Upper Cenozoic Sediments of the Lower Delaware Valley and the Northern Delmarva Peninsula, New Jersey, Pennsylvania, Delaware, and Maryland

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1067-D

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By JAMES P. OWENS *and* JAMES P. MINARD

SURFACE AND SHALLOW SUBSURFACE GEOLOGIC STUDIES IN THE EMERGED COASTAL PLAIN OF THE MIDDLE ATLANTIC STATES

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Two periods of gravel sedimentation have been outlined—one late Miocene and the other late Pleistocene

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By JAMES P. OWENS and JAMES P. MINARD

ABSTRACT

The "yellow gravels" referred to by R. D. Salisbury in 1898 and the "Trenton gravel," as defined by H. C. Lewis in 1880, were investigated along the inner edge of the New Jersey Coastal Plain in southern New Jersey and in the northern Delmarva Peninsula.

The highest level deposits, the Beacon Hill gravel, are found on only the highest hills in the New Jersey Coastal Plain. Their distribution suggests deposition from north to south across the plain. After deposition of the Beacon Hill, probably in middle or late Miocene time, a narrow valley was formed paralleling the inner edge of the New Jersey Coastal Plain between Raritan Bay and Camden. South of Camden, the valley broadened, covering much of southern New Jersey. The deposits in this valley are largely the Bridgeton Formation as we have redefined it. A second narrow valley was entrenched through the Bridgeton between Trenton and Salem, N.J. This valley broadens and covers much of the northern Delmarva Peninsula west of the Delaware River. The fill in the valley is largely the Pensauken Formation, as we have redefined it in our report. Collectively, the Beacon Hill, the Bridgeton, and the Pensauken were originally the "yellow gravels" of Salisbury. These deposits are all fluviatile in origin and were largely formed as a series of steplike downcutting channels.

The Delaware Valley between Trenton and the lower Delaware Bay region is occupied by the "Trenton gravel," which is below the average level of the "yellow gravels." Two units recognized throughout the area and informally named the Spring Lake beds and the Van Sciver Lake beds are lithologically distinct from the "yellow gravel" formations. The lithologies of the Spring Lake beds and the Van Sciver Lake beds are much more heterogeneous than those of the older formations. These two units, particularly, contain much greater amounts of silt and clay, often in thick beds. The depositional environments associated with the two units include fluviatile, estuarine, and marginal marine. Both these units are interpreted to be late Pleistocene (Sangamonian) in age.

INTRODUCTION

The late Tertiary and Quaternary was a time of extensive erosion of the inner emerged part of the northern Atlantic Coastal Plain, when large volumes of the Coastal Plain sediments and the adjacent Piedmont rocks were stripped away and transported down the river systems to the now-submerged shelf. One large valley that served as a drainageway for these sediments paralleled the entire edge of the New Jersey Coastal Plain. This valley or lowland, which was called the "great Amboy-Salem trench" (Valley), by MacClintock and Richards (1936) is approximately 160 km (100 miles) long and a maximum of 40 km (25 miles) wide. As interpreted by nearly all investigators, the sediments within this valley are a record of multiple downcuttings and infillings associated with Quaternary glaciations in the Eastern United States (Salisbury and Knapp, 1917: MacClintock and Richards, 1936, and Peltier, 1959). Actually, no firm evidence supports any specific age for most of the valley fill, but traditionally, these sediments are considered to be Quaternary.

In a general sense, the sediments in the valley that were not derived from older formations in the Coastal Plain can be separated into two general types—sediments that are extensively iron oxide stained and are referred to as the "yellow gravels" (Salisbury, 1898) and sediments that show little iron oxide staining, the "Trenton gravel" as defined by Lewis (1880).

The surficial deposits in the area in and around Trenton, N.J., were mapped by the authors at a scale of 1:48,000 (Owens and Minard, 1975). The information we obtained permitted us to evaluate the valley-fill stratigraphy as mapped by Salisbury (1909) and described later in great detail (Salisbury and Knapp, 1917).

Using our data at Trenton as a basis, we made a detailed reconnaissance throughout the rest of the "great Amboy-Salem trench" (valley) of MacClintock and Richards (1936) and then into the gravel-capped uplands of southern New Jersey and west of the Delaware River in the northern Delmarva Peninsula (fig. 1). Our studies,

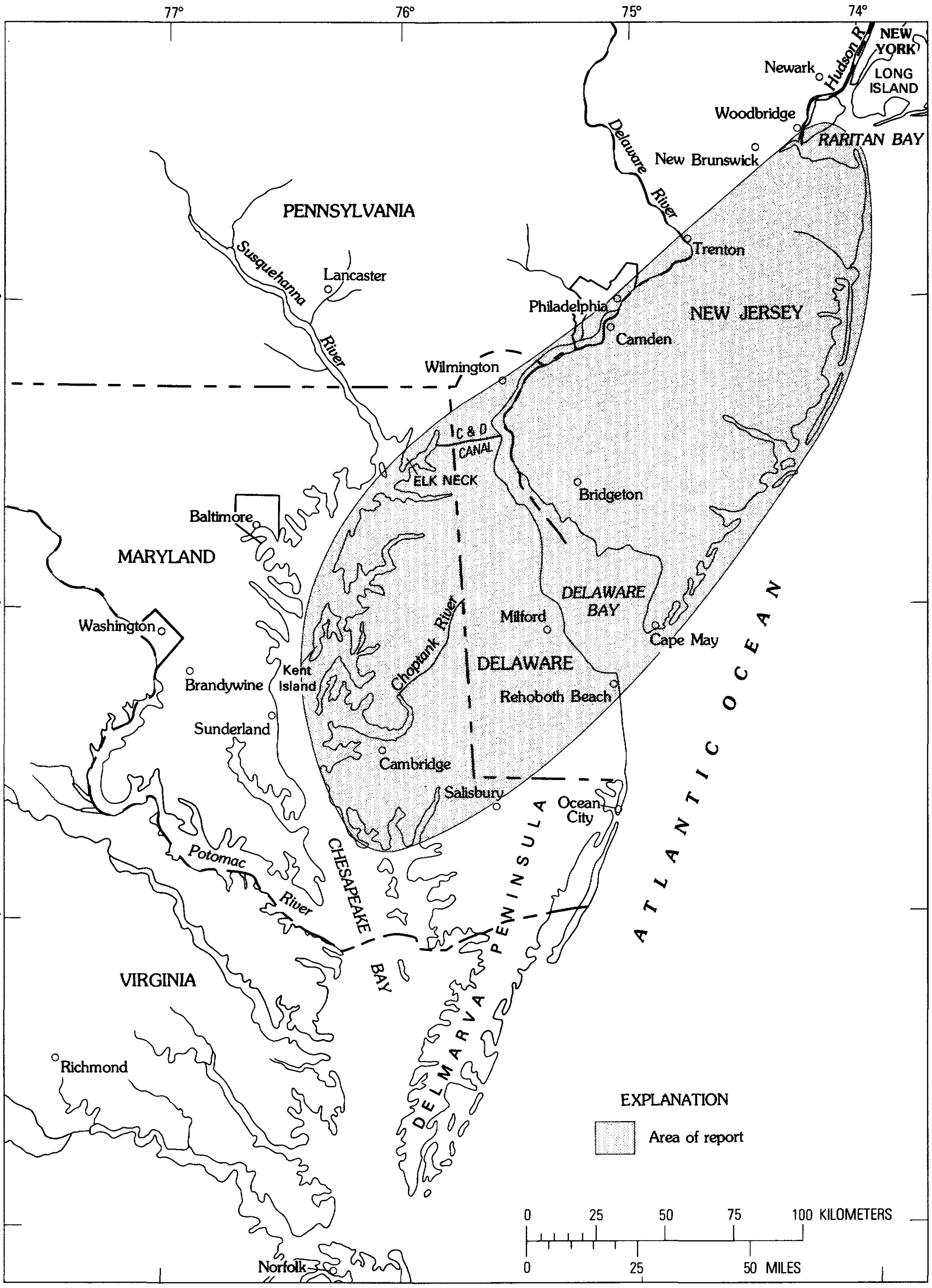

FIGURE 1.—Outline of area (patterned) investigated in this report.

which concentrated on the fluviatile and, to a lesser extent, the estuarine facies of the valley fill, are detailed in this report. The marine beds of presumed Quaternary age that fringe much of the southern Delaware-Maryland coast have been discussed by Owens and Denny (1978).

Our study is highly speculative in many places because only reconnaissance mapping was done in areas discussed in this report, as opposed to the detailed mapping carried out in areas discussed in other chapters in this series.

PHYSIOGRAPHY

The area covered in our report includes parts of two major physiographic provinces—the Atlantic Coastal Plain and the Piedmont. These provinces, however, are too generalized to be of specific use at the scale of our study; we found it convenient to further subdivide the landforms in the Coastal Plain province. Earlier, the Coastal Plain was divided into three subprovinces, as shown in figure 2 (Owens and Minard, 1960; Minard and Rhodehamel, 1969). We have modified these earlier versions into the lowland, intermediate upland, and upland Coastal Plain subprovinces (fig. 3).

Altitudes in the lowland subprovince range from 0 to 21 m (70 ft) above sea level. This subprovince forms a narrow lowland fringe along the Atlantic coast and up the larger stream valleys of this coastal region. The lowland, however, is best developed along Delaware Bay and the Delaware River as far upstream as Trenton, N.J. The higher altitudes (ca. 21 m; 70 ft) are mostly near Trenton. Smaller areas at approximately this altitude fringe the lower Delaware River and parts of Delaware Bay. Most of the lowland in this region is less than 7.4 m (25 ft) above sea level. This part of the lowland is separated from the higher elevations by a scarp that has a toe 6 to 7.4 m (20 to 25 ft) above sea level. The scarp, however, is not continuous, having been removed from some areas by the many small streams that cross it. Most of these stream valleys and large areas at lower altitudes are covered by tidal marsh and swamp deposits. Areas at higher altitudes (above 7.4 m; 25 ft) are much sandier and better drained than are the lower lying areas.

The intermediate upland has altitudes that range from 15 to 55 m (50 to 180 ft). This subprovince is separated into two major areas. One area is between Trenton and South Amboy in the Amboy-Salem trench of MacClintock and Richards (1936); the other includes most of southern New Jersey.

In the Trenton-Amboy area, where the intermediate upland is less dissected, altitudes range from 30 to 55 m (100 to 180 ft). The higher altitudes are most common along the southeastern side of the valley. Two major exceptions to this distributional pattern, however, are near Franklin Park and just south of Trenton, where altitudes reach nearly 49 m (160 ft). The intermediate upland between Trenton and South Amboy is locally very dissected, producing a hilly topography, particularly near the Raritan River in the north and the Delaware River in the south. The rest of the area is relatively flat and is characterized by a sandy surface. The largest area of the intermediate upland is in southern New Jersey. Here,

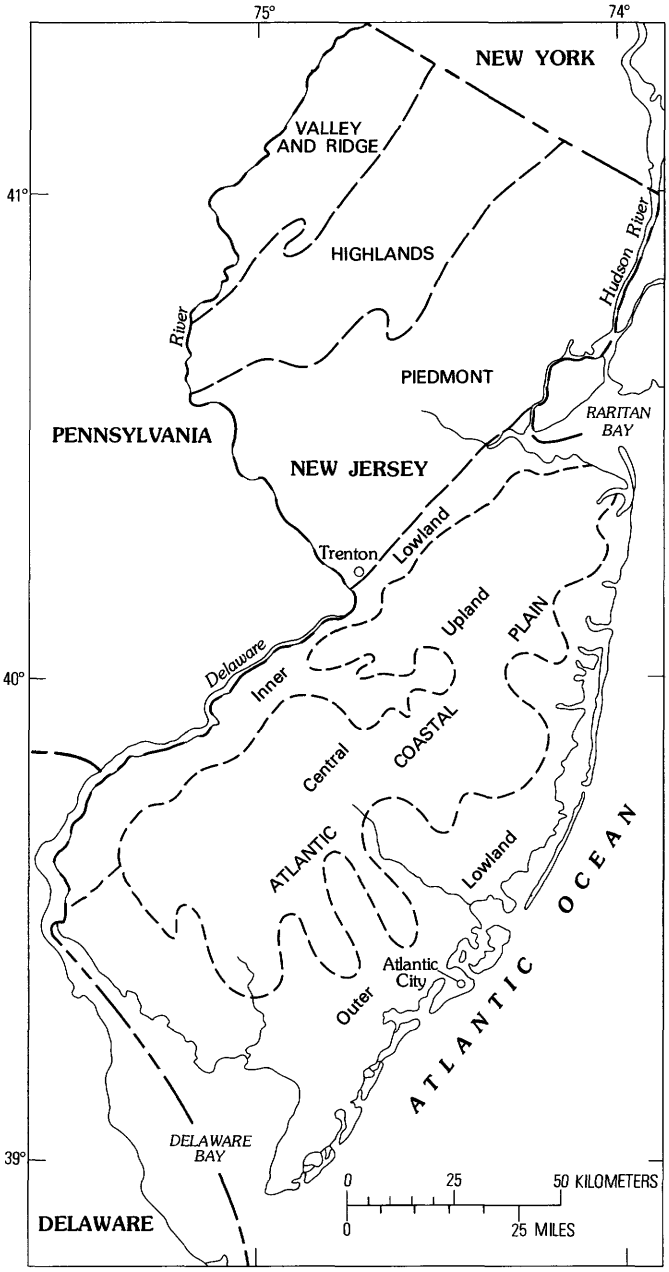

FIGURE 2.—Generalized map of physiographic provinces and subprovinces of New Jersey (Minard and Rhodehamel, 1969).

