DESCRIPTION OF MAP UNITS

for

Bedrock Geologic Map of Central and Southern New Jersey

By

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Scale 1 to 100,000, 8 cross sections, 4 sheets, each size 58x41,

USGS Map I-2540-B

DESCRIPTION OF MAP UNITS

COASTAL PLAIN SEDIMENTS

Tc Unnamed unit at Cape May (upper Pliocene) - Interbedded gravel, sand, and clay, massive to thick-bedded. Informal unit described from a corehole at the Cape May Airport. The lower 18.3 m (60 ft) consists of interbedded gravel; medium- to very coarse grained, poorly sorted sand; and thin to thick beds of medium- to dark-gray, very woody clay. Gravel clasts are typically less than 0.64 mm (0.025 in) in diameter. The upper 12.2 m (40 ft) consists of a thick-bedded, medium-gray, extensively bioturbated clay-silt, which is overlain by an extensively burrowed, fine- to medium-grained glauconitic (about 5 percent) quartz sand. Quartz and siliceous rock fragments compose most sand grains. Feldspar is present in most samples but usually constitutes less than 10 percent of the sand fraction. No calcareous macrofossils were found in the burrowed intervals. Unit is known only to occur on the Cape May peninsula where it lies within a large channel. The unit is about 60 m (197 ft) in maximum thickness. The contact with the underlying Belleplain Member of the Kirkwood Formation is sharp and unconformable; a basal gravel bed as much as 1 m (3 ft) thick is present along the contact.

The pollen assemblage in the lower part of the unit is dominated by pine and oak with somewhat lesser amounts of hickory and basswood. Spruce, hemlock, beech, alder, and black gum are minor constituents. Traces of fir, willow, birch, and sweet gum are present, as is exotic *Engelhardia*. The non-arborial pollen are a *Multisia*-type composite of the present-day Andean provenance which indicate an exotic cool climate. The lower assemblage suggests a cool-temperate climatic regimen. The pollen assemblage in the upper beds is dominated by oak and hickory with minor amounts of basswood, sweet gum, pine, and *Multisia*-type composite. Traces of cedar, willow, birch, alder, grass, and *Sphagnum* spores also are present. This assemblage probably represents a temperate climatic regimen (Les Sirkin, Adelphi University, written commun., 1991). The low percentage of exotic species is characteristic of the late Pliocene, and therefore, the unnamed unit at Cape May may be equivalent to the Beaverdam Formation of the Delmarva Peninsula of Delaware, Maryland, and Virginia.

Tch Cohansey Formation (middle Miocene, Serravallian) - Sand, white to yellow with local gravel and clay. Locally stained red or orange brown by iron oxides and (or) cemented into large blocks of ironstone. Unweathered clay is typically dark gray, but commonly weathers white where interbedded with thin beds of ironstone. Unit is a complex of interfingering marine and nonmarine facies. Sand is typically medium grained and moderately sorted although it ranges from fine to very coarse grained and from poorly to well sorted. Sand consists of quartz and siliceous rock fragments. Some beds are locally micaceous, and in the Lakehurst area, Ocean County, some beds have high concentrations of “black” sand (pseudorutile) that was once extensively mined. In general, the sand is crossbedded, although the style of crossbedding varies significantly with the paleoenvironment. Trough crossbedding predominates, especially in the nonmarine channel fill deposits, and the scale of the crossbeds varies from small to large. In some areas, planar bedding is well developed in sections that have abundant marine burrows (mostly the clay-lined trace fossil *Ophiomorpha nodosa*). Such marine-influenced beds (largely foreshore deposits) occur on the central sheet west of Asbury Park, near Adelphia, Monmouth County, north of the Lakehurst Naval Air Station, Ocean County, and at Juliustown, Burlington County (Owens and Sohl, 1969), and on the southern sheet as far north as Salem, Salem County. Gravel beds occur locally, especially in updip areas such as near New Egypt, Ocean County, in the Atlantic Highlands and in the highlands west of Barnegat, Ocean County, in the southern part of the central sheet and in mixed marine and nonmarine facies in the northeastern part of the southern sheet where gravel occurs in well-defined channels. Most of the gravel is 1.3 to 2.5 cm (0.5-1.0 in) in diameter, but pieces as long as 10 cm (4 in) are present. The gravel is composed of quartz with small amounts of black chert and quartzite. Clay commonly occurs as discrete, thin, discontinuous beds, is dark gray where unweathered, white or red where weathered. Lesser, thin laminated clay strata also are present. Locally, as near Lakehurst, thick, dark-gray, very lignitic clay was uncovered during the mining of ilmenite and is informally called the Legler lignite (Rachele, 1976). An extensive, well-preserved leaf flora was collected from a thick clay lens in a pit near Millville, Cumberland County. The leaf flora was dominated by *Alangium* sp., a tree no longer growing in eastern North America (J.A. Wolfe, written commun., 1992).

Maximum thickness in the map area is about 60 m (197 ft); however, thickness is difficult to determine because of the irregular basal contact and extensive post-depositional erosion. There is as much as 18 m (59 ft) of relief along the basal contact. The basal contact is sharp, undulatory, and directly overlain by a thin gravel bed. The Cohansey Formation unconformably overlies the Kirkwood Formation and is found in channels cut down into the Kirkwood. Where the Kirkwood consists of sandy, light-colored sediments, the basal contact of the Cohansey is drawn below crossbedded sediments. Where the Kirkwood consists of dark-colored silty beds, the basal contact is drawn between light-colored Cohansey sediments and the underlying dark-colored sediments. The Cohansey was markedly thinned because of erosion prior to deposition of overlying units in the western and southern parts of the southern sheet (Owens and Minard, 1975). The unit has been extensively eroded and stripped from large areas of the New Jersey Coastal Plain, particularly in the central sheet where outliers are common. In spite of its widespread nature, the Cohansey is poorly exposed because of its loose sandy composition, which causes it to erode easily (Newell and others, in press). Because of this same sandy nature, the Cohansey has been widely mined for sand, and manmade exposures are common in many areas.

The age of the Cohansey is controversial because no calcareous microfauna or macrofauna have been found in this formation. The best indication of age comes from pollen and spores obtained from dark carbonaceous clay. Rachele (1976) analyzed the microflora from the Legler site and noted that the Cohansey had a rich and varied assemblage including several genera labeled “exotics” which no longer occur in the northeastern United States: *Engelhardia, Pterocarya, Podocarpus*, and *Cyathea*. Greller and Rachele (1984) estimated a middle Miocene age. Ager’s (*in* Owens and others, 1988) analysis of the Cohansey from a corehole at Mays Landing also suggests a middle Miocene (Serravallian) age.

Kirkwood Formation (middle and lower Miocene, Serravallian to Aquitanian) - Consists of the Wildwood Member and an informal lower member on the central sheet and the Belleplain Member, Wildwood Member, Shiloh Marl Member, and lower member on the southern sheet. The Belleplain Member is a new member named for beds occurring in a corehole drilled by the U.S. Geological Survey at Belleplain State Forest Headquarters, Cape May County. The Wildwood Member is a new member named for beds occurring in a drillhole at Wildwood Beach, Cape May County.

Tkb Belleplain Member (middle Miocene, Serravallian) - Clay to silty clay at the base and sand at the top. Clay, massive to laminated, gray-brown, locally contains abundant diatoms and scattered small shell fragments. Sand, fine- to medium-grained, pale-gray to white, somewhat micaceous and woody with scattered shell fragments. Most Belleplain sand is quartz with lesser amounts of feldspar and mica. Pyrite is common in clayey strata. The Belleplain subcrops beneath surficial deposits where the overlying Cohansey Formation was eroded away. Along the Atlantic Ocean, the member is exposed on the southern sheet between Beach Haven Terrace, Ocean County, and Brigantine, Atlantic County, where the unit is overlain by thin to thick deposits of alluvium. The member is as much as 15 m (49 ft) thick. The basal contact with the underlying Wildwood Member is sharp and unconformable with a thin bed of reworked coarse-grained quartz sand at the base. A middle Miocene age for the Belleplain was determined from diatoms. Specifics of the diatom biostratigraphy are discussed in the Description of Subsurface Units. Shells from this unit had a strontium-isotope age estimate of 13.2 Ma (Sugarman and others, 1993).

