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Geologic Map of New Jersey: Southern Sheet

by

James P. Owens, Peter J. Sugarman, Norman F. Sohl,
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INTRODUCTION

The southern bedrock map (scale 1:100,000) is one of three maps that form the new New Jersey bedrock geologic map. The southern bedrock map covers an area of about 2340 sq mi in southern New Jersey. It is an area underlain by Coastal Plain sediments that range in thickness from a feathers edge to over 6000 ft beneath the Cape May peninsula in southernmost New Jersey. The tectonic features affecting southern New Jersey are shown in figure 1. The most prominent tectonic feature in the region is the South New Jersey high which appears to have controlled the Late Cretaceous and early Tertiary sedimentation in this part of the Salisbury embayment. Simply, these Upper Cretaceous and lower Tertiary sediments thicken northward off this high into the Raritan embayment. The high is ephemeral, however, because in the late Tertiary, mainly in Miocene time, the high subsided and was a basin (Sugarman and others, 1993). The mobile basin and arch architecture for the Atlantic seaboard basement was detailed in Owens and Gohn (1985).

The emerged New Jersey Coastal Plain has been extensively eroded since the deposition of the Cohansey Formation. Because of the unconsolidated nature of the Coastal Plain sediments, the Coastal Plain is easily eroded and can produce large volumes of alluvium.

The geomorphic nature of the New Jersey Coastal Plain is shown in figure 2 (Owens and others, 1977). This map depicts the systematic geomorphic evolution, or essentially the downcutting of the emerged New Jersey Coastal Plain following the deposition of the Cohansey Formation (middle Miocene, <13 Ma). The upland subprovince is an erosional remnant of the highly dissected Cohansey Formation. The Cohansey has been effectively removed from much of the southern part of the State. The topography in the upland subprovince is very hilly and has the greatest relief in the Coastal Plain. In spite of the removal of large volumes of sediment from this subprovince, the surface materials here are typically thin and are composed in large part of colluvial materials. The intermediate subprovince was formed during a major period of downcutting through the Cohansey Formation largely by a large stream which formed a moderately wide valley along the present inner edge of the Coastal Plain and a much broader valley in the southern part of the state which cuts across the Coastal Plain. In the latter region much of the upland was removed. Here, alluvium is much thicker than in the uplands subprovince; large areas have alluvium greater than 50 ft. This area is dissected by many small streams and has produced a greatly rolling topography. The lowland subprovince represents a continued period of downcutting and continued large scale removal of the Coastal Plain sediments largely along the present Delaware River drainage in the south and the Hudson River drainage in the north. The lowlands are dissected by many streams and the lower parts of the large streams (Delaware and Hudson) are estuaries (i.e., flooded). Lastly, the Atlantic Ocean has eroded into and

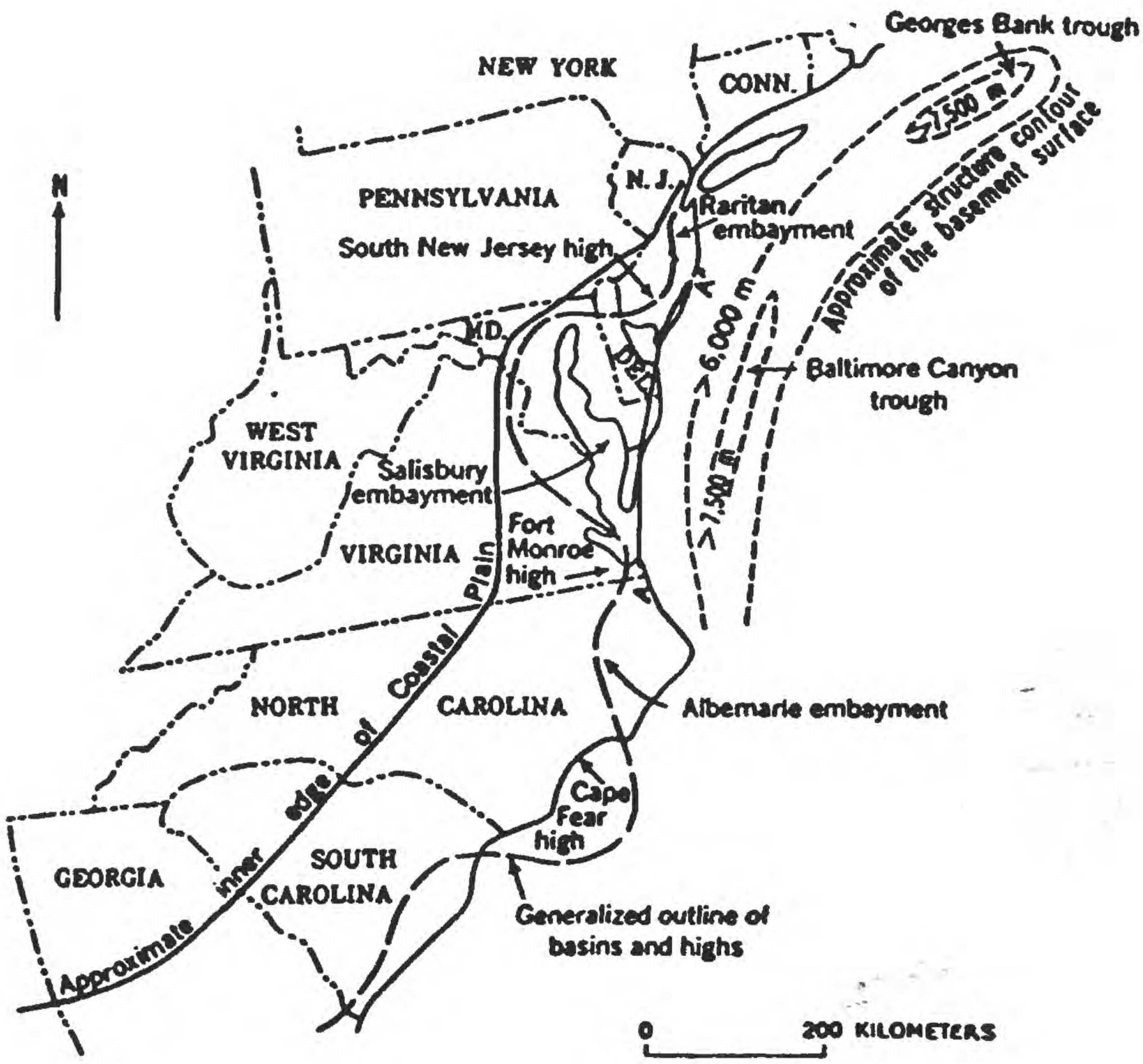

Figure 1. Map showing the major basins and highs (arches) on part of the Atlantic continental margin of North America. Of especial interest is the South New Jersey high and Raritan embayment (from Owens and others, 1968).

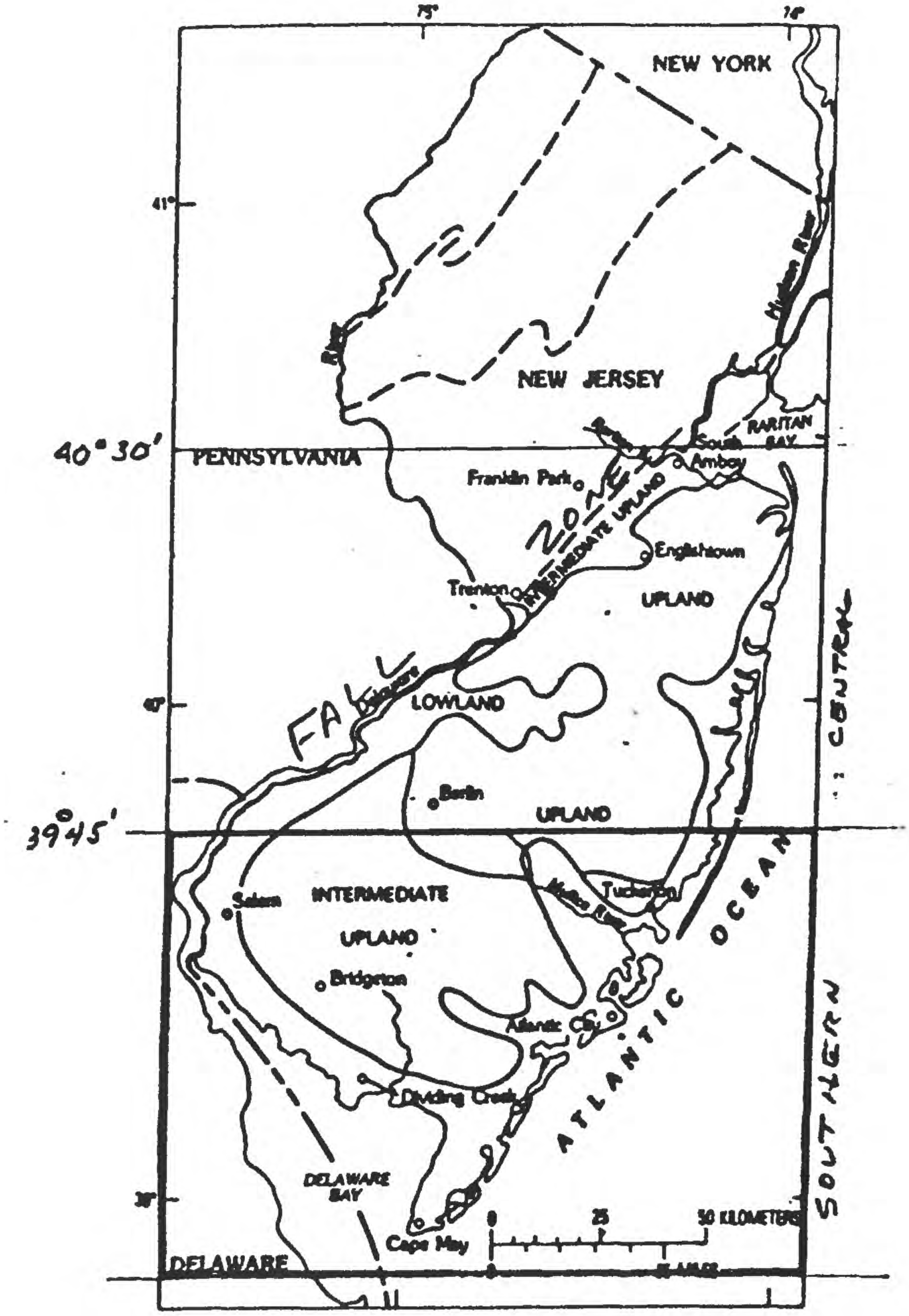

Figure 2. Generalized map of physiographic provinces and subprovinces of the New Jersey Coastal Plain (modified from Owens and others, 1977). Outlines of the central and southern sheets are also shown.

removed large parts of the eastern part of the emerged Coastal Plain. Alluvium in this subprovince varies widely in thickness but locally exceeds 120 feet in some areas.

All erosional events associated with the various subprovinces have produced a widespread blanket of alluvium of varying thickness over the Cohansey and older formations. The mapping scheme adopted in making the present State map was to produce three bedrock and three surficial maps. Within the bedrock maps of the Coastal Plain, the widespread surface alluvium has been ignored. The Coastal Plain formations shown in these heavily alluviated areas, therefore, are subcrop areas. The users of these maps are encouraged to use the bedrock and companion surficial maps in conjunction in evaluating the geology of any area within the map.

Owens and Minard (1962, 1964a, 1964b, 1964c, 1966), in the vicinity of Trenton, produced a series of maps at 1:24,000 scale in which the pre-Cohansey deposits were shown as a shaded pattern over the subcrop (bedrock) formations. The alluvium thickness was determined largely by the many auger holes used to construct each map. The auger holes were plotted on each map and the thickness of the alluvium (in feet) was plotted adjacent to the hole. The map user, therefore, knew where and how thick the alluvium was throughout each quadrangle in relation to the underlying bedrock formation although only the bedrock formation was shown on the map.

Later, using the same drill hole information, a surficial map was created which largely focused on the lithology of the surface alluvium (Owens and Minard, 1975). The user response to this two map (surface and bedrock) was favorable and should serve as a guide to using the new State map.

The map explanation is similar to that utilized with the central bedrock map. Instead of a typical short lithic description, an expanded description accompanies each unit. Outcrop thicknesses were derived to a large degree from the Woodstown 7.5 minute quadrangle (Minard, 1965).

In addition to the bedrock map, gamma-log profiles are included. One profile is essentially oriented northeast-southwest or roughly parallel to the strike of many of the formations. Two profiles are oriented northwest to southeast or are roughly dip sections for many of the units. The thickest part of the emerged New Jersey Coastal Plain is in the southern bedrock sheet in the Cape May peninsula (~6000 feet). Only one hole penetrated this thickness. The samples from this hole were cuttings and the stratigraphy in this hole is tenuous especially at depth. In fact, there are few holes to any great depth (greater than 2000 ft) in this map area. The subdivisions shown in the lower formations (mainly the Potomac Formation subdivisions) in cross-section, therefore, are very tentative. The lithostratigraphy in the post-Potomac Formation units are much more reliable. As in the central bedrock map, formation subdivisions from hole to hole throughout the subsurface was made mainly using gamma ray signatures supplemented by core samples wherever possible. Also shown in the profiles are lithologic units which do not reach the outcrop (outcrop is defined above) belt. In essence the profiles provide a three-dimensional view of the emerged Coastal Plain.

Stratigraphic changes from the previous State map (Lewis and Kümmel, 1910-1912, revised 1950) include several new and revised units. The Kmr unit from the old map has been separated into the Potomac and Magothy Formations. In addition, the Wenonah and Mount Laurel Formations have been mapped separately. New units include the Wildwood

Formation, Belleplain Formation, and an informal unit at Cape May; the Shiloh Marl is raised to formation rank and removed from the Kirkwood Formation.

ACKNOWLEDGEMENTS

Many people and organizations supplied help or data to create the southern bedrock map. As with the central bedrock, this map is produced under the COGEOMAP program, a cooperative between the United States Geological Survey and the New Jersey Geological Survey. The USGS Geologic Division, Branch of Eastern Regional Geology (J.P. Owens, Project Chief), and the Paleontology and Stratigraphy Branch (N.F. Sohl, Project Chief), provided the bulk of the geologic information. Age information for subsurface units was provided by L.M. Bybell and G.W. Andrews of the USGS. The USGS Water Resources Division in Trenton, N.J. also provided a large amount of support to the project, notably Gary Paulochok, Otto Zapesca and P.J. Leahy. This group supplied support in the drilling of some of the coreholes and provided most of the geophysical logs. An integral part of the map was to produce detailed subsurface framework. Most of the drilling was done by the personnel from the Branch of Eastern Regional Geology, primarily Donald Queen and Eugene Cobbs.

The texts for the various plates were reviewed thoroughly and intensively by Gregory Gohn of the USGS and Richard Dalton of the New Jersey Geological Survey. These outstanding reviewers improved the style and to a degree the substance of these texts.

DESCRIPTION OF MAP UNITS (Plate 1)

Tcm

Unnamed unit at Cape May (upper Pliocene)--Consists of interbedded sands, clays, and gravelly sands; massive to thick bedded. Best known and named for the sediments in a corehole at the Cape May airport. Here, the lower 60 ft of the unit consists of interbedded gravelly, very coarse-grained sands, medium- to very coarse-grained, poorly-sorted sands, and thin to thick beds of medium- to dark-gray, very woody clays. Gravel clasts in these beds are typically less than 0.25 inches in diameter. The upper 40 ft of the unit consists of a thick, medium-gray clay-silt, which is extensively bioturbated, and is overlain by an extensively burrowed, loose, fine- to medium-grained glauconitic (about 5 percent) quartz sand. No calcareous macrofossils were found in the burrowed intervals. Unit is only known to occur on the Cape May peninsula where it lies within a large channel. There, the formation is about 100 ft in maximum thickness. The basal contact with the underlying Belleplain Formation is sharp and unconformable. A gravelly sand bed as much as 3 ft thick is present along the boundary.