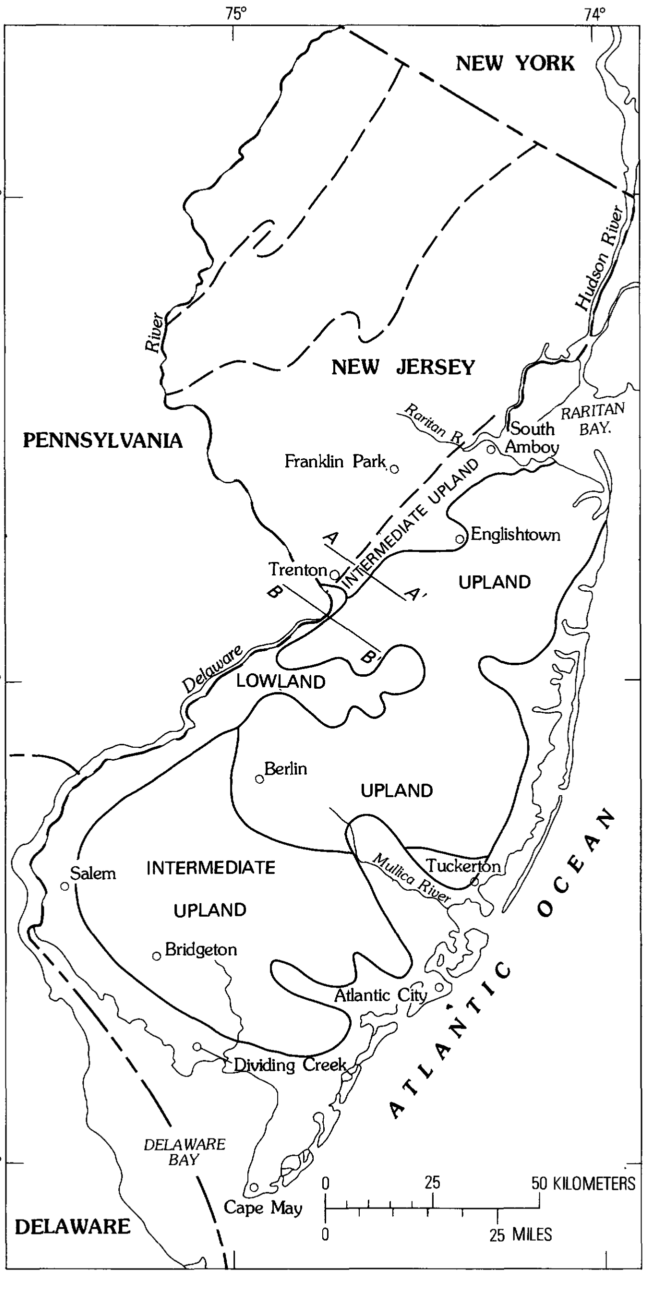

FIGURE 3.—Generalized map of physiographic provinces and subprovinces of New Jersey modified from Owens and Minard, 1960, and Minard and Rhodehamel, 1969. *A–A′* and *B–B′* are approximate locations of cross sections shown in figure 8.

altitudes range from nearly 46 m (150 ft) northwest of Salem to nearly 15 m (50 ft) just west of Atlantic City. Near Berlin, however, altitudes rise to nearly 55 m (180 ft).

The intermediate upland is bounded on the west, south, and east by the lowland. On the north, this subprovince abuts against the higher altitudes of the upland subprovince. This junction is marked by a gently eastward sloping, highly dissected scarp. Many streams have cut into this intermediate upland and have produced a generally hilly terrain. The largest of these streams, the Mullica River, has cut a broad valley across the intermediate lowland and well into the bordering upland. Much of the upland and the intermediate upland has been removed by this stream. A small segment of the intermediate upland has been separated from the main part of this subprovince by this river. The surface of the intermediate upland is typically sandy and well drained.

The upland subprovince has altitudes ranging from 61 m (200 ft) to nearly 122 m (400 ft). This subprovince covers most of the central and northern New Jersey Coastal Plain. The upland areas are more dissected than either of the other two subprovinces. This upland is very hilly and is characterized by isolated high hills surrounded by lower lying areas. Where intact, the upland surface is typically gravelly. Some of these surfaces are littered by iron oxide-cemented blocks.

REGIONAL GEOLOGIC SETTING

A generalized lithologic map of the rocks bordering the inner lowland is shown in figure 4. The Piedmont terrain along the northwestern part of the valley is a complex mixture of many rock types. Between Trenton and New Brunswick, the inner lowland subprovince is bordered by sedimentary rocks of Triassic age, mostly fine- to coarse-grained arkose of the Stockton Formation and, less commonly, red shale and red sandstone of the Brunswick Formation. Locally, large masses of diabase crop out near Princeton, N.J., and are a potential nearby source of mafic materials, particularly to the inner lowland in this region. These rocks form part of the Triassic lowlands section of the Piedmont physiographic province. From Trenton, N.J., to Wilmington, Del., the crystalline rocks crop out; these rocks are mainly metamorphic but also include some igneous rocks and a lesser amount of metasedimentary rocks of Precambrian and early Paleozoic age. Most of these rocks are very feldspathic, and locally some are abundantly micaceous, particularly the schist and gneiss of the Wissahickon Formation. These rocks are part of the Piedmont Upland section of the Piedmont physiographic province. Sediments derived from the Triassic and Jurassic basin or from the older crystalline rocks have a high feldspar and mica content; hence, they normally provide immature sediments to the late Cenozoic valleys.

The Coastal Plain rocks of Late Cretaceous through late Tertiary age are a second major sediment source. These sediments are generally found to the east and southeast in addition to underlying most of the late Cenozoic valleys. In this area, the Coastal Plain sediments can be separated into three gross lithologic units: an up-

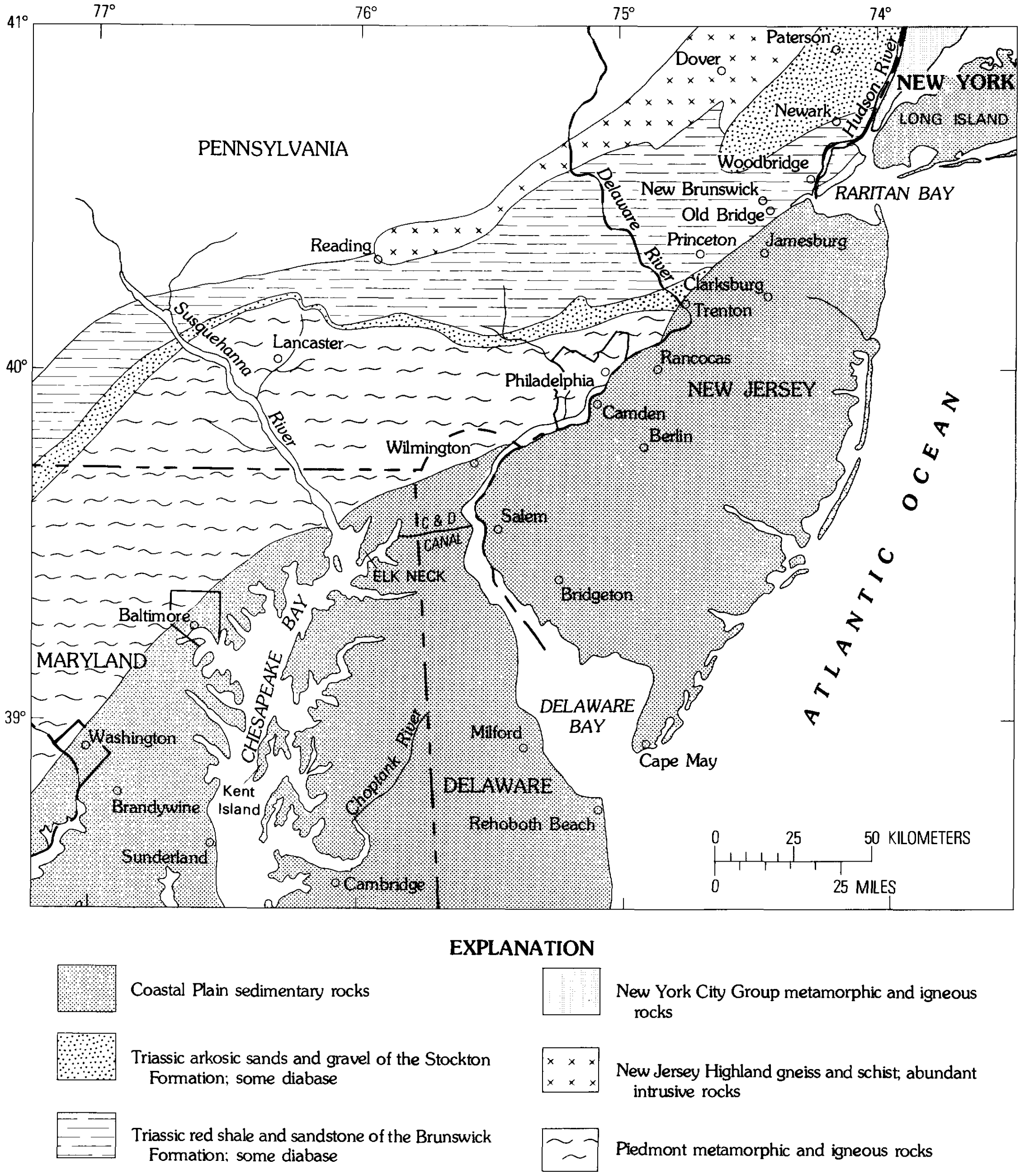

FIGURE 4.—Generalized lithologic map of rocks bordering the physiographic subprovinces shown in figure 3.

per sheet of quartz sand of Miocene beds; a middle interbedded clay and sand sequence, which contains large concentrations of glauconite and mica in addition to quartz and feldspar, in the Upper Cretaceous to Eocene beds; and a lower interbedded clay and sand sequence in which all the sand is quartz, in the lower part of the Upper Cretaceous beds. In summary, the Coastal Plain strata contributed large amounts of quartz and glauconite sand and lesser amounts of feldspar and mica to the inner lowland. Significant concentrations of feldspar are found in many of the formations (as much as 15 percent of the sand fraction), but much of the feldspar is weathered and probably could not survive any extensive recycling. It is, therefore, the green glauconite sand that is unique to the Coastal Plain rocks. Its presence and quantity in the surficial alluvium is one of the best measures of contribution from the Coastal Plain formations.

Additionally, the Coastal Plain formations were a major source of clay and silt found in the alluvial-valley deposits. The types of clay contributed by each of the Coastal Plain formations were discussed in an earlier publication (Owens and Sohl, 1969).

A third major sediment source is the glaciofluvial deposits derived from the areas north and northwest of the alluvial valleys. These deposits are distinguished from those of the other major sediment sources by the quantity of gravel and the large variety of immature rock types that they contain, such as limestone, and the abundant rock fragments in the sand fraction.

Some of the alluvial sediments may have been derived from more distant sources such as the folded Appalachians, but any contribution from such sources probably was small.

