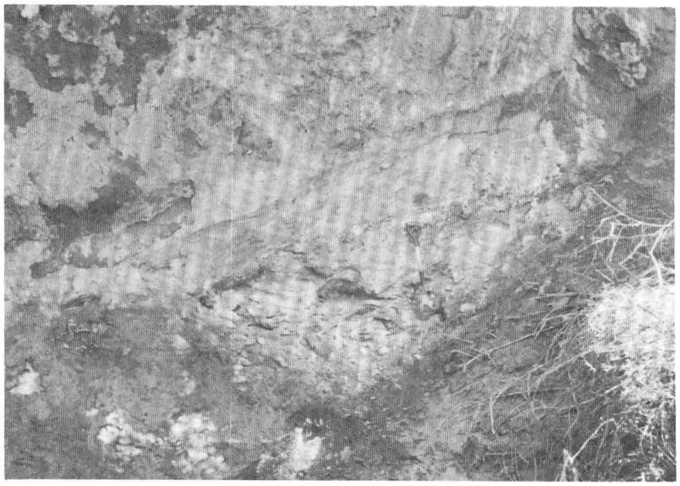
Excellent outcrops of the deltaic-marine Raritan Formation are in the many large sand and clay pits near Raritan Bay (Owens and others, 1968, fig. 7). Good exposures of the transitional-continental Raritan Formation are along the New Jersey bank of the Delaware River, particularly from Trenton southwest for several miles. The upper part of the undifferentiated Raritan-Potomac crops out along the south bank of the Chesapeake and Delaware Canal (fig. 1). The weathered multicolored upper clay-silt beds, unconformably overlain by the Magothy Formation, are shown in figure 5*B* as they were exposed 1 mile west of the bridge where Delaware Route 896 crosses the canal. These banks are now graded and seeded. The contact between the two formations is not well exposed, which may have led Pickett (1970b) to show this contact nearly half a mile to the north and not to show a reentrant along the canal from the west. The upper 120 feet of the unit crops out in the high bluffs along the west side of Elk Neck (fig. 1). For a detailed comparison of the interpretations of this section, refer to table 2.

The next good exposures of the Potomac Group are in the northwest part of the Betterton quadrangle at the mouth of the Sassafras River, and at Worton Point in the Hanesville quadrangle west of Betterton. These outcrops already have been described in this report.

UPPER CRETACEOUS SEDIMENTS

MAGOTHY FORMATION

The Magothy Formation is an exception in that its type section is not in New Jersey but on the Magothy River near Annapolis, Md. The unit was



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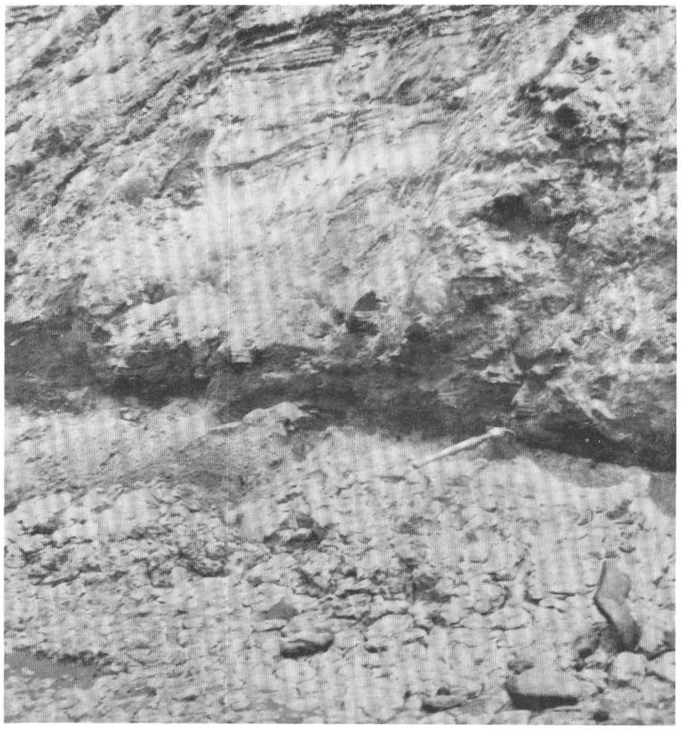

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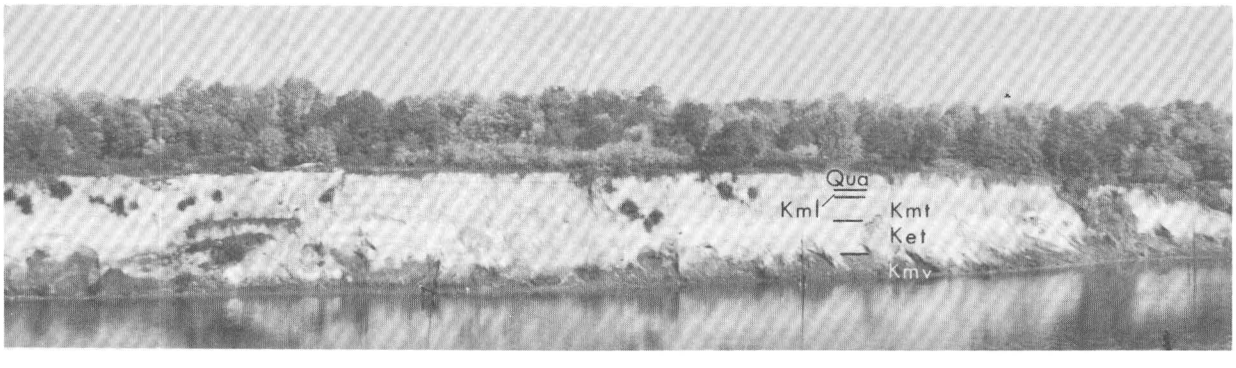

