Geology of the Sandy Hook Quadrangle In Monmouth County New Jersey

GEOLOGICAL SURVEY BULLETIN 1276

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By JAMES P. MINARD

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A description of Coastal Plain formations which are lithologically comparable with correlative units at least as far southwest as eastern Maryland

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GEOLOGY OF THE SANDY HOOK QUADRANGLE IN MONMOUTH COUNTY, NEW JERSEY

By JAMES P. MINARD

ABSTRACT

Sandy Hook quadrangle, within the northeastern Coastal Plain province, is bounded on the east by the Atlantic Ocean and on the north by lower New York Bay. The land area of the quadrangle is entirely within Monmouth County, New Jersey. The southeastern part of the quadrangle is covered by prominent hills that rise abruptly from the water or from bordering lowlands.

The Sandy Hook area contains the thickest and most complete section of Upper Cretaceous deposits (11 units altogether) in the Coastal Plain in New Jersey. Seven of these Upper Cretaceous units, as well as three Tertiary units, are exposed within the quadrangle; these 10 units constitute a total section of about 500 feet. In ascending order, the units are the Englishtown, Marshalltown, and Wenonah Formations, Mount Laurel Sand, Navesink Formation, Red Bank Sand (two members), and Tinton Sand, all of Late Cretaceous age; the Hornerstown Sand and Vincentown Formation of Paleocene age; and the Cohansey Sand of late Tertiary age.

The older rocks are the result of repetitive sedimentation; one cycle consists of a glauconite unit, overlain by a fine sandy silt unit, overlain by a coarse sand unit. Discontinuous Quaternary deposits are present, mainly in low areas. The Upper Cretaceous and lower Tertiary units consist chiefly of quartz, glauconite, montmorillonite, mixed-layer clay, kaolinite, muscovite, chlorite, lignite, and pyrite. The Cohansey Sand consists largely of quartz, ilmenite, and kaolinite. The sediments of the Quaternary deposits were derived from older formations located within and beyond the boundaries of the quadrangle. Most of the rocks are unconsolidated, but some resistant beds of iron oxide-cemented sand and gravel are present.

The Cretaceous units strike generally northeast; those of Tertiary age strike more easterly. Beds dip between 20 and 40 feet per mile southeast. Several slump blocks are present in the steep bluffs along Sandy Hook Bay and the Navesink River.

Sandy Hook is a classic illustration of an active compound recurved spit, which has lengthened about 1,000 feet in the past quarter century. Quaternary clay deposits have been discovered beneath Sandy Hook spit beach sands. A radiocarbon date of these deposits suggests that sea level may have been nearly 100 feet lower 10,000 years ago.

Resources include abundant ground water, sand, and gravel.

INTRODUCTION

LOCATION AND EXTENT OF AREA

The Sandy Hook quadrangle encompasses about 68 square miles in the northeasternmost part of the Atlantic Coastal Plain (fig. 1). About 30 square miles of the quadrangle is land, the rest is water. The land area and most of the water area is within Monmouth County, N.J. A small part of the water-covered area (the northwest corner of the quadrangle) is in Richmond County, N.Y.

PURPOSE OF INVESTIGATION

Geologic study of the Sandy Hook quadrangle was undertaken as part of a mapping program in the lower Delaware River basin. The program was designed to furnish detailed geologic information so that aquifers could be accurately located, described, and analyzed in this region of heavy industrial use of ground water. For a more complete understanding of the regional geology, correlation of the section in New Jersey with those in Delaware and Maryland was necessary.

Ten 7½-minute quadrangles have been mapped along the inner edge of the central part of the Coastal Plain in New Jersey and one in the southwestern part (fig. 2). The Sandy Hook quadrangle was mapped for two primary reasons: first, the area contains the thickest and most complete stratigraphic section in the New Jersey Coastal Plain and, second, it contains the northeasternmost well-exposed section in the Coastal Plain.

Detailed definition of the section in the southwestern, central, and northeastern parts of the Coastal Plain province in New Jersey has made it possible to correlate the formations along the entire strike distance of 100 miles. In addition, comprehensive reconnaissance in Delaware and eastern Maryland indicates that this section can also be correlated with units as far southwest as the east shore of Chesapeake Bay.

ACKNOWLEDGMENTS

The geologic study of the Sandy Hook quadrangle is part of a regional study of the formations of that part of the Atlantic Coastal Plain physiographic province that lies within the lower Delaware basin in New Jersey and Pennsylvania (fig. 1). The larger study was begun in 1957 as part of the program of the President's National Water Policy under the early supervision of J. T. Stark and A. S. Allen, and more recently, J. P. Owens.

Fieldwork was begun in May 1963 and was completed in November 1964. H. E. Gill and C. R. Faust assisted in the field mapping during May and June 1963. H. W. Ritzman, Jr., assisted with power augering

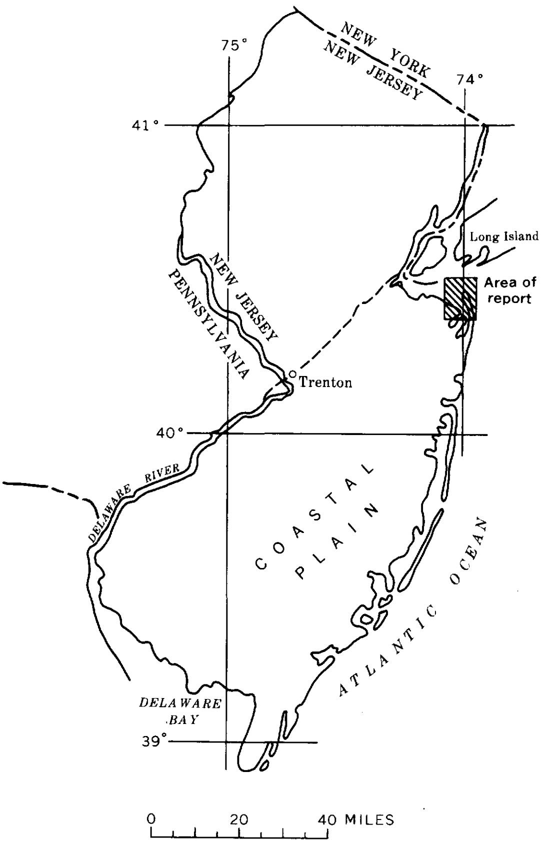

FIGURE 1.—Index map showing location of the Sandy Hook quadrangle (shaded). Short-dashed line is inner edge of Coastal Plain physiographic province.

in November 1963. Particular appreciation is expressed to Ruth Todd who identified the Foraminifera and noted their range and correlation and to N. F. Sohl who identified the megafossils. Appreciation also is expressed to Mr. George Shanklin, Director of the New Jersey Division of Water Supply and Policy, for providing a State helicopter and pilot so that the writer could photograph the slump blocks from the air.

PREVIOUS INVESTIGATIONS

Limited studies of the geology of the Coastal Plain in New Jersey began as early as the middle of the 18th century. The first definitive work of the entire area, however, was done by Rogers (1836) from 1834 to 1836. Rogers located, described, and differentiated many of

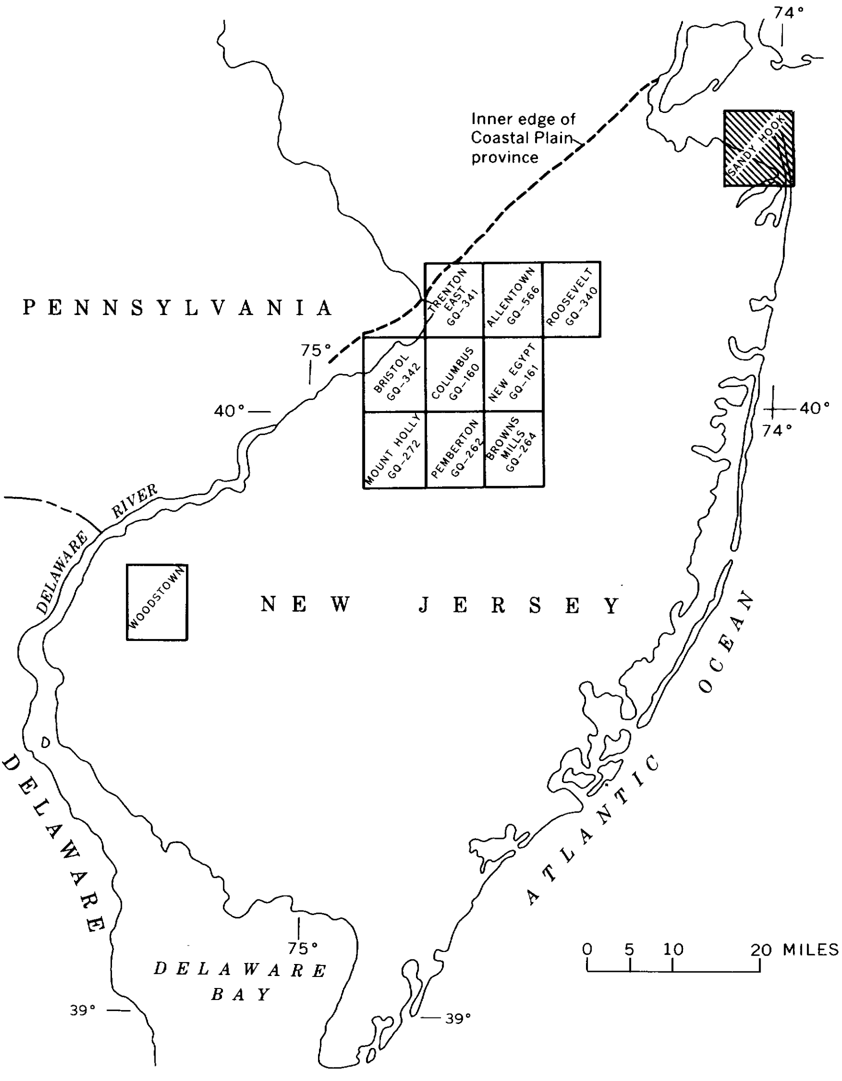

FIGURE 2.—Index map of the Coastal Plain province in New Jersey showing locations and names of the 7½-minute quadrangles mapped in the lower Delaware basin.

the Coastal Plain formations, especially that part of the section from the Woodbury Clay of Late Cretaceous age (underlies the Englishtown) through the Cohansey Sand of Miocene(?) and Pleocene(?) age. He particularly emphasized the glauconite-bearing units and their economic significance in enriching the soil. The next major report was by Cook (1868), who clarified the stratigraphy in the

Coastal Plain and emphasized the northeast trend of the formations and their gentle southeast dip (about 30 ft. per mile).

Geologic work during the quarter century 1891–1916, probably had the most influence on the present stratigraphic interpretation; it was during this period that most of the currently used formational names were established. The bulk of lithologic studies and mapping during this interval was by Clark (1894, 1898), Bascom and others (1909), Ries and others (1904), and Salisbury (1894), accompanied by the classic paleontologic study by Weller (1907) and part of the study by Whitfield (1892). Most subsequent work has been a refinement of that remarkably productive period. The majority of the subsequent workers have been paleontologists and paleobotanists who have described many new species and assigned some units to different geologic times.

PHYSIOGRAPHY

The physiography of the quadrangle is unlike that of any other coastal quadrangle in New Jersey. The most conspicuous features are the high hills that rise abruptly from sea level and the compound recurved spit (Lobeck, 1939, p. 352–353) that projects northward, more than 5 miles into the bay. The spit is a continuation of a narrow offshore bar that forms the easternmost land area of the quadrangle. Excellent dunal topography is present on parts of the spit.

A belt of hills trends slightly north of east across the southern part of the quadrangle. The hills within the belt form short alinements which trend northwest and have steep to precipitous slopes adjacent to Sandy Hook Bay and the Navesink River estuary. Several of these bluffs rise abruptly as much as 200 feet from sea level or from a low sandy beach. The highest altitudes in the quadrangle are east of Navesink where hilltops are more than 260 feet above sea level. Major drainage is northeast and southeast. The southeast-flowing streams have trenched the belt of hills, forming two prominent easterly alinements of hills.

The northwest land area is a low, flat, sandy plain; the streams on this plain flow into tidal swamps. The extreme southeastern part of the quadrangle is a flat sandy area along the south side of the Navesink River estuary. The mouth of the Navesink River has been blocked by the barrier bar, and the flow deflected northward into Sandy Hook Bay. There are many low, sandy, and muddy tidal-flat islands in the estuary.

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STRATIGRAPHY

GENERAL DISCUSSION

The exposed stratigraphic units within the quadrangle consist of a succession of 10 formations of Late Cretaceous and Tertiary ages, which have an aggregate thickness of about 500 feet, and several units of Quaternary age, which range in thickness from a few feet to more than 160 feet. The pre-Quaternary deposits consist mainly of marine clay, silt, and gravelly sand. Locally, beds within the formations have been cemented by iron oxide and iron carbonate, forming resistant layers. The Quaternary deposits range from clay to gravel and are of both marine and alluvial origin.

The exposed Upper Cretaceous formations are, in ascending order, the Englishtown, Marshalltown, and Wenonah Formations, Mount Laurel Sand, Navesink Formation, Red Bank Sand (two members), and Tinton Sand. These formations are overlain by the Hornerstown Sand and Vincentown Formation of Paleocene age, and the Cohansey Sand of Miocene(?) and Pliocene(?) age. (See pl. 1.)