STRATIGRAPHY

The surficial sediments of the Trenton area were mapped in two major classes, those sediments largely derived from the Coastal Plain and those contributed from other major sources outside the Coastal Plain (Owens and Minard, 1975). This report will discuss mainly sediments derived from outside the Coastal Plain, or essentially those in the lowland and intermediate lowland. The non-Coastal Plain sediments have been separated into five units, four of which constitute the bulk of the surficial sediment in these subprovinces. The fifth, the Beaçon Hill Gravel, as defined by Kümmel and Knapp (1904), is a series of isolated gravel patches, generally small, which crop out on many of the highest hills within the upland subprovince.

Salisbury and Knapp (1917) divided the surficial sediments of New Jersey that are below the general level of the Beacon Hill into three formations: Bridgeton, Pensauken, and Cape May. The name Cape May seems least appropriate of the three for widespread use because it largely applies to the marine beds cropping out only in the lower Delaware River valley near the coast. Additionally, we will not discuss the fill of the present Delaware River and Bay. Some of the characteristics of these sediments have been discussed by Owens and others (1974).

The stratigraphy of the valley-fill sediments in those units, as defined above, is, from youngest to oldest, as follows:

Stratigraphy in this report	*Comparable stratigraphic nomenclature used in 1975 by Owens and Minard*
Van Sciver Lake bed	"Graywacke 1."
Spring Lake beds	"Graywacke 2."
Pensauken Formation	"Arkose 1."
Bridgeton Formation	"Arkose 2."
Beacon Hill Gravel	"Upland gravels."

It is very difficult to apply classical formation techniques to largely thin, often patchy fluviatile-estuarine deposits in which facies changes are common. Because of the highly dissected nature of the older formations, correlation of isolated deposits over widely spaced areas was necessary in order to reconstruct the original shape of these formations. Some of the conclusions reached in this reconstruction, therefore, are speculative. Use of the term "formation" with a geographic name, however, is a good method for describing units that actually are a combination of lithology (rock stratigraphic) and areal position.

BEACON HILL GRAVEL ("UPLAND GRAVELS")

The name Beacon Hill was first applied to the upper gravelly beds of the "yellow gravels" by Salisbury (Salisbury and others, 1894). The name was subsequently dropped but was resurrected by Kümmel and Knapp (1904). Owens and Minard (1975) referred to these deposits as "Upland gravels."

DISTRIBUTION AND LITHOLOGY

Many of the highest hills in the inner Coastal Plain upland, at altitudes of approximately 61–105 m (200 to 350 ft), are capped by small patches of interbedded sand and gravel of varying thickness (to 12 m; 40 ft). Although these coarse clastic deposits are considered by most geologists to be Pliocene in age, no datable materials have been found in them. Their presumed antiquity is based upon their upland topographic distribution and upon their apparent advanced state of weathering, as shown by abundant iron oxide as grain coatings and cementation, weathered chert, and quartz clasts.

This upland gravel crops out at only a few localities in the New Jersey Coastal Plain, especially in a narrow band from Clarksburg on the north to Warren Grove on the south (Lewis and Kümmel, 1912, and fig. 5). In the highlands of the Clarksburg area, these beds are well exposed in several pits(Minard, 1964). Here, as elsewhere, the gravel overlies the Cohansey Sand (Miocene); these gravel deposits form channel-shaped bodies that are unconformable on the older unit (fig. 6). The Cohansey is certainly post-Kirkwood (middle Miocene) in age and younger than the Yorktown (Pliocene); it therefore will be referred to as Miocene in age in this report. Throughout this area, the Beacon Hill is as much as 12 m (40 ft) thick. Typically, the upper beds are irregularly cemented by iron oxide into hard consolidated masses. These ironstone masses commonly overlie either extensively cross-stratified light-gray to reddish-brown sand or, more commonly, horizontally bedded sandy gravel (fig. 7). Most of the gravel in these lower beds is 2.5 cm (1 in.) in average diameter. Horizontally stratified sandy

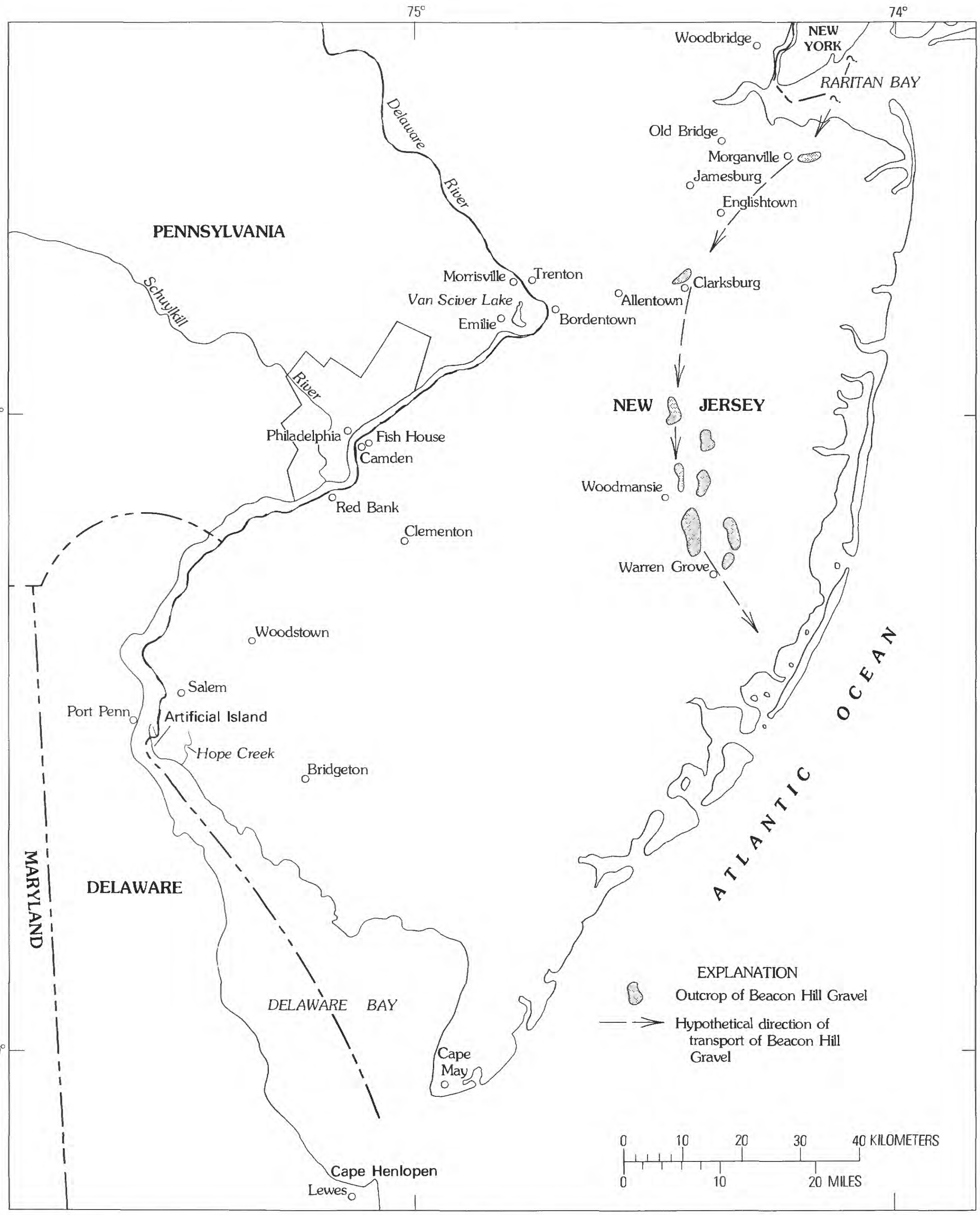

FIGURE 5.—Distribution of Beacon Hill Gravel in New Jersey (modified from Lewis and Kümmel, 1912; revised by Johnson, 1950).

FIGURE 6.—Beacon Hill Gravel unconformably overlying Cohansey Sand 1.4 km (0.9 mile) northeast of Clarksburg, N.J. Shovel head marks contact.

gravel is characteristic of many of the Coastal Plain upland deposits southwest of New Jersey (Schlee, 1957; Owens, 1969).

PETROLOGY

Pebble counts in the pits near Clarksburg have shown that quartz, quartzite, and chert are the principal constituents of the Beacon Hill. The presence of chert, locally in large concentrations, is also typical of the upland deposits outside New Jersey (Schlee, 1957; Owens, 1969). The sand in the upland deposits is nearly all quartz, and the nonopaque minerals in the heavy-mineral assemblages are dominated by the more stable minerals such as zircon, staurolite, and sillimanite. Overall, the sediments in the Beacon Hill are mature.

FIGURE 7.—Exposure showing massive to poorly developed horizontal stratification in Beacon Hill Gravel 5.4 km (3.4 miles) northeast of Clarksburg, N.J. Pebbles are mainly chert.

MODE OF DEPOSITION AND ORIGIN

The similarity in composition, altitude, and stratification of the upland deposits in the Middle Atlantic States suggests a similar mode of deposition and possibly a similar time of origin (probably Miocene). Essentially, this idea was suggested by McGee (1888) in his definition of the highest level gravel throughout the Atlantic Coastal Plain.

All investigators of the gravel agree that it is subaerial in origin. Schlee (1957) favored a fluviatile origin for these beds; others (Campbell, 1931; Owens, 1969) have suggested an alluvial-fan origin. If the Beacon Hill Gravel is a stream deposit, then the parallel stratification would indicate deposition within the upper-flow regime and therefore in streams that had a high discharge (Harms and Fahnestock, 1965). We would favor this interpretation for the Beacon Hill rather than that of an alluvial-fan origin. The absence of fossils, animal burrows, and beach-stratification, and the presence of a channel seem to preclude the possibility of a marine environment.

The distribution of the Beacon Hill sediments in New Jersey suggests transport from Morganville on the north to Warren Grove on the south (fig. 5). This directional pattern indicates a probable ancestral Hudson River transport for these deposits. The high concentrations of chert, low feldspar content, and mature heavy-mineral assemblage point to a probable Appalachian Mountain source. It seems likely that in post-Cohansey time (Miocene), a southward-flowing stream from the present Hudson River valley flowed across the New Jersey Coastal Plain to the Atlantic Ocean. These sediments predated, therefore, the formation of the Amboy-Salem valley of MacClintock and Richards (1936).

BRIDGETON FORMATION ("ARKOSE 2")

Salisbury (1898) named the Bridgeton Formation for a widespread blanket of surficial feldspathic sand. The type locality is at Bridgeton in southern New Jersey. Salisbury and Knapp (1917) later divided the Bridgeton into two phases, the "Glassboro" and the "Woodmansie." The Glassboro phase is mostly in southern New Jersey; the Woodmansie is mostly in the upland subprovince (fig. 3). The Glassboro phase, according to the authors, is locally an arkosic deposit. The Woodmansie phase is mainly a quartz sand.

DISTRIBUTION AND LITHOLOGY

In and around Trenton, brightly colored sediments (various shades of yellow-orange, red, or brown) were mapped at two levels (Owens and Minard, 1975). These sediments were called "Arkose 1" (the lower, at altitudes of 12 to 24 m; 40 to 80 ft) and "Arkose 2" (the higher, at altitudes of 27 to 46 m; 90 to 150 ft). These beds, which are within the inner lowland (the Amboy-Salem valley of MacClintock and Richards, 1936), crop out well below the Beacon Hill Gravel.

The relationships of the arkosic sediments called "Arkose 2" by Owens and Minard in 1975, the oldest surficial unit, to other units in the Amboy-Salem valley is shown in figure 8. Section *A–A′* is a profile across the valley 4.8 km (3 miles) northeast of where the Delaware River enters this lowland from the northwest. In this area, highest level arkosic sediments underlie most of the valley, essentially at altitudes of 30 to 46 m (100 to 150 ft) above sea level. Extensive drilling in this general area shows that the base of the highest arkosic sediments is highly irregular, consisting of many channels which locally extended to about 20 m (65 ft) above sea level. Section *B–B′* is a profile across the valley 9 km (3 miles) southwest of the Delaware River—lowland subprovince junction. The highest level "Arkose 2" sediments in this part of the valley occur only on scattered hills or along the valley edge at altitudes of 30 m (100 ft) or more. This profile also shows in more detail the physiography of the lowland subprovinces (fig. 3) at the northernmost extent of both subprovinces. The rapid change from the lowland to intermediate upland in this area is also evident in these profiles.