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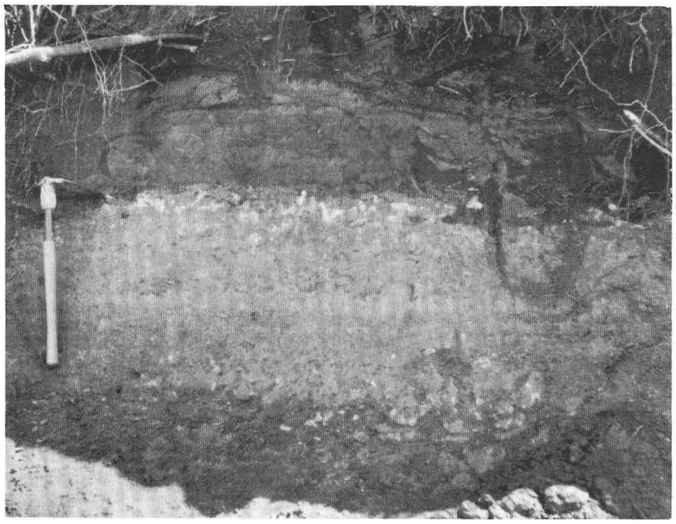

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◀ FIGURE 5.—Cretaceous and Tertiary formations of the northern Atlantic Coastal Plain. *A*, Slump block of the Mount Laurel Sand and Marshalltown Formation overlying the Englishtown Formation, along the Sassafras River between Betterton and Gut Marsh. The block probably slumped towards the Pleistocene channel to the east as the loose sand of the Englishtown was undercut by the former stream. The basal 1 foot of the Marshalltown is a clayey sheared(?) zone. The top of the shovel handle is at the Marshalltown-Englishtown contact; the shovel is 38 inches long. A few feet above is the base of the Mount Laurel, which is about 12 feet thick here. The distinctive feature of the Mount Laurel is the abundance of *Ophiomorpha nodosa*, both intact and as fragmental rubble layers. *B*, Magothy Formation overlying the Potomac Group (shovel marks contact) along the south side of the Chesapeake and Delaware Canal, 1 mile west of Delaware Route 896 bridge. The basal Magothy contains many lignitized logs; the protruding ends of some can be seen in the basal 3 feet. The Magothy is a loose carbonaceous cross-stratified sand; the Potomac is mostly red to white mottled clay. The surface of the Potomac approximately marks the high-water swash line. *C*, North bank of the Chesapeake and Delaware Canal near Summit Bridge (fig. 1). Entrance to the old channel is at the far right of the photograph. About 60 feet of section is exposed. The dark-gray basal unit, about 15 feet thick, is the Merchantville Formation (Kmv: Crosswicks Clay). The next 15 feet above, the light-gray to yellowish-gray layer, is the Englishtown Formation (Ket). Above the Englishtown is a 15-foot section of the grayish-brown Marshalltown Formation (Kmt), which is overlain by 5–6 feet of yellowish-brown basal Mount Laurel Sand (Kml). About 10–12 feet of Quaternary alluvium (Qua) caps the section. *D*, Basal Merchantville Formation overlying the Magothy Formation. This outcrop (near Trenton, N.J.) is nearly identical with many other exposures of the contact between the two formations from Raritan Bay to the Betterton quadrangle. Typically, the basal Merchantville contains glauconite, scattered pebbles, and reworked lignite fragments. *E*, Basal clayey quartz-glauconite sand of the Marshalltown overlying the clean quartz sand of the Englishtown (knife at contact). Outcrop was exposed in the excavation for the north end of the railroad bridge across the new channel of the Chesapeake and Delaware Canal just east of Summit Bridge. Similar outcrops are along the old channel. The upper part of the Englishtown is extensively bored, and the borings contain high percentages of glauconite from the overlying Marshalltown. Scattered pebbles and fragments of wood are in the basal 1 foot of the Marshalltown. *F*, Basal Tertiary Hornerstown glauconite on Upper Cretaceous Mount Laurel Sand (shovel head marks sharp contact). Cutbank along Drawyers Creek northwest of Odessa, Del. The Hornerstown is nearly all glauconite, whereas the Mount Laurel is a feldspathic quartz sand containing 10–15 percent glauconite.

originally described by Darton (1893) from the Delaware State line southwest to Bowie, Md., between Annapolis and Washington (fig. 1).

The upper part of the Magothy is well exposed in contact with the overlying Merchantville Formation along the northwest side of Grove Neck, Md. (fig. 1), just around the point (Owens and others, 1970, p. 2). Until a few years ago the Magothy was well exposed in the banks of the Chesapeake and Delaware Canal from Route 896 westward for a mile. The basal 10 feet can be seen in figure 5*B* above the unconformity on the Potomac Group. This exposure was 1 mile west of the Delaware Route 896 bridge across the canal. The lithology shown in the photograph is a lignitic white quartz sand containing many carbonized logs in the base. These banks have been graded and covered over now. Perhaps this is why Pickett's map (1970b) does not show the Magothy at least as a reentrant from the west all along the canal to the bridge.

Intermittent exposures are present all along the inner edge of the Coastal Plain in New Jersey northeast to Raritan Bay. The formation is typically about 20–40 feet thick but locally is absent in outcrop, as in the Bristol quadrangle (Owens and Minard, 1964a) just north of the Mount Holly quadrangle (fig. 1) and possibly on Maulden Mountain (table 2). Darton (1893, p. 409) showed the Magothy to be present on both Maulden and Bull Mountains on Elk Neck at the head of Chesapeake Bay and discussed it in the text (p. 412–413). Miller (1906, p. 3) also mapped the Magothy in the bluffs of the mountains, as did Owens and others (1970, fig. 5). Miller's interpretation probably was influenced by Darton's work. Darton may have mapped the Englishtown on Maulden Mountain as the Magothy. I do not believe there is any appreciable section of Magothy on the mountain. If present, it may only be 3–5 feet thick