The Quaternary deposits include a unit of marine foraminiferal clay, which underlies Sandy Hook and some of the adjacent water areas, several alluvial and beach units, and slump or landslide blocks in the steep bluffs along the eastern part of Sandy Hook Bay and along Navesink River (pl. 1).

The Upper Cretaceous and lower Tertiary formations are composed chiefly of quartz, glauconite, montmorillonite, mixed-layer clay, kaolinite, muscovite, chlorite, lignite, feldspar, and pyrite. The Cohansey Sand is composed largely of quartz, ilmenite, and kaolinite. The sediments of the Quaternary deposits were derived from older formations, located within and outside the quadrangle.

The sedimentary details, such as grain morphologies, ratios of quartz to glauconite, and colors of constituents, were determined from washed samples of the unconsolidated sediments. Mineralogy of the clay-sized fraction was determined by X-ray diffraction methods. Heavy minerals were identified using the petrographic microscope.

UPPER CRETACEOUS SEDIMENTS

ENGLISHTOWN FORMATION

The Englishtown Formation consists of laminated and thin- to thick-bedded horizontally and cross-stratified clay, silt, and sand. The basal part of the formation is typically dark-gray to medium-dark-gray sandy silty clay. The silt-clay beds are characterized by laminae of fine to very fine light-gray angular to subangular quartz sand and by abundant mica, lignite, and pyrite. The mica is mainly colorless muscovite, but a small percentage of green chloritized mica is present. Lignite fragments range from sand size to several inches in length. The larger pieces generally are flat, and many are as much as ¼ inch thick, ½–1 inch wide, and 2–4 inches long. Abundant sand-sized crystals and crystal clusters of pyrite, and about 1 percent smooth rounded fine to very fine light-olive to moderate-green grains of glauconite are present in the unweathered material. Rounded to nodular oolites and concretions of yellowwish-gray siderite, as much as 2 inches in length or width, occur locally near the base.

Within the quadrangle, the formation consists chiefly of very fine to medium quartz sand, containing as much as several percent feldspar. Coarse to very coarse subrounded to rounded sand beds are locally present (table 1). Minor amounts of rose quartz are generally present in the sand. Except near the base, clay layers are thin, generally 2 inches or less in thickness. Much of the sand is weathered and varies in color from pale yellowish brown to yellowish gray or grayish yellow and yellowish orange. Locally, the sand is cemented into massive beds of ironstone. One hill along Harmony Avenue, in the western part of the quadrangle, was capped by ironstone; but most of the hill was bulldozed away, and houses were built on the site. Another hill, just to the west along Laurel Avenue in the Keyport quadrangle, is capped by 8 feet of ironstone. Cavities in the rock have formed where lignite has weathered out. Conspicuous trough and festoon cross-stratification (McKee, and Weir, 1953, p. 387) or flow-and-plunge structure types (Salisbury, 1894, p. 198), as well as horizontally stratified sand that contains interbedded clay layers, are characteristic features (fig. 3). These internal structures and the abundance of lignite suggest a shallow-water to beach-complex depositional environment. In the clay-sized fraction, quartz, kaolinite, muscovite, and chlorite are common to major constituents. Characteristic detrital heavy minerals are zircon, tourmaline, and staurolite. Where overlain by the Marshalltown Formation, the top of the Englishtown usually contains small animal borings (1 in. across by several inches long) that are filled by quartz and glauconite sand from the Marshalltown. These filled borings give the beds a mottled appearance.

The formation generally has been reported as unfossiliferous, but recently, several fossil occurrences have been noted (Johnson and Richards, 1952, p. 2155–2156; Owens and Minard, 1964; Minard, 1965).

The soil developed on the formation is light gray, loose, and sandy, and has a fairly open vegetative cover.

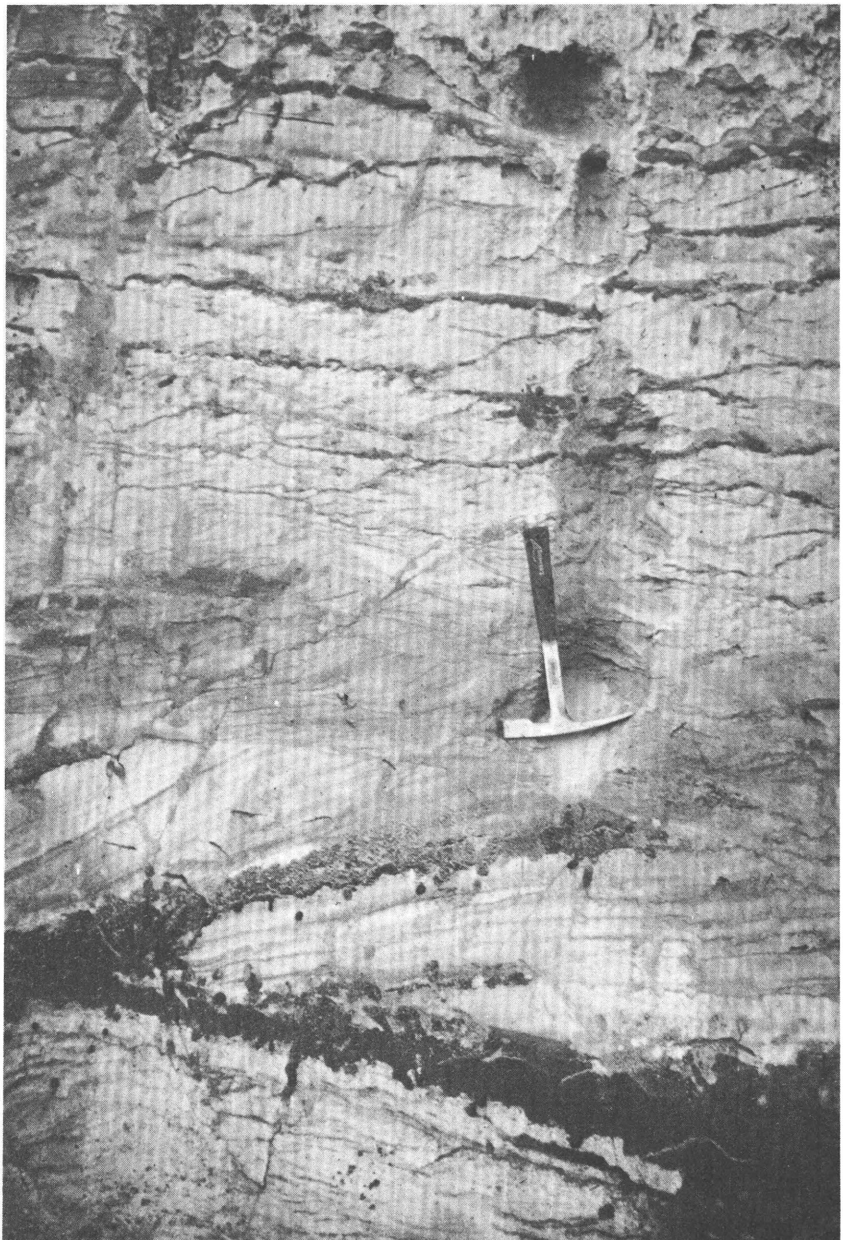

FIGURE. 3.—Cross-stratified sand in the middle part of the Englishtown Formation exposed in the hill along Harmony Avenue in the western part of the Sandy Hook quadrangle.

TABLE 1.—*Average grain size of the material constituting each formation, Sandy Hook quadrangle, N.J., in weight percent of the total sample*

[Figures represent the average of five sieve analyses of channel samples of each unit]

Grain size		Englishtown		Marshalltown	Wenonah		Mount Laurel		Navesink		Red Bank				Tinton	Hornerstown	Vincentown	Cohansey		Foraminiferal clay
											Sandy Hook Member		Shrewsbury Member							
		Lower	Upper		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper				Lower	Upper	
Gravel	Granule to pebble	----	----	----	----	----	----	3	----	----	----	----	----	----	----	----	----	14	7	----
Sand	Coarse to very coarse	----	2	----	----	----	2	2	10	35	3	2	10	16	12	5	10	26	48	----
	Medium	10	54	9	----	5	4	32	32	25	9	18	50	52	18	25	53	46	33	8
	Very fine to fine	30	31	26	17	56	54	32	32	10	52	53	30	24	38	27	23	13	11	18
Clay to silt		60	13	65	83	39	40	31	26	30	36	27	10	18	32	43	14	1	1	74

The Englishtown is the oldest exposed formation within the quadrangle. Most of its entire thickness of 140 feet is exposed; only a few feet of the basal part extend into the Keyport quadrangle to the west, where it overlies the Woodbury Clay. The formation has a nearly continuous outcrop in New Jersey from Sandy Hook southwest to the Delaware River. It extends across Delaware to at least the east shore of Chesapeake Bay, where it is only about 20 feet thick.

The Englishtown Formation underlies the flat area bordering Sandy Hook Bay in the west half of the quadrangle, and the low hills and slopes a short distance inland (pl. 1). It is poorly exposed, being largely covered by alluvium and marshes. Exposures of the unit were present in the hill just east of Harmony, but a housing development now covers the outcrop. A few feet of the upper part of the unit are exposed in a small bank on the beach between the Atlantic Highlands Yacht Harbor pier and the tank farm at the mouth of Wagner Branch, and also in the railrooad cut at the southwestern part of Leonardo, just west of BM 29 (pl. 1). There are also good exposures a short distance west of Harmony in the adjacent Keyport quadrangle. The exposures are in pits in the small hill along the west side of Laurel Avenue slightly more than 0.3 mile south of Route 36. Except for these few exposures, most information was obtained by augering.

MARSHALLTOWN FORMATION

The Marshalltown Formation is typically a greenish-black massive-bedded clayey quartz-glauconite sand and silt (table 1) where unweathered. In weathered outcrops the sand- and silt-sized fraction is greenish gray to dark greenish gray, and the clay is pale red to grayish red. The glauconite grains are mostly botryoidal silt to fine sand and constitute 20–60 percent of the formation; a few accordian-shaped grains (Galliher, 1935, p. 1587; Owens and Minard, 1960, p. B430) are present. Quartz grains are subangular to subrounded and range in size from silt to medium sand.

The major clay-sized minerals are quartz, kaolinite, muscovite, chlorite, and montmorillonite. Characteristic detrital heavy minerals are tourmaline and staurolite.

The contact with the underlying Englishtown Formation is distinct and is placed where quartz-glauconite silt-sand of the Marshalltown lies on lignitic quartz sand of the Englishtown. The basal 1 or 2 feet of the Marshalltown, which can be seen in the railroad cut at Leonardo, contains mica, lignite, and animal borings filled by quartz sand from the underlying Englishtown. Pyrite and siderite concretions are common in the basal part of the unweathered deposits.

The formation is very fossiliferous in the southwestern part of the State (Weller, 1907, p. 81–89; Mello and others, 1964; Minard, 1965), but only a few shell fragments in cuttings from an auger hole were found in the Sandy Hook quadrangle.

The soil developed on the formation is brown, loamy, and fertile and supports a varied dense vegetative cover.

Within the quadrangle, the Marshalltown is a thin conspicuous marker unit, having a fairly constant thickness ranging between 10 and 12 feet. Most previous workers reported a greater thickness in this vicinity and elsewhere in New Jersey. Clark (in Bascom and others, 1909, p. 12) reported a thickness of 30–35 feet, and Weller (1907, p. 81) and Kümmel (1940, p. 53) reported a thickness of 30–40 feet. These workers were possibly including some of the overlying Wenonah and underlying Englishtown Formations in the Marshalltown. The formation has a nearly continuous outcrop in New Jersey, from Sandy Hook southwest to the Delaware River, and extends across Delaware to at least the east shore of Chesapeake Bay.

The Marshalltown underlies the lower slopes of the low hills lying inland from the flat plain bounding Sandy Hook Bay on the south (pl. 1). It is exposed only in the southwestern part of Leonardo, in the railroad cut just west of BM 29 and in a low bank on the south side of Route 36. The contact with the underlying Englishtown can be seen in the railroad cut. The areal distribution of the Marshalltown was determined by augering through the alluvium and slope wash which mantle most of the formation.

WENONAH FORMATION

Most of the Wenonah Formation is remarkably uniform in texture, color, and mineralogy. The unweathered deposit is typically thick- to massive-bedded medium-dark-gray to dark-gray, fine to very fine subangular to angular quartz sand and silt. The formation contains a few small pieces of lignite and abundant colorless muscovite and green chloritized mica. Small grains and clusters of pyrite crystals are common where the formation is unweathered. Unweathered material was seen only in cuttings from auger holes. A trace to a few percent of fine-grained to very fine grained glauconite is present. The glauconite is of two types; smooth-surfaced light-olive to moderate-green grains and botryoidal dusky-green to greenish-black grains. Clay and silt constitute from one-third to as much as three-fourths of the rock (table 1). The sand-sized fraction is chiefly fine to very fine.

In the clay-sized fraction quartz, kaolinite, muscovite, chlorite, and carbonaceous matter are common to major constituents. Detrital heavy minerals are abundant and are characterized by both stable and unstable types; zircon, tourmaline, staurolite, garnet, and epidote are particularly representative. At the basal contact the micaceous clayey glauconitic silt and sand of the Wenonah grades down into the nonmicaceous glauconite-rich clayey silt and sand of the Marshalltown.

Although the formation is fossiliferous elsewhere (Weller, 1907, p. 91–101), only phosphatic fragments, such as shark teeth, were found here. This fossil deficiency may be attributed partly to the lack of unweathered outcrop.