The composition of the sand-sized fraction is similar throughout. Quartz and siliceous rock fragments are the principal minerals. Feldspar is present in most samples but usually constitutes less than 10 percent of the sand fraction. The heavy-mineral assemblages differ between the lower gravelly facies and the upper glauconitic facies. Heavy-mineral suites in the lower gravelly facies contain labile species including significant concentrations of hornblende and garnet. The upper glauconitic facies has little hornblende and garnet but high concentrations of zircon, tourmaline, and rutile. The clay minerals in this unit are illite/smectite, illite, and kaolinite in roughly equal proportions.

The only datable material in this unit is pollen. 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 the exotic Engelhardtia. The non-arborial pollen are a Multisia-type composite of the present Andean provenance and therefore are a probable exotic cool-climate, indicator. Overall, 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 composite. Traces of cedar, willow, birch, alder, grass, umbellifer, and Sphagnum spores are also present. This assemblage probably represents a temperate climatic regimen (L. Sirkin, written commun. 1991). The low percentages of exotic species in this unit are characteristic of the late Pliocene of this region (Beaverdam Formation of the Delmarva Peninsula), an age which we assign to the Cape May unit. Some have considered this formation to be the Cohansey Formation (Gill, 1962). As discussed in the following formation description, this cannot be the case.

Tch

Cohansey Formation (middle Miocene, Serravallian)--Sand, locally clayey, less commonly gravelly. Unweathered sand beds are typically white or pale yellow. The sands weather to various shades of red or orange which locally produce exotic weathering patterns (Leisegang banding). Less commonly, the sand beds are cemented by iron oxides. The unweathered clay beds are typically dark gray, but commonly weather to white with thin beds of ironstone. Lithologically one of the most variable units in the map area, the Cohansey Formation is a complex of interfingering marine and non-marine facies. The Cohansey is the major near-surface bedrock unit in the map area. As such, it is extensively eroded and is capped widely by younger alluvial, colluvial, and, in some areas, aeolian deposits. Because of the widespread capping deposits and its loose sandy nature, natural exposures of this unit are rare. However, because of its sandy nature, the formation is widely mined and locally well exposed in many places. The Cohansey unconformably overlies several formations. The contact is sharp, undulatory, and directly overlain by a thin gravel bed. There is as much as 60 ft of relief along this boundary. The thickness of the Cohansey is difficult to determine because of the irregular basal contact and extensive post-depositional erosion. The Cohansey was markedly thinned during emplacement of the Miocene units in the western and southern part of the map (Owens and Minard, 1975). It is estimated that the Cohansey is as much as 150 ft in the northeastern corner of the map area. The sandy beds in the Cohansey are commonly cross-bedded; trough cross beds are typical, but planar cross strata are also abundant. The size of the cosets varies from a few inches to a few feet. Marine sands occur in the updip area as far north as Salem, N.J. and the middle areas of the outcrop belt contain small to large clay-lined Ophiomorpha nodosa and other less common burrows. Iron-oxide replaced shell-"hash" concentrations were observed at a few localities in the updip areas (Newell and others, 1988). Most of the sands in the Cohansey are medium grained and moderately sorted although coarse and fine sandy beds are also common. Beds with gravel as a major component are locally common, especially in the mixed marine-non-marine facies in the northeastern corner of the map area. There, the gravel occurs in well-defined channels. Most of the gravel is one inch or less in diameter although pieces up to five inches in diameter have been observed. The gravels are mostly quartz or quartzite with lesser amounts of white or black chert. Very thin to very thick clay beds are common in the Cohansey. The clay beds are for the most part massive, but thin laminated clay strata are also present. The thicker clay beds occur in lenses that commonly contain small to very large pieces of lignitized wood. An extensive well-preserved leaf flora was collected from a very thick clay lens in the Cohansey in a pit near Millville. The leaf flora was dominated by Alangium sp., a tree no longer growing in eastern North America (J. Wolfe, written commun., 1992).

The mineralogy of the sands in the Cohansey is in part dependent on the depth of weathering. Where deeply weathered, the sands are very mature, consisting of quartz and siliceous rock fragments. Such sands have been extensively mined as glass sands. Where less weathered, as in the deeper subsurface, the feldspar content typically increases to concentrations between 5 and 10 percent of the sand fraction. The major opaque heavy minerals are ilmenite and its weathering products pseudorutile and leucoxene. The proportions of these minerals is dependent on the local intensity of the post-depositional weathering. The non-opaque heavy minerals are primarily resistant types (zircon, tourmaline, and rutile) and somewhat less resistant types (staurolite, sillimanite, and kyanite). Garnet is a common mineral in the least weathered beds. The clay minerals in the Cohansey are dominated by kaolinite and illite.

Heretofore, the age of the Cohansey was determined from its stratigraphic position or its perceived contact relations with the underlying Kirkwood Formation (conformable or unconformable) and its macro- and microflora. The palynology of upper Tertiary formations in the northeastern U.S. is only generally understood. Commonly, the Pliocene beds have less exotic species than the Oligocene or Miocene beds. If this is the case, then the Cohansey, which has a large number of exotic species, have more Miocene affinities than Pliocene, an age some have assigned to this formation. Ager (in Owens and others, 1988) discussed the microflora in the Cohansey near Mays Landing. He noted that the Cohansey had a large number of exotic species similar to those in the underlying Wildwood Formation and hence thought the Cohansey to be Miocene. The age of the Cohansey is discussed in more detail in the subsurface description.

Tbp

Belleplain Formation (middle Miocene, Serravallian)--The Belleplain Formation is a new formation named for beds occurring in a corehole drilled by the USGS at Belleplain State Headquarters in 1991. The details of this formation are discussed more fully in the subsurface section.

Clay to silty clay at the base and sand at the top. Clay, gray brown, massive to laminated, locally has abundant diatoms and scattered small shell fragments. Sand, fine to medium grained, pale gray to white, somewhat micaceous and woody, with scattered shell fragments. The Belleplain subcrops only where the overlying Cohansey Formation has been eroded away. Along the Atlantic Ocean, the formation is exposed between Brigantine and Beach Haven Terrace. In both regions, the formation is overlain by thin to thick deposits of young alluvium. The formation ranges up to 50 feet in thickness in both areas. The basal contact with the underlying unit is sharp and unconformable. A thin bed of reworked coarse-grained quartz sand occurs at the boundary.

Quartz is the major sand mineral with small amounts of feldspar and mica. Pyrite is common in the clayey strata. The opaque heavy minerals include ilmenite, leucoxene, and pseudorutile. The non-opaque minerals include a large number of species including zircon, tourmaline, rutile, hornblende, epidote, garnet, staurolite, sillimanite, kyanite, and chloritoid. The clay minerals include illite/smectite, illite, and kaolinite.

A middle Miocene age for the Belleplain was determined from its diatoms. The specifics of the diatom biostratigraphy are discussed in the subsurface section of the map (Plate 2). Shells from this unit at Heislerville had a Sr-isotope age estimate of 13.2 Ma (Sugarman anhd others, 1993).

Tw

Wildwood Formation (middle and lower Miocene, Langhian and Burdigalian)--The Wildwood Formation is a new formation named for beds in a borehole at Wildwood Beach, N.J. The formation is clay, silty, dark gray, massive to finely bedded, locally interbedded with thin beds of light-colored sand. Fossils typically are small shell fragments that primarily occur at the base of the unit. The upper beds are more sandy but also contain many thin to thick clays. The sands mostly are fine to medium grained, light gray, and commonly have dispersed woody fragments. Shell fragments also are locally present in this facies. In general, the arrangement of facies in this unit is similar to that in the Belleplain Formation. The Wildwood subcrops where the Belleplain and Cohansey Formations have been stripped away. Along Delaware Bay, the Wildwood subcrops from the Cohansey River to Fortescue. Along the Atlantic Coast, the unit subcrops from the northern boundary of the map to near Beach Haven Terrace. The maximum thickness in the subcrop area is about 60 feet. The contact with the underlying Shiloh Marl is sharp and unconformable.

Quartz is the major sand mineral with smaller amounts of siliceous rock fragments and feldspar. The opaque heavy minerals are the most abundant; these include ilmenite, leucoxene, and pseudorutile. The non-opaque fraction is dominated by zircon, sillimanite, staurolite, tourmaline, rutile, and kyanite. Much smaller amounts of hornblende, epidote, and garnet are also present. The clay minerals include illite/smectite, illite, and kaolinite.

The age of the Wildwood was determined from its diatoms, which are assigned to East Coast Zone #2 of Andrews (1988). This zone is latest Burdigalian and Langhian in age (late early and early middle Miocene).

Tsh

Shiloh Marl (lower Miocene, lower Burdigalian)--This unit is raised to formation rank. Originally these beds were described by Knapp (1904) as one of the few fossiliferous outcrops of the Kirkwood Formation. Actually this formation lies unconformably on the underlying Kirkwood Formation.

The Shiloh Marl is largely a massive, dark-gray clay with abundant large mollusks. The formation largely subcrops near the Delaware River where the overlying Wildwood and Cohansey Formations have been stripped away. The Shiloh Marl is approximately 50 ft thick in subcrop.

Diatoms recovered from the Shiloh Marl in outcrop contain the diagnostic diatom Actinoptychus heliopelta (Andrews, 1987). The presence of this diatom indicates the formation is early Miocene in age. Strontium isotopic analysis of shells from the Stow Creek outcrops yielded an age of 20.0 Ma, Burdigalian in age (Sugarman and others, 1993).

Tkw

Kirkwood Formation (lower Miocene, Aquitanian)--Sand, fine to medium grained, locally very micaceous, massive to thick bedded, rarely cross stratified at the top. White to pale gray where unweathered, mostly weathered to dark yellow, orange brown, or red. Also contains a massive or finely laminated dark-gray to dark-brownish gray clay or clay-silt (Alloway clay of Kümmel and Knapp, 1904) at base. No calcareous fossils were found in outcrop. The Kirkwood Formation crops out in a broad belt in the northwestern part of the map area where it ranges in thickness from 50 to 90 ft. The belt broadens greatly in the southwesternmost area where the Cohansey Formation and much of the upper quartz sand has been stripped away by successive entrenchments of the Delaware River. It is here that the basal clay is best exposed. The Kirkwood overlies several formations unconformably. Along the boundary, a reworked zone 2 to 4 ft thick consists of pebbly, coarse, very glauconitic quartz sand. Most of the Kirkwood is covered by younger alluvium except in the uplands near Pitman. There, the sand facies of the formation is exposed in small road cuts, or less commonly in dug sand pits. Near Woodstown the clay facies is locally exposed, especially along the larger streams. Most exposures are small but numerous. Because of the need to line landfill sites with clay, this facies is locally dug, and a few pits have provided large exposures.

The sand minerals are mostly quartz with smaller amounts of muscovite and siliceous rock fragments. Small amounts of feldspar are present in the least weathered beds of the formation. The opaque minerals are most abundant in the heavy mineral fraction. These include ilmenite, pseudorutile, and leucoxene. The non-opaque heavies include zircon, tourmaline, rutile, staurolite, sillimanite, kyanite, and andalusite. Overall, the non-opaque species are a mature suite of heavy minerals. The clay minerals in the Alloway clay of Kümmel and Knapp (1904) are kaolinite, illite and illilte/smectite.

The age of the Kirkwood could not be determined in outcrop, but it is known to be early Miocene in the subsurface.

Tvt

Vincentown Formation (Upper Paleocene, Selandian)--Sand, slightly clayey, dusky yellow to pale gray where unweathered, orange brown or red brown where weathered. Typically a medium-grained, well- to poorly-sorted quartz sand with small amounts of glauconite in the middle and upper parts of the formation. Local concentrations of small, disarticulated fossils, the "bryozoan" facies, are present in the map area. The basal 5 feet of the formation is a massive, red-brown to dark-greenish-gray, clayey, medium- to fine-grained quartz-glauconite sand. Locally, coarse shell concentrations as much as 2 ft in thickness, the "bioherm" facies, occur along the boundary with the underlying formation. The "bioherms" typically contain either the branchiopod Oleneothyris harlani or the pelecypods Pycnodonte dissimilaris and Idonearca vulgaris. The contact with the underlying Hornerstown Formation is sharp and easy to pick where a bioherm is present. Where the bioherms are absent, the contact is more difficult to establish because the basal glauconite beds of the Vincentown Formation overlie the very glauconitic Hornerstown. In general, the Vincentown glauconite beds are darker gray than the Hornerstown, and the Vincentown has considerably more quartz sand. The Vincentown crops out as a discontinuous belt in the northwestern part of the uplands (fig. 2). There, the formation is only exposed along the headwaters of streams that have eroded back into the upland. To the southwest, where the Delaware River has eroded the highlands away, the Vincentown belt widens but is covered by younger alluvium. The Vincentown ranges from 10 to 50 ft thick in its subcrop belt.

Quartz is the major sand mineral in this unit. Glauconite is abundant at the base but decreases in abundance upward through the section. Feldspar and mica are minor sand constituents. In the opaque heavy mineral fraction, ilmenite is the main species with smaller amounts of leucoxene and pseudorutile. In the heavy non-opaque fraction, hornblende, epidote, garnet, staurolite, kyanite, and tourmaline are the main minerals. Smaller amounts of zircon, rutile, sillimanite, chloritoid, and andalusite are also present. No clays were analyzed from the outcropping Vincentown.

The age of the Vincentown was primarily derived from planktonic formainifera and calcareous nannofossils. The formainifera assemblages fall within zone P4 and possibly zone P5 (Berggren and others, 1985). The nannozones found in this unit are upper NP5 through NP9. The Vincentown therefore is late Paleocene (Selandian) in age.

Tht

Hornerstown Formation (lower Paleocene, Danian)--Sand, glauconite, slightly clayey, massive, grayish green to dusky green where unweathered, dusky yellow or red brown where weathered. Unfossiliferous in outcrop. Contact with underlying unit is sharp. Locally a reworked bed of phosphatic vertebrate and invertebrate fossils, the so-called "bone bed", occurs along this boundary. More commonly, the contact is characterized by an intensely bioturbated zone in which numerous burrows filled with bright-green glauconite sand from the Hornerstown Formation project downward into the dark-gray matrix of the underlying Navesink Formation. In a few outcrops, a thin layer of medium- to coarse-grained quartz sand separate the Hornerstown from the underlying unit. The outcrop pattern of the Hornerstown resembles that of the overlying Vincentown, that is a discontinuous belt in the uplands in the northern part of the map area and a more continuous belt in the south where the highlands have been eroded back by the Delaware River. The Hornerstown is a thin, highly dissected unit with a range in thickness from 5 to 20 ft; most exposed sections are less than 10 ft thick.

The sand fraction of the Hornerstown is almost 100 percent glauconite. Stray quartz, mica, and phosphatic parts are also present. Heavy minerals are rare in this unit. The clay minerals in the Hornerstown are variable. The minerals in the clay-sized fraction are most commonly glauconite. Less commonly, the clays are mixtures of illite and illite/smectite.

