Stratigraphy of the Outcropping Post-Magothy Upper Cretaceous Formations in Southern New Jersey and Northern Delmarva Peninsula, Delaware and Maryland

GEOLOGICAL SURVEY PROFESSIONAL PAPER 674

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By JAMES P. OWENS, JAMES P. MINARD, NORMAN F. SOHL, *and* JAMES F. MELLO

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Lithostratigraphic and biostratigraphic studies confirm the persistence of four Campanian formations from northern New Jersey to northern Delaware and eastern Maryland

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By JAMES P. OWENS, JAMES P. MINARD, NORMAN F. SOHL, AND JAMES F. MELLO

ABSTRACT

Stratigraphic studies of the post-Magothy Upper Cretaceous Coastal Plain formations of the Delmarva Peninsula indicate that four of the formations recognized in New Jersey are present in northern Delaware and eastern Maryland. These are the Merchantville, Englishtown, and Marshalltown Formations and the Mount Laurel Sand; the Wenonah and Navesink Formations probably either pinch out or have been eroded away between southern New Jersey and northern Delaware. Although the four formations persist as recognizable lithostratigraphic units from New Jersey into the Delmarva Peninsula, each shows a depletion of glauconite sand toward the southwest.

Comparison of the faunas of the formations in the two areas confirms the rock stratigraphic correlations. The megainvertebrate fossils have proved to be, in this area, more useful than the microfauna in stratigraphic correlation. The *Exogyra cancellata* zone in the Mount Laurel Sand and the *E. ponderosa* zone in the Marshalltown Formation are in the same stratigraphic positions in southern New Jersey and in the Delmarva Peninsula.

INTRODUCTION

The northern Atlantic Coastal Plain was one of the earliest areas investigated geologically in North America, and a stratigraphy of Coastal Plain formations gradually evolved from the many early investigations. Much effort was devoted to the study of the sediments of Cretaceous to early Tertiary age because of their good exposure between Raritan Bay, N.J., and the Potomac River in northern Virginia. North and south of this region, younger sediments overlap and obscure the underlying Cretaceous and lower Tertiary beds. In the northern Atlantic Coastal Plain the most detailed stratigraphy of these beds was established for the west-central and northern parts of the Coastal Plain in New Jersey. In Delaware and Maryland, the stratigraphy that evolved was less detailed. One of the major reasons for the lack of knowledge of detailed stratigraphy southwest of New Jersey is that Delaware Bay and Chesapeake Bay prevent tracing along the outcrop of the New Jersey formations into Delaware and Maryland. These bays divide the outcrop belt of Upper Cretaceous and lower Tertiary formations in the northern Atlantic Coastal Plain into three parts: New Jersey, Delmarva Peninsula (east of Chesapeake Bay), and the western Maryland Coastal Plain (west of Chesapeake Bay).

In recent years, three major attempts have been made to extend the Upper Cretaceous-lower Tertiary stratigraphy of New Jersey into the Delmarva Peninsula, the flat low-lying area between the Delaware and Chesapeake Bays (fig. 1).

Since 1957 the U.S. Geological Survey has been mapping the rock stratigraphic units of the Coastal Plain in New Jersey. An area of about 600 square miles has been mapped at a scale of 1:24,000 in west-central New Jersey near Trenton and in the adjacent parts of Pennsylvania. Mapping also has been completed in the Sandy Hook quadrangle to the northeast and in the Woodstown quadrangle to the southwest (fig. 1), both in New Jersey. Reconnaissance has been done in the areas between. In addition, mapping and reconnaissance recently has been extended into the Delmarva Peninsula.

This report is divided into two parts: (1) rock stratigraphic studies and (2) biostratigraphic analysis. The region discussed extends from Sandy Hook, N.J., to Chesapeake Bay, Md. (fig. 1). The main emphasis is on the stratigraphic relationships between units of southern New Jersey and the northern Delmarva Peninsula.

PREVIOUS INVESTIGATIONS

Numerous lithostratigraphic and biostratigraphic studies have been made of Cretaceous-Tertiary rocks in the northern part of the Atlantic Coastal Plain during the past century. Only those that are particularly significant to the main topic of this paper will

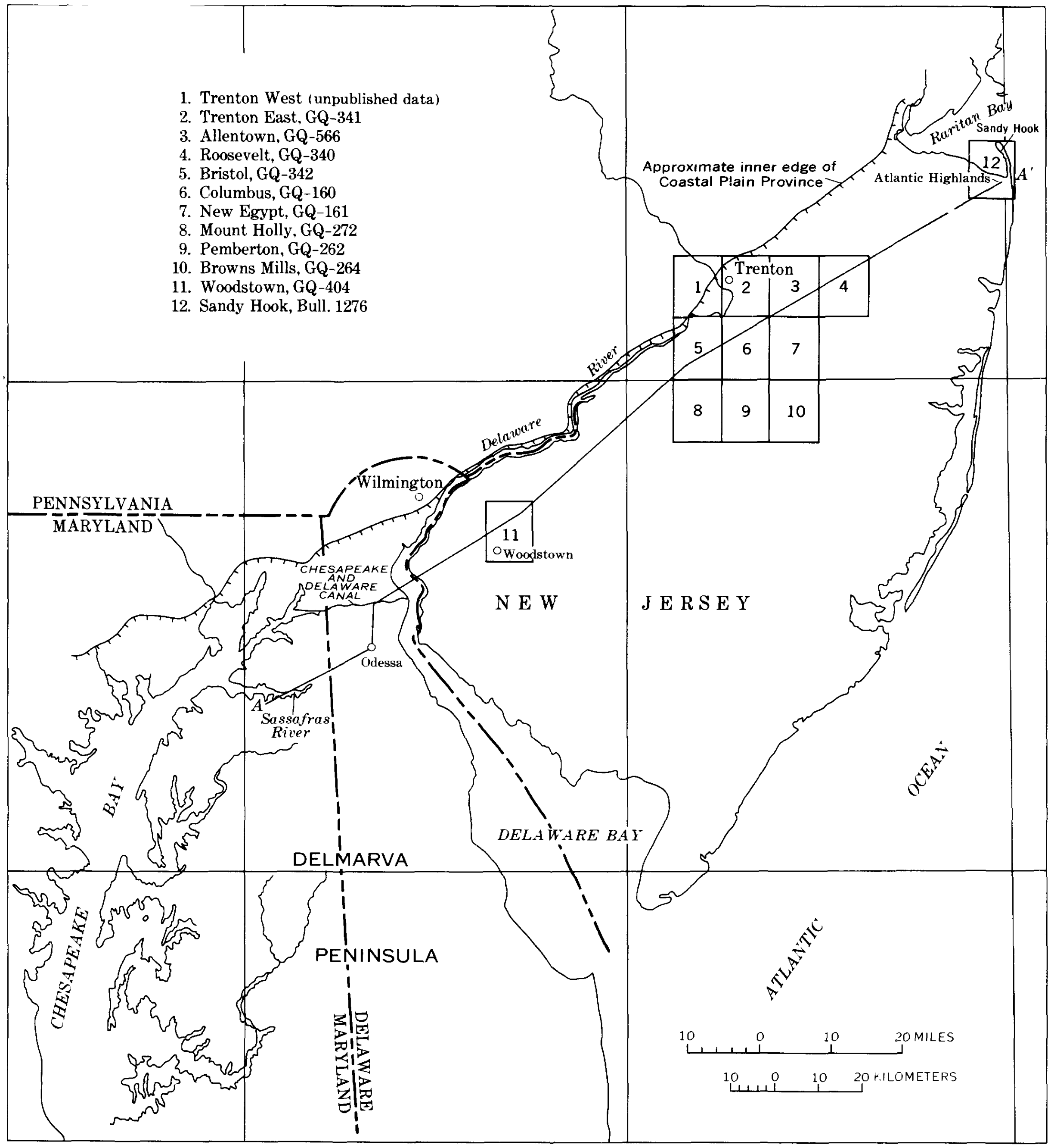

FIGURE 1.—Index map of southern New Jersey and northern Delmarva Peninsula showing locations of 7½-minute quadrangles that have been mapped. *A–A'* is line of section for figure 4.

be discussed here. More detailed discussions of early investigations have been given by Groot, Organist, and Richards (1954) for Delaware and by Greacen (1941) for New Jersey.

Detailed stratigraphic investigations of the Cretaceous formations for the entire region began with the studies of W. B. Clark and his associates during the period from 1894 to 1916. Clark, Bagg, and Shattuck (1897) proposed a stratigraphic sequence (fig. 2) from which most of the present divisions evolved. Kümmel and Knapp (1904) modified Clark's stratigraphy in New Jersey, particularly the Matawan Formation (fig. 2). Weller and Knapp (Weller, 1907) modified the earlier stratigraphic studies and further subdivided the basic units (fig. 2). This stratigraphic sequence is accepted today not only in New Jersey but also in Delaware and eastern Maryland. They were the first to define the relation be-

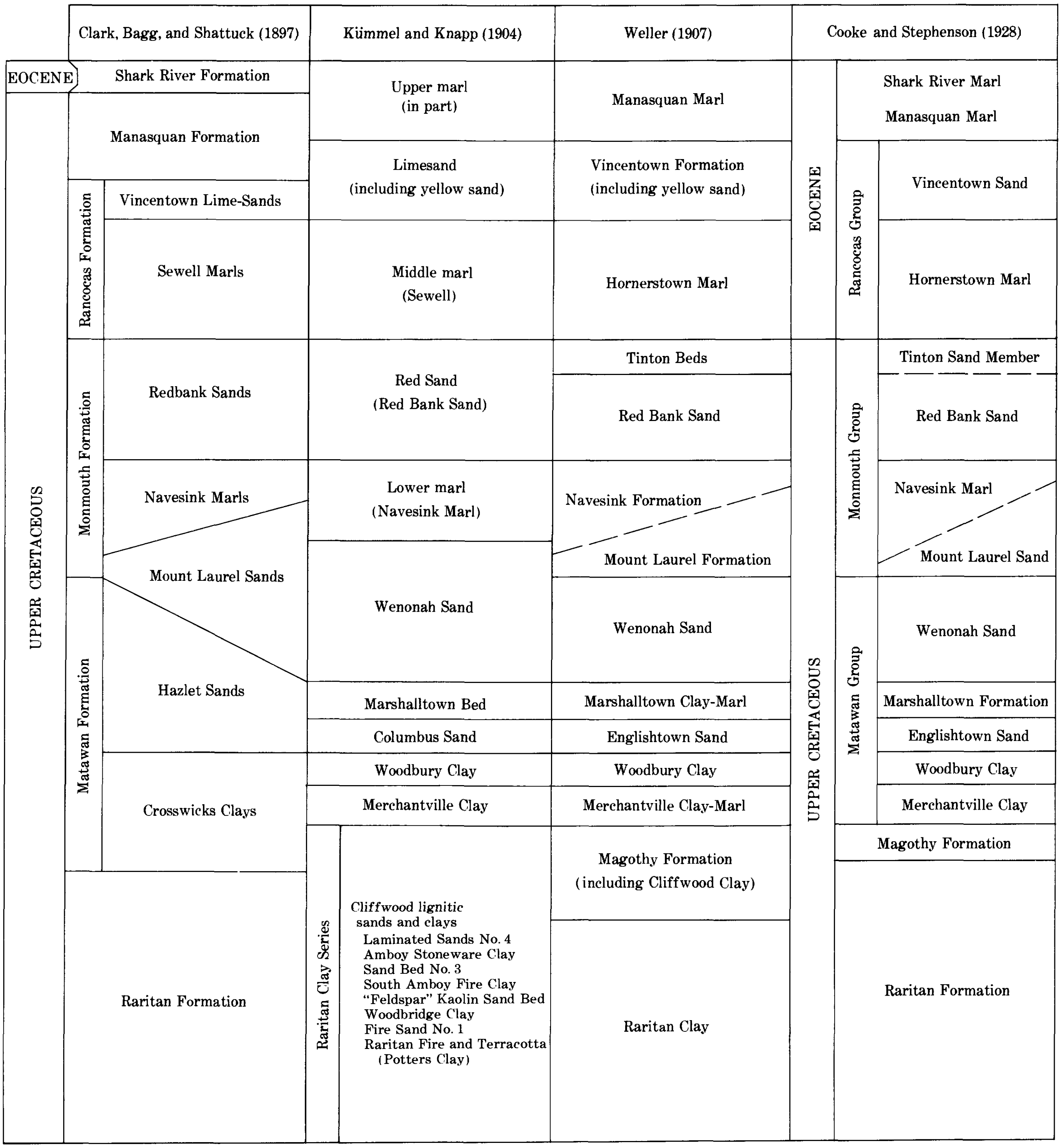

Figure 2.—Development of stratigraphic interpretations of the pre-Miocene strata in New Jersey.

tween the lithostratigraphy and the biostratigraphy of the Upper Cretaceous beds in New Jersey (Weller, 1907). Cooke and Stephenson (1928) showed that the uppermost formations assigned to the Upper Cretaceous by previous investigations were actually lower Tertiary (fig. 2).

The stratigraphic section proposed by Clark, Bagg, and Shattuck (1897) for the Coastal Plain of

Delaware and Maryland was similar to that of New Jersey. However, despite the fact that Clark continued his investigations in Delaware and Maryland well into the early 1900's, the stratigraphic section proposed in 1897 was not formally subdivided in this region as it was in New Jersey.

Carter studied the strata along the Chesapeake and Delaware Canal during 1934 and 1935, especially near Summit Bridge, Del. He (1937) applied some of the New Jersey formation names to his units (table 1). The Matawan of the area was subdivided for the first time, and the Monmouth Group, along the canal, contained only a single formation (table 1). Spangler and Peterson (1950) examined the canal section as part of a regional study of the northern Atlantic Coastal Plain. They also applied New Jersey names to the units, but their identification and correlation of units differed from Carter's (table 1). Groot, Organist, and Richards (1954) made the most recent study of the canal section before the present report (table 1). Names of stratigraphic units of New Jersey were assigned to the units, but the interpretation of the section by Groot, Organist, and Richards differed from that of Carter and that of Spangler and Peterson (table 1). The authors of this report first studied the canal section

TABLE 1.—*Stratigraphic interpretation of the formations cropping out along or nearby to the south of the Chesapeake and Delaware Canal*

[The column by Carter and the column of this report are nearly identical and are considered, by the present authors, to be the correct interpretation of the stratigraphy]

Clark (1916, p. 27)			Carter (1937, p. 245)			Spangler and Peterson (1950, p. 6, 47)			Groot, Organist, and Richards (1954, p. 7, 21)			This report	
Upper Cretaceous	Danian	Rancocas Formation				Eocene		Vincentown (Aquia)				Tertiary	Hornerstown Sand
								Unconformity					Unconformity
Upper Cretaceous	Senonian	Monmouth Formation	Upper Cretaceous Series	Monmouth Group	Navesink marl (presence inferred in area south of the canal)	Upper Cretaceous	Monmouth (Formation)	Navesink	Upper Cretaceous	Monmouth (Group)	Red Bank	Upper Cretaceous	Mount Laurel Sand
			Upper Cretaceous Series	Monmouth Group	Mount Laurel Sand								
Upper Cretaceous	Senonian	Matawan Formation	Upper Cretaceous Series	Matawan Group	Marshalltown Formation	Upper Cretaceous	Monmouth (Formation)	Mount Laurel	Upper Cretaceous	Monmouth (Group)	Navesink-Mount Laurel	Upper Cretaceous	Marshalltown Formation
Upper Cretaceous	Senonian		Upper Cretaceous Series	Matawan Group	Englishtown Sand	Upper Cretaceous	Matawan (Formation)	Wenonah	Upper Cretaceous	Matawan (Group)	Wenonah	Upper Cretaceous	Englishtown Formation
Upper Cretaceous	Senonian		Upper Cretaceous Series	Matawan Group	Crosswicks Clay is the equivalent of the Woodbury Clay and Merchantville Clay in New Jersey	Upper Cretaceous	Matawan (Formation)	Marshalltown, Woodbury, and Merchantville undifferentiated	Upper Cretaceous	Matawan (Group)	Merchantville	Upper Cretaceous	Merchantville Formation
								Unconformity					
Upper Cretaceous	Turonian	Magothy Formation	Upper Cretaceous Series	Magothy Formation		Upper Cretaceous		Magothy				Upper Cretaceous	Magothy Formation
								Unconformity					Unconformity
Upper Cretaceous	Cenomanian	Raritan Formation	Upper Cretaceous Series	Raritan Formation		Upper Cretaceous		Raritan				Upper Cretaceous	

in 1963 and mainly agree with Carter's interpretation (table 1).

The Upper Cretaceous stratigraphic nomenclature in eastern Maryland has remained much as Clark (1916) had shown. Clark's Matawan and Monmouth Formations were the standard for the east side of Chesapeake Bay (Overbeck and Slaughter, 1958) prior to this report.

In the following section, the units in New Jersey will be described in detail in order to establish their lithologic characteristics and to compare these units with those in the northern Delmarva Peninsula.

ROCK STRATIGRAPHIC STUDIES

By JAMES P. OWENS and JAMES P. MINARD

The sedimentary rocks of Late Cretaceous age in New Jersey are mostly mixed or interbedded unconsolidated sands, silts, and clays. Both allogenic (quartz, feldspar, mica, and carbonaceous debris) and authigenic (glauconite, pyrite, and siderite) minerals are abundant, although the allogenic constituents predominate.

These sedimentary rocks can be divided into 11 lithostratigraphic units which are well defined in outcrop. These have a pronounced cyclic pattern that has not been previously recognized and that has been a major cause for misidentifications in earlier regional stratigraphic studies.

NEW JERSEY

MERCHANTVILLE FORMATION

The Merchantville Formation is the oldest of the glauconite sandy units in the Coastal Plain in New Jersey (fig. 3), but unlike most of the younger greensands it consists of more than one lithofacies.

In the north, the Merchantville is mainly a sequence of thin (2–6 in.) very fine to fine-grained sandy and silty beds and, less commonly, thick (3–6 ft) beds of glauconite sand. Discontinuous layers of rounded pale-gray siderite concretions are abundant in the thin-bedded sequence. In the west-central outcrop area, the Merchantville is a thick-bedded (5–15 ft) sequence of dark-gray clayey quartz silts and dark-greenish-gray quartz-glauconite sands. In the southwest, the formation is a dark-gray massive silty fine to very fine glauconite-quartz sand. All beds in the Merchantville are poorly sorted; *So* (Trask sorting coefficient) equals 2.56 millimeters average. Fossil casts are abundant, and locally in the southwest, very fossiliferous siderite concretions are common in the lower part of the formation. The Merchantville ranges in thickness from 40 to 60 feet. The contact with the underlying Magothy is sharp and disconformable. A bed about 1 foot thick

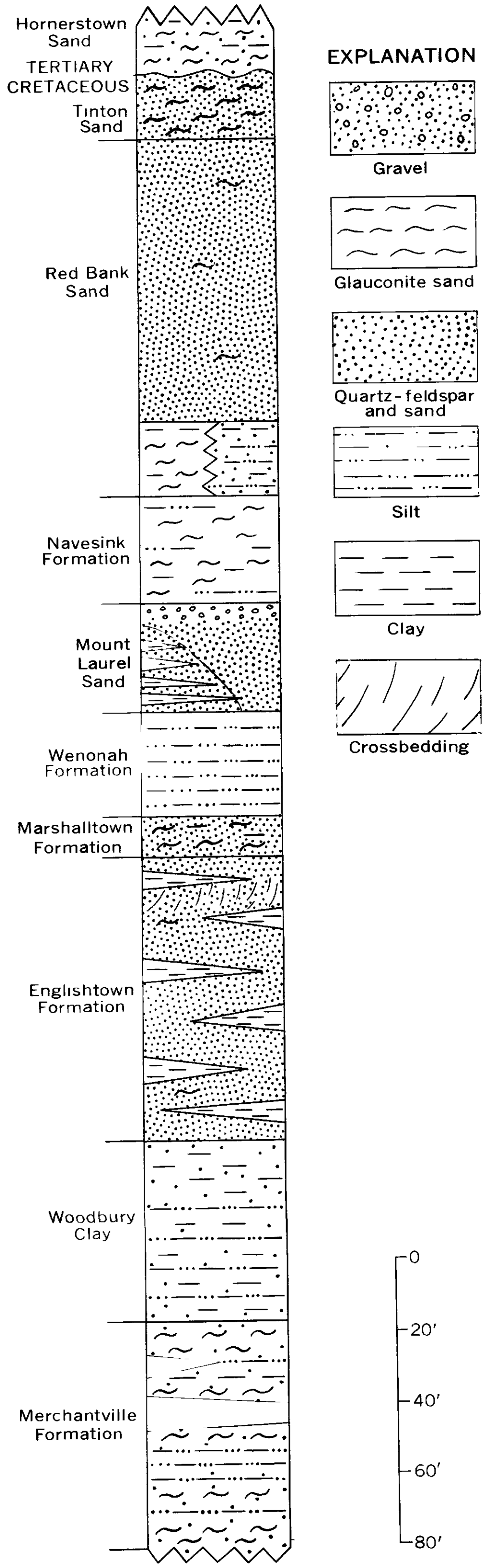

FIGURE 3.—Composite columnar section showing general thickness and lithology of Upper Cretaceous formations in the northern and west-central Coastal Plain in New Jersey.

containing reworked gravel and rounded woody fragments is present along the contact between the two units.

WOODBURY CLAY

The Woodbury Clay is chiefly a dark-grayish-black unconsolidated massive very clayey silt, except in the upper part where lentils of glauconite sand are common. It is very poorly sorted (So=2.62–4.24 mm commonly). The silt fraction consists mainly of quartz, feldspar, and mica; mica plates are also common in sand sizes. Carbonaceous matter, both finely comminuted and coarse grained, is also very abundant. Imprints of fossil shells are abundant, and locally in the southwest, well-preserved calcareous shells have been collected. The unit ranges in thickness from a maximum of 50 feet in the west-central part to zero in the southwest. It is gradational into the underlying Merchantville Formation.

ENGLISHTOWN FORMATION

The Englishtown Formation is chiefly a clastic sand that consists of more than one lithofacies. In the north where this unit is approximately 140 feet thick, it is mainly a pale-gray to white cross-stratified medium sand in the upper part and a dark-gray silt with thin quartz sandy partings in the lower part. In the west-central outcrop area, it is chiefly an intercalated thin-bedded sand-clay sequence. The Englishtown is approximately 90 feet thick in this area. In the southwest, the Englishtown thins to approximately 40 feet and is a dark-gray massive very fine to fine sand. These beds resemble the Wenonah Formation.

The sandy beds in the Englishtown are typically moderately to well sorted (So=1.35–1.58 mm). Quartz, feldspar, weathered glauconite grains, and mica are the major sand constituents. The thin clay beds in the intercalated sequences and the massive dark beds are very silty and micaceous and contain large concentrations of fine to coarse lignitized plant matter.

Few fossils have been reported from the Englishtown. Locally, fossiliferous pale-gray sideritic concentrations are present in the base of the intercalated sequences. Fossil casts are also common in the massive dark sand in the southwest.

The Englishtown grades downward into the Woodbury Clay throughout most of the outcrop, but in the southwest where the Woodbury is absent, it overlies and grades downward into the Merchantville Formation.

MARSHALLTOWN FORMATION

The Marshalltown Formation is a massive dark-greenish-gray very fine to fine sand, which locally contains abundant silt and clay. Small pebbles and granules are common in the base and middle of the formation. It is moderately to very poorly sorted (So=1.36–4.80 mm commonly). Quartz and glauconite are the common sand minerals; feldspar and mica are present in small amounts. Glauconite is abundant in the middle and upper parts of the formation; quartz and, locally, concentrations of lignitized wood are common in the base. The glauconite grains are light to dark green and very fine to fine and include several percent of "accordion" forms. Fossils are rare in the north and west-central part of the Coastal Plain but are abundant in the southwest, especially the pelecypod *Exogyra ponderosa* (Roemer). The Marshalltown is remarkably constant in outcrop thickness, ranging from 10 to 15 feet. The contact with the underlying Englishtown Formation is sharp; a thin reworked bed occurs locally along the boundary.

WENONAH FORMATION

The Wenonah Formation is an unconsolidated massive to thick-bedded dark-gray silty very fine to fine sand. It is very poorly to moderately sorted (So=1.49–2.81 mm commonly). The Wenonah is chiefly a very micaceous, glauconite-feldspar-quartz sand. Finely disseminated pyrite and sand- to silt-sized carbonaceous particles are particularly abundant. The formation has few fossils; only casts have been observed. Abundant cylindrical borings indicate that the unit ranges in thickness from a maximum of 60 feet in the west-central part of the Coastal Plain in New Jersey to a minimum of 15 feet in the southwest. The contact with the underlying Marshalltown Formation is gradational.

MOUNT LAUREL SAND

The Mount Laurel Sand is largely a clastic sand, which weathers readily to a light gray or reddish brown. These weathered beds strongly resemble the upper quartz sand unit of the Red Bank Sand for which it is commonly mistaken. The Mount Laurel consists of more than one lithofacies along strike. In the northeast, it is mostly a sequence of intercalated thin (6 in. or less) dark-gray clay and light-gray sand beds. In the west-central area, it is largely a massive sand that locally interfingers with the intercalated sequence, particularly at the base of the formation. In the southwest, the formation is mainly a massive to thick-bedded sand. A 5- to 10-foot-thick bed of pebbly coarse sand occurs everywhere in outcrop at the top of the formation. Most of the sandy facies are moderately sorted ($So = 1.15–1.87$ mm commonly), except in the upper coarser beds where the sorting is poor. Characteristically, this formation is a glauconite-feldspar-quartz sand. Locally, mica is abundant in the base. Fossils are largely in thin to thick layers throughout; the upper shell beds include *Exogyra cancellata* (Stephenson) and *Belemnitella americana* (Morton). *E. cancellata* is restricted to this formation. The Mount Laurel Sand ranges in thickness from 20 feet in the north to 70 feet in the southwest. The contact with the underlying Wenonah is typically gradational but locally may be distinct.

NAVESINK FORMATION

The Navesink Formation is a massive unconsolidated dark-greenish-gray clayey and silty medium to coarse sand. It is moderately to very poorly sorted ($So = 1.57–3.24$ mm commonly). The Navesink is primarily a clayey glauconite sand (greensand); the lower few feet contain a few percent quartz, reworked from the underlying Mount Laurel. The unit is differentiated from the quartz-glauconite lithofacies of the Red Bank Sand mainly by the lack of sand-sized mica and by the smaller amounts of carbonaceous matter. However, clay- to silt-sized mica is abundant. The Navesink is very fossiliferous, especially the base. In the north, the middle and upper parts of the formation contain fossil beds as much as 5 feet thick largely consisting of mollusks. The unit crops out along the entire inner edge of the Coastal Plain in New Jersey. Here it ranges in thickness from a maximum of 35 feet in the west-central part to 5 feet in the southwest. The contact with the underlying Mount Laurel Sand is sharp.

RED BANK SAND

The Red Bank Sand is restricted to the northern and west-central parts of the Coastal Plain in New Jersey where it forms a wedge-shaped deposit that pinches out downdip and along strike to the southwest. The formation consists of three major lithofacies: an upper quartz sand, a lower silt, and a lower glauconite sand (fig. 3).

Upper quartz sand.—The upper quartz sand is an unconsolidated massive reddish-brown fine to coarse sand, which locally contains pebbles and which is well to moderately sorted ($So = 1.17–1.83$ mm commonly). It is a glauconite-feldspar-quartz sand. Typically, it is weathered throughout and locally is cemented by iron oxides. Most of the unit is unfossiliferous, but it contains some poorly preserved reworked fossils in the base. The upper quartz sand unit ranges from 0 to 100 feet in thickness and grades into the underlying lithofacies, commonly through a transitional zone several feet thick.

Lower silt.—The lower silt crops out only in the northern part of the Coastal Plain. It is an unconsolidated massive dark-gray silty medium sand. Typically it is poorly to very poorly sorted ($So = 2.34–3.93$ mm). This lower silty unit is a moderately to very micaceous feldspar-glauconite-quartz sand; locally it contains much sand-sized carbonaceous matter and pyrite. The unit is very fossiliferous, and, locally, calcareous tests are well preserved. It is as much as 30 feet thick.

Lower glauconite sand.—The lower glauconite sand crops out only in the west-central part of the Coastal Plain. It is an unconsolidated dark-greenish-gray massive fine sand containing much clay and silt. Typically it is very poorly sorted ($So = 2.12$ mm). The sand consists of feldspar, quartz, and especially glauconite. Carbonaceous matter and sand-sized mica are especially abundant in this lithofacies. This unit is sparingly fossiliferous. It is as much as 30 feet thick, and to the north it grades laterally into the lower silty unit and downward into underlying Navesink with no perceptible break.

TINTON SAND

The Tinton Sand is an unconsolidated pale-greenish-gray sand in the base to locally reddish-brown well-indurated sandstone in the upper 8–10 feet. Induration is largely due to fine crystalline sideritic cement. The sand is mostly fine to medium. Near the top, however, it is coarse and pebbly and is very poorly sorted ($So = 3.0$ mm commonly). The Tinton is mostly a feldspar-glauconite-quartz sand to quartz-glauconite sand; glauconite is much more abundant near the top of the formation. In some areas, it contains many fossils, chiefly mollusks and *Callinassa* sp. The cephalopod *Sphenodiscus* is fairly common at the type locality. The unit is restricted to the northern part of the Coastal Plain where it attains a maximum thickness of about 25 feet. The contact with the underlying Red Bank Sand is gradational. The upper boundary with the Hornerstown is sharp and unconformable.

DISTRIBUTION OF FORMATIONS

A major stratigraphic problem in New Jersey is to determine which formations persist from the northeast, where the Upper Cretaceous section is the thickest, to the southwest, where the section is thinner and the formations are fewer. An additional problem is to determine what facies changes occur within each formation. The Upper Cretaceous sec-

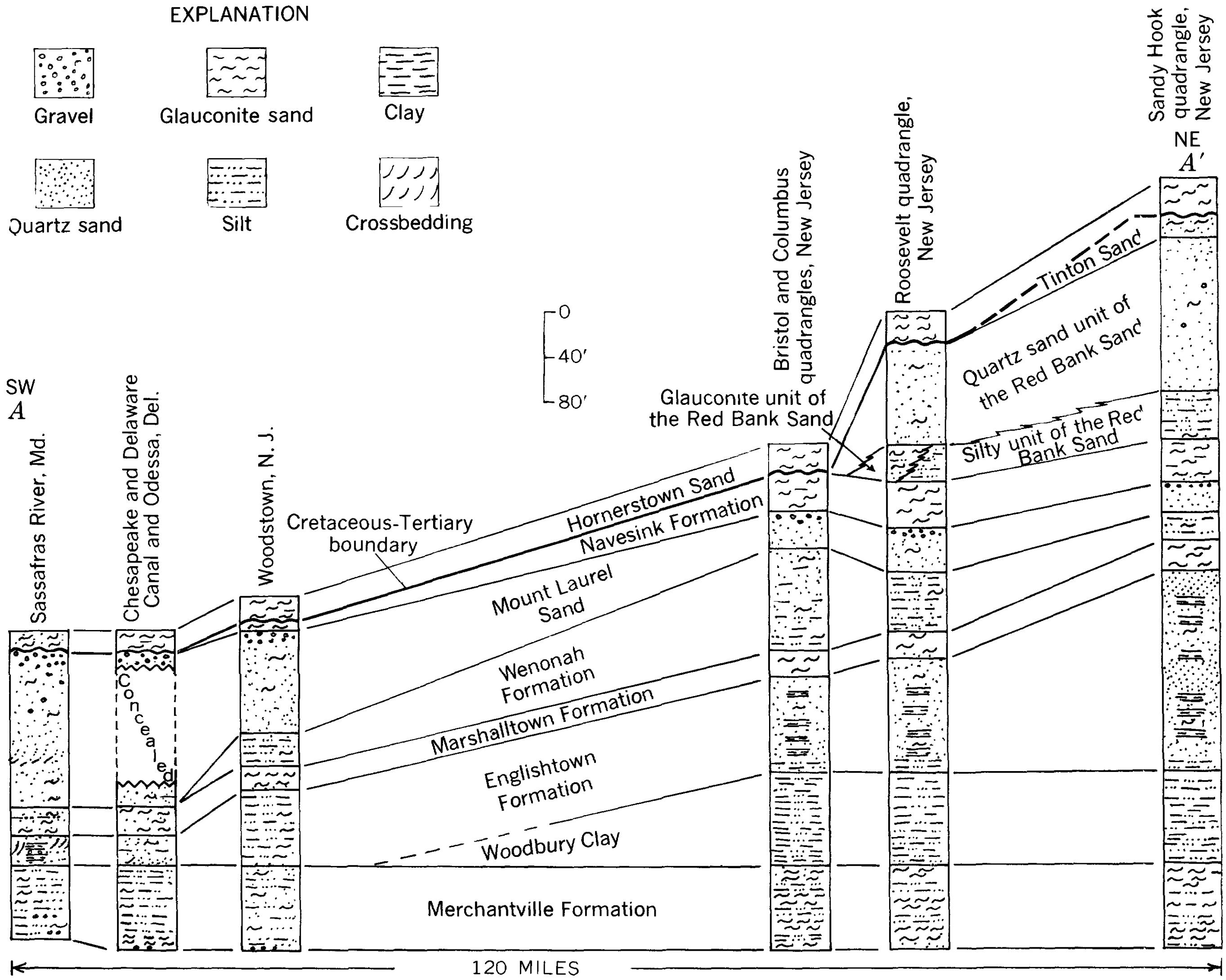

FIGURE 4.—Stratigraphic section along the Upper Cretaceous outcrop belt from southwestern New Jersey to eastern Maryland. Line of section shown in figure 1.

tion, excluding the Raritan Formation, thins from about 500 feet in the Raritan Bay area to about 250 feet at Woodstown (fig. 4). As can be seen in figure 4, major changes toward the southwest primarily involve the uppermost Cretaceous units, the Tinton, Red Bank, and Navesink. The absence and thinning of these units toward the southwest can be explained by nondeposition and (or) postdepositional erosion.