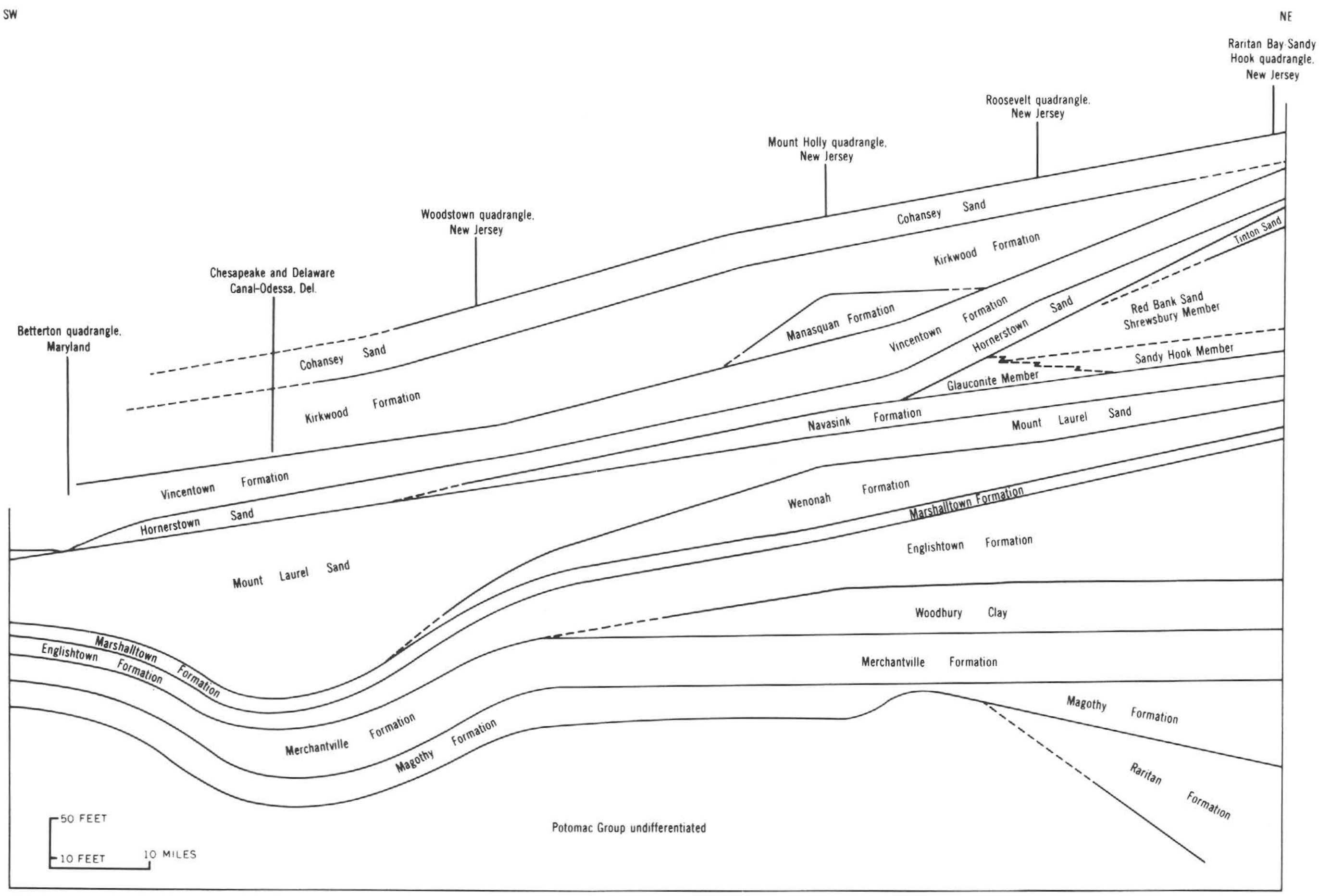

FIGURE 6.—Generalized cross section of the Cretaceous and Tertiary formations in outcrop from the Betterton quadrangle area, Maryland, to Raritan Bay and the Sandy Hook quadrangle area, New Jersey.

and would underlie the medium-gray micaceous silt to fine sand of the Merchantville and overlie the white and red clay and sand of the Potomac. If Darton was in error, it probably resulted from his working from the southwest to the northeast and mistaking the similarly appearing southwest-thinning clean yellow to brown quartz sand of the Englishtown for the Magothy.

At Raritan Bay, the upper 30–40 feet of the formation is the usual white lignitic quartz sand and intercalated black clay; it is well exposed at Cliffwood Beach (Owens and others, 1968, p. 46–47; Owens and Sohl, 1969, p. 239–242). Beneath the Cliffwood beds is a 75- to 90-foot section of laminated sands (Kümmel and Knapp, 1904, p. 168). The top of this section is marked by a layer containing abundant siderite concretions, many of which contain marine fossils. These beds were well exposed in the South Amboy quadrangle and are referred to as the Morgan beds (Owens and others, 1968, p. 46) after Berry's (1906, p. 138–141) usage of the "Morgan locality."

The entire Magothy section in New Jersey, including the Amboy Stoneware clay, Morgan beds, and Cliffwood beds, formerly was included in the upper Raritan (Cook, 1868, p. 260; Kümmel and Knapp, 1904, p. 166–172). Clark (1904, p. 438, 440) first recognized that that part (laminated sands) of this unit may be correlative with Darton's Magothy "and may necessitate the transfer everywhere of certain upper sands hitherto regarded as Raritan to the Magothy-Cliffwood series." Berry (1906) made a study of the flora from the Cliffwood beds and correlated them and the underlying laminated sands with the Magothy (p. 136).

Recent workers (Owens and Sohl, 1969, p. 239–240; Doyle, 1969a, table 2) have placed not only the Cliffwood and Morgan beds in the Magothy but also the underlying Amboy Stoneware clay, thereby lowering the contact between the Magothy and Raritan

TABLE 2.—*Interpretation of the stratigraphic section on the west side of Elk Neck*

[The author's interpretation is a refinement of the section shown by Owens and others, 1970, fig. 5]