The age of the Hornerstown could not be determined in outcrop but is known to be of early Paleocene (Danian) age in the shallow subsurface.

Kns

Navesink Formation (Upper Cretaceous, upper and middle Maastrichtian)--Sand, glauconite, clayey, medium grained, dark gray to dark gray green where unweathered, light brown or red brown where weathered. Most outcrops are weathered except along the tributaries of Raccoon Creek near Mullica Hill where fresh beds are exposed. Unit is massive or extensively bioturbated, and rarely fossiliferous, in the map area. Locally a basal bed of pebbly, coarse, glauconite-quartz sand occurs along the boundary with the underlying unit. Where the quartz sand is absent, the contact with the underlying Mount Laurel Formation is sharp (glauconite sand over a quartz sand). The Navesink Formation crops out in a thin belt across the map area. It is sporadically exposed in the northeastern part of the belt, but is more continuously exposed in the southwestern end. The Navesink ranges from 10 to 25 ft thick in the map area.

Glauconite constitutes nearly the entire sand fraction. Small amounts of quartz sand and mica are present except in the basal reworked zone. The clay minerals include illite/smectite, illite, and kaolinite.

The age of the Navesink in outcrop was determined from its macrofauna. Exogyra costata collected from the unit near Mullica Hill indicates a middle to late Maastrichtian age (Late Cretaceous).

Kml

Mount Laurel Formation (Upper Cretaceous, upper Campanian)--Sand, glauconite quartz, massive to crudely bedded, typically coarsens upward. Lower part of formation is a dark-gray, clayey, fine- to medium-grained, glauconitic (maximum 25 percent) quartz sand. Fossils are scattered throughout this interval. The glauconite and clay content decreases and the average grain size increases upward in the formation. Granules and very fine gravel are common constituents in the upper 5 ft. The upper beds are light gray where unweathered and light brown to reddish brown where weathered. Ledges, tubes, and concretions of iron-oxide-cemented sand are common in the most deeply weathered sections. The Mount Laurel Formation underlies a broad belt in the map area. Most of the formation is capped by alluvium except along the larger streams which have eroded into the upland in the northern part of the map area. The formation ranges from 50 to 110 ft thick. The basal contact with the Wenonah Formation in the northeast and the Marshalltown Formation in the southwest is gradational over several feet.

Quartz, glauconite, and siliceous rock fragments are the principal sand minerals; feldspar, muscovite and chlorite are minor constituents. The opaque heavy minerals are mostly ilmenite with much smaller amounts of pseudorutile and leucoxene. The non-opaque assemblage has a large number of species including zircon, tourmaline, rutile, hornblende, epidote, garnet, staurolite, sillimanite, kyanite, and chloritoid. The clay minerals are kaolinite, illite, and illite/smectite.

Exogyra cancellata was collected from this unit near Mullica Hill which indicates a late Campanian (Late Cretaceous) age for this unit.

Kw

Wenonah Formation (Upper Cretaceous, upper Campanian)--Sand, quartz, somewhat glauconitic, very micaceous, with abundant small pieces of lignitized wood, dark gray to medium dark gray where fresh, light brown to light greenish gray where weathered, massive, bioturbated, unfossilifeous. The formation underlies a narrow belt in the northern part of the map area and pinches out just west of Oldmans Creek where it merges with the Mount Laurel Formation. The Wenonah Formation grades into the underlying Marshalltown Formation with an increase in glauconite sand and into the overlying Mount Laurel with an increase in average grain size and decrease in mica content. The Wenonah is a maximum of 25 ft thick.

The sand minerals in this unit are mostly quartz with much smaller amounts of glauconite, mica and feldspar. The opaque and non-opaque heavy minerals are similar to those found in the Mount Laurel Formation.

The age of the Wenonah is nearly that of the Mount Laurel, late Campanian (Late Cretaceous).

Kmt

Marshalltown Formation (Upper Cretaceous, upper Campanian)--Sand, glauconite, with varying amounts of quartz, somewhat micaceous, fine to medium grained, clayey, bioturbated. Macrofossil assemblages are abundant locally, characterized by Exogyra ponderosa and Ostrea falcata. The Marshalltown Formation underlies a narrow belt in the uplands in the north, but the belt broadens to the southwest. Exposures of the Marshalltown are common along Oldsmans Creek and its tributaries near Auburn. The Marshalltown is a thin unit ranging between 10 and 20 ft thick. The contact with the underlying Englishtown Formation is sharp and unconformable. Along the contact, the Englishtown is extensively bioturbated with burrows filled with glauconite sand from the overlying Marshalltown.

Glauconite and quartz are the major sand minerals; glauconite is very abundant in the lower few feet but decreases upward to a nearly equal mixture of glauconite and quartz in the upper part of the unit. Feldspar, mica, pyrite, and phosphatic fragments are minor sand constituents. The heavy minerals and clay minerals are similar to those in the overlying Wenonah Formation.

Although planktic foraminifera are common, none of those present are age specific. The Marshalltown has been assigned to Zone CC 20-21 (Sugarman and others, 1995) of middle and late Campanian age (Perch-Nielson, 1985)+.

Ket

Englishtown Formation (Upper Cretaceous, lower Campanian)--Sand, fine to very fine grained, very clayey, medium to dark gray where unweathered, light brown, yellow or reddish brown where weathered, massive, bioturbated. The Englishtown Formation underlies a broad belt across the map area. Exposures are few except along Oldmans Creek in the north; elsewhere the Englishtown is capped by younger alluvium. The Englishtown is gradational into the underlying Merchantville Formation. The Englishtown is 40 to 50 ft thick in the map area.

The sand fraction of the Englishtown is mainly quartz with smaller amounts of feldspar, glauconite, and muscovite. The heavy-mineral assemblages are mainly the opaque minerals ilmenite, pseudorutile, and leucoxene. The non-opaque fraction is dominated by the metamorphic minerals staurolite, sillimanite, garnet, epidote, kyanite, and chloritoid. Zircon, tourmaline, and rutile are less common. Clay minerals include illite/smectite, illite, and kaolinite.

Fossil casts are present in the outcropping beds of the Englishtown, but these were not studied. An early Campanian age for the Englishtown was inferred from the age of the underlying Merchantville Formation, into which it grades.

Kmv

Merchantville Formation (Upper Cretaceous, lower Campanian)--Sand, quartz glauconite, locally very micaceous (muscovite, chlorite and less commonly, biotite) with scattered carbonized wood fragments, very silty and clayey. Massive to thick bedded, unfossiliferous. Grayish olive green to dark greenish gray where unweathered; moderate brown or moderate yellow brown where weathered. Sand is primarily glauconite at the base and quartz at the top. Underlies a broad belt in the map area. Very poorly exposed because the outcrop belt is covered by younger alluvium. The Merchantville Formation is 40 to 50 ft thick along this belt. The contact with the underlying Magothy Formation is sharp and unconformable. Typically, there is a thin zone of reworked quartz sand along the boundary.

Quartz and glauconite are the major sand minerals with much smaller amounts of mica, feldspar, and pyrite. The opaque detrital heavy mineral fraction is mostly ilminite with smaller amounts of pseudorutile and leucoxene. The non-opaque minerals include epidote, garnet, staurolite, zircon, chloritoid, tourmaline, rutile, and kyanite. The clay minerals include illite/smectite, illite and kaolinite.

No fossils were found in the outcrop belt, but fossils recovered from the shallow subsurface indicate an early Campanian (Late Cretaceous) age.

Kmg Magothy Formation (Upper Cretaceous, Santonian)--Sand, quartz, fine to coarse grained, locally gravelly (especially at the base), interbedded with thin clay or clay-silt beds mainly at the top of the formation. Sands typically white where unweathered to yellow brown or orange brown where weathered. The clays are dark gray where unweathered; the dark color is the result of finely comminuted organic matter. Larger woody fragments are a common constituent in many of the clay layers. Clays weather to gray brown or white. The formation underlies a broad belt, but because of the overlying alluvium, there are no natural exposures. The Magothy Formation is 50 to 60 ft thick in the subcrop belt.

Almost all the sand in the Magothy is quartz or siliceous rock fragments. Small amounts of muscovite and even smaller amounts of feldspar are also present. Pyrite, either as small finely dispersed grains or as larger cemented masses, is common in the unweathered beds. The heavy mineral suite consists of the opaque mineral ilmenite with much smaller amounts of pseudorutile and leucoxene. The non-opaque heavy minerals include zircon, tourmaline, and rutile with much smaller amounts of staurolite. The clay minerals are kaolinite and illlite with very small amounts of illite/smectite.

No marine fauna or flora was found in the Magothy. The age of the formation was determined from its pollen which is assigned to zone V of Wolfe and Pakiser (1971). This pollen zone is Santonian (Late Cretaceous) in age.

KpIII Potomac Formation, unit III (Upper Cretaceous, lower Cenomanian)--Sand, fine to very coarse grained, locally gravelly, complexly interbedded with thin to thick clay beds. Sands vary in color from yellow to red brown. Iron-oxide cementation is common in these beds. Clays typically are mottled red, white, and orange brown. Rarely, thin unweathered black clay beds are present. The Potomac Formation underlies a small area in the northwestern corner of the map, however, there are no known outcrops of the unit in this map area. The formation is about 150 ft thick. The Potomac is the basal Coastal Plain unit in the area. Its contact with the underlying crystalline basement is very irregular with as much as 100 ft of relief.

Quartz and siliceous rock fragments are the only sand minerals in this unit. Heavy minerals are sparse. The clay minerals are kaolinite and illite.

The age of this unit was determined from its pollen assemblage which is assigned to Zone III of Doyle and Robbins (1977). This zone is early Cenomanian (Late Cretaceous) in age.

Geologic Map of New Jersey: Southern Sheet

Explanation for Subsurface Framework (Plate 2)

INTRODUCTION

A subsurface lithostratigraphic framework was constructed for the Coastal Plain deposits of the southern bedrock map using gamma logs as the main correlation tool (Plate 2). The log correlations were augmented by lithologic and fossil data from samples in several cored or partially cored holes. Biostratigraphic analyses of several faunal and floral groups were conducted to aid in dating many of the units in the subsurface and in correlations to help erect the lithostratigraphic framework for this map area.

Gamma-log profiles were constructed roughly parallel to the strike of outcropping formations and following their dip. It has long been known that the strikes of these various formations differ, and by analogy, so do the dips. Therefore, the sections are neither true strike nor dip sections.

An additional problem, and in one sense a plus, is that large volumes of inner Coastal Plain sediments have been stripped during periods of erosion. In some cases, updip and downdip facies relations within a single unit are exposed as a result, and in other cases some units that are found mostly in the subsurface have been exhumed (such as the Manasquan and Shark River Formations).

GAMMA-LOG PROFILES

Many of the units shown on the gamma-log profiles are of marine origin. These units are distinctly unconformity bounded. Their basal unconformities are commonly marked by a distinct gamma-ray spike that represents a basal phosphatic or glauconitic lag deposit. Some of these subsurface units represent a complete transgressive-regressive cycle of sedimentation. As defined in outcrop (Owens and Sohl, 1969), these cycles are asymmetric in nature and are characterized by a glauconite sand at the base (transgressive bed), a clay-silt or clayey fine sand in the middle (also regressive) and a well sorted quartz sand at the top (regressive). Each cycle repeats the same pattern so that the typical marine cycle is unconformable at both its base and top.

In those formations consisting of marginal-marine or non-marine sediments, gamma correlations are of less value for correlation. In such units, core recovery is a necessity. In actual practice, this situation occurs at the bottom of the Coastal Plain section (Potomac, Raritan and Magothy Formations) and at the top (parts of the redefined Kirkwood and Cohansey Formations).

Correlations from the outcrop into the subsurface are commonly accompanied by facies changes, which vary from formation to formation. In some instances, the changes in lithology are abrupt where sand and silt facies change to a glauconite facies within a few miles.

In general, the gamma-log patterns vary from formation to formation and within formations locally from site to site. With some formations, the change in gamma response is abrupt from non-clayey facies to more sandy facies and in others the transition from clay to sand is gradual. Predictably, lateral facies changes within formations also produce lateral changes in gamma-log response.

Figure 3 shows the gamma ray signatures found most commonly with the different Coastal Plain units in the subsurface of New Jersey. A particularly fine gamma log from near Toms River, N.J. (well 290045) (log I) shows many of the geophysical signatures found through much of the subsurface New Jersey Coastal Plain. A second log (log III) from Barnegat Middle School shows the upper beds (upper Tertiary) in the region which were not sampled at the Toms River locality. A third log (log II) from the Freehold, New Jersey corehole is shown to illustrate features not shown in the above logs. Each of the characteristic gamma signatures are given a type letter which will then be cited with each of the formation descriptions.

1) Type A gamma signature associated with fluvial deposits (log I and II)

The Potomac Formation is an example of a very thick pile of fluvially dominated sediments deposited in part in upper to middle delta plain. These deposits consist of abruptly lensing sands or gravelly sands and clays. Figure 3 (logs I and II) shows typical logs found in this unit. This pattern consists of close to widely spaced gamma spikes deflected to the left representing thin to thick sand bodies interspersed with thin to thick spikes deflected to the right which are the clayey sediments. No consistent patterns were found between holes, which is a reflection of the abrupt facies changes within this type of environment.

2) Type B gamma signature associated with continental shelf deposits

In contrast to the fluvial deposits, facies changes within the continental shelf marine deposits are gradual. Most commonly the gamma patterns in this type unit are a thick clayey unit in the base (pattern deflected to the right) and a gradual increase in sand upward through the section producing a gradual deflection to the left. Basically this represents a cycle of sedimentation or a sequence; e.g. a transgression followed by a regression. In the New Jersey marine cycles the transgressive beds are typically middle to outer shelf deposits. The middle shelf deposits are dark-gray, carbonaceous silts or clays and the middle to outer shelf deposits are dark-colored glauconite-rich clayey sands. Both lithologies have similar geophysical signatures and thus cannot be separated using this method. Correlations, therefore, with the outcropping glauconite sands or the carbonaceous silts were not feasible and the lithologies were lumped into a single unit. The upper sands most commonly are inner shelf deposits but not the innermost. The innermost marine deposits such as barrier and back barrier deposits found elsewhere in the Coastal Plain are absent in most of the New Jersey cyclic deposits, most notably those of Late Cretaceous age. These very nearest shore deposits are assumed to have been removed by post-depositional erosion. The near shore sands are gradational with the underlying carbonaceous silts. For this reason the subsurface cycles are mapped as a single unit (table 1). Subsurface cycles are given a numerical designation, shown in table 1. Correlating the individual cycles in the subsurface was relatively easy and formed a major technique used to construct the cross sections.