A map showing the areal distribution of the Coastal Plain formations from New York to northern Virginia has been published by the U.S. Geological Survey (1967). Part of this map is reproduced in figure 5 and illustrates the authors' interpretation of the geology of southwestern New Jersey and the northern Delmarva Peninsula.

The section at Woodstown is discussed in more detail than any other from New Jersey because it is the closest area to the Delmarva Peninsula in which detailed mapping was completed.

At Woodstown (figs. 4 and 5), the Tinton and Red Bank Sands are absent, as postulated by Knapp (Weller, 1907, p. 15) and mapped by Minard (1965). The basal Tertiary unit, the Hornerstown, here rests on the Navesink and locally on the Mount Laurel in updip areas. The Navesink thins in outcrop from about 12 feet near the east boundary of the Woodstown quadrangle to zero at the west edge. Downdip or southwestward, the Navesink thickens to more than 20 feet. The wedge shape of the Navesink in this quadrangle suggests an angular unconformity between this unit and the overlapping Hornerstown Sand.

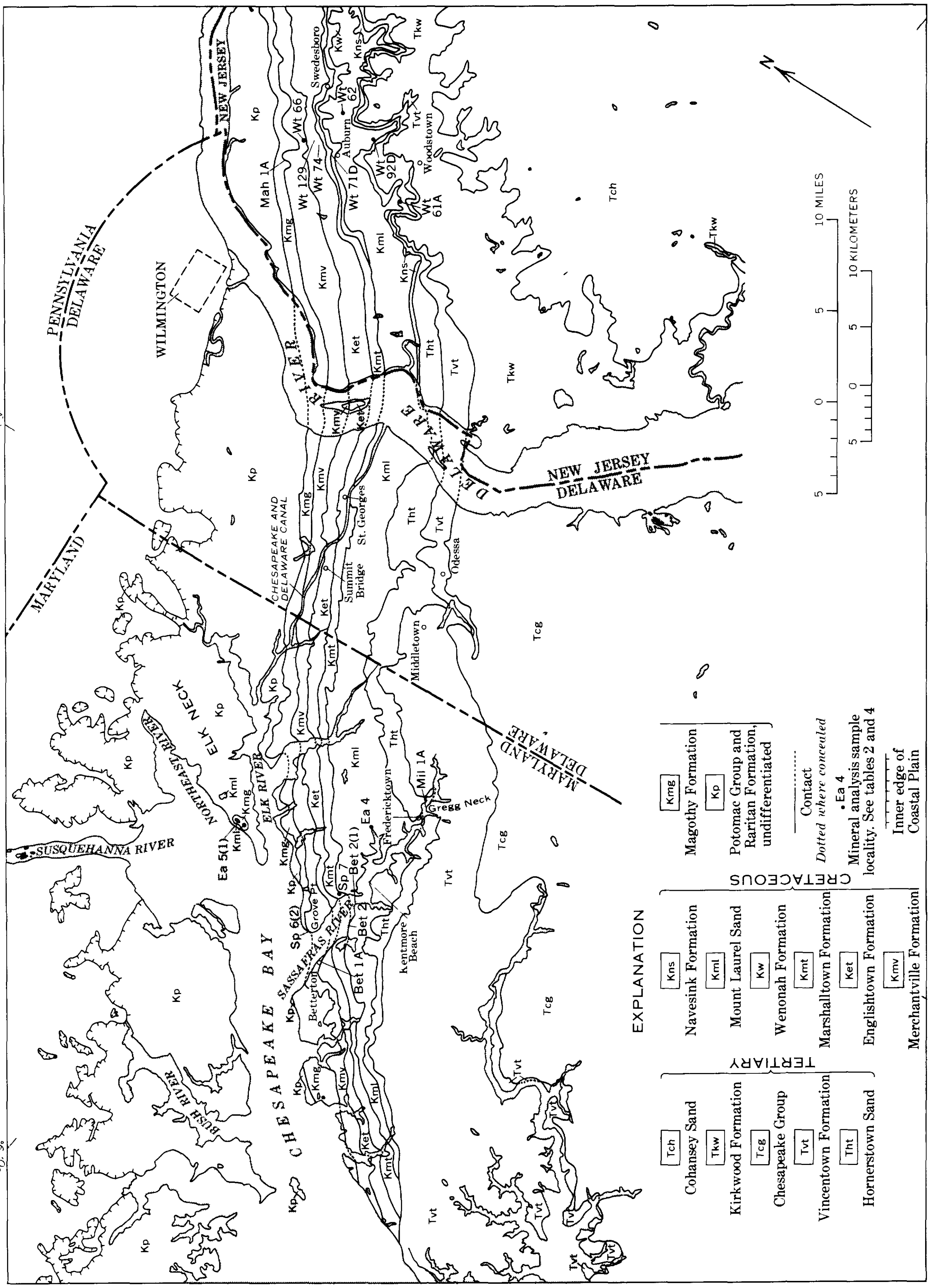

Figure 5.—Geologic map of southwestern New Jersey and northern Delmarva Peninsula. Modified from U.S. Geological Survey (1967, sheets 1B and 2B).

The Mount Laurel Sand underlying the Navesink is approximately 80 feet thick at Woodstown. This is the maximum outcrop thickness of this unit in New Jersey. Weller and Knapp (Weller, 1907, p. 103) considered the thickening of the Mount Laurel to be at the expense of the Navesink. It should be noted, however, that the underlying Wenonah also thins southwestward, and at Woodstown, the formation is only 15 feet thick. This fact suggests that the thickening of the Mount Laurel may be related to the thinning of the Wenonah because of a simple textural change from the silt (Wenonah) to a coarser sand (Mount Laurel). If the above explanation is correct, then a radical mineralogic change is not required as would be so for the change from the Mount Laurel (detrital sand) to the Navesink (authigenic sand).

The Marshalltown has virtually the same thickness and lithology at Woodstown as to the northeast; fossils, however, are abundant at Woodstown, but rare to the northeast. The Marshalltown, because of its persistent lithic characteristics, serves as an excellent stratigraphic marker in New Jersey and the Delmarva Peninsula.

The Englishtown shows a marked change in facies in the Woodstown area. In the north-central part of the quadrangle, near Swedesboro, this unit is a sequence of intercalated thin-bedded clays and sands, like much of the Englishtown to the northeast. Between Swedesboro and Woodstown, the formation changes to a thick-bedded silt and sand. At the west edge of the quadrangle, the formation is a massive dark very micaceous silty very fine to fine sand that strongly resembles the Wenonah, the basal Red Bank in the northern Coastal Plain, and the underlying Woodbury Clay in its type area. A major stratigraphic problem has been whether this dark very fine sand is the Woodbury or a facies change in the Englishtown. On the geologic map of New Jersey (Lewis and Kümmel, 1912), the Englishtown is shown to pinch out in the Woodstown quadrangle and the Woodbury to continue through. However, because the bedded clay-sand sequence of the formation laterally interfingers with the massive unit formerly mapped as Woodbury, Minard (1965) mapped the Englishtown continuously across the Woodstown quadrangle. Johnson and Richards (1952, p. 2155) reported at least 36 feet of Englishtown at Layton Lakes, which is several miles west of the Woodstown quadrangle.

The Woodbury Clay is not present in the Woodstown quadrangle and apparently pinches out northeast of Swedesboro (Minard, 1965).

The Merchantville Formation is far less glauconitic in the vicinity of Woodstown than it is to the north between Trenton and Camden. However, sufficient glauconite still occurs in the Merchantville at Woodstown to help in differentiating it from the overlying and similar but less glauconitic dark massive Englishtown.

One of the unforeseen results of the detailed mapping in several areas and examination of formations in the intervening areas was the detection of a probable basement high in southern New Jersey and northern Delaware. This conclusion was reached partly as a result of lithologic changes in the formations. These changes were most evident in the greensands. In New Jersey, several units contain glauconite in superabundance. One formation, the Hornerstown, of early Tertiary age, is commonly 30 feet thick. The sand fraction in this unit is as much as 95 percent glauconite. The other glauconite-rich units of appreciable extent are the Navesink, Marshalltown, and Merchantville Formations.

As these formations are traced from the northeast to the southwest, a marked depletion of glauconite is evident. To the northeast, these formations are excellent marker beds because of their high glauconite content. To the southwest, however, their use as stratigraphic markers is much less reliable because they have become so deficient in glauconite, or have pinched out, or have been overlapped. Accompanying the depletion of glauconite is an increase in the amount of detrital minerals, particularly quartz.

The authors believe that glauconite is primarily an authigenic mineral and is deposited in a low-energy environment in waters a few to several hundred feet deep on the middle and outer continental shelf. Based on this concept of the origin of glauconite, the glauconite depletion and the thinning or overlapping of glauconite-rich beds to the southwest and the concomitant increase in amount of detrital minerals and in grain size suggest a shoaling of the sea on a possible structural high.

SUMMARY OF ROCK STRATIGRAPHIC STUDIES IN NEW JERSEY

The important changes in the Upper Cretaceous-lowermost Tertiary section that take place from northern New Jersey southwestward to the Woodstown area are:

1. The Hornerstown Sand of early Tertiary age rests on progressively older sediments towards the southwest (fig. 4). It lies on the Tinton in the extreme north, the Red Bank in the west-central part, the Navesink in the west-central to south-

western part, and the Mount Laurel in the updip section in the southwestern part.

2. The upper quartz-sand unit of the Red Bank is absent in the southwestern part of the Coastal Plain in New Jersey as S. Weller and G. N. Knapp (Weller, 1907, p. 18) had postulated. This is significant when the interpretation of Groot, Organist, and Richards (1954, table 2) in northern Delaware is considered.
3. As a result of the erosion of progressively lower parts of the uppermost Cretaceous beds from north to south, the Navesink is only 5 feet thick in much of the updip section at Woodstown and locally is absent.
4. Thickening of the coarse sandy Mount Laurel southwestward and a concomitant thinning of the underlying finer grained Wenonah suggests shallowing of the basin of deposition during Wenonah-Mount Laurel time.
5. The Marshalltown persists with little change in lithology or thickness in outcrop throughout the entire Coastal Plain in New Jersey and therefore serves as an excellent marker bed. Concentrations of *Exogyra ponderosa* are present only in the southwest.
6. A significant reduction in the thickness of the Englishtown-Woodbury interval was produced by the pinchout of the Woodbury and by a change to a thinner, deeper water silty sand facies within the Englishtown, which here resembles the Wenonah.
7. The Merchantville also undergoes a facies change. It is largely a greensand in the Trenton-Camden area, but the glauconite content decreases markedly to the southwest, where the Merchantville is a somewhat silty fine glauconite quartz sand.
8. Within the Coastal Plain in New Jersey, the quartz-rich sandy or silty units vary more in thickness and lithology along outcrop than the glauconite-rich units, which maintain remarkable uniformity in texture, mineralogy, and thickness for the entire outcrop distance. Facies changes are present, but the changes from one texture, lithology, or thickness to another are gradual and commonly take place over many miles.
9. The most significant feature of the stratigraphy is the repetition of similar lithologies in the vertical section throughout the Upper Cretaceous beds of New Jersey. This characteristic requires a very detailed knowledge of the spatial distribution of the formations before any regional synthesis of the Upper Cretaceous stratigraphy can be made.

NORTHERN DELAWARE

Although the marine Cretaceous sediments of Delaware are lithologically similar to those of New Jersey, the authigenic mineral glauconite is generally less abundant than in formations of the same age in New Jersey. The outcropping Cretaceous section continues to thin southwestward into Delaware where the section is estimated to be only 240 feet thick (fig. 4).

There are no exposures of the complete Cretaceous section in Delaware. Even the more or less continuous exposures along the Chesapeake and Delaware Canal are incomplete because no basal Tertiary beds have ever been found. In order to locate these lower Tertiary beds and establish a top to the section, a series of shallow holes were bored south of the canal in the vicinity of Odessa, Del. (fig. 1), where Booth (1841) and Johnson and Richards (1952, p. 2158–2159) reported the early Tertiary brachiopod *Oleneothyris harlani*. The presence of Tertiary rocks in that area was also suggested by the fact that glauconite mining once flourished. The bulk of the glauconite mining in New Jersey was in the Hornerstown Sand of Paleocene age.

Studies in Delaware were concentrated at three main localities: along the Chesapeake and Delaware Canal from the new Summit Bridge to the new railroad bridge (fig. 6); from the St. Georges Bridge east to the Biggs Farm locality of Groot, Organist, and Richards (1954, fig. 5); and the general vicinity of Odessa (fig. 5) south of the canal. These localities are approximately 15 miles southwest along strike from Woodstown, N.J.

DISTRIBUTION OF FORMATIONS

The areal distribution of Upper Cretaceous and lower Tertiary beds from southern New Jersey to northern Delaware is shown in figure 5. As can be seen, four Cretaceous formations younger than the Magothy extend into the canal area: the Merchantville, Englishtown, and Marshalltown Formations, and the Mount Laurel Sand.

SECTION ALONG CHESAPEAKE AND DELAWARE CANAL NEAR SUMMIT BRIDGE

An unusually good exposure was studied in a fresh cutbank in the footings for the new railroad bridge on the south bank of the canal. About 65 feet of section was exposed (fig. 7). Weathering, always a problem in surface or near-surface studies of the Coastal Plain formations, was perceptible to a depth

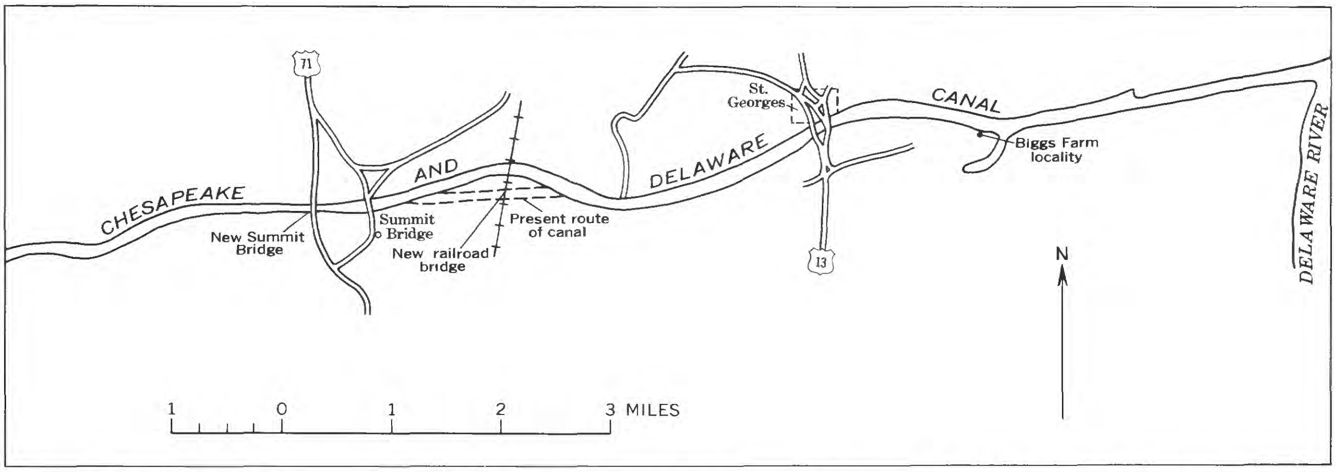

FIGURE 6.—Localities along the Chesapeake and Delaware Canal described in text (modified from Groot and others, 1954, pl. 2).

of about 50 feet. The impermeable clayey units were the least altered, but even in the more permeable sands, weathering did not mask the essential lithologic characteristics.

FIGURE 7.—Upper Cretaceous formations exposed in cutbank at site of Chesapeake and Delaware Canal railroad bridge.

Except for the Navesink and Wenonah Formations, the same lithologic units are recognized here as at Woodstown, N.J. (fig. 4). The change in facies within the Wenonah to a coarser sand southwestward in New Jersey has been carried to completion in northern Delaware where the Wenonah-Mount Laurel interval is occupied by a Mount Laurel lithology.

Particularly fine exposures of the Marshalltown, Englishtown, and the upper part of the Merchantville Formations at this locality are of special interest. It is also noteworthy that the placement of our formational boundaries is nearly coincident with those of Carter (1937) in this general area.

A measured section, which accompanies figure 8, is given below.

Measured section in excavation for railroad bridge footing on south bank of the old channel of Chesapeake and Delaware Canal 1.3 miles northeast of Summit, Del.

[Elevation of top of cut about 70 feet]

	Thickness (feet)
Wicomico(?) Formation:	
Sand, yellow-brown, very gravelly	0–10
Mount Laurel Sand:	
Sand, yellowish- to reddish-brown, somewhat clayey and silty; massive but extensively penetrated by cylindrical borings commonly etched out by wind on dry surfaces. White to buff soft irregular masses of apatite as much as 3 in. in diameter abundant in the lower 5 ft. Quartz, feldspar, and glauconite the major sand constituents (table 3); mica and apatite also present in significant concentrations. Detrital heavy minerals abundant and chiefly of metamorphic origin (table 3). Sand moderately to well sorted and mostly fine to medium (Groot, 1955, p. 147). Unit grades down into the Marshalltown, the transition taking place	

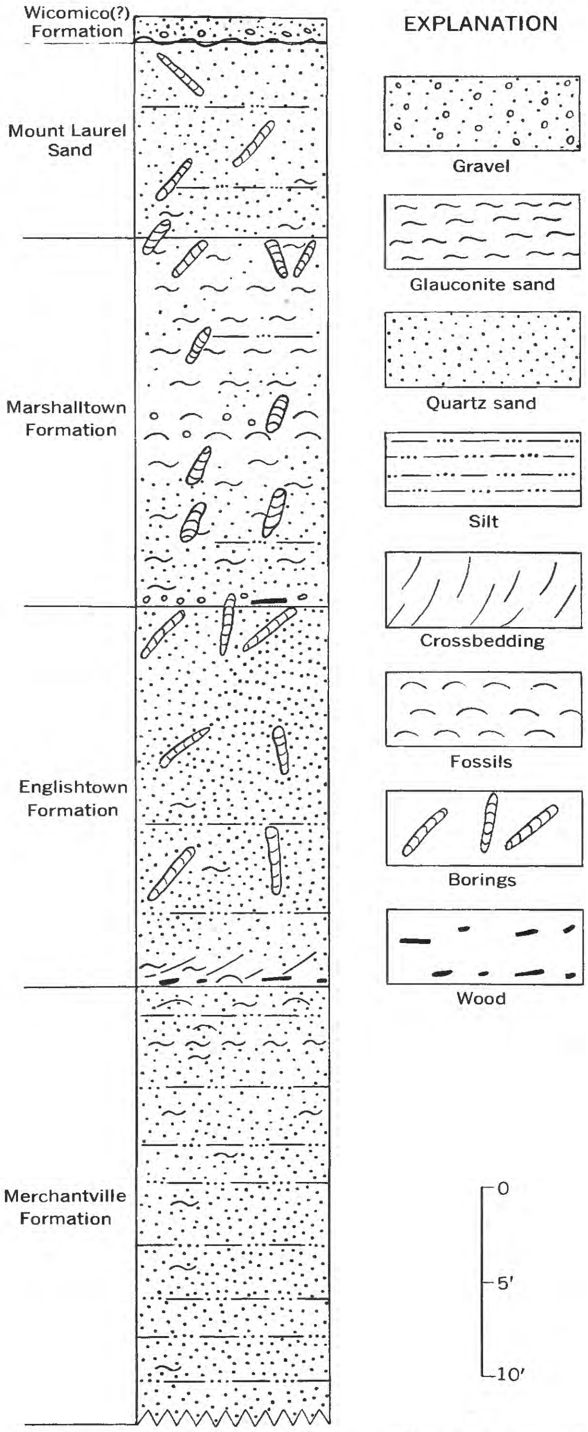

FIGURE 8.—Columnar section at the new railroad bridge excavation near Summit Bridge, Del., shown in figure 7.

Mount Laurel Sand—Continued

Thickness (feet)

in a 1-ft interval. Borings filled with quartz sand. They project downward from Mount Laurel into underlying Marshalltown 15.0

Total measured Mount Laurel Sand 15.0

Thickness (feet)

Marshalltown Formation:

Sand, clayey, silty, grayish-green; at top grades downward into greenish-black, massive. Borings similar to those in Mount Laurel, but filled with glauconite sand, common. White masses of apatite similar to those in overlying formation also occur in upper few feet of this unit. Phosphatized internal molds of shells in upper few feet, and a layer containing fairly well preserved thick calcareous shells of *Exogyra ponderosa* Roemer in the middle. Microfossils locally abundant in shell layer and associated with numerous broken translucent dark-brown bone fragments, fine quartz gravel (maximum diameter ½ in.), and fragments of black carbonized wood.

Glauconite is major sand constituent (table 3), although quartz and feldspar abundant in lower few feet of this formation. Mica common throughout. Many glauconite grains have accordian shapes similar to those described by Galliher (1935). Heavy minerals common; the assemblage and distribution virtually same as in Mount Laurel Sand.

Contact with Englishtown sharp (fig. 9). Numerous borings filled with glauconite, project below contact into underlying quartz sand. Gravel (as much as 2 in.) and large pieces of carbonized wood (as much as 8 in. long) occur locally along this boundary 14.0

Total measured Marshalltown Formation. 14.0

Englishtown Formation:

Sand, white to pale buff; upper part pale gray in lower few feet; extensively stained orange brown by iron oxides along the bedding planes. Many of beds less than 1 in. thick (fig. 10). Small-scale crossbedding thicker in lower few feet. Entire formation penetrated by excellently preserved borings (*Halymenites major* of other authors). These borings differ from those in overlying beds both in size and complexity of surface ornamentation.

Formation primarily a silty sand, fine to very fine and well sorted (Groot, 1955, p. 149). Quartz, feldspar, and mica are the primary constituents (table 3); glauconite generally a minor constituent but locally abundant. Heavy minerals abundant and chiefly metamorphic types (table 3). Contact with underlying Merchantville Formation sharp and most evident on weathered surfaces where dark carbonaceous matter leached from Merchantville. A zone of reworked sediment as much as 2 ft thick occurs locally along this boundary. Fine gravel, carbonaceous matter, rounded black to reddish-brown iron oxide fragments and less commonly small to large broken calcareous and phosphatic shell fragments distributed in this zone 14.0

Total measured Englishtown Formation 14.0

FIGURE 9.—Contact between the Marshalltown (dark) and underlying Englishtown (light). Note thin zone of reworked sediment along boundary and the numerous glauconite-filled borings in upper part of the Englishtown quartz sand.

	Thickness (feet)
Merchantville Formation:	
Sand, very fine to fine, very silty and clayey, poorly to well-sorted; pale gray in the upper 8 ft, remainder dark grayish black; thick bedded, but this feature is most evident on weathered surfaces. Quartz, glauconite, feldspar, chlorite, and muscovite the major minerals. Glauconite grains have accordion shapes similar to those in Marshalltown Formation. Pyrite and siderite important accessory minerals, particularly in upper beds. Siderite occurs in irregularly shaped gray masses. Heavy minerals abundant and similar to those found in overlying Englishtown (table 3). Fossils abundant. Most only imprints, shell material leached. A thin zone containing abundant crab claws near top of formation	23.0
Total measured Merchantville Formation.	23.0

Carter (1937, p. 271) and Groot, Organist, and Richards (1954, p. 33–34) have also made studies at or near this locality. All reports agree on the placement of formational boundaries within a few feet. Except for the lower unit (Merchantville) for which Carter used the collective name, Crosswicks Clay, his stratigraphic assignments and those of this paper are mainly the same, whereas those of Groot, Organist, and Richards are most like those of Spangler and Peterson (1950).

No lower Merchantville beds were observed in this excavation, but the engineer in charge reports an additional 24 feet of the Merchantville lithology be-

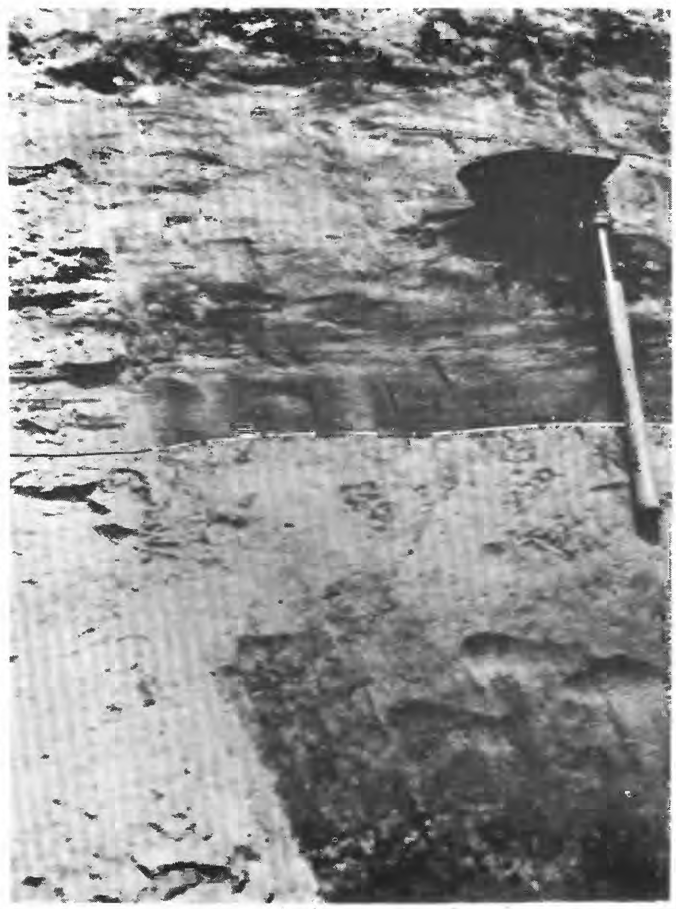

FIGURE 10.—Sharp contact between Merchantville and overlying Englishtown Formations. Thin bedding in the Englishtown is emphasized by the iron oxide staining.

low the 23 feet exposed in this cut. The total Merchantville, therefore, is about 50 feet at this site. A small section of the basal beds was temporarily exposed on the south shore of the canal 1.4 miles to the west. There, about 9 feet of Merchantville and its contact with the underlying Magothy was exposed in a long cutbank bench that was subsequently removed during widening of the canal. The contact is sharp and slightly irregular and has a 2- to 3-foot zone of reworked sediment along the boundary. The reworked zone is a dark-gray very silty and clayey very fine to fine sand. Granules and small pebbles of quartz are concentrated in this interval, as are reworked pieces of carbonized wood and large discoidal brown siderite concretions. Borings, generally filled with glauconite and quartz sand that are coarser than the surrounding very micaceous matrix, are abundant even in the wood and siderite concretions. Above this lower bed, the amount of fine gravel diminishes, and the sediment is much finer. Glauconite-filled borings are abundant even above the basal zone.

In general, the lower Merchantville beds appear to be more clayey and less micaceous and to have a higher glauconite content than the upper beds observed at the bridge pier.

SECTION 1.1 MILES WEST OF ST. GEORGES TO 1.3 MILES EAST OF ST. GEORGES AT BIGGS FARM

The Englishtown and Marshalltown Formations and the Mount Laurel Sand can be traced almost continuously along the north side of the Chesapeake and Delaware Canal from the railroad bridge eastward to St. Georges. The regional dip of the formations in this area is southeast, so that younger strata are found to the east. Unfortunately, the ground there is lower than at the railroad pier, and the outcrops are smaller. Only short sections of the younger Upper Cretaceous strata are exposed. Most of the exposures are low cutbanks at water level along the canal and are usually only a few feet high at low tide. The sharp contact between the Marshalltown and Englishtown is exposed at a few points on the north bank between 0.3 and 1.1 miles west of the St. Georges Bridge. The long distance over which this contact is exposed suggests either a more easterly strike of the Marshalltown than usual or local gentle warping of the beds. Others (Groot, 1955, p. 14, for example) have observed small folds in other beds along the canal. The undulatory contact between the two formations can be seen at low-tide level in this general region.

The Englishtown in this area is typically orange brown and semi-indurated by secondary iron oxide. Its general lithology is similar to that of the beds near the railroad pier except that it locally has small concentrations of pebbles as much as one-fourth of an inch in diameter. The *Ophiomorpha* borings are large and very abundant in this formation. Because they are better indurated than the surrounding sand, they are etched out where the beds are exposed in the intertidal zone (fig. 11). At a few localities, other fossil impressions have been exposed on the washed surfaces.

The basal beds of the overlying Marshalltown are similar to those at the railroad pier except that they are less weathered and much more fossiliferous. Well-preserved shells of *Exogyra ponderosa* and *Ostrea falcata* commonly litter the outcrop along the shores of the canal.

At St. Georges Bridge, the dark-gray Marshalltown is capped by a thin bed of orange-brown glauconite quartz sand identified by us as the basal Mount Laurel. The weathered condition of the upper bed makes it difficult, however, to be certain of this identification. If this represents the contact between the two formations, the Marshalltown is less than 10 feet thick at this locality.

The basal unit of the Mount Laurel is exposed on the south bank of the canal east of the St. Georges Bridge. About 2.5 feet of unweathered pale-gray very clayey glauconite quartz sand having composition apparently similar to that of the weathered bed just mentioned crops out for a distance of about 100 yards. In general appearance this bed resembles the Marshalltown because of its very clayey nature, but it is lighter in color. This similarity is deceptive be-

FIGURE 11.—Large *Ophiomorphia nodusa* borings in the Englishtown Formation exposed at water level along the north side of the Chesapeake and Delaware Canal east of the St. Georges Bridge. Borings of this type are present in other sandy formations but these are unusually large and well preserved.

cause the cement in this unit of the Mount Laurel is mostly clay-sized calcite rather than a complex assemblage of clay minerals as in the Marshalltown (table 4). Therefore, the basal Mount Laurel at this locality is an arenaceous calcilutite or a very calcareous glauconite quartz sand, a lithology not observed in the formation elsewhere. Lithologically, the Mount Laurel exposed at the railroad pier could have been the same as at this locality, except for leaching of the fossils and calcareous cement. Fossils are abundant along this south-bank exposure, but *Exogyra cancellata* occurs here rather than *E. ponderosa.* As noted earlier, to the northeast in New Jersey, *E. cancellata* is restricted to the Mount Laurel Sand. Locally, small dark-brown phosphatized fossils of the same types as the calcareous shells are present. The origin of these phosphatic fossils is not known, but they appear to be derived from a different source than the larger calcitic shells.

Glauconite from the *Exogyra ponderosa* bed of the Marshalltown and the *E. cancellata* bed of the Mount Laurel was dated by the potassium-argon method. Glauconite from the Mount Laurel Sand yielded an age of 70.3 ± 2.5 m.y. (million years); that from the underlying Marshalltown, 68.2 ± 2.4 m.y. (J. P. Obradovich, written commun., 1967). Although the reported age of the glauconite in the Marshalltown is younger than that from the overlying Mount Laurel, both are virtually the same if the analytical error is considered. Both determinations, however, indicate a Late Cretaceous age for these beds.

Sporadic exposures of this lower Mount Laurel calcareous bed were found along the south bank of the canal from the St. Georges Bridge to the Biggs Farm locality (fig. 6) about 1 mile to the east. A hole augered at this locality penetrated approximately 16 feet of the light-gray fossiliferous calcareous Mount Laurel. The lower contact with the Marshalltown was difficult to establish precisely because of contamination from above. Unequivocal Marshalltown was obtained 10 feet below the 16 feet of basal Mount Laurel, so that the thickness assigned to the calcareous part of the Mount Laurel is a minimum.

The Biggs Farm locality is a favorite fossil-collecting site. It is also of special interest because it is there that Groot, Organist, and Richards (1954, p. 37) described a section of what they termed "Red Bank and Navesink-Mount Laurel undifferentiated." The fauna from this locality was described by Richards and Shapiro (1963) and is discussed later in this report in the section "Biostratigraphic analysis." This is probably the locality referred to by Spangler and Peterson (1950, p. 47) in which the Vincentown and Navesink are in contact.

The authors disagree with these formation designations and suggest instead that this entire outcrop is Mount Laurel. At this locality, the basal 2.5 feet of the cut is the same calcareous bed described at St. Georges Bridge. This calcareous bed is in sharp contact with the overlying yellowish-brown medium somewhat glauconitic quartz sand (fig. 12). The contact is highly irregular, apparently a reflection of the uneven leaching of the underlying calcareous bed.

To test our interpretation, three samples were collected, one from the basal shell zone (Navesink-Mount Laurel as used by Groot, Organist, and Richards (1954)) and two approximately 6 feet apart above this bed (Red Bank as used by Groot and others). These were compared with each other and with a sample from the basal Mount Laurel exposed at the railroad excavation near Summit Bridge.

The detrital components of the three samples were concentrated and compared petrographically. It was assumed that these detrital components would be more likely to resist the effects of subaerial oxidation than would the authigenic constituents. No significant differences were found in these samples either in the light fractions (less than 2.80 sp gr) or in the heavy fractions (greater than 2.80 sp gr, table 3). No significant difference in size, shape, or total glauconite percentage was found between the sands. These sands were then compared with the lower Mount Laurel from the railroad bridge, and, except

FIGURE 12.—Contact between the lower light-colored very clayey calcareous beds and the upper darker very sandy beds of the Mount Laurel at the Biggs Farm locality. Leaching of the calcareous beds has produced an irregular contact.

for minor variations in the percentages of the heavy and light minerals, the samples were nearly identical. The major difference is in the quartz-glauconite ratio, but the sample from the railroad bridge is from the base of the unit, and concentrations of reworked glauconite might be expected in this basal interval.

Because of similarities in lithology and regional stratigraphic position, we conclude that these localities are part of a single lithologic entity, the Mount Laurel Sand.