Tkw Wildwood Member (middle and lower Miocene, Langhian and Burdigalian) - Clay, silty, massive to finely bedded, dark-gray to olive-gray, locally interbedded with thin beds of light-colored sand. Contains small shell fragments primarily at base. Upper beds are more sandy than lower beds but also contain many thin to thick beds of clay. The sand is fine to medium grained, light gray, and commonly has dispersed wood fragments. Shell fragments are locally present in this facies. Basal beds are micaceous, locally diatomaceous, and contain wood fragments. Quartz is the major sand constituent with minor amounts of siliceous rock fragments and feldspar. The Wildwood subcrops beneath surficial deposits where the Belleplain Member and Cohansey Formation were stripped away. Along Delaware Bay, the Wildwood subcrops from near the Cohansey River to Fortescue, Cumberland County. Along the Atlantic Coast, the unit subcrops from Bay Shore Park to near Beach Haven Park, Ocean County. The maximum thickness of the unit is about 18 m (59 ft). The contact with the underlying Shiloh Marl Member is sharp and unconformable. Diatoms from the Wildwood Member are from the East Coast Diatom Zone (ECDZ)

2 of Andrews (1988) indicating a latest Burdigalian and Langhian age (late early and early middle Miocene).

Tks Shiloh Marl Member (lower Miocene, lower Burdigalian) - Clay, massive, dark-gray with abundant large mollusks. Unit subcrops near the Delaware River where the overlying Wildwood Member and Cohansey Formation have been stripped away. The Shiloh Marl Member averages about 30 m (98 ft) thick. Diatoms recovered from the Shiloh from the ACGS-4 corehole 5.3 km (3.2 mi) northwest of Mays Landing, Atlantic County, contain the diagnostic diatom *Actinoptychus heliopelta* (Andrews, 1987) indicating an early Miocene age. Strontium-isotope analysis of shells yielded an age of 20 Ma (Burdigalian) (Sugarman and others, 1993).

Tkl Lower member (lower Miocene, Burdigalian and Aquitanian) - Sand and clay. Upper sand facies: sand, typically fine- to medium-grained, massive to thick-bedded, locally crossbedded, light-yellow to white, locally very micaceous and extensively stained by iron oxides in near-surface beds. The thick-bedded strata commonly consist of interbedded fine-grained, micaceous sand and gravelly, coarse- to fine-grained sand. Some beds are intensely burrowed. Trough crossbedded strata with high concentrations of ilmenite and a few burrows are most commonly seen in the Lakewood quadrangle. Lower clay facies: clay and clay-silt, massive to thin-bedded, dark-gray, micaceous, contains wood fragments, flattened lignitized twigs, and other plant debris. Locally, the clay has irregularly shaped sand pockets, which may represent some type of burrow. In the least weathered beds, the sand of the upper sand facies is principally quartz and muscovite with lesser amounts of feldspar. The light-mineral fraction of the dark-colored clay has significantly more feldspar (10-15 percent) and rock fragments (10-15 percent) than the upper sand facies, where the feldspar was probably leached during weathering. The basal beds have a reworked zone 0.3 to 1.2 m (1-4 ft) thick that contains fine- to very coarse grained sand and, locally, gravel. These beds are very glauconitic and less commonly contain wood fragments. Reworked zones are present throughout the lower member. The lower member consists of a lower fine-grained, clayey, dark-colored, micaceous sand (transgressive) and an upper massive or thick-bedded to crossbedded, light-colored sand (regressive). The lower, dark clayey unit was formerly called the Asbury Park Member. The clay-silt was previously called the Asbury Clay by Kümmel and Knapp (1904).

The upper sand facies has been observed only in pits and roadcuts. It is poorly exposed because of its sandy nature. In the central sheet, the lower clay facies is exposed in pits north of Farmingdale, Monmouth County; in a few cuts along the Manasquan River, north of Farmingdale; and along the Shark River, northeast of Farmingdale. In the southern sheet, the lower clay facies is exposed only where the Coastal Plain was deeply entrenched and stripped away. In the southwesternmost part of the southern sheet, for example, the Cohansey Formation and much of the upper sand facies were stripped away by successive entrenchments of the Delaware River.

On the central sheet, the lower member ranges in thickness from 20 to 30 m (66-98 ft) along strike, but thickens to over 60 m (197 ft) to the southeast. On the southern sheet, the unit ranges in thickness from 15 to 25 m (49-82 ft). The age of the lower member is based on the presence of the diatom *Actinoptychus heliopelta*, which was recovered from an exposure southwest of Farmingdale near Oak Glen, Monmouth County (Goldstein, 1974). This diatom places the lower member in the lower part of the ECDZ 1 of Andrews (1987), indicative of an early Miocene (Burdigalian) age (Andrews, 1988). Sugarman and others (1993) report strontium-isotope ages of 22.6 to 20.8 Ma, thereby extending the age of the unit to Aquitanian.

Tsr Shark River Formation (upper and middle Eocene, Priabonian through Lutetian) - Glauconite sand, silt, and clay, medium- to coarse-grained, light-brown to medium-gray, locally indurated at top and noncalcareous throughout. Mollusk impressions (mainly *Venericardia perantiqua*) were observed in the Farmingdale quadrangle. The Shark River is exposed only at a few localities in the central sheet near Farmingdale, Monmouth County, along the Manasquan and Shark Rivers and in several tributaries to Deal Lake near Asbury Park in the Asbury Park quadrangle (Sugarman and Owens, 1994). Most outcrops are small, less than 3 m (10 ft) in height. The contact with the underlying Manasquan Formation was not observed. The Shark River is about 18 m (59 ft) thick and consists of two fining-upward cycles: a glauconite sand is present at the base and a clay or silt is present at the top of each cycle. Calcareous

nannofossils in subsurface Shark River sections indicate Zones NP 14 through NP 18 (Martini, 1971) (middle Eocene and early late Eocene).

Tmq Manasquan Formation (lower Eocene, Ypresian) - Consists of several lithologies. In the northern part of the central sheet, unit consists of a lower, clayey, quartz-glauconite sand, which is exposed intermittently along the Manasquan River near Farmingdale, Monmouth County, and an upper, fine-grained quartz sand or silt, which is exposed along Hog Swamp Brook west of Deal, Monmouth County. The Farmingdale Member and the Deal Member (of Enright, 1969) are not used on this map because they are not continuous through the outcrop belt or in the subsurface.

The formation is best exposed in the central sheet from the Fort Dix Military Reservation, Burlington County, southwestward to the Medford Lakes quadrangle. Here the lower part of the formation consists of 5 m (16 ft) of medium- to coarse-grained, massive, dark-grayish-green, glauconite-quartz sand. The lowest 1 m (3 ft) mostly contains calcareous debris and phosphatized internal fossil molds reworked from the underlying Vincentown Formation. The upper part of the formation is approximately 8 m (26 ft) thick and is mostly a very clayey, blue-green to pale-gray, quartz-glauconite (about 20 percent glauconite) sand. Locally, the glauconite content of this interval is variable, and the unit becomes almost a blue-green clay-silt, especially near Pemberton, Burlington County (Owens and Minard, 1964a). Casts and molds of mollusks (especially *Venericardia perantiqua*) occur in outcrop. The age of the formation was determined from microfauna in unweathered subsurface beds. Calcareous nannofossils indicates upper Zone NP 9 to mid Zone NP 14 (early Eocene).