Miller (1906, p. 3)		This report		
Formation	Thickness (feet)	Formation	Thickness (feet)	Description
Lafayette	10	Upland gravel	10	Well-oxidized alluvial sand and gravel.
Matawan	20.5	Mount Laurel Sand (Monmouth)	35	Mostly fine to medium greenish- to brownish-gray feldspathic quartz sand containing 10–15 percent glauconite grains. Coarse sand to granules are common in the upper part; animal borings and small (¼–⅜ in.) pebbles are common in the lower part.
Magothy	41	Marshalltown Formation (Matawan)	3	Clayey fine dusky-green glauconite (30–40 percent) quartz sand with some colorless mica and weathered feldspar grains.
		Englishtown Formation (Matawan)	10	Coarsely micaceous, fine, light-gray, clean quartz sand containing many dark opaque heavy minerals.
		Merchantville Formation (Matawan)	20	Very micaceous, fine to very fine, silty quartz sand. Oxidized at the top, beneath the porous Englishtown, to very light gray and pinkish gray, grading down through pale red purple to grayish orange pink to medium dark gray and dark gray at base. The basal 1 foot is a layer of quartz pebbles in a white to light-gray clayey sand matrix.
Raritan	115	Potomac Group	150	Very light gray and yellowish-orange through light-brown alternating layers of clay, silt, and sand. Sand ranges from fine to very coarse, and some layers are strongly cross stratified. Clay is mostly near the top and base. Colors of the clay include moderate red, very light gray, and pale red purple.
Patapsco	8			

to the top of the Old Bridge Sand (Barksdale and others, 1943, p. 66). On the basis of pollen, Wolfe and Pakiser (1971, fig. 6) placed even the Old Bridge Sand Member in the Magothy.

MERCHANTVILLE FORMATION

The Merchantville Formation is a fairly uniform and persistent unit in its surface exposure along the inner edge of the Coastal Plain from Betterton northeast to Raritan Bay. It ranges in thickness from about 20 to 50 feet in this region. The formation is well exposed along the point of Grove Neck where it is largely a micaceous somewhat glauconitic dark-gray fine sand to silt. The thinnest measured section was found in the high bluffs on the west side of Elk Neck where only 20 feet of the unit is present (table 2). Miller (1906, p. 3) showed the Matawan here, but his Matawan was the Mount Laurel, and the Merchantville was the lower part of his Magothy. The Merchantville was inadvertently omitted from Elk Neck on the generalized map by Owens and others (1970, fig. 5).

Until 1965, outcrops were exposed along the Chesapeake and Delaware Canal for a distance of nearly 3 miles. The unit is nearly 50 feet thick here, and the lithology is similar to that on Grove Neck. After 1965, much of the exposure was covered when the canal banks were graded, bermed, and seeded. However, although not delineated on Pickett's map (1970b), good exposures are still present in the old channel cutbanks along the north side of the canal east of Summit Bridge. Nearly horizontal beds of the Mount Laurel, Marshalltown, Englishtown, and Merchantville (fig. 5*C*) extend along the abandoned old channel for much of its length.

As the outcrop is traced northeast to the vicinity of Trenton, the formation contains more glauconite, particularly in the lower part where it typically is a silty, clayey, glauconite sand. The contact with the underlying Magothy is everywhere sharp and distinct (fig. 5*D*). There are many good exposures near Raritan Bay where the material is dug for use in the manufacture of brick.

Throughout most of the outcrop belt in New Jersey, the Merchantville is overlain by the Woodbury Clay, which is similar in appearance and lithology to the Merchantville but is finer grained, being largely a clay-silt. Near Trenton, these formations aggregate nearly 100 feet in thickness and were formerly known as the Crosswicks Clay (Clark, 1897, p. 315–329; 1898, p. 178; 1904). The two units were lumped as one because, even though they were quite readily separable into two distinct units in parts of New Jersey, they became similar towards the southwest. Also the total thickness is only half as much (50 ft) in Delaware as it is in central New Jersey. Because of the coarser grain size of the upper part of the Crosswicks in the Woodstown quadrangle, Minard (1965) omitted the Woodbury and mapped the unit as Merchantville. This same section was retained on the engineering map of the Northeast Corridor (U.S. Geol. Survey, 1967) and by Owens and others (1970).

In retrospect, Carter's (1937) usage of Crosswicks Clay for the post-Magothy–pre-Englishtown interval in the canal may have been a wise choice because in the Woodstown quadrangle, in Delaware, and into the Betterton quadrangle the upper part of the Merchantville may actually be more closely affiliated with the Woodbury in age and fossil assemblage (N. F. Sohl, oral commun., 1970). Clark (1916, p. 68) recognized that "the Summit Bridge fauna is probably the equivalent not of the Merchantville alone but of both the Merchantville and the Woodbury."

ENGLISHTOWN FORMATION

The Englishtown Formation in the Betterton quadrangle is nearly the terminus of a southwest-thinning wedge of sand with interbedded clay. The unit is 140 feet thick in the type area in the northern part of the Coastal Plain in New Jersey (Minard, 1969, p. 9) and thins quite uniformly along the 125-mile strike-line distance to Betterton, where it is 15–18 feet thick. A 10-foot-thick section of the sand crops out in the bluff on the west side of Elk Neck (fig. 1; table 2). The next good exposures to the northeast are along the Chesapeake and Delaware Canal where 14 feet of the sand is exposed (Owens and others, 1970, p. 13). The best exposure at present on the canal is along the old channel where the railroad crosses the canal. All other exposures have been graded and seeded. The Englishtown crops out nearly horizontally along most of the north bank of the old channel (fig. 5*C*), as it did in the excavation for the north pier of the railroad bridge across the new channel (Owens and others, 1970, fig. 7). Formerly, sand beds of the formation cropped out at water level for some distance 0.8 mile west of Saint Georges where the sand contains many *Ophiomorpha nodosa* borings which have been cemented by iron oxide (Owens and others, 1970, fig. 11; Pickett and others, 1971, fig. 7). Before 1965, the Englishtown was shown on the "Geologic Map of New Jersey" (Lewis and Kümmel, 1912) as extending into the Woodstown quadrangle from the northeast and as pinching out about halfway across. Minard (1965) showed the formation extending all the way across. This mapping seemed justified by the lithology and was later substantiated by a good section along the canal 20 miles farther southwest where Carter (1937, p. 256–258) had carefully studied and described it; it was also substantiated by the fact that Johnson and Richards (1952, p. 2155) had recognized the unit southwest of Woodstown.