SECTION NEAR ODESSA

In the two previously described sections, the Cretaceous-Tertiary boundary was not exposed nor was it seen anywhere eastward along the Chesapeake and Delaware Canal. As already indicated, the section at the Biggs Farm locality probably is basal Mount Laurel. In southern New Jersey, the Mount Laurel is 80 feet thick, and it is reasonable to assume an equal or greater thickness of this unit in northern Delaware. In addition, in southern New Jersey, the uppermost Cretaceous bed is the Navesink Formation, but here it is very thin or absent in the updip areas. The problems, therefore, in northern Delaware, are to determine: (1) the thickness of the Mount Laurel, (2) the presence or absence of the Navesink, (3) the top of the Cretaceous section, and (4) the character of the lowest Tertiary formation. As indicated previously, some older publications reported the occurrence in a greensand of a characteristic Paleocene fossil, *Oleneothyris harlani* (Morton), in the vicinity of Odessa. This fossil is commonly found along or above the Hornerstown-Vincentown contact in New Jersey. The presence of the highly glauconitic Hornerstown Sand or its lateral equivalent in Delaware is, therefore, strongly suggested.

Groot, Jordan, and Richards (1961, p. 24), in their guidebook to the geology of the area, described an outcrop at the western edge of Odessa, whose stratigraphic placement was uncertain because of its unfossiliferous nature. At this locality, about 4 feet of glauconite sand with a lithology similar to that of the Hornerstown Sand of New Jersey overlies a pebbly glauconite quartz sand that is similar to the upper beds of the Mount Laurel. (See descriptions accompanying fig. 3.) Because of the thinness and weathered nature of the upper glauconite sand at this locality, a series of holes was augered east and north of Odessa to ascertain the thickness and trend of this unit and to obtain less weathered samples. The thickness, about 20 feet, and lithology are nearly identical to the Hornerstown Sand of New Jersey (Minard and others, 1969). In New Jersey, the Hornerstown Sand consistently has a very diagnostic green glauconite clay matrix. The green clay matrix of the sand at Odessa is identical. Another unique feature of the Hornerstown in New Jersey is the abnormally high potassium oxide content of the glauconite grains as compared with Cretaceous glauconite pellets. The grains from the Odessa sample were analyzed and have a potassium oxide content of 8.1 percent (H. J. Rose, written commun., 1963). Such high values are typical of the Hornerstown rather than of the Cretaceous glauconite (Owens and Minard, 1960, p. B431). Subsequent radiogenic age determinations (potassium-argon method) of the glauconite sand yielded an age of 63.8 ± 2.1 m.y. (J. P. Obradovich, written commun., 1967). This date is compatible with a very early Tertiary age (Kulp, 1961).

In summary, in the vicinity of Odessa the spatial and lithologic relationships indi ate that the Hornerstown Sand rests directly on the Mount Laurel Sand and that the Navesink Formation, which is only 4–5 feet thick updip at Woodstown, is completely absent at Odessa and in the nearby shallow subsurface. Certainly, if this interpretation is correct, then the quartz sand at the Biggs Farm locality could not be the Red Bank but is the Mount Laurel. The stripping of the upper beds of the Upper Cretaceous sequence and the onlap of the basal Paleocene beds onto progressively older beds toward the southwest has continued. If the Mount Laurel has the same rate of dip here as at the canal, then it is calculated that the unit is about 170 feet thick in this part of Delaware. This is a reasonable estimate if the regional trend of southward thickening of the Mount Laurel continues into northern Delaware.

Figure 13 is a composite section showing our interpretation of the stratigraphic sequence in the northern Delaware coastal plain.

COMPARISON OF THE UPPER CRETACEOUS FORMATIONS IN NORTHERN DELAWARE AND SOUTHERN NEW JERSEY

The foregoing descriptions permit a comparison of the stratigraphic sequences of the two regions. The stratigraphic sequence near and along the canal is as follows:

Formation	*Age*
Hornerstown	Paleocene
Mount Laurel	Late Cretaceous
Marshalltown	Do.
Englishtown	Do.
Merchantville	Do.

The above sequence has a distinct cyclic sedimentation pattern (fig. 14*A*). Cycle one consists of a glauconite sand (basal Merchantville) overlain by a silt (upper Merchantville) which grades up into a quartz sand (Englishtown). Then the pattern is repeated and another cycle completed: glauconite sand (Marshalltown), grading up into a calcareous silt (basal Mount Laurel), which is overlain by a quartz sand (upper Mount Laurel). The glauconite sands are interpreted as representing transgressive beds, and the quartz silts and sands are interpreted as representing the regressive facies of the cycles. Two cycles occur in the Upper Cretaceous sediments at the canal; 3½ cycles occur in the Upper Cretaceous sediments of New Jersey (fig. 14). The fewer cycles in Delaware are most likely the result of a more intense early Tertiary period of erosion than occurred in northern New Jersey. The uppermost beds,

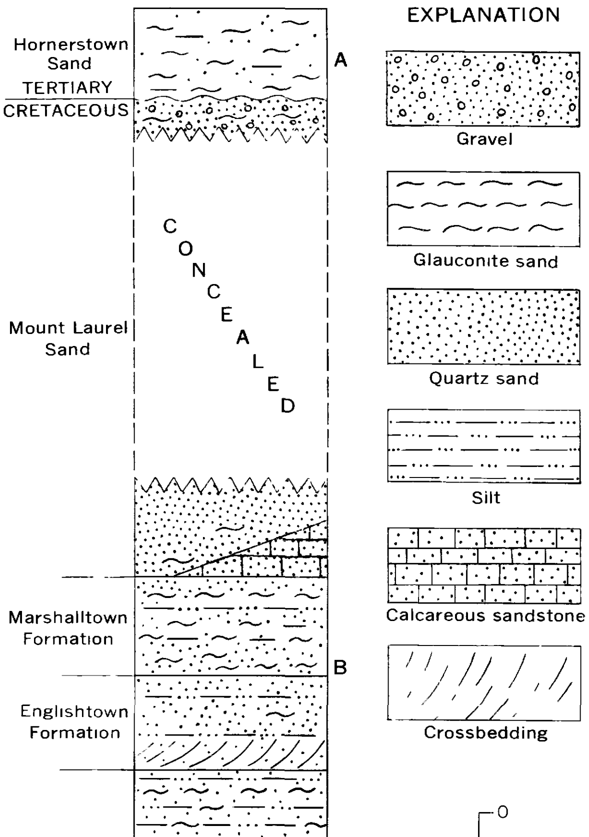

FIGURE 13.—Composite columnar section of Upper Cretaceous stratigraphic relations in the northern Delaware Coastal Plain. A, At Odessa. B, At new railroad bridge and east to Biggs Farm. C, On south bank of canal at the new Summit Bridge.

the Tinton, Red Bank, and Navesink, were stripped away during the erosional period. In addition, the deposits of a single cycle from New Jersey and Delaware are somewhat different. A complete sedimentation cycle in New Jersey (fig. 14*B*) consists of an upper quartz sand, a middle very micaceous quartz sand or silt, and a lower glauconite sand. In Delaware, the middle clastic silt is present in the first cycle but is replaced by calcareous silt in the second cycle. An intermediate calcareous silt does not occur in the Upper Cretaceous beds of New Jersey but is present in the Paleocene Vincentown Formation.

Much of the confusion in correlations over long distances in the northern Atlantic Coastal Plain is due to the failure to recognize the cyclic nature of these sediments. The repetition of generally similar lithologies, coupled with poor formational descriptions and lack of good maps, left most stratigraphers dependent on biostratigraphic correlations. Unfortunately, most of the outcropping units are unfossiliferous or lack a diagnostic fauna. Frequently such correlations were based on widely spaced samples.

The quartz sand units, particularly beds in the Red Bank and Mount Laurel Sands, are most commonly confused by regional stratigraphers. Cook (1868, p. 268) and Clark, Bagg, and Shattuck (1897, p. 335) confused these two units in their early studies in New Jersey. Only through the precise tracing of the two units in the field, was Knapp (in Weller, 1907, p. 17–20) able to demonstrate the correct spatial distribution of the sands. The same misidentification of the Mount Laurel as the Red Bank appears to have been made by Groot, Organist, and Richards (1954) in the Chesapeake and Delaware Canal section. Once they assumed that the Mount Laurel was the Red Bank, the underlying glauconite-rich unit (Marshalltown) was understandably misidentified as the Navesink. The same reasoning applied to the quartz sand beneath the Marshalltown. This sand was identified as the Wenonah rather than the Englishtown. (For details of the stratigraphic sequence, see fig. 3.) Further complicating the interpretation was the fact that the geologic map of New Jersey (Lewis and Kümmel, 1912) shows the Englishtown pinching out near Swedesboro in the Woodstown quadrangle. However, mapping by Minard (1965) showed that the Englishtown continues southwest and the Woodbury Clay pinches out. This mapping also showed that the Mount Laurel thickens rapidly at the expense of the underlying Wenonah.

The interpretation of the canal section, however, was clearly predictable and was verified by lithol-

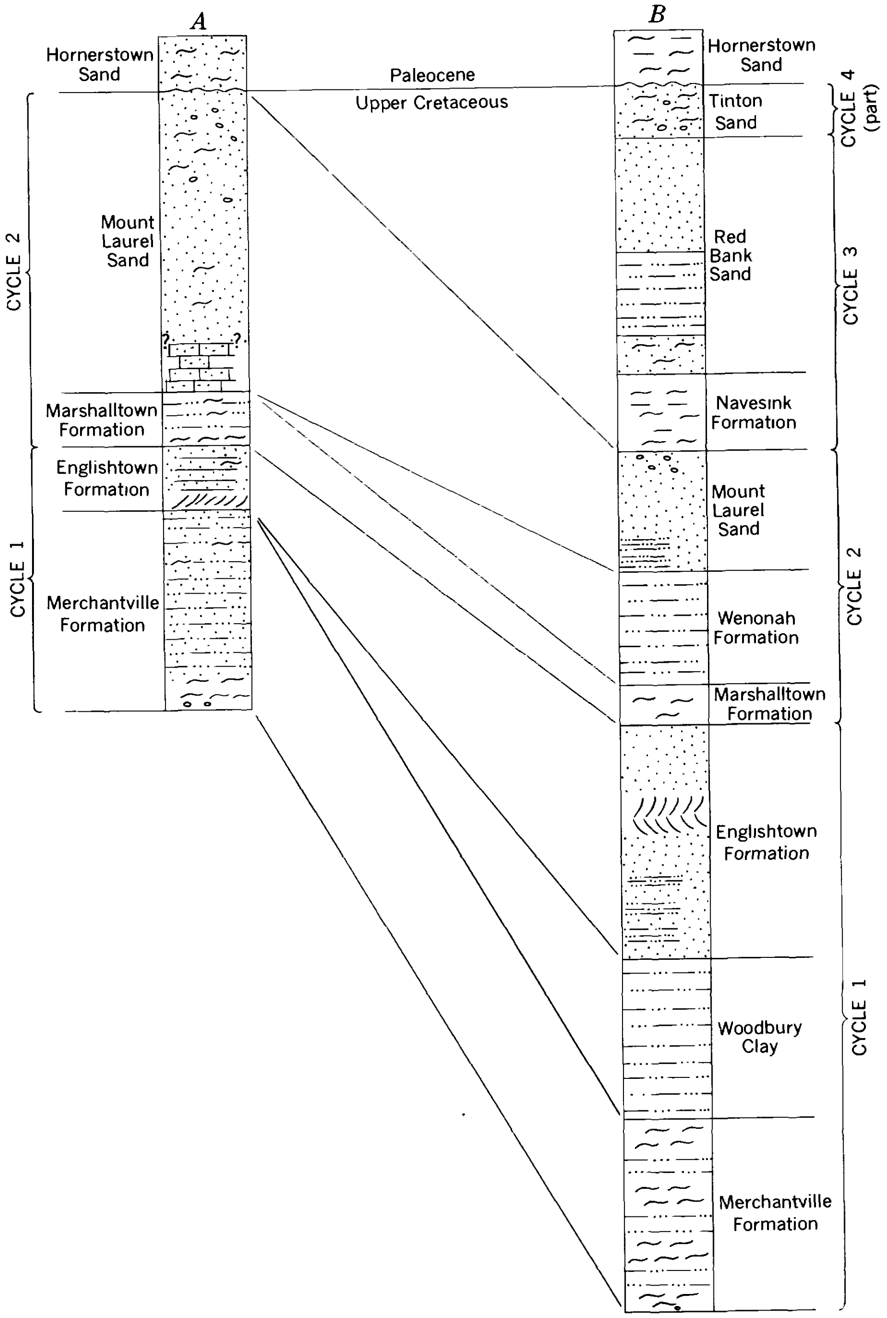

FIGURE 14.—Schematic columnar sections showing differences between Upper Cretaceous cyclic deposits in Delaware (*A*) and New Jersey (*B*). Lithic symbols are the same as those in figure 13. Drilling by the U.S. Geological Survey during recent investigations in Delaware has now provided complete lithologic data for these units. (See fig. 13.)

ogies and faunal associations, the following facts being kept in mind:

1. Pinchout of the Red Bank in the central Coastal Plain in New Jersey.
2. Removal of the Navesink by a pre-Hornerstown erosion and deposition of the Hornerstown on the Mount Laurel in updip sections in southern New Jersey.
3. Thinning of the Wenonah towards the southwest.
4. Continuation of the Englishtown southwestward from Woodstown.

FIGURE 16.—Cutbank along Chesapeake Bay at Grove Point exposing the light-colored Magothy at the base of the bluff in sharp, flat contact with the dark-colored Merchantville Formation. The Merchantville is unconformably overlain by sand and gravel of the Wicomico(?) Formation. Photograph by L. C. Conant.

siderite-cemented(?) platelets. In the upper part of the formation, intercalated thin (2–4 in.) beds of black clay and light fine to medium sand beds interfinger with the dark-gray silts.

The Merchantville grades upward into about 20 feet of intercalated thin beds of black silty clay and white micaceous sand. Many of the sandy layers have small-scale trough cross-stratification. Most of the sand is fine to medium. Pebbles as large as one-fourth of an inch in diameter are common in many of the sands. Large concentrations of coarse carbonaceous material commonly associated with coarse mica grains are common in the dark clay beds. The well-bedded character, lithology, and stratigraphic position of this unit indicate that it is unquestionably the Englishtown Formation. This formation is exposed along the south bank of the Sassafras at Betterton Beach.

The thin-bedded Englishtown is overlain by about 15 feet of massive dark-gray glauconite quartz sand, which we have assigned to the Marshalltown. The lower 6–8 feet of the Marshalltown is dark-gray quartz glauconite sand that contains granules and some small pebbles in the base. The glauconite sand content decreases rapidly above this bed, and the upper part of the formation is largely a dark-gray quartz silt. Borings filled with light-gray more clayey sediment are extensive in the upper Marshalltown (fig. 17). Fossil casts also seen in this photograph are common in the middle of the formation. The entire thickness of the formation is well exposed at several localities along the north side of the Sassafras River. The formation is only exposed at one locality on the south side of the Sassafras River just east of Betterton.

The Marshalltown grades upward into the yellowish-brown to pale-yellow quartz sand of the Mount Laurel sand (fig. 18). The Mount Laurel is exceptionally well exposed in the bluffs along both banks of the Sassafras River between Betterton and Fredericktown (fig. 5). At some localities, more than 60 feet of Mount Laurel is exposed in a single bank. The lower 20–25 feet of the formation is a massive fine quartz sand containing small amounts of glauconite sand. Thin discontinuous borings filled with glauconite sand are well developed in these beds. Overlying this basal massive sand is a series of thick horizontal beds (averaging 10–15 ft), which are commonly sharply differentiated from each other. The horizontal bedding is largely produced by variations in average grain size from bed to bed. Most of

FIGURE 17.—Dark massive-bedded Marshalltown Formation, north bank of Sassafras River, 2 miles east of Grove Point. Borings filled with lighter colored clayey sediment are extensive. Photograph by L. C. Conant.

FIGURE 18.—Gradational contact between the light-colored Mount Laurel Sand and dark-colored Marshalltown Formation exposed at the same locality as figure 17. Upper part of Marshalltown is weathered pale gray. Photograph by L. C. Conant.

the beds consist of pale-gray to brown medium sand, although beds of fine and coarse sand are common. Granules and pebbles are present in most of these upper beds. In general, the average grain size is coarser in the upper beds than in the base. Most of the beds are massive, although some, particularly in the middle of the formation, have large-scale cross-stratification.

The mineralogy from bed to bed is similar—quartz, glauconite, and feldspar are the major sand constituents. Sample Ea 4, table 2, has a typical composition for the upper Mount Laurel in this region. As can be seen, glauconite is abundant and is exceptionally coarse; some beds contain large concentrations of coarse to very coarse glauconite grains.

Large thick-shelled fossils replaced by iron oxides are common in the middle and upper parts of the Mount Laurel Sand particularly at Fredericktown along the north side of the Sassafras River and near Kentmore Beach along the south side of the river. Because of the poor state of preservation of these fossils, precise paleontologic identification is very difficult, but they establish the marine origin of these beds. *Ophiomorphia* borings are also widespread throughout this unit.

At Gregg Neck (fig. 5), a promontory on the south bank of the river east of Fredericktown, the Hornerstown-Mount Laurel contact is well exposed in a borrow pit and a nearby roadcut. The sharp contact between the Hornerstown glauconite sand and the underlying quartz sand of the Mount Laurel is virtually the same here as at Odessa, Del. About 15 feet of Mount Laurel is exposed beneath the Hornerstown at Gregg Neck. This relationship indicates that throughout the northern Delmarva Peninsula the Navesink Formation is absent and the Hornerstown in outcrop rests directly on the Mount Laurel. Along the eastern shore of Chesapeake Bay, the Mount Laurel is a very thick unit, as much as 170 feet thick. The best exposures of the Mount Laurel in the northern Delmarva Peninsula are along the Sassafras River where most of the formation can be seen.

SUMMARY OF ROCK STRATIGRAPHIC STUDIES IN EASTERN MARYLAND

The section along the eastern shore of Chesapeake Bay is similar to that at the Chesapeake and Delaware Canal except that all units were apparently deposited nearer shore. Nearshore deposition is indicated by (1) decrease in the glauconite content in the Cretaceous units, particularly in the Merchantville Formation, (2) change in the bedding characteristics in most units from massive to thin through thick bedded (Merchantville, Englishtown, and Mount Laurel), or the development of cross-stratification (Mount Laurel), and (3) increase in general coarseness of clastic material (Merchantville, Marshalltown, and Mount Laurel) and abundance of carbonaceous matter, particularly large pieces of wood (Merchantville, Englishtown, and basal Marshalltown).

In interpreting the stratigraphy of the eastern shore of Maryland, the terms Matawan and Monmouth Formations are no longer useful, and it is recommended that these terms be abandoned in eastern Maryland and that the New Jersey stratigraphic nomenclature be adopted, thereby eliminating the dual nomenclature that has prevailed for many years. The Matawan Formation of eastern Maryland would be replaced by (in ascending order) the Merchantville, Englishtown, and Marshalltown Formations, and the Monmouth would be replaced by the Mount Laurel Sand. The areal distribution of the beds in eastern Maryland is shown in figure 5.

PETROLOGIC STUDIES

A general survey of the petrologic characteristics of the Upper Cretaceous-lowermost Tertiary formations was made in order to compare the lithologies of all the formations from Woodstown, N.J., and the eastern shore of Maryland.

5. Pinchout of the Woodbury in the area northeast of Swedesboro.

EASTERN MARYLAND

The lower formations of Late Cretaceous age are well exposed along the Chesapeake and Delaware Canal in northern Delaware, but the uppermost formation, the Mount Laurel Sand, especially its middle and upper beds, is poorly exposed. To better examine the uppermost Cretaceous beds, a series of traverses was made along the Sassafras River in eastern Maryland.

Bluffs, some more than 60 feet high, occur along the east-west-oriented Sassafras River, from near Fredericktown, Md., westward to Chesapeake Bay (fig. 5). The stratigraphic sequence exposed in these bluffs ranges from the Vincentown Formation of Paleocene age to the Potomac Group of Early Cretaceous age. Locally, deep, wide channels filled by gravelly sand of Quaternary age have cut deeply into the older formations and interrupt the nearly continuous sequence of formations.

Iron oxide staining and cementation is common in many of the more sandy formations. Many of the more soluble constituents, such as calcareous shells, pyrite, siderite, and carbonaceous matter, have been selectively removed or converted to other mineral phases during weathering. In spite of these widespread weathering effects, the same units noted along the canal have retained sufficient lithologic identity to be recognized in these bluffs. Some lithic changes, like those in the area from Woodstown, N.J., to northern Delaware, have taken place in all the units in the area between the canal and eastern Maryland. Thus, the Upper Cretaceous sequence, the Merchantville, Englishtown, Marshalltown, and Mount Laurel can be traced as recognizable lithostratigraphic units to the eastern shore of Chesapeake Bay. Figure 15 is a composite stratigraphic section of the Upper Cretaceous-lower Tertiary sequence of this region.

The total calculated thickness of the Upper Cretaceous section in eastern Maryland is approximately 240 feet. A southwestward thinning of this section from Delaware to eastern Maryland is not evident.

DISTRIBUTION OF FORMATIONS

The Merchantville is well exposed on the south bank of the Sassafras River, west of Betterton Beach, and also at Grove Point on Chesapeake Bay on the north side of the mouth of the Sassafras River. A typical section of the Merchantville Formation averages 40–60 feet in thickness in New Jersey, whereas it is approximately 40 feet thick along the Sassafras River. The formation overlies the Magothy

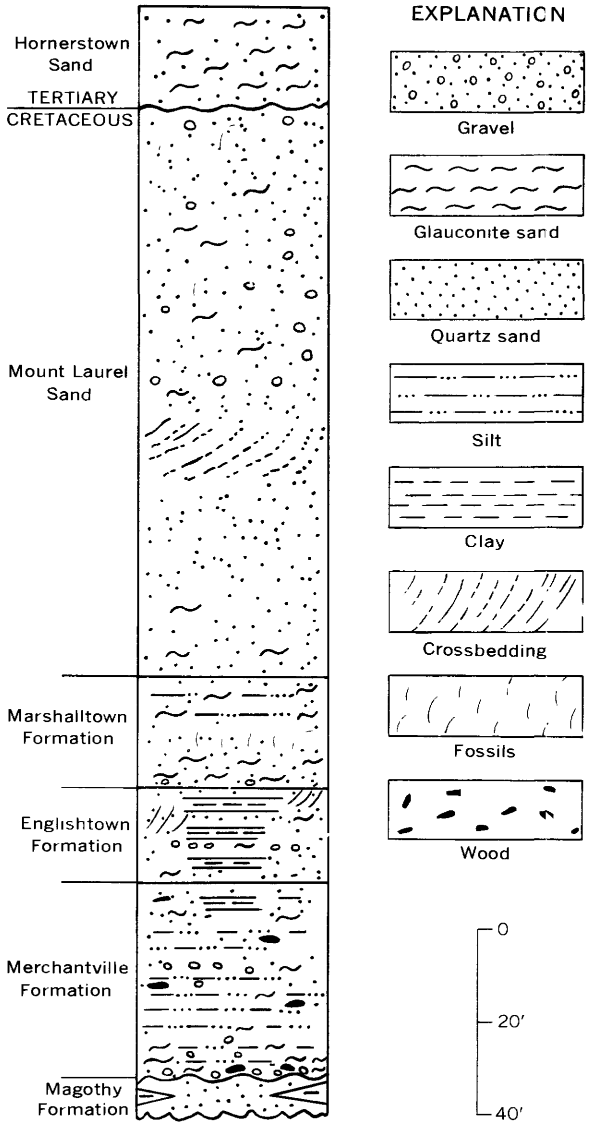

FIGURE 15.—Composite columnar section showing Upper Cretaceous formations in eastern Maryland.

with a sharp but broadly undulatory contact in this area (fig. 16). The basal foot of the Merchantville is reworked sediment containing pieces of gravel as much as 1 inch in diameter, carbonized pieces of wood as much as several inches long and abundant coarse sand. Overlying this basal interval is a sequence of thick beds (averaging 10 ft) which are sharply differentiated from each other. These beds consist largely of dark very micaceous silt to very fine sand. Concentrations of very coarse sand and fine pebbles are abundant in some of the beds, and these tend to emphasize the bedding in this unit. Large to small woody pieces are abundant in the entire formation. An unusual feature in some of the lower beds is an abundance of thin indurated, Groot (1955) and Groot and Glass (1960) examined some of the petrologic characteristics of the Coastal Plain formations in this general region. In the latter publication concerning the petrology of these formations, Groot and Glass (1960) discussed the clay minerals and heavy minerals in the formations. They noted that the marine sediments are primarily characterized by an illite-montmorillonite clay assemblage in association with a full suite of heavy minerals. A full suite is defined as a mineral assemblage that contains significant concentrations of any two of the following minerals: epidote, chloritoid, garnet, and hornblende. These minerals are presumed to be relatively susceptible to intensive weathering conditions. The nonmarine sediments characteristically contain kaolinite as the major clay mineral and have a limited heavy-mineral suite. A limited suite, therefore, is one that does not have significant concentrations of the relatively unstable minerals. Groot and Glass (1960) also observed that many formation assemblages varied along strike but that these differences could be explained by a change in provenance or preferential segregation in the clay fractions because of crystal-size sorting. Diagenetic effects were considered unimportant controls on these mineral assemblages.

In our petrologic studies of the Upper Cretaceous and lower Tertiary formations, the techniques of Groot and Glass were adopted and were supplemented by light-mineral studies and the determination of glauconite-clastic ratios.

HEAVY-MINERAL ANALYSES

Samples of all the formations of southern New Jersey, northern Delaware, and eastern Maryland were studied for their heavy-mineral content (tables 2 and 3, and fig. 19). The results generally agree with those reported from northern Delaware by Groot (1955). Groot, however, subdivided many of the mineral groups (for example, the epidote group); we did not. All formations examined are characterized by full suites of heavy minerals, the terminology of Groot and Glass (1960) being used.

Variations in heavy-mineral types and concentrations, however, do occur between the formations in a single area and in the same formations from one area to another. In the Merchantville and Mount Laurel, the garnet and epidote content decreases from Woodstown to the eastern shore of Maryland (fig. 19). In the Englishtown, epidote content also decreases southwestward, but garnet decreases only southwest of Delaware. Epidote also shows the same general decrease to the southwest of Delaware in the Marshalltown, but garnet increases southwestward from Woodstown, N.J. Chloritoid also appears to vary systematically from area to area, but the trend is the reverse from that noted for garnet and epidote. As can be seen in figure 19, chloritoid content increases toward the southwest. None of the other minerals show any significant trends like those cited above.

Despite the limited number of samples studied from the Chesapeake and Delaware Canal area, it is apparent that detrital heavy-mineral assemblages have little value in stratigraphic correlations. Local source-rock variations, particularly within the metamorphic rocks of the nearby Piedmont province, apparently are significant enough to produce markedly different heavy-mineral assemblages in the same stratigraphic horizons within short distances. It can be stated, however, that the high percentages of metamorphic minerals in the Coastal Plain formations indicate that the Piedmont was a major source land during the Late Cretaceous.

LIGHT-MINERAL ANALYSES

Petrographic studies of the light-mineral fractions (tables 2 and 3 and fig. 20*A*) reveal that four major components are present: common quartz, feldspar, polycrystalline quartz and rock fragments.

Common quartz is the major sand-sized light mineral in these formations. Variations in the percentages within the formations are shown in tables 2 and 3, and figure 20*A* shows the average for each of the formations. This mineral is at least 66 percent to as much as 93 percent of any light-mineral component of the sand fraction. No significant trends in the common quartz distribution, however, were discernible in the formations of a single region or within the regions.

Feldspar makes up 3–18 percent of the sand-sized light-mineral fraction in the formations and averages about 10 percent. Generally, the formations in eastern Maryland have less feldspar than the other regions. Most of the feldspar grains are badly altered in all formations from southern New Jersey to eastern Maryland. Typically, all grains have refractive indices of <1.54, and a large number have microcline twinning. The bulk of this fraction, therefore, is potassic feldspar. Some grains, however, are untwinned and have a cloudy appearance. The degree of alteration in association with the low indices tends to mask whether these are orthoclase or untwinned albite. An occasional grain with plagioclase twinning was observed, but these are not common. Although two major feldspar families are present, potassic feldspar is more abundant by far.

TABLE 2.—*Heavy- and light-mineral content, in percent, and glauconite-clastic ratios from Woodstown quadrangle, New Jersey, and from eastern Maryland*

[Approximate sample localities are shown in fig. 5. Tr., trace; N.d., not determined. Glauconite not counted in mineral analyses. Number in parentheses means that more than one sample was located at that locality]

Name of formation and field number	Specific gravity >2.80; particle size <0.177, >0.074 mm: Opaque minerals			Nonopaque minerals																	Specific gravity <2.80; particle size <0.149, >0.074 mm				Glauconite-clastic ratio; particle size <0.42, >0.062 mm	
	Ilmenite	Brown ilmenite and (or) iron oxides	Leucoxene	Zircon	Rutile group	Tourmaline	Epidote group	Hornblende	Garnet group	Staurolite	Sillimanite	Kyanite	Andalusite	Chloritoid	Muscovite	Biotite	Chlorite	Sphene	Siderite	Pyroxene	Common quartz	Polycrystalline quartz	Feldspar	Rock fragments	Glauconite	Clastics
Woodstown quadrangle, New Jersey																										
Hornerstown Sand:																										
Wt 61A[1]	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	99	1
Mount Laurel Sand:																										
Wt 62	95	2	3	30	10	5	2	....	2	27	12	....	2	7	....	1	1	....	....	1	85	2	13	....	12	88
Wt 92D	77	6	17	2	3	6	10	3	40	20	3	7	3	3	....	....	....	....	....	....	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.
Marshalltown Formation:																										
Wt 71D	76	10	14	12	4	7	12	....	10	29	7	7	9	2	....	1	....	....	....	....	85	..	8	7	59	41
Englishtown Formation:																										
Wt 129	91	2	7	25	5	9	4	2	7	21	7	2	3	1	6	5	3	....	....	....	81	4	14	1	2	98
Wt 74	48	2	50	1	2	4	12	....	10	4	Tr.	2	1	16	22	4	9	....	13	....	83	5	12	Tr.	N.d.	N.d.
Merchantville Formation:																										
Wt 66	86	1	13	8	7	6	21	Tr.	20	10	4	5	1	7	Tr.	1	2	....	8	....	93	2	4	1	25	75
MaH 3A	86	3	11	6	6	10	27	Tr.	19	9	4	2	....	5	2	1	9	Tr.	....	....	N.d.	N.d.	N.d.	N.d.	16	84
Eastern Maryland																										
Hornerstown Sand:																										
Mil 1A	80	6	14	9	11	6	24	4	5	26	Tr.	3	3	6	....	3	....	....	....	....	86	3	11	....	70	30
Mount Laurel Sand:																										
Ea 4	79	....	21	6	5	6	4	...	....	36	12	6	9	4	6	6	....	....	....	....	84	1	15	....	34	66
Ea 5(1)	81	10	9	11	20	13	....	....	....	39	7	6	2	....	....	2	....	....	....	....	N.d.	N.d.	N.d.	N.d.	6	94
Bet 2(1)	89	2	9	21	12	12	6	....	1	22	5	2	2	11	2	4	....	....	....	....	N.d.	N.d.	N.d.	N.d.	7	93
Marshalltown Formation:																										
Bet 2	77	2	21	20	5	5	4	....	20	17	3	3	2	5	12	4	....	....	...	....	92	4	4	....	7	93
Sp 7	93	1	16	19	5	12	3	....	21	18	6	1	Tr.	7	1	6	....	1	....	....	N.d.	N.d.	N.d.	N.d.	16	84
Englishtown Formation:																										
Bet 1A	62	8	30	4	15	19	Tr.	....	....	15	9	6	....	21	7	4	....	....	....	....	84	11	5	....	2	98
Merchantville Formation:																										
Bet 1	64	3	33	1	9	8	....	....	20	11	....	1	Tr.	40	7	2	1	....	....	....	87	10	3	....	4	96
Sp 6(2)	71	5	24	49	6	8	....	....	6	9	1	1	....	11	7	1	1	....	....	....	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.

[1]Too small a sample to make an analysis.

Rock fragments and polycrystalline quartz are the other common light components. Their distribution is more erratic than the feldspar or common quartz. Rock fragments and polycrystalline quartz are more abundant in northern Delaware than in southern New Jersey or in eastern Maryland.

A plot of the data in figure 20*A* showed that, in the four categories counted, no definite trends were evident either within a group of formations in a single area or within a single formation from one area to another. The data, however, do indicate a probable metamorphic source for a large volume of these sediments.

Because these light minerals constitute the bulk sediment in the clastic sands (Englishtown and Mount Laurel), they determine the composition of the rock and hence their rock-type classification. The relatively feldspathic nature is apparent, and these sands can properly be classed as protoquartzites (Pettijohn, 1957) or subgraywackes (Krynine, 1948). Except for variations in glauconite sand content, the Englishtown and Mount Laurel maintain a uniform composition from southern New Jersey to eastern Maryland. In fact, the clastic light minerals are distributed throughout the silts and greensands in nearly the same proportions as in the clastic sands throughout this region.

GLAUCONITE-CLASTIC RATIOS

During field mapping a gradual decrease in glauconite sand content to the southwest was observed in nearly all formations, especially those of Late Cretaceous age. To quantify this observation, samples of the sands were electromagnetically processed to determine glauconite-clastic ratios (tables 2 and 3 and fig. 20*B*).

