Cretaceous-Tertiary Boundary in New Jersey Delaware, and Eastern Maryland

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

CONTRIBUTIONS TO STRATIGRAPHY

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The basal Tertiary Hornerstown Sand unconformably overlaps progressively lower truncated beds in the underlying Cretaceous section southwestward through New Jersey, Delaware, and eastern Maryland

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ABSTRACT

The Cretaceous-Tertiary boundary in New Jersey has been described as both conformable and unconformable. The advocates of each interpretation have been about evenly divided for the past 75 years. Recent geologic quadrangle mapping of more than 600 square miles in the Coastal Plain of New Jersey and detailed reconnaissance in parts of Delaware and eastern Maryland have enabled the authors of this report to offer evidence of the unconformable nature of the contact for 120 miles along the strike. The thinning of the stratigraphic section, the pinchout of some units in outcrop, and the overlap of the basal Tertiary on progressively lower beds in the Cretaceous section from northeast to southwest are evident. Determination of the distinguishing lithologic characteristics, fixing the spatial distribution, and recognition of the cyclical nature of the Coastal Plain formations have aided in determining the unconformity, the changes along the strike, and the correlation of the formations from New Jersey through Delaware into eastern Maryland. In addition to structure and overlap, worn phosphatic and sideritic fossils and pieces of rock reworked from the underlying Cretaceous formations into the base of the overlying Tertiary formations suggest an unconformity similar to that recognized in the southeast part of the Atlantic Coastal Plain and in the Gulf Coastal Plain. Because early workers considered the conspicuous angular unconformity between the lower Eocene and middle Miocene formations to be the Cretaceous-Tertiary boundary, they may have overlooked the more subtle unconformity at the presently accepted Cretaceous-Tertiary boundary.

INTRODUCTION

There are two opposing interpretations for the Cretaceous-Tertiary boundary in the northern Atlantic Coastal Plain, particularly in New Jersey. The first interpretation is that the boundary is gradational and that there was continuous deposition

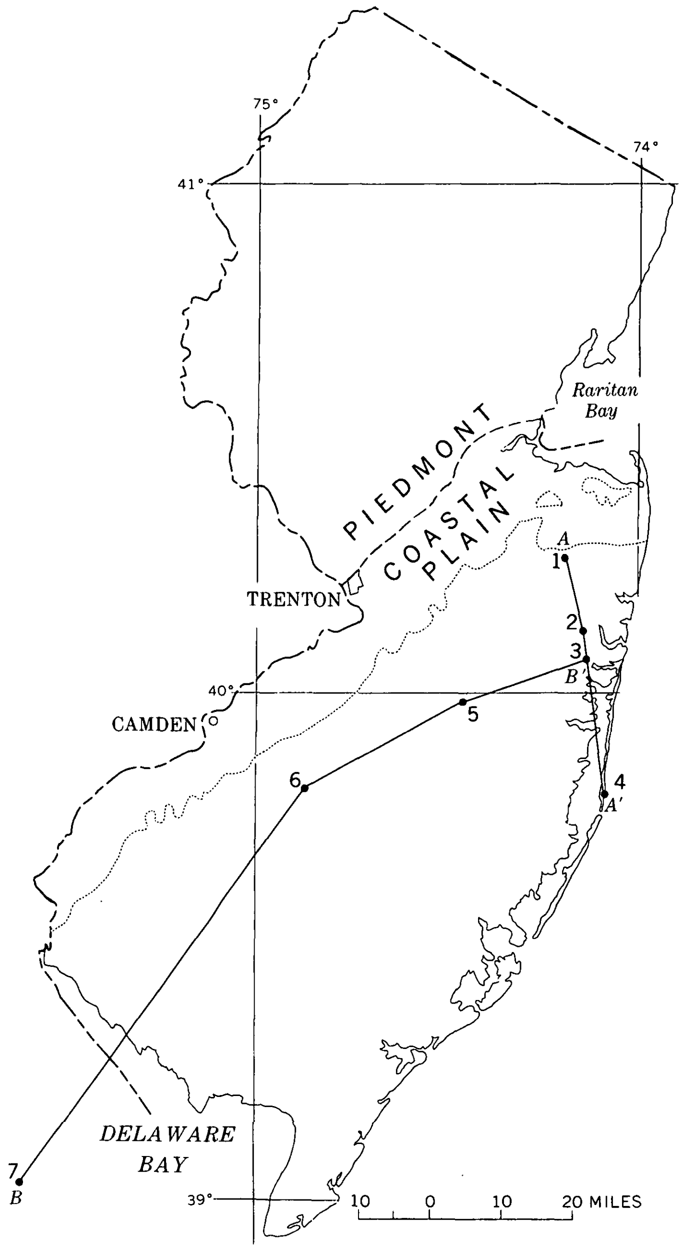

FIGURE 1.—Map of New Jersey showing locations of the Cretaceous-Tertiary boundary (dotted line) and the cross sections shown in figures 8 and 9. 1, Colts Neck 1; 2, Allaire 1; 3, Laurelton; 4, Island Beach 1; 5, Butler Place 1; 6, New Brooklyn 3; 7, Dover, Del.

across it; the second interpretation is that the boundary is unconformable and that there was a period of erosion between deposition of the formations of latest Cretaceous age and those of earliest Tertiary age. There is much clear evidence for the second interpretation but virtually none for the first. The authors of this report recognize a definite unconformity between the Cretaceous and Tertiary formations in New Jersey, Delaware, and eastern Maryland and offer what they consider conclusive evidence for the existence of this unconformity.

The Cretaceous-Tertiary boundary in New Jersey is near the inner edge of the Coastal Plain physiographic province which constitutes somewhat more than half the total area of the State (fig. 1). The formations that crop out in this region are generally unconsolidated sediments of Late Cretaceous, Tertiary, and Quaternary ages; this report is primarily concerned with the uppermost Cretaceous and lowermost Tertiary units (fig. 2).

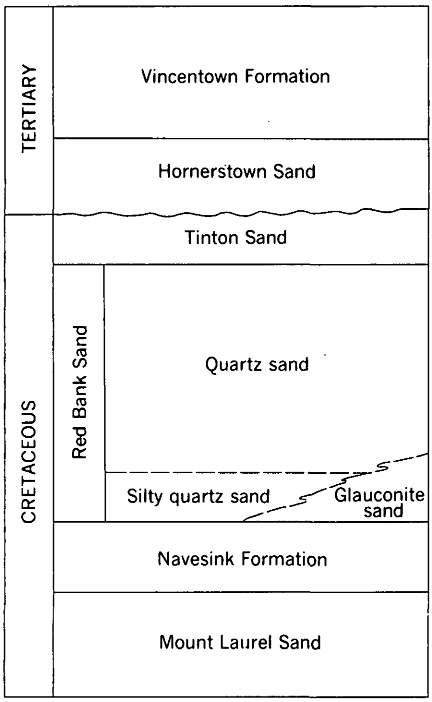

FIGURE 2.—Uppermost Cretaceous and lowermost Tertiary formations in New Jersey.

Two of the authors (Minard and Owens) have completed detailed field mapping in nine 7½-minute quadrangles in the Coastal Plain of New Jersey in which this boundary is present. These quadrangles extend from Sandy Hook in the northeast to Woodstown in the southwest (fig. 3). Local reconnaissance mapping was

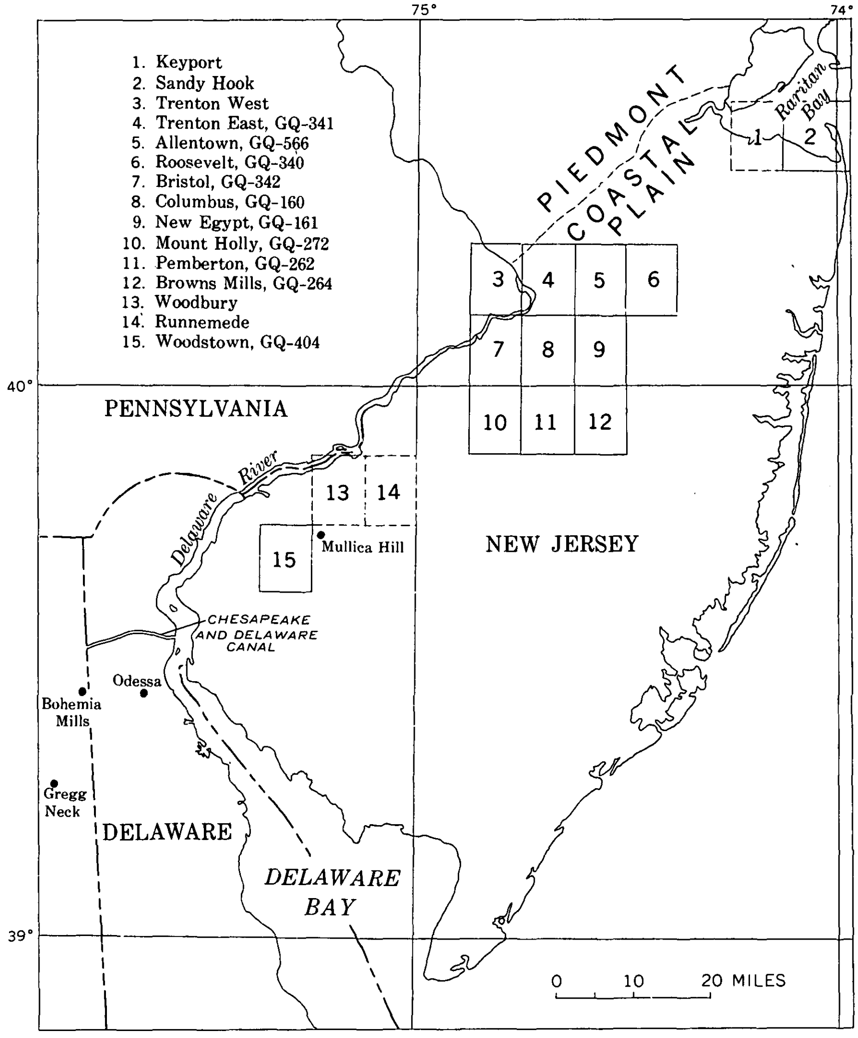

FIGURE 3.—Index map of southern New Jersey showing locations of 7½-minute quadrangles partly or completely mapped by Minard and Owens. Solid outlines of quadrangles indicate geologic mapping completed; dashed outlines indicate reconnaissance mapping. The Cretaceous-Tertiary boundary is present in quadrangles 2, 5–11, and 13–15.

done and outcrops were examined in the intervening quadrangles. Although most of the detailed mapping was in New Jersey, the Cretaceous-Tertiary boundary was examined in New Castle County in northern Delaware and in Cecil and Kent Counties in eastern Maryland. In all places, the boundary lies between the Hornerstown Sand of Paleocene age and the underlying formation of Cretaceous age. In this report, Minard and Owens are primarily responsible for the stratigraphy and mapping, Sohl for the macropaleontology, Gill for the subsurface correlation, and Mello for the micropaleontology.