Tvt Vincentown Formation (upper Paleocene, Selandian) - Sand, quartz, medium-grained, well- to poorly sorted, dusky-yellow to pale-gray; weathers orange brown or red brown, typically very glauconitic and clayey near base; glauconite decreases up section. Feldspar and mica are minor sand constituents. Unit best exposed in the Pemberton, New Egypt, and Mount Holly quadrangles of the central sheet where the overlying formations have been stripped away. The Vincentown Formation is as much as 30 m (98 ft) thick and averages 3 to 15 m (10-49 ft) in its subcrop belt. Where unweathered the unit is generally a shelly sand; where weathered the unit is largely a massive quartz sand. The unweathered sand of the Vincentown is exposed intermittently along the Manasquan River near Farmingdale, Monmouth County. The calcareous nature of the unweathered Vincentown was observed in several coreholes in the vicinity of Farmingdale. The contact with the underlying Hornerstown Formation is disconformable; locally shell beds (bioherms) up to 1.5 m (5 ft) thick are found along the contact. Shells in the bioherms are typical of a restricted environment and contain the brachiopod *Oleneothyris harlani* (Morton) in the lower beds and the oyster *Pycnodonte dissimilaris* in the upper beds. The basal contact and the *Oleneothyris* bioherms are exposed along Crosswicks and Lahaway Creeks and their tributaries. Where bioherms are absent, the basal contact is difficult to place within a sequence of glauconite beds. In general, glauconite beds of the Vincentown are darker gray than glauconite beds of the Hornerstown, and the Vincentown has more quartz sand. Upper beds of the Vincentown are as much as 12 m (39 ft) thick and are mostly silty, dark-gray to green-gray, massive, glauconite sand that contains a small percentage of quartz. Calcarenite or coquina, characterized by an abundance of bryozoans, occurs locally along the western belt. These fossiliferous beds, 6 to 7.5 m (20-25 ft) thick, are best exposed along Shingle Run in the New Egypt quadrangle area and in streams that cross the Vincentown outcrop belt in the Pemberton quadrangle.

Calcareous nannofossils, present in some Vincentown outcrops, are from Zones NP 5 (the *Oleneothyris* beds) and NP 9 (late Paleocene). Vincentown sediments are much more fossiliferous in the subsurface and contain Zones NP 5 through NP 9, inclusive. Therefore, the Vincentown corresponds in age with the Aquia Formation of Virginia and Maryland. Numerous studies of the foraminifera of the Vincentown from calcareous beds in the western outcrop belt indicate that the Vincentown includes the planktic foraminifera Zones P3b through P6a (Olsson and others, 1988). A potassium-argon age of 56.4±18 Ma was determined for basal beds near New Egypt, Ocean County (Owens and Sohl, 1973).

Tht Hornerstown Formation (lower Paleocene, Danian) - Sand, glauconite, fine- to medium-grained, locally clayey, massive, dark-gray to dusky-green; weathers dusky yellow or red brown, extensively bioturbated, locally has a small amount of quartz at base. Glauconite grains are typically dark green and have botryoidal shapes. The Hornerstown weathers readily to iron oxide because of its high glauconite

content. The Hornerstown in most areas is nearly pure glauconite greensand. The Hornerstown crops out in a narrow belt throughout most of the western outcrop area. In the northern part of the central sheet, it is extensively dissected and occurs as several outliers. Throughout its outcrop belt in the central sheet, the Hornerstown unconformably overlies several formations: the Tinton Formation in the extreme northern area; the Red Bank Formation in the northwestern and west-central areas; and the Navesink Formation in the west-central and southern areas. In the southern sheet, it unconformably overlies the Mount Laurel Formation. The unconformable basal contact locally contains a bed of reworked phosphatic vertebrate and invertebrate fossils. For the most part, however, the basal contact is characterized by an intensely bioturbated zone in which many burrows filled with bright green glauconite sand from the Hornerstown Formation project down into the dark-gray matrix of the underlying Navesink Formation. In a few exposures, a thin layer of medium- to coarse-grained quartz sand separates the Hornerstown from the underlying unit. The Hornerstown is 1.5 to 7 m (5-23 ft) thick.

A Cretaceous age was assigned to this unit by Koch and Olsson (1977) based, in part, on a vertebrate fauna found at Sewell, Gloucester County. However, early Paleocene calcareous nannofossil Zones NP 2-4 were found in a core at Allaire State Park, Monmouth County. This is the only locality in New Jersey where Zone NP 2 was observed; otherwise, the Hornerstown is confined to Zones NP 3 and NP 4. Lowermost Paleocene Zone NP 1 was not identified, and it is thought that the Cretaceous-Tertiary boundary in New Jersey may be unconformable. A complete Cretaceous-Tertiary boundary section was recovered at the Bass River borehole (ODP Leg 174AX). It contained the uppermost Maastrichtian calcareous nannofossil *Micula prinsii* Zone below a spherule layer and the basal Danian planktonic foraminiferal *Guembeletria cretacea P0* Zone just above the layer (Olsson and others, 1997).

Kt Tinton Formation (Upper Cretaceous, upper Maastrichtian) - Sand, quartz, and glauconite in varying proportions, very clayey and locally indurated by siderite into hard, massive ledges. Sand is dark gray to dark yellow where unweathered; where weathered, siderite changes color of unit to orange brown because of iron oxides, and the formation is stained or cemented in exotic patterns. The Tinton crops out in the northern part of the central sheet from Sandy Hook, Monmouth County, to the northernmost part of the Roosevelt quadrangle, near Perrineville. Unit unconformably overlies the Red Bank Formation in the high hills of the northern Coastal Plain, most notably near Perrineville and Morganville, Monmouth County. In these updip areas, fine gravel, 1 cm (0.4 in) maximum diameter, or large shell concentrations are found along the basal contact. The typical basal bed is a massive, glauconitic (10-35 percent), fine- to medium-grained quartz sand with scattered gravel. The massive character of the basal bed is the result of extensive bioturbation. Burrows, filled with glauconite sand of the Tinton, project down into the quartz sand of the underlying Red Bank Formation.

At lower elevations downdip, the Tinton is less weathered, much darker, more glauconitic, and typically indurated. The type locality on Pine Brook at Tinton Falls, Monmouth County, is in this downdip area. At Tinton Falls, 7 to 8 m (23-26 ft) of the Tinton is exposed and has a higher glauconite content than in the updip area. Glauconite at Tinton Falls is light green to pale yellow, and many of the grains have a smooth polished surface that is almost lustrous. Thin sections of the Tinton reveal that many of the grains are oolitic (Owens and Sohl, 1973). X-ray analyses indicate the presence of mixed clay minerals; therefore, the unit is not pure glauconite.

The Tinton Formation at Tinton Falls has scattered molds of calcitic fossils and aragonitic shells. Richards (1958) recorded 30 species of mollusks from the Tinton in this area. Of importance are *Sphenodiscus lobatus, Cucullaea (Idonearca) littlei*, and *Scabrotrigonia cerulia*. In New Jersey, *Scabrotrigonia cerulia* is restricted to the Tinton. All three species are common to the upper Maastrichtian *Haustator bilira* Zone of Sohl (*in* Owens and others, 1977). Strontium-isotope analysis on calcareous shells from the Tinton yielded ages of 66.2 to 65.6 Ma or a late Maastrichtian age (Sugarman and others, 1995).