Instead of showing the Englishtown pinching out in the Woodstown quadrangle, Minard (1965) showed the Woodbury Clay pinching out (fig. 6). In retrospect, because of the gradational contact between the Merchantville and Woodbury and between the Woodbury and Englishtown, the sandier nature of the Woodbury in the area, and the inconclusiveness of the faunal data, there very likely may be a 15-foot section of the Woodbury in the Woodstown quadrangle, and it may also be present in the canal, but it is difficult to distinguish from the underlying Merchantville. It may also persist into the Betterton quadrangle, where again it would be difficult to distinguish from the Merchantville. This difficulty led early workers to use the name Crosswicks Clay for the Merchantville-Woodbury undifferentiated (see the preceding section on the Merchantville).

The Englishtown is well exposed in the area east of Trenton where it is about 90 feet thick (Owens and Minard, 1966). Here and in the Sandy Hook quadrangle (Minard, 1969) it is mostly clean horizontally and cross-stratified sand interbedded with thin to thick layers of clay.

MARSHALLTOWN FORMATION

The Marshalltown Formation is one of the thinnest but most uniform and persistent of the Upper Cretaceous units. From Sandy Hook to Betterton it ranges in thickness from about 10 to 18 feet and is an easily recognizable clayey quartz-glauconite sand in most of its outcrop. It tends to be less glauconitic along the Sassafras River than it does to the northeast.

The formation crops out along the Sassafras River and is well exposed in the banks of the Chesapeake and Delaware Canal, particularly along the old channel at the railroad bridge, where it overlies the Englishtown in sharp contrast (fig. 5*E*).

The formation is very fossiliferous in the vicinity of the canal (Carter, 1937, p. 258–261; Owens and others, 1970, p. 41–44) and in the Woodstown quadrangle (Weller, 1907, p. 82–85; Mello and others, 1964). Numerous exposures are present all along the outcrop belt from Woodstown (Minard, 1965) through central New Jersey (Minard and others, 1964; Owens and Minard, 1966; Owens and Sohl, 1969, p. 274–276) to Sandy Hook (Minard, 1969).

MOUNT LAUREL SAND

Lithologically, the Mount Laurel is a fairly uniform sand along its 125-mile outcrop from Sandy Hook, N.J., to Betterton, Md., but it has a wide range in thickness; it is about 20 feet thick in the northern part of the Coastal Plain in New Jersey (Minard, 1969, p. 12; Minard and others, 1961, p. C65) and thickens to about 80 feet in the Woodstown quadrangle to the southwest (Minard, 1965). The unit progressively thickens towards the southwest where it occupies the entire Maestrichtian interval (fig. 6). An auger hole just west of Odessa, Del., penetrated 170 feet of this unit. From Odessa and vicinity, the unit thins towards the southwest to about 60 feet thick at the western border of the Betterton quadrangle.

The formation is well exposed in many places along the Sassafras River. Internal structures include massiveness, thick horizontal beds, and cross-stratified beds. About 35 feet of the formation is exposed near the top of the bluff on the west side of Elk Neck. This exposure was shown previously as Matawan (Miller, 1906, p. 3). The next good exposures to the northeast are in the banks of the Chesapeake and Delaware Canal, where the unit was identified as the Mount Laurel by Carter (1937, p. 262–265), U.S. Geological Survey (1967), Owens and others (1970, p. 11–16), and Pickett (1970b). The unit was identified as the Red Bank by Groot and others (1954, p. 21, 28, 29) and Jordan (1962, p. 13–18), and as the Vincentown by Spangler and Peterson (1950, p. 47, 57). Although Pickett (1970b) correctly identified it as the Mount Laurel, the formation does not overlap and cut out the Marshalltown and part of the Englishtown as he shows it near Summit Bridge. The unit overlies only the Marshalltown and uniformly with a gentle southeasterly dip. This relationship is clearly exposed in cutbanks near and in the old channel on the north side of the canal near Summit Bridge (fig. 5*C*).

Good sections of the formation are exposed all along the inner edge of the Coastal Plain in New Jersey from the southwest part (Minard, 1965; Owens and Sohl, 1969, p. 276; Johnson and Richards, 1952, p. 2158) through the central part (Minard and Owens, 1962; Owens and Minard, 1966; Dorf and Fox, 1947, p. 21, 22) to the shores of Raritan Bay (Minard, 1969, p. 14).

Earlier in this report, the Mount Laurel Sand in the Betterton quadrangle was defined as the thick unit in the interval between the Marshalltown Formation of Late Cretaceous age below and the Hornerstown Sand and Vincentown Formation, of Paleocene age, above. It was also noted that beds younger than the Mount Laurel are locally present at the top of the Cretaceous in the Betterton area.

During field mapping, a persistent distinctive bed of glauconite-rich coarse sand, 8–10 feet thick, was noted near the middle of the Mount Laurel Sand (as mapped in this report) from Odessa, Del., to the Betterton quadrangle. This bed was penetrated at a depth of 80–85 feet in an auger hole near Odessa, where the Mount Laurel section is 170 feet thick. At Gregg Neck on the south side of Sassafras River (fig. 1), the glauconite bed was penetrated at a depth of 70–75 feet where the Mount Laurel section is about 150 feet thick. The bed also was penetrated at a depth of 65–70 feet in the southeast part of the Betterton quadrangle where the Mount Laurel section is about 130 feet thick. All these auger holes were started not more than a few feet below the top of the Mount Laurel and the base of the lowermost Tertiary unit.

One of the better exposures of the bed is in the 60-foot-high bluff on the south side of Sassafras River a short distance west of Kentmore Park, just east of the Betterton quadrangle.

The glauconite bed, where unweathered, is medium- to dark-gray clayey coarse to very coarse feldspathic quartz sand containing as much as 50 percent glauconite. Granules are abundant, and some pebbles as much as 1 inch in diameter are present. The glauconite is mostly greenish-black coarse to very coarse botryoidal grains or irregular aggregates of grains.

In all places augered, the glauconite bed is characterized by abundant Foraminifera and megafossils. Table 3 shows Foraminifera identified by Ruth Todd (U.S. Geol. Survey) from two of the auger holes. N. F. Sohl (U.S. Geol. Survey) was able to identify several megafossils retrieved in cuttings from the bed in the Odessa auger hole. These include a *Belemnitella* specimen and an *Exogyra* specimen. Fragments of unidentifiable oyster shells were in cuttings from the glauconite bed and at several other horizons in all holes.