As mapping progressed, it became evident that some units thin and others thicken in outcrop toward the southwest; several show minor lithologic changes in that direction, although their gross lithologic similarity is readily apparent. Several units in the northeast part of the Coastal Plain in New Jersey thin progressively toward the southwest until they are absent in outcrop (fig. 4). The thinning is generally from top to bottom and from northeast to southwest; as the section is examined in a southwest direction, more of the upper parts of the thinning units are absent

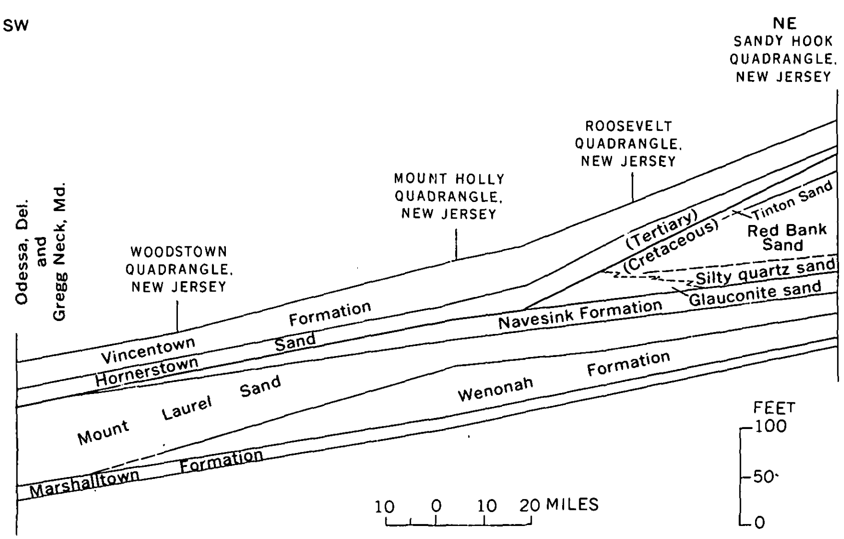

Figure 4.—Upper Cretaceous formations (above the Englishtown) and lower Tertiary formations, from the Odessa, Del., and Gregg Neck, Md., vicinities in the southwest to Sandy Hook quadrangle, New Jersey, in the northeast. The diagram shows (1) thicknesses of units in outcrop, (2) overlapping and absence of units at least at the surface, and (3) facies change in the Red Bank Sand.

until the entire unit thins to zero. The most complete stratigraphic section is in the vicinity of Raritan Bay, N.J.; progressively less complete sections are in the vicinities of Mount Holly and Woodstown, N.J., and the least complete sections are in the vicinities of Odessa, Del., and Gregg Neck, Md.

PREVIOUS WORK

Most of the work that established the Cretaceous-Tertiary stratigraphy of the Coastal Plain in New Jersey was done by W. B. Clark, G. N. Knapp, H. B. Kümmel, and Stuart Weller from about 1891 to 1916. Although refinements have been made and time lines shifted, their original work remains largely valid and is still the basis for the present accepted stratigraphy. Mapping at a scale of 1:125,000 was completed during that period in parts of the Coastal Plain near Trenton and Camden, N.J. Mansfield (1923) delineated the glauconite-bearing formations along their entire outcrop in New Jersey at a scale of 1: 62,500. Since then, very little detailed mapping has been done until that begun by Owens and Minard in 1957.

Most of the paleontological studies undertaken after 1920 were based on the stratigraphy established by the early workers, particularly the lithologic studies and mapping by Knapp, mainly unpublished, and the accompanying paleontological studies of Weller (1907). Because such an emphasis was placed on refining the biostratigraphy, it seemed clear to the present authors that lithostratigraphy of equal refinement, based on detailed lithologic mapping, was needed to provide an adequate framework into which the paleontological work could be properly fitted. The detailed mapping of the early workers had covered only a small part of the Coastal Plain. The present mapping by Owens and Minard was started in the classic study area of Knapp and Weller in the vicinities of Blacks and Crosswicks Creeks south of Trenton, N.J., and was extended both northeast and southwest along the strike to include areas along the total outcrop distance in New Jersey. This mapping, at a scale of 1: 24,000, is the most detailed systematic lithologic mapping of appreciable areal extent that has been done in the Coastal Plain of New Jersey. Probably the most important contribution of this work has been the detailed lithologic descriptions of the formations which enable other workers to recognize the stratigraphic positions of the formations more exactly than was possible previously and to readily distinguish between the formations by lithologic criteria alone, regardless of the degree of weathering, alteration, or lack of fossils.

HISTORY OF THE BOUNDARY DISCUSSION

Clark (1898, p. 182) was apparently the first to consider the possibility of an unconformity at the base of the Hornerstown. Later, however, Clark (in Bascom and others, 1909, p. 13–14) stated that the Hornerstown lies conformably on the Red Bank and Tinton Sands and merges downward into the Navesink Formation where the Red Bank and Tinton are absent.

Weller (1907, p. 137) did not recognize an unconformity at the base of the Hornerstown. He reasoned that the glauconite sand in the central part of the Coastal Plain, which occupies the same interval as the Red Bank Sand farther northeast, was deposited without interruption into the Hornerstown Sand. He considered the disappearance of the Red Bank Sand to the southwest not as a break in sedimentation or as an overlap unconformity, but as a change in the nature and thickness of the sediments along the strike.

Kümmel (in Lewis and Kümmel, 1915, p. 68) first stated that the Hornerstown seems to rest conformably on the Tinton in the north and on the Red Bank where the Tinton is absent and that deposition was continuous from the Navesink into the Hornerstown farther south where the Red Bank is absent. Later (Kümmel, 1940, p. 126–127), he suggested that there was a considerable period of erosion prior to deposition of the Tertiary formations, during which at least 120 to 140 feet of Cretaceous section was removed southwest of Sykesville (west part of New Egypt quadrangle, fig. 3) and even more was eroded farther southwest where the Hornerstown rests on the Mount Laurel Sand.

Cooke and Stephenson (1928, p. 144) considered the Hornerstown unconformable and transgressive on the Upper Cretaceous formations. As evidence for this unconformity they cited the presence of reptilian bones reworked from the underlying Creaceous sediments in the base of the Hornerstown. They believed that the Midway Group was absent in Maryland and New Jersey and that the Cretaceous-Eocene contact there recorded a much greater time hiatus than in the Gulf of Mexico region. They also thought that the reality of the break between the Cretaceous and Eocene sediments in New Jersey was confirmed by diastrophic evidence; the Hornerstown rests on the Tinton in the northeast and completely transgresses and overlaps the Red Bank Sand and Navesink Formation at Mullica Hill, where it rests on the

Mount Laurel Sand. In their paper, Cooke and Stephenson furnished faunal evidence suggesting that the three supposed Upper Cretaceous formations (Hornerstown, Vincentown, and Manasquan) actually were early Tertiary in age. The fact that earlier workers belived these formations to be of Late Cretaceous age may partly explain why they overlooked the unconformity at the base of the Hornerstown, especially because a more obvious unconformity could be seen at the base of the Kirkwood (the then supposed base of the Tertiary).

Jennings (1936) agreed with the new trend and favored an unconformity. He stated (p. 164) that "the unconformity between the underlying Cretaceous and Eocene Hornerstown is marked, as the Hornerstown rests on successively older beds as the outcrop is followed toward the southwest, cutting out successively the Tinton, Red Bank and the upper part of the Navesink."

Spangler and Peterson (1950) returned to the earlier views of Clark (1898), Weller (1907), and Kümmel (1940) and stated (p. 52, 49, 56 respectively) that "the Hornerstown overlies the Tinton conformably * * *," that "toward the south, where the Tinton is missing, the Red Bank grades into the overlying Hornerstown," and that "the gradational character from the Cretaceous beds below indicates that deposition was continuous from Cretaceous to Eocene * * *." They explained the position of the Hornerstown directly on the Navesink by stating (p. 51) that "deposition of beds called Navesink on the southwest was contemporaneous with the Tinton and Red Bank deposition in Monmouth County and continued without interruption into the Hornerstown (Eocene)." They showed (p. 55) a questionable disconformity at one place where the Hornerstown lies on the Navesink, but did not elaborate. They concluded (p. 52) that the Hornerstown "evidently pinches out under the overlap unconformity of the overlying Vincentown, for in the cuts of the Chesapeake and Delaware Canal the Hornerstown Formation is missing and the Vincentown is found resting on the Navesink." The Hornerstown is not present in the canal but it is present a short distance to the south and it rests directly on the Mount Laurel Sand (figs. 4, 5). The units that Spangler and Peterson (1950) referred to as the Vincentown and Navesink in the canal and that Groot and others (1954, p. 7), called the Red Bank Sand and Mount Laurel and Navesink undifferentiated, had previously been correctly identified by Carter (1937, p. 245) as the Mount Laurel Sand and the Marshalltown Formation.