Red Bank Formation (Upper Cretaceous, upper and middle Maastrichtian) - Consists of two thick named lithofacies and one thin unnamed lithofacies. In the northernmost outcrop belt of the central sheet, Olsson (1963) named the upper thick facies the Shrewsbury Member and the lower thick facies the Sandy Hook Member. These lithofacies merge with an unnamed thin, dark-gray, very micaceous, quartz-

glauconite sand to the southwest. This unnamed glauconite lithofacies was mapped in detail in the Roosevelt (Minard, 1964), Allentown (Owens and Minard, 1966), and New Egypt (Minard and Owens, 1962) quadrangles on the central sheet. The Red Bank, like the overlying Tinton, crops out only in the northern part of the central sheet from Sandy Hook, Monmouth County, to near New Egypt, Ocean County. The scale of the map permits showing only the thicker Sandy Hook and Shrewsbury Members. The contact with the underlying Navesink Formation is gradational over several feet. The Sandy Hook Member and the unnamed glauconite member near New Egypt have similar sand and clay mineral compositions.

Smith (*in* Owens and others, 1977) determined that the Red Bank Formation is of late middle and late Maastrichtian age based primarily on the presence of the ammonite *Sphenodiscus lobatus* and the planktic foraminifera in the Sandy Hook Member from the Poricy Brook locality, Monmouth County. The concurrence of *Rugoglobigerina scotti* and *Globotruncana contusa* place this member well above the base of the *Gansserina gansseri* Subzone in the upper Maastrichtian. Sugarman and others (1995) assigned a late Maastrichtian CC26 Zone to the unit. Wolfe (1976) assigned pollen from the Sandy Hook Member to the Maastrichtian CA6/MA-1 Zone. Strontium-isotope age estimates for the Red Bank average 65.8 Ma (Sugarman and others, 1995).

Krbs Shrewsbury Member - Sand, quartz, fine- to coarse-grained, somewhat clayey and micaceous, mostly massive with local small-scale crossbedding, light-yellow to red or dark-brown, slightly glauconitic at the base. Feldspar is a minor sand constituent. The Shrewsbury is extensively burrowed but is otherwise unfossiliferous. Locally, small *"Callianassa"*-type burrows are present. Maximum thickness is over 30 m (98 ft) in the highlands near Matawan. Unit thins southwestward and pinches out near Arneytown, Ocean County. The transition to the underlying Sandy Hook Member occurs within several feet and is characterized by an increase in clay, quartz, silt, mica, and fine pieces of wood downward.

Krbsh Sandy Hook Member - Sand, quartz, fine-grained, clayey, very micaceous, massive, dark-gray, fossiliferous. Feldspar, muscovite, chlorite, and biotite are minor sand constituents. Well exposed at Poricy Brook in the Long Branch quadrangle. The Sandy Hook is much thinner than the overlying Shrewsbury Member and is a maximum of 10 m (33 ft) thick.

Kns Navesink Formation (Upper Cretaceous, Maastrichtian) - Sand, glauconite, medium-grained, clayey and silty, massive, dark-gray to dark-gray-green, extensively bioturbated, locally contains large calcareous shells; sand-size mica, locally abundant; weathers light brown or red brown. Basal quartz sand is fine- to coarse-grained, pebbly, massive, light-yellow, and somewhat glauconitic, as much as 2 m (7 ft) thick and formed by the reworking of the underlying Mount Laurel Formation (Owens and others, 1977). *Exogyra costata* and the belemnite *Belemnitella americana* occur in the basal quartz sand. Crops out in a narrow belt throughout map area. Fresh exposures occur along tributaries of Raccoon Creek near Mullica Hill, Gloucester County. The Navesink is 3 to 7.5 m (10-25 ft) thick. The Navesink and Red Bank deposits represent a transgressive (Navesink)-regressive (Red Bank) cycle of sedimentation (Owens and Sohl, 1969). The cycle is unconformity-bounded at top and bottom. Within the cycle, the formational contact is gradational.

The age of the Navesink was determined from both the macrofauna and microfauna. Planktic foraminifera from the lower part of the Navesink are indicative of the *Rugotruncana subcircumnodifera* Subzone of early Maastrichtian age (Smith, *in* Owens and others, 1977). The upper part contains the mollusks *Exogyra costata, Sphenodiscus lobatus*, and *Pycnodonte vesicularis* indicating a middle to late Maastrichtian age. Planktic foraminifera from the upper part represent the *Gansserina gansseri* Subzone of middle Maastrichtian age (Smith, *in* Owens and others, 1977). Pollen in the Navesink and Sandy Hook Member of the Red Bank are similar; the Navesink microflora is a CA6/MA-1 Zone in Wolfe's (1976) classification. The Navesink, therefore, ranges from early to late Maastrichtian. Sugarman and others (1995) assigned a middle Maastrichtian Zone CC 25 to the Navesink.

Kml Mount Laurel Formation (Upper Cretaceous, upper Campanian) - Sand, quartz, massive to crudely bedded, typically coarsens upward, interbedded with thin clay beds. Glauconite and feldspar are minor sand constituents. Muscovite and biotite are abundant near the base. Lower part of formation is a

fine- to medium-grained, clayey, dark-gray, glauconitic (maximum 25 percent) quartz sand. Typically weathers to white or light yellow and locally stained orange brown by iron oxides. Small pebbles scattered throughout, especially in the west-central area. Locally, has small, rounded siderite concretions in the interbedded clay-sand sequence. Granules and gravel are abundant in the upper 1.5 m (5 ft). Upper beds are light gray and weather light brown to reddish brown. The Mount Laurel is 10 m (33 ft) thick from the Roosevelt quadrangle to the Runnemede quadrangle in the central sheet. Thickness varies in the northern part of the map area due, in part, to extensive interfingering of this formation with the underlying Wenonah Formation. Weller (1907) and Kümmel (1940) recognized only about 1.5 m (5 ft) of the Mount Laurel in the north. In this report those beds are assigned to the overlying Navesink Formation. The interbedded sequence, the major facies in the north, ranges to about 4.5 m (15 ft) thick. These interbeds have well-developed large burrows (Martino and Curran, 1990), mainly *Ophiomorpha nodosa*, and less commonly *Rosselia socialis*. The Mount Laurel is gradational into the underlying Wenonah Formation. A transition zone of 1.5 m (5 ft) is marked by an increase in clay, silt, and mica into the Wenonah, especially in the west-central area of the central sheet.

The oyster *Agerostrea falcata* occurs in the lower part of the formation. *Exogyra cancellata* and *Belemnitella americana* are abundant in upper beds in the west-central area of the central sheet (New Egypt quadrangle). The Mount Laurel Formation is of late Campanian age based on the assignment of Zone CC 22b to the formation by Sugarman and others (1995) and the occurrence of *Exogyra cancellata* near Mullica Hill, Gloucester County.

Kw Wenonah Formation (Upper Cretaceous, upper Campanian) - Sand, quartz and mica, fine-grained, silty and clayey, massive to thick-bedded, dark-gray to medium-gray; weathers light brown to white, extensively bioturbated, very micaceous, locally contains high concentrations of sand-sized lignitized wood and has large burrows of *Ophiomorpha nodosa*. Feldspar (5-10 percent) is a minor sand constituent. Unit crops out in a narrow belt from Sandy Hook Bay on the central sheet and pinches out southwest of Oldmans Creek, Salem County, on the southern sheet. Isolated outliers of the Wenonah are detached from the main belt in the central sheet area. Thickness is about 10 m (33 ft) in the northern part of the central sheet, 20 m (66 ft) in the southwestern part of the central sheet, and 7.5 m (25 ft) in the southern sheet. The Wenonah is gradational into the underlying Marshalltown Formation. A transition zone of several meters is marked by a decrease in mica and an increase in glauconite sand into the Marshalltown.