The glauconite bed and the association of *Exogyra cancellata* and *Belemnitella americana* in the sands a few feet below the glauconite bed at Bohemia Mills, Md., about 6 miles west of Odessa, Del., led the author to misinterpret the stratigraphy of the area (Minard and others, 1969, p. H18). In New Jersey, the *Belemnitella* and *Exogyra* are abundant in a bed near the top of the Mount Laurel Sand, a few feet below the Navesink Formation. This association can be seen at many places in New Jersey in outcrop all the way southwest to Mullica Hill, just northeast of the Woodstown quadrangle.

In outcrop the overlying Navesink thins from about 30 feet in the northern part of the New Jersey Coastal Plain to zero in the Woodstown quadrangle and just southwest of it (fig. 6). From here southwest into Delaware and eastern Maryland, the basal Tertiary unit, the Hornerstown Sand, overlies the Mount Laurel Sand of Cretaceous age (fig. 6). The contact between the two units is sharp both lithologically and in color (figs. 2*D*, 5*F*). On the assumption that the *Exogyra* and *Belemnitella* shell bed at Bohemia Mills, west of Odessa, is in nearly the same stratigraphic position near the top of the Mount Laurel as it consistently is in New Jersey, and in the belief that the Navesink was absent, the overlying glauconite bed was interpreted to be the Hornerstown Sand (Minard and others, 1969, p. H18, table 1).

However, after auger holes were sunk near Odessa, at Gregg Neck, and in the Betterton quadrangle, as noted earlier, and in each place the coarse glauconite bed was found near the stratigraphic middle of the unit mapped as Mount Laurel, a reexamination of the Bohemia Mills section was made. On the basis of the knowledge (1) that the Mount Laurel section was 170 feet thick at Odessa, a few miles to the east, and 150 feet thick at Gregg Neck, a few miles to the southwest, and (2) that the Mount Laurel section below the glauconite bed at Bohemia Mills was only about 75 feet thick (about what would be expected for the unit below the glauconite bed near its stratigraphic middle), a detailed examination of the lithology immediately ruled out the glauconite bed being Hornerstown and confirmed its identity as Mount Laurel, primarily on the basis of

TABLE 3.—*Foraminifera from the coarse glauconitic bed near the stratigraphic middle of the Mount Laurel Sand, as mapped in the Betterton quadrangle.*

[Identified by Ruth Todd, U.S. Geological Survey. Samples were from a depth of 65–75 ft below the surface and from the base of the Hornerstown Sand. One hole was augered at Gregg Neck and one in the southeast part of the Betterton quadrangle]

Anomalina rubiginosa Cushman
A. aff. *A. pseudopapillosa* Carsey
Anomalinoides highlandicus Olsson
Astacolus navarroanus (Cushman)
Bulimina kickapooensis Cole
Cibicides coonensis (Berry)
C. subcarinatus Cushman and Deaderick
Cibicidina wadei (Berry)
Citharina wadei (Kelley)
Dentalina basiplanata Cushman
Gaudryina monmouthensis Olsson
Globigerina (*Biglobigerinella*) *biforaminata* Hofker
G. (*Rugoglobigerina*) *rugosa* Plummer
Globulina lacrima Reuss
Guembelitria cretacea Cushman
Guttulina adhaerens Olszewski
Gyroidina depressa (Alth)
Heterohelix globulosa (Ehrenberg)
Lenticulina munsteri (Roemer)
L. navarroensis (Plummer)
Loxostomum plaitum (Carsey) *limbosum* Cushman
Marginulina plummerae Cushman
Pernerina redbankensis Olsson
Planulina correcta (Carsey)
Pseudoclavulina sp.
Pseudoguembelina costulata (Cushman)
Pseudouvigerina seligi (Cushman)
Pulsiphonina prima (Plummer)
Vaginulina taylorana Cushman

the type of glauconite present. Unlike typical Hornerstown glauconites, which are uniform green medium botryoidal grains in a green clayey matrix, the glauconite in the bed at Bohemia Mills is typical of that from the middle bed of the Mount Laurel section, that is, coarse to very coarse greenish-black aggregates of botryoidal grains intermixed with coarse to very coarse quartz grains and granules in a gray clay matrix. Therefore, the shell bed in the Mount Laurel at Bohemia Mills is just below the middle of the formation (as mapped in the Betterton quadrangle), about 80–85 feet below the top, as noted at all nearby localities.

Another possibility, however, is worthy of consideration. As discussed earlier, there are beds at the top of the Mount Laurel section in the Betterton quadrangle that are younger than those typical of the Mount Laurel. These beds may be present also to the northeast, at least as far as Odessa, Del. In the Betterton quadrangle, these beds were recognized in outcrop only along Lloyd Creek. The exposures are in several cutbanks in the upper part of the southeastern tributary, 0.9 mile east-northeast of Stillpond and 0.55–0.65 mile northwest of the junction of Routes 298 and 442, 1.15 miles east of Stillpond. The 40-foot contour crosses the creek in about the middle of the outcrop area. The sediments are medium-gray to medium-dark-gray silty to clayey glauconitic quartz sand with some mica and feldspar. Fossils are abundant in one outcrop and include *Cucullaea* and *Cardium* specimens in addition to gastropod specimens and ammonites (table 4). The most diagnostic fossil recovered is a specimen of *Sphenodiscus*. This ammonite is typically found in the Red Bank and Tinton Sands in New Jersey (table 1) and is not known from lower in the section than the Navesink Formation. In the Mount Holly quadrangle (Minard and others, 1964), a specimen of *Sphenodiscus lobatus* Tuomey was recovered from the reworked zone between the Navesink and Hornerstown a short distance beyond the featheredge pinchout of the Red Bank Sand (fig. 6).