3) Type C gamma signature associated with superposed deep water sequences

Some of the lower and middle Paleogene formations are the deepest water marine deposits preserved in the Coastal Plain. These include all or parts of the Vincentown,

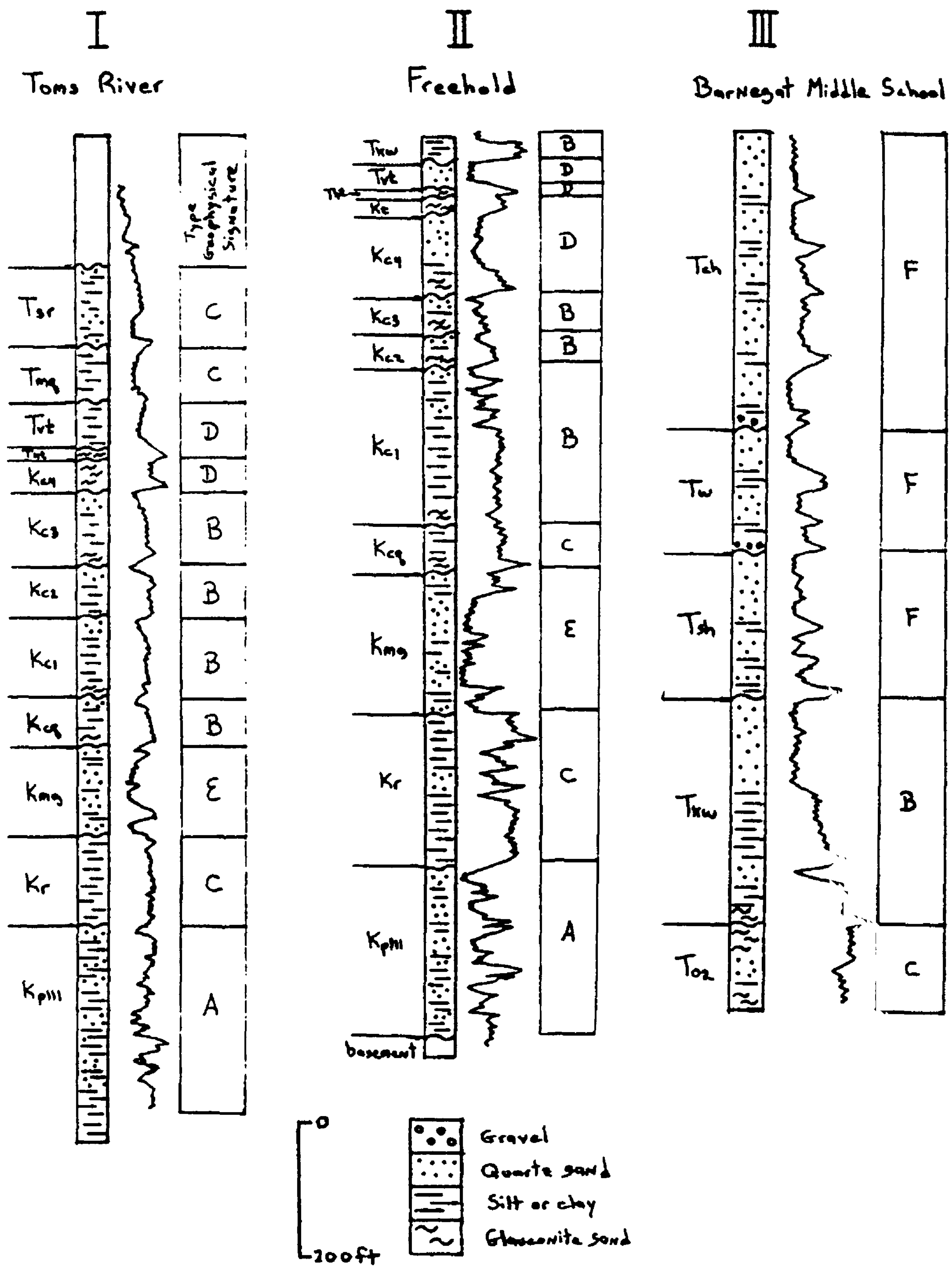

Figure 3. Diagram showing the relationship between lithology and associated geophysical signature in three partially or fully cored drill holes. Geophysical logs are a major correlation tool in the subsurface of the Coastal Plain and a wide variety of gamma logs are found. The geophysical signature or signatures have been assigned a letter designation that is discussed as most typical for each formation in the unit descriptions. Unit symbols are the same as map symbols.

Table 1. Surface to subsurface correlations, southern bedrock sheet.

Surface	Subsurface
Unnamed unit of Cape May	
Cohansey Formation	Cohansey Formation
Belleplain Formation*	Belleplain Formation*
Wildwood Formation*	Wildwood Formation*
Shiloh Marl**	Shiloh Marl**
Kirkwood Formation**	Kirkwood Formation**
[absent]	To_2 cycle
[absent]	To_1 cycle
[absent]	Te cycle
[absent]	Shark River Formation
[absent]	Manasquan Formation
Vincentown Formation	Vincentown Formation
Hornerstown Formation	Hornerstown Formation
Navesink Formation	Kc_4 cycle
Mount Laurel Formation	
Wenonah Formation	Kc_3 cycle
Marshalltown Formation	
[absent]	Kc_2 cycle
Englishtown Formation	Kc_1 cycle
Merchantville Formation	
[absent]	Cheesequake Formation*
Magothy Formation	Magothy Formation
[absent]	Raritan Formation
Potomac Formation, unit III	Potomac Formation, unit III
[absent]	Potomac Formation, unit II
[absent]	Potomac Formation, unit I

* New Name

** Revised name

Manasquan and Shark River Formations. These units are typically very fine grained with varying amounts of fine-grained clasts and fine- to medium-grained glauconite sand. Gamma logs in these units typically have a flat field throughout as commonly found with clayey units. What is interesting in the Tertiary as compared with the Cretaceous units is the presence of a pronounced gamma spike commonly found at the base of the lower Tertiary units. This phenomenon often is used to separate units of similar lithology in the subsurface.

4) Type D gamma signature associated with marine deposits which undergo abrupt facies changes downdip (figure 3)

Facies changes are common in nearly all the Coastal Plain formations. As described above, abrupt facies changes are commonplace in the non-marine environment. Conversely facies changes in the Cretaceous shelf deposits are typically gradual. In some of the marine units, however, notably with the Vincentown Formation and the Red Bank and Navesink Formations in the central sheet, the updip to downdip facies changes are rapid. Figure 4 shows three logs within the Red Bank and Navesink cycle from the central sheet arranged in an updip-downdip direction. The distance between the holes is about 11 miles. Basically the change of facies in this case is from the full cycle described in the continental shelf type in the updip to only a glauconite sand or thick clay (the lithology of the basal facies in a fully developed cycle). One interpretation of the change within this cycle is that the upper most clastic facies were stripped post-depositionally whereas another interpretation could be non-deposition of the coarser clastic facies. Fossil data support the latter interpretation as the downdip glauconite sand is frequently the age equivalent of the entire cycle. Therefore the lithic association shown in the three logs is the result of a change in facies from the shallower water middle and upper part of the updip cycles to the deeper water facies in the downdip beds (condensed section).

5) Type E gamma logs not fitting any of the above examples (logs I and II)

The Magothy Formation has a gamma log typical of those found with the most sandy facies (logs I and II). The unusual gamma signature of this unit is due to the presence of thin to thick interstratified clayey beds, and most particularly, the persistence of the sand throughout most of the Coastal Plain. No other sandy Coastal Plain unit maintains its sandy character so far into the deep subsurface. In outcrop the Magothy is largely delta front facies or essentially a marginal marine-non-marine deposit. The few samples collected from this unit in the deep subsurface suggests a similar depositional origin. It would appear that the Magothy represents an environment which would produce a sheet of sand over a large area in a marginal marine system, e.g., mixed marine-non-marine. In the case of the Magothy, the sheet sand would have been produced in a slowly regressing delta system with the distal end being continually reworked producing a dominantly sandy facies. This geologic environment produced the broad sheet sand associated with this unit.

6) Type F gamma signature associated with an interstratified marginal marine-non-marine units (log III)

This type of gamma log is commonly found in the upper Tertiary units which are on average the most sandy formations in the central bedrock map. This type of gamma log with relatively thick woody clay strata about 10 to 20 ft thick (increasing radioactivity or deflected to right) interstratified with thicker sand beds (decreased radioactivity or deflected to left) are

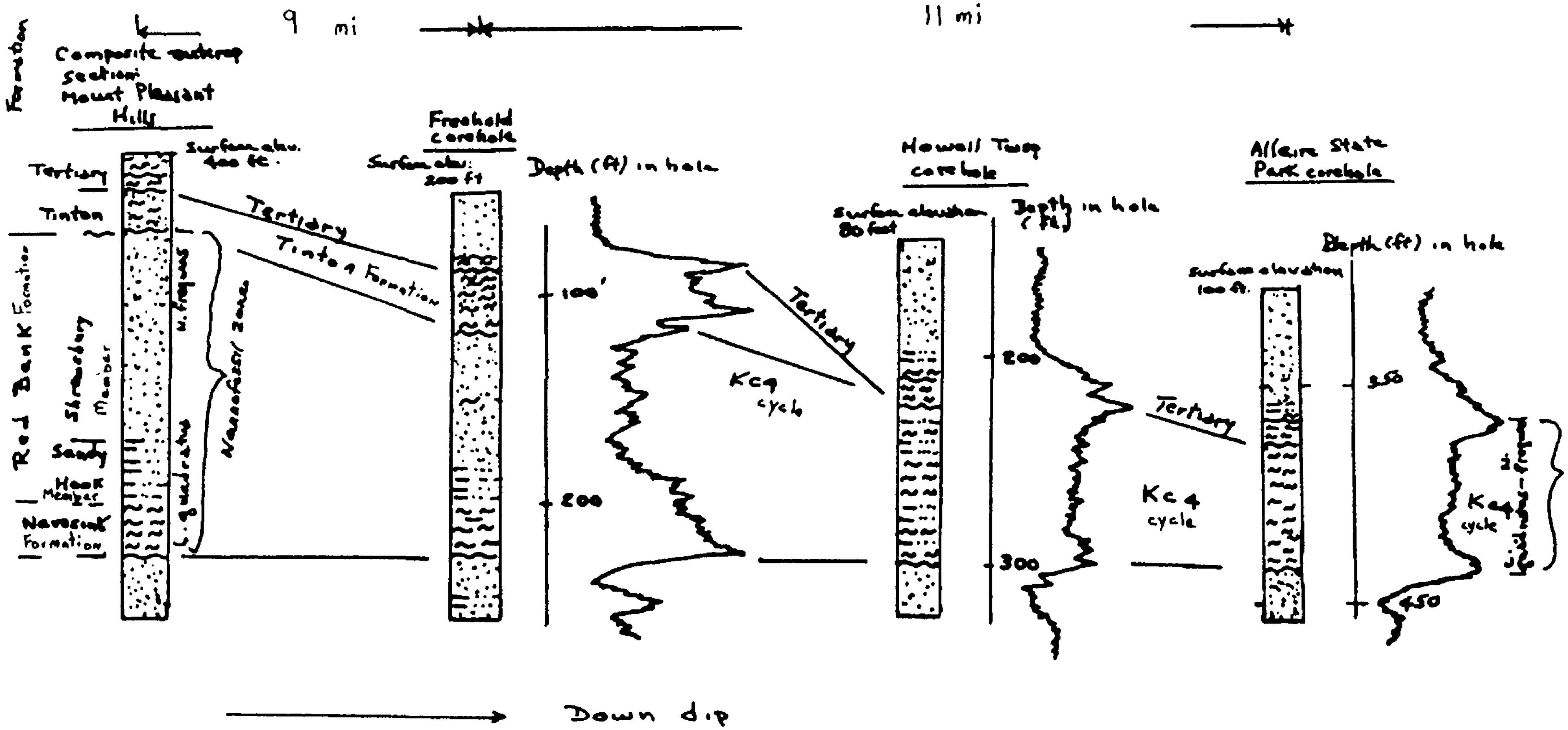

Figure 4. Facies changes exhibited within the Red Bank Formation and Navesink Formation cycle of sedimentation from a full cycle in outcrop and in the Freehold corehole to a single lithology in the deep subsurface of the Allaire corehole. The full cycle-single lithology are time equivalents. The downdip lithic change, therefore, represents a facies change to a deeper water lithology or a condensed section.

typical of this marine-non-marine transitional zone.

STRATIGRAPHIC NOMENCLATURE

Table 1 shows the surface to subsurface correlation for the Coastal Plain units in this map area. Three new units are introduced in this map area: an informal unit at Cape May and the Wildwood and Belleplain Formations. A major problem in this map area is the Potomac Formation. The outcropping Potomac Formation consists of abruptly lensing clays, sands, and less common gravels. Palynological studies of these fluvial sediments in New Jersey outcrops revealed that these sections contained pollen assemblages belonging to zone III of Doyle and Robbins (1977). South of New Jersey, outcropping sediments of the Potomac Formation contained pollen representative of the older zones I, IIa, and IIb. Regionally, the distribution of these biozones grossly outlines depositional basins, or perhaps prograding depositional lobes of different ages. The southern New Jersey bedrock may encompasses all three lobes, the older two occurring only in the subsurface. The fluvial to deltaic facies of the youngest biozone are fringed by and interfinger with marginal-marine facies in the subsurface. For these reasons the biozones were used to define three depositional cycles within the Potomac Formation. These units are given informal numerical designations that reflect their palynozone assignments until such time when a sufficient number of coreholes have been drilled to outline their geometry and lithic and paleontologic character.

Thirteen new or redefined stratigraphic units are shown on the southern bedrock map. Most of these units are present only in the subsurface or in the subcrop areas (those covered by thinner alluvium). Seven subsurface units are informally designed as cycles. The marine Upper Cretaceous cycles characteristically form a well developed asymmetrical pattern of sedimentation that consist of a basal transgressive glauconite-rich sand, a middle clayey or silty massive unit typically rich in mica and woody fragments, and an upper quartz-rich regressive sand. Many of the subsurface correlations, however, are based on gamma-ray log patterns. Using this technique the glauconite sands and clayey silts are indistinguishable in most cases. Additionally, the upper quartz sands tend to pinch out toward the downdip areas. Consequently, distinguishing individual facies within the downdip area is not feasible and, for example, three formations of the outcrop constitutting a large-scale cycle of sedimentation are correlated with a single cycle (Kc_3) in the profiles (Table 1). These cycles are given a numerical designation (Kc_1-Kc_4) with Kc_1 the oldest and Kc_4 the youngest. Three other unnamed units are Paleogene in age (Te, To_1, To_2). Two of these units (Te, To_1) are a single lithology and represent truncated sections. The other unit (To_2) is also truncated, but also shows some facies effects. All three units are also considered to represent cycles. There are also five new or redefined Neogene formations in this map area. All thirteen units are discussed below.

A) Cheesequake Formation: New formation named for outcrop in the northern New Jersey Coastal Plain. This formation has a limited outcrop belt, but is widespread in the subsurface. Here it lies in a broad basin which slopes to the southeast. Thicknesses range as much as about 80 ft in this basin. The formation unconformably overlies the Magothy

Formation and is overlain by the Kc_1 cycle. A geophysical log through the unit indicates the formation is more clayey at the base and sandy at the top.

B) Kc_1 cycle: Informal name for sediments which include the Merchantville and Englishtown Formations in outcrop. This formation is widespread in the subsurface where it lies in a basin which is thickest in the central part (as much as 155 ft) and thins southward toward the coast where it is about 50 ft thick. The Kc_1 cycle unconformably overlies the Cheesequake and is overlain by the Kc_2 cycle. Geophysical logs through this formation indicate it is primarily a clay-silt or clayey glauconite sand in most of the subsurface.

C) Kc_2 cycle: Informal name for a unit which does not reach the outcrop belt. Nonetheless the basin associated with this cycle is quite large and extends northward into the adjoining map area. The thickness of this cycle is as much as 200 ft. The Kc_2 cycle unconformably overlies the Kc_1 cycle and is overlain unconformably by the Kc_3 cycle. Geophysical logs reveal that this unit consists of interbedded sands and clay silts or clayey sands.