Fossil casts are abundant in the Wenonah. Weller (1907) reported *Flemingostrea subpatulata* Hop Brook in the Marlboro quadrangle indicating a late Campanian age. Wolfe (1976) placed the Wenonah microflora in his CA5A assemblage, considered to be of late Campanian age. Kennedy and Cobban (1994) identified ammonites including *Baculites* cf. *B. scotti, Didymoceras* n. sp., *Menuites portlocki, Nostoceras (Nostoceras) puzosiforme* n. sp., *Nostoceras (Nostoceras)* aff. *N. colubriformus, Parasolenoceras* sp., *Placenticeras placenta, P. minor* n. sp., and *Trachyscaphites pulcherrimus*. The presence of *M. portlocki* and *T. pulcherrimus* indicates late, but not latest, Campanian.

Kmt Marshalltown Formation (Upper Cretaceous, upper and middle Campanian) - Sand, quartz and glauconite, fine- to medium-grained, silty and clayey, massive, dark-gray; weathers light brown or pale red, extensively bioturbated. Very glauconitic in basal few meters; glauconite concentration decreases upward so that in upper part of unit, quartz and glauconite are nearly equal. Feldspar, mica, pyrite, and phosphatic fragments are minor sand constituents. Locally, very micaceous (mostly green chlorite) with sparse carbonized wood fragments. Fine-grained pyrite abundant throughout formation. Local thin, pebbly zones with large fossil impressions occur in the middle of the formation. In the upper part of the formation, quartz increases to about 40 percent. Unit crops out in a narrow belt throughout the map area and forms isolated outliers in the central sheet. Best exposures are along Crosswicks Creek in the Allentown quadrangle. In the southern sheet, the Marshalltown underlies a narrow belt in the uplands and broadens to the southwest. Many Marshalltown exposures occur along Oldmans Creek and its tributaries near Auburn, Gloucester County. The contact with the underlying Englishtown Formation is sharp and unconformable. The basal few centimeters of the Marshalltown contain siderite concentrations, clay balls, and wood fragments reworked from the underlying Englishtown. Many burrows, some filled with glauconite, project downward into the Englishtown for about one meter (3 ft)

giving a spotted appearance to the upper part of the Englishtown (Owens and others, 1970). The Marshalltown is the basal transgressive unit of a sedimentation cycle that includes the regressive deposits of the overlying Wenonah and Mount Laurel Formations resembling the overlying Red Bank Formation to Navesink Formation cycle in its asymmetry.

Within the map area, only a few long-ranging megafossils occur in the Moorestown quadrangle (Richards, 1967). To the south, in the type area, Weller (1907) reported diverse molluskan assemblages indicating a Campanian age. More importantly, Olsson (1964) reported the late Campanian foraminifera *Globotruncana calcarata* Cushman from the upper part of the formation. No *G. calcarata* were found during our investigations. Wolfe (1976) assigned the pollen assemblage of the Marshalltown to the CA5A Zone considered to be Campanian. The Marshalltown has most recently been assigned to Zone CC 20-21 (Sugarman and others, 1995) of middle and late Campanian age (Perch-Nielsen, 1985).

Ket Englishtown Formation (Upper Cretaceous, lower Campanian) - Sand, quartz, fine- to coarse-grained, gravelly, massive, bioturbated, medium- to dark-gray; weathers light brown, yellow, or reddish brown, locally interbedded with thin to thick beds of dark clay. Abundant carbonaceous matter, with large lignitized logs occur locally, especially in clay strata. Feldspar, glauconite, and muscovite are minor sand constituents. Sand is extensively trough crossbedded particularly west of Mount Holly, Burlington County. In a few places in the western outcrop belt, trace fossils are abundant, typically the burrow *Ophiomorpha nodosa*. Unit is pyritic, especially in the carbonaceous-rich beds where pyrite is finely disseminated grains or pyritic masses as much as 0.6 m (2 ft) in diameter. Lowest part of unit is a massive sand that contains small to large, soft, light-gray siderite concretions. The Englishtown underlies a broad belt throughout the map area and ranges from about 45 m (148 ft) thick in the northern part of the central sheet to 30 m (98 ft) thick in the western part of the central sheet to 15 m (49 ft) in the southern sheet. Best exposures occur along Crosswicks Creek in the Allentown quadrangle and along Oldmans Creek. The basal contact with the underlying Woodbury Formation or Merchantville Formation is transitional over several meters. The age of the Englishtown in outcrop could not be determined directly but was inferred from stratigraphic position and pollen content. Wolfe (1976) designated the microflora of the unit as Zone CA4 and assigned it to the lower Campanian.

Kwb Woodbury Formation (Upper Cretaceous, lower Campanian) - Clay-silt, dark-gray; weathers brown and orange pink. Iron oxides fill fractures or form layers in the most weathered beds. Unit is massive except at the base where thin quartz sand layers occur. Locally, thin stringers of pale-greenish-brown, smooth-surface glauconite occur near the top. Unit conspicuously micaceous throughout and contains finely dispersed pyrite, carbonaceous matter, and small pieces of carbonized wood as much as 30 cm (12 in) in length. Small siderite concretions are abundant in the Woodbury in the northern part of the outcrop belt. Unit forms a broad belt in the central sheet from Sandy Hook Bay, southwest to area around East Greenwich, Gloucester County, where it pinches out or changes facies. The Woodbury maintains a thickness of about 15 m (49 ft) throughout most of its outcrop belt.

Fossil imprints are abundant. An extensive Woodbury macrofauna was described by Weller (1907) from siderite concretions from a tributary to the Cooper River in the Camden quadrangle. This assemblage is unusual in that it is the only existing outcrop of the Woodbury where calcareous and aragonitic shells are still intact. Most fossils are small, fragmented, and concentrated in small pockets, but larger intact calcareous fossils are scattered throughout the Woodbury. Weller (1907) recorded 57 species from this locality. In addition, this is the same locality that contains fossils of the dinosaur *Hadrosaurus foulkii*. Pollen collected from the Woodbury was assigned to the CA3 Zone by Wolfe (1976). Biostratigraphic data suggest that the Woodbury is of early Campanian age.

Kmv Merchantville Formation (Upper Cretaceous, lower Campanian) - Sand, glauconite, locally has high quartz content, very clayey and silty, massive to thick-bedded, grayish-olive-green to dark-greenish-gray; weathers moderate brown or moderate yellow brown. Mica, feldspar, and pyrite are minor sand constituents. Very micaceous at base. Locally, has extensive iron incrustations in near-surface weathered beds. Fossil molds are mostly phosphatic. Fossils typically occur in siderite concretions. No calcareous fossils were found in outcrop. The Merchantville forms a continuous narrow to wide belt throughout the map area. The unit is about 6 m (20 ft) thick in the northern part of the central sheet,

about 20 m (66 ft) thick in the Trenton area, and 12 to 15 m (39-49 ft) thick throughout the southern sheet. The formation is best exposed in the Trenton East quadrangle, mainly in the tributaries on the western side of Blacks Creek and south of Bordentown, Burlington County, where the entire thickness of the formation can be seen in gullies (Owens and Minard, 1964b). The basal contact with the underlying Magothy or Cheesequake Formations is sharp and disconformable. At most places, a reworked zone about 0.3 to 1 m (1-3 ft) thick is present at the base. This basal bed contains reworked lignitized wood, siderite concretions as much as 13 cm (5 in) in diameter, scattered pebbles and coarse-grained quartz sand and is burrowed. Most burrows project downward into the underlying formations. The Merchantville is the basal bed of a lower Campanian transgressive-regressive cycle that includes the overlying Woodbury and Englishtown Formations. Merchantville faunas were analyzed by Sohl (*in* Owens and others, 1977) who concluded that northern fauna represented deposition on a lower shoreface or in the transition to an inner shelf, whereas the southern fauna was a deeper water assemblage, probably inner shelf.