The lithology and fauna of the sediments cropping out along Lloyd Creek are similar to those of the Red Bank Sand of the northern New Jersey Coastal Plain. The Red Bank Sand pinches out between the Roosevelt and Mount Holly quadrangles (fig. 6) as a wedge of sediments thinning southwest from its type area near Raritan Bay. The unit in the same stratigraphic position in the Betterton quadrangle may be the featheredge of a similar wedge. The sediments at Lloyd Creek originated in a different source area than did those of the Red Bank of New Jersey, the Red Bank being derived from the environs of the Raritan embayment, and the unit in the Betterton quadrangle being derived from the environs of the Salisbury embayment (Owens and Sohl, 1969, fig. 2).

A short distance downstream from the outcrops along Lloyd Creek, and lower in the section, is a bed of greenish-gray silty, clayey coarse to very coarse sand and granules with some small pebbles and nearly 50 percent glauconite. About 3–4 feet of the bed

TABLE 4.—*Megafossils from the upper part of the Upper Cretaceous section along Lloyd Creek*

[Identified by N. F. Sohl, U.S. Geological Survey. R, rare occurrence (1–5 specimens); C, common occurrence (6–25 specimens); A, abundant occurrence (>25 specimens). All fossils in this collection are molds; most are internal molds, but those taxa listed with specific names are preserved as external impressions. *Turritella bilira*, *T. unionensis*, and *Sphenodiscus* sp. are of Maestrichtian Age by any paleontologic criteria. Regionally, the best correlation would seem to be with the Red Bank of New Jersey and certainly with the "Monmouth" as we know it in the Round Bay quadrangle and the "Monmouth" at the type section near Brightseat, Md., just east of the District of Columbia. There is no comparable unit, either lithic or biostratigraphic that occurs on the Chesapeake and Delaware Canal. The unit is probably more closely related to the history of the western shore (Chesapeake Bay–Salisbury embayment) sequence than to the northern (Raritan) embayment. (N. F. Sohl, written commun., Aug. 2, 1972)]

Pelecypoda:	
Cucullaea sp	A
Glycymeris sp	R
Ostrea sp	C
Ostrea mesenterica Morton	R
Lopha falcata Morton	A
Exogyra sp	R
Gryphaeostrea vomer Morton	R
Trigonia sp	R
T. angulicostata Gabb?	R
Veniella sp	C
Syncylonema sp	R
Cardium sp	C
C. aff. *C. eufaulense* Conrad	R
Lithophaga sp	R
Kummelia sp	C
Gastropoda:	
Turritella sp	C
T. bilira Stephenson	R
T. unionensis Sohl	R
Aporrhaid indet	
Paladmete cf. *P. laevis* Sohl	R
Acteon sp	R
Gastropods indet	
Cephalopoda:	
Baculites sp	C
Discoscaphites sp	R
Sphenodiscus sp	R
Eutrephoceras sp	R
Coelenterata:	
Micrabacia sp	R
Chaetopoda:	
Hamulus onyx Morton	R
Serpula sp	R
Crustacea:	
Crab hands and fingers	C
Vertebrata:	
Shark teeth	R

crops out above creek level. It is overlain by greenish-gray fine clayey sand grading up into medium to fine, medium-dark-gray to dark-gray glauconitic quartz sand. Molds and casts of fossil gastropods and pelecypods are abundant in the outcrop, particularly in the coarse bed. Crab claws and leg segments are common in the upper finer sediments. The coarse bed has the same lithology as the one described in the preceding pages of this section, and in the earlier Mount Laurel section, as being near the stratigraphic middle of the Mount Laurel Sand in the Betterton quadrangle and adjacent areas.

The coarse bed also crops out in at least two other places in the Betterton quadrangle. The outcrops are in cutbanks in tributaries to Stillpond Creek above the tidal flats. If the sediments above the coarse bed are markedly younger than the beds below it, then the coarse bed may not be near the stratigraphic middle of the Mount Laurel but at the top. This suggested assignment immediately brings to mind the startlingly similar unit that is at the top of the Mount Laurel and that continues into the basal Navesink; this unit is typical of this interval in many places in New Jersey. Clark (1898, p. 184–185) realized that the Red Bank did not occur in southern New Jersey but recognized about 60 feet of Red Bank sands in the Sassafras River basin.

In conclusion, it appears that in the Betterton quadrangle the glauconitic sand unit above the Marshalltown to the coarse bed presently shown near the stratigraphic middle of the Mount Laurel is correlative with the type section Mount Laurel of New Jersey. The section above the coarse bed is younger and appears correlative in lithology and age to the Red Bank Sand of New Jersey.

The question now arises as to the stratigraphic assignment of the coarse glauconite-rich bed. As mentioned earlier, it is startlingly similar to the coarse bed at the top of the Mount Laurel and at the base of the Navesink in New Jersey. The problem is where to put this bed—at the top of the Mount Laurel (as is done in New Jersey) or at the base of the section above it. If placed at the top of the Mount Laurel, the coarsening upwards must be explained by reverse graded bedding (Bishop and Force, 1969). If a normal fining-upwards cycle (Thayer, 1970, p. 194) is considered, the coarse bed would be placed in the base of the overlying sequence. This latter assignment fits well in the cyclic sedimentation proposed by Owens and Sohl (1969, p. 257). The coarse bed would constitute the basal transgressive glauconite unit overriding and reworking the underlying unit. The beds just above the glauconite bed in the Betterton quadrangle are clay-silt layers grading up into sand beds, following the pattern proposed by Owens and Sohl (1969, p. 257).

If the coarse glauconitic bed is correlated with the basal Navesink, if the overlying clay-silt to fine sand is correlated with the basal Red Bank (Sandy Hook Member), and if the upper medium to coarse sand is correlated with the upper Red Bank Sand (Shrewsbury Member), a remarkable similarity to the New Jersey section is evident, in addition to compatibility with the proposed cyclic sedimentation.

No attempt has been made here to map the beds in the upper part of the Mount Laurel section separately because lithologic and faunal evidence is not yet conclusive enough to justify this. It is hoped that continuation of mapping, as planned near Round Bay on the west side of Chesapeake Bay, will throw additional light on this still unresolved problem. Preliminary investigations in the Round Bay area show similar beds of virtually the same age containing a similar fossil suite lying directly on probable lowermost Matawan; the Marshalltown and Englishtown faunas appear to be absent (N. F. Sohl, U.S. Geol. Survey, oral commun., Oct. 1971.).