"Arkose 2" near Trenton is an extensively cross stratified feldspathic quartz sand stained reddish brown to depths of as much as 5 m (15 ft). Widespread black iron(?) oxides in this weathered zone occur as small circular segregations or as thin laminae in the lighter colored cross strata. Below the reddened zone, the sand is either yellow or white and irregularly stained reddish to orange brown. Locally, beds of fine gravel are present, but distinct layers of clay or silt are rare in this region.

Northeast of the area of section *A–A′*, "Arkose 2" has about the same lithology as at Trenton. Thus, near Raritan Bay, where these deposits are widely dug, as shown in a typical exposure (fig. 9), they are mostly a light-colored cross-stratified sand containing scattered

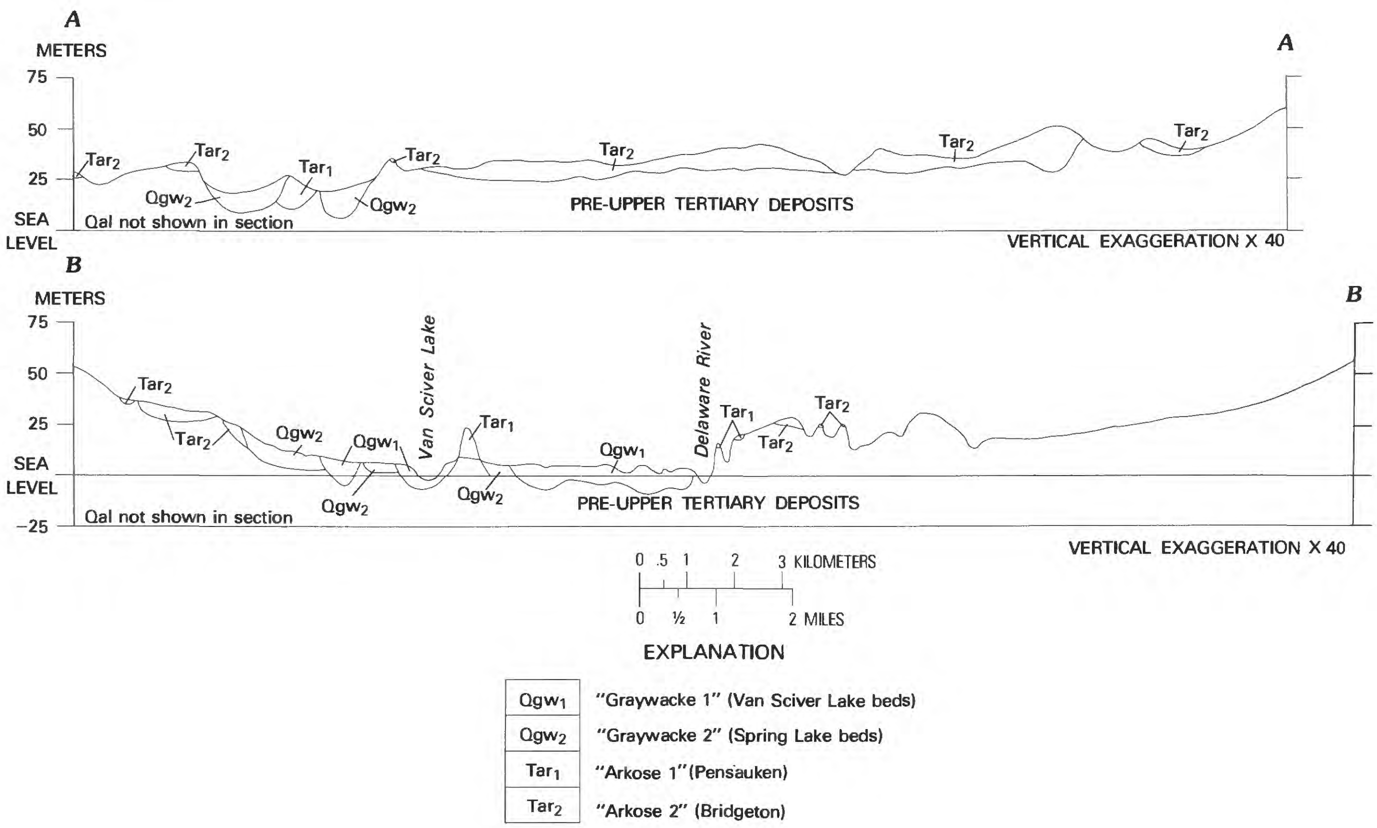

FIGURE 8.—Profiles across the inner lowland near Trenton, N.J. Section *A–A′* is 4.8 km (3 miles) northeast of where the Delaware River enters the inner lowland. Section *B–B′* is 4.8 km (3 miles) southeast of point. Approximate location of sections is shown in figure 3.

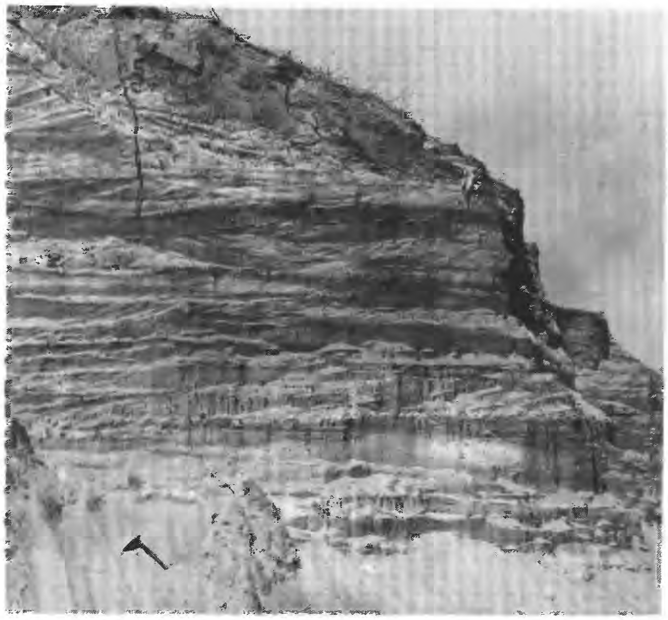

FIGURE 9.—Feldspathic quartz sand of Bridgeton Formation ("Arkose 2") in upper valley at Old Bridge, near Raritan Bay, N.J. Maximum boulder size in deposit at this locality is about 61 cm (24 in.). Bulk of gravel is mostly vein quartz, chert, and quartzite. Smaller amounts of red shale, red sandstone, crystalline rocks, and rounded ironstone gravel are also present.

pieces of gravel. Not shown in this photograph but present in most exposures in this area are the near-surface more massive reddish sandy beds.

Small fan-shaped masses are present at places along the border of "Arkose 2" in this region. These fan-shaped deposits, which are generally at somewhat higher altitudes than are the surficial sediments in the main valley, apparently were deposited in tributaries to the main (Bridgeton; "Arkose 2") valley. The tributary sediments differ between localities, reflecting, in large part, the rocks in their drainage basin. In one such fan-shaped deposit near Englishtown, for example, the tributary sediments are very glauconitic, thus indicating a Coastal Plain and specifically a marine Upper Cretaceous-lower Tertiary strata provenance.

From southwest of Trenton to the vicinity of Clementon, "Arkose 2" only occurs on scattered high hills similar to those shown in section *B–B′* (fig. 8). In southern New Jersey, the intermediate upland (fig. 3) is capped by "Arkose 2." This upland, which is the largest (but discontinuous) exposure of this unit in New Jersey, covers approximately 3,072 km² (1,200 sq. miles). The lithology of the beds in this area is very similar to that in the north (fig. 10*A* and *B*). The same general arrangement of massive dark-red very clayey sands over a lighter colored extensively coarse stratified sand (fig. 10*A*, specifically) is common throughout this region, as it is in many

FIGURE 10.—*A*. Bridgeton Formation 14.4 km (9 miles) northeast of Salem on southeast edge of Woodstown, N.J. Surface altitude of pit about 49 m (160 ft). Note upper massive clayey unit at top of formation, a characteristic of this unit.

areas northeast of Trenton. The type locality of the Bridgeton Formation, at Bridgeton, N.J., as defined by Salisbury (1898), is in this area, and we shall adopt this name for "Arkose 2" henceforth in this report. We wish to reiterate that our definition of the Bridgeton differs from that of Salisbury and Knapp (1917), mainly because we have included the surficial beds of the intermediate upland between Trenton and South Amboy in the Bridgeton rather than in another unit (Pensauken) as they did.

The type exposure of the Bridgeton no longer exists. The closest exposure of the Bridgeton Formation in this area is shown in figure 10*B*, and, as can be seen, the Bridgeton is here a cross-stratified sand. To the west, the Bridgeton maintains much the same lithology but has in addition many thin brown clay-silt beds.

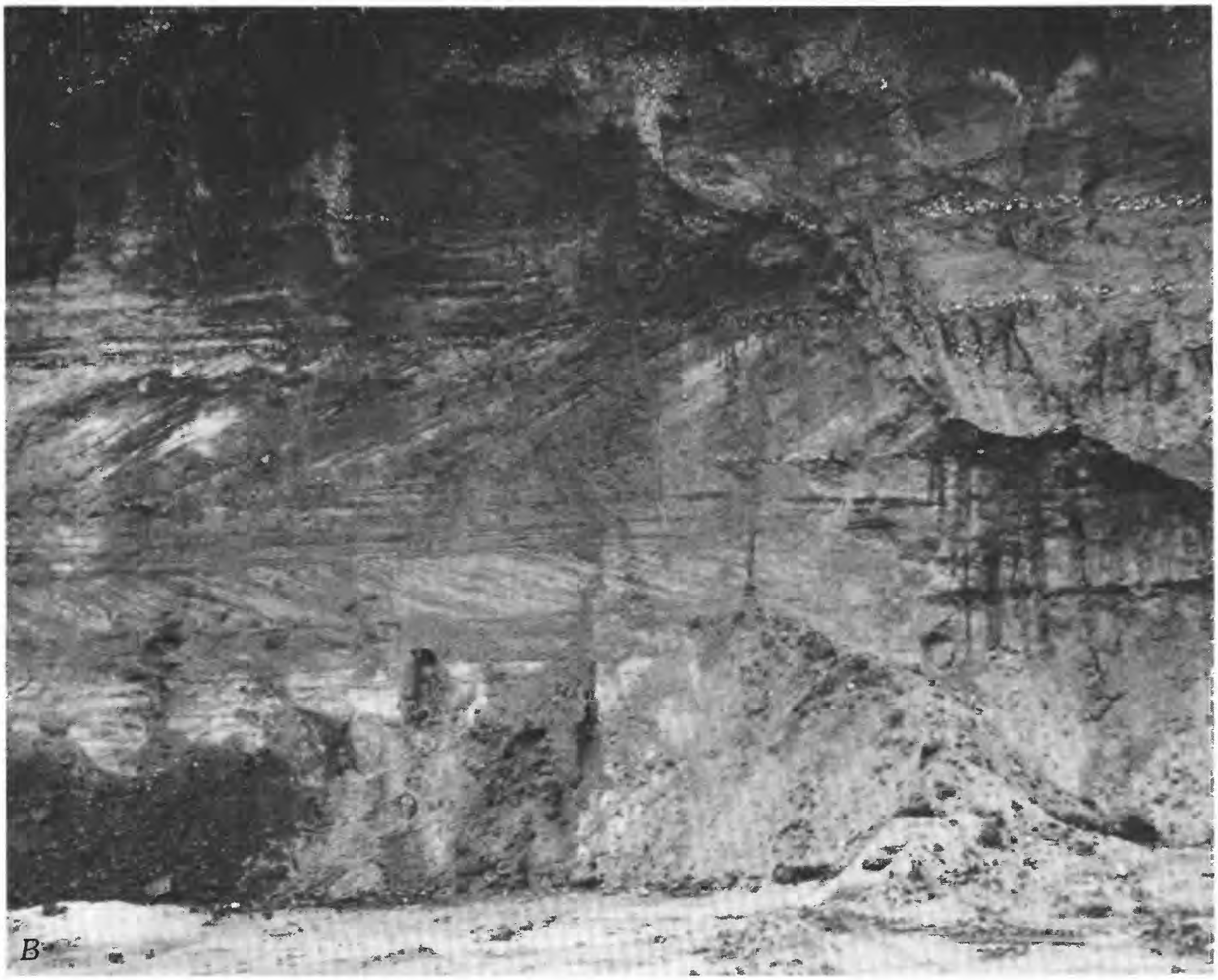

FIGURE 10.—*B*. Bridgeton Formation in southern New Jersey, 9.75 km (6.2 miles) due west of Bridgeton, N.J. Sandy and gravelly nature of formation can be seen. The scale of cross stratification is larger here than normal, but the dark massive upper clayey sand is still present.