The soil developed on the formation is brown and loamy, and supports a fairly dense and varied vegetative cover.

Before mapping under the present project, the Wenonah was not a clearly defined unit. The Wenonah and the overlying Mount Laurel Sand were previously mapped as a single unit, despite the fact that they had different names, fauna, and group assignments. The Wenonah and Mount Laurel were first mapped separately by Owens and Minard (1962) in the Columbus quadrangle (fig. 2). They have been mapped separately, where present, in all the subsequent quadrangles completed in the present mapping program (fig. 2).

The thickness of the Wenonah in the Sandy Hook quadrangle and vicinity was previously reported as 50 or 55 feet (Weller, 1907, p. 91) and about 35 feet (Kümmel, 1940, p. 118). The actual thickness in the quadrangle is 25–30 feet. The greater thickness assigned to the unit by earlier workers can probably be attributed to their including most of the Mount Laurel with the Wenonah. The formation has a nearly continuous outcrop in New Jersey, from Sandy Hook southwest to about the Delaware River. The Wenonah progressively thins from the central part of the Coastal Plain southwestward and is not present in Delaware.

The formation underlies lower slopes of the hills in the middle part of the land area of the quadrangle (pl. 1). Weathered parts of the formation were seen only in a few temporary excavations and cutbanks. Exposures were present in a 10-foot-high bank near the junction of Thompson and Hamilton Streets in Leonardo and in a roadcut in the small outlier on Middletown Road.

MOUNT LAUREL SAND

The basal 15–20 feet of the formation consists of thin-bedded very fine to medium glauconitic quartz sand, interbedded with thin layers of clay and silt. A few coarse and very coarse grains are present (table 1). The sand is yellowish gray, dark yellowish orange, and light gray where weathered and greenish gray to dark greenish gray where fresh. The clay and silt are pale red where weathered and dark gray where fresh. Both horizontal beds and crossbeds are present in the sand, whereas the clay and silt beds are virtually horizontal. The clay and silt beds locally constitute as much as half the sequence. Some thin layers of sand and clay contain abundant lignite and are very micaceous. The mica is mainly colorless muscovite, but some green chloritized mica is present. Glauconite occurs chiefly as smooth rounded sand-sized grains and constitutes several percent of the sand fraction. Locally, many ellipsoidal and tubelike siderite concretions, as much as several inches in diameter or length, are present.

The upper 5–10 feet of the formation is chiefly a thick-bedded pebbly medium to coarse glauconitic quartz sand; it ranges from light olive gray and yellowish gray where weathered to dark gray and dark greenish gray to greenish black where fresh. Quartz granules and small pebbles ($\frac{1}{4}$–$\frac{3}{8}$ in. in diameter) are abundant, and pebbles as much as 1 inch in diameter occur near the very top of the formation. A considerable amount of mica occurs in thin layers to within a few feet of the top. Glauconite within the top 2 or 3 feet may constitute as much as half the sand fraction. Fragments of fossils, sand-sized ovoid apatite pellets, and animal borings filled by glauconite sand from the overlying Navesink Formation are present in this interval.

Quartz, kaolinite, and muscovite are the major constituents of the clay-sized fraction. Characteristic detrital heavy minerals include tourmaline, staurolite, garnet, hornblende, and epidote.

The basal contact is gradational, but it can be determined in outcrop on the basis of internal structures; the Mount Laurel consists of alternate thin beds of sand and clay, whereas the Wenonah is massive-bedded uniform silt and sand. The contact is placed at the base of the thin-bedded sequence.

Many fossils are present in the upper part of the sand and in the contact zone with the overlying Navesink Formation. Most of these fossils are rounded or broken reworked pieces of internal molds. *Belemnitella americana* and *Exogyra costata* are present in the upper zone here, as they are in the Trenton area and as far southwest as eastern Maryland. Other fossils include shark and crocodilian teeth, gastropods, *Cucullaea* sp., *Cardium* sp., and *Longoconcha* sp. For a comprehensive listing of the fossils, refer to Weller (1907, p. 103–136).

Soil developed on the formation is similar to that on the Wenonah.

The Mount Laurel Sand was redefined in the New Egypt quadrangle by Minard, Owens, and Todd (1961) and was both mapped and described as a separate unit by Owens and Minard (1962) in the Columbus quadrangle. Weller (1907, p. 103) assigned a thickness of 3–5 feet to the Mount Laurel in the bluff outcrops along Sandy Hook Bay. Kümmel (1940, p. 52) assigned a thickness of 5 feet to the unit in the Sandy Hook area, but as much as 60 feet in the area to the southwest (1940, p. 118). Most subsequent workers assigned only a few feet to the Mount Laurel in the Sandy Hook area. The unit is actually about 25 feet thick in the quadrangle.

Because no previous workers gave lithologic descriptions detailed enough to separate the Mount Laurel from the Wenonah placement of the contact between them was not attempted. Present mapping has shown that the bulk of the Mount Laurel in the Sandy Hook quadrangle resembles the underlying Wenonah in grain size and mineralogy. The previous generalized description of the Mount Laurel as a coarse glauconitic quartz sand and the Wenonah as a fine micaceous sand is not always adequate for separating them northeast of Trenton. Typically, the Mount Laurel is a massive-bedded medium to coarse sand in southwestern New Jersey; whereas a fine-grained thin-bedded sequence is present in the lower part of the sand east and northeast of Trenton. These lower thin-bedded layers constitute the bulk of the unit in the Sandy Hook quadrangle; they formerly were placed in the Wenonah Formation, largely because of their fine-grained micaceous nature. Probably the best way to distinguish the two formations in outcrops where they appear to be similar in mineralogy and grain size is by their internal structures. The Wenonah is characteristically massive to thick bedded whereas the Mount Laurel is thin bedded, except in the upper several feet where it also is thick bedded. The for-

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mation has a nearly continuous outcrop in New Jersey, from Sandy Hook southwest to the Delaware River, and extends as a thick unit across Delaware to at least the east shore of Chesapeake Bay.

The Mount Laurel Sand underlies lower slopes of hills and, locally, valley bottoms. A nearly complete section is exposed in the bluff between Atlantic Highlands and Hilton (pl. 1). The upper part is exposed in pits and cutbanks along the south side of Route 35 near Middletown Road and on the east side, south of Mountain Hill Road. The bedded sequence was well exposed beneath surficial deposits in a storm drain ditch in the housing development between Sleepy Hollow and Chapel Hill Roads just south of Highland Road. Both the horizontally and cross-stratified sequence were exposed in the embankment next to the parking lot of the supermarket at the southwest corner of the intersection of Route 35 and Middletown Road (fig. 4). Exposures also were seen in the banks of the small creek behind the supermarket.

NAVESINK FORMATION

The unweathered Navesink Formation typically is a massive- to thick-bedded clayey glauconite sand. Clay and silt constitute about 30 percent of the formation (table 1). The remaining 70 percent consists almost entirely of very fine to coarse glauconite sand, most of which consists of medium to coarse dusky-green to greenish-black and olive-black botryoidal grains. A small amount of quartz occurs mainly as coarse grains and granules in the basal few feet, but also as a trace of fine grains throughout. Sand-sized clusters of pyrite crystals are common in the unweathered rock. Phosphatic fragments also are locally present, mainly near the base. In weathered outcrop the formation is dark greenish gray to brownish gray and grayish brown.

In the clay-sized fraction, kaolinite, montmorillonite, chlorite, muscovite, and quartz are common to major minerals. Detrital heavy minerals are sparse and are represented by tourmaline and staurolite.

The contact with the underlying Mount Laurel Sand is distinct and unconformable; the Navesink basically consists of a clayey glauconite sand lying on a clayey quartz sand. It contains reworked phosphatized fossil fragments in the basal foot or two.

Fossils are abundant in some outcrops (in the bluffs along Sandy Hook Bay), both in the base and near the middle of the formation. *Choristothyris plicata* (Say), *Gryphaea convexa* (Say), and *Gryphaea mutabilis* Morton are typical. Other fossils noted include *Pecten venustus* Morton, *Exogyra costata* Say, *Ostrea falcata* Morton, and *Belemnitella americana* (Morton). The better preserved fossils (including calcareous shells) are located several feet above the base of the formation. For a detailed listing of fossils refer to Weller (1907, p. 105–130).

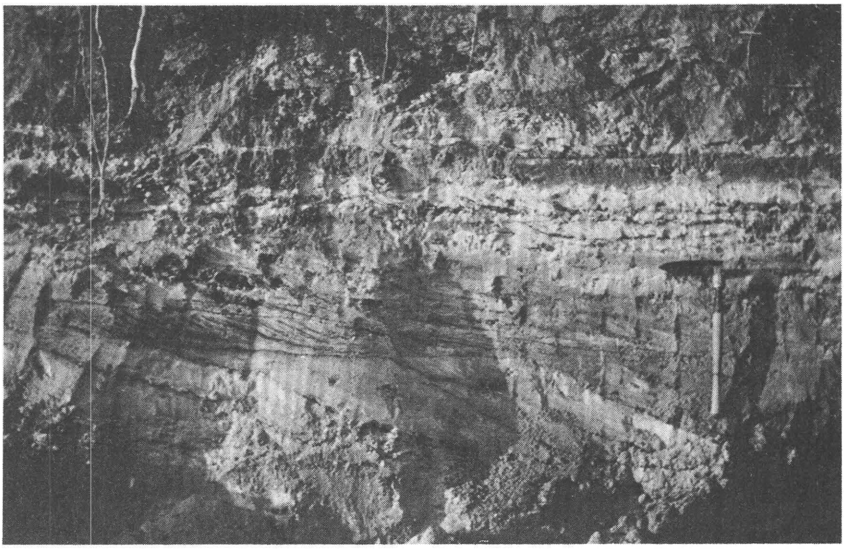

FIGURE 4.—Horizontal and cross-stratification in the Mount Laurel Sand exposed in the banks on the southwest side of the intersection of Middletown Road and Route 35, in the southwestern part of the Sandy Hook quadrangle.

Soil developed on the Navesink is very fertile and friable, and where it is present on broad, flat areas, the land is highly prized and utilized.

The Navesink Formation is a distinctive glauconite unit that is about 25 feet thick here. Clark (1894, p. 336–337) had reported a thickness of 40–60 feet for the formation, but he included the underlying Mount Laurel Sand and part of the overlying Red Bank Sand with the Navesink. Later, Clark (1898, p. 183–184) separated the Navesink and Mount Laurel and assigned a thickness of 12–50 feet to the Navesink. He probably included some of the basal Red Bank Sand with the Navesink, as did Miller in 1956 (p. 726–727). The Navesink mapped in the Sandy Hook quadrangle is the glauconite unit as defined in the Columbus quadrangle report (Owens and Minard, 1962) and in the New Egypt quadrangle report (Minard and Owens, 1962), and as mapped in the other quadrangles in the lower Delaware basin (fig. 2). The formation has a nearly continuous outcrop in New Jersey, from Sandy Hook southwest to the Woodstown quadrangle. It is only a few feet thick in Woodstown and thins to zero a short distance to the southwest. The Navesink is not present in outcrop in Delaware or eastern Maryland.

The type section of the formation is described (Clark, 1894, p. 336–337) from outcrops near the village of Navesink in the Sandy Hook quadrangle (pl. 1) and from outcrops along the north bank of the

Navesink River in both the Sandy Hook and Long Branch quadrangles. The formation underlies lower and middle slopes of hills in most of the area and is exposed in many places. Several outcrops can be seen in pits along the south side of Route 35 between Middletown and Tindall Roads, in revetments for railroad cars east of Garrett Hill on the Naval Reservation, in the west side of the hill on Mountain Hill Road, in the railroad cut at the northwest edge of Middletown, and in roadcuts and pits elsewhere in the southwestern part of the quadrangle. The best exposures are in the bluffs along Sandy Hook Bay east of Atlantic Highlands where the entire thickness of the formation is exposed and the basal contact with the Mount Laurel can be seen. The basal contact can also be seen in a pit on the east side of Route 35 just south of Mountain Hill Road, but the rocks are weathered there. The basal contact also was penetrated in several auger holes.

RED BANK SAND

The Red Bank Sand is a thick formation which is exposed only in the northern part of the Coastal Plain in New Jersey. It is as much as 120 feet thick in this quadrangle, but thins and wedges out about 40 miles to the southwest (Owens and Minard, 1962). The type area, described by Clark (1894, p. 337), is near the town of Red Bank, N.J., in the quadrangle adjacent to the south, although the best exposures are in the Sandy Hook quadrangle.

The formation is subdivided into lower and upper members, as was previously done in the New Egypt quadrangle (Minard and Owens, 1962), although they were not then given formal names. In the Sandy Hook quadrangle, these members are assigned the names proposed by Olsson (1963, p. 651–652); the lower member is the Sandy Hook, the upper member is the Shrewsbury.

The Red Bank Sand underlies the middle and upper slopes of most of the high hills in the southwestern part of the quadrangle and the lower and middle slopes of the hills in the southeastern part (pl. 1). It is exposed in many roadcuts and cutbanks in the south-central and southeastern parts of the quadrangle and in pits along Route 36. Excellent exposures can be seen in the bluffs along the northern side of Navesink River. Almost continuous exposures are present for hundreds of yards along the bases of these bluffs. The lower member is well exposed west of Locust Point, whereas the upper member is largely exposed in the bluffs near the horizontal control stations, Hart and Lower.