Macrofossils occur as internal and external molds and include the ammonites *Menabites (Delawarella) delawarensis* and *Scaphites (Scaphites) hippocrepis* III. The *Scaphites* is of the type III variety of Cobban (1969) and is indicative of the lower, but not the lowest, Campanian. More recently, Kennedy and Cobban (1993), detailing the ammonite assemblage that includes *Baculites haresi, Chesapeakella nodatum, Cryptotexanites paedomorphicus* sp., *Glyptoxoceras* sp., *Menabites (Delawarella) delawarensis, M. (Delawarella) vanuxemi, Menabites (Bererella)* sp., *Pachydiscus (Pachydiscus)* sp., *Placenticeras placenta, Pseudoscholenbachia* cf. *P. chispaensis, Scaphites (Scaphites) hippocrepis* III, *Submortoniceras punctatum, S. uddeni*, and *Texanites (Texanites)* sp., concluded that the Merchantville is of late early Campanian age. Wolfe (1976) indicated that the Merchantville microflora was distinct from overlying and underlying units and designated it Zone CA2 of early Campanian age.

Kcq Cheesequake Formation (Upper Cretaceous, lower Campanian and upper Santonian) - Clay and clay-silt, micaceous, thin-bedded to laminated, dark-gray; weathers light tan. Contains abundant wood fragments intercalated with light-colored, fine-grained micaceous quartz sand and is rarely crossbedded. Rock fragments and feldspar are minor sand constituents. Small cylindrical burrows occur in the updip area. Abundant, rounded, pale-gray siderite concretions (about 8 cm (3 in) in diameter) occur in thin discontinuous beds. Sand interfingers rapidly within a short distance with extensively bioturbated, dark-gray, very micaceous, somewhat woody clay-silt. The basal clay-silt has extensive cylindrical burrows filled with fine-grained, light- to medium-green botryoidal glauconite. The basal contact with the underlying Magothy Formation is sharp. Reworked siderite concretions and some glauconite and coarse-grained quartz sand are found along the contact within the Cheesequake. Unit exposed only in the South Amboy and Keyport quadrangles. The unit is about 14 m (46 ft) thick.

The age of the Cheesequake was determined from pollen (Litwin and others, 1993), which indicates the unit is between the Merchantville Formation microflora (CA2 Zone of Wolfe, 1976, lower Campanian) and the uppermost Magothy microflora (?*Pseudoplicapollis cunceata-Semioculopollis* verrucosa Zone of Christopher, 1979, upper Santonian). It is probable that the Cheesequake Formation contains the Santonian-Campanian boundary. This unit was not recognized by Petters (1976) who concluded that the Magothy and Merchantville interfingered in the subsurface and the Merchantville was, in part, Santonian.

Kmg Magothy Formation (Upper Cretaceous, middle and lower Santonian) - Sand, quartz, fine- to coarse-grained, locally gravelly (especially at the base), white; weathers yellow brown or orange brown, interbedded with thin-bedded clay or dark-gray clay-silt mainly at the top of the formation. Muscovite and feldspar are minor sand constituents. Large wood fragments occur in many clay layers. Clay weathers to gray brown or white. Formation characterized by local vertical and lateral facies changes. The Magothy is best exposed and thickest (about 80 m (262 ft)) in the Raritan Bay area. The outcrop belt is widest in the north and narrows to the southwest. The formation is about 25 m (82 ft) thick or less in the southern sheet. The formation is poorly exposed because of its sandy nature and its widespread cover by younger sediments.

The old geologic map of New Jersey (Lewis and Kümmel, 1910-1912, revised 1950) showed the Magothy to consist of only one lithology (Cliffwood beds at Cliffwood Beach, Monmouth County). Subsequent

pollen studies of the Magothy and the underlying Raritan Formation showed most of the Raritan to be the same age as the Magothy. Wolfe and Pakiser (1971) redefined and considerably expanded the Magothy. Kümmel and Knapp (1904) had already recognized that the Magothy, as used here, contained a large number of lithologies. At the time of their study, the Magothy was extensively mined for clay and sand and was well exposed. Their subdivisions had economic designations (for example, Amboy stoneware clay). Barksdale and others (1943) later gave geographic names to these subdivisions, discussed individually below.

The lower contact of the Magothy in the Delaware River valley is difficult to place because the lower part of the Magothy is lithically similar to the underlying Potomac Formation. The contact is placed at the base of the lowest dark-gray clay in the Magothy. The best faunas from the Magothy were obtained from siderite concretions and slabs in and near Cliffwood Beach representing only the top of the formation. These faunas were discussed in detail by Weller (1904, 1907) and supplemented by Sohl (*in* Owens and others, 1977). The presence of *Ostrea cretacea* in the Cliffwood Beach fauna suggests that the upper part of the Magothy is late Santonian in age. Wolfe and Pakiser (1971) and Christopher (1979, 1982) discussed the microfloral assemblage in the Magothy. Christopher subdivided the Magothy into three zones: *Complexipollis exigua-Santalacites minor* (oldest), ?*Pseudoplicapollis longiannulata-Plicapollis incisa* (middle), and ?*Pseudoplicapollis cuneata-Semioculopollis verrucosa* (youngest). The oldest zone, originally considered to be as old as Turonian, was subsequently considered to be post-Coniacian Christopher, 1982). The middle and upper zones are also probably Santonian. Christopher (1979) followed the nomenclature for the subdivisions elaborated upon earlier. The Cliffwood and Morgan beds, and, presumably the upper thin-bedded sequence, would include the youngest pollen zone; the Amboy Stoneware Clay Member and perhaps the uppermost part of the Old Bridge Sand Member, the middle pollen zone; and the lower part of the Old Bridge Sand Member and South Amboy Fire Clay Member, the oldest pollen zone. The Magothy is considered herein to be of Santonian age.

Cliffwood beds - Typically very sandy, horizontally bedded to crossbedded, mainly small-scale trough crossbeds. Thin layers of dark, fine, carbonaceous matter are interbedded with sand. Carbonaceous units are conspicuously micaceous; the sand is less so. Sand is typically fine to medium grained and locally burrowed. Burrows include the small-diameter *Ophiomorpha nodosa* and some that are not clay lined. Slabs of dark-reddish-brown siderite were common at the base of the bluff at Cliffwood Beach before the outcrop was covered. Some of these slabs had many fossil molds, typically a large number of pelecypods. Lower in the section, between high and low tide level, there is a pale-gray clay-silt about 1.5 m (5 ft) thick with many small reddish-brown siderite concretions. These concretions have many fossils that were described in detail by Weller (1904). The Cliffwood beds are about 7.5 m (25 ft) thick in outcrop. Equivalents of the Cliffwood beds are exposed near the Delaware River between Trenton and Florence, Burlington County. These beds are mainly sand, as are those at Cliffwood Beach, but they tend to have more crossbedding than the typical Cliffwood strata and no burrows or marine fossils. In addition, beds of quartz gravel are present in the Cliffwood near Riverside, Burlington County.

Morgan beds - Occur only in the northern part of the central sheet. They consist of interbedded, thin, dark-colored clay and fine-grained, light-colored, micaceous sand. Clay is locally more abundant in the Morgan than in the Cliffwood beds. Sand ranges from massive to locally crossbedded and locally has fine organic matter. This unit is exposed only in the South Amboy quadrangle where it is as much as 12 m (39 ft) thick. It grades downward into underlying clay.

Amboy Stoneware Clay Member - Crops out only in the South Amboy quadrangle in the central sheet and is mainly dark-gray, white-weathering, interbedded clay and silt to fine-grained quartz sand. Clay has abundant, fine, carbonaceous matter and fine mica flakes. Small cylindrical burrows are abundant in this unit. Locally, the clay is interbedded with sand and contains large pieces of lignitized, bored (*Teredolites*) logs. Large slabs of pyrite-cemented sand are associated with the woody beds. Amber occurs in some of the wood. Unit is approximately 7.5 m (25 ft) thick, but pinches out along strike. The Amboy Stoneware is disconformable on the underlying sand.