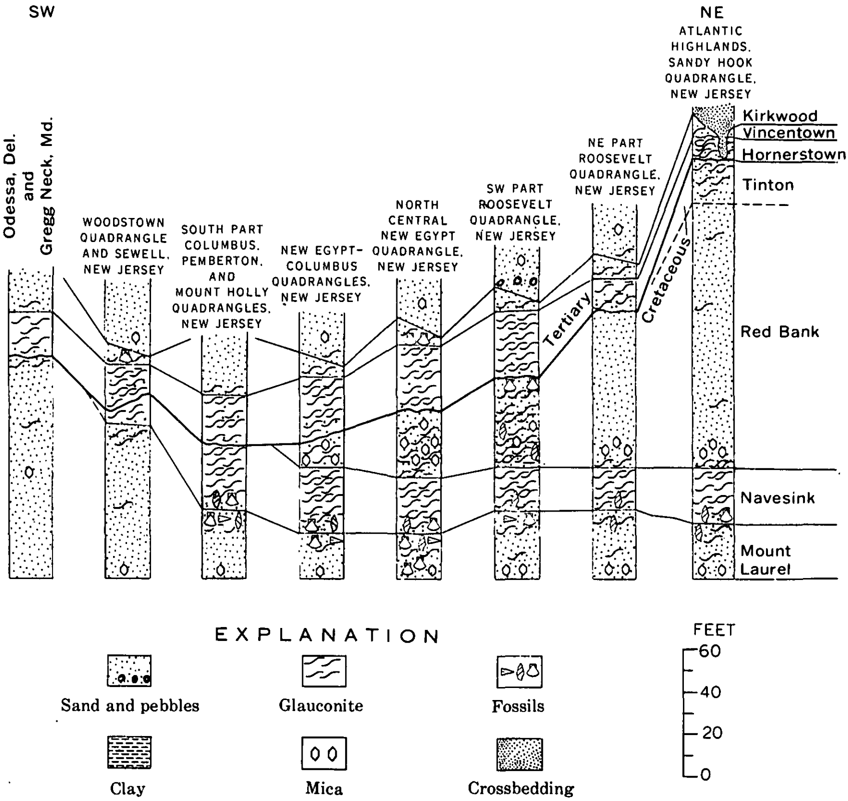

FIGURE 5.—Stratigraphic sections along the outcrop from Odessa, Del., and Gregg Neck, Md., in the southwest to Sandy Hook quadrangle, New Jersey, in the northeast. Sections include formations of Late Cretaceous and early Tertiary age (fig. 2). The Kirkwood Formation (Miocene), undifferentiated from the Cohansey in Sandy Hook, is shown here partly in contact with the Hornerstown.

Johnson and Richards (1952) opposed Spangler and Peterson's (1950) facies change concept (later supported by Olsson, 1963, p. 656) and suggested (p. 2157) nondeposition or subsequent erosion to explain the absence of the Red Bank in the southern part of the State.

Fox and Olsson (1955, p. 736) stated the evidence for an unconformity clearly and concisely: "Stratigraphic evidence indicates an unconformity between the Cretaceous and Tertiary formations. The Hornerstown rests successively from northeast to southwest on the Tinton, the Red Bank, and the Navesink. In each case the Hornerstown lies on a weathered surface and the basal few feet contain fragments of the underlying formation."

Miller (1956, p. 722, 728) considered that Fox and Olsson demonstrated and proved the existence of an unconformity in their 1955 paper. He further stated (p. 725) that an unconformity occurs between the Hornerstown Sand and Navesink Formation along their western outcrop as is well shown at Mullica Hill.

Dorf and Fox (1957, p. 3, 10), along with Richards, Groot, and Germeroth (1957, p. 198), favored pre-Hornerstown erosion and an unconformity at the Cretaceous-Tertiary boundary. After first definitely favoring an unconformity (1955), Fox and Olsson later (1960, p. 8) took a less definite stand and stated that an unconformity may be suggested by the spheroidal weathering of the top of the Tinton. In 1960, Olsson (p. 3) almost completely withdrew from his earlier advocacy of a Cretaceous-Tertiary unconformity by recognizing only probable small disconformity in some areas and no suggestion of a physical break elsewhere. In 1963 he stated (p. 646) that in most places the boundary appears gradational. At about the same time, Jordan (1963) had completed a study of cuttings from nine water wells in the Coastal Plain of Maryland, Delaware, and New Jersey. He stated (p. 195) that "* * * the presence of an unconformity is not evident; on the contrary, deposition appears to have been continuous."

Evidence offered in support of a gradational Cretaceous-Tertiary boundary and continuous deposition was not conclusive, nor was it necessarily based on systematic lithological studies and accurate stratigraphic locations. Rather, it was often based on faunal content of samples obtained either from wells or from outcrops which were not always accurately identified as to formation. Many of the more recent workers in the Coastal Plain of New Jersey and Delaware have depended disproportionately on interpretation of literature rather than on detailed mapping and lithological studies to provide the adequate framework necessary for correct interpretations. It is understandable that mistakes in formational identification were made, particularly if the workers were not intimately familiar with the often subtle lithologic differences.

Although formation boundaries had been rather accurately delineated by some earlier workers, no one ever provided sufficiently detailed descriptions so that the formations could readily be differentiated, especially by those less familiar with the primary criteria than the original mappers. The formations in the Coastal Plain region discussed in this paper form a cyclical sequence, and, on cursory examination, some formations seem fairly similar to others. Distinguishing characteristics include morphologies of glauconite grains, type and amount of mica and carbonaceous matter, ratio of glauconite to quartz, heavy mineral suites, types of clays, internal structures, and weathering characteristics.

Many of the formations are rather thin (thicknesses measured in tens of feet); and unless the detailed lithologic characteristics of each formation are well known, identification and determination of stratigraphic position are difficult. The similarity of formations, thinness, repetitious sequence, and appreciable differences in appearance of weathered and unweathered material from the same formation have been the main stumbling blocks for those employing only paleontology as a tool to designate and map formations.

Detailed mapping clearly shows that the basal Tertiary formation, the Hornerstown Sand, rests on successively older formations from northeast to southwest. This was recognized and noted by many workers, including some proponents of a conformable boundary. It has been argued that mere absence of formations in a stratigraphic section does not prove an unconformity, as the formations may never have been deposited. Proponents of such a thesis must, however, still explain the fact that a younger formation overlaps successively older formations along its strike. Detailed examination of the boundary in outcrop shows features widely considered by many workers, including conformity advocates, to be associated with unconformities. These features include: (1) weathering of the top surface of the uppermost Cretaceous formations, whether it is the Tinton, Red Bank, Navesink, or Mount Laurel, (2) the presence of reworked phosphatic and sideritic shells and concretions at the contact, and (3) the incorporation of these and other fossils and pieces of material from the underlying Cretaceous formations in the basal part of the Tertiary formation.

DETAILS OF THE BOUNDARY IN OUTCROP—NORTHEAST TO SOUTHWEST

The Cretaceous-Tertiary boundary is well exposed in the southeast part of Sandy Hook quadrangle (figs. 1, 3). It is also exposed at the well-known Beers Hill locality (actually in a roadcut at the west end of Crawford Hill) in the Keyport quadrangle to the west (fig. 3). Excellent exposures are present in pits on either side of Route 36 just east of Atlantic Highlands, in the bluff on Raritan Bay just west of Waterwitch, and in the bluffs along the north side of the Navesink River estuary just west of Sea Bright. These exposures are all in the Sandy Hook quadrangle and all have basically the same relationship—3 or 4 to 10 or 12 feet of Hornerstown glauconite sand lying on the weathered surface of the Tinton. The Hornerstown is mostly grayish green to dusky green, but is partly moderate to dusky red, particularly at the top. It is medium-grained glauconite sand with a little clay and quartz; glauconite grains are nearly all botryoidal.

The Tinton is about 20 feet thick and is mostly reddish-brown and yellowish-brown fossiliferous (table 1) glauconitic quartz sand cemented and encrusted by iron oxides. The glauconite content ranges from several percent near the base to about 90 percent of the sand fraction at the top. The quartz sand in the Tinton is medium to very coarse grained and contains quartz granules. The angularity of many of the coarse grains and granules is a distinctive feature. Part of the glauconite is well weathered; it ranges from dark green and greenish gray to olive gray and light yellowish brown and varies in morphology from botryoidal to accordion forms. Undoubtedly much of the iron present as cement in the ledges, encrustations, and concretions was derived from weathering of the glauconite, because there is more glauconite in the less weathered interiors of concretions than there is in cemented parts of the sand.

The Tinton grades down into about 120 feet of Red Bank Sand. The Red Bank is mostly weathered, reddish-brown to yellowish-brown, medium- to coarse-grained, slightly glauconitic quartz sand; it grades down into a medium- to fine-grained silty quartz sand at the base. The sand locally is indurated by iron oxide into resistant ledges and concretionary masses. Generally, the basal 15 to 20 feet of sand is not weathered and is the original medium to dark gray. The basal few feet of the Red Bank contains appreciable amounts (5–10 percent) of glauconite, mostly in medium-sized botryoidal grains similar to those in the underlying Navesink, but some have accordion forms. Abundant mica, considerable pyrite and carbonaceous matter, and abundant mega- and microfossils are present in the basal unweathered part of the Red Bank. The megafossils include calcareous shells and, where weathered, molds coated with iron oxide. The microfossils include a large suite of Foraminifera. Olsson described nearly 70 species of Foraminifera from the basal Red Bank Sand in the bluff on Raritan Bay just west of Waterwitch (Olsson, 1960, p. 5, loc. NJK–103).