Excellent exposures also are present in the bluffs along Sandy Hook Bay, from the mouth of Navesink River west to Atlantic Highlands Yacht Harbor. The best and most complete exposure is in the bluff along Bay View Street at Waterwitch, about 300 feet southeast of a slump block (pl. 1). Except for a few feet of the base, the entire 120-foot section is nearly continuously exposed. In addition, four of the overlying formations also are exposed in the top of the bluff. The underlying Navesink Formation can be seen in contact with the lower member of the Red Bank Sand in the roadbank about 800 feet southeast of the bluff exposure.

SANDY HOOK MEMBER

The Sandy Hook Member is the lower member of the Red Bank Sand. It is typically a compact dark-grayish and brownish-black massive-bedded feldspathic quartz sand. The sand is clayey and silty, fine to very fine (table 1), and very micaceous. Mica is chiefly colorless muscovite, but green chloritized mica is abundant. Sand-sized lignite and clusters of pyrite crystals are present, and glauconite is abundant (10–15 percent) within the basal few feet. Although the glauconite is chiefly in medium to coarse botryoidal grains similar to those in the underlying Navesink, accordion and tabular forms are also present. The Sandy Hook Member ranges in thickness from about 15 to 30 feet. In some outcrops there are many siderite concretions that are typically light brown to moderate or grayish brown on a weathered surface and light olive to medium gray on a fresh surface. The siderite concretions range in shape from spherical concretionary masses to conical-pointed cylinders, and are from several inches to several feet in diameter and length. Some concretions contain unweathered material in the center.

In the clay-sized fraction, quartz, kaolinite, montmorillonite, muscovite, pyrite, and carbonaceous matter are common to major constituents. Characteristic detrital heavy minerals are garnet, staurolite, and tourmaline.

The contact with the underlying Navesink Formation is lithologically distinct, although the colors are similar. The basal part of the Sandy Hook Member is a clayey very micaceous glauconitic quartz sand, whereas the Navesink is a clayey glauconite sand.

Both microfossils and megafossils are abundant in several outcrops. The magafossils occur as both molds and calcareous shells within the basal 10 feet; the microfossils (largely Foraminifera) occur as well-preserved tests. Good fossil locations are in the bases of the bluffs at Waterwitch and west of Locust Point, in the cutbank behind the church school at the northwest edge of Middletown, and in a roadcut along the southeast side of the railroad on the Naval Reservation, about 0.6 mile north of Highland Road. A few of the typical megafossils are *Trigonia* sp., *Ostrea* sp., *Turritella vertebroides* Morton, and *Eutrephoceras dekayi* (Morton). For a detailed listing of megafossils, refer to Weller (1907, p. 138–141), and for microfossils, refer to Olsson (1960, p. 5—field location NJK–103—and p. 6–44, 47–55).

Soil developed on the member is a clayey sand which usually is not very well drained.

SHREWSBURY MEMBER

The Shrewsbury Member is the upper member of the Red Bank Sand. It is composed of massive-bedded silty fine to medium (table 1) feldspathic quartz sand. The sand ranges in color from yellowish gray and grayish orange pink to light moderate and moderate reddish brown. The member is about 100 feet thick in the quadrangle. Many (10 percent) coarse grains and some (2 percent) very coarse grains are present, particularly in the upper half of the formation (table 1). Glauconite is sparse and rock fragments—shale, sandstone, and schist—are abundant. Muscovite is common in the lower part. Grains are mainly subangular to subrounded, but many angular grains are present. This member characteristically is oxidized to shades of reddish brown; but where it is not oxidized, it is generally gray. Ledges and masses of ironoxide-cemented sand occur locally; some of the masses have bizarre shapes, such as pipe and honeycomb structures, whereas other oxidized and cemented zones impart a bedded appearance to the sand (fig. 5).

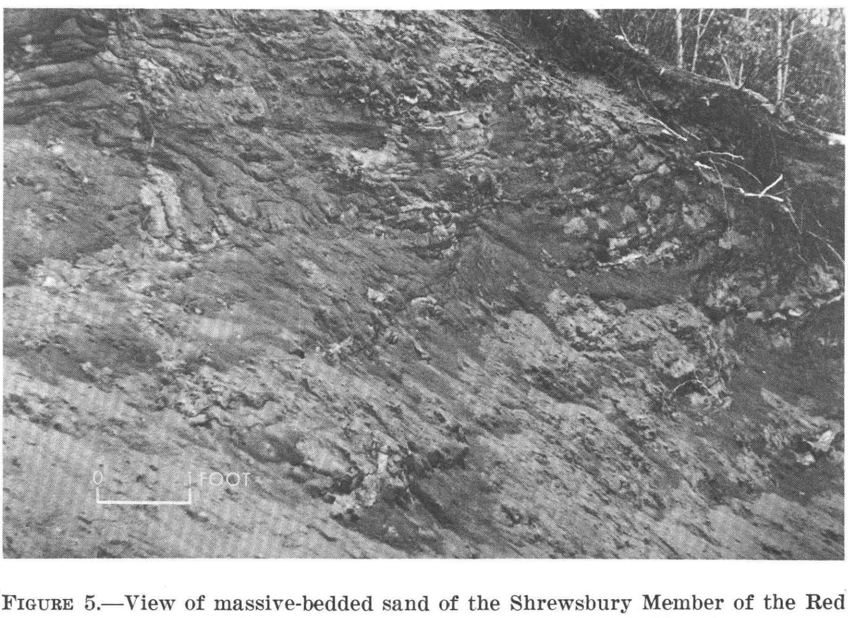

FIGURE 5.—View of massive-bedded sand of the Shrewsbury Member of the Red Bank Sand exposed in the bluff just east of slump block A (figs. 11, 12). Iron-oxide crusting and banding impart a bedded appearence to the sand.

In the clay-sized fraction, quartz and kaolinite are the major minerals. Characteristic detrital heavy minerals are tourmaline, sillimanite, and staurolite.

The contact with the underlying Sandy Hook Member is gradational over a vertical distance of several feet. Locally, the two members appear to interfinger, but this is generally a weathering feature. The conspicuous difference between the two members is the color, a reddish-brown sand lying on a dark-gray sand. It may seem that the upper member is merely a deeply weathered and eluviated phase of the formation; but sand size is finer, and clay, silt, and mica are much more abundant in the lower than in the upper member. The high silt-clay content of the lower member probably is responsible for its being oxidized less than the upper member.

Fossils in the Shrewsbury Member are sparse, and none were found in the quadrangle. Weller (1907, p. 140) reports several species of poorly preserved pelecypods from the town of Red Bank, N.J., in the Long Branch quadrangle just to the south.

Soil developed on the member is loose and sandy.

TINTON SAND

The Tinton is massive-bedded clayey medium to very coarse feldspathic quartz-glauconite sand to glauconitic quartz sand. In the Sandy Hook quadrangle the sand is stained, crusted, and cemented by iron oxide. Color ranges from dark yellowish orange and light brown to moderate brown and moderate yellowish brown and from light olive gray to grayish olive. The Tinton is poorly sorted; grain size ranges from clay and silt (10–30 percent) to very coarse (table 1). Rounded to angular very coarse sand grains and granules of quartz and feldspar are abundant in the upper part of the formation; one small pebble, 9 millimeters in diameter, was noted. Glauconite constitutes as much as 60–80 percent of the sand fraction in the upper part of the formation. Both glauconite content and grain size decrease downward. In the lower part of the formation the sand is largely medium to coarse, and glauconite constitutes only about 15–20 percent of the sand fraction; the bulk of the remainder is quartz. Glauconite grains are chiefly botryoidal, but many accordian-shaped and tabular grains are present.

In some outcrops the Tinton has conspicuous irregular concentric weathering patterns, several inches to several feet in diameter (fig. 6). Iron oxide and iron carbonate cement thin bands of sand in these concretionary patterns. In several outcrops the cemented upper few feet of the sand form an indurated ledge of weathered reddish-brown sandstone beneath the overlying unconsolidated dusky-green Hornerstown Sand.

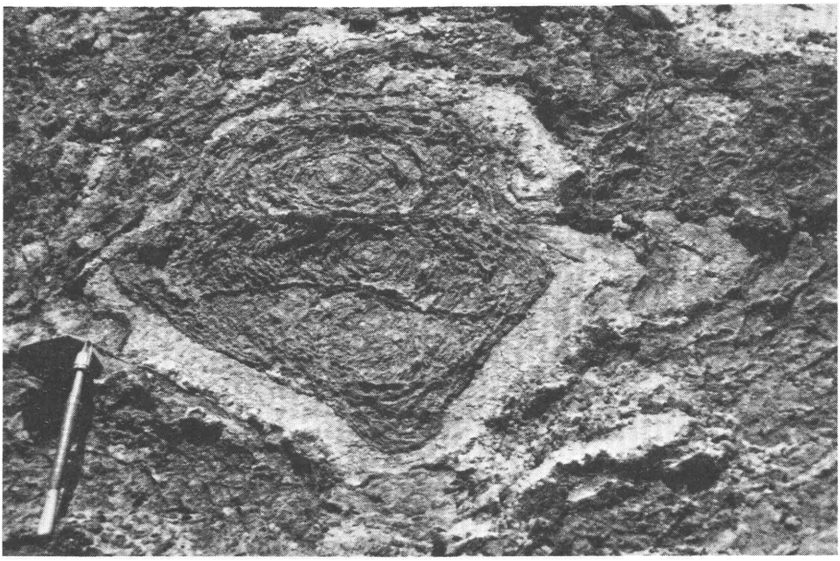

FIGURE 6.—Concentric concretionary pattern common in the Tinton Sand in the Sandy Hook quadrangle. Cemented by iron oxide and iron carbonate. Exposed in the large pits along Route 36 south of Hilton.

X-ray diffraction patterns of the clay-sized fraction were poor, and minerals were indeterminate, probably because of intense weathering and oxidation. Glauconite is abundant in the heavy-mineral suite, but detrital heavy minerals are very sparse. A few grains of muscovite, tourmaline, and staurolite were noted.

The contact with the underlying Shrewsbury Member of the Red Bank Sand is gradational over several feet and is placed at the base of poorly sorted fairly glauconitic quartz sand. The underlying Shrewsbury Member is better sorted (about 70–80 percent fine to medium grained), less clayey, and contains, at most, only a few percent glauconite.

Many fossils are present at Tinton Falls (Long Branch quadrangle to the south) and Beers Hill (Keyport quadrangle to the west), but only poorly preserved molds of a pelecypod (*Camptonectes*) and animal borings were found in the sand in the Sandy Hook quadrangle. Weller (1907, p. 146) lists about a dozen different species and Norman F. Sohl, U.S. Geological Survey, has identified many more species from Tinton Falls (written commun., Oct. 22, 1965). In some localities, fossil molds and casts are thickly coated by vivianite.

A clayey sandy soil, developed on the few level upland areas, supports a fairly thick and varied vegetative cover.

The Tinton Sand is here mapped and described as a separate formation. Previously, it was described as the uppermost member of the Red Bank Sand. Cook (1868, p. 261, 268–269) probably was the first to recognize it as a distinct unit and referred to it as the "Indurated green earth." Weller (1905, p. 159) states that "for both faunal and stratigraphic reasons the indurated green earth of Cook is separated from the Red Bank Sand, and is recognized as a distinct formation to which the name Tinton beds is applied." Weller, however, did not map the unit separately. Mansfield (1922, pl. 3) showed the Tinton as a separate map unit (as mapped by George Knapp in Mansfield, 1922, p. 4), but still considered it a member of the Red Bank Sand. This member status continued through the many subsequent reports, including the New Jersey State geological report by Kümmel (1940, p. 119). Kümmel recognized it as different from the Red Bank but did not show it separately on the State map. Olsson (1963, p. 653), in one of the most recent papers describing the Tinton, considered it a separate formation but also did not show it on a map.

The Tinton, like the Red Bank, is exposed only in the northern part of the Coastal Plain in New Jersey. It is as much as 20 feet thick in the Sandy Hook quadrangle. Weller (1907, p. 145) considered it 22 feet thick in the type area at Tinton Falls, N.J., Long Branch quadrangle, and he and Olsson (1963, p. 653) believed that the Tinton thinned southwest and wedged out near Red Valley in the Roosevelt quadrangle, New Jersey. Mansfield (1922, pl. 3) showed the Tinton wedging out near Smithburg, just east of the Roosevelt quadrangle. Mansfield's interpretation better agrees with the relations found in the eastern part of the Roosevelt quadrangle (Minard, 1964) where many auger holes penetrated the glauconite sand of the Hornerstown and passed directly down into the slightly glauconitic feldspathic quartz sand of the typical upper Red Bank. The unit Weller and Olsson interpreted as the Tinton in the Roosevelt quadrangle was mapped by Minard (1964) as a transitional bed in the Red Bank. At Emleys Hill, in the southwestern part of the Roosevelt quadrangle, this transitional bed lies below the upper quartz sand of the Red Bank (Shrewsbury Member) and above the lower glauconite sand of the Red Bank (equivalent to the Sandy Hook Member), not at the top of the Red Bank as would be true if it were the Tinton. Farther southwest the upper quartz sand is absent, and the transitional unit lies at the top of the Red Bank section. Previous workers were possibly misled by the apparent higher stratigraphic position of the transitional beds (which resemble the Tinton); whereas the units are only higher topographically, because of the domal structure at Emley's Hill (Minard and Owens, 1966).