The most obvious changes occur in the Merchantville, Marshalltown, and Hornerstown (fig. 20*B*),

TABLE 3.—*Heavy- and light-mineral concentrations, in percent, and glauconite-clastic ratios from localities in the vicinity of the Chesapeake and Delaware Canal*

[Sample localities are shown in figs. 1 and 6; number after railroad bridge pier indicates depth in feet below ground level. Samples from bridge pier are listed in distance from upper surface. Glauconite not counted in mineral analyses. Tr., trace]

		Specific gravity >2.80; particle size <0.177, >0.074 mm																				Specific gravity <2.80; particle size <0.149, >0.074 mm				Glauconite-clastic ratio; particle size <0.42, >0.062 mm	
		Opaque minerals			Nonopaque minerals																						
Formation	Locality	Ilmenite	Brown ilmenite and (or) iron oxides	Leucoxene	Zircon	Rutile group	Tourmaline	Epidote group	Hornblende	Garnet group	Staurolite	Sillimanite	Kyanite	Andalusite	Chloritoid	Muscovite	Biotite	Chlorite	Sphene	Siderite	Pyroxene	Common quartz	Polycrystalline quartz	Feldspar	Rock fragments	Glauconite	Clastics
Hornerstown Sand	Odessa	73	7	20	5	6	1	6	2	19	35	....	7	8	6	....	5	....	Tr.	....	....	81	....	10	9	89	11
Mount Laurel Sand	do	93	2	5	10	4	2	15	2	30	19	8	4	2	4	....	....	....	....	....	....	71	1	18	10	45	55
	Biggs Farm, 6 feet above high tide.	84	9	7	14	7	3	18	2	13	22	8	4	4	4	....	1	....	....	....	....	72	....	17	11	7	93
	Biggs Farm, high-tide level.	79	10	11	4	4	4	18	5	26	19	3	7	1	5	3	1	....	....	....	....	76	Tr.	11	13	4	96
Marshalltown Formation	Bridge pier, 25	90	1	9	8	9	5	19	2	17	17	9	5	2	4	....	2	....	1	....	....	78	1	16	5	15	85
	27	80	9	11	15	10	9	22	2	8	17	2	3	3	5	1	1	1	1	....	....	81	1	12	6	60	40
	32	71	12	17	8	6	9	22	....	15	19	1	3	Tr.	8	3	5	1	....	....	....	81	1	10	8	58	42
	39	85	2	13	14	7	6	30	1	15	10	2	1	1	5	2	4	1	1	....	....	66	3	13	18	15	85
Englishtown Formation	Bridge pier, 41	51	3	46	2	1	6	26	1	9	8	4	3	6	12	2	7	12	1	....	....	83	2	8	7	6	94
	44	71	7	22	Tr.	9	7	10	1	18	8	1	2	2	28	5	4	5	....	....	....	81	Tr.	6	13	8	92
	51	78	5	17	10	3	7	14	1	26	8	1	1	1	7	8	2	11	Tr.	....	....	80	1	8	11	11	89
	53	71	8	21	6	7	12	20	1	17	9	3	2	2	7	4	3	6	1	....	....	86	1	9	4	20	80
Merchantville Formation	Bridge pier, 55	52	20	28	5	2	6	13	....	11	8	1	1	....	8	17	7	15	1	5	....	82	5	10	3	10	90
	62	81	2	17	23	Tr.	3	13	....	13	8	Tr.	....	Tr.	4	6	2	6	Tr.	22	....	85	4	8	3	22	78
	70	77	1	22	6	1	9	18	....	13	5	Tr.	1	Tr.	11	10	6	11	....	9	Tr.	81	6	11	2	25	75
	76	60	12	28	6	1	2	10	....	11	5	....	1	1	7	14	4	16	....	22	....	88	4	8	....	11	89

the formations in which glauconite sand is a major constituent. In each of these formations glauconite content gradually decreases between Woodstown, N.J., and the Chesapeake and Delaware Canal, and then there is a further abrupt decrease to the eastern shore of Chesapeake Bay. The glauconite depletion is less evident in the quartz sand units, the Englishtown and Mount Laurel. The overall trend, however, is toward glauconite depletion from northeast to southwest, which suggests a nearer shore depositional site for most of these formations in the southwest.

CLAY-MINERAL ANALYSES

Part of the study of the Coastal Plain sediments by Groot and Glass (1960) was an analysis of the clay minerals. In the marine Cretaceous section, to which our study was restricted, these units, according to Groot and Glass, should be characterized by an illite-montmorillonite assemblage in which kaolinite and chlorite are present, but as minor constituents.

Montmorillonite is present occasionally in the Merchantville Formation and Mount Laurel Sand, whereas it is common in the Marshalltown and Englishtown Formations (table 4). Illite and (or) muscovite are present in some but not all samples. Kaolinite is common in most samples, nearly in the same abundance as montmorillonite.

Groot and Glass (1960, p. 279) ascribed the lack of kaolinite in the Marshalltown in the southwest to deeper water deposition. The present authors found no such relationship; in fact, kaolinite was consistently present in higher concentrations than montmorillonite in the Marshalltown in the Delmarva Peninsula. The Marshalltown in the southwest is probably a shallower water facies than it is to the northeast, as shown by the general decrease in glauconite sand.

In addition to the major clay minerals, there are significant concentrations of clay-sized siderite in the Merchantville and Englishtown Formations at the Chesapeake and Delaware Canal. Sepiolite is also present in some of the samples from the same area but in much smaller amounts (table 4). Groot and Glass did not discuss these two minerals in their report.

From the analyses, it is evident that the clay-sized assemblages are complex mixtures of many clay and nonclay minerals. These complex clay mixtures characterize the marine formations in the northern Atlantic Coastal Plain. The characteristic illite-montmorillonite assemblage suggested by Groot and Glass for the marine formations is not consistently present. Our study was too restricted areally to answer the basic question whether differences in clay mineralogy and the abundances of the various clay minerals resulted from segregation because of crystal size or diagenesis or both.

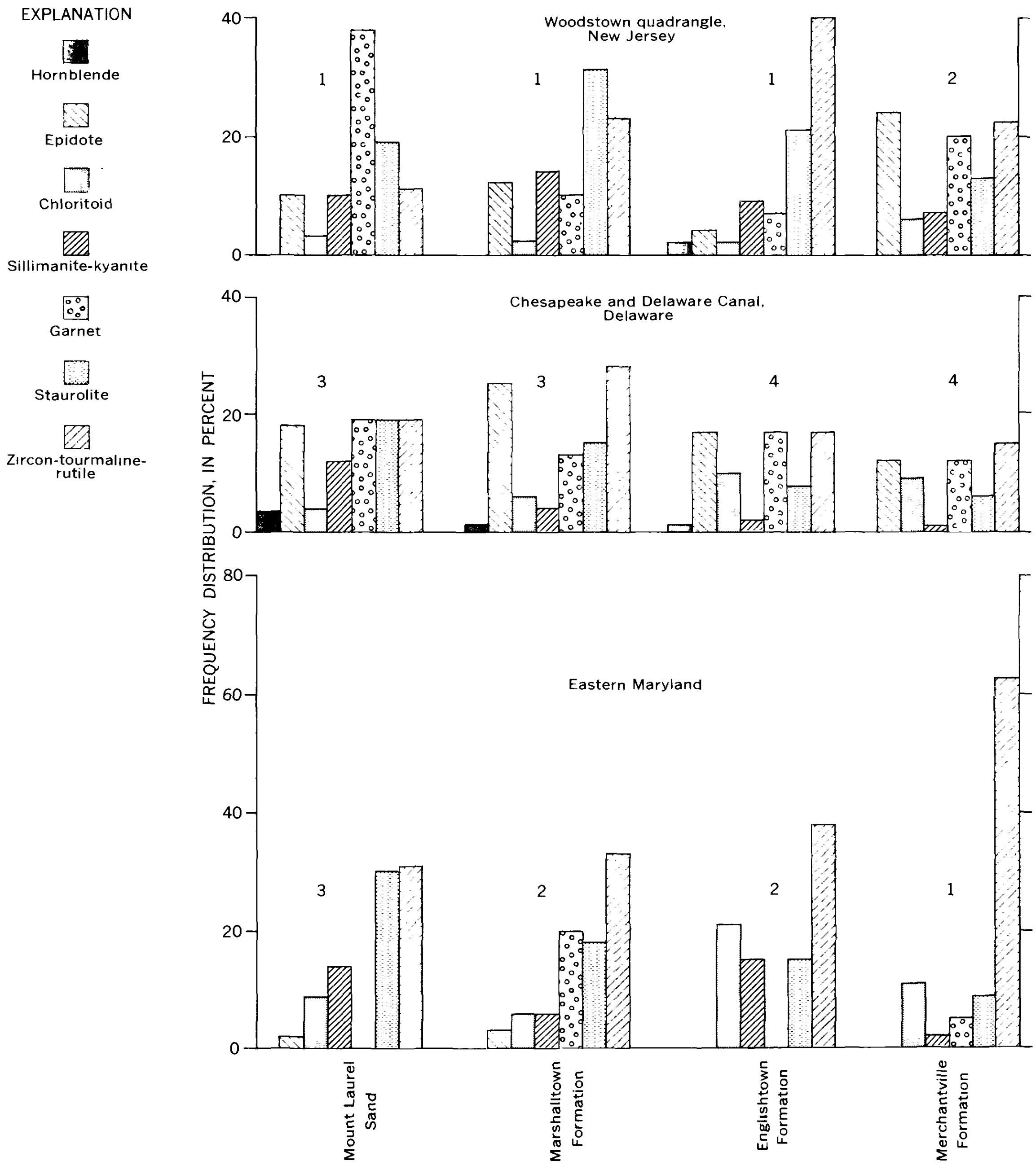

FIGURE 19.—Histograms showing frequency distribution of some of the heavy minerals listed in tables 2 and 3. Number above each histogram indicates the number of samples averaged to obtain percentage of each mineral.

CONCLUSIONS

The main points revealed by this rock stratigraphic analysis of the Upper Cretaceous Coastal Plain sequence of New Jersey, Delaware, and eastern Maryland are:

1. Lithostratigraphic comparison shows that four formations of Late Cretaceous age, the Merchantville, Englishtown, Marshalltown Formations, and the Mount Laurel Sand, can be recognized throughout the region.
2. The Upper Cretaceous section thins in outcrop from 500 feet in the northern Coastal Plain in New Jersey to 240 feet in the eastern shore of Maryland. The thinning was accomplished in two ways: (1) nondeposition and (2) erosion. Erosion is largely responsible for the removal of the Tinton, Red Bank, and Navesink Formations to the southwest.
3. Many stratigraphic misidentifications have resulted from failure to recognize the repetition of similar lithologies in cycles, especially the more sandy units such as the upper Red Bank

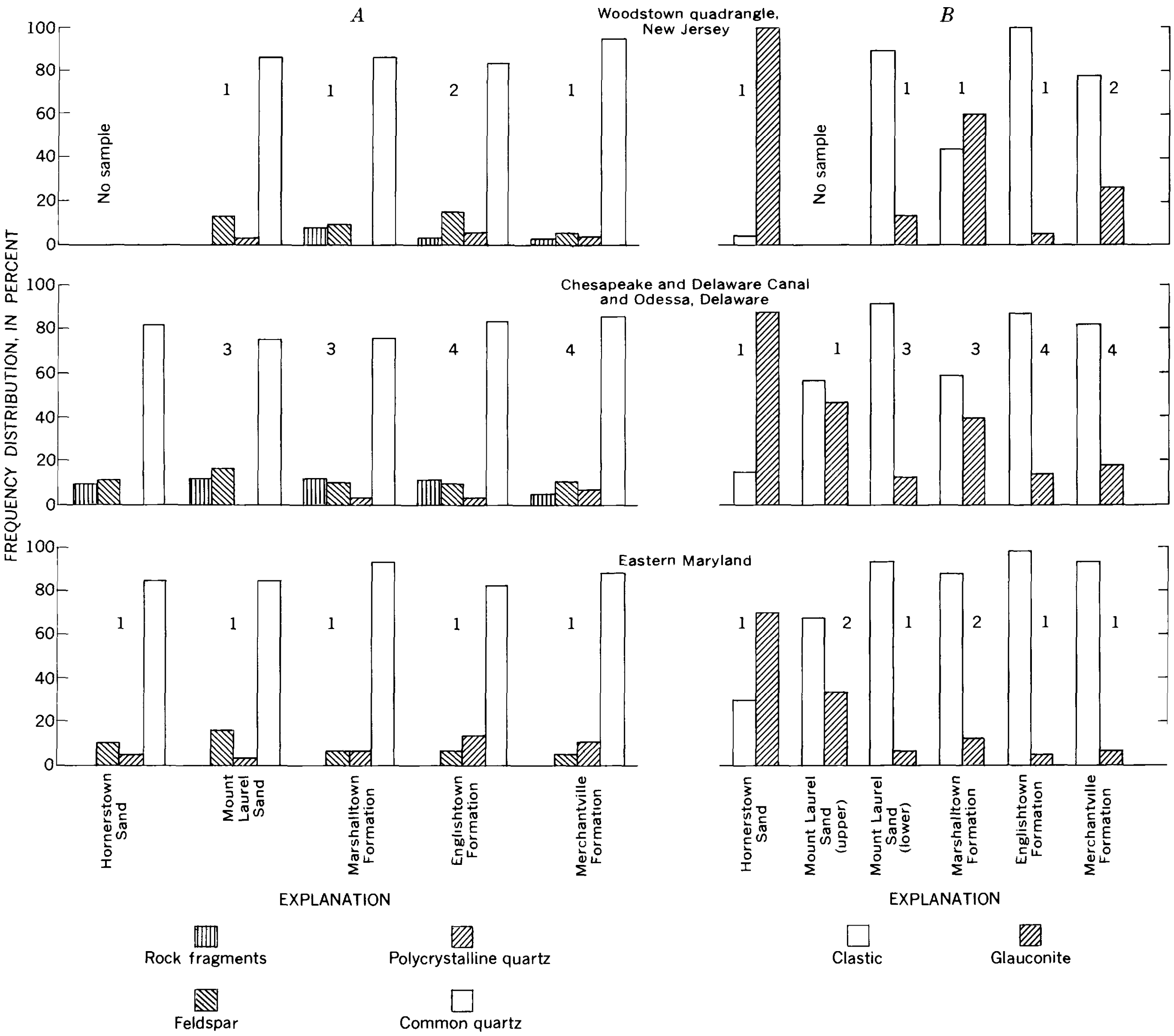

FIGURE 20.—Frequency distribution listed in tables 2 and 3 for (*A*), three light minerals and rock fragments (sp gr < 2.80) and (*B*), glauconite-clastic ratios. Clastics include all nonmagnetic components—mostly quartz, feldspar, and muscovite. Number above each histogram indicates the number of samples averaged to obtain percentage of each mineral.

Sand and massive Mount Laurel Sand, or the silty beds of the lower Red Bank Sand and Wenonah Formation.

4. The dominantly authigenic glauconite-rich units show a more consistent thickness and lithology along outcrop than the dominantly allogenic quartz sand units. The consistency in thickness and lithology of the Marshalltown is especially noteworthy.
5. Borings—crustacean, worm, and molluscan—are common in all the more sandy and silty units. The dominant boring is *Ophiomorpha* (*Halymenites*) *major*, of earlier authors, and the reported restriction of this form to the Wenonah Formation is not warranted. It is diagnostic of the sandier units (the nearer shore facies) such as the Mount Laurel Sand and the Englishtown and Wenonah Formations.
6. Changes of facies are gradual and for the most part are mappable.
7. The Upper Cretaceous section thins gradually southwestward. In the same general direction, there is a tendency to lose the deeper water or greensand facies.

TABLE 4.—*Minerals in clay-silt range in the formations discussed in the text*

[Determined by X-ray spectrometer. Numbers indicate peak-height ratios from X-ray traces. M, major. Tr., trace. Sample localities are shown in figs. 5 and 6. Number after railroad bridge pier indicates depth in feet below surface]

Formation	Field number or locality	Quartz	Kaolinite	Montmorillonite	Chlorite	Mixed layer	Sepiolite	Siderite	Calcite	Apatite	Feldspar	Illite	Vermiculite	Mica-glauconite
Hornerstown Sand.	Wt 61A	..	...	...	...	...	...	...	...	...	...	...	...	5
	Odessa	..	...	...	...	Tr.	...	...	...	...	...	...	...	4
	Mil 1A	..	...	...	...	1	...	...	...	...	...	...	...	3
Mount Laurel Sand.	Wt 62	M	1+	1−	...	...	...	...	...	...	...	1+	...	...
	Biggs Farm, 6 feet above high tide.	M	2+	Tr.	1−	...	Tr.	...	...	...	...	2+	Tr.	...
	Biggs Farm, high-tide level.	M	Tr.	...	...	...	...	...	6	...	...	1−	...	...
	Bridge pier, 25	M	Tr.	...	...	...	...	Tr.	...	1−	1−	1−	...	...
	Ea 4	M	1	...	1−	1−	...	...	...	...	...	1	...	...
	Wt 71D	M	1	1−	...	1	...	...	5	...	...	1−	...	...
Marshalltown Formation.	Bridge pier, 27	M	1	1−	1−	...	...	Tr.	...	1+	...	1	...	...
	39	M	1−	1−	1−	...	2	...	1	...	...	1−	...	...
	Bet 2	M	2	...	Tr.	...	...	...	...	...	...	2	Tr.	...
	Wt 129	M	3	3	1−	1−	...	...	...	...	...	2	...	...
Englishtown Formation.	Bridge pier, 41	M	2	2	...	...	Tr.	...	...	...	Tr.	...	1	...
	44	M	1	...	...	...	Tr.	...	...	...	1	...	...	...
	51	M	...	...	...	...	...	3	...	...	...	1−	...	...
	53	M	...	...	...	1	2	1−	...	...	...	1+	...	...
	Bet 1A	M	1+	1+	...	1−	...	...	...	...	...	1+	...	...
	Wt 66	M	1	Tr.	1	1	...	...	...	...	...	...	...	...
Merchantville Formation.	Bridge pier, 55	M	1−	Tr.	1−	...	Tr.	3	...	...	...	1	...	...
	62	M	1−	...	...	Tr.	...	4	...	...	...	1−	...	...
	70	M	1−	...	...	...	...	2	...	...	...	1−	Tr.	...
	76	M	Tr.	...	1−	...	...	2	...	...	...	1−	...	...
	Bet 1	M	3	...	Tr.	...	...	...	...	...	Tr.	3	...	...

BIOSTRATIGRAPHIC ANALYSIS

By NORMAN F. SOHL and JAMES F. MELLO

The prime objective of this section is to integrate the biostratigraphic interpretations with those derived from the rock stratigraphy. In order to do this it was necessary not only to evaluate the stratigraphic distribution of faunas along the Chesapeake and Delaware Canal but to attempt to relate them to other parts of the Coastal Plain. To understand the problems facing those attempting to use the available information for purposes of correlation, one must first realize the limitations imposed by the nature of the record. Therefore a critical analysis of the New Jersey Late Cretaceous larger invertebrate fauna has been given as a necessary prelude to rational application of the data.

Primary responsibility for the opinions expressed in the sections dealing with the megapaleontology and for the correlation charts rests with Sohl. The interpretations presented in the micropaleontologic section are those of Mello.

MEGAPALEONTOLOGIC STUDIES

NORTHERN ATLANTIC COASTAL PLAIN

PROBLEMS OF REGIONAL CORRELATION

Correlation of the Upper Cretaceous sequence of the northern Atlantic Coastal Plain with other areas has been based primarily upon the megafossils. The main basis for correlation has been the two broad zones of *Exogyra costata* and *Exogyra ponderosa,* proposed by Stephenson in 1914, that are recognized along the Coastal Plain from New Jersey to Mexico. Stephenson later (1923, pl. 8) proposed another zone, that of *Exogyra cancellata,* which was included in the lower part of the *E. costata* zone (fig. 23), but it was not until 1933 that he recognized the *E. cancellata* zone in the Mount Laurel Sand of New Jersey. The confusion surrounding the relationships of the New Jersey Cretaceous sequence to others of the Coastal Plain was well expressed in the 1942 correlation chart (Stephenson and others, 1942, p. 436):

> The absence of sharply defined faunal zones of regional extent in some parts of the series and lack of knowledge as to the number and vertical distribution of the diastems and unconformities have rendered difficult the accurate vertical placing of some of the recognized lithologic units; this difficulty has been experienced especially in the North Atlantic Coastal Plain***.

Recent summaries, such as that of Richards and others (1958, 1962), have done little to refine the correlation, offering only such broad and undocu-

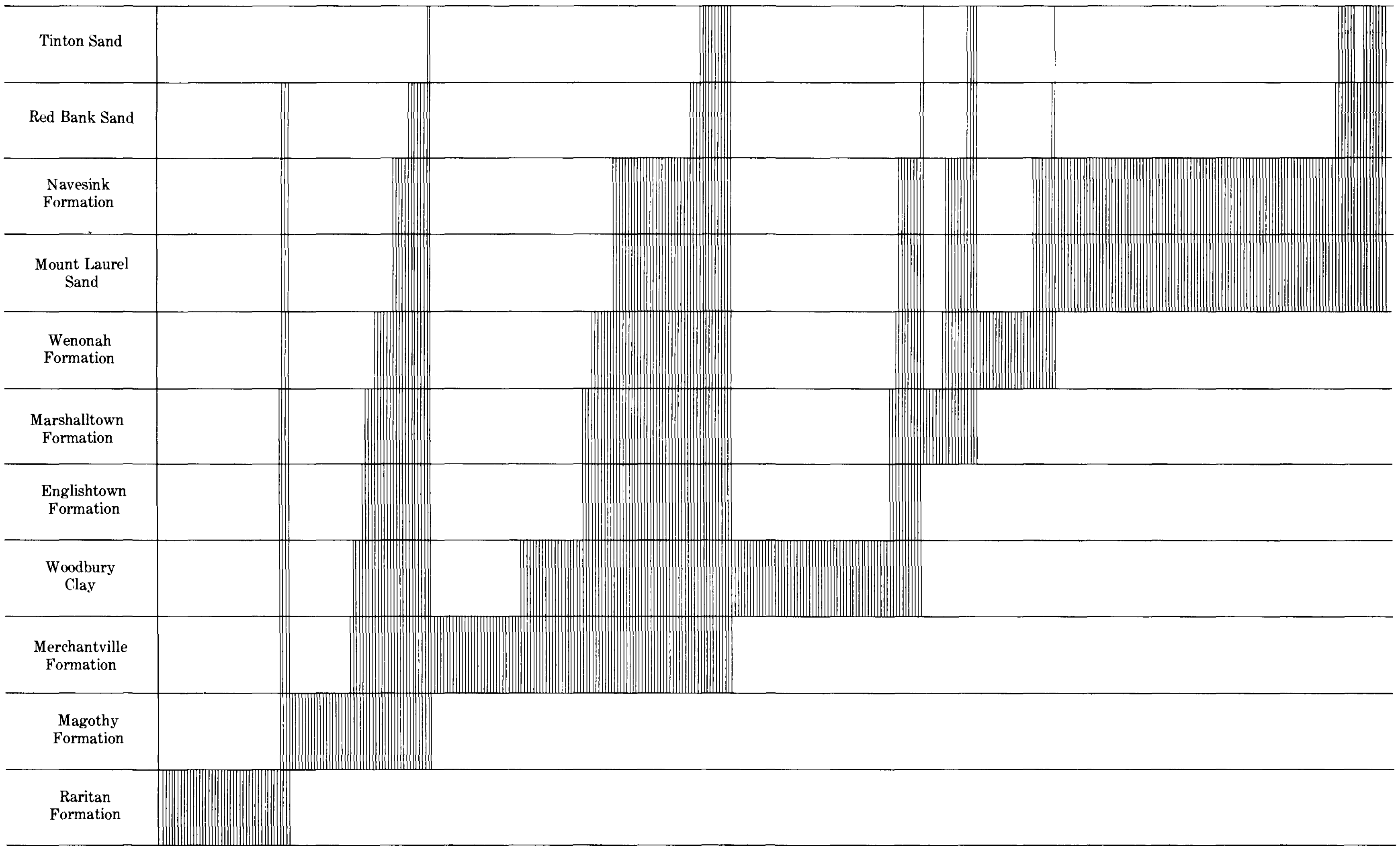

FIGURE 21.—Ranges of molluscan species from the Upper Cretaceous rocks of New Jersey. Each vertical line represents the stratigraphic range of one species. (Data compiled from Richards and others, 1958, 1962.)

mented correlations as "the Monmouth group is roughly equivalent to the Peedee Formation of the Carolinas, the Navarro of Texas and part of the Maestrichtian of Europe" (Richards and others, 1958, p. 17).

That this condition exists is superficially astounding. Perhaps because of the proximity of this area to eastern centers of research, the New Jersey Cretaceous sequence and its fauna, through the efforts of such men as Morton, Gabb, Conrad, Whitfield, Clark, and Weller was, at an early date, better known and more thoroughly investigated than any other area on the Coastal Plain. By 1907, Weller, in his exhaustive monograph on the New Jersey Cretaceous faunas, had seemingly set a firm foundation for future study of the Upper Cretaceous biostratigraphy of the northern Atlantic Coastal Plain. According to the most recent summary by Richards and others (1958, 1962), there are 428 species of mollusks in the Upper Cretaceous sequence of New Jersey. Figure 21 is a plot of these species, each vertical line illustrating the total range of an individual species as cited in Richards and others (1962). With such a large fauna and the large number of supposed stratigraphically restricted species one might assume that zonation would be simple. Why then is this not so?

One reason why this seeming wealth of biostratigraphic information has not yielded more precise correlation is that the majority of the described species have never been reported outside New Jersey and Delaware. For example, 99 of the 148 species of gastropods and 173 of the 249 species of pelecypods (about 77 percent of the described species) were erected solely for New Jersey specimens. This endemic aspect is not so real as it is a reflection of taxonomic provinciality and poor state of preservation of the fauna.

The effect of state of preservation of the fauna is shown in figure 22 in which the number of species based upon internal molds or steinkerns is plotted against the number based on well-preserved material or mixed well-preserved and steinkern material. For example, about 80 percent of the gastropod species are based upon internal molds, many of which are not determinable even at the generic level. Further critical analysis of the gastropod fauna shows that 32 percent of the described species have been correctly identified to genus, 38 percent have been incorrectly identified generically, and the remaining 30 percent are generically indeterminate. The biostratigraphic utility of the pelecypods is hampered, furthermore, by citation of an overlong range that comes from assignment of steinkerns to species based upon well-preserved specimens from a different stratigraphic level.

When species described from other areas are cited as occurring in New Jersey, it is difficult to reconcile

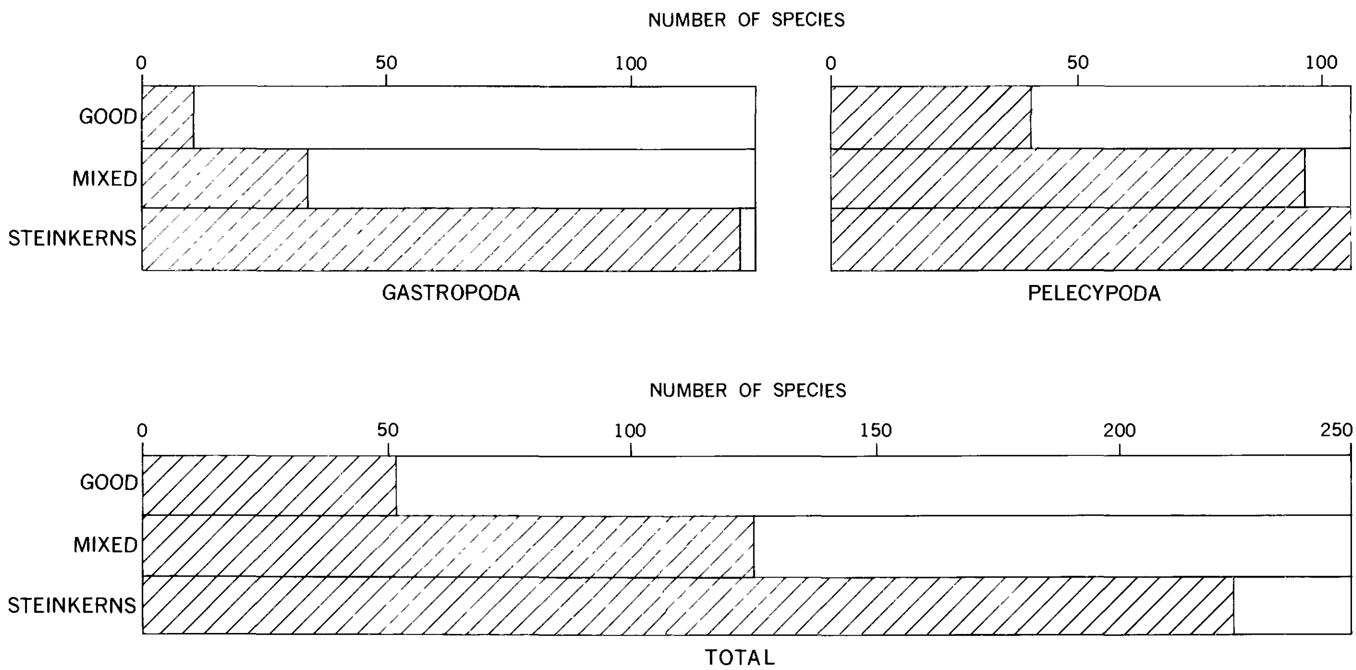

FIGURE 22.—State of preservation of the described Late Cretaceous pelecypod and gastropod fauna of New Jersey. Good, species described from well-preserved specimens. Mixed, species description based on both well-preserved and poorly preserved specimens. Steinkerns, species descriptions based entirely upon internal molds.

their ranges in New Jersey with their stratigraphic ranges elsewhere in the Coastal Plain. History plays a part in this story. Most of the species in question were described in the mid-1800's by T. A. Conrad and W. M. Gabb from the Campanian and Maestrichtian of the Ripley, Owl Creek, and Prairie Bluff Formations of Alabama and Mississippi. The early paleontologists in New Jersey naturally looked to these descriptions for comparison with their material. Knowledge of the stratigraphy was scant, and they can be forgiven their misidentifications, but later workers with much more information available have done little to rectify the situation, treating these early identifications as inviolate.

These circumstances are sufficient to explain why correlation based upon megainvertebrates is imprecise for the Cretaceous formations of the northern Atlantic Coastal Plain, but to these impediments to the utilization of the available biostratigraphic information, we must add the common lack of precise geographic and stratigraphic information as to the source of the collections. For example, Weller and others believed that the Mount Laurel Sand and Navesink Formation could not be distinguished on either faunal or lithic grounds. This opinion has led to lumping of the faunas of the two formations and thus the unnecessary lengthening of the stated ranges of many of the species (fig. 21). Minard and Owens (1962) have amply demonstrated that the two units can be lithically differentiated and mapped, and, as discussed herein, the faunas differ as well.

The biostratigraphic problems outlined in the preceding discussion will obviously not be solved until there is a thorough and critical revision of the available information that involves extensive collecting of fossils from carefully measured and precisely located stratigraphic sections. Such investigations are in progress by the authors and others.

REVISED CORRELATIONS

Figure 23 is an attempt at a more refined correlation of the Upper Cretaceous formations of the northern Atlantic Coastal Plain. It is based upon reinterpretation of existing data coupled with preliminary results of investigations now in progress. As is obvious, much reliance is placed upon the use of ammonites as a biostratigraphic tool. Because of the general rarity of distinctive ammonites in the faunal assemblages of this region, other types of mollusks have previously been used (for example, *Exogyra*). However, from new finds, the literature, and information from older collections in such institutions as the Yale Peabody Museum, it was found that more than 30 species of ammonites occur in the area. The inoceramids, another useful but neglected tool, are now under study, and it is hoped that they will eventually yield additional aid in zoning the stratigraphic sequence. At present, this information permits more detailed correlation than did the three broad zones based upon *Exogyra*. In addition, some correlations can be made between the Coastal Plain and the western interior.

The correlation chart includes only generalized stratigraphic columns for areas outside the northern Atlantic Coastal Plain. The numbers included with the formation names indicate the occurrence of certain species in that unit, the names of which are given at the left-hand margin along with the range of the species as represented by the vertical lines associated with the species.

Correlation of the Merchantville, Englishtown, and Marshalltown Formations and the Mount Laurel Sand is dealt with separately and in detail in other parts of this paper, but some departures from the correlation chart by Stephenson and others (1942) need clarification.

Considering first of all the stages (fig. 24), it has been common practice to equate the Monmouth Group (the Mount Laurel Sand and younger Cretaceous formations) with the Maestrichtian Stage, and the Matawan Group (Merchantville through the Wenonah Formations) with the Campanian. The Mount Laurel Sand and equivalent units of the *Exogyra cancellata* zone in the gulf coast have yielded ammonites (*Anaklinoceras, Didymoceras,* and baculites) of the *Baculites compressus* zone fauna, which strongly suggest a mid-late Campanian age. Recent finds of scaphitid ammonites in the Monmouth Formation of the western shore of Maryland are, according to W. A. Cobban (written commun., January 1965), similar to those in the *Baculites clinolobatus* zone of the uppermost part of the Pierre Shale in the western interior, to which he assigns an early Maestrichtian age. On the Coastal Plain and the western interior, the widespread discoidal ammonite *Sphenodiscus* first appears in beds at about the same stratigraphic level as the Maryland ammonite. In terms of the New Jersey sequence, this would place the Campanian-Maestrichtian boundary in the upper part of the Navesink Formation. The base of the Campanian lies somewhat below but close to the base of the Merchantville Formation where *Scaphites hippocrepis* (DeKay) occurs.