TABLE 1.—*Megafossils in the Cretaceous-Tertiary interval*

[The fossils were found in the basil few feet of the Hornerstown Sand or in the upper few feet of the underlying Cretaceous unit]

Location	Formation	Fossils
Beers Hill, Keyport quadrangle, New Jersey.	Tinton	*Sphenodiscus lobatus* (Tuomey). *Cardium (Pachycardium)* sp. *Cardium (Granocardium) kümmeli* (Weller). *Trigonia cerulia* Whitfield. Gastropod? indet. Worm? burrows. *Neithea* sp.
Ivanhoe Brook, south-central part of the Roosevelt quadrangle, New Jersey.	Inlier of the upper part of the lower Red Bank (transitional beds).	*Crenella serica* Conrad. *Syncylonema simplicus* Conrad. *Gryphaeostrea vomer* Morton. Bryozoa.
South-flowing tributary to Lahaway Creek in the southwest part of the Roosevelt quadrangle, New Jersey.	Hornerstown (just below siderite ledge).	*Cucullaea vulgaris* Morton. *Gryphaea* sp. Fusid gastropod indet. *Baculites columna* Morton. *Baculites* sp.
Contact Creek 1¾ miles north of New Egypt in the New Egypt quadrangle, New Jersey.	Hornerstown (just below siderite ledge).	*Cucullaea vulgaris* Morton. *Gryphaeostrea vomer* Morton. *Pyropsis* sp. *Clione* sp.
Florentine pit two-thirds of a mile northwest of Kirbys Mill in the Mount Holly quadrangle, New Jersey.	Basal Hornerstown and upper part of Navesink.	*Sphenodiscus lobatus* (Tuomey). *Cucullaea vulgaris* Morton.
Inversand pit near Sewell in the southeast part of the Woodbury quadrangle, New Jersey.	Basal Hornerstown and upper part of Navesink.	*Cucullaea* sp. *Gryphaeostrea vomer* Morton. *Pycnodonte* sp. Indeterminate gastropod molds. Coral. Vertebral disc. Teeth.
Roadbank opposite old pit in the Hornerstown on the east side of Great Bohemia Creek at Bohemia Mills, Md. (west of Odessa, Del.).	Mount Laurel	*Belemnitella americana* (Morton). *Exogyra cancellata* Stephenson.

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The next area toward the southwest where the boundary was mapped in detail is in the Roosevelt (Minard, 1964), New Egypt (Minard and Owens, 1962), Columbus (Owens and Minard, 1962), Pemberton (Owens and Minard, 1964a), and Mount Holly (Minard and others, 1964) quadrangles, and on Mount Holly in the southern part of the Bristol quadrangle (Owens and Minard, 1964b). The lower glauconite member of the Red Bank is present in outcrop in the Roosevelt, New Egypt, and Columbus quadrangles. This member was referred to as early as 1907 by Weller (p. 137), who considered it contemporaneous with typical Red Bank to the northeast and gradational into the overlying Hornerstown. Although mention subsequently was made of a dark sandy clay in the basal part of the Red Bank, no particular reference was made to its being primarily a glauconite sand in the New Egypt area until Olsson (1960, p. 1–4) attempted to establish it as a new and separate formation equivalent to and replacing the Hornerstown and Tinton and bridging the Cretaceous-Tertiary boundary. Minard and Owens (1962) mapped this unit as the lower member of the Red Bank Sand in the New Egypt quadrangle.

The section of Red Bank in the northern part of the Roosevelt quadrangle is lithologically very similar to the section at Sandy Hook, except that it is only about 80 feet thick compared with about 120 feet at Sandy Hook (fig. 5). The Red Bank thins southward in the Roosevelt quadrangle to only about 30 feet thick in the southwest corner. There it is nearly all clayey glauconite sand, as it is in most of its outcrop in the New Egypt quadrangle. This southwestward thinning is probably partly a result of removal of the upper quartz sand by erosion and partly a result of depositional thinning of a wedge of sand away from the former shoreline, the coarse quartz sand representing the near-shore facies and the micaceous clayey glauconite sand representing the deeper water facies farther from shore.

Because of the southwestward thinning of the Red Bank, the Hornerstown lies on progressively lower parts of the section in that direction. In the north and west-central part of the Roosevelt quadrangle, the Hornerstown lies on 30 to 70 feet of the quartz sand in the upper part of the Red Bank in an area of about 10 to 12 square miles. In the southern and southwestern part of the quadrangle, it lies on the basal glauconite sand of the Red Bank. The transgressive relation of the basal Tertiary Hornerstown Sand to the uppermost Cretaceous Red Bank Sand is evident in the northern part of the New Egypt quadrangle and is similar to the relation in the Roosevelt quadrangle, except that less of the quartz sand of the Red Bank is present. Updip the Hornerstown lies on the upper quartz sand of the Red Bank, which is about 20 feet thick and grades down into the basal glauconite sand, which is about 30 feet thick. In about 1 mile downdip the upper quartz sand wedges out, and the Hornerstown lies on the basal glauconite sand of the Red Bank. This relation is present in the remainder of the New Egypt quadrangle and in a small area in the east-central part of the Columbus quadrangle.

The basal glauconite sand of the Red Bank thins from 30 feet in the central part of the New Egypt quadrangle to only a few feet at the boundary of the Columbus and New Egypt quadrangles. It pinches out northwest of Tilghmans Corner, in the east-central part of the Columbus quadrangle, and glauconite sand of the Hornerstown lies directly on the next older formation of Cretaceous age, the glauconite sand of the Navesink. This relation continues southwestward into the Woodstown quadrangle, the Hornerstown lying on progressively lower parts of the Navesink section until only 3 or 4 feet of the basal part of Navesink remains in northern updip outcrops. In Delaware and eastern Maryland, the Navesink has been eroded or is completely overlapped, and the Hornerstown lies directly on the Mount Laurel Sand.

The thinning of the Red Bank Sand toward the southwest is shown diagrammatically in figures 4 and 5. The diagrams show that the thickness of the quartz sand decreases more than the increase in thickness of the lower glauconite sand unit, which constitutes the entire Red Bank in the central part of the New Egypt quadrangle. It is the superposition of one glauconite sand on another as in the New Egypt quadrangle and to the southwest, along with the difficulty in separating them lithologically, that has masked the Cretaceous-Tertiary boundary in this region. The break between the Hornerstown and the quartz sand of the Red Bank in the northern parts of the Roosevelt and New Egypt quadrangles is also obscure. The boundary there is on the sides of high wooded hills and is effectively hidden under slope wash from the overlying Kirkwood Formation, but it can be located readily by digging and augering in selected places.

Although both the Hornerstown and basal Red Bank are basically glauconite sands in the New Egypt area, differences are apparent where they are in contact. Where these units are largely unweathered, the color difference is marked. The Hornerstown is dusky green, and the Red Bank is grayish black to dark gray.

The Hornerstown generally has a dusky-green clay matrix; the basal Red Bank has a dark-gray clay matrix. The Red Bank generally contains abundant mica and carbonaceous matter, whereas the Hornerstown commonly contains little of either. The grains of glauconite in the Hornerstown are nearly all botryoidal, whereas the Red Bank contains many accordion grains.

Where the Hornerstown lies on the Navesink, the difference is also apparent, mostly as a color contrast. Both are glauconite sands; and when washed, the glauconite grains are very similar, largely medium grain size and botryoidal. In outcrop or in cuttings from an auger hole, however, the color difference is distinct, largely because of difference in the clay content. The Hornerstown is dusky green, whereas the Navesink is a greenish black to brownish gray or grayish brown.

Where the Hornerstown lies on the quartz sand of the Red Bank, the upper part of the Red Bank is weathered and sand grains are coated by iron oxide; the basal part of the Hornerstown contains considerable quartz. Where the Hornerstown lies on the glauconite sand of the Red Bank, the basal beds contain sideritized slabs of sandstone and phosphatized reworked Cretaceous fossils. Where it lies on the Navesink, the Hornerstown contains pieces of the Navesink and phosphatized Cretaceous fossils (*Cucullaea, Sphenodiscus*) reworked into the base (fig. 6*A*; table 1).

In the Woodstown quadrangle, the contact between the Hornerstown and Navesink is marked by a zone of borings filled by glauconite sand of the Hornerstown and extending down into the Navesink. Again the color difference is distinct. The same features also are clearly evident in the Inversand pit (fig. 6*B*), in the southeast corner of the Woodbury quadrangle.

Just northwest of Odessa, Del., green glauconite sand of the Hornerstown Sand, containing considerable quartz sand in the base, is exposed in a borrow pit. The Hornerstown lies on the greenish-brown to yellowish-brown glauconite quartz sand of the Mount Laurel Sand. Borings filled by glauconite sand of the Hornerstown extend down into the upper few feet of the Mount Laurel. Johnson and Richards (1952, p. 2158) considered the strata near Odessa to be similar to the Hornerstown in New Jersey, but Groot, Jordan, and Richards (1961, p. 18, 24) recognized neither the Hornerstown nor the Mount Laurel there. They labeled the section beneath the Pleistocene sand and gravel "Lower Tertiary series(?)." Because only a few feet of Hornerstown is exposed near Odessa, trenching and augering were done a short