The Tinton generally has received only cursory attention and most descriptions are inadequate. Cook (1868, p. 268) merely referred to it as greenish indurated earth; Clark (1898, p. 185), as greenish-gray or reddish clay; Weller (1905, p. 155), as glauconitic indurated sand; and Mansfield (1922, p. 11), as green indurated clayey and sandy glauconitic marl. Kümmel (1940, p. 119) virtually repeated Mansfield's description. Olsson (1963, p. 653) gives the best and most detailed description of the unit, in and near the type area. The sand is variable in lithology, color, and outcrop expression. In its type area at Tinton Falls it is chiefly greenish-gray coarse indurated quartz-glauconite sand that is very fossiliferous. At the well-known Beers Hill locality, in the roadcut at the west end of Crawford Hill in the Keyport quadrangle, it is largely a glauconite sand containing minor amounts of quartz.

The Tinton underlies steep, middle to upper slopes of the highest hills in the southeastern part of the quadrangle. It is well exposed in the bluffs at Waterwitch and along the north side of the Navesink River near its mouth, and in the pits along Route 36 south of Hilton (pl. 1).

TERTIARY SEDIMENTS

HORNERSTOWN SAND

The Hornerstown typically is dusky-green to grayish-olive and grayish-olive-green massive-bedded clayey glauconite sand. In the Sandy Hook quadrangle, it is oxidized in the upper few feet to moderate reddish brown and dusky red. This oxidation probably is largely due to its topographic position above the water table and the good internal drainage in the sand above. Several percent quartz sand is present throughout the unit, and as much as 30 percent occurs in the basal and upper 1 or 2 feet. Grain size in the entire unit ranges from clay to coarse sand (table 1). Clay and silt constitute about half the formation here. This high percentage of fines may be due in part to the advanced stage of weathering and breakdown of the soft glauconite grains. In some outcrops the intensely weathered and oxidized upper 1 or 2 feet is nearly all clay. In other outcrops the upper few inches to several feet consists of clay ironstone. Glauconite grains are chiefly medium to coarse in size, and botryoidal. Quartz grains are mainly medium, but they range from fine to coarse. A little mica is present as coarse to very coarse plates.

In the clay-sized fraction, glauconite is the only common mineral, a characteristic which is unique to this formation throughout most of its outcrop in New Jersey. Some other formations contain glauconite in the clay-sized fraction, but not to the nearly complete exclusion of other clay-sized material. Glauconite is abundant in the heavy-mineral suite, but detrital heavy minerals are sparse; these include hornblende, muscovite, staurolite, tourmaline, and zircon.

The contact with the underlying Tinton is distinct and unconformable. In most outcrops, green to olive-gray glauconite of the Hornerstown lies on highly oxidized, iron oxide-crusted, and indurated quartz-glauconite sand of the Tinton. Evidence for the unconformity is (1) truncation and overlap, by the Hornerstown, of increasingly older units toward the southwest; (2) reworked material in the base of the Hornerstown; and (3) the irregular, eroded upper surface of the Tinton.

No fossils were found within the Hornerstown here, although to the southwest, fossils are present at the base. These fossils have almost certainly been reworked from the underlying formation. They include *Cucullaea vulgaris* (Morton), gastropods, and rarely, *Sphenodiscus lobatus* (Tuomey) (Minard and others, 1964). Weller (1907, p. 155-160) lists about 20 different fossils from the Hornerstown. The author, however, thinks that most of these are actually from the overlying Vincentown, as discussed by Minard and others (1964), and were placed in the Hornerstown by Weller, only with reservation (1907, p. 159).

Because of the narrow steep outcrop that is characteristic of the formation here, very little soil is developed on it. Elsewhere, it is a rich loamy friable soil similar to that on the Navesink.

The Hornerstown is one of the most distinctive and easily recognizable units in the Coastal Plain in New Jersey. It is of Paleocene age and is the basal unit of the Tertiary System in New Jersey. It also occurs in Delaware and eastern Maryland as an almost equally distinctive unit. Very little controversy existed among previous workers regarding the lithic identity or thickness of this unit. It ranges in thickness from about 5 to 15 feet in the Sandy Hook quadrangle, and is about 30 feet thick in the type area at Hornerstown in the New Egypt quadrangle to the southwest (Minard and Owens, 1962). Formerly, it was thought to be of late Cretaceous age, but Cooke and Stephenson (1928, p. 139–148) furnished faunal evidence that suggested a lower Tertiary age for the Hornerstown, as well as for the overlying Vincentown and Manasquan Formations.

The formation underlies middle to upper slopes of the highest hills in the southeastern part of the quadrangle and forms a narrow band of outcrop around these hills (pl. 1). It is well exposed near the tops of several bluffs; one at Waterwitch on Sandy Hook Bay, and those near the horizontal control stations, Lower and Hart, along the north side of the Navesink River. It also is well exposed in several pits, three of which are along Route 36 in the southeastern part of the quadrangle; two of these pits, one on each side of the highway, are south of Hilton, and one is north of the highway, about 0.7 mile east. Other pits in which the Hornerstown is exposed are near the hilltop along Monmouth Avenue, about 1 mile west of the town of Navesink, and one is in the hillside, about 0.35 mile west of Navesink Lighthouse. The formation also crops out in the roadbank along the south side of Navesink Avenue where it joins Route 36, and in the roadbank in the side of the high hill along the north side of Riverside Drive.

VINCENTOWN FORMATION

The Vincentown is thick- to massive-bedded medium glauconitic (1-5 percent) quartz sand. It is typically light greenish to yellowish gray, but locally, is oxidized to mottled moderate red and moderate olive brown. Some iron oxide cementation is present at or near the base of weathered sections. One- to two-inch pods of nearly pure glauconite sand occur near the base. Glauconite constitutes nearly half the sand fraction in the basil few feet. Grain size ranges from clay to coarse sand, but generally more than half is medium sand (table 1). Coarse grains constitute only a few percent; these are mainly quartz, but they include a few grains of glauconite. Quartz grains are generally subangular to subrounded, but many angular and some rounded grains are present; glauconite grains are botryoidal. Muscovite and green chloritized mica are present. Much of the sand is fairly loose and clean, but in some outcrops as much as 25 percent clay and silt are present. A small amount of feldspar is present as light-gray weathered grains. In the clay-sized fraction, kaolinite and mica are the common minerals. Characteristic detrital heavy minerals are tourmaline and staurolite. Mica is fairly abundant. Glauconite, both detrital and authigenic, is abundant in the heavy-mineral suite.

The contact with the undelying Hornerstown appears gradational. Although the basal few feet are highly glauconite, the underlying Hornerstown is much more so. The contact is placed at the base of the quartzose glauconite sand, and in some outcrops, is marked by clay-ironstone layers. Animal boring or pods, filled by glauconite or quartz sand, are present both above and below the contact. The glauconite-filled borings or pods are chiefly in the base of the Vincentown; the quartz-filled ones, in the upper part of the Hornerstown.

No fossils were found in the formation within the quadrangle; but elsewhere, the formation is one of the most fossiliferous in the Coastal Plain of New Jersey, and contains abundant Foraminifera and Bryozoa. Weller (1907, p. 161–171) and many others have described the paleontology of this unit; for reference to several of the more important papers, see Minard and Owens (1962). The nearest outcrop of the well-known basal shell bed of *Oleneothyris harlani* (Morton) and *Gryphaea dissimilaris* Weller probably is in the Long Branch quadrangle, at Turtle Mill near Eatontown, N.J. (Rogers, 1836, p. 51–53).

Because of the narrow steep outcrop characteristic of the formation in the Sandy Hook quadrangle, very little soil is developed on it. Elsewhere, a loose sandy soil, which supports a fairly open vegetative cover, is developed.

The Vincentown is of Paleocene age. Before 1928 the formation was thought to be of Late Cretaceous age (Weller, 1907); but faunal evidence by Cooke and Stephenson (1928) suggested the early Tertiary age which has been confirmed by many subsequent workers. It crops out almost continuously in the Coastal Plain in New Jersey and is present in Delaware and Maryland, where it is called the Aquia Formation. The formation ranges in thickness from 0 to 35 feet in the Sandy Hook quadrangle, and is as much as 50 to 60 feet thick in the New Egypt area (Minard and Owens, 1962; Bascom and others, 1909, p. 14).

The formation underlies steep, middle and upper slopes of the high hills in the southeastern part of the quadrangle and forms a narrow band of outcrop around these hills (pl. 1). The thickest sections are downdip, in the southeast area. The formation thins to zero updip to the northwest, where it is truncated by the overlying Cohansey Sand. The Vincentown is well exposed near the tops of the same bluffs in which the Hornerstown is exposed, in the same pits along Route 36, and in the pit in the hillside about 0.35 mile west of Navesink Light.

COHANSEY SAND

The Cohansey is composed chiefly of somewhat pebbly medium to coarse quartz sand; however, much fine and very coarse sand and granules are also present (table 1). The distinctive characteristic of the sand is the well-formed cross-stratification (fig. 7) of planar, trough, and festoon types (McKee and Weir, 1953, p. 387), or flow-and-plunge structure types (Salisbury, 1894, p. 198). The sand is typically yellowish gray and grayish to pale yellowish orange, except where stained grayish red to moderate brown by iron oxide.

About 1 percent clay is present as a coating on sand grains or, locally, as pinkish- or yellowish-gray thin layers near the base of the sand. Weathered feldspar is present in small amounts, and ilmenite is abundant (2–3 percent by weight), particularly in the base. Scattered grains of mica, chiefly colorless, but some black, are also present. Quartz grains are chiefly subangular to subrounded, but some are well rounded and frosted; a few abraded quartz crystals are present. The upper part of the Cohansey contains many small pebbles, most of which are less than 1 inch in diameter. A few pebbles are larger, and one cobble 8 inches long was found. The pebbles are mainly of quartz

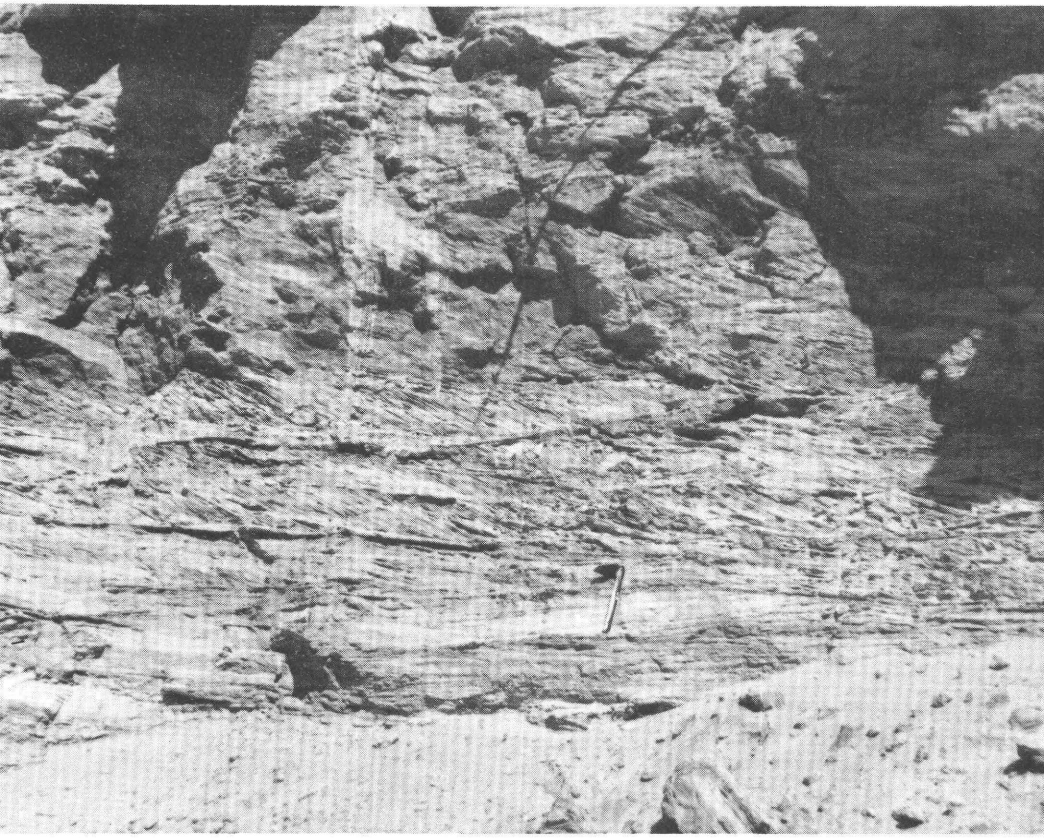

FIGURE 7.—Cross-stratification in the Cohansey Sand exposed in the large pit along the south side of Route 36 south of Hilton.

but some are of chert or sandstone, and a few are from metamorphic rocks. Most of the upper gravel layers are firmly cemented by iron oxide into resistant ledges, which probably are responsible for the high hills and considerable relief in this quadrangle. Cemented layers are also locally present throughout the entire formation and may include layers of clean loose sand.

In the clay-sized fraction, kaolinite and quartz are the common minerals. Detrital heavy minerals include abundant dark opaques and zircon.

The basal contact is distinct and unconformable. In most outcrops the cross-stratified quartz sand beds of the Cohansey lie on the massive-bedded glauconitic quartz sand of the Vincentown. Locally, however, the basal contact is highly irregular and cuts down through the underlying formations, so that the Cohansey lies on the Tinton. In the large pit on the south side of Route 36, south of Hilton, two channels have been cut down through the Vincentown and Hornerstown (fig. 8). The channels are about 50–100 feet wide, and the contact has as much as 15 feet of relief within a horizontal distance of 20–25 feet. Blocks of Vincentown, 4–6 feet across, are lying in the channels and are completely engulfed by the Cohansey. Here, some of the basal beds in the Cohansey are fine to very fine micaceous sand and silt, and resemble the Kirkwood Formation of Miocene age, which underlies the Cohansey nearly everywhere in the New Jersey Coastal Plain. Because of their limited extent and discontinuous nature, these beds are not mapped separate from the Cohansey.