The Upper Cretaceous formations of the northern Atlantic Coastal Plain range in age from Ceno-

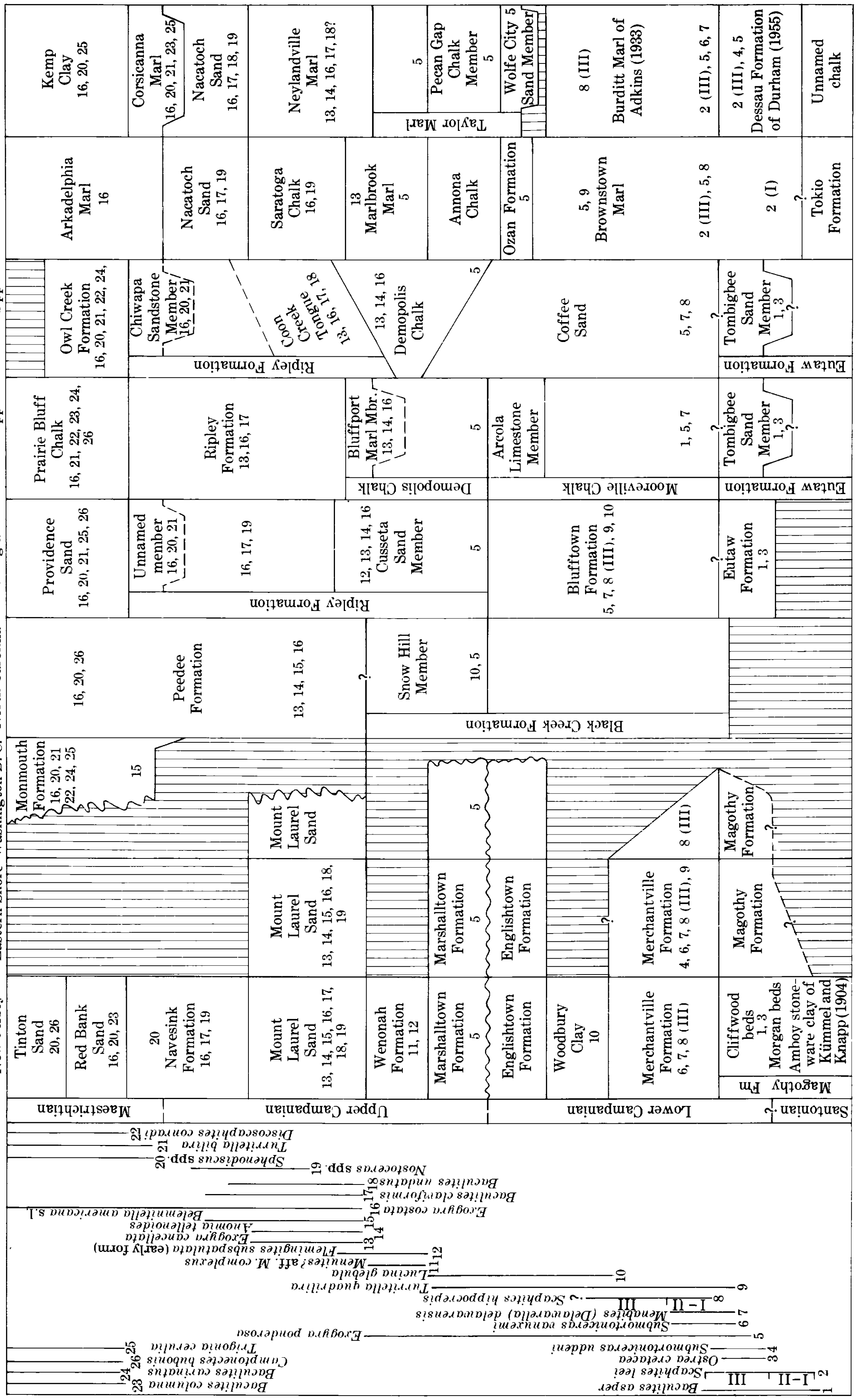

FIGURE 23.—Correlation of the Upper Cretaceous post-Raritan formations.

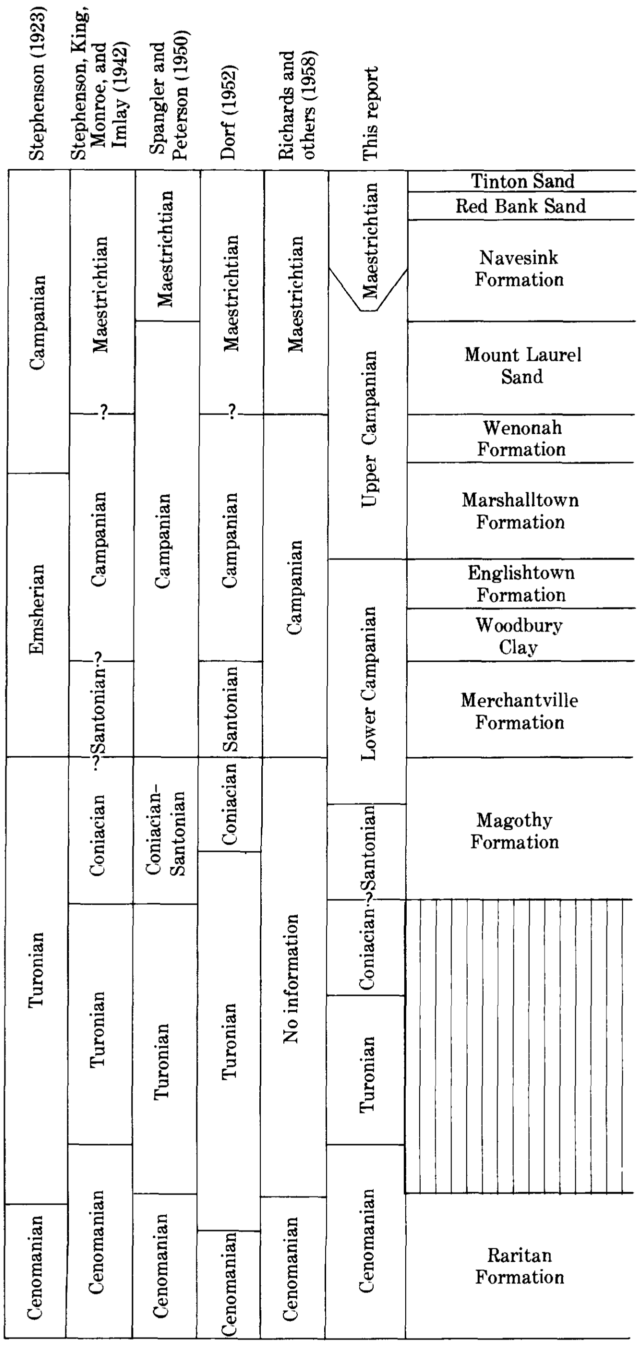

FIGURE 24.—Comparison of stage nomenclature as it has been applied to the Upper Cretaceous sequence in New Jersey.

manian to Maestrichtian. The Raritan Formation is the oldest of these. According to Stephenson (1954), the Woodbridge clay of Kümmel and Knapp (1904) of the Raritan Formation contains a marine fauna of Cenomanian age and most probably would equate with the mid-Cenomanian-age faunas. The Amboy stoneware clay of Kümmel and Knapp (1904), formerly considered as the uppermost unit of the Raritan Formation, contains pollen of Santonian age (J. A. Wolfe, oral commun., 1968; Doyle, 1969, table 2), and is now considered the basal unit of the Magothy Formation. On the basis of field relationships, the Raritan appears restricted to the Raritan Bay area of New Jersey. The white clays exposed at the base of the Chesapeake and Delaware Canal section belong to the Potomac Group lithologically, but may, at least in part, be of Cenomanian age.

The next highest unit, the Magothy Formation, is of Santonian to early Campanian age. Marine faunas have been found only in the upper part of the formation, and these are restricted to the northernmost outcrops in the vicinity of Cliffwood, N.J. As indicated in figure 23, *Baculites asper* Morton ranges from the late Santonian into the early Campanian. Another significant species, *Ostrea cretacea* Morton, has been reported from the Magothy of the Cliffwood area by Richards and others (1958, p. 1040). This species is a common form in the Tombigbee Sand Member of the Eutaw Formation of the gulf coast in units considered of late Santonian to early Campanian age. On the basis of pollen and spore analysis, J. A. Wolfe (oral commun., 1968) has assigned the Amboy stoneware and Morgan beds to the late Santonian, but he states that the Cliffwood flora contains elements previously known only from the Campanian. Thus, there appears to be a significant time gap separating the Raritan and Magothy Formations. There are no dateable marine Turonian or Coniacian rocks cropping out in the northern Atlantic Coastal Plain or, for that matter, to the south, until the Alabama outcrops.

The age of the Merchantville Formation is discussed later, but it is a readily correlative early Campanian unit.

J. B. Reeside Jr. (in Richards and others, 1962, p. 126), reported that an ammonite closely akin to *Scaphites leei* Reeside occurs in the Woodbury Clay. The specimen more likely belongs to *S. hippocrepis* III of Cobban, a species that is a component of the early Campanian faunas of the western interior and the Coastal Plain.

The Englishtown Formation has a small fauna in Delaware and virtually no fauna in New Jersey, so that at present little can be done in terms of precise correlation.

The Marshalltown Formation fauna is discussed in detail later. Its fauna is of late early or early late Campanian age.

The Wenonah Formation cannot be distinguished with ease at present on a faunal basis. The ammonite *Placenticeras* does occur in the formation, but its lineage on the Coastal Plain is too poorly understood to aid in correlation at present. Another ammonite, *Menuites*? aff. *M. complexus* (Hall and Meek), is reported from the formation by Reeside (in Richards and others, 1962, p. 122). This species occurs in the early late Campanian Gregory Member of the Pierre Shale in the western interior; however, Reeside expressed the opinion that the New Jersey specimen probably represented a distinct but related species. The only other significant form reported from the Wenonah Formation in New Jersey is *Flemingites subspatulata* (Forbes) (see Richards and others, 1958, p. 106). Sohl (1964a, fig. 12) has indicated that this species ranges through that part of the *Exogyra costata* zone above the zone of *E. cancellata*. Later studies in the Cretaceous rocks of the Chattahoochee River region of Georgia and Alabama have shown that *F. subspatulata* is part of an evolving lineage beginning with smaller and thinner early forms appearing in the Cusseta Sand Member of the Ripley Formation just below the first occurrence of *E. cancellata*. The normal large thick-shelled form ranges through the *E. costata* zone of the Ripley Formation and gives rise, in the basal part of the Providence Sand, to a large but more slender, less curved, and sharper beaked form. The specimens figured by Weller (1907) and by Richards and others (1958) are internal molds, but in size, shape, and the reflection of resilifer and muscle scar they are certainly suggestive of the early form of *Flemingites subspatulata* that occurs in the upper part of the Cusseta Sand Member. Thus, the Wenonah Formation appears to correlate with the uppermost part of the *Exogyra ponderosa* zone and perhaps the lowest part of the *E. cancellata* zone.

As discussed more fully later, the assemblage of ammonites and other mollusks in the Mount Laurel Sand is of mid-late Campanian age and can be correlated readily with units throughout the Atlantic and Gulf Coastal Plains.

The age limits of the Navesink Formation are at present a problem. The presence of *Baculites claviformis* Stephenson in the lower part of the formation and the one specimen of *Sphenodiscus* (Minard and others, 1969, p. H13), recovered supposedly from the upper part of the formation, suggests a close equivalency with the Nacatoch Sand of Texas. A recent collection of ammonites made by H. Mendrych of North Arlington, N.J., from the lower part of the Navesink Formation at the classic Atlantic Highlands section, has, according to W. A. Cobban (written commun., 1968), yielded specimens that are closely related to western interior and gulf coast species. Species of *Exiteloceras, Nostoceras,* and *Scaphites* (*Hoploscaphites*) are represented. In total, they are closely related to species from late Campanian *Baculites cuneatus* and *B. reesidei* zones of the Pierre Shale. In summation, the Navesink Formation appears to range in age from late Campanian to earliest Maestrichtian.

The Tinton and Red Bank Sands of New Jersey contain a varied assemblage, including a number of stratigraphically restricted but widespread species such as *Baculites columna* Morton which occur in equivalent formations as far away as Texas and the western interior. Other species such as *Trigonia cerulia* Whitfield (=*T. haynesensis* Stephenson) found in the Providence Sand of Georgia and in the highest beds of the Peedee Formation are restricted in distribution to the East Gulf and Atlantic Coastal Plains. These formations are definitely of Maestrichtian age but how much of this stage is represented is debatable. At present I (Sohl) feel that on the outcrop, the Tinton and Red Bank represent no more than the lower half of the Maestrichtian and that the overlying formations rest unconformably on the Cretaceous sequence throughout the northern Atlantic Coastal Plain (see also Minard and others, 1969).

SUMMARY OF CRETACEOUS MEGAFAUNA

In the northern Atlantic Coastal Plain, precise correlation based on megafossils has been hindered by:

1. Dependence on comparison of poorly preserved New Jersey fossils with well-preserved fossils of other areas.
2. Misidentification of well-preserved material.
3. Taxonomic provinciality, which has erroneously lent the New Jersey fauna an endemic aspect.
4. Poor documentation as to source of collections.
5. Lumping together of assemblages from more than one formation.
6. Misidentification of formations.

Revised correlation based primarily on ammonite occurrence shows that:

1. The Upper Cretaceous formations of northern New Jersey range in age from the Cenomanian Raritan Formation at its base to the early Maestrichtian Tinton Sand at its top.
2. On the Chesapeake and Delaware Canal, the lowermost fossiliferous Upper Cretaceous unit, the Magothy, is of Santonian to early Campanian age, and the uppermost unit, the Mount Laurel Sand, is early late Campanian.
3. Nowhere in the region are there dateable marine beds of Turonian or Coniacian age.

CRETACEOUS MEGAFAUNA FOSSILS FROM THE CHESAPEAKE AND DELAWARE CANAL

The fossils from the Chesapeake and Delaware Canal section, like those from New Jersey, are commonly poorly preserved. Calcitic oyster shells are, however, well preserved in some places. Fortunately, sideritic concretions and phosphatic nodules are present in most rock units, and these afford external molds of sufficient quality to allow precise determination.

In tables 5, 7, and 8, those taxa marked by an asterisk are known only as internal molds. Except where distinctive characters are shown, no attempt has been made to perpetuate the illusion of certain identification by assigning such molds to a species. Some molds can be assigned to a group composed of similar species. For example, some molds of the pelecypod *Nucula*, can be placed in the *percrassa* lineage and others in the *amica* lineage, but they cannot be assigned with certainty to an individual species. Many gastropods from the canal that are listed only as indeterminable internal molds could perhaps be assigned to species described from New Jersey, but as this would be only a comparison of similar internal molds of uncertain affinities, it seems more a semantic exercise than a taxonomic determination.

MERCHANTVILLE FORMATION

FAUNAL CHARACTERISTICS

The Merchantville Formation contains the largest megainvertebrate fauna of any formation exposed along the canal. One hundred and three genera and subgenera of mollusks (see table 5) are represented (56 pelecypods, 40 gastropods, 5 ammonites, 2 scaphopods). Seventy-six species are definitely assigned to or compared with previously described species. The remainder are represented by material sufficient only for generic placement.

Fossils occur mainly in concretions that are concentrated in zones in the lower and more coarsely clastic part of the Merchantville. Fossils are rarer

TABLE 5.—*Megainvertebrate distribution in the Merchantville Formation in the Chesapeake and Delaware Canal area and New Jersey*

[▲, Occurrence of the species outside the Merchantville Formation of the canal area; ×, rare occurrence (1–5 specimens); ●, common occurrence (5–15 specimens); ■, abundant occurrence (15+ specimens); *, known only as internal molds]

	Chesapeake and Delaware Canal																						New Jersey						
					In situ																								
					Lower			Middle and Upper					Position uncertain																
	Englishtown	Marshalltown	Mount Laurel	Excavation for bridge abutment	17715	17736	17756	17757	17693	17754	17740	17689	17687	17703	17695	17738	17719	17700	17739	17691	17749	Spoil banks	Magothy	Merchantville	Woodbury	Englishtown	Marshalltown	Wenonah	Mount Laurel-Navesink
Pelecypoda:																													
Nucula whitfieldi Weller?								×	×		×						×				×		▲	▲	▲		▲	▲	
slackiana (Gabb)									×											×	×	×			▲				
Nuculana cf. *N. compressifrons* (Whitfield)																			×		×	×		▲	▲				
Nuculana? sp									×										×			×							
Yoldia papyria (Conrad)?																						×			▲				
Trigonia sp									×			×																	
**Trigonia* sp						×																							
Nemodon cf. *N. neusensis* (Stephenson)																						×							
sp													×									×							
Arca sp								×											×	×		×							
Barbatia carolinensis (Stephenson)																						×							
Breviarca cf. *B. haddonfieldensis* Stephenson																×			×		×	×			▲				
sp						×													×			×							
Idonearca cf. *I. vulgaris* (Morton)																		×									▲		▲
sp					×	×			×	×											×	×							
**Idonearca* sp				×					×							×													
Glycymeris sp					×			×														×							
**Pinna laqueata* Conrad						×			×													×		▲	▲			▲	▲
**Pinna* sp						×									×	×						×							
Lithophaga sp													×									×							
Pteria cf. *petrosa* Conrad				×																		×	▲					▲	
Gervilliopsis ensiformis (Conrad)																						×		▲	▲		▲	▲	▲
Inoceramus sp				×					×													×							
Syncyclonema simplicius (Conrad)			▲													×						×							
conradi (Whitfield)	▲							×								×			×		×	×	▲	▲					▲
Camptonectes bellisculptus (Conrad)	▲	▲						×	×					×				×		×		×	▲	▲			▲	▲	▲
Neithea quinquecostata (Sowerby) of Weller		▲	▲						×												×	×		▲			▲		▲
Plicatula n. sp											×											×							
Lima sp		▲																		×									
Exogyra ponderosa Roemer													×														▲		
Ostrea mesenterica Morton		▲	▲																×		×	×							▲
falcata Morton	▲	▲	▲						●									×	×			×					▲		
**Ostrea* sp													×								×								
Anomia cf. *A. argentaria* Morton	▲	▲	▲												×							×	▲	▲	▲		▲	▲	▲
cf. *A. radiata* Weller													×											▲	▲				
Paranomia scabra Morton		▲	▲																×			×		▲			▲		▲
Astarte? sp									×													×							
Crassatella cf. *C. roodsensis* Stephenson																						×							
cf. *C. carolinensis* Conrad																						×							
cf. *C. newkirkensis* Stephenson																				×									
Crassatella sp									×										×		×	×							
Vetericardia sp																					×								
Lucina sp																						×							
Aenona? sp																			×	×		×							
Linearia metastriata Conrad	▲		▲		×				×					×					×			×	▲	▲	▲		▲	▲	
contracta Whitfield																×		×											▲
magnoliense Stephenson								×							×	×			×		×	×					▲		▲
Tellina sp											×		×									×							
**Tellina* sp																				×									
Unicardium cf. *U. umbonatum* (Whitfield)		▲					×																				▲		▲
Solyma sp																						×							
Cardium (*Pachycardium*) *spillmani* Conrad																			×			×		▲					▲
(*Criocardium*) sp								×														×							
(*Granocardium*) *tenuistriatum* (Whitfield)						×			●		●	×									×	×	▲	▲		▲	▲	▲	▲
dumosum Conrad		▲	▲			×												×			×	×		▲	▲			▲	
n. sp								×																					
(*Trachycardium*) *eufaulensis* Conrad			▲																			×					▲		▲
(*Trachycardium*?) *uniformis* Weller								×																	▲				
longstreeti Weller	▲																					×						▲	
spp				×					×							×			×	×		×							
Isocardia sp							×																						
Cymbophora? sp																	×		×			×							
Etea cf. *E. carolinensis* Conrad	▲								×											×									
sp											×										×								
**Etea*? sp													×																
Veniella conradi Weller non Conrad		▲	▲					×													×	×		▲	▲			▲	▲
Aphrodina sp							×															×							
Cyprimeria sp																					×								
Legumen planulatum (Conrad)																				×									
concentricum Stephenson									×						×				×			×			▲				
n. sp																				×									
Anatymya sp																						×							
Pholadomya occidentalis (Morton)																×		×		×		×	▲	▲	▲				
Pholas cithara Morton																						×							
Pholas? sp													×																

TABLE 5.—*Megainvertebrate distribution in the Merchantville Formation in the Chesapeake and Delaware Canal area and New Jersey*—Continued

[▲, Occurrence of the species outside the Merchantville Formation of the canal area; ×, rare occurrence (1–5 specimens); ●, common occurrence (5–15 specimens); ■, abundant occurrence (15+ specimens); *, known only as internal molds]

	Chesapeake and Delaware Canal																						New Jersey						
					In situ																								
					Lower			Middle and Upper						Position uncertain															
	Englishtown	Marshalltown	Mount Laurel	Excavation for bridge abutment	17715	17736	17756	17757	17693	17754	17740	17689	17687	17703	17695	17738	17719	17700	17739	17691	17749	Spoil banks	Magothy	Merchantville	Woodbury	Englishtown	Marshalltown	Wenonah	Mt. Laurel-Navesink
Pelecypoda—Continued																													
Caesticorbula crassiplica (Gabb)		▲						×	×	×	×				×					×	×	×		▲	▲			▲	▲
Caryocorbula sp																					×								
Parmicorbula sp									×		×																		
Corbula cf. *C. swedesboroensis* Weller															×							×	▲	▲	▲		▲		
sp																			×			×							
Panopea decisa Conrad		▲							×		×											×	▲	▲	▲			▲	▲
Kummelia sp									×																				
Cymella bella Conrad	▲							?	×	×	×					×				×	×	×	▲	▲	▲			▲	
cf. *C. ironensis* Stephenson																				×									
Liopistha alternata Weller?			▲																×					▲					
cf. *L. protexta* (Conrad)	▲			×				×	×						×						×	×		▲				▲	▲
Gastropoda:																													
Urceolabrum mantachiensis Sohl?																				×		×							
Calliomphalus (Calliomphalus) paucispirilus Sohl						×															■								
(Planolateralis) n. sp									×																				
Laxispira lumbricalis Gabb		▲						●	×	×						●				×	■	×		▲	▲				
Turritella merchantvillensis Weller						×	×	×	●				■		×	●	×	×	×	●	●	×		▲					
cf. *T. merchantvillensis* Weller				×		×			×											×		×		▲					
n. sp									×																				
Haustator quadrilira (Johnson)	▲	▲						×					×			×				×		×	▲		▲	▲			
Cerithium cf. *C. weeksi* Wade																×													
Cerithiella n. sp																						×							
Opalia (Opalia?) n. sp																						×							
Acrilla? n. sp																						×							
Graciliala johnsoni (Stephenson)				×		●	●	●	●				●			■				●	■				▲				
sp								×	×							×	×		×	×		×							
Arrhoges (Latiala) cf. *A. (L.) lobata* (Wade)																					×	×							
(Latiala) sp									×	×			×		×					×		×							
**Anchura?* sp																×													
Pterocerella aff. *P. poinsettiformis* Stephenson																					×								
Tundora cf. *T. tuberculata* Stephenson																×		×	×										
Xenophora sp													×								×	×							
Trichotropis squamosus (Gabb)																						×							
cf. *Vanikoropsis ambigua* (Meek and Hayden)																						×							
Gyrodes aff. *G. major* Wade																						×							
cf. *G. spillmani* Gabb																						×							
spp									×	×											×	×							
Euspira aff. *E. rectilabrum* (Conrad)	▲																					×							
sp																				×	×	×							
Pseudamaura lepta Sohl					×				×							×			×		×	×		▲	▲				
**Ecphora?* sp																					×	×							
Sargana cf. *S. stantoni* (Weller)																						×							
Cantharulus? sp																					×								
Anomalofusus? sp																						×							
Drilluta aff. *D. distans* (Conrad)																						×							
Drilluta? sp																						×							
Bellifusus n. sp					×			×														×							
Hercorhynchus n sp.																				×									
Pyrifusus sinucostatus Sohl																					×								
Pyropsis sp																						×							
Napulus n. sp																			×		×	×							
Liopeplum cf. *L. thoracicum* Stephenson																						×							
Longoconcha sp																						×							
Paladmete cf. *P. cancellaria* Conrad						×				×					×	×					×	×							
n. sp.								×	×							●					×	×							
Caveola sp																					×	×							
Amuletum n. sp																						×							
Acteon sp									×							×					×								
Nonactaeonina sp											×										×								
Ringicula n. sp																				×									
Anisomyon cf. *A. borealis* (Meek and Hayden)									×																				
Cephalopoda:																													
Baculites cf. *B. minerensis* Landes								×											×										
sp																×						×							
Scaphites hippocrepis (Dekay)				×					×				×									×		▲					
Placenticeras placenta (Dekay)					×	×			×							×			×		×	×	▲	▲	▲		▲	▲	
Submortoniceras uddeni Young																						×							
Menabites (Delawarella) delawarensis (Morton)																						×		▲					
Ammonite undet																						×							
Scaphopoda:																													
Dentalium subarctuatum Conrad									×									×		×		×		▲	▲				
Cadulus obnatus Conrad																		×							▲				
Chaetopoda:																													
Serpula sp																			×		×	×							
Hamulus major Gabb										×									×	×	×	×							
Longitubus sp																						×							
Indeterminate echinoids						×					×							×				×							

TABLE 5.—*Megainvertebrate distribution in the Merchantville Formation in the Chesapeake and Delaware Canal area and New Jersey*—Continued

Merchantville Formation

17715. Material in place at water's edge on north side of Chesapeake and Delaware Canal at station 56+500, Delaware. Collected by C. W. Carter, 1935–37.
17736. North side Chesapeake and Delaware Canal at station 53+500, Delaware. Collected by C. W. Carter, 1935–37.
17756. North side of Chesapeake and Delaware Canal at station 53+500, about 1,300 ft west of Summit Bridge, Del. Fossils taken from formation at water's edge and up to 6 ft above water in the bank. Collected by C. W. Carter, 1935–37.
17757. South side of Chesapeake and Delaware Canal at station 53+200, Delaware. Material taken from concretions collected in place at water's edge. Collected by C. W. Carter, 1935–37.
17693. Clay lens in top of formation, south side of Chesapeake and Delaware Canal, approx at station 65+000, Delaware. Collected by C. W. Carter, 1935–37.
17754. South side of Chesapeake and Delaware Canal at station 62+550, Delaware. Material from a dry lens in top of formation. Collected by C. W. Carter, 1935–37.
17740. From the fossiliferous clay lens at top of Crosswicks Clay (equivalent to Merchantville Formation and Woodbury Clay), north side of Chesapeake and Delaware Canal, approx at station 61+000, Delaware. Collected by C. W. Carter, 1935–37.
17689. Upper Cretaceous. In sandy top of formation at water's edge on west side of Summit Bridge, Chesapeake and Delaware Canal, Del. Collected by C. W. Carter, 1935–37.
17687. Friable material in a sandy lens about 3 ft thick and 300 ft long in top of Merchantville at the Penn Central Railroad's Chesapeake and Delaware Canal bridge (formerly Pennsylvania, Baltimore, and Washington bridge) on south side of the canal, Delaware. Collected by C. W. Carter, 1935–37.
17703. At station 63+000 (south side) about 1 mile east of Maryland-Delaware line, Chesapeake and Delaware Canal, Del. Collected by C. W. Carter, 1935–37.
17695. South side of Chesapeake and Delaware Canal (in place) at station 62+500, Delaware, approx 1 mile east of Maryland-Delaware line. Collected by C. W. Carter, 1935–37.
17738. South side Chesapeake and Delaware Canal at station 62+000, Delaware. Collected by C. W. Carter, 1935–37.
17719. Station 59+850 (north side), 3,000 ft east of Maryland-Delaware line, Chesapeake and Delaware Canal, Del. Collected by C. W. Carter, 1935–37.
17700. Material in place at station 59+850, north side of Chesapeake and Delaware Canal, 1¼ miles west of Summit Bridge, Del. Collected by C. W. Carter, 1935–37.
17739. North side Chesapeake and Delaware Canal at station 57+000, Delaware. Collected by C. W. Carter, 1935–37.
17691. South side of Chesapeake and Delaware Canal (in place) at station 62+, Delaware. Approx 1 mile east of Maryland-Delaware line. Collected by C. W. Carter, 1935–37.
17749. South side Chesapeake and Delaware Canal at station 55+500, Delaware. Material contained in concretions in place at water's edge. Collected by C. W. Carter, 1935–37.
28824. Near base of excavation for abutments of new railroad (Penn Central) bridge over Chesapeake and Delaware Canal just west and approx 1,600 ft south of old bridge, New Castle County, Del. Collected by N. F. Sohl, R. W. Imlay, and Jack Wolfe, 1963.

Collections from spoil banks

17692. Old dump (1925 dredging) on road from Summit Bridge to Kirkwood, Del., 2½ miles east of Summit Bridge. Collected by C. W. Carter, 1935–37.
17696. Old disposal area on north side of Chesapeake and Delaware Canal, at station 53+500, Delaware. Collected by C. W. Carter, 1935–37.
17698. Old dump (1925 dredging) on road from Summit Bridge to Kirkwood, Del., ½ mile east of Summit Bridge. Collected by C. W. Carter, 1935–37.
17688. Disposal area north side Chesapeake and Delaware Canal at the Penn Central Railroad's Chesapeake and Delaware Canal bridge, Delaware. Collected by C. W. Carter, 1935–37.
16225. Dredgings from Chesapeake and Delaware Canal, north side, about a mile east of Summit Bridge, New Castle County, Del. Collected by L. W. Stephenson, Sept. 17, 1932.
16579. Chesapeake and Delaware Canal, Deep Cut, Del. Collected by L. W. Stephenson.
15896. Chesapeake and Delaware Canal, from dredgings thrown out of the canal on the north side within 2,000 ft west of Summit Bridge, New Castle County, Del. Collected by L. W. Stephenson, Sept. 2, 1931.

in the upper part of the formation in the finer grained and more micaceous beds. For the most part, fossils in these micaceous clayey silts occur as poorly preserved impressions, but Carter, during his collecting from the canal section, made several collections from "clay lenses in the top of the formation" (see table 5, locs. 17693, 17754). No fossils from so high a position within the Merchantville were collected during this survey.

Though the specimens are devoid of shell material, when the sideritic concretions from the lower part of the formation are split, they yield excellent external molds associated with the internal molds. Latex rubber impressions of the external molds show all the characters of sculpture and form, and when combined with the characters of the columella and aperture that can be learned from examination of the internal molds, identification can be precise. In table 5, the first three columns from left to right list the species found in common in the Merchantville and the other fossiliferous formations of the canal section. In the next columns to the right, the collections from the Merchantville are arranged in stratigraphic order. The specimens in collections listed as "position uncertain" were found in place but are not assignable to a specific level; they most probably belong to the lower part of the formation.

In summary, the formation bears a larger and more diverse fauna in its lower than in its upper beds. Throughout the formation, gastropods are individually more abundant and diverse than the pelecypods. In all other formations along the canal, pelecypods are more abundant. In addition, cephalopods, primarily *Placenticeras* and *Menabites* (*Delawarella*), are more abundant here than in the overlying formations. In some places individual concretions may be composed almost wholly of a single species. The deposit-feeding aporrhaid and filter-feeding turritellid snails are the most abundant elements of the fauna. The algal or algal-detritus feeder *Calliomphalus* and possible mucous-string feeder *Laxispira* are also common snails that are abundant in some collections. No single pelecypod is abundant, but *Pinna, Legumen, Pholadomya,* and *Panopea* are of common occurrence. This abundance of deeper burrowing types of clams and the general sparcity of epifaunal pelecypods contrasts strongly with the faunas of the other formations along the canal in which epifaunal clams (oysters, pectens) and shallow burrowers such as the cardiids predominate.

COMPARISON WITH THE NEW JERSEY MOLLUSCAN FAUNA

The Merchantville fauna of the Chesapeake and Delaware Canal compares closely with that of the Merchantville and Woodbury Formations of New Jersey. Species common to other formations are primarily those that, according to Richards and others (1962), range through most of the section. For instance, *Gervilliopsis ensiformis* (Conrad) and *Pecten* (*Camptonectes*) *bellisculptus* (Conrad) range from the Merchantville through the Mount Laurel Sand and Navesink Formation in New Jersey. Fortynine species present in the Merchantville Formation of the Chesapeake and Delaware Canal also occur in New Jersey. These are distributed as follows:

	Number of species
Mount Laurel Sand-Navesink Formation	19
Wenonah Formation	17
Marshalltown Formation	16
Englishtown Formation	2
Woodbury Clay	26
Merchantville Formation	30
Magothy Formation	13

The similarity of the Merchantville fauna of the canal section to that of the Woodbury in New Jersey is not surprising. In New Jersey, the Merchantville has yielded 118 species of mollusks, 66 of which, or more than 50 percent, also are reported from the Woodbury. The common occurrence of the stratigraphically restricted species *Scaphites hippocrepis* (DeKay) and *Menabites* (*Delawarella*) *delawarensis* (Morton) in the Merchantville of both States, however, is strong evidence that the Chesapeake and Delaware Canal fauna correlates with the Merchantville fauna of New Jersey rather than with that of the Woodbury. (See fig. 23.)

Age and correlation

The Merchantville Formation is accepted here as early Campanian in age (fig. 23), on the basis of the occurrence of the widespread ammonite species *Scaphites hippocrepis* (DeKay). This species occurs in rocks of this age from the western interior of the United States to Western Europe (Cobban, 1969). *Scaphites hippocrepis* has long been used as a zonal index in the western interior. A recent study by Cobban (1969) on the *Scaphites leei* Reeside and *Scaphites hippocrepis* lineages in the western interior has special bearing on the age of the Merchantville Formation. Cobban (1969, p. 6) has divided each species into three stratigraphically restricted types. *Scaphites leei* forms I and II are of late Santonian age. *S. leei* form III is basal early Campanian and is followed in sequence by *Scaphites hippocrepis* forms I, II and III, all, however, being early Campanian. Cobban maintains that all forms illustrated from the Merchantville Formation by Reeside (in Richards and others, 1962, pl. 71, figs. 1–7), as well as those assigned by Reeside to *S.* aff. *S. leei* (Reeside, in Richards and others, 1962, pl. 71, figs. 8–11) belong to *S. hippocrepis* form III. All the additional material in the Merchantville collections was submitted to him, and these specimens he also assigned to *S. hippocrepis* III.