TERTIARY SEDIMENTS

HORNERSTOWN SAND

The Hornerstown Sand is one of the most uniform, distinctive, and easily recognized units in the northern Atlantic Coastal Plain. It is typically dusky-green glauconite sand with a dusky-green glauconite clay matrix and contains varying proportions of quartz sand. Glauconite consists mostly of single, botryoidal, medium grains and constitutes 50–95 percent of the unit. Quartz sand is more abundant at the base where the unit overlies quartz sandy units such as the Mount Laurel; quartz sand content also increases throughout the unit towards the southwest. The Hornerstown is about 30 feet thick at its type locality in central New Jersey. This basal Tertiary unit thins towards the southwest and progressively overlaps lower truncated beds in the underlying Cretaceous section, until in the Betterton quadrangle it conformably overlies the Mount Laurel Sand (fig. 6) and is only 8–12 feet thick. Locally it is absent, particularly in the eastern part of the quadrangle.

The Hornerstown previously was not mapped as a separate unit in Maryland except by Owens (U.S. Geol. Survey, 1967), but now has been mapped by the author in the Betterton quadrangle (this report) and by Conant in Cecil County (unpub. data). The entire thickness of the formation is exposed at Gregg Neck where the basal contact with the Mount Laurel can be seen (fig. *2D*). The Hornerstown may only be present in Maryland in outcrop in the Eastern Shore region.

In Delaware before 1971 (Pickett and Spoljaric), the Hornerstown had not been mapped or recognized as a separate unit except by Owens (U.S. Geol. Survey, 1967). Jordan discussed it quite thoroughly (1962, p. 18–26) and assigned letter designations A, B, C, plus the name Rancocas to the section which includes the Hornerstown and Vincentown interval (p. 14). The Hornerstown is shown as Rancocas on the "Generalized Geologic Map of Delaware" (Spoljaric and Jordan, 1966). It crops out along Drawyers Creek just northwest of Odessa in and near a gravel pit (Groot and others, 1961, p. 24; Spoljaric and Woodruff, 1970, p. 6; Jordan, 1962, p. 18; Minard and others, 1969, p. H16). The basal few feet, which is a distinctive green clayey glauconite, is exposed and lies in sharp contrast on the Mount Laurel Sand (fig. *5F*). Miller (1906) mapped this exposure as Rancocas and placed it in the Cretaceous. The writer augered three holes through the Hornerstown in the vicinity of Odessa and penetrated as much as 18–20 feet of glauconite (Minard and others, 1969, p. H17, H18).

Many good exposures are present all along the outcrop in New Jersey from the Woodstown area (Minard, 1965; Richards and others, 1957, p. 219, 230), through central New Jersey (Dorf and Fox, 1957, p. 21, 22; Minard and others, 1964; Owens and Minard, 1962, 1964b; Minard and Owens, 1962; Minard, 1964) to the Sandy Hook area (Minard, 1969).

VINCENTOWN FORMATION

The Vincentown Formation is a fairly uniform and persistent unit, although not as distinctive as the Hornerstown. It typically is a glauconitic quartz sand. In many places it contains fossils in such abundance and thickness that it is called a limesand or limestone (Rogers, 1836, p. 10–12; Cook, 1868, p. 261; Clark, 1898, p. 170). At and near its type section in central New Jersey it contains thick layers of calcareous material in the form of whole and fragmental megafossils and microfossils. The fauna has been studied by many people; one example is a report by Loeblich and Tappan (1957). Greacen (1941) did a detailed study of the formation, as have numerous others.

In many places no fossils are evident, and the section is a greenish-gray thick quartz sand containing a trace to several percent glauconite. Part of the formation, however, is exceedingly glauconitic and commonly contains as much as 50 percent glauconite; in some areas it even exceeds that amount. The largest percentage of glauconite tends to be in the lower part of the formation.

Weathered beds are typically grayish brown or reddish brown, and iron oxide forms crusts and indurated layers. Where fossil shells were present they have dissolved and only molds remain. The formation lithologically strongly resembles the Mount Laurel Sand and upper Red Bank Sand, particularly where weathered. This similarity has caused difficulties in identification by previous workers and was discussed in the preceding section on the Mount Laurel.

Outcrops in Maryland northeast of Betterton are neither as numerous nor as good as those of the Cretaceous units, but the formation can be seen in roadcuts and pits along the outcrop. Exposures in Delaware are not abundant but can be seen in the Middletown-Odessa-Noxontown Pond area, where Miller (1906) mapped the Hornerstown and Vincentown combined as the Rancocas (at that time thought to be of Cretaceous age). On the same map, Miller showed the equivalent beds in adjacent Maryland as Aquia. In fact he mapped these equivalent units in the headwaters of the Sassafras River as Aquia across the State line into Delaware. Jordan (1962, p. 21–23) considered and rejected the New Jersey names of Hornerstown and Vincentown for the lower Tertiary units in Delaware. He decided to retain the New Jersey name Rancocas, which he partly divided into lettered units (p. 14–23). However, Pickett and Spoljaric (1971) mapped the unit as Vincentown.

The formation is well exposed in New Jersey from Woodstown (Minard, 1965) through central New Jersey (Minard and others, 1964; Owens and Minard, 1964b) to Sandy Hook (Minard, 1969, p. 24).

Although the formation has been mapped as Aquia in Maryland, in this report it is mapped as Vincentown, as was done by the U.S. Geological Survey (1967) in Maryland and in Delaware, because of its lithological and paleontological similarity to the New Jersey section and its continuity throughout its outcrop belt from northeast to southwest. The calcarenite facies of the Vincentown persists at least as far southwest as Artificial Island in the Delaware River near the mouth of the Chesapeake and Delaware Canal (Owens, U.S. Geol. Survey, written commun., Jan. 1972). The basal *Oleneothyris harlani* shell bed, which is present in many places in New Jersey from Sandy Hook to Woodstown, is also present in Delaware (Pickett, Delaware Geol. Survey, oral commun., June 1971), western Maryland, and Virginia (Johnson and Richards, 1952, p. 2158–2159), and in North Carolina (Druid Wilson, U.S. Geol. Survey, written commun., August 1971).

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