CONFIGURATION OF THE BRIDGETON VALLEY FILL

On the basis of mapping and drilling near Trenton, reconnaissance north and south of this area, and a review of the literature, two maps were constructed. One shows the contours on the surface (fig. 11) and the other, contours on the base (fig. 12) of the Bridgeton Formation. The surface map was drawn by plotting the highest altitude at which the Bridgeton was found in any given quadrangle. Because parts of the intermediate upland subprovince are very dissected, restoration of the surface contours sometimes required projections over large distances. These contours thus are generalized and locally are very speculative. Other areas are urbanized, and exposures are few; in these areas, contours were drawn on the basis of interpretations in other geologic literature (mostly Greenman and others, 1961).

The contour map on the base of the formation was based on the average value of the lowest altitudes noted in any given sector of the quadrangle. In some areas, a few channels extended below this average altitude, but their depth was so anomalous to the general pattern that they were disregarded.

In general, the map (fig. 11) shows the downvalley slope at the top of the Bridgeton from an altitude of more than 56 m (180 ft) near Old Bridge in the upper part of the valley to about 15 m (50 ft) near Pleasantville in the lower part. The gradient pattern is complicated by the tributary valleys along the edge of the Bridgeton outcrop. Five of the larger tributary valleys are shown on

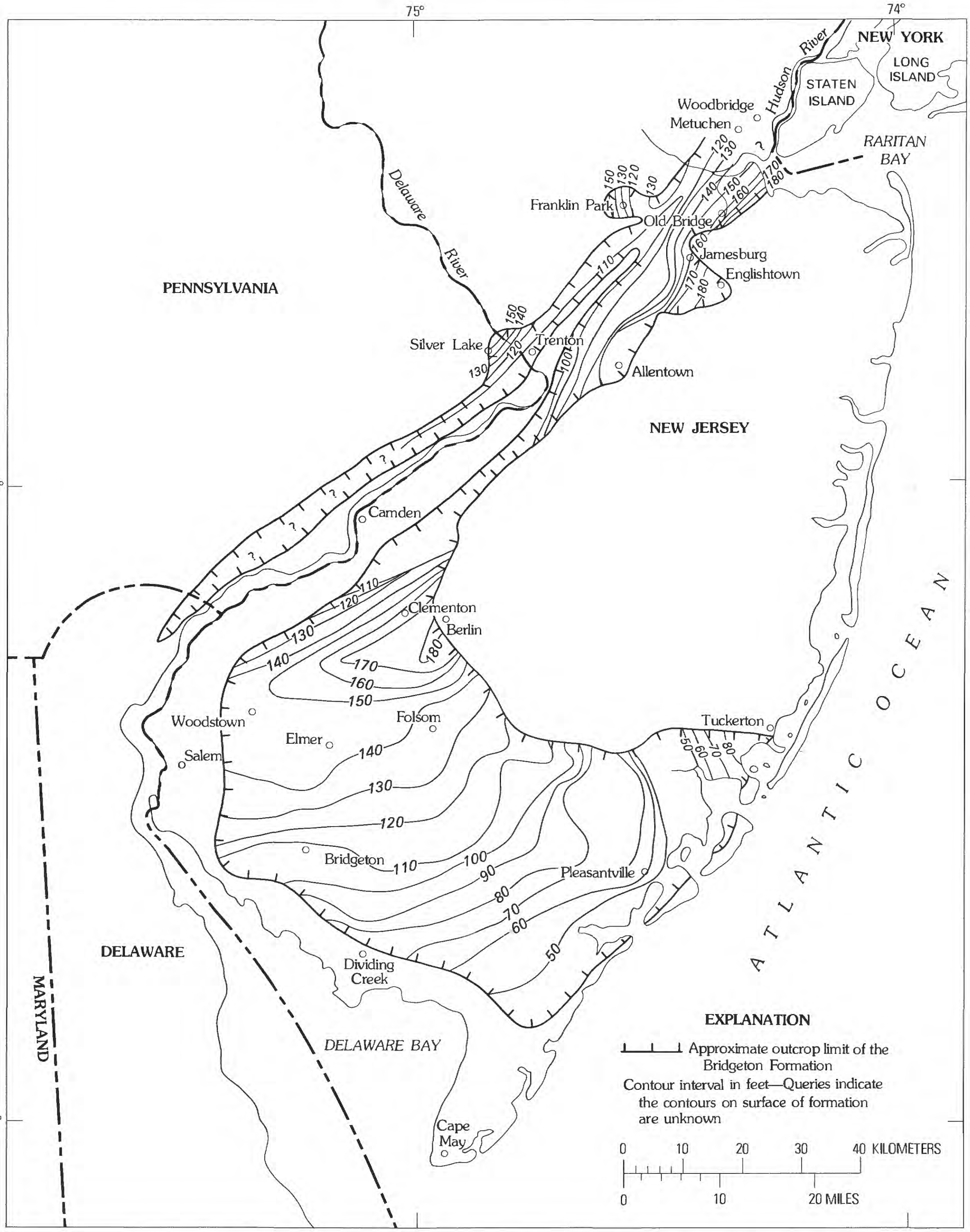

FIGURE 11.—Contour map showing configuration of the surface of the Bridgeton Formation.

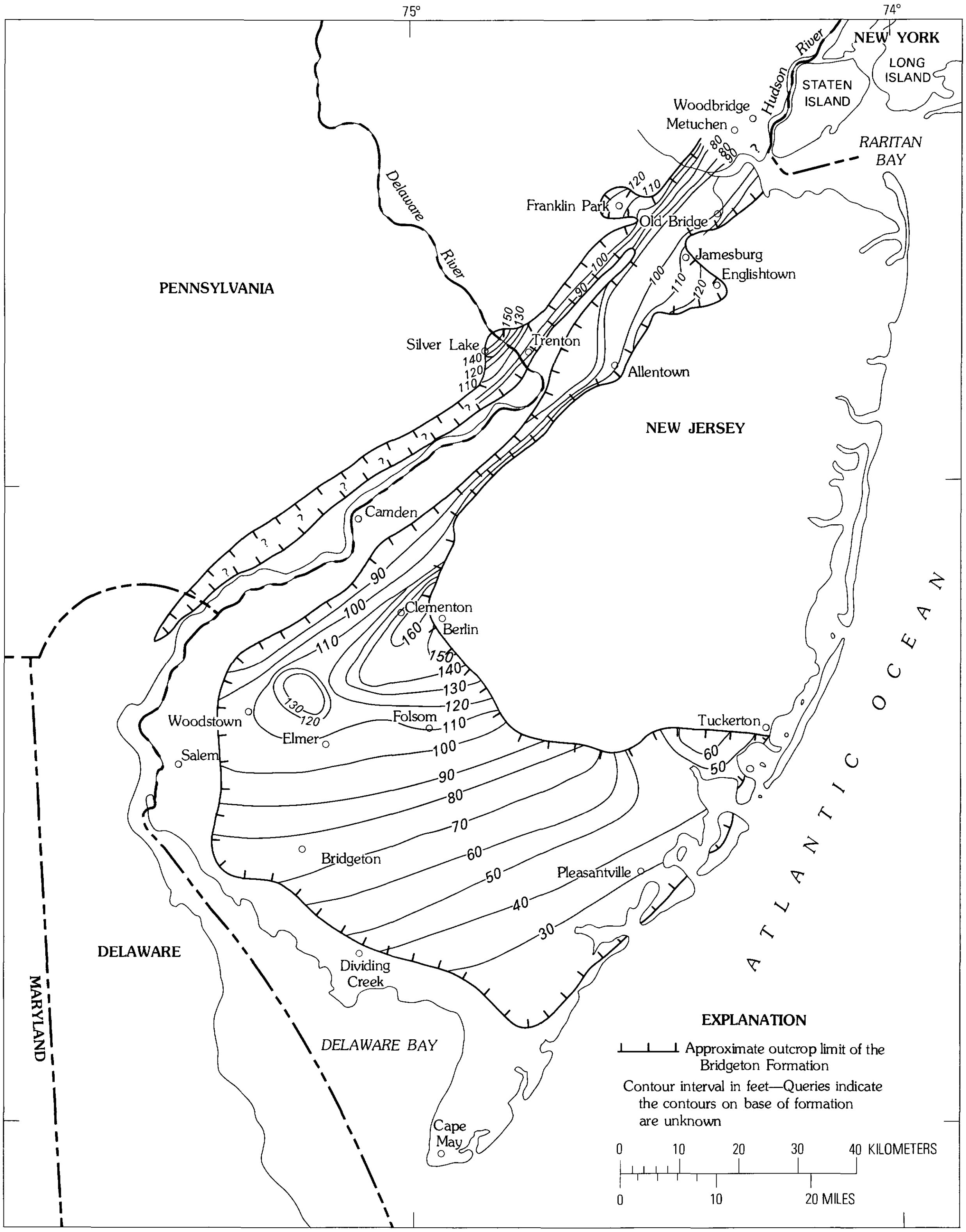

FIGURE 12.—Contour map showing configuration of the base of the Bridgeton Formation.

this map; near Englishtown, Franklin Park, Silver Lake, Clementon, and Tuckerton. These tributary valleys typically are at higher altitudes than the main- or trunk-valley fills. In addition, the map also shows significant variations across the main valley. For example, the surface of the Bridgeton slopes from an altitude of more than 56 m (180 ft) near Old Bridge on the eastern edge of the valley to about 36 m (120 ft) on the western side near Metuchen.

In southern New Jersey, the Bridgeton has a general southeastward slope from about 46 m (150 ft) in the northwest to 15 m (50 ft) in the southeast. Two exceptions to this pattern in this southern area are near Clementon and Tuckerton. At Clementon, one of the fan-shaped masses present along the valley edge is at higher altitudes than the Bridgeton of the valley to the west. Here the Bridgeton is at altitudes of slightly more than 56 m (180 ft). The sediments of the beds in this fan-shaped mass are similar in appearance to those shown in figure 10A but have significantly lower feldspar content. These tributary-valley sediments were derived in large part from the quartz-rich Cohansey Sand, which crops out in the upland to the east. In addition, reworked pieces of ironstone from the older formations are common gravel constituents.

Although many fewer control points were used to construct the contour map drawn on the base of the formation (fig. 12) than were used to make the surface-contour map (fig. 11), the data complement the surface map. In general, where the surface of the deposits is lower, the base of the deposits is lower. This relationship suggests that the Bridgeton was formed by a series of channels that progressively downcut as they migrated across the Bridgeton valley. The alluvium in the channels coalesced to form a continuous but sloping sheet of gravel across the intermediate upland. The absence of high-altitude deposits south of Allentown and north of Clementon (fig. 11) suggests that the Bridgeton river removed the older, higher deposits here as it migrated westward, downcutting to progressively lower altitudes. Thicknesses within the Bridgeton vary, largely depending upon the amount of postdepositional stripping. In those areas where the sand appears less dissected, this unit averages 9 to 15 m (30 to 50 ft) in thickness. The maximum known thickness is, however, nearly 24 m (80 ft) near Allentown, N.J., in the northern intermediate upland (Owens and Minard, 1966).

VECTORAL PROPERTIES

The widespread well-developed cross stratification in the Bridgeton makes this an ideal unit in which to study dispersal patterns based upon measurements of crossbedding directions. The mean direction of the crossbeds at all the major stations have been plotted in figure 13. These data are the summation of 120 individual dip azimuth readings. The data show some scatter, but the trend of the crossbeds in the northern part of the Bridgeton valley parallels the outcrop pattern of the formation (that is, southwest). In the southern outcrop, azimuth readings are more scattered, but a general easterly and southeasterly trend is apparent.

Figure 14 recasts the data in a moving-average diagram. This technique has been used and discussed in many publications and has been summarized by Potter and Pettijohn (1963). In general, this type of diagram smooths out the scatter irregularities and focuses upon the major dip directions.