Old Bridge Sand Member - Predominantly a light-colored sand, extensively crossbedded and locally interbedded with dark-gray laminae; clay is highly carbonaceous, woody, in discontinuous beds,

especially near the base. The scale of crossbedding varies from small to large. Locally, small burrows are present. Unit is as much as 12 m (39 ft) thick and rests disconformably on the underlying unit.

South Amboy Fire Clay Member - Basal member of the Magothy Formation. Unit resembles the Amboy Stoneware Clay Member, particularly in its lensing character. Unit is best exposed in the central sheet in the South Amboy quadrangle and in the Delaware River valley at the base of the bluffs at Florence. The South Amboy is a dark, massive to finely laminated clay, locally oxidized to white or red. Unit fills large channels and has local concentrations of large, pyrite-encrusted, lignitized logs. Some of the clay is slumped, suggesting post-depositional undercutting during channel migration. The clay is interbedded with fine- to medium-grained, crossbedded sand. The basal contact with the underlying Raritan is well exposed in the Sayre and Fisher Pit in Sayreville, Middlesex County, where the contact is marked by a deeply weathered gravel zone.

Kr Raritan Formation (Upper Cretaceous, upper Cenomanian) - Consists of an upper clayey silt (Woodbridge Clay Member) and a lower sand (Farrington Sand Member). Formation occurs only in northern part of central sheet.

Woodbridge Clay Member - Silt, clayey, dark-gray; weathers to red brown or white, locally interbedded with light-gray, clayey, fine- to very fine grained sand (primarily quartz and mica with little feldspar). Very micaceous (muscovite, chlorite, and biotite) in both silty and sandy beds. Very woody, mostly fine pieces in layers and coated with pyrite. Locally, tree stumps, in upright position, are found near base of unit as are transported individual logs several feet in length. Siderite occurs in discontinuous beds and as flattened slab concretions as much as 0.6 m (2 ft) in maximum diameter. Fossil casts of marine mollusks are present, particularly near the top of the formation. Locally, well-developed burrows of *Ophiomorpha nodosa* filled with iron oxides weather out of the clay-silt. The Woodbridge is approximately 20 m (66 ft) thick in the vicinity of Sayreville, Middlesex County, where the South River has stripped away the overlying Magothy Formation, and it crops out in many places in the Perth Amboy and New Brunswick quadrangles to the north, but not in the quadrangles to the south or southwest. The Woodbridge does not crop out in the Delaware River valley southwest of Trenton. The late Cenomanian ammonites *Metoicoceras bergquisti* and *Metengonoceras* sp. were described from the upper part of the Woodbridge (Cobban and Kennedy, 1990). Pollen from the unit belongs to the *Complexipollis-Atlantopollis* Assemblage Zone of latest Cenomanian and early Turonian age (Christopher, 1979, 1982).

Farrington Sand Member - Sand, quartz, fine- to medium-grained, crossbedded, very micaceous, white, interbedded with thin to thick, dark, silt beds. Rock fragments are a minor sand constituent. No burrows were observed in the unit. Unit is exposed only in pits dug below the overlying Woodbridge Clay Member. Typically, thickness is about 9 to 10.5 m (30-34 ft). Pollen from the Farrington is similar to the pollen in the Woodbridge.

Kp_3 Potomac Formation, unit 3 (Upper Cretaceous, lower Cenomanian) - Sand, fine- to coarse-grained, locally gravelly, crossbedded, light-colored, interbedded with white or variegated red and yellow, massive clay, and rarely dark-gray, woody clay. The Potomac Formation crops out only in the Delaware River valley where the river and its tributaries have eroded away the overlying formations. The Potomac has been mapped in a broad belt parallel to the inner edge of the Coastal Plain. Although mapped in a broad belt, the Potomac is very poorly exposed because of the widespread cover of surficial sediments. The best exposures occur where surficial material is mined away in the Camden area. Unit is about 45 m (148 ft) thick. Contact with the overlying Magothy Formation is difficult to pick where the basal Magothy also contains variegated clays. Most of the basal Magothy has more dark-colored clay, and the contact was drawn by using this criterion. The basal contact of the Potomac with the underlying crystalline rock is not exposed in New Jersey. Biostratigraphically, the Potomac has been separated into pollen zones I, II, and III (Doyle, 1969; Doyle and Robbins, 1977). Samples from the Potomac Formation in the Camden area and along the Delaware River nearby contain pollen assemblages of early Cenomanian age (Zone III) (Les Sirkin, written commun., 1988)

ROCKS OF THE NEWARK BASIN

Intrusive rocks

Jd Diabase (Jurassic) - Concordant to discordant, predominantly sheet-like intrusions of medium- to fine-grained diabase and dikes of fine-grained diabase; dark-greenish-gray to black; subophitic texture. Dense, hard, sparsely fractured rock composed mostly of plagioclase (An_{50-70}), clinopyroxene (mostly augite), and magnetite-ilmenite. Orthopyroxene (En_{75-80}) is locally abundant in the lower part of the sheets. Accessory minerals include apatite, quartz, alkali feldspar, hornblende, sphene, zircon, and rare olivine. Diabase in the map area was derived primarily from high-titanium, quartz-tholeiite magma. Sedimentary rocks within about 300 m (984 ft) above and 200 m (656 ft) below major diabase sheets are thermally metamorphosed. Red mudstone is typically altered to indurated, bluish-gray hornfels with clots or crystals of tourmaline or cordierite. Gray argillitic siltstone is typically altered to brittle, black, very fine grained hornfels. Sills are 365 to 400 m (1,197-1,312 ft) thick. Dikes range in thickness from 3 to 10 m (10-33 ft) and are many kilometers long.

Sedimentary and volcanic rocks of the Newark Supergroup

Brunswick Group

Jp Preakness Basalt (Lower Jurassic) - Basalt, coarse-crystalline, very dark greenish gray to black. Texture is subophitic; plagioclase and augite crystals are nearly equal in size; no fine-grained groundmass. Plagioclase (An_{55-60}) is subhedral, mostly 0.2 to 0.3 mm (0.008-0.012 in) long, with a few crystals up to 2 mm (0.08 in) long. Clinopyroxene and orthopyroxene grains are equant, mostly anhedral, 0.3 mm (0.012 in) average diameter. Iron-titanium oxides are mostly interstitial, 0.2 to 0.5 mm (0.008-0.02 in) in diameter. Thickness of unit is unknown in Sand Brook syncline.

Jf Feltville Formation (Lower Jurassic) - Mostly fine-grained, feldspathic sandstone, coarse siltstone, and silty mudstone, brownish-red to light-grayish-red. Fine-grained sandstone is moderately well sorted, cross laminated, and contains 15 percent or more feldspar; interbedded with mudstone, indistinctly laminated, bioturbated, and calcareous in places. A thin bed (0-2 m (0-7 ft) thick) of black, microlaminated carbonaceous limestone and gray calcareous mudstone occurs near the base and contains fish and plant fossils, and thermally mature hydrocarbons. Thickness of unit in the Sand Brook syncline is about 155 m (509 ft).

Jo Orange Mountain Basalt (Lower Jurassic) - Basalt, fine-grained to aphanitic, dark-greenish-gray, composed mostly of calcic plagioclase and augite; crystals smaller than 1 mm (0.04 in). Unit consists of three major tholeiitic lava-flow sequences, each about 80 m (262 ft) thick. Lowest flow is generally massive with widely spaced curvilinear joints; middle flow is massive or has columnar joints; lower part of uppermost flow has pillow structures and upper part has pahoehoe flow structures. Thickness in map area is about 160 m (525 ft).