Other stratigraphically important Merchantville species are listed on the correlation chart (fig. 23). In total, these ammonites afford strong evidence for correlation with the sections in other areas. *Scaphites hippocrepis* III is present in the Matawan Group of Maryland (Gardner, 1916). This occurrence indicates an extension of Merchantville Formation equivalents to the western shores of Chesapeake Bay. Units equivalent to the Merchantville Formation may be represented by certain parts of the Black Creek Formation of North Carolina, but until more carefully collected and stratigraphically controlled material is available from that area, no refined correlation should be attempted. The *Scaphites hippocrepis*-*Menabites* (*Delawarella*) *delawarensis* fauna is represented in the medial part of the Blufftown Formation of Georgia and Alabama, in the lower part of the Coffee Sand of Mississippi (Sohl, 1964b, p. 350), and in the Brownstown Marl of Arkansas. In Texas, the Dessau Formation of Durham (1955), the Gober Tongue of the Austin Chalk, and the Burditt Marl of Adkins (1933) contain this fauna plus *Submortoniceras uddeni* Young (1963), which occurs also in the Merchantville Formation of the canal section (table 5, USGS 16225). The specimen from the canal area is unfortunately from a Merchantville concretion from a spoil-pile collection and therefore cannot be precisely placed at a given level within the formation. However, along the canal, most of the sideritic concretions were observed to occur near the base of the formation.

In the western interior, the Eagle Sandstone, the Telegraph Creek Formation, and equivalent units contain *Scaphites hippocrepis.*

It is obvious in view of the above discussion that the Merchantville Formation is one of the more easily correlated units in the Upper Cretaceous strata of the Coastal Plain and that it is virtually coordinate in a time sense to at least the upper part of the *Scaphites hippocrepis* range zone. Evidence that the formation may include equivalents of somewhat older units is the presence in a spoil-bank collection of *Submortoniceras uddeni* which should occur lower in the section than *Scaphites hippocrepis* III. In essence the evidence suggests that the Merchantville Formation is of early Campanian age but that it does not include beds of earliest Campanian age. The missing interval of earliest Campanian time is equivalent to the ranges in the western interior of the chronologic subspecies *Scaphites leei* III and *S. hippocrepis* I and II of Cobban. This time interval may be represented by part of the Magothy Formation, as is suggested on the correlation chart (fig. 23).

ENGLISHTOWN FORMATION

Throughout its extent in New Jersey, the Englishtown Formation is virtually unfossiliferous. Fossils

TABLE 6.—*Megainvertebrate distribution in the Englishtown Formation in the Chesapeake and Delaware Canal area and New Jersey*

[▲, Occurrence of the species outside the Englishtown Formation of the canal area; ×, rare occurrence (1–5 specimens); ●, common occurrence (5–15 specimens); ■, abundant occurrence (15+ specimens)]

	Chesapeake and Delaware Canal							New Jersey						
	Merchantville	Marshalltown	Mount Laurel	16224	29578	29579	29582	Magothy	Merchantville	Woodbury	Englishtown	Marshalltown	Wenonah	Mount Laurel-Navesink
Pelecypoda:														
Nucula sp	....	....	....	×	×	....	....	....	....	....	....	....	....	....
Nuculana aff. *N. marlboroensis* (Weller)	....	....	....	....	×	....	....	....	....	....	....	....	▲	....
sp	....	....	....	....	....	×	×	....	....	....	....	....	....	....
Trigonia (*Pterotrigonia*) cf. *T.* (*P.*) *bartrami* Stephenson	....	....	....	×	....	....	....	....	....	....	....	....	....	....
(*Scabrotrigonia*) sp	....	....	....	×	....	....	....	....	....	....	....	....	....	....
Nemodon sp	....	....	....	×	....	....	....	....	....	....	....	....	....	....
Glycymeris aff. *G. mortoni* (Gabb)	....	....	....	●	●	....	....	....	▲	....	....	....	....	▲
Volsella julia (Lea)	....	....	....	....	....	×	....	....	▲	▲	....	....	....	....
Pinna sp	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Pteria sp	....	....	....	×	....	....	×	....	....	....	....	....	....	....
Inoceramus? sp	....	....	....	×	....	....	....	....	....	....	....	....	....	....
Camptonectes bellisculptus (Conrad)	▲	▲	....	×	....	....	×	....	▲	▲	....	▲	▲	▲
Camptonectes? *burlingtonensis* (Gabb)	....	....	....	×	....	....	....	....	▲	▲	....	....	▲	....
Syncyclonema conradi (Whitfield)	▲	....	....	....	×	×	×	....	....	....	....	....	....	....
Lima reticulata Forbes	....	....	▲	×	....	....	....	....	....	....	....	▲	▲	▲
Exogyra sp	....	....	....	×	....	....	....	....	....	....	....	....	....	....
Crassostrea tecticosta (Gabb)	▲	....	....	×	....	....	×	....	....	....	....	....	▲	....
Lopha falcata Morton?	▲	▲	▲	×	×	×	×	....	....	....	....	▲	....	▲
Anomia argentaria Morton	▲	▲	▲	×	×	....	....	....	....	....	....	▲	▲	▲
Crassatella? sp	....	....	....	×	....	....	....	....	....	....	....	....	▲	....
Scambula perplana Conrad	....	....	....	....	....	×	....	....	....	....	....	....	▲	....
Vetericardia sp	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Lucina sp	....	....	....	×	×	....	....	....	....	....	....	....	....	....
Aenona aff. *A. eufaulensis* Conrad	....	....	....	....	....	×	×	....	....	....	....	▲	▲	▲
Linearia metastriata Conrad	▲	▲	▲	×	×	×	....	▲	▲	▲	....	▲	▲	....
Tellina sp	....	....	....	....	×	....	....	....	....	....	....	....	....	....
Cardium (*Trachycardium*) *longstreeti* Weller?	▲	....	....	●	●	×	●	....	....	....	....	▲	....	....
(*Granocardium*) sp	....	....	....	×	×	....	....	....	....	....	....	....	....	....
Cymbophora sp	....	....	....	....	×	×	×	....	....	....	....	....	....	....
Etea cf. *E. carolinensis* Conrad	▲	....	....	×	....	....	....	....	....	....	....	....	....	....
Legumen ellipticum Conrad?	....	....	....	×	....	....	....	....	....	....	....	....	....	▲
Leptosolen biplicatus Conrad	....	....	....	....	....	....	×	▲	▲	▲	....	....	▲	▲
Parmicorbula cf. *P. bisulcata* Conrad	....	....	....	×	×	×	....	▲	▲	▲	....	....	....	....
Cymella bella Conrad	▲	....	....	×	....	....	....	....	▲	▲	....	....	▲	▲
Liopistha protexta Conrad?	▲	....	▲	×	....	....	×	....	▲	....	....	....	▲	▲
Gastropoda:														
Pachymelania n. sp	....	....	....	....	×	....	....	....	....	....	....	....	....	....
Haustator quadrilira (Johnson)	▲	▲	....	×	×	....	....	▲	....	▲	▲	....	....	....
Turritella cf. *T. lorillardensis* Weller	....	....	....	×	....	....	●	....	....	▲	....	....	....	....
Graciliala sp	....	....	....	....	×	×	×	....	....	....	....	....	....	....
Arrhoges (*Latiala*) sp	....	....	....	....	....	....	●	....	....	....	....	....	....	....
Tuba aff. *T. bella* Conrad	....	....	▲	....	×	....	....	....	....	....	....	....	....	....
Xenophora sp	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Euspira aff. *E. rectilabrum* (Conrad)	▲	....	▲	×	×	....	×	....	....	....	....	....	....	....
Gyrodes sp	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Pseudomaura meekana (Whitfield)?	....	▲	....	....	....	....	×	....	▲	▲	....	....	....	....
Morea cf. *M. marylandica* Gardner	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Napulus sp	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Volutomorpha sp	....	....	....	×	....	....	....	....	....	....	....	....	....	....
Caveola sp	....	....	....	....	×	....	....	....	....	....	....	....	....	....
Paladmete aff. *P. cancellaria* (Conrad)	....	....	....	....	×	....	....	....	....	....	....	....	....	....
Chaetopoda:														
Hamulus sp	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Serpula sp	....	....	....	×	....	....	....	....	....	....	....	....	....	....
Echinodermata:														
Hardouinea? sp	....	....	....	×	....	....	×	....	....	....	....	....	....	....
Cidaroid	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Vertebrata:														
Fish vertebrae	....	....	....	....	×	....	....	....	....	....	....	....	....	....

TABLE 6.—*Megainvertebrate distribution in the Marshalltown Formation in the Chesapeake and Delaware Canal area and New Jersey*—Continued

Englishtown Formation

16224. Chesapeake and Delaware Canal, north side, at post 40+500, about 1 mile east of the Penn Central Railroad's Chesapeake and Delaware Canal bridge (formerly Pennsylvania, Baltimore, and Washington bridge), New Castle County, Del. Collected by L. W. Stephenson, Sept. 16, 1932.

29578. Reddish-brown sand at water level along north bank of Chesapeake and Delaware Canal about one-fourth of a mile west of the St. Georges Bridge, Del. Collected by Arthur H. Hopkins, May 1967.

29579. Low-tide level beneath main *Ophiomorpha* level, north side of Chesapeake and Delaware Canal about 0.4 mile west of the St. Georges Bridge, Del. Collected by N. F. Sohl and J. P. Owens, June 22, 1967.

29582. Low-tide level beneath *Ophiomorpha* bed in upper part of formation on north side of Chesapeake and Delaware Canal about 0.6 mile west of the St. Georges Bridge, Del. Collected by N. F. Sohl and J. P. Owens, June 22, 1967.

have been recovered from few localities, and Richards and others (1962, p. 209–229) record only two species (*Cardium tenuistriatum* Whitfield and *Turritella quadrilira* Johnson) from all its outcrops. In addition, *Cymella bella* has been found by the author in the Allentown quadrangle of New Jersey. At most localities along the Chesapeake and Delaware Canal, the major organic remains are *Ophiomorpha* borings that form an interlocking network on weathered surfaces. However, locally in the area west of the St. Georges Bridge, the upper foot or so of the formation bears a dominantly molluscan fauna preserved as impressions in a case-hardened and concretionary sandstone. Several specimens have also been recovered from *Ophiomorpha* burrow fillings. The total fauna, listed in table 6, consists of representatives of 33 genera and subgenera of pelecypods and 15 genera of gastropods.

With the exception of the genus *Pachymelania*, this assemblage is consistent with a shallow-water sand-facies fauna. *Pachymelania* is a thiariid typical of the types that are of upper estuarine low-brackish to fresh-water tolerance. Because the *Pachymelania* specimens show little wear or other evidences of long transport, they further suggest that the fauna lived not only in shallow water but near shore. The great abundance of *Ophiomorpha* burrows is consistent with such shallow-water conditions.

Although burrows are abundant in the other formations along the canal, they appear to have been made by some other organism than *Ophiomorpha*. The longitudinal striations on the walls of many suggest some type of crab; others may well have been created by worms.

Many of the most common fossils in the Englishtown fauna such as *Cardium* (*Trachycardium*) and *Turritella* are also common elements in the faunas of other formations along the canal. *Glycymeris*, however, is rare in other formations but common in several collections from the Englishtown.

The lack of any significant fauna in the Englishtown Formation of New Jersey precludes comparison with the fauna along the canal. Similarly, the general lack of stratigraphically restricted species in the Englishtown fauna of the canal section does not allow for regional correlation.

MARSHALLTOWN FORMATION

FAUNAL CHARACTERISTICS

The Marshalltown Formation of the Chesapeake and Delaware Canal section contains representatives of 72 genera of mollusks (39 pelecypods, 30 gastropods, 3 cephalopods) (table 7). Many of these are represented only by internal molds and thus are not subject to precise specific determination. Fossils occur in great abundance and are generally concentrated in certain beds rather than scattered through the formation. The ostreids are generally abundant and occur both as well-preserved calcitic shells and as internal molds. In the excavation for the Penn Central Railroad's Chesapeake and Delaware Canal bridge abutments, the Marshalltown is exposed in its full thickness (see section, p. 13). Here, *Exogyra ponderosa* Roemer is especially abundant, well preserved, and concentrated in a single bed. *Pycnodonte mutabilis* (Morton) is likewise very abundant and well preserved and is found with *Exogyra* along the canal at water level immediately west of St. Georges Bridge where the contact with the Mount Laurel Sand is seen. In these upper beds are local concentrations of articulated valves of *Lopha falcata* (Morton) that form rounded patches as much as 10 or 12 inches in diameter. The specimen orientation suggests that these concentrations may be derived from disintegration of a stalked plant to which the oysters were attached.

Shell material may adhere to some of the internal molds, or on some specimens the external molds may be impressed upon the internal molds. These circumstances give sufficient information about the external sculpture to indicate specific relationship.

The Marshalltown fauna of the canal section is distinctive, especially in its abundance of *Exogyra ponderosa*, *Lopha falcata*, large *Trigonia*, *Cardium*, *Cucullaea*, and *Cyprimeria*. These genera occur in other rock units in the canal section, but not in the abundance seen in the Marshalltown.

This characteristic assemblage extends at least 25 miles to the southwest where the Marshalltown Formation is well exposed and where its fauna can be collected on the north bank of the Sassafras River in Maryland.

Although borings are abundant in the Marshalltown, they are not of the *Ophinomorpha* type. This

TABLE 7.—*Megainvertebrate distribution in the Marshalltown Formation in the Chesapeake and Delaware Canal area and New Jersey*

[▲, Occurrence of the species outside the Marshalltown Formation of the canal area; ×, rare occurrence (1–5 specimens); ●, common occurrence (5–15 specimens); ■, abundant occurrence (15+ specimens); *, known only as internal molds]

	Chesapeake and Delaware Canal																		New Jersey						
	Merchantville	Englishtown	Mount Laurel	28822 Excavation	17727	16223	17702	17718	17730	17735	17708	17731	17721	17699	17717	29511	29506	Disposal areas	Magothy	Merchantville	Woodbury	Englishtown	Marshalltown	Wenonah	Mount Laurel
Pelecypoda:																									
**Nucula percrassa* species group				×						×							×		▲	▲	▲		▲	▲	
Nuculana sp				×																					
**Trigonia thoracia* Morton of Weller				×		×	●	×	×	×				×		■	●	▲		▲			▲	▲	
Nemodon sp. (large)				×																					
**Cucullaea* cf. *C. tippana* Conrad of Weller				●	×	×	×	●		×			●	×		■	■	▲							
Lithophaga sp																		▲							
**Inoceramus*? sp																×	×	▲							
Camptonectes bellisculptus (Conrad)	▲	▲		×													×			▲	▲		▲	▲	▲
Chlamys n. sp. cf. *C. cretosus* DeFrance				×																					
Neithea quinquecostata Sowerby of Weller	▲		▲	×			×						×			●	×	▲		▲			▲		▲
**Pecten* sp				×														▲							▲
**Spondylus* sp													×			×	×	▲							
Lima lorillardensis Weller				×														▲			▲				
**Lima* cf. *L. kerri* Stephenson							×										×								
Crenella serica Conrad																	×								
Exogyra ponderosa erraticostata Stephenson				■												×	×	▲					▲		
ponderosa Roemer	▲			■	×		■	●					●			■	■	▲					▲		
*sp						×	×			×						×	×	▲							
Pyncnodonte mutabilis Morton	▲		▲	×		×	×	×										▲							
convexa Say																		▲						▲	▲
**Gryphaea* sp							●				×	×	●			●	×								
Gryphaeostrea vomer Morton			▲	●												×	×						▲		▲
**Gryphaeostrea*? sp							×										×	▲							
Lopha falcata (Morton)	▲	▲	▲	×		×	■	●					×			■	●	▲					▲		▲
Ostrea mesenterica Morton	▲		▲	×			×		×							×	×								▲
*sp				×																					
Anomia argentaria Morton	▲	▲	▲	×														▲	▲	▲	▲		▲	▲	▲
cf. *A. argentaria* Morton	▲							×																	
Paranomia scabra Morton	▲		▲	●												●	×						▲		▲
Crassatella cf. *C. vadosa* Morton				×			×					×													
Crassatella? sp					×													▲							
**Crassatella* sp							×						×		×	×									
Vetericardia sp				×																					
Lucina cf. *L. parva* Stephenson				×																	▲				
**Lucina* sp													×												
Linearia cf. *L. metastriata* Conrad	▲	▲	▲													×			▲	▲	▲		▲	▲	
(large)																×									
**Umbonicardium* cf. *U. umbonatum* (Whitfield)	▲			×		×	●	×								●	■	▲					▲		
Cardium (Granocardium) dumosum Conrad	▲		▲	×			×	×								■	■	▲		▲	▲			▲	
**Cardium* spp.				■	×	×	■	●	●	●	●	×	●	×	×	■	■	▲							
Brevicardium parahillanum Wade			▲													×									
**Cymbophora* sp				×													×								
**Etea* sp																×	×	▲							
Veniella conradi Morton of Weller	▲		▲	×				×		×						×	×	▲		▲	▲			▲	
Aphrodina cf. *A. tippana* Conrad				×													×							▲	
**Cyprimeria excavata* (Morton)				●			●	●		×						●	●	▲					▲		
**Cyprimeria* sp. (large)									×	×		×	×			×	×	▲							
**Tenea* sp				×																					
Caesticorbula crassaplica (Gabb)	▲		▲													×	×			▲	▲			▲	▲
Caryocorbula sp																×									
**Panopea decisa* Conrad	▲			×													×	▲	▲	▲	▲			▲	▲
**Gastrochaena* sp								×										▲							
Martesia sp																×									
Gastropoda:																									
Patella tentorium Morton				×																					▲
Margaritella sp				×																					
Laxispira lumbricalis Gabb	▲																×						▲		
**Laxispira* sp								×																	
Turritella marshalltownensis Weller?									×														▲		
Haustator quadrilira Johnson	▲	▲		×			×										×		▲	▲		▲			
trilira Conrad			▲	×																				▲	
cf. *H. lenolensis* Weller				×																▲	▲				
Turritella cf. *T. tippana* Conrad				×															▲				▲		
**Turritella* sp				■		×	●	●	×			×	×	×		■	■	▲							
Melanatria? cf. *M. cretacea* Wade							×																		
Tuba sp				×																					
**Anchura*? sp				●			×									×	●								
Graciliala? sp																	×								
**Arrhoges (Latiala)* sp																	×								
Capulus n. sp							×																		
**Gyrodes abyssinus* (Morton)			▲	×									×	×		×		▲							▲
**Gyrodes petrosus* (Morton)				×																▲				▲	
Amauropsis meekana Whitfield		▲		×													×			▲	▲				
Euspira sp																	×								
Cypraea cf. *C. mortoni*							×																		
*Bussinid sp																		▲							
Buccinopsis sp																×	×								
Bellifusus cf. *B. curvicostasus* (Wade)																	×								
**Bellifusus* sp					×																				
Ornopsis cf. *O. (Pornosis) digressa* Wade																	×								
Ripleyella sp																	×								
Hercorhynchus sp				×																					
Pyrifusus? sp							×																		
**Pyropsis* sp				●			×	×								●	×	▲							
**Pyropsis*? sp																		▲							
Napulus cf. *N. reesidei* Sohl				×													×								
**Longoconcha* sp				●			×			×						×	×	▲							
**Volutomorpha* sp							×									×									

TABLE 7.—*Megainvertebrate distribution in the Marshalltown Formation in the Chesapeake and Delaware Canal area and New Jersey*—Continued

[▲, Occurrence of the species outside the Marshalltown Formation of the canal area; ×, rare occurrence 1–5 specimens); ●, common occurrence (5–15 specimens); ■, abundant occurrence (15+ specimens); *, known only as internal molds]

	Chesapeake and Delaware Canal																		New Jersey						
	Merchantville	Englishtown	Mount Laurel	28822 Excavatior	17727	16223	17702	17718	17730	17735	17708	17731	17721	17699	17717	29511	29506	Disposal areas	Magothy	Merchantville	Woodbury	Englishtown	Marshalltown	Wenonah	Mount Laurel
Gastropoda—Continued																									
Paladmete cancellaria (Conrad) ?	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
**Acteon cretacea* Gabb	....	....	....	×	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	▲	....	....	▲	▲
**Avellana bullata* (Morton)	....	....	▲	×	....	....	×	....	....	....	....	....	×	....	....	....	×	▲	....	▲	....	....	....	....	....
Bulla macrostromata Gabb	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....	....
Cephalopoda:																									
Didymoceras? sp	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Anapachydiscus sp	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Parapachydiscus sp	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....	....	....
Porifera:																									
Clione sp	....	....	....	●	....	....	●	....	....	....	....	....	....	....	....	●	■	▲	....	....	....	....	....	....	....

Marshalltown Formation

28822. Excavation for abutments of new segment of Penn Central Railroad's Chesapeake and Delaware Canal bridge (formerly Pennsylvania, Baltimore, and Washington bridge) just west and approx 1,600 ft south of old bridge, New Castle County, Del. Collected by N. F. Sohl, R. W. Imlay, and Jack Wolfe, 1963.
17727. Material in place 500 ft west of Penn Central Railroad's Chesapeake and Delaware Canal bridge, south side of canal, Delaware. Collected by C. W. Carter, 1935–37.
16223. Five to 10 ft above base of formation, Chesapeake and Delaware Canal, south side, 600 ft west of the Penn Central Railroad's Chesapeake and Delaware Canal bridge, opposite post 47, New Castle County, Del. Collected by L. W. Stephenson, Sept. 15, 1932.
17702. South side of Chesapeake and Delaware Canal, 100 yd west of Penn Central Railroad's Chesapeake and Delaware Canal bridge, Del. Collected by C. W. Carter, 1935–37.
17718. South side of Chesapeake and Delaware Canal, 50–1,000 ft west of Penn Central Railroad's Chesapeake and Delaware Canal bridge, Del. Collected by C. W. Carter, 1935–37.
17730. South side of Chesapeake and Delaware Canal at station 46+700, Delaware. Material taken from near top of bank. Collected by C. W. Carter, 1935–37.
17735. Station 46+500 on south side of Chesapeake and Delaware Canal, Del. Collected by C. W. Carter, 1935–37.
17708. North side Chesapeake and Delaware Canal at station 47+500, Delaware. Collected by C. W. Carter, 1935–37.
17731. South side Chesapeake and Delaware Canal at station 50, Delaware. Collected by C. W. Carter, 1935–37.
17721. South side Chesapeake and Delaware Canal at station 50+000, about 2,000 ft east of Summit Bridge, Del. Collected by C. W. Carter, 1935–37.
17699. Station 50, south side of Chesapeake and Delaware Canal, 2,400 ft east of Summit Bridge, Del. Collected by C. W. Carter, 1935–37.
17717. Material in place in Marshalltown on south side of Chesapeake and Delaware Canal, 100 ft east of Summit Bridge. Collected by C. W. Carter, 1935–37.
29511. South side Chesapeake and Delaware Canal, 0.8 mile west of Penn Central Railroad bridge, 27 ft above water level. Collected by N. F. Sohl and E. G Kauffman, 1966.
29506. Upper part of formation immediately below the Mount Laurel Sand about 75–100 yds west of St. Georges Bridge, north bank of Chesapeake and Delaware Canal. Collected by E. G. Kauffman and N. F. Sohl, 1966.

fact, coupled with the greater diversity of the fauna and general lithic character, suggests that the Marshalltown was deposited in somewhat deeper water than the Englishtown Formation. The common concentration of fossils in beds suggests some transportation of the fauna, but the articulated nature of many of the bivalves would indicate that transportation was not far. Some parts of the fauna, for example the aforementioned concentrations of bivalved specimens of *Lopha falcata*, may represent in situ faunas.

Groot, Organist, and Richards (1954, p. 24) stated that the Marshalltown Formation does crop out along the canal but that,

> In New Jersey the Marshalltown Formation contains the index fossil *Exogyra ponderosa*. Numerous specimens of this pelecypod were found in spoil banks and along the north shore of the canal between the railroad bridge and station 3. Presumably these were dredged from below sea level. Similar specimens of *E. ponderosa* were also found along the spoil bank of the canal between Lorwood Grove and St. George's.***

The authors then suggest that the Marshalltown Formation may be present and recognizable in the subsurface. Their interpretation that the Marshalltown is absent on the outcrop is predicated on the belief that there are no beds of Marshalltown lithology between the units they picked as Merchantville and those designated as Wenonah. They suggested that although Carter had called some beds Englishtown, the presence of "*Halymenites major*" indicated that these beds actually belonged to the Wenonah because the Englishtown of New Jersey lacked these supposed diagnostic borings. *Ophiomorpha* (=*Halymenites* of Groot and others) ghost-shrimp borings, however, have little age significance, for they are common to beach or shallow near-shore sand deposits of Cretaceous to Holocene age. Thus, this is an ecologic and not a biostratigraphic correlation. Once these so-called Wenonah sands are accepted as Englishtown, one does not seek a Marshalltown equivalent below them but above them, and certainly it is there in the outcrop and not the subsurface as was proposed by Groot, Organist, and Richards (1954). Thus, at least the lower part of the Mount Laurel-Navesink section they give for their station 3 (Groot and others, 1954, p. 35) is actually Marshalltown. Evidence for this is amply shown by the specimen from this locality that they illustrate on their plate 4, figure 2, as an example of *Exogyra cancellata* Stephenson, a misidentification of a specimen that the figure clearly shows to be an example of *E. ponderosa.* In their interpretation, therefore, the Marshalltown Formation is included in their Mount Laurel-Navesink.

Comparison with the New Jersey molluscan fauna

Approximately 35 species present in the Marshalltown Formation of the Chesapeake and Delaware Canal section also occur in New Jersey. These are distributed as follows:

	Number of species
Mount Laurel Sand-Navesink Formation	14
Wenonah Formation	14
Marshalltown Formation	16
Englishtown Formation	1
Woodbury Clay	13
Merchantville Formation	15
Magothy Formation	6

There is no clear-cut correlation here, as the higher values correspond closely to the formations containing the largest faunas. In addition, most of the species are those that are long ranging in New Jersey (table 7; fig. 21). Seventy percent of the genera also occur in the Merchantville Formation, but the Marshalltown fauna differs by being rich in ostreid elements and by the lack of any abundance of cephalopods and crustacean remains. Although 80 percent of the genera of the Marshalltown fauna are also found in the Mount Laurel Sand and the fauna of both formations contain an abundance of oysters, the Marshalltown fauna is less diverse and lacks the belemnites common to the Mount Laurel. The best positive correlation of the Marshalltown fauna along the canal with that of the Marshalltown of New Jersey rests in the occurrence in both areas of abundant *Exogyra ponderosa.* Although this is a longer ranging species in the rest of the Coastal Plain, it is apparently abundant only in the Marshalltown Formation in the northern Atlantic Coastal Plain. In addition, *Umbonicardium* is restricted to the Marshalltown Formation in New Jersey, as are *Turritella marshalltownensis* Weller and *Cyprimeria excavata* (Morton).

The fauna of the Marshalltown Formation is distinctive in its composition, preservation, and in the abundance of certain species from the overlying and underlying units along the canal. Compared with the younger Wenonah faunas of New Jersey, there is little similarity, but a greater similarity with the older faunas of New Jersey is evident.

Age and correlation

As indicated in figure 23, the Marshalltown Formation is in the upper part of the *Exogyra ponderosa* range zone. This is consistent with the fact that the costations present on the early part of the shell of many specimens suggest the form called *Exogyra ponderosa erraticostata* Stephenson which is most common elsewhere in the upper part of the range zone of *E. ponderosa.* The general lack of knowledge of mollusks from this part of the section in other parts of the Coastal Plain, the lack of distinctive ammonites, and the fact that most of the well-preserved faunal elements present belong to long-ranging species makes precise correlation difficult. On the basis of the gross character of the representatives of such genera as *Cyprimeria, Aphrodina, Crassatella,* and *Turritella,* the Marshalltown fauna is certainly no older than the faunas to be found in the upper part of the Blufftown Formation of Georgia and Alabama, the upper part of the Coffee Sand of Mississippi, or the Wolfe City Sand and Pecan Gap Chalk Members of the Taylor Marl of Texas. The few heteromorph ammonites that have been collected from the formation are too poorly preserved to be of much aid other than to indicate a general Campanian age. The available information from the total fauna suggests a late but not latest Campanian age.

MOUNT LAUREL SAND

Faunal characteristics

Along the Chesapeake and Delaware Canal, fossiliferous exposures of the Mount Laurel Sand occur intermittently from immediately west of St. Georges Bridge, where the contact with the subjacent Marshalltown Formation is seen, to about 1½ miles east of St. Georges Bridge at Biggs Farm.

Preservation of the fauna in the Mount Laurel Sand varies widely. The basal beds near St. Georges Bridge yield well-preserved specimens of ostreids, such as *Pyncnodonte, Exogyra, Anomia,* and *Paranomia,* and of the pecten *Neithea;* all have shells of calcite. The aragonitic-shelled clams and gastropods are preserved only as phosphatized internal molds. At Biggs Farm the calcitic-shelled forms are similarly well preserved, but the rest of the fauna is a mixture both of internal molds and aragonitic shells converted to phosphate, a most unusual occurrence. At both localities, it is common for the chambers of the sponge borings in the shells to be phosphatized, although the calcitic shell material is preserved.

Near the base of the formation immediately east of St. Georges Bridge is a bed of *Pyncnodonte* shells with almost no associated fauna except for a few specimens of *Exogyra cancellata.* Higher in the sequence, the fauna becomes more diverse. The patchy distribution of the phosphatic material, as pockets of concentration, shows that some transportation if not reworking of the material is involved.

Richards and Shapiro (1963) have published on the fauna from the Biggs Farm locality. The following notes may help to clarify the nomenclatural differences between their list and that included in table 8.

Nuculana pittensis (Stephenson): Here included under *N. longifrons* (Conrad).

Yoldia gabbana (Whitfield): This species appears to belong in *Nuculana* and is based on indeterminate internal molds from New Jersey.

Nemodon grandis sohli Richards and Shapiro: Indeterminate internal molds.

Cucullaea neglecta Gabb: Long-ranging composite New Jersey species known only from internal molds. (= *Cucullaea* sp. herein.)

Arca rostellata Morton: Based on internal molds from an unknown stratigraphic level in Alabama. This material is better placed in *Arca* n. sp.

Arca obesa (Whitfield): Based on poor material from the Merchantville Formation of New Jersey: here included with the preceding in *Arca* n. sp.

Glycymeris mortoni (Conrad): A "wastebasket" term for internal molds of *Glycymeris* from all formations in New Jersey.

Inoceramus proximus Tuomey: Type specimen lost, unfigured and inadequately described, probably from the Eutaw Formation of Mississippi.

Ostrea monmouthensis Weller: A variant of *O. mesenterica* Morton.

Ostrea panda Morton: A good species, but I have not been able to verify the report by Richards and Shapiro.

Ostrea biggsi Richards and Shapiro, 1963: Appears to be only a variety of *O. mesenterica.*

Gryphaea convexa (Say): *Pyncnodonte mutabilis* of my list.

Trigonia mortoni Whitfield: Based on indeterminate internal molds from the Marshalltown. Well-preserved specimens from this locality are here placed in *T. eufaulensis* Gabb.

Pecten whitfieldi Weller: Not found.

Lima obliqua Gardner: A misidentification. The Richards and Shapiro specimen is an internal mold belonging in *Pteria.*

Corimya tenuis Whitfield: Internal molds of doubtful generic affinities.

Vetericardia crenalirata (Conrad): Here termed *V.* aff. *V. subcircula* Wade.

Cardium wenonah Weller: Internal molds of doubtful placement here placed in *Cardium* sp.

Cardium whitfieldi Weller?: Same as preceding.

Tellina gabbi Gardner: Internal molds, may belong in *Aenona.*

Corbula crassiplica Gabb: Belongs in genus *Caesticorbula.*

Weeksia deplanata (Johnson): Based on internal molds from the Prairie Bluff Chalk of Alabama = *Weeksia* sp. of this report.

Emarginula ladowae Eichman: Only *Emarginula* seen at this locality; belongs to a new species.

Margarites abyssina (Gabb) and *M. depressa* Gardner: Based on internal molds here considered to be *Calliomphalus* sp.

Margaritella pumila Stephenson to *Margaritella* sp.

Polinices altispira (Gabb): Based on internal molds, probably equivalent to *Amaurellina stephensoni* (Wade) of this report.

Laxispira lumbricalis Richards and Shapiro [non Gabb]: Belongs in *L. monilifera* Sohl (1964b, p. 361).

Turritella encrinoides Morton: Based on internal molds here treated as *Turritella* sp.

Anchura rostrata (Gabb): Indeterminable molds probably in wrong order.

Anchura pennata (Morton): Molds assignable to *Arrhoges (Latiala)* sp. indet.

Cypraea grooti Richards and Shapiro, new species: An internal mold.

Napulus whitfieldi (Weller): Probably equals *N. reesidei* Sohl of this report.

Pyropsis richardsoni (Tuomey)?: Based on unfigured, lost, internal molds from an unknown locality and stratigraphic level in Mississippi. Equal to *Pyropsis* sp. of this report.

Bellifusus medians (Whitfield)?: Based on indeterminate internal molds.

Turricula sp.: A Holocene and later Tertiary genus.

Cinulia naticoides (Gabb): Indeterminate internal molds.

Cylichna recta (Gabb): Species based on indeterminable internal molds from the Paleocene Hornerstown Formation.

Scaphites hippocrepis (DeKay): Misidentified; belongs in *Hoploscaphites* sp.

Menabites delawarensis (Morton): Misidentified; for if it had been identified correctly, like the preceding, its occurrence in the Mount Laurel Sand would be the only place between Mexico and New Jersey where this fossil occurs at this stratigraphic level.