Techniques commonly used for plotting the azimuth data are a simple arithmetic mean (used by Schlee, 1957, on the gravelly sediments in southern Maryland), or a vectoral mean (used by Jordan, 1964, in Delaware). The first technique is simple to calculate but is not recommended for dip azimuth readings that have a wide scatter (Potter and Pettijohn, 1963). In such a case, the more complex vectoral calculation is recommended. If, however, the data have only moderate or small scatter, then the simple arithmetic mean is just as accurate (Potter and Pettijohn, 1963). Our data have sufficiently small scatter to use the simple arithmetic-mean technique. The resultant diagram (fig. 14) seems to bear out this contention. The calculated paleocurrent readings show a strong tendency to be oriented to the southwest in the northern part of the Bridgeton valley and to the south, then southeast, and finally eastward progressively down the valley. A comparison of these data with the figures showing the contoured top and base of the Bridgeton (figs. 11 and 12) suggests that the emplacement of the channels carrying the arkosic sediments into the southern valley is not unlike that in the northern valley; that is, a series of channels shifting and downcutting to progressively lower elevations. In the southern valley, the highest and presumably the oldest channels are in the northern wall. To the south-southwest, the younger channels progressively cut to lower altitudes; the lowest lying channels in the extreme southern end of the gravel sheet would therefore be the youngest. Essentially, this was the same explanation proposed by Hack (1955) and Schlee (1957) for the upland gravels of southern Maryland.

Figure 15 is a schematic representation showing the paleocurrent trends during deposition of the Bridgeton. This interpretive diagram is strikingly similar to the one by Schlee (1957) for the upland gravels (Brandywine) in southern Maryland. If correlations based on altitude have any validity, then the Bridgeton of New Jersey and Pennsylvania is younger than the upland gravel sheet of southern Maryland and represents another period of downcutting by one of the major streams in the northern Atlantic Coastal Plain.

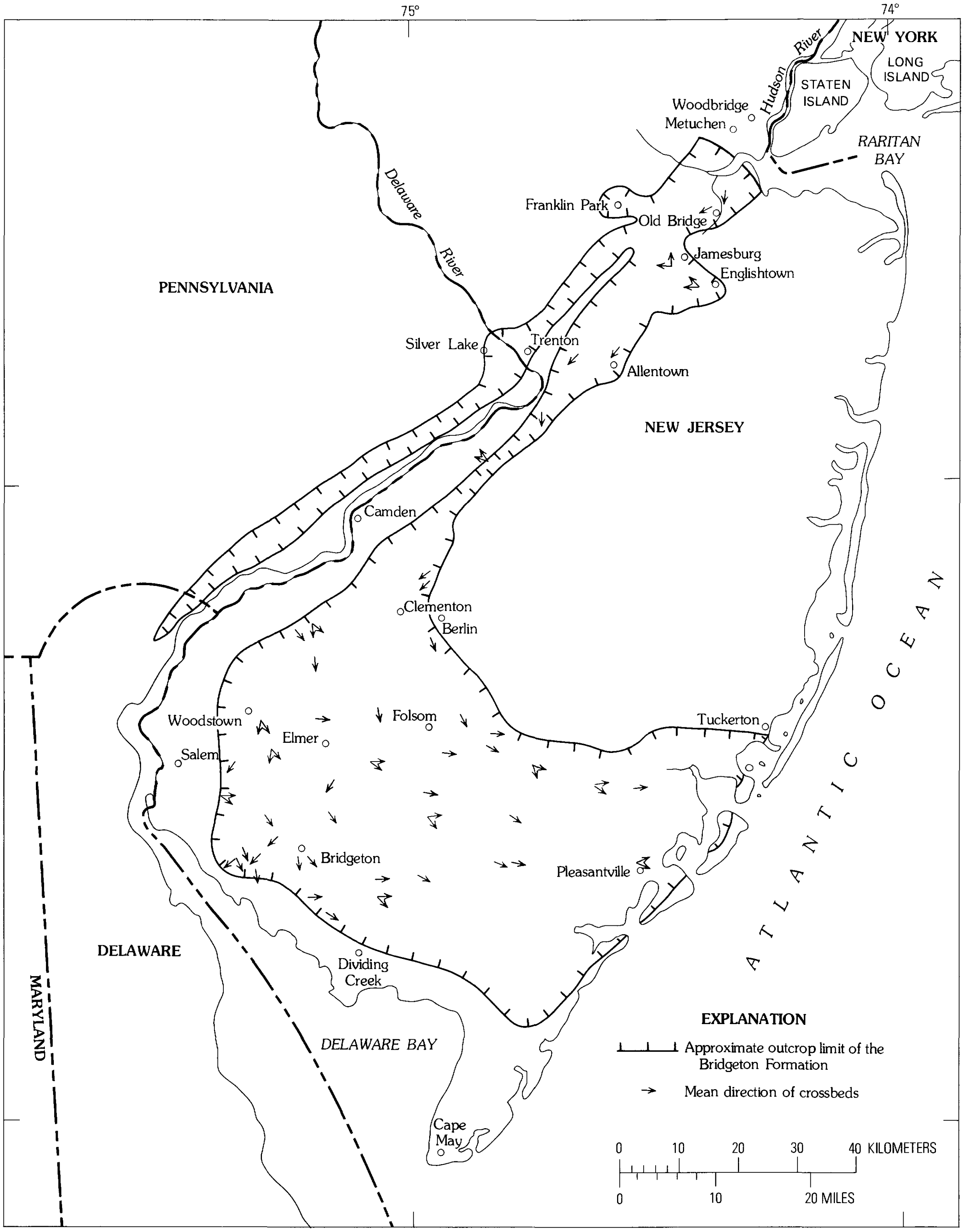

FIGURE 13.—Mean direction of crossbeds measured at several localities in the Bridgeton Formation.

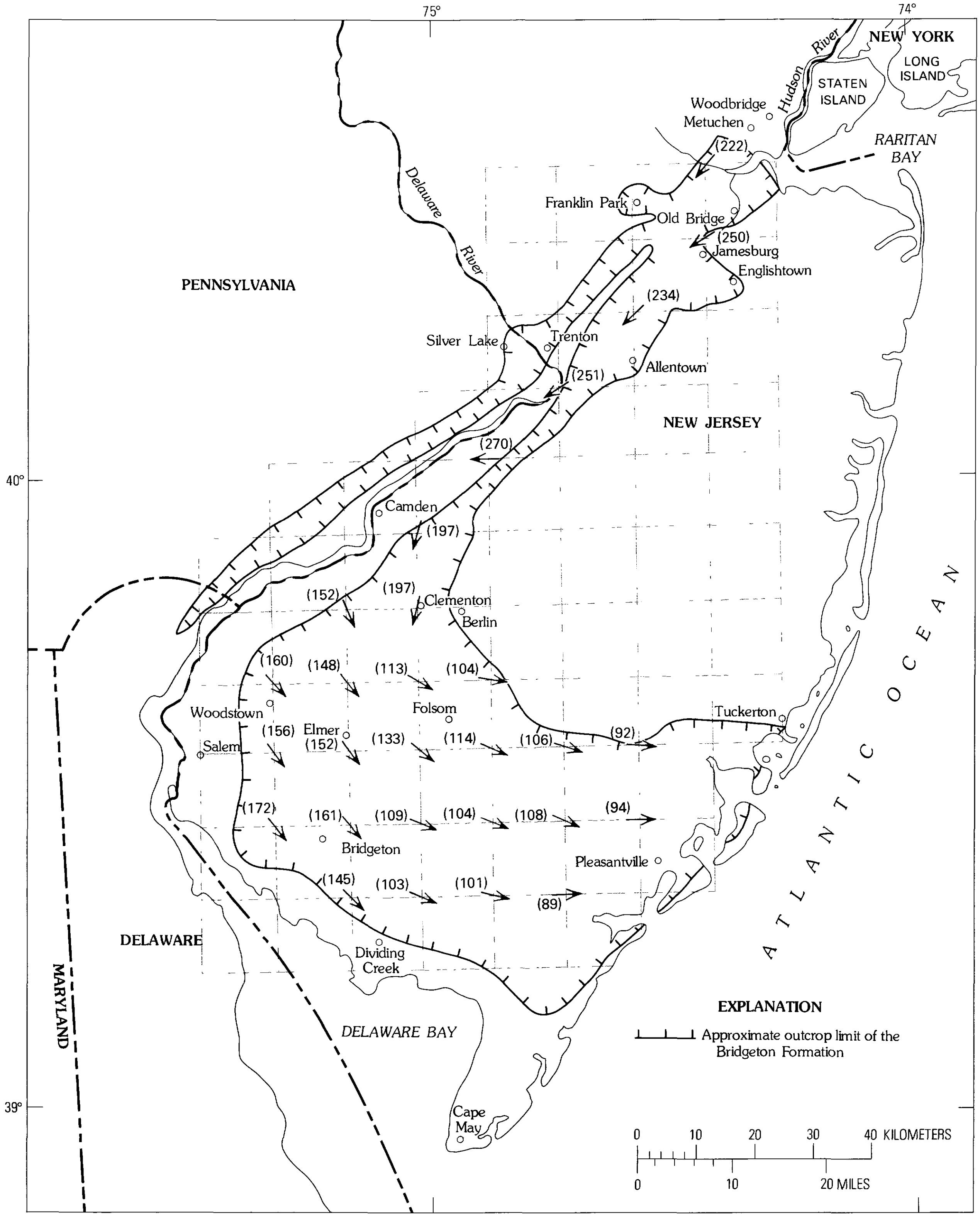

FIGURE 14.—Plot of moving averages of crossbedding orientation in the Bridgeton Formation. Outcrop area of formation is divided into squares approximately 13 km (8 miles) on a side. The azimuthal average of the crossbedding was calculated from all readings within each square. The average crossbedding azimuth orientation for each square where readings were taken is shown as an arrow whose center is in the upper left-hand corner of the square. The actual average orientation in degrees is in the parentheses at the end of each arrow.

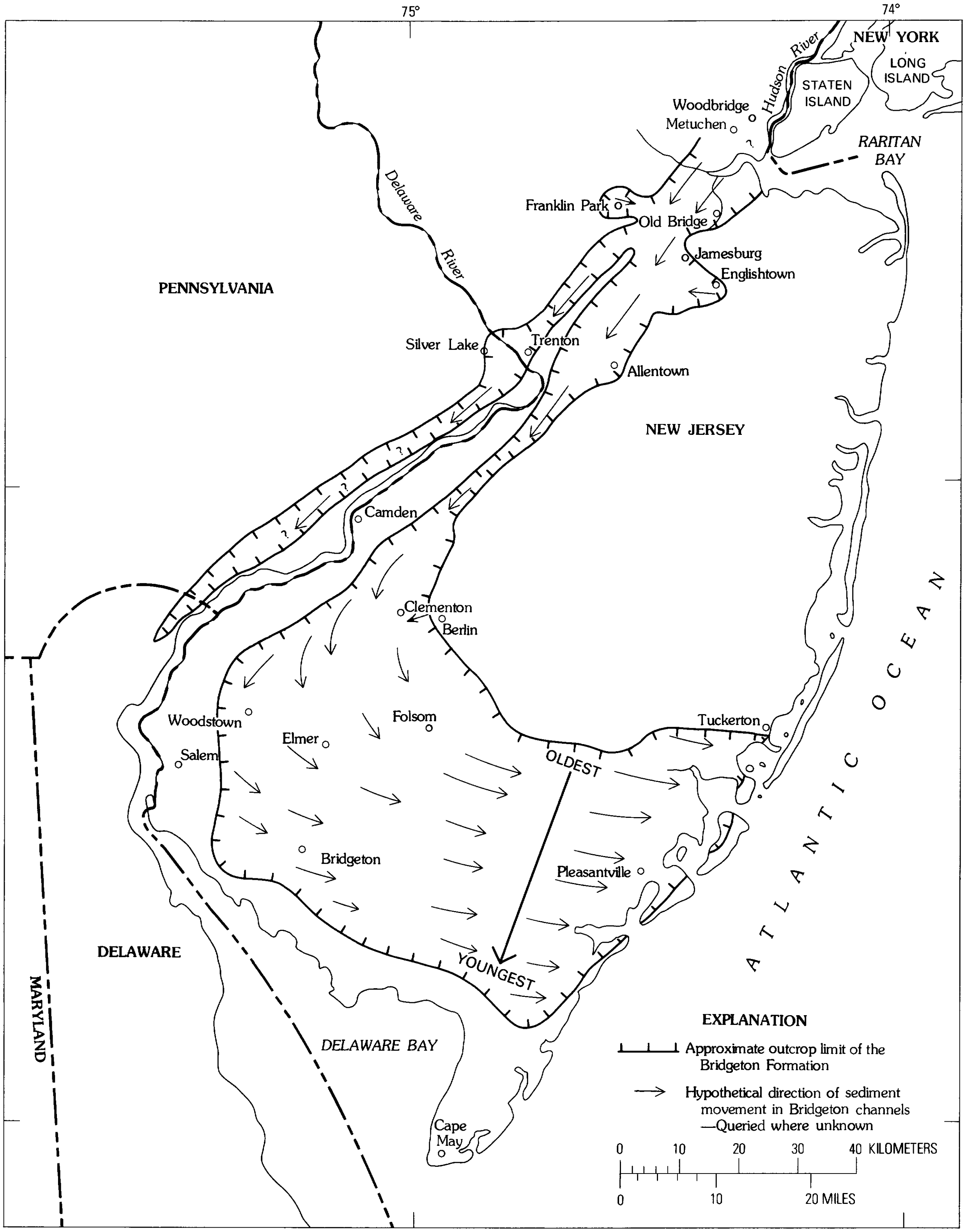

FIGURE 15.—Schematic plot of paleocurrent trends during deposition of the Bridgeton Formation. Direction of downcutting is shown in southern New Jersey.