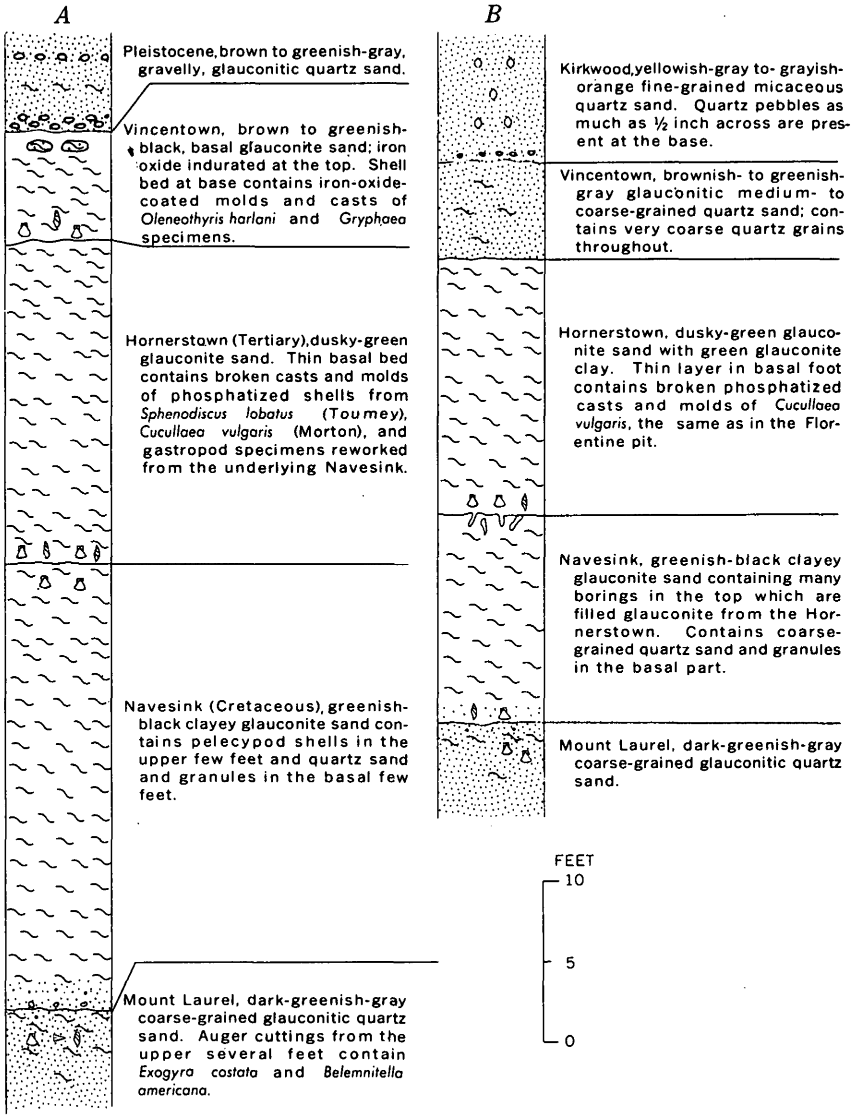

FIGURE 6.—Stratigraphic sections of the formations (*A*) in the Florentine pit in the central part of the Mount Holly quadrangle and (*B*) in the Inversand pit near Sewell in the southeast part of the Woodbury quadrangle (fig. 3). The lower 23 feet of the Navesink and upper few feet of the Mount Laurel in the Florentine pit, and the lower 6 feet of the Navesink and upper part of the Mount Laurel in the Inversand pit were not exposed, but were penetrated by augering. See figure 5 for explanation of lithologic symbols.

distance up the hill. The auger penetrated 18 to 20 feet of material of Hornerstown lithology, indicating that the Quaternary gravel and sand in the pit is a local channel deposit. The authors of this report augered holes at two other places, one 2 miles northeast of Odessa, and one 3¾ miles east-northeast of Odessa. In each hole they drilled through about 20 feet of green quartz-glauconite sand of Hornerstown lithology which was underlain by the greenish-gray coarse to granule-size quartz sand of the Mount Laurel.

About 5¾ miles west of Odessa, the Hornerstown is exposed in an old pit at Bohemia Mills, Md., where it overlies the Mount Laurel. The upper part of the Mount Laurel at this location contains abundant *Exogyra cancellata* and *Belemnitella americana* specimens (table 1). An excellent exposure can be seen at Gregg Neck, Md. (fig. 3), about 12¼ miles southwest of Odessa. The exposure is in a bank at the boatyard on the south side of the Sassafras River. About 10 feet of Mount Laurel is exposed and is overlain by 18 to 20 feet of Hornerstown, which in turn is overlain by 5 to 6 feet of Vincentown (Aquia) capped by Quaternary gravel. The Hornerstown and the fossiliferous upper part of Mount Laurel are also exposed in the banks behind the boatyard and post office at Fredericktown, Md., about 1¼ miles west of Gregg Neck. The farthest west that both lithologies were seen was about 10 miles southwest of Fredericktown, in the eastern part of the Betterton quadrangle. The units in all these places are basically the same as at Odessa, except for the abundance of fossils in the upper part of the Mount Laurel at Fredericktown and Bohemia Mills.

MEGAFOSSILS IN THE BOUNDARY INTERVAL

The macroinvertebrate fauna pertinent to the discussion of the Cretaceous-Tertiary boundary problem of the northern part of the Atlantic Coastal Plain is not large, but it does support the thesis of unconformity. At most places where the boundary is exposed, fossils are neither abundant nor well preserved immediately above or below the contact. Table 1 lists collections from selected outcrops at or near the boundary from near the northern limit of outcrop in New Jersey (top) to the southern limit in Maryland (bottom). The fossils listed are those collected during the present survey; pertinent previous collections cited in the literature are discussed below.

Comparison between the fauna from Beers Hill, N.J., and that from Bohemia Mills, Md., supports the interpretation that there is a progressive loss of Cretaceous section from north to south along the outcrop. The relationships of the fauna from the Tinton at Beers Hill are clear. (See Richards and others, 1958, 1962, for listings of additional mollusks.) The presence of *Sphenodiscus lobatus* (Tuomey) is sufficient to indicate that the unit lies high in the Cretaceous. Elsewhere in the Atlantic and Gulf Coastal Plains this species occurs only in units that are stratigraphic equivalents of the upper part of the Navesink Formation and of the Tinton and Red Bank Sands. These include the Providence Sand, Ripley and Owl Creek Formations, and the Prairie Bluff Chalk of the Eastern gulf coast. Similarly *Trigonia cerulia* Whitfield is found in the Providence Sand of Georgia and the Monmouth Formation of Maryland (Gardner, 1916, p. 585), both at the top of the Cretaceous sequence. *Cucullaea littlei* (Gabb) has been reported from Beers Hill by Weller (1907, pl. 33, figs. 1, 2) and is also common from Red Bank equivalents in the Georgia to Mississippi area. The remainder of the fauna is composed of species having longer or uncertain ranges.

The fauna from the Tinton Sand contrasts strongly with that from the uppermost part of the Cretaceous section at Bohemia Mills, Md. (Gardner, 1916). There, a few feet below the Hornerstown Sand, richly fossiliferous beds yield an assemblage typical of the Mount Laurel Sand of New Jersey. Of special note is the association of *Belemnitella americana* (Morton) and *Exogyra cancellata* Stephenson. These two fossils have been reported to range from the Mount Laurel through the Navesink in New Jersey, but the authors of this report believe this range is exaggerated because of misidentification of formations. At all localities that the authors examined, the association is restricted to the Mount Laurel Sand; and therefore the total Mount Laurel and Navesink fauna of the literature probably needs reevaluation in the light of present definition of the formations. The main concern here is that the Bohemia Mills fauna correlates with units near the base of the *Exogyra costata* zone elsewhere in the Coastal Plain. This is much lower stratigraphically than the Cretaceous-Tertiary boundary in northern New Jersey. In terms of time, the Paleocene Hornerstown Sand rests on beds of early Maestrichtian age in northern New Jersey, but on beds of late Campanian age in Maryland (fig. 7).

Between these two areas, the biostratigraphic evidence is less positive but is certainly consistent with the progressive south-

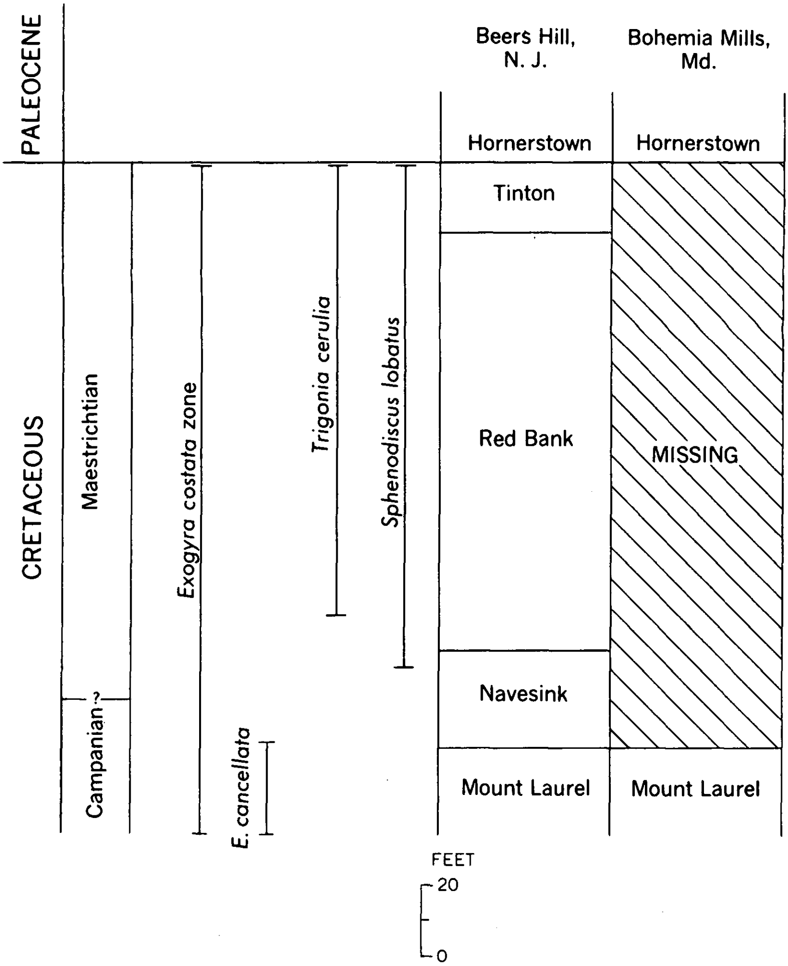

FIGURE 7.—Time-stratigraphic position of the Hornerstown Sand in the northeast (Keyport quadrangle, New Jersey, fig. 3) and 120 miles to the southwest at Bohemia Mills.

ward loss of the upper part of the Cretaceous section. The first locality south of Beers Hill is in the Red Bank Sand on Ivanhoe Brook in the south-central Roosevelt quadrangle. There the Red Bank contains only a small fauna that does not afford precise information. Most species are long ranging, but in New Jersey, *Crenella serica* Conrad is known only from the Red Bank Sand.