D) Kc_3 cycle: Informal unit which is equivalent to the Marshalltown, Wenonah and Mount Laurel Formations in outcrop. In the subsurface this unit underlies a broad basin in which the sediments are thickest in a large depocenter near the outcrop belt. The sediments of the Kc_3 cycle is unconformity bounded and is overlain by Kc_4 cycle. Geophysical logs reveal that this unit has a clayey unit at the base and a clastic unit at the top.

E) Kc_4 cycle: Informal unit which is equivalent lithically to the Navesink Formation in the outcrop belt. The unit thickens down dip to a maximum of 75 ft. The unit tends to thin westward. The maximum thickness is in a trough in the north-central part of the subsurface near Hammonton. The Kc_4 cycle unconformably overlies the Kc_3 cycle and is unconformably overlain by the Hornerstown Formation. Geophysical logs indicate this cycle is a clayey unit in the subsurface. What is unique about its geophysical signature is the large gamma spike at the base and less commonly at the top of the unit.

F) Te cycle: Informal name for a Paleogene cycle designated Te which does not reach the surface. This unit was referred to as the ACGS Alpha unit in a corehole near Mays Landing (Owens and others, 1988). This unit underlies a broad basin in the eastern part of the subsurface. The sediments lie within a broad trough which tends to thicken northward (up to 155 ft). Geophysical patterns vary within this unit but primarily are those associated with very clayey units. Locally a quartz sand geophysical pattern is found at the top of the unit. The unit overlies the Shark River Formation with a sharp contact.

G) To_1 cycle: Informal name for a Paleogene cycle found only in the subsurface. It was formerly includedd in the ACGS Beta unit in this map area (Owens and others, 1988). Unit occurs only in a small basin restricted to the eastern edge of the New Jersey Coastal Plain. This unit has a maximum thickness of 145 ft. Geophysical logs through this unit indicate the unit is mostly clayey.

H) To_2 cycle: Informal name for a unit which does not reach the surface. This unit was formerly included in the ACGS Beta unit in a corehole near Mays Landing (Owens and others, 1988). This unit underlies a broad basin whose base dips to the southeast. Sediments, primarily glauconite quartz sands, are as much as 250 ft thick. The To_2 cycle overlies the To_1 cycle and older units where To_1 pinches out unconformably. Geophysical logs through the unit indicate it is primarily a sand at the top and a more clayey clay-silt or glauconite sand at the base..

I) Kirkwood Formation and Shiloh Marl: The Kirkwood Formation was named by Knapp (1904) for a light-colored, massive, quartz sand in outcrops near Kirkwood. New Jersey. The composition of the formation was amended and the outcropping Alloway and Asbury Park Clay Members were added to the formation (Kümmel and Knapp, 1904). The age of the Kirkwood in outcrop was determined from shells at the top of the formation in shallow pits along Stowe Creek near Shiloh, New Jersey. The Shiloh Marl was made a member of the Kirkwood Formation by Clark and others (1909). In our report, the Shiloh Marl is raised to formation rank because in the subsurface in the southern bedrock sheet the Shiloh can be separated from the underlying Kirkwood lithically, isotopically, and in the gamma logs.

In the southern bedrock sheet the Shiloh Marl crops out in a small area west of Bridgeton, N.J. Most of the formation lies within a basin which dips to the southeast. Maximum thickness within the basin lies within two small depocenters where thicknesses range up to 175 ft. The Shiloh Marl overlies the To_2 cycle and in a small area the Shark River Formation. The Shiloh Marl overlies the Kirkwood Formation unconformably. Geophysical logs through the Shiloh Marl show that it is mainly a clayey unit at the base and in the deeper subsurface a sand at the top. There is no gamma spike associated with the lower boundary of the formation.

The underlying Kirkwood Formation is much thicker than the Shiloh Marl. This unit is widespread in outcrop and in the subsurface. Thicknesses vary throughout the basin but range to more than 250 ft locally. The greatest thicknesses are in the eastern part of the basin. The Kirkwood unconformably overlies the Vincentown Formation, Manasquan Formation, Shark River Formation and Shiloh Marl. Geophysical logs through this unit reveal that it has a variety of lithologies but in general is sandy in the top and clayey in the base. There is no gamma spike associated with the basal boundary.

J) Wildwood Formation: New formation named for the sediments overlying the Shiloh Marl in the Wildwood, NJ borehole. The Wildwood only crops out where the overlying units have been stripped away along the Delaware Bay and the Atlantic Ocean. This formation lies within a basin which dips to the southeast. The Wildwood sediments are more than 260 ft thick in the deeper parts of the basin. Geophysical logs through this unit indicate it is characterized by shifting patterns of clay and sand. There is a tendency, however, to having clay in the base and sand at the top.

K) Belleplain Formation: New formation named for sediments overlying the Wildwood Formation in the Belleplain Forest, NJ corehole. The Belleplain Formation is restricted to the southern bedrock map. The Belleplain crops out only where the overlying formations have been stripped away along Delaware Bay and along the Atlantic Ocean. The formation lies within a basin in which the sediments dip to the southeast. Thicknesses of the sediments are as much as 300 ft making this unit the thickest of the Neogene formations. Geophysical logs from the formation show variable sand-clay mixtures with a weak tendency toward having more clayey sediments at the base and sands at the top.

L) Unnamed unit at Cape May: Informal name for a unit which only is present in the southernmost part of the state. For the most part this unit is present in a deep channel underlying the Cape May Peninsula. Geophysical logs indicate this unit is mostly sand with interbeds of thin to thick clays.

DESCRIPTION OF SUBSURFACE UNITS
(Plate 2)

Tch Cohansey Formation (middle Miocene, Serravallian)--In the northern part of the map area, in the subsurface, the formation is primarily thick bedded to locally cross-bedded sand, fine to coarse grained, with local beds of fine gravel. Light brown to yellow brown where weathered. The depth of weathering ranges from 79 feet at Mays Landing, ACGS #4 corehole (Owens and others, 1988) to 225 feet at 150X-Atlantic City corehole. Unweathered beds are dark brownish gray to dark gray, and commonly have small to large pieces of carbonized wood mixed with the sand. In the southeastern part of the map area and in the off-shore wells the Cohansey Formation becomes more clayey. Clays typically are in discrete beds interbedded with sand. In the extreme southern part of the map near the Belleplain Forest headquarters the formation consists of thin to thick beds of fine to medium micaceous quartz (both colorless and green) sands and dark-gray to grayish-brown woody clays. The sands are locally coarsely stratified (typically small amplitude crossbeds) and locally are highly bioturbated. The clays also are extensively bioturbated. These beds represent the deepest marine beds found in the Cohansey in the New Jersey Coastal Plain.

The Cohansey lies unconformably on several formations in this map area. There is some relief along this boundary. The contact is sharp and commonly consists of a thin bed of fine gravelly (as much as 0.75 in. maximum diameter) sand. The original thickness of the Cohansey is difficult to ascertain because of extensive erosion of the formation. The formation lies in a broad channel and is thickest in the thalweg near Atlantic City where the formation, which is below sea level, is nearly 400 ft thick. The base of the formation rises rapidly to the south and north of this channel axis. For example, the base of the formation is only 70 ft below sea level in the Belleplain II corehole. The sand mineralogy of the subsurface Cohansey is mostly less mature than in the outcropping beds. Even in the weathered subsurface beds, small amounts of feldspar (up to 10 percent of the sand fraction), typically K-feldspars, are present. The heavy mineral suites typically show little change from outcrop into the weathered beds of the subsurface. The unweathered sand beds include some epidote, which apparently was removed by weathering in the overlying beds. The feldspar content in the weathered versus unweathered beds is not significantly different.

The clay minerals in the weathered beds are primarily kaolinite-illite/smectite along with lesser amounts of illite and kaolinite.

In downdip areas near Belleplain State Forest, the Cohansey contains marginal marine and shelfal facies. The shelfal facies are interbedded, highly bioturbated, micaceous, slightly glauconitic quartz sands and massive clays. Most of the sands in the Cohansey are medium grained and moderately sorted although coarse and fine sandy beds are also common. Beds with gravel as a major component are locally common in the mixed marine-non-marine facies in the northeastern corner of the map area. Here, the gravel occurs in well defined channels. Most of the gravel is one inch or less in diameter, although locally clasts up to five inches in diameter have been observed. The gravels are mostly quartz or quartzite with lesser amounts of white and black chert.

Thin to thick clay beds are common in the Cohansey in this map area. The clay beds are for the most part massive, but thin laminated clay strata are present. The thicker clay beds occur in lenses which commonly have small to very large pieces of lignitized wood. An extensive, well preserved leaf flora was collected from a very thick clay lens in the Cohansey near Millville. The leaf flora were dominated by an Alangium sp., a tree type no longer growing in eastern North America (J. Wolfe, written commun., 1992). The mineralogy of the sands in the Cohansey is in part dependent on the depth of weathering. Where deeply weathered, the sands are very mature, consisting only of quartz and siliceous rock fragments. Such sands have been extensively mined as glass sands. Where less weathered as in the deeper subsurface, the feldspar content increases, typically in concentrations between 5 to 10 percent of the sand fraction. The major opaque heavy minerals are ilmenite and its weathering products pseudorutile and leucoxene. The proportions of these minerals to each other is dependent on the intensity of the post depositional weathering. The non-opaque heavy minerals are primarily the resistant types, zircon, tourmaline and rutile, and the somewhat less resistant types, staurolite, sillimanite and kyanite. Garnet, and more rarely epidote, are minerals found in the least weathered beds. The clay minerals in the Cohansey are dominated by kaolinite and illite in the non-marine beds, while illite/smectite is common in the unweathered marine clays.

Heretofore, the age of the Cohansey was postulated from its stratigraphic position, its perceived contact relations with the underlying Kirkwood Formation (conformable or unconformable), or its macro- and microflora. The palynology of upper Tertiary formations in the northeastern U.S. is, however, only generally understood. Commonly, the Pliocene beds have less extant species than the Oligocene or Miocene beds. If this is the case, then the Cohansey, which has a large number of exotics of some species, has more Miocene affinities than Pliocene, an age some have assigned to this formation. Ager in Owens and others (1988) discussed the microflora in the Cohansey near Mays Landing. He noted that the Cohansey had a large number of exotics similar to those in the underlying Kirkwood (Wildwood Formation) and because of this, thought the Cohansey to be Miocene. The pollen was examined in the marine facies in the Belleplain Forest (L. Sirkin, personal commun. 1991). As Ager had found at Mays Landing, the Cohansey at Belleplain had a large variety of exotics in a warm temperate to subtropical pollen assemblage. Exotics found at Belleplain include Engelhardtia, Pterocarya, Cyrilla, Podocarpus, Planera, Epilobium, Symplocos, Clethra, Gordonia, and Cyathea. The major sources of tree pollen at Belleplain are pine, oak and hickory (L. Sirkin, personal commun. 1991). Although no calcareous fossils were recovered from the marine facies at Belleplain, a dinoflagellate assemblage was recovered. As noted by L. de Verteuil (written commun., 1991), the contained dinocyst flora at Belleplain can be correlated with the known dinocyst assemblages from the Choptank and lower part of the St. Marys Formation of the

Chesapeake Bay region and therefore is middle Miocene in age. These dinoflagellate data therefore confirm the Miocene rather than the Pliocene age for the Cohansey. Strontium ages were run on shells from the base of the Cohansey in one of the off-shore wells (ACOW #1). The age was approximately 11.0 Ma or essentially the uppermost middle Miocene or upper Serravallian. The Cohansey, therefore, based on strontium ages is the same age as that indicated by the dinoflagellates.

Gamma logs from the Cohansey are typically type F (fig. 3) except where it is mostly marine as at Belleplain Forest. The gamma signature here is type E.

Tbp

Belleplain Formation (middle Miocene, Serravallian)--New formation found in a corehole at Belleplain Forest headquarters (Belleplain II). The Belleplain occurs between 72 to 223 ft below sea level in the Belleplain II hole. The lower 35 ft is massive to horizontally laminated, dark-gray clay or silty clay with common small, thin-walled mollusks. These beds are very diatomaceous. A thin gravel bed, containing gravel up to 0.375 in. in diameter, is present along the boundary with the underlying Wildwood Formation. The gravel is mainly quartz with small amounts of phosphatized vertebrate remains and sharks teeth. This basal clayey unit is overlain by as much as 75 ft of mostly sand. The lower 4 ft of the sand is interbedded with clay and dark-gray, woody, fine to medium sands. These grade up into a massive, rarely cross-bedded, bioturbated, medium- to dark-gray, fine to medium, micaceous (some very coarse plates) quartz sand. The sands in the upper 35 ft of this interval become coarser grained and are extensively stained gray brown by humates. The upper 30 ft is again more clayey. Most of this interval is dark-gray, laminated clay with common thin interbeds of find to medium micaceous quartz sand. Flaser bedding is common in this upper dominantly clayey unit. No calcareous fossils are present in the upper clayey interval.

The Belleplain Formation is restricted to the southern bedrock sheet. Most of the basin is subsurface except where younger Pleistocene units have deeply entrenched through the overlying Cohansey Formation and exposed the Belleplain Formation. The Belleplain is greater than 300 ft thick along the coast from Strathmere to Cape May City. The Belleplain basin is considerably smaller than the overlying Cohansey basin.

Mineralogically, the sands in the Belleplain are mostly quartz with a minor amount of siliceous rock fragments. Potassic feldspar is a common constituent but typically is less than 10 percent of the sand fraction. There are a large number of heavy minerals, mostly ilmenite with lesser amounts of pseudorutile and leucoxene. Zircon, tourmaline, rutile, staurolite, sillimanite, kyanite, hornblende, epidote, garnet, chloritoid, and andalusite are present in the non-opaque fraction. The clay minerals are mostly illite/smectite and much smaller amounts of kaolinite and illite.

The age of the Belleplain was determined using a combination of different fossil materials. There is a large diatom assemblage that includes Rhaphoneis clavata, Rhaphoneis gemmifera, Delphineis novacaesarea, Actinoptychus marylandicus, Delphineis augustata, Delphineis penelliptiica, Rhaphoneis scutula and Coscinodiscus lewisianus. Andrews (1988) considers this assemblage to be characteristic of East

Coast Diatom Zone #6 (E.C.D.Z. #6) or Bed 15 (uppermost part of the Calvert Formation of the Chesapeake Bay region).

Silicoflagellates recovered from the Belleplain Formation include Distephanus staurocanthus, Distephanus crux crux, Corbisema triacantha and Bachmannocena apliculata. The co-existence of the diatom Coscinodiscus lewisianus with the silicoflagellate Distephanus stauracanthus indicates an age of 13.2 to 12.3 Ma (D. Bukry, USGS, written commun., 1990). An independent check of this age range is provided by strontium-isotope analyses of the shells in this formation. The strontium-isotope ages range from 14.7 to 12.3 Ma with a range of 13.2 to 12.3 Ma for three samples in the Belleplain core. The isotopic ages confirm the paleontologic middle Miocene age for the formation. Pollen assemblages from the base of this formation in the Belleplain core contain spruce, pine, oak, hickory, and poplar (all abundant) and black gum, sweet gum, maple, birch, and Myrica (all minor). Exotics include Podacarpus, Planera, Engelhardtia/Momipites, Clethra, Cyrilla, and Symplocos. This assemblage is a mixture of cool-temperate forms (spruce; a nearby upland assemblage) and warm-temperate forms (oak, hickory, and exotics; a lowland assemblage). The pollen assemblage in the upper part of the formation lacks the cool-temperate elements and is, overall, a warm-temperate microflora, thus indicating a general warming of the climate upward through the formation.