COMPARISON WITH THE NEW JERSEY MOLLUSCAN FAUNAS

Of the 99 species (table 8) here listed from the Mount Laurel Sand of the Chesapeake and Delaware Canal area, 36 occur in New Jersey. They are distributed as follows:

	Number of species
Mount Laurel Sand-Navesink Formation	27
Wenonah Formation	13
Marshalltown Formation	12
Englishtown Formation	0
Woodbury Clay	11
Merchantville Formation	15
Magothy Formation	2

Comparison with the Mount Laurel-Navesink strata of New Jersey is obvious, but precise correlation is difficult because of the lack of differentiation of the faunas of the Mount Laurel Sand and the Navesink Formation in the literature. Weller (1907) and Richards and others (1958, 1962) have considered the formations inseparable and therefore have listed their faunas together. The fauna of the Mount Laurel Sand is, however, distinct from that of the Navesink. The common association of *Exogyra cancellata* Stephenson, *Anomia tellinoides* Morton, and *Belemnitella americana* (Morton) characterizes the Mount Laurel fauna from New Jersey to Maryland. These species do not occur together in the Navesink Formation, which, in turn, characteristically bears a fauna with the brachiopod *Chorystothyris* and other restricted species. The consistent composition of the

TABLE 8.—*Megainvertebrate distribution in the Mount Laurel Sand in the Chesapeake and Delaware Canal area and New Jersey*

[▲, Occurrence outside the Mount Laurel Sand of the canal area; ×, rare occurrence (1–5 specimens); ●, common occurrence (5–15 specimens); ■, abundant occurrence (15+ specimens); *, known only as internal molds]

	Chesapeake and Delaware Canal											New Jersey						
	Merchantville	Marshalltown	Englishtown	Richards and Shapiro	St. Georges 29585	Biggs - lower 26634, 27749	Biggs - lower 29507	Biggs - upper 26635	Biggs - upper 29510	Biggs - float 29508	Biggs - float 29509	Magothy	Merchantville	Woodbury	Englishtown	Marshalltown	Wenonah	Mount Laurel
Pelecypoda:																		
Nuculana longifrons (Conrad)	----	----	----	▲	----	■	●	----	●	●	●	----	----	▲	----	----	----	----
Perissonata stephensoni (Richards)	----	----	----	▲	----	×	×	----	×	----	×	----	▲	▲	----	----	▲	▲
**Perissonata* cf. *P. protexta* Gabb?	----	----	----	----	----	×	----	----	----	----	×	----	----	----	----	----	----	▲
Trigonia eufaulensis Gabb	----	----	----	----	×	●	×	----	----	×	●	----	▲	▲	----	----	▲	----
**Trigonia* sp	----	----	----	----	----	×	×	----	×	×	----	----	----	----	----	----	----	----
Nemodon eufaulensis Gabb	----	----	----	▲	----	×	----	----	----	----	----	----	▲	----	----	▲	----	▲
sp	----	----	----	----	----	●	----	----	----	----	----	----	----	----	----	----	----	----
Arca cf. *A. macnairyensis* Wade	----	----	----	----	----	×	×	----	----	×	----	----	----	----	----	----	----	----
n. sp	----	----	----	----	----	●	×	----	----	----	----	----	----	----	----	----	----	----
Breviarca richardsi Harbison?	----	----	----	----	----	×	----	----	----	×	----	----	----	----	----	----	----	----
Barbatia sp	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----
Cucullaea sp	----	----	----	----	■	×	----	----	----	×	×	----	----	----	----	----	----	----
Glycymeris sp	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----
Postiligata crenata Wade	----	----	----	▲	----	●	●	----	●	×	●	----	----	----	----	----	----	----
wordeni Gardner	----	----	----	----	----	×	●	----	----	×	----	----	----	----	----	----	----	----
Lithophaga sp	----	----	----	----	×	×	----	----	----	×	----	----	----	----	----	----	----	----
**Gervilliopsis* sp	----	----	----	----	----	×	----	----	----	----	×	----	----	----	----	----	----	----
Inoceramus sp	----	----	----	▲	----	×	×	----	----	×	●	----	----	----	----	----	----	----
Neithea quinquecostata Sowerby	▲	▲	----	----	×	●	×	----	×	×	×	----	▲	----	----	▲	----	▲
Radiopecten mississippiensis (Conrad)	----	----	----	----	●	×	----	----	----	----	----	----	----	----	----	----	----	----
Pecten (*Pecten*?) *venustus* Morton	----	----	----	▲	×	×	●	----	●	×	----	----	----	----	----	▲	----	▲
Syncyclonema simplicius Conrad	▲	----	▲	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----
Plicatula mullicanensis Weller	----	----	----	----	----	×	×	----	----	----	----	----	----	----	----	----	----	▲
Lima reticulata Lyell and Forbes	----	----	▲	▲	----	×	×	----	----	×	----	----	▲	----	----	▲	▲	▲
sp	----	----	----	----	×	×	----	----	----	----	----	----	----	----	----	----	----	----
Exogyra cancellata Stephenson	----	----	----	▲	●	■	●	----	●	●	●	----	----	----	----	----	----	▲
Pyncnodonte mutabilis Morton	▲	▲	----	----	■	×	●	----	×	×	×	----	----	----	----	----	----	----
Gryphaeostrea vomer Morton	----	▲	----	▲	----	×	×	----	----	----	●	----	----	----	----	▲	----	▲
Lopha falcata Morton	▲	▲	▲	▲	×	■	●	----	×	●	■	----	----	----	----	▲	----	▲
mesenterica Morton	▲	▲	----	----	----	×	●	----	----	×	×	----	----	----	----	----	----	▲
Ostrea plumosa Morton	----	----	----	----	×	×	----	----	×	----	×	----	----	▲	----	▲	▲	▲
sp	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----
Anomia tellinoides Morton	----	----	----	▲	×	■	■	----	■	■	■	----	----	▲	----	----	----	▲
argentaria Morton	▲	▲	▲	▲	×	×	×	----	----	----	×	▲	▲	▲	----	▲	▲	▲
Paranomia scabra Morton	▲	▲	----	▲	●	×	×	----	----	×	----	----	▲	----	----	▲	----	▲
Vetericardia aff. *V. subcircula* Wade	----	----	----	----	----	●	×	----	×	×	×	----	----	----	----	----	----	----
Lucina parva Stephenson	----	----	----	▲	----	●	●	----	----	----	×	----	----	▲	----	----	----	----
sp	----	----	----	----	----	----	----	----	----	×	----	----	----	----	----	----	----	----
Tellina cf. *T. georgiana* Gabb	----	----	----	▲	----	×	×	----	----	----	----	----	----	----	----	----	▲	----
sp	----	----	----	----	----	----	----	----	----	×	----	----	----	----	----	----	----	----
Linearia metastriata Conrad	▲	▲	▲	▲	----	●	----	----	----	----	●	▲	▲	▲	----	▲	▲	----
n. sp. (large)	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----
Unicardium sp	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----
Cardium (*Trachycardium*) *eufaulensis* Conrad	▲	----	----	▲	----	×	----	----	----	----	----	----	----	▲	----	----	----	▲
(*Granocardium*) *dumosum* Conrad	▲	▲	----	▲	----	×	×	----	----	----	----	----	▲	▲	----	----	▲	----
aff. *C.* (*G.*) *kummeli* Weller	----	----	----	▲	----	----	----	----	----	×	----	----	----	----	----	----	----	▲
Cardium aff. *C. donohuensis* Stephenson	----	----	----	----	----	----	----	----	----	×	----	----	----	----	----	----	----	----
**Cardium* spp	----	----	----	----	----	●	----	----	----	×	×	----	----	----	----	----	----	----
Brevicardium parahillanum (Wade)	----	▲	----	▲	----	●	----	----	----	----	×	----	----	----	----	----	----	----
Cymbophora subtilis Stephenson	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----
**Cymbophora* spp	----	----	----	▲	----	●	×	----	----	----	----	----	----	----	----	----	----	----
Etea sp	----	----	----	----	----	×	----	----	----	×	----	----	----	----	----	----	----	----
Veniella conradi Morton	▲	▲	----	----	----	×	×	----	----	----	×	----	▲	▲	----	----	▲	▲
Aphrodina? *eufaulensis* (Conrad) of Wade	----	----	----	----	----	×	----	----	----	×	×	----	----	----	----	▲	▲	▲
Cyprimeria sp	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----	----
**Legumen* sp	----	----	----	▲	----	×	----	----	----	----	----	----	----	----	----	----	----	----
Clavagella armata Morton	----	----	----	----	----	●	----	----	----	----	×	----	----	----	----	----	----	----
Caestocorbula crassiplica (Gabb)	----	----	----	▲	----	×	×	----	×	----	×	----	▲	▲	----	----	▲	▲
**Kummelia*? sp	----	----	----	----	----	×	----	----	×	----	×	----	----	----	----	----	----	----
Liopistha protexia (Conrad)	▲	----	----	----	----	●	×	----	----	×	×	----	----	----	----	----	----	----

TABLE 8.—*Megainvertebrate distribution in the Mount Laurel Sand in the Chesapeake and Delaware Canal area and New Jersey*—Continued

[▲, Occurrence outside the Mount Laurel Sand of the canal area; ×, rare occurrence (1–5 specimens); ●, common occurrence (5–15 specimens); ■, abundant occurrence (15+ specimens); *, known only as internal molds]

	Chesapeake and Delaware Canal											New Jersey						
	Merchantville	Marshalltown	Englishtown	Richards and Shapiro	St. Georges 29535	Biggs - lower 26634, 27749	Biggs - lower 29507	Biggs - upper 26635	Biggs - upper 29510	Biggs - float 29508	Biggs - float 29509	Magothy	Merchantville	Woodbury	Englishtown	Marshalltown	Wenonah	Mount Laurel
Pelecypoda—Continued																		
Cuspidaria cf. *C. grandis* Stephenson	----	----	----	----	----	×	----	----	----	----	----	----	▲	----	----	----	▲	▲
sp	----	----	----	----	----	×	----	----	----	----	×	----	----	----	----	----	----	----
Gastropoda:																		
**Weeksia* sp	----	----	----	▲	----	×	----	----	----	----	----	----	----	----	----	----	----	----
Emarginula n. sp	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----
Calliomphalus (*Calliomphalus*) *americanus* Wade?	----	----	----	▲	----	×	×	----	----	----	×	----	----	----	----	----	----	----
cf. *nudus* Sohl	----	----	----	▲	----	×	×	----	----	----	----	----	----	----	----	----	----	----
**Calliomphalus* (*Calliomphalus*) sp	----	----	----	▲	----	■	●	----	----	×	●	----	----	----	----	----	----	----
Calliomphalus (*Planolateralis*) sp	----	----	----	▲	----	×	----	----	×	----	----	----	----	----	----	----	----	----
**Margaritella* sp	----	----	----	▲	----	×	----	----	×	×	●	----	----	----	----	----	----	----
Architectonica cf. *A. voragiformis* Stephenson	----	----	----	▲	----	×	----	----	----	----	×	----	----	----	----	----	----	----
Pseudomalaxis sp	----	----	----	▲	----	×	----	----	----	----	----	----	----	----	----	----	----	----
Mathilda n. sp	----	----	----	----	----	----	----	----	----	×	×	----	----	----	----	----	----	----
Tuba bella Conrad	----	----	----	----	----	----	----	----	----	----	×	----	----	----	----	----	----	----
sp	----	----	----	----	----	×	----	----	----	×	×	----	----	----	----	----	----	----
Belliscala cf. *B. creideri* Stephenson	----	----	----	▲	----	×	----	----	----	----	----	----	----	----	----	----	----	----
Nudivagus sp	----	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----
Laxispira monilifera Sohl	----	----	----	----	----	×	×	----	----	----	----	----	----	----	----	----	----	----
Haustator trilira Conrad	----	▲	----	▲	×	●	●	----	----	×	----	----	----	----	----	----	▲	----
Turritella vertebroides Morton?	----	----	----	▲	----	×	----	----	----	----	----	----	----	----	----	----	----	▲
**Turritella* sp	----	----	----	----	●	×	×	----	----	----	----	----	----	----	----	----	----	----
Turritella macnairyensis Wade	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----	----
Cerithium weeksi Wade	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----
**Cerithium* sp	----	----	----	----	----	----	×	----	----	----	×	----	----	----	----	----	----	----
Arrhoges sp	----	----	----	----	×	----	----	----	×	----	----	----	----	----	----	----	----	----
**Drepanochilus* sp	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----
Pterocerella cf. *P. poinsettiformis* Stephenson	----	----	----	----	----	×	----	----	----	----	×	----	----	----	----	----	----	----
Xenophora cf. *X. leprosa* Morton	----	----	----	----	×	×	×	----	----	×	----	----	----	----	----	----	----	▲
Euspira rectilabrum Conrad	----	----	----	----	----	●	●	----	----	×	×	----	----	----	----	----	----	----
Amaurellina stephensoni (Wade)	----	----	----	----	----	■	×	----	----	×	×	----	----	----	----	----	----	----
Pseudomaura lirata (Wade)	----	----	----	----	----	×	----	----	×	----	×	----	----	----	----	----	----	----
Gyrodes americanus Wade?	----	----	----	----	----	----	----	----	----	×	----	----	----	----	----	----	----	----
**Gyrodes abyssinus* (Morton)	----	▲	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	▲
**Gyrodes* sp	----	----	----	----	×	●	----	----	----	----	----	----	----	----	----	----	----	----
Tintorium? sp	----	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----
Sargana sp	----	----	----	----	----	×	----	----	×	----	----	----	----	----	----	----	----	----
Bellifusus curvicostatus (Wade)	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----
sp	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----	----
Woodsella typica Wade	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----
Remera? sp	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----
Hercorhynchus sp	----	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----
Anomalofusus substriatus Wade?	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----
Napulus reesidei Sohl	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----
Pyropsis cf. *P. perlata* Conrad	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----
sp	----	----	----	----	●	----	----	----	----	----	----	----	----	----	----	----	----	----
**Longoconcha* sp	----	----	----	----	×	×	----	----	----	----	----	----	----	----	----	----	----	----
**Volutomorpha* sp	----	----	----	----	×	×	----	----	----	----	----	----	----	----	----	----	----	----
Beretra sp	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----
Caveola sp	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----
Paladmete gardnerae Wade	----	----	----	----	----	×	×	----	----	----	×	----	----	----	----	----	----	----
Acteon sp	----	----	----	----	----	×	×	----	----	×	----	----	----	----	----	----	----	----
Eoacteon percultus Sohl	----	----	----	----	----	×	×	----	----	----	----	----	----	----	----	----	----	----
Parietiplicatum cf. *P. conicum* (Wade)	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----
**Avellana bullata* (Morton)	----	▲	----	----	----	----	×	----	----	----	----	----	▲	----	----	----	----	▲
**Ellipsoscapha* sp	----	----	----	▲	----	----	----	----	----	×	----	----	----	----	----	----	----	----
Cylichna secalina Shumard	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----
sp	----	----	----	▲	----	×	----	----	----	×	×	----	----	----	----	----	----	----
Anisomyon? *jessupi* Richards and Shapiro	----	----	----	▲	----	×	----	----	×	×	×	----	----	----	----	----	----	----
Scaphopoda:																		
Dentalium intercalatum Wade	----	----	----	▲	----	×	×	----	----	×	----	----	----	----	----	----	----	----

TABLE 8.—*Megainvertebrate distribution in the Mount Laurel Sand in the Chesapeake and Delaware Canal area and New Jersey*—Continued

[▲, Occurrence outside the Mount Laurel Sand of the canal area; ×, rare occurrence (1–5 specimens); ●, common occurrence (5–15 specimens); ■, abundant occurrence (15+ specimens); *, known only as internal molds]

	Chesapeake and Delaware Canal											New Jersey						
	Merchantville	Marshalltown	Englishtown	Richards and Shapiro	St. Georges 29585	Biggs - lower 26634, 27749	Biggs - lower 29507	Biggs - upper 26635	Biggs - upper 29510	Biggs - float 29508	Biggs - float 29509	Magothy	Merchantville	Woodbury	Englishtown	Marshalltown	Wenonah	Mount Laurel
Cephalopoda:																		
Eutrephoceras dekayi (Morton)					×				×		×		▲					
Baculites cf. *B. undatus* Stephenson								×										
sp				▲		×				×	×		▲	▲				▲
Hoploscaphites sp						×												
Anaklinoceras sp						×												
Didymoceras sp																		
Didymoceras? sp						×												
Belemnitella americana (Morton)				▲		■	●		●	●	●							▲
Porifera:																		
Clione sp					●		●			×	×							
Coelenterata:																		
Micrabacia hilgardi Stephenson						●	×		●	×	●							
Wadeopsamea? sp						×												
Bryozoa:																		
Cheilostomata						×	×				×							
Brachiopoda:																		
Lingula? sp						×												
Terebratulina cooperi Richards and Shapiro				▲		×	●		×									
Echinodermata:																		
Cidaroidea (one test and spines)						×												
Comatulid crinoid						×												
Chaetopoda:																		
Hamulus onyx Morton						×												
Serpula sp						●	●			×	●							
Arthropoda (Decapoda):																		
Crab claw						×					×							

Mount Laurel Sand

29585. "Gryphaea" bed in bench 150–300 yd east of St. Georges Bridge, south bank Chesapeake and Delaware Canal, Delaware. Collected by Buddenhagen, Sohl, Kauffman, 1966.
26634. South bank of the Chesapeake and Delaware Canal, about 300 yd west of light 13 and 1.35 miles (airline) due east of St. George's Bridge, from 0 to 6.0 ft above low-tide line, New Castle County, Del. Collected by N. F. Sohl, 1957.
27749. South bank of the Chesapeake and Delaware Canal about 300 yd west of light 13 and 1.35 miles east of St. Georges Bridge 0–6 ft above low tide, New Castle, Del. Collected by N. F. Sohl, 1960.
29507. Biggs Farm locality on the Chesapeake and Delaware Canal, south bank, about 300 yds west of light 13 and 1.35 miles (airline) due east of St. Georges Bridge. Collection near water level in place, New Castle County, Del. Collected by Buddenhagen, Kauffman, and Sohl, 1966.
26635. Locality same as above but at from about 6 to 10 ft above low-tide level. Collected by N. F. Sohl, Aug. 22, 1957.
29510. Locality same as for 29507 but from shell bed at base of bluff.
29508. Locality same as for 29507 but from float on beach.
29509. Locality same as for 29507 but from spoil pile along road.

Mount Laurel fauna in this northern part of the Atlantic Coastal Plain is not only significant but impressive.

The following fossils from the Mount Laurel Sand were collected along a tributary of Crosswicks Creek about 1.2 miles east-northeast of Arneytown, N.J. The forms marked by an asterisk are found in both New Jersey and Delaware. Plus marks indicate occurrence of the species in the *Exogyra cancellata* zone elsewhere in the Coastal Plain.

Pelecypoda:
- +**Trigonia eufaulensis* Gabb
- *Cucullaea* sp.
- *Glycymeris* sp.
- *Inoceramus* sp.
- *Chlamys* n. sp.

Pelecypoda—Continued
- +**Radiopecten weeksi* Stephenson
- +**Syncyclonema simplicius* (Conrad)
- *Crenella* sp.
- *Lithophaga* sp.
- *Plicatula mullicaensis* Weller?
- +**Lima reticulata* Forbes
- *Lima whitfieldi* Weller
- +**Lima acutilineata* Conrad
- +**Exogyra cancellata* Stephenson
- +**Ostrea tecticosta* Gabb
- +**Anomia perlineata* Wade
- +**Crassatella vadosa* Morton?
- +**Vetericardia subcircula* Wade
- +**Lucina* cf. *L. mattiformis* Stephenson
- +**Linearia metastriata* Conrad
- *Brevicardium* sp.
- +**Veniella conradi* (Morton)
- +**Panope decisa* Conrad

Pelecypoda—Continued
- *Parmicorbula* sp.
- +**Corbula* cf. *C. torta* Stephenson
- +**Caesticorbula crassiplica* (Gabb)
- *Kummelia* sp.
- +**Liopistha protexta* Conrad

Gastropoda:
- *Emarginula* n. sp.
- +**Calliomphalus* (*C.*) *americanus* Wade
- *Calliomphalus*? n. sp.
- +**Margaritella pumila* Stephenson?
- +**Pseudomalaxis pilsbryi* Harbison
- *Tintorium* sp.
- **Nudivagus*? sp.
- +**Laxispira monilifera* Sohl
- + *Arrhoges* (*Latiala*) cf. *A.* (*L.*) *lobata* (Wade)
- +**Euspira rectilabrum* (Conrad)
- + *Fusinus macnairyensis* (Wade)
- **Anomalofusus*? sp.
- *Pyrifusus*? sp.
- +**Napulus* cf. *N. reesidei* Sohl
- +**Bellifusus curvicostatus* (Wade)
- + *Paleopsephaea* cf. *P. mutabilis* Wade
- + *Lupira variabilis* (Wade)
- *Eoacteon* sp.
- *Cylichna* sp.

Scaphopoda:
- *Dentalium* sp.

Cephalopoda:
- +**Eutrephoceras dekayi* (Morton)
- **Belemnitella americana* (Morton)

Porifera:
- **Clione* sp.

Echinodermata:
- Echinoid plates

Coelenterata:
- + *Micrabacea rotatalis* Stephenson?

Worms:
- +**Hamulus onyx* Morton

Arthropoda:
- Crab claws

Vertebrata:
- Shark teeth
- Dermal scutes

This list indicates not only the close correspondence of the faunas of the Mount Laurel Sand of New Jersey and Delaware but an equally close correspondence to the faunas from equivalent units of the *Exogyra cancellata* zone in other parts of the Coastal Plain.

Age and correlation

The age and correlation of the Mount Laurel Sand is well documented. The fauna is a part of the characteristic and widespread assemblage of the *Exogyra cancellata* zone that may be traced from New Jersey to Mexico. The correlation chart (fig. 23) indicates some of the more significant correlative fossils. As noted on the chart, the Mount Laurel Sand can be traced from New Jersey into Maryland, where at Bohemia Mills (Gardner, 1916) it still carries the same distinctive assemblage of *Exogyra cancellata*, *Anomia tellinoides*, *Belemnitella americana*, and others.

At present, this assemblage has not been definitely identified on the western shore of Chesapeake Bay. Farther south in North Carolina, the Mount Laurel is correlative with the lower part of the Peedee Formation. In the Gulf Coastal Plain, equivalents in age are the upper part of the Cusseta Sand Member and perhaps the lowest part of the unnamed middle part of the Ripley Formation of the Chattahoochee River region (Georgia-Alabama), the uppermost part of the Demopolis Chalk (Bluffport Marl Member) in Alabama and Mississippi, and the Coon Creek Tongue of the Ripley Formation in Tennessee, but not in Mississippi. In the western Gulf Coastal Plain, the Saratoga Chalk of Arkansas and the Neylandville Marl of Texas bear this same fauna. In Mexico, the same zone is recognizable in the lower, but not lowest, part of the Cardenas Formation of San Luis Potosi. The presence in the Mount Laurel Sand and its equivalents of heteromorph ammonites like *Didymoceras*, *Anaklinoceras*, and *Baculites* of the *Baculites compressus* fauna suggests a correlation with medial parts of the Pierre Shale of the western interior. The assemblage is late Campanian in age.

Navesink and younger formations

There is no faunal evidence at the Biggs Farm locality (1½ miles east of St. Georges, Del.) of any unit as young as the Navesink Formation. *Chorystothyris* and other characteristic species of the Navesink are absent and have not been found in collections from spoil banks near Reedy Point east of Biggs Farm. The citation by Groot, Organist, and Richards (1954, p. 43) of the presence of *Exogyra cancellata* in both the Mount Laurel Sand and Navesink Formation along the canal is thus in error. Extensive collections made recently from their locality 3 where they list *E. cancellata* as occurring have yielded only *Exogyra ponderosa* and *E. ponderosa erraticostata*, all derived from the Marshalltown Formation. More convincing, is that the specimen figured in Groot, Organist, and Richards (1954, pl. 4, fig. 2) as an example of *Exogyra cancellata* lacks obvious cancellations or costations and is in fact a young specimen of *E. ponderosa*. The same error was made by Richards and others (1958, pl. 21, fig. 1), who erroneously assigned to *E. cancellata* a specimen of *E. ponderosa* that had faint costations on the early part of the shell (as is typical of the species high in its range zone). Similarly, there is no faunal evidence for the presence of the Red Bank Sand along the canal, as proposed by Groot, Organist, and Richards (1954). In New Jersey, the Red Bank carries a fauna with forms such as *Sphenodiscus* (fig. 23) that are diagnostic of an early Maestrichtian age. No such forms have been found along the canal. Recent excavations of the old Biggs Farm locality have provided fresh exposures, and fossils collected through the total sequence are assignable to the *Exogyra cancellata* range zone of late Campanian age.

SUMMARY OF MEGAPALEONTOLOGIC STUDIES

1. The Cretaceous section along the Chesapeake and Delaware Canal has yielded four distinct megafaunal assemblages assignable respectively to the Merchantville, Englishtown, and Marshalltown Formations and the Mount Laurel Sand.
2. Along the canal no invertebrates have been found in the basal unit—the clays of the Potomac Group—and the overlying Magothy Formation has produced only unidentified plants.
3. The presence of marine faunas equivalent to those of the Raritan, Woodbury, Wenonah, or Navesink Formations, or Red Bank Sand has not been demonstrated.
4. The faunas of the fossiliferous units are characterized as follows:
   - A. Merchantville Formation: Abundance of gastropods—*Graciliala* (floods of immature forms), *Arrhoges, Calliomphalus, Laxispira,* and *Palademete;* the common occurrence of the ammonites *Scaphites hippocrepis* and *Menabites* (*Delawarella*) *delawarensis;* and an abundance of decapod crustacean remains.
   - B. Englishtown Formation: Abundance of *Ophiomorpha* burrows and a molluscan assemblage dominated by *Cardium* (*Trachycardium*), *Glycymeris, Lopha,* and *Turritella.*
   - C. Marshalltown Formation: Abundance of *Exogyra ponderosa, Trigonia, Cyprimeria excavata, Crassatella, Cucullaea,* and *Cardium.*
   - D. Mount Laurel Sand: Association of *Exogyra cancellata, Anomia tellenoides,* and *Belemnitella americana.*

MICROPALEONTOLOGIC STUDIES

The status of the study of Foraminifera in the Cretaceous of the Atlantic Coastal Plain can be contrasted in several respects with the status of megainvertebrate studies. The most important difference is the scarcity of published data on the Foraminifera, which is partly due to the belated appreciation of the value of Foraminifera in correlation and paleoecologic interpretation. As a result, there are few localities in which Foraminifera have been described in the Coastal Plain; this makes it difficult to develop meaningful correlation within the region on the basis of the Foraminifera. On the other hand, when present, foraminiferal faunas are usually well preserved and quite diverse, often containing 50 or more species. However, very few paleoecologic interpretations have been made on the basis of these faunas, and detailed morphologic and phylogenetic studies have been limited to the planktonic Foraminifera. At present, relatively little is known about Atlantic Coastal Plain Cretaceous benthonic Foraminifera.

The intensive study given the planktonic forms has resulted in their wide use in regional and especially interregional correlation. However, because of the detailed morphologic features used in species identification and because of the varying phylogenies and consequent ranges that have been proposed, there is diversity of opinion in the literature as to the definitive characteristics of subspecies, species, and genera, and their ranges. This increased refinement of diagnostic morphologic criteria has made many of the older generalized descriptions either unusable or equivocal.

A complete review of the study of Cretaceous Foraminifera reported from the Atlantic Coastal Plain is not warranted here, but the recent work of Olsson (1960, 1964), which is considered later, does have direct bearing on the faunal interpretations made.

SAMPLING PROCEDURES AND SAMPLE DESIGNATIONS

Forty-two samples from the three Upper Cretaceous formations exposed in and near the Chesapeake and Delaware Canal were examined for Foraminifera. The samples were washed through a 200-mesh sieve, dried, and floated on carbon tetrachloride. Thirteen samples yielded Foraminifera, and nine contained identifiable specimens. Only one of the nine samples that contained identifiable specimens, sample U from the Englishtown Formation, failed to yield abundant well-preserved specimens. Only 30–35 specimens, assignable to 10 species, were recovered from this sample. The very small size of the specimens, the presence of all species in the physically overlying Marshalltown Formation, and the incongruity of a predominantly planktonic assemblage in sediments deposited in a probable near-shore shallow-water environment combine to strongly suggest that the Foraminifera in this sample are contaminants from the Marshalltown Formation.

TABLE 9.—*Distribution of microfauna in the Englishtown and Marshalltown Formations and Mount Laurel Sand in southern New Jersey and northern Delaware*

	U	V	W	X	Y	Z	D	C	B	A	Austin	Taylor	Navarro	Comments
Bulimina reussi Morrow	×	×	×	×	×	×	×	×	×	×	×	×	×	
Gaudryina stephensoni Cushman	×	×	×	×	×	×	....	×	×	×	×	×	×	
Globigerinelloides messinae Bronnimann	×	×	×	×	×	×	×	×	×	×	....	....	....	Late Campanian and early and late Maestrichtian in New Jersey and Delaware.
Globotruncana? subrugosa Gandolfi	× ?	×	×	×	×	....	....	×	×	×	....	....	....	Late Campanian of New Jersey and Delaware (Marshalltown Formation).
Gyroidina depressa (Alth)	×	×	×	×	×	×	....	×	×	×	×	×	×	
Hedbergella planispira (Tappan)	×	×	×	×	×	×	×	×	×	×	....	....	....	Do.
Heterohelix globulosa (Ehrenberg)	×	×	×	×	×	×	×	×	×	×	....	×	×	Santonian and Coniacian of the western interior United States.
Neobulimina canadensis Cushman and Wickenden var. A.	×	×	×	×	×	×	....	×	×	....	×	×	×	Varietal form from the late Campanian Pierre Shale.
spinosa Cushman and Parker	×	×	×	×	×	×	×	×	×	×	....	×	×	Early and late Maestrichtian of New Jersey (Redbank Sand and Navesink Formation). Campanian of Colombia.
Rugoglobigerina macrocephala Bronnimann	×	×	×	×	....	×	....	....	×	×	....	....	....	
Anomalina nelsoni Berry	....	×	×	×	×	....	....	....	×	....	....	×	×	
rubiginosa Cushman	....	×	×	×	×	×	....	×	×	....	....	×	....	Maestrichtian of Europe.
Astacolus cf. *A. cretaceus* (Cushman)	....	×	....	....	×	....	....	×	....	....	....	×	×	
Bolivina watersi Cushman	....	×	....	....	....	....	....	....	....	....	....	×	×	
Bolivinitella eleyi (Cushman)	....	×	....	....	....	....	....	....	....	....	....	×	....	Do.
Bolivinoides decoratus australis Edgell	....	×	....	×	×	....	....	....	....	....	....	....	....	Upper Campanian or lower Maestrichtian of Australia.
Bulimina kickapooensis Cole	....	×	×	×	×	....	....	×	....	....	×	×	×	
rudita Cushman and Parker	....	×	....	×	....	....	....	×	....	×	×	×	×	
Caucasina cf. *C. pusilla* (Brotzen)	....	×	....	×	×	....	....	....	....	....	....	....	....	Upper Cretaceous of Sweden.
vitrea (Cushman and Parker)	×	×	....	×	×	....	....	×	....	....	×	×	×	
Cibicides beaumontianus d'Orbigny	....	×	....	....	....	×	....	....	....	....	....	×	×	
cf. *C. harperi* (Sandidge)	....	×	×	×	×	×	....	×	×	×	....	....	×	
Citharina cf. *C. multicostata* (Cushman)	....	×	....	....	....	×	....	....	....	....	×	×	×	
Dentalina basiplanata Cushman	....	×	....	....	×	×	....	....	×	....	....	×	×	
legumen Reuss	....	×	....	×	....	....	....	×	....	×	×	×	×	
Frondicularia archiaciana d'Orbigny	....	×	....	....	×	×	....	×	×	....	....	×	×	
Globotruncana? cretacea (d'Orbigny)	....	×	×	×	×	×	....	×	×	×	....	....	....	Late Campanian of Delaware (Marshalltown Formation).
fornicata (Plummer)	....	×	....	×	×	....	....	×	×	×	....	....	....	Late Campanian of Delaware and late Campanian and early Maestrichtian of New Jersey (Marshalltown Formation and Mount Laurel Sand).
linneiana (d'Orbigny)	....	×	....	×	×	×	....	×	....	×	....	....	....	Do.
subcircumnodifer (Gandolfi)	....	×	×	×	×	×	....	×	×	×	....	....	....	Late Campanian and early and late Maestrichtian of New Jersey and Delaware (Marshalltown Formation, Mount Laurel Sand, Navesink Formation, and Redbank Sand).
tricarinata (Quereau)	....	×	....	×	....	×	....	× ?	....	×	....	....	....	Late Campanian? and early and late Maestrichtian of New Jersey and Delaware (Marshalltown? and Navesink Formations and Redbank Sand).
Globulina lacrima Reuss s. l	....	×	....	×	×	×	....	×	×	×	×	×	×	
Gyroidina globosa (Hagenow) of Cushman	....	×	....	×	....	×	....	×	×	×	×	×	×	
Heterohelix pulchra (Brotzen)	....	×	×	×	×	×	....	×	×	×	×	×	....	Maestrichtian of New Jersey.
Loxostoma gemma (Cushman)	....	×	....	×	....	×	×	×	....	×	....	....	×	Upper Campanian of Israel.
plaita plaita (Carsey)	....	×	×	....	×	×	....	×	....	×	....	×	×	
Marginulina sp. A	....	×	....	....	×	×	....	×	×	....	....	....	....	
Neobulimina n. sp	....	×	....	....	....	×	....	....	....	×	....	....	....	
canadensis Cushman and Wickenden var. B.	....	×	×	×	×	×	....	×	....	....	×	×	×	Varietal form also occurs in the late Campanian Pierre Shale.
Nodosaria affinis Reuss	....	×	....	×	×	×	....	×	×	×	×	×	×	
amphioxys Reuss	....	×	....	×	×	....	....	....	....	....	....	×	×	
obscura Reuss	....	×	....	×	×	×	....	×	....	....	....	×	×	
Nonionella austinana Cushman	....	×	×	×	×	×	....	×	....	....	×	×	....	
Nuttallinella? n. sp	....	×	....	×	×	....	....	×	....	×	....	....	....	Also occurs in the late Campanian Pierre Shale.
Oolina n. sp	....	×	....	....	×	×	....	×	....	×	....	....	....	Do.
Planulina cf. *P. spissocostata* Cushman	....	×	....	×	×	×	....	×	×	....	....	×	×	
taylorensis Cushman	....	×	×	×	×	×	....	×	×	....	....	×	×	
Pseudoguembelina excolata costulata Cushman.	....	×	....	....	×	×	....	×	....	×	....	×	×	
Pseudouvigerina sp. aff. *P. seligi* (Cushman)	....	×	....	....	×	....	....	×	....	....	....	....	×	
Pullenia americana Cushman	....	×	....	×	×	×	....	×	×	×	....	×	×	
Sigmomorphina semitecta terquemiana (Fornasini).	....	×	....	×	×	×	....	×	×	×	....	×	×	
Stilostomella stephensoni (Cushman)	....	× ?	....	× ?	×	×	....	× ?	....	....	×	×	×	
Textularia ripleyensis Berry	....	×	×	....	×	×	....	×	×	×	....	×	×	
Dentalina basitorta Cushman	....	....	×	....	×	....	....	....	....	....	....	×	×	
Dorothia glabrella Cushman	....	....	×	....	....	....	....	....	....	....	×	×	....	
Eouvigerina americana Cushman	....	....	×	....	×	×	....	×	....	....	×	×	×	
Fissurina marginata (Walker and Jacob)	....	....	×	....	×	×	....	×	×	....	....	....	×	Campanian of California and Tertiary of Trinidad.
Gaudryina sp. A	....	....	×	....	×	....	....	....	....	....	....	....	....	
Globotruncana rosetta (Carsey)	....	....	×	....	....	....	....	×	....	....	....	....	....	Late Campanian of Delaware and late Campanian and early Maestrichtian of New Jersey (Marshalltown Formation and Mount Laurel Sand).
Hoeglundina cf. *H. supracretacea* (ten Dam)	....	....	×	....	....	....	....	....	....	....	....	×	×	
Lagena sulcata semiinterrupta Berry	....	....	×	....	×	×	....	×	×	×	....	....	×	
Marginulina taylorana Cushman	....	....	×	....	×	....	....	....	....	....	....	×	×	
Pseudonodosaria appressa (Loeblich and Tappan).	....	....	× ?	×	×	....	....	....	....	×	....	×	×	
Pyrulina cf. *P. cylindroides* Roemer	....	....	×	....	×	....	....	....	×	....	....	×	×	
Bulimina n. sp.?	....	....	....	×	....	....	× ?	×	....	....	....	....	....	
Dentalina cf. *D. consobrina* d'Orbigny	....	....	....	×	×	×	....	×	....	....	....	×	×	
Eouvigerina hispida Cushman	....	....	....	×	×	×	....	×	×	....	....	×	×	
Globorotalites michelinianus (d'Orbigny)	....	....	....	×	×	×	×	×	×	×	×	×	....	
Lingulina sp. A	....	....	....	×	×	....	....	....	....	....	....	....	....	
Neoconorbina n. sp	....	....	....	×	×	×	....	×	×	×	....	....	....	
Ramulina cf. *R. arkadelphiana* Cushman	....	....	....	×	×	....	....	×	....	....	....	....	×	
Anomalina cf. *A. pseudopapillosa* Carsey	....	....	....	....	×	....	×	....	....	....	....	....	×	
Astacolus sp. 2	....	....	....	....	×	....	....	....	....	....	....	....	....	
Bolivinopsis rosula (Ehrenberg)	....	....	....	....	×	×	....	×	×	×	×	×	×	
Clavulinoides trilatera trilatera (Cushman)	....	....	....	....	×	....	....	×	×	....	....	×	×	
Dentalina gracilis d'Orbigny	....	....	....	....	×	×	....	×	....	×	×	×	×	
'Discorbis' n. sp	....	....	....	....	×	....	....	×	....	×	....	....	....	
Fissurina orbignyana (Seguenza)	....	....	....	....	×	....	....	....	× ?	....	....	....	×	Upper Coniacian of Austria.
Globotruncana arca (Cushman)	....	....	....	....	×	×	....	×	× ?	....	....	....	....	Uppermost Campanian and Maestrichtian of New Jersey and Santonian to Maestrichtian in California.