A specimen of *Baculites columna* Morton has been found in the southwestern part of the Roosevelt quadrangle on a tributary of Lahaway Creek. This specimen and the phosphatic internal molds of other mollusks noted are reworked into the basal part of the Hornerstown Sand. In the Gulf Coastal Plain, *B. columna* occurs in the Corsicana Marl of Texas and the Prairie Bluff Chalk of Mississippi and Alabama. Its presence suggests that the fossils were reworked from units higher than the Navesink, probably from the Red Bank. A similar but less diagnostic fauna occurs on Contact Creek. Farther south at the Florentine pit in the Mount Holly quadrangle, the basal Hornerstown has yielded *Sphenodiscus lobatus* (Tuomey) in addition to the ubiquitous *Cucullaea vulgaris* Morton. As presently interpreted, the *Sphenodiscus* could not have been reworked from beds older than the upper part of the Navesink Formation. Similar relationships of Hornerstown on Navesink can be seen in the pit at Sewell still farther to the south. There Miller (1956, p. 728) has found *Terebratulina atlantica* Morton in the Navesink Formation (the middle greensand of his usage). Numerous phosphatic internal molds of mollusks, especially *Cucullaea* and *Pycnodonte*, occur in the lower beds of the Hornerstown. The next fossiliferous beds close to the contact occur at Bohemia Mills, discussed above, and at Fredericktown, Md., where sands with a fauna like that of the Mount Laurel Sand of the Chesapeake and Delaware Canal are overlain by the Hornerstown Sand.

In summary, the macroinvertebrate fauna suggests that the Hornerstown Sand lies on progressively older sediments from the north in New Jersey to the south in Maryland. The magnitude of the time gap involves at least the lower part of the Maestrichtian and the upper part of the Campanian.

DETAILS OF THE BOUNDARY IN THE SUBSURFACE

The position of the Cretaceous-Tertiary boundary can be determined by lithologic differences, geophysical patterns, and planktonic Foraminifera in the subsurface in seven deep wells in New Jersey and Delaware. These data confirm the interpretation that the contact is unconformable.

Figures 8 and 9 are cross sections showing correlations based on natural gamma-ray logs. Section *A–A′* (fig. 8) extends downdip from Colts Neck to Island Beach State Park, N.J. (fig. 1). Section *B–B′* (fig. 9) extends approximately along the strike from Laurelton, N.J., to Dover, Del. (fig. 1). The wells were selected as representative of those in the area from which detailed geologic and paleontologic data are available. Gamma-ray logs from all the available wells in the Coastal Plain of New Jersey have basically the same characteristic patterns for the individual formations at the Cretaceous-Tertiary boundary.

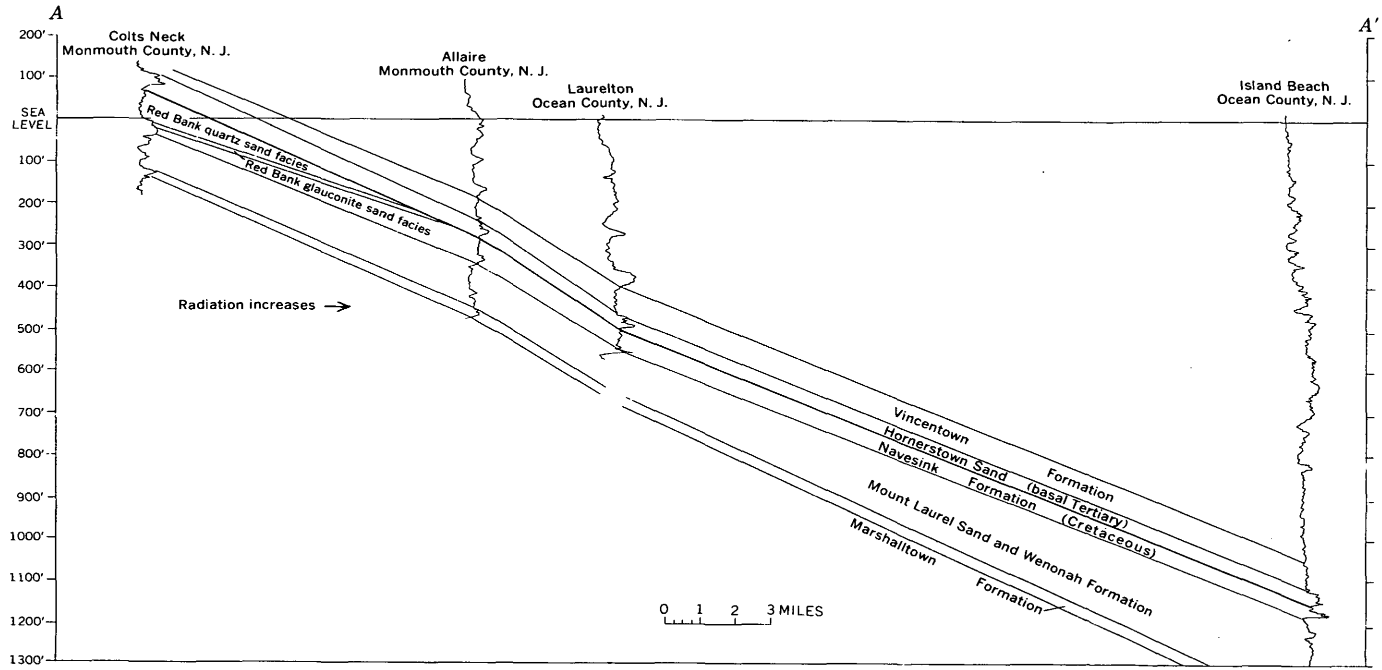

FIGURE 8.—*Geologic cross section A–A′ from* **Colts Neck to Island Beach State Park, N.J., based on gamma-ray logs. See figure 1 for location of line of section.**

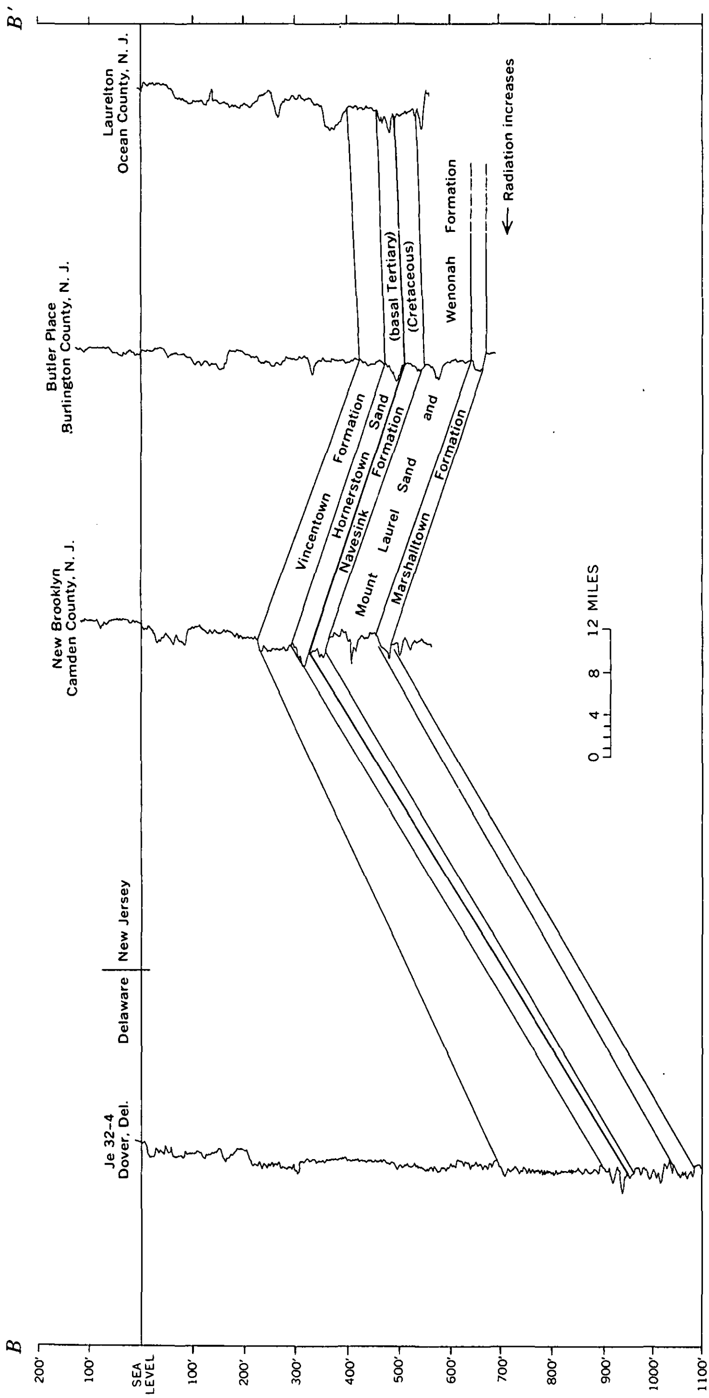

FIGURE 9.—Geologic cross section *B–B′* from Dover, Del., to Laurelton, N.J., based on gamma-ray logs. See figure 1 for location of line of section.

The Allaire well in Monmouth County (figs. 1, 8) was drilled by cable-tool methods in December 1963 as part of the cooperative ground-water program between the U.S. Geological Survey and the State of New Jersey. The Cretaceous-Tertiary boundary is well defined in this well, and the stratigraphic section and faunal content are typical of the six other wells listed in this paper. Detailed lithologic descriptions are given, and Foraminifera listed are representative of all the wells.