Gamma-ray values are high for the clayey unit at the base (transgressive deposits) and low for the sandy unit at the top (regressive deposits). This high-low couplet is a very distinctive gamma-ray pattern that is typical of most marine units in the New Jersey Coastal Plain (fig. 3, type B). These units are unconformity-bounded sequences that represent an asymmetric transgressive to regressive cycle of sedimentation.

Tw

Wildwood Formation (middle and lower Miocene, Langhian and Burdigalian)--New formation named for a well drilled at Wildwood, N.J. Formation occurs between 525 to 785 ft below sea level in the Wildwood drill hole. Typically consists of a very fossiliferous, micaceous, dark-gray clay-silt interbedded with pale, gray-brown, fine- to medium-grained sand in lower half of the formation. The upper half of the formation is more sandy (mostly fine micaceous quartz sand), commonly interbedded with thin gray-brown micaceous clays; wood fragments are common. Bedding in this interval varies from thin to laminated. The basal contact with the underlying unit is sharp and has considerable relief. A bed, up to 3 ft thick, of fine gravel (0.375 in. in maximum diameter) with pieces of quartz and worn shells, commonly occurs along the boundary. The Wildwood basin is somewhat larger than that of the overlying Belleplain basin. Most of the formation is subsurface except where younger formations have entrenched into the Wildwood Formation along Delaware Bay and along the Atlantic Ocean (Plate 1). Thicknesses of the unit vary widely because of the undulating basal boundary. The maximum thickness penetrated was in the Wildwood well (260 ft).

Mineralogically, the sands and clays in the Wildwood are similar to those in the overlying Belleplain Formation. The age of the Wildwood was determined from its diatoms and strontium-isotope age estimates of its mollusk shells. The diatom assemblages in this unit fall within Andrews (1988) East Coast Diatom Zone 2, thus indicating a considerable time loss between this formation and the overlying Belleplain (Zone 6). Zone 2 is in the Delphineis ovata Zone and contains the characteristic diatoms Sceptroneis caduceus, Rhaphidodiscus marylandicus, Cosinodiscus lewisianus, Rhaphoneis margaritata, Rhaphoneis scalaris, Delphineis lineata, Rhaphoneis fusiformis, Rhaphoneis wicomicoensis, Sceptroneis granidis and Sceptroneis hungarica. Sr 87/86 ratios on shells from this interval indicate an age range from 17.4 to 15.5 Ma (Sugarman and others, 1993). The isotopic and paleontologic ages suggest that the Wildwood Formation straddles the early-middle Miocene boundary (Langhian-Burdigalian boundary). Pollen from the Wildwood has warm-temperate affinities in the lower part of the formation and mixed warm- and cool-temperate affinities in the upper part, suggesting an overall cooling of the climate upward through this unit. Collectively, the Wildwood Formation and Belleplain Formation constitute the section that Woolman (1889-1902) assigned to his "great diatom bed".

Gamma-logs vary because of the extensive dissection of the upper beds by younger units. Where the formation is most intact, the typical gamma log is one dominated by a clay pattern (fig.3, type F).

Tsh

Shiloh Marl (lower Miocene, Burdigalian)--Unit raised to formation rank; previously included as a member of the Kirkwood Formation in the report on the ACGS corehole near May Landing, N.J. (Owens and others, 1988). In that report the Shiloh occurs between 245 and 385 ft.

The Shiloh Marl consists of a lower dark-gray, clayey, locally fossiliferous (typically thin-walled, small mollusks), micaceous or laminated clay interbedded with very fine-grained sand and an upper pale-brown to medium-gray, massive, fine gravelly, medium to coarse sand with scattered thin-walled mollusks. Thin, dark-gray clay layers with thin layers of lignite are common in this interval. The Shiloh basin is slightly larger areally than the overlying Wildwood basin. Like the Wildwood, this basin lies mainly within the southern bedrock sheet. Thicknesses vary within the basin but are a maximum of 175 ft.

The sand mineralogy of the Shiloh is similar to that of the overlying Wildwood Formation. Most of the sand is quartz with lesser amounts of potassium feldspar (6 to 16 percent of the sand fraction). The heavy mineral suites are mostly opaque (brown ilmenite and leucoxene with smaller amounts of ilmenite). The non-opaque suites have a large number of species, including zircon, tourmaline, epidote, garnet staurolite, sillimanite, kyanite, rutile, chloritoid and andalusite. The clay minerals are mainly illite/smectite but large amounts of illite and kaolinite are present.

The age of the Shiloh is early Miocene (Burdigalian) as determined from its diatom content. The Shiloh contains Actinoptychus heliopelta (E.C.D.Z. #1 of Andrews, 1987, 1988). Strontium age determinations on shells from this unit yielded ages of 20.9 to 19.7 Ma confirming the early Burdigalian age. Pollen studies indicate that the Shiloh has unusually high concentrations of Fagus (beech). Other pollen includes Quercus (oak), Carya (hickory), Pinus (pine), and Ulmus (elm), along with exotics. Overall the assemblage, except possibly for the high Fagus, indicates a warm, temperate climate during this time.

Gamma-ray signatures from this unit are type F (fig. 3) except where the Shiloh has been truncated by younger units. In these cases only the lower clayey unit is intact and the geophysical log is type C.

Tkw Kirkwood Formation (lower Miocene, Aquitanian)--Complex unit in which facies changes are common. In outcrop, some of the Kirkwood Formation is a light colored quartz sand (Grenloch facies of Isphording, 1970). The facies pinches out rapidly in the subsurface and the formation is primarily a dark-gray, massive to finely laminated clay (Alloway clay of Kümmel and Knapp, 1904). This clay facies occurs as far south of Clayton where the lower part changes to a fossiliferous clayey silt. South of a line connecting Bridgeton to Atsion a sand is present at top of the formation. This sand thickens to over 75 ft at the coast where it is part of the "800 foot" sand, the principal aquifer in the coastal region. The lower clayey facies thickens to over 100 ft in the coastal region. Here, this lower facies is mostly dark-gray clayey silt which is locally very fossiliferous.

The basal contact with underlying formation is sharp and unconformable. Commonly there is a 1 to 3 foot zone along this boundary in which coarse quartz sand and some gravel are present. Because of the quartz sandy nature of the Kirkwood in outcrop, some considered the Kirkwood and Cohansey Formations to be transitional (Isphording, 1970). Obviously this is not the case as there are three other formations (Shiloh Marl, Wildwood Formation and Belleplain Formation) lying between the Kirkwood and Cohansey. The Kirkwood basin is much larger than the underlying Shiloh basin. The original extent basin is unknown because the inner margin has been eroded away.

Mineralogically, quartz and siliceous rock fragments are the major sand minerals. Feldspars typically constitute less than 10 percent of the sand fraction except in the reworked beds where they make up as much as 25 percent of the sand. Mica and woody fragments are minor constituents. In the heavy mineral assemblages the opaque mineral ilmenite and its weathering products pseudorutile and leucoxene are the major constituents. In the non-opaque fractions, zircon, tourmaline, rutile, staurolite, sillimanite, kyanite, and garnet are the common minerals. Hornblende, epidote, chloritoid, and biotite are less abundant. The clay mineral suite contains nearly equal amounts of illite/smectite, illite, and kaolinite.

The age of the Kirkwood was determined from its planktic foraminifera and diatoms, and from strontium isotope age estimates. The foraminiferal assemblage includes Globigerina praebulloides, Globigerinoides trilobus G. altiapertures and Globorotalia siakensis. These species are characteristic of the lower Miocene Zone 5 of Blow (1969) of Burdigalian age. The diatom assemblage is characterized by Actinoptychus heliopelta, Aulacodiscus rogersii, Sceptroneis caduceus, Triceratium acutum, Odentella minuta, and Cosinodiscus lewisianus. These diatoms are characteristic of East Coast Diatom Zone 1 of Andrews (1988), which he considers to be early Miocene (Burdigalian) in age. The Sr 87/86 ratios of shells from this formation indicate ages from 23 to 20.2 Ma (Aquitanian) which we adopt as the age of this formation (Sugarman and others, 1993). The pollen in the clay facies of the Kirkwood, as determined from the Mays Landing (ACGS) drill hole, are oak, hickory, and pine with smaller amounts of beech, black gum, sweet gum, alder, elm, linden, and birch. The sandy facies has essentially the same assemblage but has unusually high concentrations of beech. Exotic species such as Podocarpus and Momipites are common in the formation. The cool floral elements found in the overlying Belleplain and Wildwood Formations were not found in the Kirkwood.

Gamma-log patterns vary within the formation from place to place. In the updip area the patterns are typical of clayey sediments (type C). In the deeper subsurface, the basal clay-upper sand couplet is the characteristic pattern (type B).

To_2

To_2 cycle (upper Oligocene, Chattian)--New unit defined for sediment occurring between 934 to 1184 ft below sea level in a corehole near Atlantic City, N.J. In the core hole near Mays Landing this unit was provisionally included in the ACGS Beta unit (Owens and others, 1988). In this report the unit is informally designated To_2 cycle. The unit consists of three facies in a vertical section, a lower glauconite sand, a middle clay-silt and an upper quartz sand, which is an expansion of the description in the Mays Landing hole.

The lower glauconite sand at Atlantic City is a massive moderate-green, clayey, fine to medium quartz (10 to 20 percent) glauconite sand. Glauconite grains in this interval are dark green, fine to medium grained and have botryoidal shapes. Small shell fragments are abundant and scattered mica plates are present in this facies. At Atlantic City this facies is about 60 ft thick.

The lower glauconite sand grades into a medium- to dark-gray, massive to thick-bedded clay-silt which has common thin to thick interbeds of glauconite sand. As below, this facies has abundant thin-walled mollusks and washed samples reveal this unit has an abundant microfauna. This facies is about 80 ft thick. The clay-silt facies is overlain by a massive to thick-bedded, olive-gray to greenish-gray, fine- to coarse-grained (mostly medium to coarse grained) sand with scattered granules. Worn, rounded shell fragments are common in some of the sand beds. Quartz and glauconite proportions vary in these upper sand beds with the glauconite content ranging between 20 to 40 percent of the sand. Most of the glauconite grains in this facies have highly polished surfaces and are a moderate brown to dark green color. The presence of abundant brown glauconite is not found in any of the other glauconite rich formations in this part of the Coastal Plain. This facies is about 80 ft thick at Atlantic City and 90 ft in the core hole near Mays Landing. Areally the upper quartz sand is the most widespread facies of this formation. The To_2 cycle unconformably overlies the To_1 and Te cycles. The contact is sharp and a thin reworked sandy zone high in glauconite occurs at the base of the unit.

Mineralogically, the upper sand is primarily quartz and glauconite. Feldspar and rock fragments typically total less than 10 percent of the sand. Heavy minerals are not abundant in any part of the formation. Ilmenite and pseudorutile are the major opaque minerals. Zircon, tourmaline, rutile, staurolite, sillimanite, kyanite, and garnet are the most abundant non-opaque heavies. The clay minerals are primarily illite, kaolinite, and illite/smectite.

The age of the To_2 cycle was determined from its microfauna and less reliably from strontium analyses of shells. Microfauna from the sandy and clayey facies differ. The sandy facies, especially those beds from the shallower parts of the basin, yield mixed microfaunal assemblages of widely different ages. This suggested extensive stripping of older updip beds during the emplacement of these sands and the mixing of faunas. In the deeper parts of the basin, the nannofossils are less mixed and suggest assignment to zone NP24-NP25 of latest Oligocene age (Chattian). Planktic foraminifera and nannofossils were obtained from the clay-silt facies near Atlantic City. Typical foraminifera include Globigerina ciperoensis, G. juvenilis, G. praebulloides and Globorotalia sp. (R. Poore, USGS, written commun., 198?). Characteristic nannofossils include Zygrhablithus bijugatus, Cyclicargolithus cf., C. abisectus and Spenolithus moriformis (L. Bybell, written commun., 1988). Taken collectively, these fossils indicate a late Oligocene (Chattian) age. Sr 87/86 analyses of shells from the Mays Landing core indicate an age of 28.4 and 27.6 Ma (Chattian) (Miller and Poore, 1990). Approximately the same ages were obtained from this unit in the Atlantic City core hole. Pollen was examined only from the sandy facies. Oak, hickory, beech, black gum, sweet gum, willow, birch, alder, and pine are present and these indicate a warm climate. Exotic species include Podocarpus, Momipites, and Alangium.

Gamma-ray logs through the formation at its thickest point show a gradation from a lower clay to an upper sand (type C) that is interpreted, in conjunction with core data, to represent a transgression followed by a regression.

To_1

To_1 cycle (lower Oligocene, Rupelian)--Sand, dark greenish gray to olive black, fine grained, clayey, micaceous, woody, locally shelly; finely laminated and extensively bioturbated. Glauconitic at base with only scattered glauconite grains above where quartz is the major sand mineral. Grades upward into dark-gray, laminated to thin-bedded clay and clay-silt interbeds. Thin walled shells are common in the lower part of this sequence. Near top of unit, fine to very fine somewhat micaceous glauconite quartz sands are interbedded with the clays.

The To_1 cycle lies within a small basin which occurs mostly in the southern bedrock sheet. Thickness is as much as 145 ft. The To_1 cycle overlies the Te cycle with a sharp contact. The boundary is marked by extensive burrows filled with glauconite sand projecting several inches downward into the underlying unit. The sand fraction in this unit is dominated by quartz and to a lesser degree, glauconite. Feldspar and mica are minor constituents. Most of the opaque heavy mineral suite is ilmenite and leucoxene; pseudorutile is a minor constituent. The non-opaque heavy minerals are mainly epidote, garnet, sillimanite, and chloritoid. Tourmaline, staurolite, zircon, kyanite, and hornblende are less common. Clay minerals in this unit resemble those found in the overlying To_2 cycle.

The presence of the coccolith Cycloccolithus formosus suggests assignment to NP21 of early Oligocene age (Rupelian). Pollen studies indicate that this unit was deposited in a warm-temperate to subtropical climatic regime. The pollen assemblage is characterized by a flood of oak and oak-like pollen. The introduction of this flora marks a change from the largely tropical to subtropical microfloras of the underlying units (Ager, in Owens and others, 1988).

Gamma-ray logs through this unit have a characteristic clayey signature (type C). No regressive sandy facies was found in the upper part of the formation suggesting the removal of this facies before the emplacement of the overlying unit.

Te

Te cycle (upper Eocene, Priabonian)--Complex unit consisting of several lithofacies. In the updip area in the ACGS core hole at Mays Landing where this unit was provisionally included in the ACGS Alpha unit, it consists of two small upward coarsening cycles (subunits B and C of Owens and others, 1988). In the downdip area near Atlantic City, the unit is primarily a massive to thinly laminated, blue-green to pale-green clay, less commonly a clay-silt with thin interbeds of fine-grained glauconite quartz sand. Fossils, either fine thin-walled mollusks or calcareous microfauna, are abundant throughout this whole unit. The basal 3 ft is a dark-green, fine-grained glauconite sand which rests with sharp contact on the underlying Shark River Formation. There is, however, very little reworked sediment along this boundary.

The Te basin is somewhat larger than the overlying To_1 basin. In general the unit thickness does not vary greatly; the maximum known thickness is at Mays Landing where it is 155 ft.