PETROLOGY

The Bridgeton sand is, for the most part, very feldspathic. Because feldspar content generally exceeds that of rock fragments, this unit was earlier called an arkosic deposit ("Arkose 2" of Owens and Minard, 1975). Actually the sand in this unit ranges from an arkosic to a subarkosic deposit. In the northern outcrops of the Bridgeton, the major sand minerals are quartz, microcline, and plagioclase (most commonly oligoclase). In the southern outcrops, quartz and microcline are the principal sand minerals, and plagioclase is a rare constituent. Mica (principally muscovite) is locally abundant, but, for the most part, it is present in surprisingly low amounts. Along the southeast side of the upper valley, the feldspathic sediments of the Bridgeton are overlapped and less commonly interfinger with highly glauconitic sediments derived from the glauconite-bearing Upper Cretaceous and lower Tertiary formations exposed in the Coastal Plain upland to the east. Such sediments are particularly widespread in the large tributary to the main trunk of the upper valley near Englishtown, N.J.

The nonopaque heavy minerals in most of the Bridgeton Formation are characterized by a large number of species, notably the metamorphic minerals. Essentially, these assemblages are classed as a full (immature) suite and are decidedly less mature than those in the Beacon Hill. The major opaque minerals are ilmenite, leucoxene, and, locally, magnetite. Magnetite is particularly abundant in the northern outcrop area, especially from Trenton northeastward. The nonopaque minerals also show considerable variation from outcrop to outcrop, but from Trenton to Raritan Bay, these assemblages commonly have higher concentrations of hornblende.

Several authors have noted the occurrence of gibbsite in the upper beds of the feldspathic sand in the Amboy-Salem trench (Krebs and Tedrow, 1958; Lodding, 1961; and Bowman, 1969). Bowman also studied the distribution of gibbsite ("lateritization") in the feldspathic sand, principally between Camden and Raritan Bay. He adopted the existing stratigraphic terminology; hence, in his view, the formation of gibbsite was in the "Pensauken." We expanded this study to cover all the feldspathic sediments in New Jersey and the northern Delmarva Peninsula. We found that gibbsite (plus halloysite, kaolinite, and goethite) was abundant in the near-surface beds (our Bridgeton) but was less abundant in the near-surface beds of the other formations of this region. In a crude sense, therefore, we examined the soil development within these units and noted that gibbsite and especially halloysite and endellite had formed as much as 9 m (30 ft) below the surface in the Bridgeton. These minerals are, however, particularly abundant in the reddish to reddish-brown near-surface beds of the Bridgeton.

AGE

The age of the Bridgeton has always been speculative, but, as noted earlier, all previous investigators have considered this unit to be Pleistocene. The youngest unit overlain by the Bridgeton is the Cohansey Sand. Gibson (1970) considered the Cohansey to be equivalent to the Yorktown Formation, which is now thought to be early Pliocene in age (Hazel, 1971). Rachele (1974) studied the pollen and spores from the Cohansey Sand near Lakehurst, N.J. She favored a late Miocene or early Pliocene age range for the pollen assemblages. Actually, the age she cited (approximately 18 m.y.) would be early to early middle Miocene. In spite of these most recent studies, the age of the Cohansey must still be considered uncertain. All we can state with any degree of certainty is that the Cohansey overlies beds of early middle Miocene age (Kirkwood Formation = upper part of Calvert Formation of Maryland). The best data regarding the age of the Bridgeton is its stratigraphic relationship to the Pensauken Formation. The Pensauken Formation, which cuts the Bridgeton, is late Miocene in age; therefore, the Bridgeton is at least this old. If the unit is indeed Miocene rather than Pleistocene in age, the extensive weathering is easier to understand.

MODE OF DEPOSITION AND ORIGIN

Minor sedimentary structures and the channel shape of the sedimentary deposits within the Bridgeton are typical of those found in fluviatile environments. No marine or estuarine beds were found in this unit even near the coast, though Salisbury and Knapp (1917) thought marine beds might be present in this area. The most obvious features, abundant loose sand and gravel, extensive cross stratification, and lack of marine trace fossils are typical of channel-fill deposits, specifically point-bar and channel-lag gravels (Allen, 1965). The finer overbank deposits are also an important indicator of a fluviatile depositional environment, but they are only found at a few localities (the pits at Old Bridge and Woodstown). These overbank sediments, because of their high topographic position and fine-grained nature, may have been more easily eroded than the coarser clasts of channel-fill origin and hence were stripped off large areas.

The channels, which appear to be the major depositional environment in this unit, are spatially arranged higher on one side of the deposit than on the other. This arrangement suggests a series of migrating downcutting channels. This situation is evident in both the northern and southern outcrops. In the latter area, the degrading channels have formed a broad, sheet deposit similar to that formed by the upland gravels of southern Maryland (Hack, 1955; Schlee, 1957). Apparently a highland similar to the Coastal Plain upland (fig. 3) was once present over all of southern New Jersey. This upland was systematically eroded away as the channels first entrenched into it and then migrated southward against it during Bridgeton time, ultimately producing a relatively flat, southeast-sloping surface in this area. In the northern part of the valley, the migrating channels were restricted to a much smaller area, and in many areas, the older higher level deposits are absent; they probably were eroded as the lower level channels shifted from one side of the valley to the other. As a result, only remnants of these higher level deposits remain here. From the surface evidence still available in this upvalley area, the Bridgeton deposits downcut from altitudes somewhat more than 60 m (200 ft) above sea level to a low of about 30 m (100 ft) across the valley. The base of the deposits ranges in altitude from 45 m (150 ft) to 18 m (60 ft) above sea level in this general area. In the southern part of the valley, the channels have surface altitudes as low as 15 m (50 ft) above sea level and bases as low as 8 m (25 ft). At the coast, the arkosic sediments appear to be fluviatile all the way to a subdued ocean-facing scarp where they are eroded or overlapped by younger sediments. How much farther eastward and southward those fluviatile beds extended is now conjectural, but Schlee and Pratt (1970) showed a large patch of "yellow gravels" off the coast of New Jersey that appears to be on trend with the direction of transport of the arkosic sediments.

Hack (1955) and Schlee (1957) both discussed the hypothesis, first advanced by Mackin, that the size and depth of the river occupying the channels could be determined from the thickness of the alluvium in any single channel. If this hypothesis is correct, then most of the Bridgeton channels averaged about 12 m (40 ft) in depth.

Studies of the crossbedding azimuths in the Bridgeton indicate that the major sediment transport in the northern part of the valley was from northeast to southwest, essentially paralleling the axis or thalweg of the Amboy-Salem valley of MacClintock and Richards (1936). This interpretation supports the view of Salisbury and Knapp (1917) as to the position of the main trunk of this stream beyond its present northeast limit. An ancestral Hudson drainage for this river system, therefore, is possible if not probable. Howell and Hale (1946) and, with less certainty, Campbell and Bascom (1933) suggested that the major trunk of the stream occupying this valley came from northern New Jersey rather than southeastern New York. In both these reports, the authors stressed the occurrence of black fossiliferous cherts, which they thought were derived from the Paleozoic limestones in northern New Jersey. Essentially the same sequence of rocks crops out along the present Hudson River drainage in southeastern New York. Some sediment also may have been contributed from northern New Jersey rocks to the main valley. Figure 11 shows a tributary joining the main trunk in this area. In fact, the presence of another tributary of equal size directly across the valley near Jamesburg, N.J., suggests that this area was the confluence of two major tributaries joining the master valley northeast of this junction. The ancestral Hudson seems to have been the master stream in this area during Bridgeton time.

Evidence of the existence of a major ancestral Delaware River drainage during Bridgeton time is lacking, at least where the present river now enters the lowland at Trenton. Campbell and Bascom (1933) agreed with this interpretation, but not Salisbury and Knapp (1917) or Peltier (1959), who favored the existence of the Delaware as a major drainageway for these sediments during the entire Quaternary.

The crossbedding data in the southern outcrops suggest that the streams left the inner edge of the Coastal Plain and flowed southeast and east to the Atlantic and downcut across this region in arcuate-shaped channels. Salisbury and Knapp (1917), for the most part, were the only investigators to examine the Bridgeton in this southern region in any detail. Their conclusions regarding the depositional environment for these sediments in this area were vague. For example, they thought that the Bridgeton might be a marine unit. They did, however, recognize the regional eastward dip of the Bridgeton.

The coarseness and composition of the Bridgeton clasts led most previous investigators to postulate a glacial-outwash origin for this unit. Typically, however, outwash deposits are a complex of many lithofacies characterized by rapid textural variations. Certainly this is not true in the Bridgeton, where sand is by far the major constituent throughout its entire outcrop. Tectonic or eustatic effects then appear to have been a more likely cause or causes for the abundance of sand clasts in the Bridgeton. The youngest dated beds in the New Jersey Coastal Plain are the Kirkwood (middle Miocene) and, with less certainty, the Cohansey (middle? to upper middle? Miocene). The Cohansey crops out at altitudes of more than 90 m (300 ft) and the Kirkwood, as much as 60 m (200 ft) above present sea level. Both are marine or marginal marine units; therefore, since Cohansey time, the New Jersey Coastal Plain has been uplifted at least 90 m (300 ft). The localization of the northern part of the Bridgeton roughly paralleling the course of the Hudson River also seems significant. Of all the river systems in the Middle Atlantic States, the ancestral Bridgeton and a short reach of the Potomac River are the only ones that parallel the Coastal Plain-Piedmont boundary. In the case of the northernmost part of the Bridgeton and its probable extension into the Hudson Valley, a fault-system control is possible if not probable. Certainly a horst-graben origin has been discussed for the Hudson-Lake George-Lake Champlain drainage basins (Isachsen and Wold, 1977). We would suggest that localization of the northern part of the Bridgeton valley might have been controlled by this Hudson-Lake George fault system and that a major movement along this system took place in late Miocene time. Such a structural control would not only have localized the course of the Bridgeton river but would also have supplied fresh feldspathic clasts from the underlying crystalline rocks in the Hudson River valley.

PENSAUKEN FORMATION ("ARKOSE 1")

Salisbury (1898) named the Pensauken Formation. The type locality was the exposures of surficial sediments in gravel pits along Pensauken (now spelled Pennsauken) Creek at Palmyra, N.J. Later, Salisbury and Knapp (1917) provided a better definition of this unit; this definition has since been used by most investigators of the formation. Salisbury and Knapp believed that the Pensauken, like the Bridgeton, consisted of two major lithofacies. One lithofacies was primarily reworked Coastal Plain sediments; the other was primarily sediment derived from rocks outside the Coastal Plain. The reworked Coastal Plain rocks were characterized by glauconite sand and a low feldspar content, whereas the non-Coastal Plain sediments were typically very feldspathic.