TABLE 9.—*Distribution of microfauna in the Englishtown and Marshalltown Formations and Mount Laurel Sand in southern New Jersey and northern Delaware*—Continued

	U	V	W	X	Y	Z	D	C	B	A	Austin	Taylor	Navarro	Comments
Globotruncana ventricosa White	....	....	....	....	× ?	×	....	×	....	×	....	....	....	Coniacian to Maestrichtian.
Heterohelix planata (Cushman)	....	....	....	....	×	....	....	×	....	....	....	×	....	Maestrichtian of Egypt.
sp. aff. *H. pulchra* (Brotzen)	....	....	....	....	×	....	....	×	....	....	×	×	....	*H. pulchra*, to which this species is closely allied, also occurs in the Maestrichtian of New Jersey.
Lagena sp. aff. *L. quadralata* Brady	....	....	....	....	×	....	....	×	....	....	....	....	....	This form also occurs in the late Campanian Pierre Shale.
substriata Williamson	....	....	....	....	×	....	....	×	....	×	....	×	×	
Lingulina sp. B.	....	....	....	....	×	....	....	....	....	....	....	....	....	
Marginulina sp. C	....	....	....	....	×	....	....	....	....	....	....	....	....	
sp. D	....	....	....	....	×	....	....	× ?	....	....	....	....	....	
Pseudotextularia elegans elegans (Rzehak)	....	....	....	....	×	×	....	....	×	×	....	....	....	Uppermost Coniacian to Maestrichtian.
Seabrookia stewarti Olsson	....	....	....	....	×	....	....	....	....	....	....	....	....	Only previously reported occurrence is from the Maestrichtian of New Jersey.
Anomalinoides n. sp.?	....	....	....	....	....	×	....	×	....	....	....	....	....	
Astacolus sp. 1	....	....	....	....	....	×	....	....	....	....	....	....	....	
Gaudryina cf. *G. bulloides* Olsson	....	....	....	....	....	×	....	×	×	....	....	....	....	Only previously reported occurrence is from the Maestrichtian Redbank Sand of New Jersey.
n. sp	....	....	....	....	....	×	....	×	....	×	....	....	....	
Marginulina sp. B	....	....	....	....	....	×	....	....	×	....	....	....	....	
Nodosaria cf. *N. navarroana* Cushman	....	....	....	....	....	×	....	×	×	×	....	....	×	
Planulina sp. aff. *P. correcta* (Carsey)	....	....	....	....	....	×	....	×	×	×	....	....	×	
Plectina watersi Cushman	....	....	....	....	....	×	....	....	×	....	....	....	×	Senonian of Bulgaria.
Pleurostomella subnodosa Reuss	....	....	....	....	....	×	....	×	....	....	....	×	....	Santonian-Maestrichtian of New Jersey and elsewhere.
Praeglobotruncana havanensis havanensis (Voorwijk).	....	....	....	....	....	×	....	×	....	....	....	....	....	Upper Campanian and Maestrichtian of New Jersey and elsewhere.
Schackoina multispinata Cushman and Wickenden.	....	....	....	....	....	×	....	....	....	×	×	×	....	Maestrichtian of Trinidad.
Clavulinoides cf. *C. insignis* (Plummer)	....	....	....	....	....	....	....	×	....	....	....	....	×	
?*Dentalina aculeata* d'Orbigny	....	....	....	....	....	....	....	×	....	....	....	×	....	
Eponides haidingerii (d'Orbigny)	....	....	....	....	....	....	....	×	....	....	....	×	....	Lower upper Campanian of Bavaria.
Gaudryina cf. *G. ellisorae* Cushman	....	....	....	....	....	....	....	×	....	....	×	×	....	
Pernerina n. sp.?	....	....	....	....	....	....	....	×	....	....	....	....	....	
Anomalinoides pinguis Jennings?	....	....	....	....	....	....	....	....	....	×	....	×	....	Mount Laurel Sand and Navesink Formation of New Jersey.
Astacolus cf. *A. jarvisi* (Cushman)	....	....	....	....	....	....	....	....	....	×	....	....	×	Reported with question from the Campanian of California.
Dorothia stephensoni Cushman	....	....	....	....	....	....	....	....	....	×	×	×	×	
Quadrimorphina allomorphinoides (Reuss)	....	....	....	....	....	....	....	....	....	×	×	×	×	
Spiroplectammina mordensis Wickenden	....	....	....	....	....	....	....	....	....	×	....	....	....	Santonian? and Campanian of Alaska.

A. Mount Laurel Sand, from the Chesapeake and Delaware Canal at Biggs Farm, 6–8 ft above the top of the Marshalltown Formation.
B. Mount Laurel Sand, from the same stratigraphic position and locality as sample A.
C. Mount Laurel Sand, south side of the Chesapeake and Delaware Canal, about 100 yd east of the bridge on U.S. Route 13; from a conspicuous *Pyncnodonte* bed, about 3 ft above the top of the Marshalltown Formation.
D. Mount Laurel Sand, same locality as sample C, from inside a closed *Pyncnodonte* shell.
Z. Marshalltown Formation, north side of the Chesapeake and Delaware Canal, immediately west of the bridge on U.S. Route 13; within the upper 1–2 ft of the formation.
Y. Marshalltown Formation, north side of the Chesapeake and Delaware Canal, 100 yd west of the U.S. Route 13 bridge at St. Georges, in the upper foot of the formation and associated with *Exogyra ponderosa*.
X. Marshalltown Formation, south side of the Chesapeake and Delaware Canal, 1.5 miles northeast of Summit Bridge, Del., from the upper part of the formation, in an excavation for a railroad bridge pier.
W. Marshalltown Formation, south bank of Oldmans Creek at Camp Kimble, near Auburn, southwest New Jersey (Mello and others, 1964, p. B61).
V. Marshalltown Formation, same locality data as for X, but from the middle part of the formation.
U. Englishtown Formation, same locality as for sample X, but from the base of the formation.

Faunas from the nine fossiliferous samples are compared with the fauna reported from a single sample of the Marshalltown Formation at Auburn, N.J. (Mello and others, 1964). From these 10 samples, a total of 111 species of Foraminifera were identified, of which 93 are positively or tentatively assigned to previously named species. Eight species are considered to be new or probably new, and 10 are given temporary letter or number designations. Table 9 indicates the distribution of the species in the samples, and shows their Cretaceous ranges.

TAXONOMIC REVISIONS

Comparisons have been made between the specimens from the Marshalltown Formation at Auburn, N.J. (Mello and others, 1964, p. 63) and specimens from the nine Chesapeake and Delaware Canal samples included in this study. Many species are represented by better specimens in the Chesapeake and Delaware Canal samples than in the Auburn sample, and comparisons have shown that several species were incorrectly identified from the Auburn sample. Also, several species present in the Auburn sample but not identified previously could be identified after comparison with the Chesapeake and Delaware Canal faunas. Modifications and additions to the Auburn species list are shown in the following summary.

AGE INTERPRETATIONS

Repetition of lithologies, thinness of the lithologic units, and scarcity of good exposures has severely hampered stratigraphic and biostratigraphic study of the Cretaceous deposits on the Atlantic Coastal Plain. Stratigraphic interpretations made earlier in this report are the framework within which the fossil evidence presented here is considered and against which other interpretations are compared.

Olsson (1960, 1964) was the first in more than 30 years to systematically study Foraminifera from the Cretaceous rocks in this region, and his taxonomic work has been extensively used in this study, chiefly for the comparison of planktonic Foraminifera.

Mello, Minard, and Owens, 1964	*This report*
Not identified	*Anomalina nelsoni* Berry
Do	*Cibicides* cf. *C. harperi* (Sandidge)
Do	*Dorothia glabrella* Cushman
Pseudogaudryinella capitosa (Cushman)	*Gaudyrina stephensoni* Cushman
Not identified	*Gaudryina* sp. A
Biglobigerinella biforaminata (Hofker)	*Globigerinelloides messinae* Bronnimann
Not identified	*Globotruncana? cretacea* (d'Orbigny)
Globotruncana cretacea Cushman	*Globotruncana rosetta* (Carsey)
Globigerina (*Rugoglobigerina*) *rugosa* Plummer?	*Globotruncana? subrugosa* Gandolfi
Globotruncana wilsoni Bolli	*Globotruncana subcircumnodifer* (Gandolfi)
Lagena cf. *L. acuticosta* Reuss	*Lagena sulcata semiinterrupta* Berry
Bolivina incrassata Reuss	*Loxostoma plaita plaita* (Carsey)
Bulimina prolixa Cushman and Parker	*Neobulimina canadensis* Cushman and Wickenden var. A.
Pseudoglandulina cf. *P. lagenoides* (Olszewski)	*Pseudonodosaria appressa* (Loeblich and Tappan)
Not identified	*Rugoglobigerina macrocephala* Bronnimann

Olsson (1964, p. 160) reported on planktonic Foraminifera from one sample of the Mount Laurel Sand and two samples of the Marshalltown Formation in New Jersey, and on two samples of the Mount Laurel-Navesink Formations (undifferentiated) from the Chesapeake and Delaware Canal, Del.

Of the planktonic species identified both in this study and by Olsson (1964), the following have ranges that include at least part of the late Campanian and at least part of the Maestrichtian: *Hedbergella planispira, Globotruncana cretacea, G. subrugosa, G. linneiana, G. rosetta, G. fornicata, G. tricarinata, G. subcircumnodifer, Globigerinelloides messinae,* and *Praeglobotruncana havanensis* (=*petaloidea* of Olsson).

The only two planktonic species recovered in this study which do not have ranges extending from the late Campanian into at least the earliest Maestrichtian are *Rugoglobigerina macrocephala* and *Globotruncana arca,* both of which Olsson reported only from the Maestrichtian. Bandy (1967, p. 20) cited a Coniacian to Maestrichtian range for *G. arca. R. macrocephala,* a rare species in seven samples from both the Marshalltown Formation and Mount Laurel Sand, was reported from the Campanian of Colombia by Gandolfi (1955, p. 46).

The balance of evidence from the planktonic Foraminifera, supported by several benthonic species with restricted ranges, indicates a late Campanian or earliest Maestrichtian age for both the Marshalltown and Mount Laurel samples studied. Table 9 lists the occurrences of the identified species in the samples and shows the ranges of many through the Austin, Taylor, and Navarro provincial stages of the Gulf Coastal Plain, as reported by Cushman (1946).

It is noteworthy that Olsson's (1964) usage of the term Mount Laurel-Navesink Formation in conjunction with his two samples from the Chesapeake and Delaware Canal is based exclusively on lithologic character. He clearly points out the difference in age attributed to this unit along the canal with respect to the ages of the Mount Laurel Sand and Navesink Formation in New Jersey. The descriptions of collecting localities given by Olsson (1964, p. 160) indicate that his sample, DK5, from the Mount Laurel Sand-Navesink Formation, was taken at approximately the same stratigraphic level and within 200 feet geographically of samples C and D of this study. His sample DK6, also from the Mount Laurel-Navesink Formation, is apparently from the same stratigraphic level and geographic position as samples A and B of this study. Within the stratigraphic framework developed in this paper, samples C and D are from the Mount Laurel Sand, within 3 feet of the top of the Marshalltown Formation; samples A and B are from the Mount Laurel Sand 6–8 feet above the top of the Marshalltown Formation.

The presence of each planktonic species in samples from both the Mount Laurel Sand and Marshalltown Formation makes it impossible to differentiate these formations, on this basis, as to age. In addition, 88 out of the total of 111 species occur both in the Mount Laurel Sand and in the Marshalltown Formation. No species represented by a large number of specimens in any one sample fails to appear in both formations, and nearly all the species restricted to one or the other formation are represented by fewer than five specimens in any sample. The persistence of such a large percentage of species, including the supposedly rapidly evolving planktonic species, suggests that deposition of the Mount Laurel Sand followed close upon the cessation of deposition of the Marshalltown Formation. In light of this interpretation, it is possible that the absence of the Wenonah Formation between the Marshalltown and Mount Laurel is due to the loss of identity of the Wenonah by facies change within the lower part of the Mount Laurel in the sampled area.

Close faunal similarity, such as is found here between the Mount Laurel Sand and Marshalltown Formation, is suggestive of secondary faunal mixing, although this seems unlikely for these samples. Nearly all specimens from both formations show no abrasion or breakage which might be indicative of transportation, and faunas from both formations are large and diverse in addition to being largely composed of the same species. Also, samples 8 feet or more above and below the contact retain the same faunal character, further suggesting that mixing is not the cause for the similarities.

ENVIRONMENTAL INTERPRETATIONS

Although it is dangerous to attempt close definition of depositional environment in the absence of specimen counts, sediment analysis, and complete faunal representation, it does seem quite evident that the faunas recovered from the Mount Laurel Sand and Marshalltown Formation were deposited under open marine conditions like those existing over the middle continental shelves during the Holocene. The chief factors favoring this interpretation are the generally very high diversity of Foraminifera and the frequency of occurrence of planktonic specimens in the samples. The faunal similarities discussed above strongly indicate that the depositional environments for the Marshalltown and Mount Laurel through the stratigraphic interval and in the area studied were identical or very closely similar. It should be emphasized here that these interpretations pertain only to the glauconite-bearing calcareous beds of the Mount Laurel and not to the medium to coarse quartz sand beds found in the upper part of the formation.

A simple clustering program was carried out in an attempt to determine what, if any, differences exist between the recovered faunas that might indicate consistent environmental differences between the two formations. The nature of the data itself put rigorous restrictions on the coefficients of correlation that could be used. Each of the samples was floated on carbon tetrachloride before picking. This procedure undoubtedly alters the faunal composition and largely invalidates the significance of specimen counts. The logic presented by Simpson (1960) concerning the selection of coefficients of correlation is applicable here, and Simpson's index 2 is used. Comparability of samples is calculated as:

$$\frac{C}{N1} \times 100$$

where C equals the number of species common to two samples, and $N1$ equals the total number of species present in the smaller sample. For ease in visualization of relationships, the values thus calculated were clustered using the weighted pair-group method with arithmetic averages (Mello and Buzas, 1968). The calculated relationships between samples are shown in figure 25. Sample U, from the Englishtown Formation, was deleted before clustering because of its probable contamination.

Examination of the clustering (fig. 25) shows no subdivision into separate Mount Laurel and Marshalltown clusters. Instead, the samples are grouped rather heterogeneously, and this indicates that, at least on the basis of presences and absences, the faunas from the two formations cannot be differentiated. The faunas from these samples are also similar with regard to relative abundances of species. Although no single species is consistently dominant, a small group of species is collectively dominant in all samples, and many species are consistently scarce in all samples. In view of these faunal similarities, it seems warranted to conclude that environmental factors necessary for the existence of the foraminiferal species found in the Marshalltown Formation persisted during the deposition of the Mount Laurel Sand.

SUMMARY OF MICROPALEONTOLOGIC STUDIES

Eight samples were examined from the Mount Laurel Sand and Marshalltown Formation along the Chesapeake and Delaware Canal, Del., and one sample from the Marshalltown Formation at Auburn, N.J. Faunas from the two formations cannot be

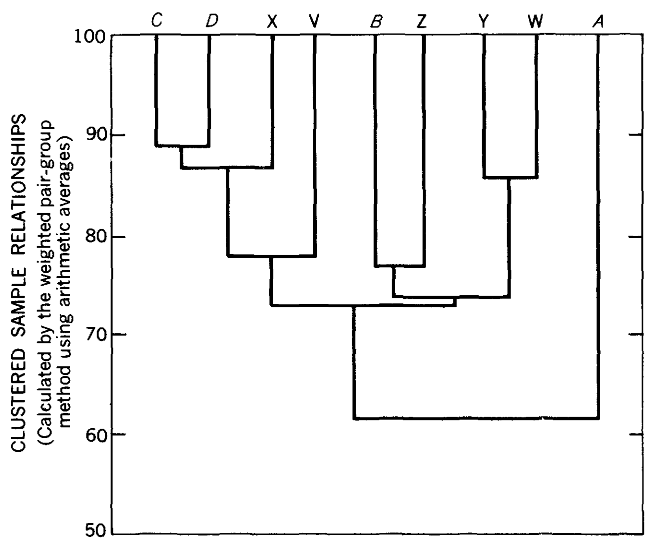

FIGURE 25.—Clustering of nine samples from the Mount Laurel Sand (italicized letters) and Marshalltown Formation.

distinguished from each other on the basis of species presences and absences; they are also generally alike with regard to commonness and scarcity of constituent species. The ubiquity of most planktonic species in the samples and the presence of all planktonic species in both formations indicate that through the intervals sampled the two formations are of late Campanian to earliest Maestrichtian age. The absence of the Wenonah Formation west of the Delaware River is possibly the result of facies change within the basal Mount Laurel Sand rather than of erosion or nondeposition. Comparisons of the total faunas from both formations strongly suggest a close similarity in living environments.

SELECTED REFERENCES

Adkins, W. S., 1933, The geology of Texas. Part 2, The Mesozoic systems in Texas: Texas Univ. Bull. 3232, p. 239–518.

Bandy, O. L., 1967, Cretaceous planktonic foraminiferal zonation: Micropaleontology, v. 13, no. 1, p. 1–31, figs. 1–13.

Bascom, F. L., and Miller, B. L., 1920, Description of the Elkton-Wilmington quadrangles [Md.-Del.-N.J.-Pa.]: U.S. Geol. Survey Geol. Atlas, Folio 211, 22 p.

Booth, J. C., 1841, Memoir of the geological survey of the State of Delaware; including the application of the geological observations to agriculture: Dover, Del., 188 p.

Carter, C. W., 1937, The Upper Cretaceous deposits of the Chesapeake and Delaware Canal of Maryland and Delaware: Maryland Geol. Survey [Rept.] v. 13, p. 237–281.

Clark, W. B., 1916, The Upper Cretaceous deposits of Maryland: Maryland Geol. Survey, Upper Cretaceous [Volume], p. 23–110.

Clark, W. B., Bagg, R. M., and Shattuck, C. R., 1897, Upper Cretaceous formations of New Jersey, Delaware, and Maryland: Geol. Soc. America Bull., v. 8, p. 315–358.

Cobban, W. A., 1969, The Late Cretaceous ammonites *Scaphites leei* Reeside and *Scaphites hippocrepis* (DeKay) in the western interior of the United States: U.S. Geol. Survey Prof. Paper 619, 29 p., 5 pls.

Cook, G. H., 1868, Geology of New Jersey: Newark, New Jersey Geol. Survey, 900 p.

Cooke, C. W., and Stephenson, L. W., 1928, The Eocene age of the supposed late Upper Cretaceous greensand marls of New Jersey: Jour. Geology, v. 36, no. 2, p. 139–148.

Cushman, J. A., 1946, Upper Cretaceous Foraminifera of the Gulf Coastal region of the United States and adjacent areas: U.S. Geol. Survey Prof. Paper 206, 241 p., 66 pls.

Dorf, Erling, 1952, Critical analysis of Cretaceous stratigraphy and paleobotany of Atlantic Coastal Plain: Am. Assoc. Petroleum Geologists Bull., v. 36, no. 11, p. 2161–2184.

Doyle, J. A., 1969, Cretaceous angiosperm pollen of the Atlantic Coastal Plain and its evolutionary significance: Harvard Univ., Arnold Arboretum Jour., v. 50, no. 1, p. 1–35.

Durham, C. O., Jr., 1955, Stratigraphic relations of Upper Cretaceous volcanics in Travis County, Texas, *in* Corpus Christi Geol. Soc. Ann. Field Trip, Mar. 1955: 6 unnumbered pages following p. 55.

Gabb, W. M., 1877, Notes on American Cretaceous fossils with descriptions of some new species: Acad. Nat. Sci. Philadelphia Proc., 1876, p. 276–324.

Galliher, E. W., 1935, Geology of glauconite: Am. Assoc. Petroleum Geologists Bull., v. 19, no. 11, p. 1569–1601.

Gandolfi, Rolando, 1955, The genus *Globotruncana* in northeastern Colombia: Bulls. Am. Paleontology, v. 36, no. 155, 109 p., 10 pls., 12 figs.

Gardner, J. A., 1916, Mollusca, *in* Berry, E. W., and others, Systematic paleontology, Upper Cretaceous: Maryland Geol. Survey, Upper Cretaceous [Volume], p. 371–733, pls. 12–45.

Greacen, K. F., 1941, The stratigraphy, fauna, and correlation of the Vincentown Formation: New Jersey Dept. Conserv. and Devel., Geol. Ser. Bull. 52, 83 p., 1 pl.

Groot, J. J., 1955, Sedimentary petrology of the Cretaceous sediments of northern Delaware in relation to paleogeographic problems: Delaware Geol. Survey Bull. 5, 157 p.

Groot, J. J., and Glass, H. D., 1960, Some aspects of the mineralogy of the northern Atlantic Coastal Plain, *in* Swineford, Ada, ed., Clays and clay minerals—Proceedings of the 7th National Conference on Clays and Clay Minerals, Washington, D.C., Oct. 20–23, 1958: New York, Pergamon Press, p. 271–284.

Groot, J. J., Jordan, R. R., and Richards, H. G., 1961, Atlantic Coastal Plain Geological Association, 2d Field Conference, September, 1961: Newark, Del., Atlantic Coastal Plain Geol. Assoc., 41 p.

Groot, J. J., Organist, D. M., and Richards, H. G., 1954, Marine Upper Cretaceous formations of the Chesapeake and Delaware Canal: Delaware Geol. Survey Bull. 3, 62 p., 7 pls.

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

Jordan, R. R., 1962, Stratigraphy of the sedimentary rocks of Delaware: Delaware Geol. Survey Bull. 9, 51 p.

Krynine, P. D., 1948, The megascopic study and field classification of sedimentary rocks: Jour. Geology, v. 56, no. 2, p. 130–165.

Kulp, J. L., 1961, Geologic time scale: Science, v. 133, no. 3459, p. 1105–1114.

Kümmel, H. B., and Knapp, G. N., 1904, The clays of the Cretaceous formation, *in* Ries, Heinrich, Kümmel, H. B., and Knapp, G. N., The clays and clay industry of New Jersey: New Jersey Geol. Survey Final Rept., v. 6, p. 149–203.

Lewis, J. V., and Kümmel, H. B., 1912, Geologic map of New Jersey, 1910–1912: New Jersey Geol. Survey, scale 1:250,000 (revised 1931 by H. B. Kümmel and 1950 by M. E. Johnson).

Mansfield, G. R., 1923, Potash in the greensands of New Jersey: U.S. Geol. Survey Bull. 727, 146 p., 10 pls.; reprinted as New Jersey Div. Geology and Waters, Geol. Ser. Bull. 23.

Mello, J. F., and Buzas, M. A., 1968, An application of cluster analysis as a method of determining biofacies: Jour. Paleontology, v. 42, no. 3, p. 747–758.

Mello, J. F., Minard, J. P., and Owens, J. P., 1964, Foraminifera from the *Exogyra ponderosa* zone of the Marshalltown Formation at Auburn, New Jersey: U.S. Geol. Survey Prof. Paper 501–B, p. B61–B63.

Minard, J. P., 1964, Geology of the Roosevelt quadrangle, New Jersey: U.S. Geol. Survey Geol. Quad. Map GQ–340.

——— 1965, Geological map of the Woodstown quadrangle, Gloucester and Salem Counties, New Jersey: U.S. Geol. Survey Geol. Quad. Map GQ–404.

——— 1963, Pre-Quaternary geology of the Browns Mills quadrangle, New Jersey: U.S. Geol. Survey Geol. Quad. Map GQ–264.

Minard, J. P., and Owens, J. P., 1963, Pre-Quaternary geology of the Browns Mills quadrangle, New Jersey: U.S. Geol. Survey Geol. Quad. Map GQ–264.

Minard, J. P., Owens, J. P., and Nichols, T. C., 1963, Pre-Quaternary geology of the Mount Holly quadrangle, New Jersey: U.S. Geol. Survey Geol. Quad. Map GQ–272.

Minard, J. P., Owens, J. P., Sohl, N. F., Gill, H. E., and Mello, J. F., 1969, Cretaceous-Tertiary boundary in New Jersey, Delaware, and eastern Maryland: U.S. Geol. Survey Bull. 1274–H, 33 p.

Minard, J. P., Owens, J. P., and Todd, Ruth, 1961, Redefinition of the Mount Laurel Sand (Upper Cretaceous) in New Jersey: U.S. Geol. Survey Prof. Paper 424–C, p. C64–C67.

Olsson, R. K., 1960, Foraminifera of latest Cretaceous and earliest Tertiary age in the New Jersey Coastal Plain: Jour. Paleontology, v. 34, no. 1, p. 1–58, pls. 1–12, figs. 1, 2.

——— 1964, Late Cretaceous planktonic Foraminifera from New Jersey and Delaware: Micropaleontology, v. 10, no. 2, p. 157–188, 7 pls.

Overbeck, R. M., and Slaughter, T. H., 1958, The groundwater resources, *in* The water resources of Cecil, Kent, and Queen Annes Counties: Maryland Dept. Geology, Mines and Water Resources Bull. 21, p. 1–382.

Owens, J. P., and Minard, J. P., 1960, Some characteristics of glauconite from the Coastal Plain formations of New Jersey: U.S. Geol. Survey Prof. Paper 400–B, p. B430–B432.

———1962, Pre-Quaternary geology of the Columbus quadrangle, New Jersey: U.S. Geol. Survey Geol. Quad. Map GQ–160.

———1964a, Pre-Quaternary geology of the Pemberton quadrangle, New Jersey: U.S. Geol. Survey Geol. Quad. Map GQ–262.

———1964b, Pre-Quaternary geology of the Trenton East quadrangle, New Jersey-Pennsylvania: U.S. Geol. Survey Geol. Quad. Map GQ–341.

———1964c, Pre-Quaternary geology of the Bristol quadrangle, New Jersey-Pennsylvania: U.S. Geol. Survey Geol. Quad. Map GQ–342.

Pettijohn, F. J., 1957, Sedimentary rocks: 2d ed., New York, Harper & Bros., 718 p.

Richards, H. G., and others, 1958, 1962, The Cretaceous fossils of New Jersey: New Jersey Bur. Geology and Topography Bull. 61, 2 v.: 266 p., 237 p.

Richards, H. G., and Shapiro, Earl, 1963, An invertebrate macrofauna from the Upper Cretaceous of Delaware: Delaware Geol. Survey Rept. Inv. 7, 37 p., 4 pls

Simpson, G. G., 1960, Notes on the measurement of faunal resemblance: Am. Jour. Sci., v. 258–A, p. 300–311.

Sohl, N. F., 1964a, Neogastropoda, Opisthobranchia, and Basommatophora from the Ripley, Owl Creek, and Prairie Bluff Formations: U.S. Geol. Survey Prof. Paper 331–B, p. 154–344, pls. 19–52.

——— Gastropods from the Coffee Sand (Upper Cretaceous) of Mississippi: U.S. Geol. Survey Prof. Paper 331–C, p. 345–394, pls. 53–57.

Spangler, W. B., and Peterson, J. J., 1950, Geology of the Atlantic Coastal Plain in New Jersey, Delaware, Maryland, and Virginia: Am. Assoc. Petroleum Geologists Bull., v. 34, no. 1, p. 1–99.

Stephenson, L. W., 1914, Cretaceous deposits of the eastern Gulf region *and* Species of *Exogyra* from the eastern Gulf region and the Carolinas: U.S. Geol. Survey Prof. Paper 81, 77 p., 21 pls.

——— 1923, Cretaceous formations of North Carolina; Part I, Invertebrate fossils of the Upper Cretaceous formations: North Carolina Geol. and Econ. Survey, v. 5, pt. 1, 604 p., 102 pls.

——— 1933, The zone of *Exogyra cancellata* traced 2,500 miles: Am. Assoc. Petroleum Geologists Bull., v. 17, no. 11, p. 1351–1361.

——— 1954, Additions to the fauna of the Raritan formation (Cenomanian) of New Jersey: U.S. Geol. Survey Prof. Paper 264–B, p. 25–43.

Stephenson, L. W., Cooke, C. W., and Mansfield, W. C., 1932, Chesapeake Bay region: Internat. Geol. Cong., 16th, Washington, D.C., 1933, Guidebook 5, Excursion A–5, 49 p., 9 pls.

Stephenson, L. W., King, P. B., Monroe, W. H., and Imlay, R. W., 1942, Correlations of the outcropping Cretaceous formations of the Atlantic and Gulf Coastal Plain and Trans-Pecos, Texas: Geol. Soc. America Bull., v. 53, no. 3, p. 435–448, chart.

U.S. Geological Survey, 1967, Engineering geology of the Northeast Corridor, Washington, D.C., to Boston, Mass. —Coastal Plain and surficial deposits: U.S. Geol. Survey Misc. Geol. Inv. Map I–514–B, 8 sheets.

Weller, Stuart, 1907, A report on the Cretaceous paleontology of New Jersey, based upon the stratigraphic studies of George N. Knapp: New Jersey Geol. Survey, Paleontology Ser., v. 4, 2 v.: 1107 p.

Young, Keith, 1963, Upper Cretaceous ammonites from the Gulf Coast of the United States: Texas Univ. Pub. 6304, 373 p., 82 pls.

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