No fossils were found in the formation in the Sandy Hook quadrangle, and it is generaly unfossiliferous elsewhere. Woolman (1897), however, reported molluscan fossils from the Cohansey interval near Millville, N.J., and Hollick (1900, p. 197–198) reported well-preserved fossil-plant remains from one locality near Bridgeton, N.J., both in the southwestern part of the State. Hollick considered the flora more nearly comparable with certain European upper Miocene types than with collections of Eocene and Miocene plants from the Western United States. He further explained that European flora supposedly was more advanced; therefore, the Miocene of Europe compares with the Pliocene of America. Kümmel and Knapp (in Ries and others, 1904, p. 139) state that, although the paleontologic evidence did not allow determination of the age of the beds, it suggested a Pliocene age.

The soil developed on the formation is very sandy and locally contains many ironstone fragments. The vegetative cover is somewhat open and consists chiefly of oaks, but much laurel is present as undergrowth.

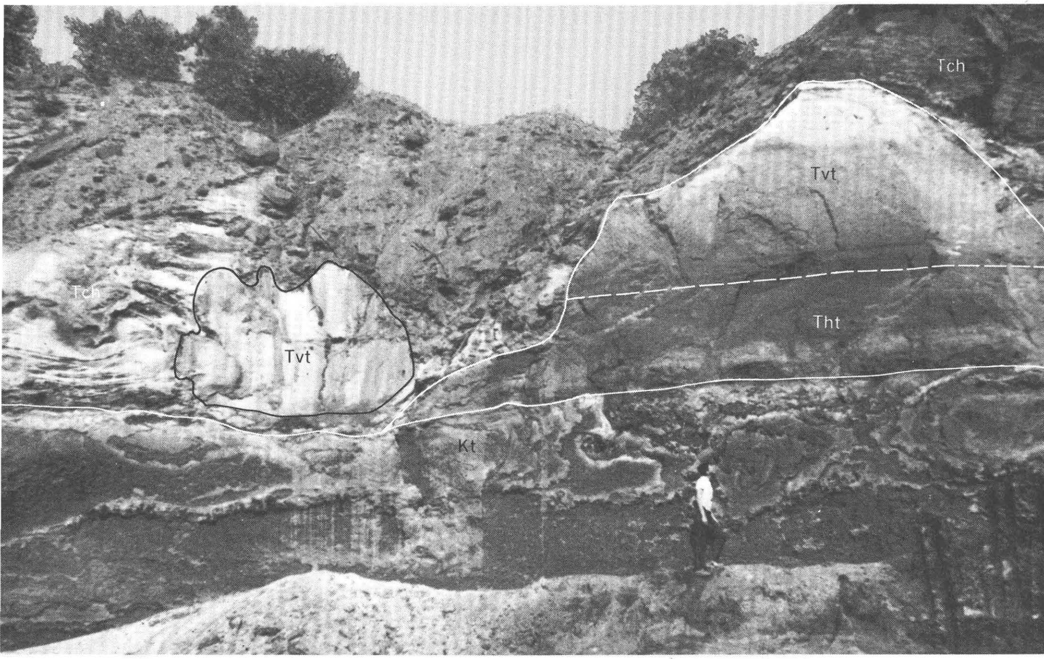

FIGURE 8.—View of the unconformable basal contact of the Cohansey Sand exposed in the large pit along the south side of Route 36, south of Hilton. The separate block of Vincentown is detached and engulfed by Cohansey. Tch, Cohansey Sand; Tvt, Vincentown Formation; Tht, Hornerstown Sand; Kt, Tinton Sand.

The Cohansey is the unit that covers most of the emerged Coastal Plain in New Jersey. It is presently considered to be of Miocene(?) and Pliocene(?) age and is the youngest Tertiary Formation in the Sandy Hook quadrangle. To the southwest, it is underlain by the Kirkwood Formation of Miocene age, but the Kirkwood is absent in the Sandy Hook quadrangle; and although a few local thin beds in the base of the Cohansey resemble the Kirkwood, they are included in the Cohansey here. The formation ranges in thickness from several feet to as much as 65 feet.

The Cohansey underlies the upper slopes and tops of the highest hills in the southeastern part of the quadrangle (pl. 1). Excellent exposures are present in the large pits along Route 36, south of Hilton, and in the side of the hill (alt 266 ft), 0.7 mile east of these pits. Other exposures are in small pits in the hilltops south of Waterwitch and Highlands; in the upper part of the bluff at Waterwitch; in the bluff just northwest of Hart horizontal control station along the north side of Navesink River; and in the pits in the hilltop along Monmouth Avenue west of Navesink.

QUATERNARY DEPOSITS

GLAUCONITIC SAND

The glauconitic sand is largely well-stratified medium to very coarse alluvial sand. Some gravel occurs as thin layers throughout the unit, but mostly in the base, where it is locally cemented by iron oxide. Pebbles, 2 inches or less in diameter, are also scattered throughout the unit. Layers of clay, silt, and peat are locally present. Colors range from shades of gray and greenish gray to shades of brown. Sand is composed chiefly of quartz and some feldspar. Glauconite generally constitutes 2–10 percent of the sand, and is locally even more abundant near the base where the unit rests on glauconite-bearing formations. Pebbles are composed chiefly of rounded quartz and less amounts of rounded pieces of ironstone, sandstone, and argillite; igneous and metamorphic pebbles are sparse. The sand beds are mainly thin and horizontal, but some are cross stratified. Near the base of hills, slabs of ironstone, derived from the topographically higher Cohansey, Tinton, and Red Bank Sands, are common in the upper few feet of the deposit. These slabs probably reached their present position by slope wash and creep.

The largest areas of the glauconitic sand are in the western and north-central parts of the land area of the quadrangle. The sand ranges in thickness from a few feet to as much as 30 feet.

A radiocarbon date of 14,150 B.P. ± 450 years was obtained from peat lying on stratified glauconitic sand exposed in a drainage ditch about 1,000 feet south of Highland Road and about 800 feet east of Sleepy Hollow Road (dating by Meyer Rubin, U.S. Geological Survey, written commun., 1964, sample W–1457). This date suggests that the underlying sand is at least that old at this location, but the date does not necessarily hold for other glauconitic sand deposits. Some deposits are probably younger, and some older, than the dated deposit.

The deposits underlie the hill slopes below 100 feet altitude, valley bottoms bordering streams, and the broad, flat areas bordering Sandy Hook Bay and the south side of Navesink River (pl. 1). Exposures are limited mainly to pit walls and cutbanks. One pit is located south of Route 35 at the west edge of the quadrangle; one just east of Route 35, southeast of the junction with Mountain Hill Road; and one along the south side of McClees Creek, just north of Cooper Road. The distribution of the deposits was determined largely from small outcrops and by augering.

FORAMINIFERAL CLAY

Deposits of foraminiferal clay underlie parts of Sandy Hook spit (pl. 1), but they are not exposed. The depths and thicknesses of these deposits were determined by cuttings from five auger holes, three of which were located east of Spermaceti Cove. The deposit is important because of its stratigraphic position, fauna, and age.

The foraminiferal clay is composed of medium- to dark-gray or dark-greenish-gray glauconitic silt and slay, containing as much as 26 percent very fine to medium quartz sand (table 1). Glauconite occurs as rounded dusky-green and moderate-green silt to fine sand. Colorless and green chloritized mica and sand-sized clusters of pyrite crystals are present. Some samples contain much fresh, dusky-brown plant matter, and several samples initially had faint to strong odors of hydrogen sulfide. Kaolinite, chlorite, and mica are the major clay minerals.

FAUNA

A rich assemblage of fossils is present in most samples but is sparse in a few. Except for the one hole (pl. 1, hole 10) at Seabright, the fossils are nearly all Foraminifera, and mainly (95 percent) *Elphidium clavatum* Cushmann (Ruth Todd, written commun., Feb. 11, 1964; June 1, 1965). Some ostracodes are also present (Joseph Hazel, written commun., June 1, 1965). Megafossils include many small thin-shelled pelecypods (3/8–5/8 in. across). All the fossils appear fresh and retain delicate surface ornamentation. The pelecypod shells retain an iridescent aragonite luster.

SIGNIFICANCE OF FAUNA

The Foraminifera do not indicate a specific age because all species have been recorded from beds at least as old as Pliocene, and they range to the present. The Foraminifera, however, do indicate conditions of the depositional environment. In a recent study, Buzas (1965, p. 63–64) defined three foraminiferal zones now existing in Long Island Sound. *Elphidium clavatum* is most abundant at mean depths of 12 meters; *Bucella frigida* (Cushmann), at 25 meters; and *Elphidium advena* (Cushmann), at 29 meters. The proliferation of *E. clavatum* at comparatively shallow depths in temperate waters suggests that the foraminiferal clay may have been deposited in a similar environment, despite the fact that some deposits are now found at 40-meter depths.

Weiss (1954, p. 143) states that the foraminiferal assemblage in the Gardiners Clay of Long Island (characterized by a predominance of *Elphidium clavatum*) is indicative of shallow-water deposition and suggests a depositional environment similar to that in the bays which presently fringe the southern shore of Long Island.

CORRELATION AND AGE

The foraminiferal clay is similar in lithology, fauna, and topographic position to much of the Gardiners Clay of Long Island, N.Y. Because of the stratigraphic position of the Gardiners Clay below the Jacob Sand and Manhasset Formation which are believed to be of Wisconsin age (Weiss, 1954, p. 146), the Gardiners is considered an interglacial deposit of Sangamon age. At the type locality on Gardiners Island, between the flukes at the east end of Long Island, the upper beds described by Fuller (1914, p. 92) are varved clay (Weiss, 1954, p. 148). Weiss believes that because the Gardiners is considered Sangamon, only the lower fossiliferous beds should be assigned to the Gardiners. These lower beds are the beds which are similar, lithologically and faunally, to the foraminiferal clay of Sandy Hook.

The foraminiferal clay under Sandy Hook seems to consist of at least three separate lenses at two different depths (pl. 1). Enough plant material for radiocarbon dating was obtained from the northernmost lens (pl. 1, hole 3). The material dated was from the upper 7 feet of the deposit at a depth of 85–92 feet below sea level. The date, furnished by Meyer Rubin, U.S. Geological Survey, was 9840 B.P. ± 300 years (written commun. 1965, sample W–1633). This date agrees closely with those obtained elsewhere, at similar depths below present sea level.

If the Gardiners Clay is of Sangamon age (probably 90,000 years B.P., or older) it is not correlative with at least the dated deposit under Sandy Hook. Recovery of organic matter from other holes was insufficient to permit dating by radiocarbon techniques. Possibly, the other clay deposits are of a different age or ages than the one dated. Regardless, the deposits seem more a product of environment (shallow, sheltered, temperate water) than of a specific time.

In an attempt to determine if the foraminiferal clay deposits are present farther west, a hole was augered from the end of the shortest Navy pier, 1.3 miles from shore, in the central part of Sandy Hook Bay (pl. 1, hole 13). The hole bottomed at 107 feet below sea level and penetrated only bottom mud and alluvial deposits to a depth of 75 feet below sea level; the remainder of the hole was in the Englishtown Formation.

WEATHERING OF THE UNDERLYING SURFACE

Auger cuttings indicate that the Cretaceous deposits beneath Sandy Hook were subaerially weathered before deposition of the foraminiferal clay and the overlying and interfingering sand of the spit complex. Cuttings from depths of 143–152 feet in hole 3 (pl. 1) were moderate-yellowish-brown clay and sand of the Englishtown Formation, weakly cemented by iron oxide. Where penetrated beneath younger Cretaceous units elsewhere in the quadrangle, the fresh Englishtown is typically dark gray and contains pyrite. The Mount Laurel, where not weathered, is also typically dark gray, but cuttings of the formation from hole 8 (pl. 1) were weathered yellowish brown clayey sand. Cuttings of the Navesink Formation in hole 9 were less weathered, but this unit does not weather as rapidly as, or to the degree that, the others do.

Hole 10 at Sea Bright is directly opposite the mouth of the Navesink River (pl. 1). The Cretaceous surface is lower here than at hole 9, just to the north. If the river flowed directly out to sea before it was deflected by the spit-building process in the early stages of the formation of Sandy Hook, it could have eroded the Cretaceous surface below that to the north at hole 9.

BEACH SAND

Beach and dune sands make up all of Sandy Hook spit, the offshore bar from which the spit extends, the south shore of Sandy Hook Bay, and all or parts of some of the islands in the Navesink River estuary (pl. 1). Similar deposits along the shores of the Navesink River estuary were not mapped because of their narrow, thin, and discontinuous nature.

The beach sand is composed principally of quartz from underlying and nearby formations; however, glauconite grains mainly reworked from the nearby older formations, form as much as several percent of the beach sand. The glauconite grains impart a dark-green to dark-gray speckled appearance to the sand. Grain size ranges from clay to small pebbles, but the sand is mainly medium to coarse. The sand is fairly clean and loose; it therefore shifts about readily.