The Hornerstown Sand is approximately 44 feet thick in the Allaire well and is between 340 and 384 feet below the surface. Sample 134 is from a depth of 340 feet. It is medium-dark-gray, clayey, and silty glauconitic sand. The clay is mixed-layer montmorillonite-chlorite and illite and imparts a mottled appearance to the sample. The washed residue remaining on the 230-mesh sieve is a fine- to medium-grained sand containing approximately 98 percent glauconite. Glauconite grains are nearly all botryoidal; about 1 percent are accordion and tabular forms. Pyrite crystals and shell material (foraminiferal) in about equal abundance constitute the remaining 2 percent.

Sample 135 at a depth of 350 feet, sample 136 at 360 feet, and sample 137 at 370 feet are all nearly the same as sample 134, except that they are dark greenish gray. Glauconite content of the washed residue ranges from about 92 percent to 95 percent. The remainder of the residue is composed of angular quartz grains, pyrite, shell material, and muscovite. Sample 138 is the same except for a grayish-black color.

Sample 139, at a depth of 390 feet, is from the top of the Navesink Formation. It is greenish-black, mottled, micaceous, pyritic, and clayey-glauconite sand. The clay is mostly illite and montmorillonite and includes minor amounts of chlorite. The washed residue is fine- to coarse-grained sand (95 percent glauconite). The glauconite grains are botryoidal and have frosted surfaces. Pyrite crystals, angular to subangular quartz grains, and muscovite and chloritized mica constitute the remainder of the washed residue. Sample 140 from the Navesink Formation, at a depth of 400 feet, is nearly identical to sample 139.

The well samples show that the Hornerstown in the subsurface is a dark-greenish-gray, mottled, silty and clayey-glauconite sand. The distinct change from dark-greenish-gray glauconite sand to dark-gray rather clayey finely micaceous quartz sand in the underlying Navesink Formation is readily discernible in well samples or auger cuttings. In Monmouth County the change from the Hornerstown glauconite to the underlying quartz sand of the Red Bank is also very distinct.

The gamma-ray logs, which record the natural radioactivity of the sediments, furnish a detailed record of lithologic variation in the individual formations in the Coastal Plain. The Hornerstown Sand has a very distinctive three-pronged gamma-ray pattern. This three-pronged pattern distinguishes the Hornerstown in all the wells logged to date in the Coastal Plain of New Jersey. The pattern of increased radiation is probably attributable to a concentration of phosphatic material near the unconformity.

Four core samples from the Allaire well were examined for Foraminifera to confirm the placement of the Cretaceous-Tertiary

TABLE 2.—*Foraminifera from the Allaire 1 test well, Monmouth County, N.J.*

	Depth below surface (feet)			
	370	380	390	400
Planktonic species:				
Globigerina triloculinoides Plummer	x	------	------	------
Globorotalia compressa (Plummer)	x	------	------	------
Globorotalia cf. *inaequispira* Subbotina	x	------	------	------
Globorotalia cf. *perclara* Loeblich and Tappan	x	------	------	------
Globorotalia pseudobulloides (Plummer)	x	------	------	------
Globorotalia pseudobulloides (Plummer) ?	x	------	------	------
Globigerinoides daubjergensis (Bronnimann)	x	x	------	------
Globorotalia imitata Subbotina	x	x	------	------
Globorotalia perclara Loeblich and Tappan	x	x	------	------
Chiloguembelina morsei (Kline)	x	x	------	x
Globorotalia convexa Subbotina	------	x	------	------
Globorotalia reissi Loeblich and Tappan	------	------	x	------
Hedbergella cf. *planispira* (Tappan)	------	------	x	------
Heterohelix globulosa (Ehrenberg)	------	------	x	------
Heterohelix cf. *navarroensis* Loeblich	------	------	x	------
?Rugoglobigerina jerseyensis Olsson	------	------	x	------
Rugoglobigerina reicheli pustulata Bronnimann	------	------	x	------
Globigerinelloides messinae (Bronnimann)	------	------	x	x
Rugoglobigerina rugosa (Plummer)	------	------	x	x
Globigerinelloides messinae subcarinata Bronnimann ?	------	------	------	x
?Globorotalia strabocella Loeblich and Tappan	------	------	------	x
Guembelitria cretacea Cushman	------	------	------	x
Heterohelix cf. *pulchra* (Brotzen)	------	------	------	x
Benthonic species:				
Alabamina midwayensis Brotzen	x	------	------	------
Bulimina arkadelphiana Cushman and Parker	x	------	------	------
Buliminella elegantissima (d'Orbigny)	x	------	------	------
Eouvigerina cf. *hispida* Cushman	x	------	------	------
Fissurina oslatus (Shifflett)	x	------	------	------
Gyroidinoides subangulata (Plummer)	x	------	------	------
Oolina n. sp	x	------	------	------
Bulimina pseudocacuminata Olsson	x	x	x	------
Cibicides sp. 1	x	x	x	x
Ellipsonodosaria plummerae Cushman ?	x	x	x	x
Pulsiphonina prima (Plummer)	x	x	x	x
Tappanina selmensis (Cushman)	x	x	x	x
Parrella convexa Olsson	x	------	x	------
Globulina lacrima Reuss	x	------	------	x
Bolivinoides compressa Olsson	------	x	------	------
Pseudouvigerina cf. *seligi* (Cushman)	------	x	------	------
Cibicides cf. *harperi* Sandidge	------	x	x	x
Gyroidina girardana Reuss	------	x	x	x
Buliminella fusiforma Jennings	------	------	x	------
Loxostoma plaitum (Carsey)	------	------	x	x
Pseudouvigerina seligi (Cushman)	------	------	x	x
Bolivina cretosa Cushman	------	------	------	x
Bulimina referata Jennings ?	------	------	------	x
Bulimina reussi Morrow	------	------	------	x
?Gyroidina depressa (Alth)	------	------	------	x
Hoeglundina supracretacea (ten Dam)	------	------	------	x
Planularia dissona (Plummer)	------	------	------	x
Vaginulina navarroana Cushman	------	------	------	x

boundary by geophysical and lithologic criteria. The samples were taken from depths of 370, 380, 390, and 400 feet. The samples were washed on a 230-mesh sieve, dried, and floated on carbon tetrachloride. Only the part of the sample that floated was examined for Foraminifera. The species identified are shown in table 2. Most of the identifications were checked against type or comparative material in the U.S. National Museum collections.

A distinct change in the planktonic foraminiferal faunas between the samples from 380 and 390 feet is obvious. The samples at 370 and 380 feet contain a number of planktonic species indicative of a Paleocene age. The presence of *Globigerinoides daubjergensis* (Bronnimann) in the samples from 370 and 380 feet and the presence of *Globorotalia compressa* (Plummer) in the sample from 370 feet indicate that both samples are in the lower Paleocene (Danian) *compressa-daubjergensis* zone (Loeblich and Tappan, 1957, p. 176, fig. 28). Of the planktonic species identified from these two samples, only *Globorotalia* cf. *inaequispira* Subbotina, represented by one specimen, and *Globorotalia convexa* Subbotina, also represented by one specimen, occur higher than the *compressa-daubjergensis* zone, according to Loeblich and Tappan (1957). The presence of these two species in these samples may be due to minor contamination.

The presence of one specimen of *Globorotalia reissi* Loeblich and Tappan in the sample from 390 feet and one partial specimen of *?Globorotalia strabocella* Loeblich and Tappan and five specimens of *Chiloguembelina morsei* (Kline) in the sample from 400 feet may be due to similar contamination. Aside from the presence of these three species, the samples from 390 feet and 400 feet contain a planktonic fauna characteristic of Late Cretaceous age, including abundant specimens of *Heterohelix globulosa* (Ehrenberg), *Rugoglobigerina rugosa* (Plummer), and *Globigerinelloides messinae* (Bronnimann) (table 2). The benthonic Foraminifera recovered from these samples also support the placement of the samples from 370 and 380 feet in the Paleocene and those from 390 and 400 feet in the Cretaceous.

In the other wells examined but not described here, the Cretaceous-Tertiary boundary is surprisingly similar, at least lithologically. The Hornerstown Sand is the most uniform. In the Navesink Formation, the percentage of clay matrix increases downdip.

EVIDENCE AGAINST A GRADATIONAL BOUNDARY

Olsson, one of the main proponents of a conformable and transitional Cretaceous-Tertiary boundary, introduced a new formation, the New Egypt, which would partly bridge the boundary (Olsson, 1960, p. 1–4; 1963, p. 646). In 1960, he showed this new unit to lie between, or to be equivalent to, the Tinton Member of the Red Bank Sand and the Hornerstown Sand, but in 1963, he showed it to be equivalent to the Navesink Formation, Red Bank Sand (two members), Tinton Sand, and Hornerstown Sand. Although he described this new unit as primarily a downdip facies, he also described it in outcrop. The correlations are based almost entirely on faunal content of well cuttings. At all places in outcrop or in the shallow subsurface of the areas mapped by Owens and Minard (fig. 3), there is no change in sequence in the part of the stratigraphic section (as established by Weller and Knapp in 1907) that is pertinent to this discussion. The sequence of Mount Laurel, Navesink, Red Bank, Tinton, and Hornerstown is everywhere complete. Only toward the southwest are units missing (figs. 4, 5). The New Egypt Formation of Olsson is equivalent only to the lower member of the Red Bank of Minard and Owens (1962). This lower member is overlain conformably by the upper quartz sand of the Red Bank, or overlain uncomformably by the glauconite sand of the Hornerstown where the upper quartz sand is absent. Olsson (1963, p. 658) pointed out that if an angular unconformity is present at the Cretaceous-Tertiary boundary, the Hornerstown should rest in the north on the Tinton and farther southwest should rest on the quartz sand of the Red Bank for a considerable area. He stated that "A stratigraphic relation such as this is not present at the surface; in fact, wherever the Cretaceous-Tertiary boundary is exposed, glauconite units lie above and below the boundary." However, as attested by Dorf and Fox (1957, p. 10, 11) and by Olsson (1963, p. 661), the Hornerstown does rest on the Tinton to the north; as stated earlier in this report, the Hornerstown also lies on the upper quartz sand of the Red Bank for a considerable area in the northern and west-central parts of the Roosevelt quadrangle and in the extreme northern part of the New Egypt quadrangle.