JTrp, JTrpg Passaic Formation (Lower Jurassic and Upper Triassic) - Predominantly red beds consisting of argillaceous siltstone; silty mudstone; argillaceous, very fine grained sandstone; and shale; mostly reddish-brown to brownish-purple, and grayish-red. Upper Triassic gray lake deposits (Trpg) consist of gray to black silty mudstone, gray and greenish- to purplish-gray argillaceous siltstone, black shale, and medium- to dark-gray, argillaceous, fine-grained sandstone and are abundant in the lower half of the Passaic Formation. Red beds occur typically in 3- to 7-m (10- to 23-ft-)-thick, cyclic playa-lake-mudflat sequences and fining-upward fluvial sequences. Lamination is commonly indistinct due to burrowing, desiccation, and paleosol formation. Where layering is preserved, most bedforms are wavy parallel lamination and trough and climbing-ripple cross lamination. Calcite- or dolomite-filled vugs and flattened cavities, mostly 0.5 to 0.2 mm (0.02-0.08 in) across, occur mostly in the lower half. Sand-filled burrows, 2 to 5 mm (0.08-0.2 in) in diameter, are prevalent in the upper two-thirds of the unit. Desiccation cracks, intraformational breccias, and curled silt laminae are abundant in the lower half. Lake cycles, mostly 2 to 5 m (7-16 ft) thick, have a basal, greenish-gray, argillaceous siltstone; a medial, dark-gray to black, pyritic, carbonaceous, fossiliferous, and, in places, calcareous lake-bottom fissile mudstone or siltstone; and an upper thick-bedded, gray to reddish and purplish-gray argillaceous siltstone with desiccation cracks, intraformational breccias, burrows, and mineralized vugs. Gray lakebeds occur in groups of two to five

cycles although they also occur as single cycles in some parts of the formation. Several lakebed sequences consisting of one or two thick groups of drab-colored beds as much as 30 m (98 ft) thick or more can be traced over tens of kilometers. Many gray-bed sequences are locally correlated within fault blocks; some can be correlated across major faults or intrusive rock units. Thickness of the formation between Sourland Mountain and Sand Brook syncline is about 3,500 m (11,483 ft).

Trl, Trlr Lockatong Formation (Upper Triassic) - Predominantly cyclic lacustrine sequences of silty, dolomitic or analcime-bearing argillite; laminated mudstone; silty to calcareous, argillaceous very fine grained sandstone and pyritic siltstone; and minor silty limestone, mostly light- to dark-gray, greenish-gray, and black. Grayish-red, grayish-purple, and dark-brownish-red sequences (Trlr) occur in some places, especially in upper half. Two types of cycles are recognized: freshwater-lake (detrital) and alkaline-lake (chemical) cycles. Freshwater-lake cycles average 5.2 m (17 ft) thick. They consist of basal, transgressive, fluvial to lake-margin deposits that are argillaceous, very fine grained sandstone to coarse siltstone with indistinct lamination, planar or cross lamination, or are disrupted by convolute bedding, desiccation cracks, root casts, soil-ped casts, and tubes. Medial lake-bottom deposits are laminated siltstones, silty mudstones, or silty limestones that are dark gray to black with calcite laminae and grains and lenses, or streaks of pyrite; fossils are common, including fish scales and articulated fish, conchostracans, plants, spores, and pollen. Upper regressive lake margin, playa lake, and mudflat deposits are light- to dark-gray silty mudstone to argillitic siltstone or very fine grained sandstone, mostly thick bedded to massive, with desiccation cracks, intraformational breccias, faint wavy laminations, burrows, euhedral pyrite grains, and dolomite or calcite specks. Alkaline-lake cycles are similar to freshwater-lake cycles, but are thinner, averaging 3 m (10 ft), have fewer fossils (mainly conchostracans), and commonly have red beds, extensive desiccation features, and abundant analcime and dolomite specks in the upper parts of cycles. Thickness near Byram is about 1,070 m (3,510 ft). The formation thins to the southeast and northeast; thickness near Princeton is less than 700 m (2,297 ft).

Trs, Trsc Stockton Formation (Upper Triassic) - Predominantly medium- to coarse-grained, light-gray, light-grayish-brown, or yellowish- to pinkish-gray arkosic sandstone and medium- to fine-grained, violet-gray to reddish-brown arkosic sandstone; with lesser, reddish to purplish-brown, silty mudstone, argillaceous siltstone, and shale. Some coarse-grained sandstone in lower part contains thick beds of conglomerate (Trsc) which have been mapped in the vicinity of Stockton. Sandstone, deposited in high-gradient stream channels, is mostly planar bedded with scoured bases containing pebble lags and mudstone rip-up clasts. Upper part of channel beds are burrowed. Large-scale trough crossbeds occur in some very coarse grained sandstone beds; smaller scale trough and climbing-ripple cross lamination occur in the upper part of channel sequences and in finer grained sandstone beds. Typical floodplain mudstones are irregularly thin bedded and extensively burrowed. Floodplain beds are thicker and more numerous in the central Newark basin, near the Delaware River. Thickness of the unit (including Trsc) near Stockton is about 1,240 m (4,068 ft).

PIEDMONT ROCKS

Rocks of the Trenton prong

Cc Chickies Quartzite (Lower Cambrian) - Interbedded medium-grained, crossbedded, medium-bedded, vitreous quartzite, and medium- to thin-bedded, light-gray muscovite-quartz schist that locally contains tourmaline in upper part of unit. Lower part contains scattered bodies of quartz-pebble conglomerate and much less quartz-muscovite schist that contains lenses of pure quartzite. Unit unconformably overlies the Middle Proterozoic rocks. Unit shown in cross section (*A*-*A'*) only.

Zv Metavolcanic rocks (Late Proterozoic) - Sequence of conformably layered volcanic rocks of fine-grained to aphanitic, greenish-gray, retrogressively metamorphosed greenstone, greenschist, and basalt. Greenschist contains clots and lenses of blue quartz and abundant sulfide. Unit does not crop out and is known only from subsurface borings and artificial exposures. Interpreted to be Late Proterozoic by Volkert and Drake (1993) on the basis of geochemical similarity to Late Proterozoic metadiabase dikes in New Jersey Highlands.

Ygb Gabbro (Middle Proterozoic) - Medium- to coarse-crystalline, medium- to dark-gray foliated rock composed principally of plagioclase (An_{35}) and clinopyroxene. Contains minor amounts of garnet, biotite, and sulfide. The rock is more siliceous than typical gabbros.

Yg Gneiss, granofels, and migmatite (Middle Proterozoic) - Gneiss and granofels range in composition from felsic to intermediate to mafic; intermediate compositions predominate. Contains a wide variety of rock types including graphitic schist and marble. Many rocks were injected by a granitoid that has blue quartz and augen of potassic feldspar and are arteritic migmatites. One body of gneiss contains a 1 m by 0.5 m (3 by 2 ft) phacoid of gabbro that is interpreted to be an olistolith. Unit probably represents a sequence of metasedimentary and metavolcanic rocks that have been heavily injected and migmatized by felsic magma.

Ya Amphibolite (Middle Proterozoic) - Medium-grained, very dark gray to black, and foliated; consists of hornblende and andesine. Some exposures exhibit crosscutting bodies of white plagioclase pegmatite.

Obducted rocks

CZw Wissahickon Formation (Lower Cambrian and Late Proterozoic) - Fine- to medium-grained biotite-quartz-plagioclase schist and gneiss that contains thin amphibolite layers. Schist and gneiss in alternating layers suggest a turbidite sequence of shale and graywacke. The rocks are at high metamorphic grade, and, in places, the more pelitic parts have partly melted forming veins of migmatite. Some exposures show evidence of polymetamorphism as micaceous minerals occur both within the schistosity and as static porphyroblasts.