The dune sand is chiefly medium grained and better sorted than the beach sand. The dunes, which are mostly on Sandy Hook, are partly stabilized and fairly well covered by bushes and grass. The thickness of the deposits ranges from a few feet in the narrow strips along the shores to more than 160 feet on Sandy Hook (pl. 1).

Sandy Hook has lengthened appreciably during the past half century. Comparison of the "Geologic Map of New Jersey" (Lewis and Kümmel, 1912) with the U.S. Geological Survey, Sandy Hook 7½-minute quadrangle (revised 1954) indicates an increase in length of about 4,000 feet during that time interval. Aerial photographs (fig. 9) show that during the 21 years between 1940 and 1961, the spit was extended northward about 1,000 feet, and an area of about 65 acres was added to the end of Sandy Hook. Some of this growth was at the expense of the spit elsewhere, particularly along the open-ocean front. Yasso (1965, p. 704) reports a considerable loss of sand at Spiral Beach (fig. 10) and also from the crescentric beach at the lower right of

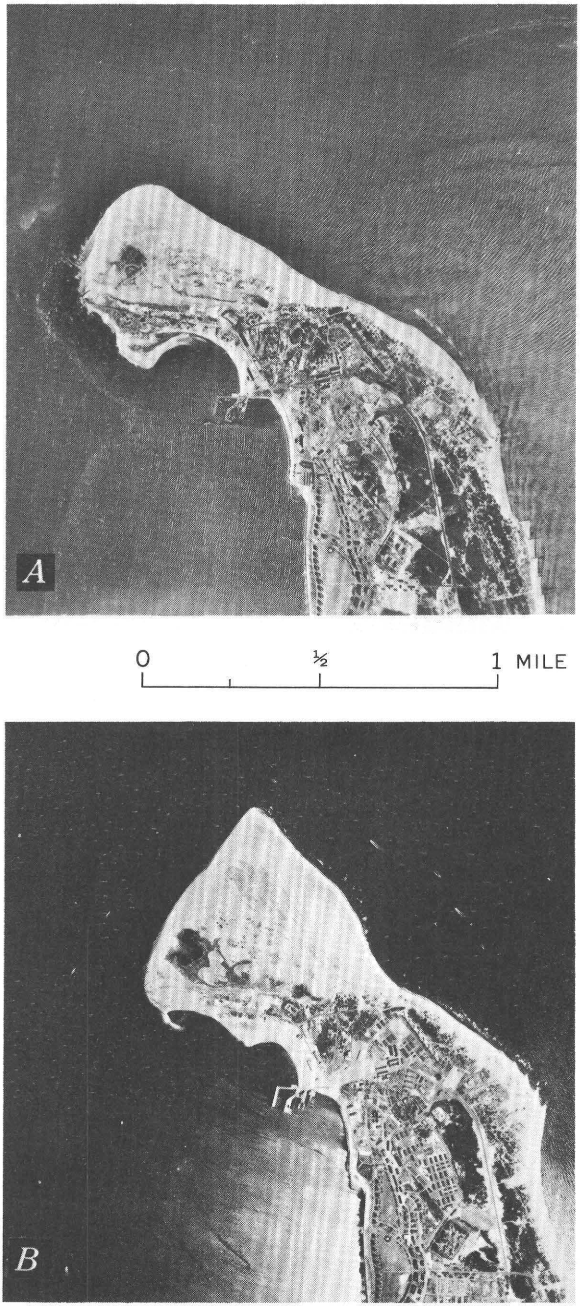

FIGURE 9.—Vertical aerial photographs of the north end of Sandy Hook spit. Photograph *A* taken in April 1940; *B* taken in May 1961 shows growth of spit. Photographs by Aero Service Corp.

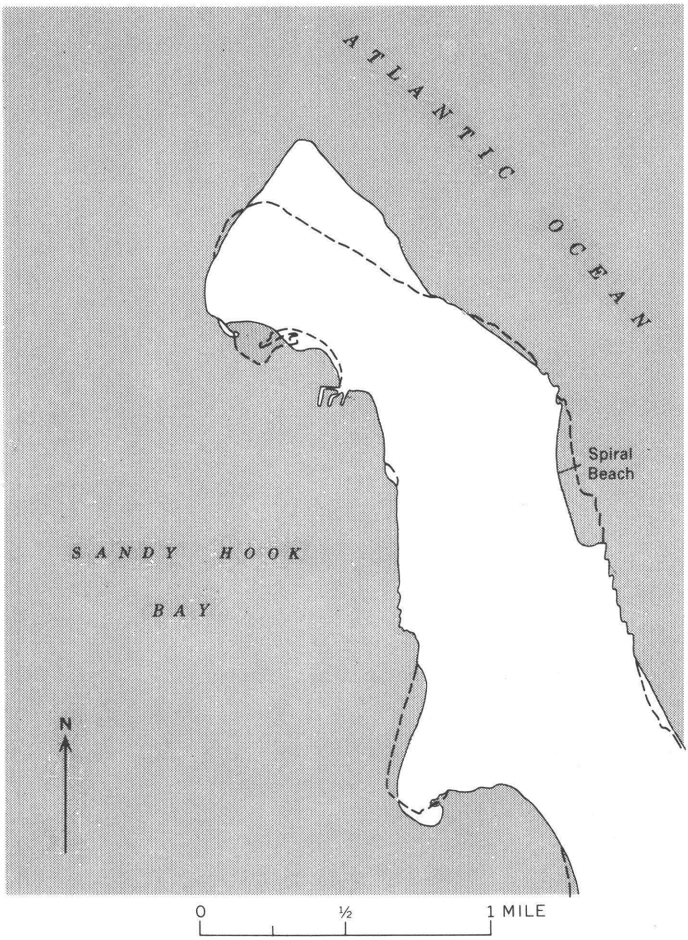

FIGURE 10.—Outline of the northern part of Sandy Hook spit. The dashed line represents the outline of the spit in 1940; the solid line represents the outline in 1961.

photograph *B* (fig. 9) during a storm in March 1962. A comparison of the outlines of approximately the northern third of the spit, as recorded on the vertical aerial photographs in 1940 and 1961, is shown in figure 10. It seems that more sand has been added to some parts of the spit than has been removed from others. Therefore, some sand must have been obtained from farther south and possibly some from the ocean bottom. Groins, along the northern part of the spit, and a large seawall, along the barrier bar and southern part of the spit, have been constructed to curtail the loss of sand from the open ocean side of Sandy Hook.

RECENT ALLUVIUM

Deposits in and along present streams and accumulations at the bases of some steep slopes are mapped as Recent alluvium. The deposits are derived mainly from the underlying and nearby formations and therefore reflect the local lithologies. The Recent deposits are composed largely of sand and gravel, but they contain silt, clay, and peat. The deposits are generally small in areal extent and thin (5–10 ft thick), but locally are as thick as 20 feet.

TIDAL-MARSH DEPOSITS

Tidal-marsh sediments include deposits in swampy areas near the mouths of streams and on the islands in the Navesink River estuary that are subject to tidal flooding. They consist largely of organic-rich saturated muds containing minor amounts of sand, and are characterized by aquatic plant growths. Some fill has been placed on these deposits; but because of their limited extent, the fills have not been mapped separately.

STRUCTURE

ATTITUDE OF BEDDING

The general strike of the pre-Quaternary formations in the Sandy Hook quadrangle is somewhat more eastward than it is farther southwest in New Jersey. This may be only a local variation from the regional structural trend, such as that in the area east of Trenton (Minard and Owens, 1966, p. B16–B19), or it may indicate a major strike change in the northern part of the Coastal Plain.

The Cretaceous units strike about N. 50–60° E. and dip southeast, 40 feet per mile. The Tertiary units strike about N. 60–70° E. and usually dip more gently southeast than the Cretaceous units. There seems to be some structural anomaly in at least the Tertiary units. The base of the Hornerstown Sand is nearly horizontal near Hilton (pl. 1), but the dip increases sharply southeastward, in the hills south of Highlands. The base of the formation near the Hart horzontal control station is 100 feet lower than it is 1 mile northwest. This relationship may be due to an increase in dip, or it may be the result of displacement along faults or slumps. Several northeast-trending lines in the groups of high hills south of Highlands, as seen on aerial photographs, strongly suggest the presence of faults or slumps. Because of the scarcity of outcrops and the highly dissected topography, which prevents augering in critical areas, it was not possible to demonstrate the existence of faults or slumps there.

SLUMP BLOCKS

DESCRIPTION

There are several slump block in the bluffs in the quadrangle. The two most clearly defined blocks are in the bluff along the south side of Sandy Hook Bay between Atlantic Highlands and Highlands (pl. 1). These blocks presently are stabilized, and about 20 houses are built on their upper surfaces, mainly on the western block. The long axes of the blocks parallel the shoreline. The western block is 400 feet wide and 2,500 feet long; the eastern block is 450 feet wide and 1,400 feet long. Both blocks have the curved convex inner outline (which fit into the concave scarp face) common to slump blocks (fig. 11) and have rotated against the bluff. These features are typical in the Toreva-block of Reiche (1937, p. 538) and the slump blocks of Strahler (1940, p. 288–289) and Sharpe (1938, p. 68). Similar slump blocks in similar beds, on the north shore of Long Island, are shown and described by Fuller (1914, p. 55–56). Fuller refers to these as "landslides," but the term "slump block" is used here to emphasize downward displacement and backward rotation.

Of the two blocks along Sandy Hook Bay, the eastern block (A, figs. 11 and 12) is the most clearly defined and best exposed. Parts of five formations, which have been downdropped as much as 85 feet from the outcrop in the main bluff face above, are exposed in a cut through a small hill on the upper surface of the block. The block is actually composed of at least two separate slump blocks; one which included the entire mass, and a secondary one which downdropped farther than the original block (fig. 13). This secondary block is the one in which parts of four formations (Tinton, Hornerstown, Vincentown, and Cohansey) rest on a fifth (Shrewsbury Member of the Red Bank Sand). A hole was augered at the base of the bluff, at about the midpoint of the main slump block, to determine in which formation the failure occurred. The location of the hole (16) is shown on the geologic map (pl. 1) and in the cross section in figure 13; the log of the hole is given on plate 2. The Navesink is in place in the bluff on both sides of the block. The first in-place formation penetrated in the auger hole was the Wenonah, at a depth of 30 feet. The slump, therefore, probably occurred in the Navesink and Red Bank, and much of the toe has been removed by erosion. The present erosion slope of the bluff face apparently continues for some distance below the present beach deposits.

A third, less clearly defined, slump block is present in the bluff just west of Locust Point (pl. 1) along the north shore of the Navesink River estuary. Slump features are not exposed in this block, as they are in the eastern block along Sandy Hook Bay; nor is there a good scarp

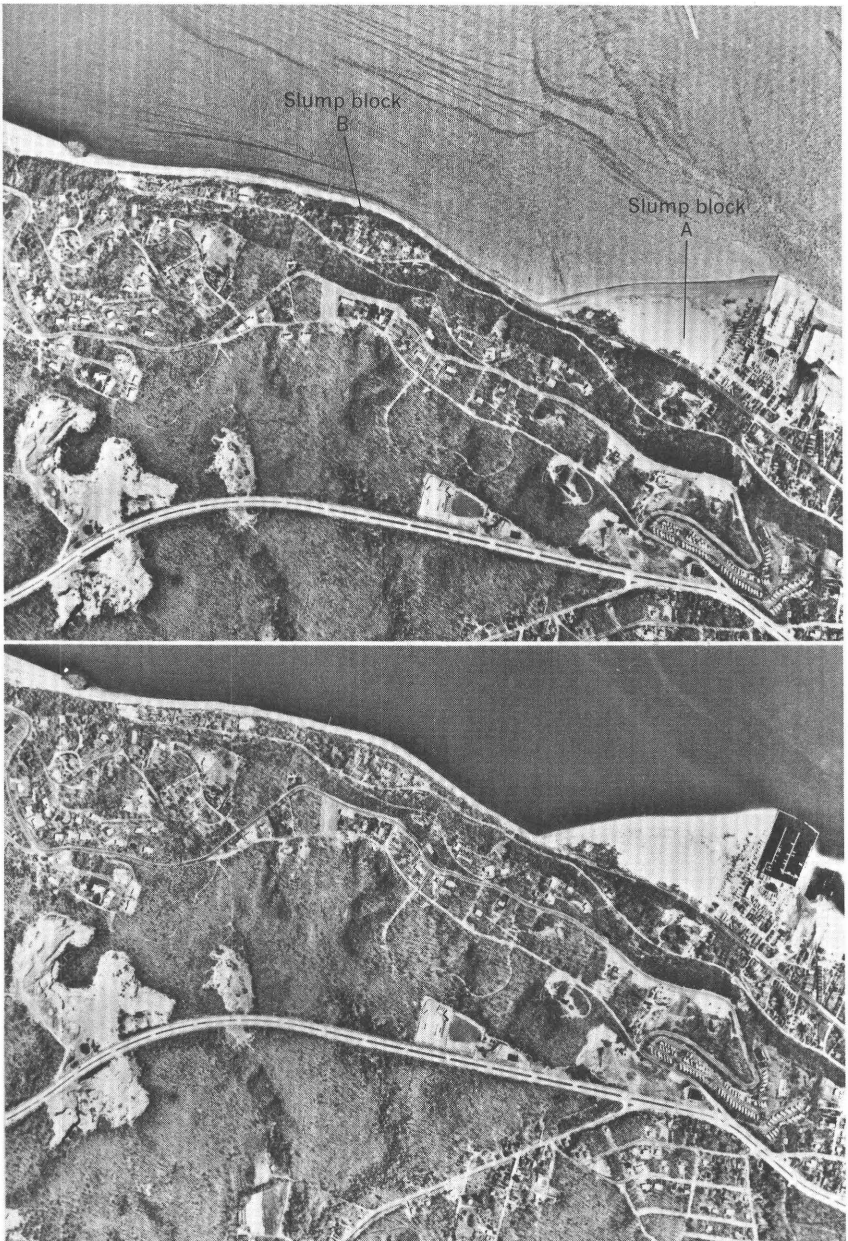

FIGURE 11.—Stereoscopic pair of vertical aerial photographs showing slump blocks along the steep bluff bordering the south shore of Sandy Hook Bay. Top is north; scale 1:20,000. Photographs by Aero Service Corp.