The sand and clay mineralogy of the Te cycle in the updip areas is similar to that of the To_1. In the downdip area, because of the very clayey nature of the unit, only the clay mineralogy was investigated. The lower half of the unit is primarily illite/smectite with small amounts of illite. No kaolinite is present in this part of the unit. In the upper half of the unit, kaolinite steadily increases to the top of the unit where it is nearly a third of the total clay content.

The age of the Te cycle was determined from its calcareous nannofossils and foraminifera. The nannofossils indicate an age from upper Zone NP18 to Zone NP21 (Owens and others, 1988). NP18 is marked by the first occurrence of Chiasmolithus oamaruuensis and the absence of Isthmolithus recurvus. The consistent occurrence of Cyclococcolithus formosus indicates the presence of NP21 at the top. Based on the nannofossil assemblage, the Te cycle is late Eocene and early Oligocene in age. Represented planktic foraminifera zones are the Turborotalia cocoaensis / Turborotalia cerroazulensis Zone and the Turborotalia cunialensis Zone (Poore and Bybell, 1988), which have the same age range as the nannofossil zones. Sr 87/86 age determinations on shells from this unit yielded ages of 37.1-35.8 Ma, although the lower age limit is constrained by the flatness of the strontium isotope curve near 38.0 Ma (Miller and others, 1990). Pollen assemblages from the upper part of the Te cycle in the Mays Landing core contain Momipites, Podocarpus, Castanea type, black gum, hickory, elm, pine, linden, Sapotaceae, Ericalles, and small amounts of oak and oak-like pollen indicating a warm temperate climate during the deposition of this unit.

Gamma-logs from this unit, because of their very fine grained nature, are typically type C.

Tsr Shark River Formation (upper and middle Eocene, Priabonian through Lutetian)--Typically more sandy (quartzose) in the updip areas and more clayey downdip. Updip beds are cyclic with a dark-green, somewhat clayey fossiliferous, fine- to medium-grained, glauconite-quartz (25 percent) sand at the base. This bed is about 40 ft thick. There is a general increase in quartz sand upward and a change in color to dark gray or brownish gray. Locally some of the beds are more clayey and have more calcareous shell fragments. The Shark River Formation in the updip area near Bridgeton, N.J., is about 170 ft thick. The downdip facies is commonly olive-green to yellow-green, massive to laminated, very clayey, fine-grained glauconite sand in the lower part of the formation and has a similar lithology at the top where the glauconite sand is medium to coarse grained. All of the Shark River lithologies in the downdip area are extensively bioturbated. The Shark River underlies most of the map area and the formation is thickest (more than 200 ft) in a trough which lies near the middle of the map area. The Shark River does not crop out in the southern bedrock sheet. The contact between the Shark River and the underlying Manasquan Formation is sharp. A thin zone of reworked sediment, mostly glauconite sand, granules of quartz, and phosphatic debris, occurs along the boundary. On most gamma-ray logs through this boundary, there is a sharp gamma high reflecting the concentration of phosphatic sediment.

Mineralogically, most of the sand fraction in the Shark River is quartz and glauconite. Small amounts of feldspar, mica, and siliceous rock fragments are also present. The heavy mineral suites are nearly equal amounts of opaque and non-opaque minerals. The non-opaque minerals include a large variety: zircon, tourmaline, rutile, hornblende, epidote, garnet, staurolite, sillimanite, kyanite, and chloritoid. Clay minerals include illite/smectite, illite and kaolinite.

Calcareous nannofossils and foraminifera were used to date this unit. Where the unit is thickest, the nannofossils range from the upper part of zone NP14 (Rhabosphaera inflata, Nannotetrina cristata, Nannotetrina fulgens) to the lower part of zone NP18 (Chiasmolithus oamaruensis). The planktic foraminifera zones range from the Turborotalia frontosa Zone at the base to the Turborotalia pomeroli/Turborotalia cerroazulensis Zone at the top. A middle to early late Eocene age for the Shark River is indicated by these zones (Poore and Bybell, 1988).

The vertical arrangement of facies in this formation is from a transgressive (mostly clayey) facies at the base to a regressive (more sandy) facies at the top. The gamma-ray log patterns (fig. 3, type C) show this general pattern throughout the Shark River basin.

Tmq Manasquan Formation (lower Eocene, Ypresian)--Clay to clay-silt, green to gray green, massive to finely laminated, and extensively bioturbated. Calcareous microfossils are abundant in this unit. This formation underlies most of the map area but does not crop out. In general, the formation thickens to the southeast where it is more than 200 ft thick. The basal contact with the underlying Vincentown Formation is sharp. A thin zone, typically two feet thick, of reworked glauconite sand, phosphatic debris, and sparse quartz granules occurs at the base. Gamma-ray logs through the Manasquan

Formation have a large gamma spike along the basal boundary. There is very little sand in the Manasquan except for scattered grains of glauconite. The clay minerals in this formation are mostly illite/smectite with small amounts of illite and kaolinite. Some samples have small amounts of the zeolite clinoptilolite.

The age of the Manasquan was determined from its calcareous nannofossils and to a lesser degree its foraminifers. The lower part of the Manasquan is assigned to upper zone NP9 defined by the nannofossils Campyosphaera dela and Lophodolithus nascens. The upper part of the formation lies within zone NP13. This zone is characterized by the last appearance of Tribrachiatus orthostylus and the first appearance of Discoaster lodoensis (Poore and Bybell, 1988). The foraminifera Planorotalites palmerae has a range near the end of the early Eocene, an age also indicated by the nannozone NP13 (Poore and Bybell, 1988).

Gamma-ray logs through the Manasquan in this map area show very little variation and have a pattern typical of very clayey lithologies (fig.3, type C). The transgressive-regressive sedimentation pattern found in many of the overlying units was not present in the Manasquan possibly because the Manasquan may represent a middle to outer shelf depositional environment.

Tvt

Vincentown Formation (upper Paleocene, Selandian)--Upper part is fine- to very fine-grained, dark-gray, massive, bioturbated, very clayey and silty, very micaceous, glauconite (35 to 40 percent) and quartz (60 to 65 percent) sand. Lower part is sand, massive, dark gray green, less micaceous and clayey, and progressively more coarse grained and glauconitic downward. The lower 15 ft of the formation is a clayey, fine- to medium-grained glauconite sand. Locally, there is an accumulation of disarticulated calcareous shells along the boundary with the underlying Hornerstown Formation. These shells are commonly the brachiopod Oleneothyris harlani or the mollusk Gryphaea dissimilaris. Where the shell bed is absent it is difficult to separate glauconite sand of the basal part of the Vincentown Formation from the underlying Hornerstown, which also is a glauconite sand. Gamma logs through this interval show that there is a small gamma spike along the contact between the glauconite sands. Samples of the Vincentown were available only from the middle of the basin. As in northern New Jersey, the formation is significantly more clayey downdip. Based on geophysical log interpretations in the deepest subsurface, this unit has a maximum thickness of about 125 ft.

Mineralogically, the sand fraction in the Vincentown is glauconite and quartz in varying proportions. Feldspar, rock fragments, and mica are minor constituents. Heavy minerals are sparse. In the opaque fraction, ilmenite and leucoxene are the major minerals and pseudorutile is subordinate. In the non-opaque fraction, the labile minerals hornblende, epidote, and garnet are abundant, staurolite, sillimanite, and kyanite are common, and the most resistant minerals zircon, tourmaline, and rutile are sparse. The clay-mineral suite is dominated by illite/smectite with lesser amounts of illite and kaolinite.

The age of the Vincentown is best indicated by its calcareous nannofossils (Bybell, 1992). The lower Oleoneothyris shell bed falls within the upper part of zone NP5 (late Paleocene, Selandian). Common nannofossils in zone NP5 are Biantholithus sparcus, Cyclagelosphaera reinhardtii, Ellipsolithus bollii, Fasciculithus ilii, Lanternithus duocavis, Scapholithus fossilis and Semihololithus biskayae. Common nannofossils in zone NP9 are Biantholithus astralis, Chiasmolithus bidens, Discoaster salisburgensis, Fasciculithus involutus, Fasciculithus schaubii, Fasciculithus thomasii and Lopodolithus nascens. The upper part of the Vincentown falls within the upper part of Zone NP9 and therefore is late Paleocene in age.

Gamma-ray logs of the Vincentown typically reflect the glauconitic and clayey nature of the units and show little variation throughout the subcrop of this map area (fig. 3, type D).

Tht Hornerstown Formation (lower Paleocene, Danian)--Sand, glauconite, clayey to very clayey, extensively bioturbated, medium green in the shallow subsurface. Common to abundant microfauna in the subsurface are not present in the outcrop. In the deep subsurface the Hornerstown Formation cycle of sedimentation consists of glauconite sand at base, overlain by a thin laminated clay-silt which grades upward into a fine-grained, clayey glauconite quartz sand.

The Hornerstown basin covers nearly all the southern bedrock sheet. The formation throughout the basin is very thin rarely exceeding 10 ft in thickness. The basal contact with the underlying Kc_4 cycle is difficult to place because both this unit and the Hornerstown are glauconitic sands. In those areas where cores were available, the basal Hornerstown contains dark brown phosphatic debris. Less commonly the boundary is marked by extensive burrows filled with glauconite sand which project downward into the underlying unit.

This formation is nearly all glauconite sand. The clay minerals in the Hornerstown are glauconite and illite/smectite.

The age of the Hornerstown is early Paleocene (Danian) based on the presence of calcareous nannofossil Zones NP3 or NP4, and foraminifera Zones P1a to P1c (Liu, written commun., 1993).

Gamma logs from the Hornerstown are type D (fig. 3). Commonly, however, the Hornerstown logs have a very large gamma kick at the base of the formation. This large basal gamma kick is one of the most common geophysical signatures found throughout the subsurface of the New Jersey Coastal Plain.

Kc_4 Kc_4 cycle (Upper Cretaceous, Maastrichtian)--Sand, glauconite, clayey, massive, bioturbated, dark greenish gray in upper part; medium-gray, massive, slightly clayey, fine- to very coarse-grained, glauconite-quartz sand with common quartz granules and coarse shell fragments locally in the lower 5 to 8 ft. These lower beds have a large number of burrows which are filled with glauconite sand and project downward into the underlying glauconite beds. The Kc_4 cycle lies within a basin that underlies most of this map area; it thickens to the southeast from about 15 ft in the shallow subsurface to about 75 ft in the deeper parts of the basin. The basal quartz sand represents reworked sediment resting on the unconformity between sandy beds of the Kc_4 cycle and the underlying Kc_3 cycle; this bed is not found everywhere along this boundary.

Mineralogically, the sand in the upper beds is nearly all glauconite with trace amounts of quartz and mica. Detrital heavy minerals are rare in this unit. Clay minerals are primarily illite/smectite with small amounts of kaolinite and illite. Quartz and glauconite are the major sand minerals in the lower sandy facies. Small amounts of feldspar, mica, and brown phosphatic debris are also present. In the heavy mineral suite, the non-opaque minerals are more abundant than the opaque minerals The major non-opaque minerals are garnet, epidote, staurolite, kyanite, and hornblende. Minor non-opaque minerals are andalusite, rutile, chloritoid, and zircon. The opaque minerals are mainly ilmenite and leucoxene. The clay-mineral suite has considerably more kaolinite in the sandy facies than in the glauconite facies.

Calcareous nannofossils were used to date the Kc_4 cycle although planktic foraminifera and ostracodes are common. There is a thin section assignable to the Nephrolithus frequens Zone at the top of the Kc_4 cycle and a much thicker section assignable to the Lithraphidites quadratus Zone below (P. Valentine, USGS written commun., 1988). These zones indicate a middle to late Maastrichtian age. The thinness of the N. frequens Zone, when compared to the greater thicknesses of this zone in the Kc_4 cycle to the north, suggests that the Kc_4 cycle in the southern bedrock sheet is a beveled cycle rather than a condensed section.

The gamma pattern for the Kc_4 cycle is very distinctive. The unit is bounded by a large gamma-ray spike at its base and a similar spike at the base of the overlying Hornerstown Formation. Between the gamma-ray spikes, the gamma-ray values remain high because of the high glauconite content (fig. 3, type D).

Kc_3

Kc_3 cycle (Upper Cretaceous, upper Campanian)--Consists of two major lithofacies, a lower clayey, glauconite quartz sand and an upper well-sorted quartz sand. The lower facies is a medium- to dark-gray-green, massive, extensively bioturbated, clayey, somewhat micaceous glauconite-quartz (20 percent at the base to 50 percent in the upper part) sand. Scattered megafossils are present in these beds. This facies is about 50 ft thick in the shallow subsurface and in the downdip areas. The upper sand is thickest in the shallow subsurface. There, it consists of medium-gray-green, massive to thick-bedded, medium-grained, quartz-glauconite (5 to 15 percent) sand. Large fossils, Exogyra sp., Ostrea sp. and Belemnitella sp. are scattered throughout these sandy beds. The sandy beds are a maximum of 100 ft thick in the shallow subsurface and thin rapidly downdip. The Kc_3 basin underlies the entire map area and has a general southeast dip. In general, this unit is thickest updip. The basal contact with the underlying cycle is sharp; a thin bed of reworked sediment is present along the boundary.

Mineralogically, quartz and glauconite are the major sand minerals. Feldspar, mica, pyrite, woody fragments, and phosphatic debris are minor sand constituents. Non-opaque heavy minerals are more abundant than the opaques. The non-opaque minerals are mostly garnet, epidote, staurolite, hornblende, and tourmaline with minor chloritoid, zircon, and rutile. In the opaque fraction, ilmenite is dominant with much smaller amounts of leucoxene. Clay-mineral suites are about equal mixtures of illite/smectite, illite, and kaolinite.

The age of the Kc_3 cycle was determined using a variety of fossils. Belemnitella americana guards occur throughout the upper sand. Traditionally this fossil was regarded as Maastrichtian in age. More recent data based on strontium isotope ratios suggests that it may be late Campanian in age (Sugarman and others, 1995). Planktic and benthic foraminifera are common in the lower part of the formation; however, the recovered assemblages proved not to be age specific. Ostracodes in the lower and middle parts of the cycle were more useful in establishing the age of this unit. Common forms include Limburgina verricula, Fissocarinocythere huntensis, Anticythereis reticulata, Planileberis(?) costatana, and Phacorhabdotus cf. P. texanus. This assemblage indicates a late Campanian age (Gohn, 1992).

Gamma-ray logs in the shallow subsurface a transgressive-regressive cycle, a clay pattern in the base and a sand pattern at the top (fig. 3, type B). Downdip, the upper sand is missing and the entire formation has the clay pattern (strong deflection to the right) (type C). There is no gamma spike along the basal boundary.

Kc_2

Kc_2 cycle (Upper Cretaceous, middle Campanian)--Sand, mostly glauconite with varying amounts of quartz (less than 20 percent on average), fine to medium grained, clayey, fossiliferous, and dark gray in the basal 5 ft. Grades upward rapidly into dark-gray, massive, slightly sandy clay-silt. The clay-silt is very micaceous and has abundant small black woody fragments. Small, thin-walled mollusks are common in these strata. In the upper part of the cycle, thin beds of light-colored, fine- to very fine-grained quartz-glauconite (5 percent average) sand are interbedded with equally thin, dark-gray, micaceous, woody clay. Woody fragments, mica, and rare thin-walled mollusk shells also are present in this interval. These beds are extensively bioturbated. The unit is about 30 ft thick in the shallow subsurface and tends to thicken downdip. The down-basin thickening is speculative because it is based only on geophysical log interpretations and not on cores. The basal contact with the underlying Kc_1 cycle is sharp, but there is very little reworked sediment along the boundary.