Olsson (1963, p. 659) concluded that "One of the great enigmas of the geologic column is the marked faunal change that takes place at the Cretaceous-Tertiary boundary. This is especially true of the planktonic Foraminifera; and so far the present status of information indicates a complete change in genera and species." Olsson attempted to explain this faunal change as the result of a possible change in the chemistry of the sea, which disrupted a food chain on which the existence of many organisms depended. He also indicated (1963, p. 658) that because the basal Hornerstown contains Cretaceous fossils, accumulation of the greensand of the Hornerstown may have begun during Cretaceous time. The implication is that continuous deposition of glauconite took place across the boundary. The basal Hornerstown does contain Cretaceous fossils, but they are phosphatized, sideritized, and reworked, as, for example, the *Cucullaea* and gastropods at Contact Creek (table 1). Although in 1963 Olsson (p. 660) only listed fossils from his New Egypt Formation on Contact Creek, he previously (Fox and Olsson, 1955, p. 736) mentioned reworked fossils and rock fragments in the basal Hornerstown; immediately above these fossils and rock fragments were large slabs of sideritic sandstone. The presence of phosphate and siderite along the Cretaceous-Tertiary boundary in many places suggests an unconformity. Cretaceous fossils reworked into the base of the Tertiary are common elsewhere in the Coastal Plain (Cooke and Stephenson, 1928, p. 144; Sohl, 1960, p. 38–42; Smith, 1962, p. 164). Possibly Olsson (1963, p. 659) suggested continuous deposition because the boundary lies between two glauconite-rich units in much of the Coastal Plain in New Jersey and because it is difficult to make a lithological distinction between the units. (In the northeastern part of the Coastal Plain, the boundary lies between the Hornerstown and Tinton; toward the southwest, it lies between the Hornerstown and basal Red Bank; and farther southwest, it lies between the Hornerstown and the Navesink.) Sometimes there is also difficulty in distinguishing between quartz sand units at or near the boundary. Near Red Valley in the southwest part of the Roosevelt quadrangle, Fox and Olsson (1960, p. 9) placed the New Egypt Formation above the Red Bank Sand. As the authors of this report interpret the section at this locality, Olsson's New Egypt Formation is the lower member of the Red Bank (a clayey glauconite sand) which lies on the Navesink (also a clayey glauconite sand). Fox and Olsson undoubtedly included the lithologically similar Navesink in the New Egypt, because the quartz sand, which they call Red Bank (underlying Olsson's New Egypt Formation and including the Navesink), is actually the Mount Laurel (fig. 10). Olsson (1958) made this mistake previously in stating that the upper

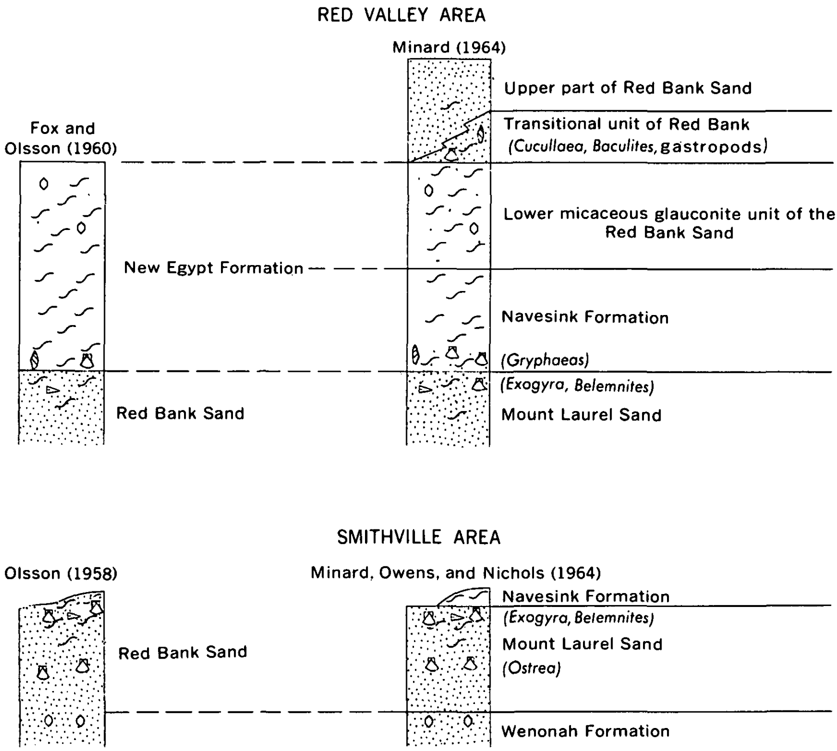

FIGURE 10.—Stratigraphic sections from Olsson (1958) and Fox and Olsson (1960) compared with those of Minard (1964) and Minard, Owens, and Nichols (1964) from the same areas. Red Valley is in the southwest part of Roosevelt quadrangle; Smithville is in the northeast part of the Mount Holly quadrangle (fig. 3). See figure 5 for explanation of lithologic symbols.

quartz sand of the Red Bank extended to Smithville (northeast corner Mount Holly quadrangle). There he mistook the Navesink for his New Egypt and assumed that the underlying Mount Laurel (including the Wenonah) was the Red Bank Sand (fig. 10). This same misidentification and assignment to the incorrect stratigraphic position was made nearly a century ago by G. H. Cook, and again by W. B. Clark in the 1890's, at Mount Holly, a short distance to the west (Knapp, in Weller, 1907, p. 17–20).

Miller (1956, p. 723–728) favored both an unconformity and a gradational contact at the boundary. He partly explained his view by suggesting that an unconformity would be expected nearer shore and that a conformable relationship would be expected farther out. This is reasonable. but he introduced other data which tend to confuse the picture. He stated that his middle greensand unit is probably a southwestward extension of the Red Bank. He extended it as far as Sewell, but there it demonstrably is the Navesink, whereas to the northeast at New Egypt the middle greensand undoubtedly is the basal Red Bank glauconite sand (Olsson's New Egypt). Miller partly justified his extension of the Red Bank to Sewell on the basis that Groot and others (1954, p. 28) recognized the Red Bank in Delaware, Groot's Red Bank in Delaware, however, is actually the Mount Laurel (Carter, 1937, p. 245); once again, Mount Laurel was misidentified as the Red Bank. Miller (1956, p. 723) stated that his middle greensand is "almost indistinguishable lithologically" from the overlying Hornerstown and that this suggests more of an affinity with the Hornerstown than with the Navesink, which he described as a glauconitic quartz sand. He showed (p. 727, fig. 2) the Navesink interfingering with the Red Bank at the Atlantic highlands.

Both the "units" in his photograph are basically quartz sands; one is dark, one is light. These are not two different units; they merely reflect a difference in weathering in the same basal fine clayey quartz sand of the Red Bank. Olsson (1958, p. 16) also disagreed with Miller's interpretation and correctly recognized this fact. The Navesink lies some feet below and does not interfinger with the Red Bank in such a manner. Other than coarse quartz sand and granules in the basal few feet, the sand fraction of the Navesink is nearly pure glauconite.

SUMMARY

The Hornerstown Sand of Paleocene age (the basal Tertiary formation on the Coastal Plain of New Jersey) successively overlaps older formations toward the southwest where erosion has progressively removed more of the upper part of the Cretaceous section. In a distance of 120 miles along the strike, the Hornerstown lies on four different formations: the Tinton Sand, the Red Bank Sand, the Navesink Formation, and the Mount Laurel Sand. Its base is stratigraphically about 170 feet lower at Odessa, Del., and Gregg Neck, Md., than in the Sandy Hook quadrangle, New Jersey. The upper part of the underlying Cretaceous units generally is weathered to some degree. Siderite-cemented sandstone is present in the Cretaceous-Tertiary boundary interval (table 1), and reworked phosphatized Cretaceous fossils and fragments of Cretaceous rocks occur in the basal few feet of the overlapping Hornerstown Sand. The Hornerstown is remarkably uniform in thickness and lithology along its outcrop for at least 120 miles, although its basal part locally may reflect the lithology of the underlying unit.

Detailed field mapping led the authors first to recognize the unconformity, then to extend it along the strike, and to predict and confirm stratigraphic relations in adjacent areas. Recognition of the unconformity in New Jersey, Delaware, and eastern Maryland (1) helps explain the considerable time gap at the boundary indicated by the faunas, (2) facilitates determination of stratigraphic position by demonstrating what units have been eroded, and (3) aids correlation between formations in New Jersey, Delaware, and eastern Maryland. The unconformity at the Cretaceous-Tertiary boundary is also compatible with the unconformity recognized in most of the Gulf Coastal Plain, largely on the same criteria as those we have found in New Jersey.

The unconformity in New Jersey may have been overlooked originally because earlier workers included the three basal Tertiary formations in the Cretaceous and assumed that the Cretaceous-Tertiary boundary lay at the conspicuous angular unconformity at the base of Kirkwood Formation of Miocene age. The unweathered basal Kirkwood lies directly on the unweathered upper part of the Manasquan, of Eocene age. The relation appears conformable when reviewed in single outcrop, despite the fact that a time gap exists. When the contact is accurately mapped over a broad area, the unconformity becomes apparent, because the Kirkwood overlaps three increasingly older formations beneath the Manasquan. This is also the procedure used to demonstrate the unconformable relation between the Hornerstown and the underlying Cretaceous formations. The lack of weathered material beneath the Hornerstown in many outcrops and the lack of a distinct break in these outcrops are thought by some workers to indicate a transitional boundary. It can also be explained, however, as the result of removal and reworking of any weathered material that was present during the transgression of the sea in which the Hornerstown was deposited.

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