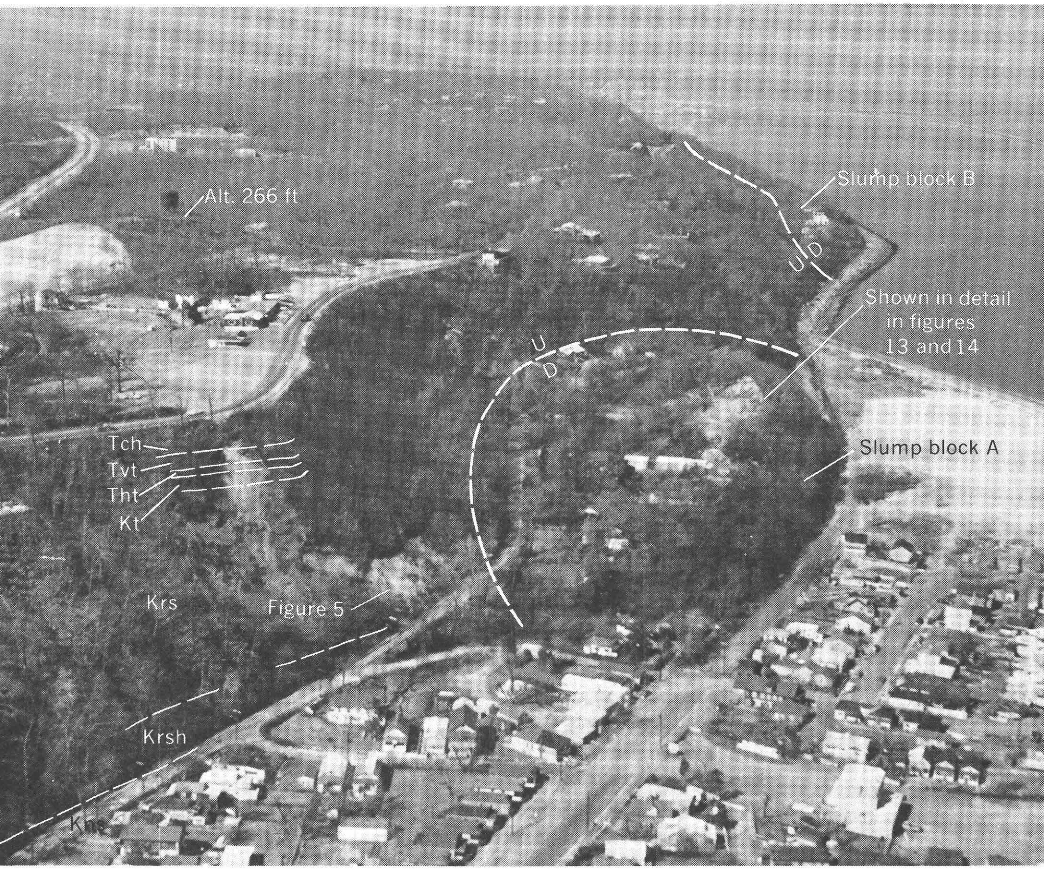

FIGURE 12.—Oblique aerial photograph (looking west) of slump blocks A and B. The concave scarp behind block A (outlined by road on top) and the outward bulges at the bases of both slump blocks can be seen. The units at the top of the bluff, on the left, are exposed in the cutbank in block A, where they have been displaced 85 feet vertically downward (fig. 13). See figure 13 for explanation of letter symbols.

outline like both of those along Sandy Hook Bay. However, the base of the Sandy Hook Member of the Red Bank is exposed on both sides of the block (pl. 1) as much as 7 feet above water level, whereas in the block, the base of this unit is several feet below water level. The block has apparently dropped about 15 feet.

CROSS SECTION

A cross section of slump block A, just west of Waterwitch, is shown in fig. 13. Part of the slump, or fault plane, of the small secondary block is shown in figure 14; the fault plane dips about 40° N, and

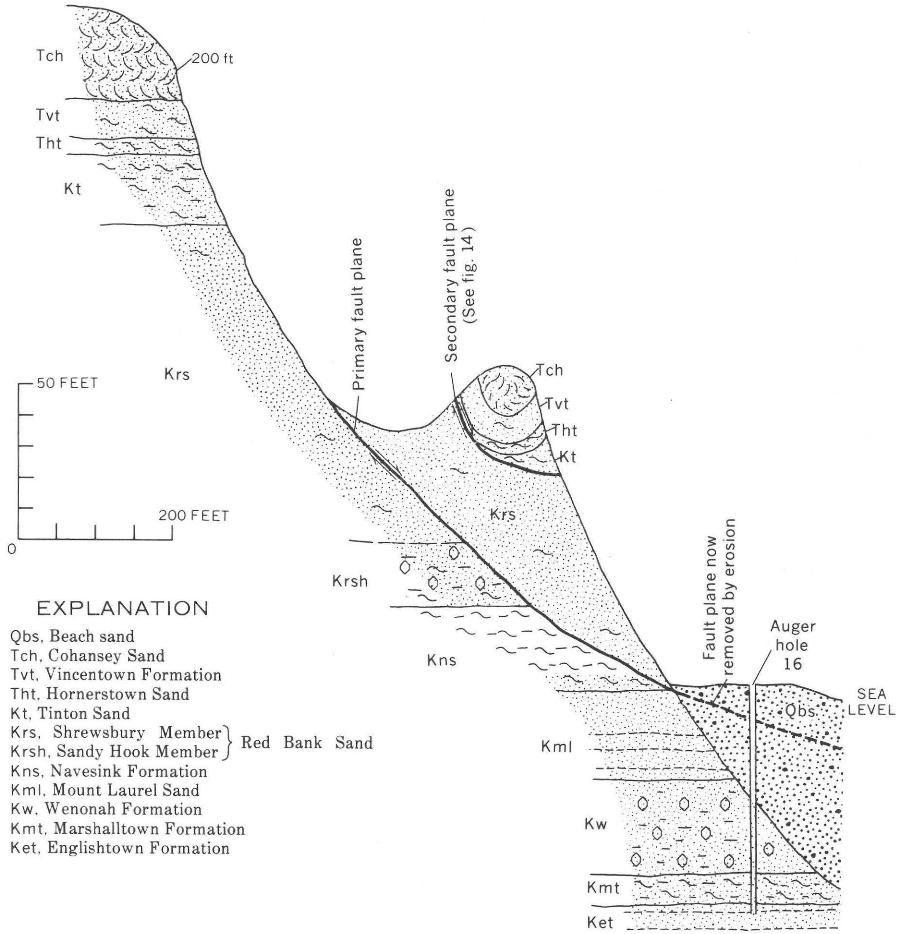

FIGURE 13.—Cross section (looking west) of slump block A (figs. 11, 12) in the bluff just west of Waterwitch. Vertical displacement of the small secondary block is about 85 feet. Vertical exaggeration × 4. See plate 1 for explanation of lithologic symbols. See plate 2 for log of auger hole.

bedding in the formations above has been dragged nearly parallel to it. The rotation of the block has caused the beds in the outer edge of the block to dip in toward the bluff at about 40–45°. An apparent inclined layering that resembles bedding has been imparted to the massive sand of the Shrewsbury by the drag mechanism. This can be seen as alternate light-and-dark layering in figure 14. The Hornerstown lies above this layered sand. A wedge of Tinton underlies the outer thicker part of the Hornerstown, and parts of the Vincentown and Cohansey are above (fig. 13).

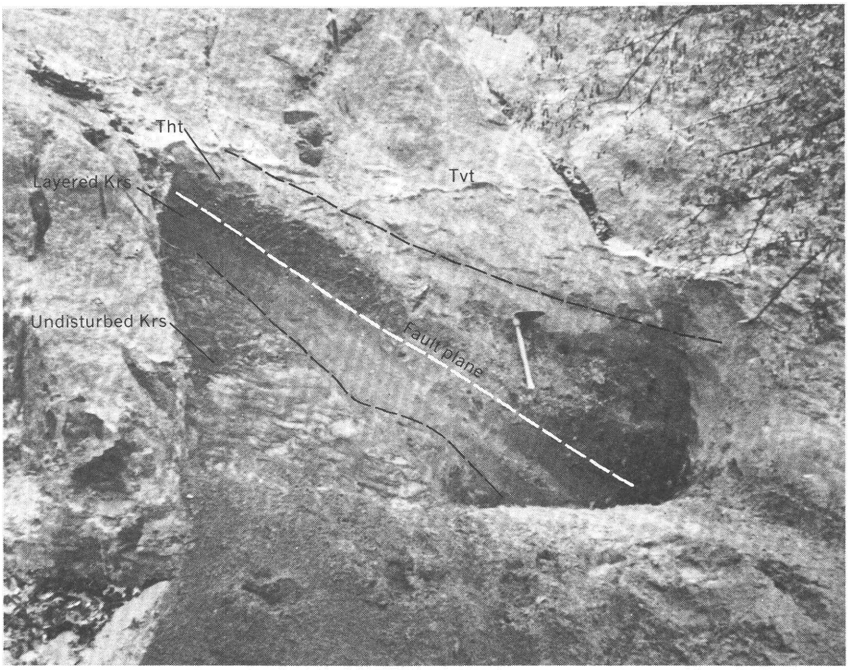

FIGURE 14.—View (looking west) of fault plane bounding small secondary block in slump block A (figs. 11–13). See figure 13 for more complete slump-block relations. Layering in the Shrewsbury Member (Krs) of the Red Bank Sand is the result of drag. Tvt, Vincentown Formation; Tht, Hornerstown Sand.

CAUSES

Fuller (1914, p. 55) attributed the landslides along the north shore of Long Island primarily to wave action from the open ocean. These slides probably are very recent because the scarps are bare, fresh, and little modified (Fuller 1914, pls. XII–XIV).

The blocks in the Sandy Hook area most likely slumped when the sea was actively eroding and undercutting the base of the bluffs, possibly at a sea level lower than the present one. Wave action along the bases of the bluffs is presently weak, because the barrier bar and Sandy Hook spit effectively block waves from the open ocean.

If the blocks slid as a result of undercutting by waves, the slumping probably occurred before the formation of the barrier bar and spit. The radiocarbon date from plant material, obtained from 90 feet below sea level beneath Sandy Hook (just north of Spermaceti Cove), indicates that the spit did not extend this far north 9840 B.P. ±300 years. Therefore, the blocks probably date from about that time or earlier. Also, slump blocks, along the Navesink River and the steep headland at its mouth, may have supplied some of the large quantities of sand needed to build the bar and spit a distance of 5–6 miles northward and to a thickness of at least 160 feet near the north-south midpoint of the spit (pls. 1 and 2, auger hole 2).

ECONOMIC ASPECTS

GROUND WATER

Large quantities of ground water are available from the formations which underlie the Sandy Hook quadrangle, particularly those which do not crop out. There are many deep wells, most of which bottom in the water-bearing sands of the Raritan Formation at depths between 400 and 1,000 feet. Two presently active wells at Fort Hancock on Sandy Hook (pl. 1) have a capacity of 300–500 gallons per minute. One well flows at the surface at the rate of 5–20 gallons per minute. The several military installations, towns, and industrial complexes obtain an adequate water supply from wells in the Raritan Formation, which yields some of the best quality water in the area. The Englishtown Formation has a large ground water potential, which at present is probably best developed in this area. The chemical quality of the water and the amount of dissolved solids are discussed by Seaber (1962). Shallow wells in the Shrewsbury Member of the Red Bank Sand and the Mount Laurel Sand yield an adequate water supply for individual homes. Many springs, some of which are used for domestic supplies, flow from the base of the Red Bank Sand.

SAND AND GRAVEL

Abundant sand is available from several of the formations, but the Cohansey contains the best quartz sand and has the least silt and clay (table 1). The Cohansey also contains several percent gravel, most of which is composed of hard quartz and sandstone pebbles.

The hole augered at the end of the shortest (1.3 miles long) Navy pier (pls. 1 and 2, hole 13), gave evidence that the bottom of Sandy Hook Bay may be an important source of sand and gravel. Much of the bottom of the entire bay area (Sandy Hook and Lower New York Bays in the quadrangle, and Raritan Bay to the west) may be underlain by similar sand and gravel deposits. If so, the deposits probably could be easily dredged. Some particles of Triassic shale, which were found in hole 13, would detract from the quality of the material but should not seriously impair its use for some purposes.

BUILDING STONE

Some of the coarse sand and gravel in the Cohansey is firmly cemented by iron oxide. Much of this rock is in uniform layers and has been used extensively in the past for the construction of buildings and retaining walls. Much of the stone could be quarried as part of a sand-and-gravel operation.

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