Mineralogically, quartz and glauconite are the major sand minerals. Smaller amounts of mica (both green and colorless), feldspar, and wood fragments are present. The opaque heavy minerals include ilmenite and leucoxene in nearly equal amounts. Non-opaque heavy minerals are more abundant than the opaques. They include large concentrations of chloritoid and smaller amounts of epidote, garnet, kyanite, rutile, and tourmaline. The clay mineral assemblage is similar to that of the overlying Kc_2 cycle.

The Kc_2 cycle is difficult to date precisely because of a paucity of microfossil data and the non-diagnostic nature of the mollusks. There is, however, a small ostracod assemblage which includes Fissocarinocythere gapensis, Haplocytheridea insolita, Ascetoleberis rugosissima, and Veenia spoori. These forms indicate a middle Campanian age (Gohn, 1992).

Gamma-ray logs of this unit indicate uniformly clayey sections (fig. 3, type B). A regressive sand facies is not present and presumably was stripped away during emplacement of the overlying Kc_3 cycle.

Kc_1 Kc_1 cycle (Upper Cretaceous, lower Campanian)--Consists of two major lithofacies. The lower facies consists of dark-gray-green, massive to thick-bedded, clayey, slightly micaceous, quartz (20 percent maximum) glauconite sand. The sand size and the quartz/glauconite ratio increase upward through the section. Macrofossils are rare in this facies but foraminifera, calcareous nannofossils and ostracodes are common to abundant in the upper part. This facies is 60 to 80 ft thick in the shallow subcrop. The lower facies is gradational into the upper facies. The upper facies consists of dark-gray, massive, locally shelly, somewhat sandy, very fine, very micaceous clay-silt. Small woody fragments are scattered throughout. This facies is about 60 ft thick in the shallow subcrop. The beds within this basin dip southeastward and are thickest in the middle of the map area. The basal contact with the underlying Magothy and Cheesequake Formations is sharp. A thin bed of gravelly (0.5 in maximum) sand commonly occurs along this contact.

Glauconite and quartz are the major sand-fraction minerals in the Kc_1 cycle. Feldspar, mica, and phosphatic vertebrate remains are minor constituents. The opaque and the non-opaque heavy minerals are similar to those in the overlying Kc_2 cycle. The clay minerals are primarily illite/smectite with smaller amounts of illite and kaolinite.

The age of the Kc_1 cycle was determined from calcareous nannofossils and ostracodes in the Clayton, N.J. core. Nannofossil taxa at the base include Marthasterites furcatus, Broinsonia parca parca, Calculites obscurus, Cribosphaera ehrenberbii, Eiffellithus turisiffeli, Gartnerago costatum, Micula decussata and Watznnaueria barnesae. The forms suggest assignment to the early Campanian Zone CC18 (D. Bukry, written commun., 1990). Nannofossil taxa from the upper part of the cycle include Biscutum spp., Broinsonia parca parca, B. sp. cf. B. parca constricta, Calculites obscurus, Eiffellithus eximus, E. turriseiffeli, Gartnerago costatum, Kamptnerius magnificus, Microrhabdulus decoratus, Micula decussata, Prediscosphaea cretacea, Reinhardites anthophorus, Watznaueria barnesae and W. biporta. These taxa suggest assignment to Zone CC19 of early Campanian age. Ostracode assemblages from the middle and upper part of the cycle contain the species Brachycythere pyriforma and Alatacythere cheethami (Gohn, 1992) which indicate an early Campanian age.

Gamma-ray logs through this unit show very little variation reflecting its clayey glauconitic nature (fig. 3, type B). The sandy Englishtown Formation, which is the upper unit of the cycle in outcrop, is not present in the subsurface.

Kcq Cheesequake Formation (Upper Cretaceous, lower Campanian and upper Santonian)--Clay-silt grading to sand at the top. Does not crop out and is known only for the few drill-hole geophysical logs which penetrate this formation. This new formation underlies most of the map area. The Cheesequake Formation thickens to the south where it reaches a maximum of about 80 ft beneath the Cape May peninsula.

A sample from a core hole near Buena shows the clay mineralogy is primarily illite/smectite with smaller amounts of illite and kaolinite.

The age of the Cheesequake Formation is latest Santonian to earliest Campanian as determined from pollen in outcrops located near Cheesequake (Litwin and others, 1993) in northern New Jersey. Calcareous nannofossils from the Buena corehole sample fall with nannofossil Zone CC18 or earliest Campanian (D. Bukry, written commun., 1993).

The typical geophysical gamma signature in the Cheesequake is type B (fig. 3, log I) suggesting the Cheesequake is a complete transgressive-regressive package.

Kmg Magothy Formation (Upper Cretaceous, middle and lower Santonian)--Sand light gray to white, fine to coarse grained, locally very gravelly (pebbles are less than 0.5 in.) especially in updip areas. Carbonized wood (several inches long) and colorless mica are scattered throughout the sands. The sands are typically cross stratified, some are massive, and a few are horizontally bedded. Black to dark-gray, very carbonaceous clays are locally interstratified with the sands. No calcareous fossils were recovered from the Magothy Formation in the shallow subsurface. Downdip at Buena N.J., the Magothy is primarily a massive to finely laminated, dark-gray, woody, clay-silt. The Magothy thins generally to the southwest although the basin appears to dip to the southeast.

The sands of the Magothy are primarily quartz with smaller amounts of rock fragments, mica, and minor feldspar. The opaque heavy minerals include ilmenite and leucoxene. The common non-opaque heavy minerals include zircon, tourmaline, and staurolite; less common minerals are garnet, rutile, and kyanite. Authigenic pyrite is common throughout the formation. The clay minerals are dominated by illite/smectite with smaller amounts of kaolinite and illite in the updip. Downdip at Buena, chlorite is an important clay mineral in this unit.

The age of the Magothy is best defined by its pollen. Christopher (1979) placed this palynoflora in his zone V of early and late Santonian age. He also recognized three subzones within zone V, the Complexiopollis exiqua-Santalacites minor Zone (lowest), the Pseudoplicapollis longiannulata-Plicapollis incisa Zone (middle), and the ?Pseudoplicapollis cuneata-Semioculopollis verrucosa Zone (highest). All these subzones are present in the Magothy in this map area. Petters (1976) reported an extensive marine fauna from his Magothy and Merchantville unit from the Anchor-Dickenson well near Cape May City. Because the samples from this hole are cuttings and came from great depth, these age determinations and stratigraphic picks are suspect.

Gamma-ray logs from the Magothy are similar throughout the subsurface. The log patterns dominantly indicate sandy beds in the updip areas, but thick clay beds are common in the downdip areas where they are interbedded with the sands (fig. 1, type E). In the Buena core hole there are no sands in the Magothy and the unit which is all clay or silt has a type C (fig. 3) geophysical signature.

Kr Raritan Formation (Upper Cretaceous, upper Cenomanian)--Clay, silty, dark gray, massive, shelly. Restricted to the deep subsurface in this map area and only penetrated in a few wells from which only scattered samples were obtained. Petters (1976) examined the subsurface in this region and proposed a new formation, the Bass

River Formation, which included the Raritan Formation. Based on his age determination it seems likely that he lumped the Raritan with the shelfal facies of the underlying unit. The name Bass River therefore is not used in this report. The Raritan lies within a basin that trends essentially north-south through the map area. Thickness values were derived from interpretations of geophysical logs from the few drill holes that encountered this formation; accordingly, these values are speculative. It is estimated that the Raritan is a maximum of 300 feet in the southernmost part of the state. Clayey samples were only obtained in our study for mineralogic analysis from the Buena core hole.

It is assumed that the Raritan is late Cenomanian to possibly early Turonian in age, as determined from northern New Jersey section. In outcrop to the north, the Raritan is early late Cenomanian in age (Cobban and Kennedy, 1990) on the basis of ammonites. Pollen from these outcrops belong to the Complexiopollis-Atlantopollis Zone (Zone IV, Christopher, 1979). Downdip, Petters (1976) reports the planktic foraminifer Marginotruncana helvetica, a middle Turonian marker from beds assigned to pollen Zone IV at Toms River, N.J.

Gamma-ray logs for the Raritan indicate clayey sections throughout the subsurface (fig. 3, type C).

KpIII Potomac Formation, unit III (Upper Cretaceous, lower Cenomanian)--Dominantly clay to clay-silt, thinly laminated to thick bedded, lensing, mottled red, white, and orange brown, less commonly dark gray and woody, with thin beds of very fine- to medium-grained sand, micaceous, massive or small-scale cross bedding, white to orange brown, also lensing. Those lithologies are typical of the shallow subsurface. Downdip, these lithologies interfinger with thin to thick beds of marine clay-silt, commonly glauconitic and locally shelly. These marine beds are most prevalent in the southernmost part of the map area. Potomac Formation, unit III underlies all of this map area. The beds have a general dip to the southeast and thicken from about 200 ft in the shallow subsurface to somewhat over 700 feet in the southernmost part of the state. The latter thickness was determined from geophysical logs because samples from this region consisted only of unreliable cuttings. Farther south near Salisbury, Md., Zone III beds were cored. There, the thickness of these beds is comparable to that seen in the Dickenson well in southernmost New Jersey. Zone-III sediments in the Ohio-Hammond drill hole near Salisbury, Md., like those in the Dickenson well, are mostly clay or silt. On the basis of the largely massive thin to thick horizontal bedding, the paucity of fossils and glauconite, and the alternation of lignitic clays and fine sands, the beds at Salisbury most likely are a delta-margin deposit with some marine influence. Whether a similar lithologic sequence is present at Dickenson I is uncertain; Petters (1976), based on the cuttings from this well, interpreted this section to be marine.

The sand mineralogy of the updip sections differ from that of the downdip sections. Updip, the only light minerals are quartz and siliceous rock fragments. The opaque heavy minerals are mainly ilmenite with small amounts of leucoxene and the non-opaque minerals are mostly zircon, tourmaline, staurolite, kyanite, and garnet.

The clay minerals are typically kaolinite and illite. Rarely, a few beds have high concentrations of illite/smectite. Downdip in the Delmarva Peninsula (Ohio-Hammond well report, Anderson, 1948), the light sand minerals are mostly quartz (90 percent) and feldspar (oligoclase, 10 percent). The opaque heavy minerals are listed as black, presumably ilmenite. The non-opaque heavy minerals are primarily epidote-group minerals with lesser amounts of zircon, staurolite, garnet, and hornblende. No clay minerals were determined in these cores.

The age of unit III was determined from two major fossil groups, pollen in the non-marine deposits and foraminifera in the marine sections. The pollen assemblages in Zone III differ from those of the younger Zone IV by the lack of Normapolles elements. Typical forms found in Zone III in New Jersey are Tricolpites vulgaris, Tricolpites nemejci, Tricolporoidites bohemicus, Tricolporoidites sp. A, Tricolporoidites sp. B, Ajatipollis sp. A and Tricolporopollenites sp. B (Doyle and Robbins, 1977). In the marine facies, Petters (1976) reports a planktic foraminiferal suite containing Rotalipora greenhornensis and Praeglobotruncana delrioensis. Both the pollen and foraminiferal assemblages suggest an early Cenomanian age.

Gamma-ray logs in the non-marine sections indicate dominantly clayey strata with thin to thick interdigitated sand beds. Gamma-ray logs in the marine sections indicate clayey beds throughout.

KpII Potomac Formation, unit II (Lower Cretaceous, Albian)--Clay, typically mottled in reds, whites, and yellow browns, less commonly dark gray; massive to finely laminated, locally very woody, rarely pyritic. Interstratified with loose pale-gray to white-weathering, yellow, or orange-brown, cross-stratified to thinly bedded, fine- to very coarse-grained sand. Sands commonly occur in well-defined channels. These non-marine facies are typical of the formation throughout most of the map area. It is possible these non-marine facies interfinger with glauconitic marine beds in the lower Delmarva Peninsula (Anderson, 1948). This unit underlies nearly all the map area. In general, the unit has a southeast dip and a range in thickness from 300 feet in the shallow subsurface to an estimated thickness of over 1200 feet in the extreme downdip.

Mineralogically, the sands are mostly quartz with small amounts of siliceous rock fragments. Small amounts of feldspar are reported in the marine facies to the south (Anderson, 1948). The opaque minerals are leucoxene and ilmenite. Non-opaque minerals include staurolite, tourmaline, kyanite, zircon, and rutile. The clay minerals are a mixture of kaolinite and illite.

The age of Potomac Formation, unit II was determined from its pollen. Pollen Zone II is divided into three sub-Zones IIA, IIB, and IIC. Zone IIA contains Apiculatisporis babae, "Monosulcites" chaloneri, Perotriletes pannuceus, Tricolpites miromunus, "Tricolpopollenites" parvulus, Tricolpites sagax, T. georgenis, and "Retitricolpites" vermimurus. The age of this assemblage is near the early-middle Albian boundary. Zone IIB is defined by Cicatricosisporites patapscoensis, C. subrotundus, "Lycopodiumsporites" cerniidites, Neoraistricka robusta, and Retitulatisporites arcuatus. Subzone IIB is probably early to middle late Albian in age. Zone IIC is characterized by Ruqubivesiculites rugosus, Tricolporoidites subtilis, "Tricolporopollenites" distinctus and Tricolporodi minimus. The age of this subzone is latest Albian.

Gamma-ray logs through this unit show that thick beds of clay and sand are typical (type A).

KpI Potomac Formation, unit I (Lower Cretaceous, Barremian)--Clay, mottled red, white, or orange brown, less commonly dark gray or black, woody, locally with large masses of siderite. Beds are a few inches to several feet thick, massive or finely laminated, and lensing. Interbedded with fine- to coarse-grained, white to light-gray sands which are typically cross-stratified at typically small scales (less than two feet in thickness). Locally, the sands have a small to large concentration of gravel. This is the typical cycle-I facies in the shallow to intermediate subsurface. These sediments lie within an arcuate basin in which the sediments generally thicken toward the south where they are about 1000 feet thick. In the deep subsurface, the non-marine facies of the updip area interfingers with the marine facies, based on data from the Ohio-Hammond core hole in the Delmarva Peninsula (Anderson, 1948). There macro- and microfossiliferous, glauconitic sand beds are interstratified with dark-gray lignitic clays and light-colored feldspathic sands and gravelly sands in what is interpreted to be a marginal-marine or delta-front environment (Owens and Gohn, 1985).

Mineralogically, sands in the non-marine facies are mature orthoquartzites which have limited heavy mineral suites. The clay mineral assemblages are also mature, consisting largely of kaolinite and illite. The subsurface beds to the south of New Jersey are reported to be arkosic but no statistical data was presented (Anderson, 1948). In the same report, the opaque heavy minerals are classified as black (ilmenite?) and brown (pseudorutile?). The non-opaque heavy-mineral suite is dominated by zircon, staurolite, and garnet with smaller amounts of tourmaline and rutile. No clay mineralogy was reported for these sediments.

The sediments of this unit fall within pollen Zone I. Characteristic pollen in this zone are Kuylisporites lunaris, Ephedripites virginiaensis, Lilacidites sp. A, L. sp. B, and Stellatopollis sp., but these are rare. Zone I can usually be distinguished from Zone II by the absence of the Zone-II index species cited above (Doyle and Robbins, 1977). The age of Potomac unit I is probably Barremian.

Gamma-ray logs from this unit show that sands are much more abundant than in units II and III but the unit is essentially type A.

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