Within the Amboy-Salem valley, Salisbury and Knapp (1917) proposed that the Pensauken clasts occurred in two distinct plains. The lower plain, Swedesboro, was nearest the Delaware River at altitudes of 15 to 24 m (50 to 80 ft). This plain apparently could be traced from just northeast of Salem to Trenton. The higher plain, Woodstown, is at altitudes approximately 15 m (50 ft) higher than the Swedesboro plain. The Woodstown plain is southeast of the Swedesboro plain and can be traced from near Woodstown on to Trenton. Northeast of Trenton, Salisbury and Knapp (1917) could not recognize the twofold division of the Pensauken; the formation covered the entire valley, even though these deposits were at the level of the Woodstown plain.

Salisbury and Knapp (1917) proposed that the twofold morphological subdivision in the lower Delaware Valley also represented a lithologic subdivision. The lower Swedesboro plain deposits were largely arkosic, and the upper Woodstown plain deposits were largely reworked Coastal Plain sediments.

DISTRIBUTION AND LITHOLOGY

In the Amboy-Salem valley at Trenton, sediments similar in lithology and color to the Bridgeton are present at surface altitudes of 15 to 24 m (50 to 80 ft) above sea level. These sediments were mapped as "Arkose 1" (Owens and Minard, 1975); together with the Bridgeton and Beacon Hill, they were originally the "yellow gravels" of Salisbury (1898).

The arkosic sediments are in two tiers at Trenton (fig. 8); the higher tier was mapped by us as "Arkose 2" (Bridgeton) and the lower, as "Arkose 1." This relationship is critical in evaluating the Salisbury and Knapp interpretation of the geology of these sediments. These authors believed that the regional gradient of the Bridgeton as determined in southern New Jersey would preclude beds of this age being present at Trenton. Our interpretation differs in that we recognize two periods of arkosic sedimentation (Bridgeton and "Arkose 1").

The outcrop pattern of "Arkose 1" is very narrow just north of Trenton. Here these sediments were recognized only in the Assunpink Creek valley. Salisbury and Knapp (1917) traced similar sediments north of Assunpink Creek valley a short distance into the valley of the Millstone River. North of this area, no "Arkose 1" sediments have been reported.

Just south of Trenton, the outcrop of "Arkose 1" broadens; these sediments occur locally in valleys between interflures capped by the Bridgeton Formation. The base of "Arkose 1" is irregular, consisting of a series of channels, some of which extend nearly to sea level. "Arkose 1" in this general region consists typically of interbedded sand and gravelly sand (fig. 16).

Most of the gravelly beds are horizontal, and the sand is horizontal to crossbedded (typically large amplitude, about 1 m (3 ft). The gravel in this unit at Trenton is typically coarse; boulders to 1.5 m (5 ft) in size are common. The gravel in "Arkose 1" is typically coarser than in the higher level Bridgeton deposits in this general area. The gravel assemblage in "Arkose 1" is heterogenous, consisting largely of quartz, quartzite, and chert. Saprolitized crystalline and metamorphic rocks are present, as are red sandstone, siltstone, and shale (Triassic). Another common feature in the "Arkose 1" beds is widespread cementation of the sand and gravelly sand (fig. 17).

Southwest of Trenton, the outcrop of "Arkose 1" broadens, and near Moorestown, it merges with the Swedesboro plain of Salisbury and Knapp (1917). Included in the plain downvalley is the type locality of the Pensauken Formation at Palmyra, N.J. Therefore, we now would include "Arkose 1" in the Pensauken Formation but would restrict its usage in New Jersey to the sediments largely underlying the Swedesboro plain.

The type locality of the Pensauken has long since been mined out. Pits in the same general region, however, were still available at the time of our investigation (fig. 18). The Pensauken beds here are largely iron oxide-ce-

FIGURE 16.—Pensauken ("Arkose 1") beds at Turkey Hill, 3.8 km (2.4 miles) south of Morrisville, Pa. Hill has surface altitude of nearly 24 m (80 ft). Bedding in this formation is largely horizontal, although locally the sandy beds have large-scale (>1 m; >3 ft) crossbeds.

mented, extensively cross-stratified feldspathic sand. Not shown in this photograph are thin horizontal beds of glauconite sand that overlie the feldspathic beds throughout most of this region. Thus, at the type locality on the Swedesboro plain, both major lithofacies of the Pensauken are present and are not restricted to separate plains as reported by Salisbury and Knapp (1917). This spatial relationship of glauconite sand over feldspathic sand is similar to that noted at several locations in the Bridgeton Formation. We mapped the glauconite sand, however, as a separate unit (as in Owens and Minard, 1975).

Exposures of the Pensauken arkose beds are few in New Jersey. In the northern Delmarva Peninsula, however, exposures of the surficial beds of arkosic composition are widespread, particularly along the Chesapeake and Delaware Canal and west along Chesapeake Bay and its major tributaries (fig. 19). In the upper peninsula area, the provenance of the arkosic deposits is of considerable interest because of the proximity of these beds to the Susquehanna River drainage. Elk Neck, a small promontory, projects into the northern part of the bay across the trend of the Susquehanna River. Altitudes in the central part of this promontory reach a maximum of

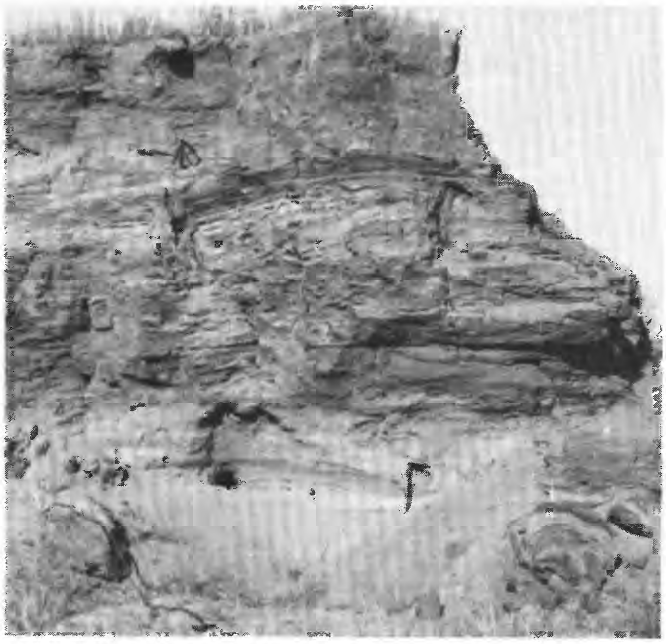

FIGURE 17.—Iron oxide-cemented beds in the Pensauken Formation on north side of Centerton Road, 4 km (2.5 miles) east of Moorestown, N.J.

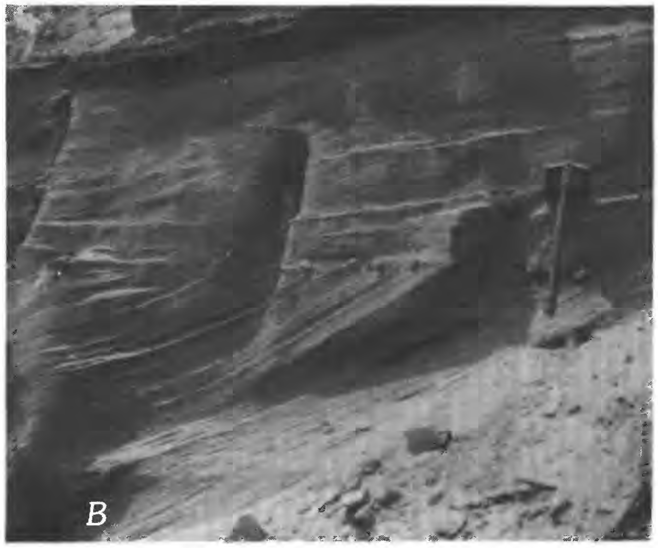

FIGURE 18.—*A*. Pensauken Formation near type locality at Palmyra, N.J. Pit on west side of U.S. Route 73, 0.4 km (0.25 mile) from junction with U.S. Route 130. Beds are extensively stained and locally cemented by iron oxide. *B*. Close-up of base of cut shown in *A*, illustrating style and scale of cross stratification in the Pensauken in the northern part of the outcrop.

nearly 120 m (400 ft) above sea level or well above the surface level of the nearby Pensauken beds to the east. Along the east side of the promontory, arkosic beds form a series of descending terrace deposits. On the west side of this landform, no similar arkosic terraces or beds are present. Additionally, no sediments of Pensauken lithology are present in the lower Susquehanna valley. On the basis of these observations, the Pensauken beds in the Delmarva Peninsula are probably of Delaware Valley origin. Well south of Elk Neck, some arkosic sediments of the Pensauken lithology might possibly have been introduced into the Delmarva Peninsula from the Susquehanna River, but there is no strong evidence to support such a supposition. We have concluded that most if not all the Pensauken sediment in the Delmarva Peninsula was transported here from the Delaware River valley.

Southward down the peninsula, abundant clay-silt beds are found in the Pensauken, although sand, locally gravelly sand, is still dominant. Iron oxide staining and local cementation are common, as are light-green clay galls (fig. 20). Along an irregular line running from Salisbury, Md., to Milford, Del., the Pensauken is overlapped by younger formations and is only known in the subsurface southeast of the line.

CONFIGURATION OF PENSAUKEN VALLEY FILL

In general, the shape of the Pensauken Formation is similar to that of the Bridgeton, that is, narrow upper valley fill and broad lower valley fill. When the surface of the Pensauken (fig. 21) is compared with that of the Bridgeton (fig. 11), it is evident that the two-arkoses concept within the "yellow gravels," as postulated by Salisbury and Knapp (1917), is indeed valid in a regional sense. Clearly, the surface of the Pensauken has an average lower surface altitude than that of the Bridgeton. The map also shows the regional southeast slope of these beds as opposed to the southwest slope of those in the Bridgeton.

Figure 22 also shows the general southeast slope of the deposits. This map, however, also reveals an unexpected

FIGURE 19.—*A*. Pensauken Formation north of the Elk River in the upper Chesapeake Bay region. Here the Pensauken is in a well-defined channel in the Potomac Group of Cretaceous age. Channel fill is largely sand with a thick gravel layer near the top and is approximately 24 m (80 ft) thick. *B*. Close-up of planar crossbedding and thicknesses of crossbeds at this locality.

low paralleling Elk Neck in the northern part of the lower valley. These beds may be a younger unit but have no fossils, and because of the similarity of the lithology to that of the rest of the Pensauken, we have included these beds in the Pensauken Formation.

PETROLOGY

Some authors have suggested that a lithic differentiation between the Pensauken and Bridgeton is not possible (MacClintock and Richards, 1936). Others have reported it possible but very difficult (Salisbury and Knapp, 1917). In our interpretation of these two formations, the only area where they are in contact is in the inner lowland (fig. 3) between Trenton and Salem, N.J. We mapped part of this lowland in detail near Trenton (Owens and Minard, 1975) and found that in addition to the differences in altitude between the two units, each had mappable lithic differences. Figure 18 shows a typical lithology in the Pensauken near Palmyra, N.J., where the formation consists of interstratified sand and gravelly sand. Gravel of the size and concentration shown are common in the Pensauken but are uncommon in the Bridgeton in this area. Another lithic difference is in the much larger concentrations of reworked Coastal Plain sediments in the Pensauken; such concentrations are evidenced by larger amounts of glauconitic sand even in the highly feldspathic beds and channels largely filled by Coastal Plain quartz gravels near the present Delaware River. Salisbury and Knapp (1917) observed that this Pensauken sand commonly was cemented by iron oxide. We noted that this cementation certainly was present in this area (fig. 17) and was common at several localities downvalley from the Trenton area. In fact, many of the characteristics just cited can be found in the Pensauken beds throughout the upper part of the valley.

Petrographic studies of the sand throughout the Pensauken show that it is mostly a subarkose but locally is either feldspathic enough to be classed as an arkose or quartz-rich enough to be classed as a protoquartzite. Typically, the Pensauken sand contains both plagioclase (oligoclase) and microcline in both New Jersey and the Delmarva Peninsula. This distribution in the Pensauken is in marked contrast to that of the Bridgeton in which the two feldspars are present only in the northernmost outcrops of that formation.

FIGURE 20.—*A*. Pensauken Formation near Harrington, Del. Pit is near the southern edge of the Pensauken outcrop. The formation here is still largely sand. Crossbedding is less distinct and on a smaller scale on the average than in the upvalley regions. *B*. Closeup showing the indistinct crossbedding and a row of pale-green rounded clay clasts. Clay galls of this type are common in the Pensauken in the downvalley region.

The nonopaque heavy minerals in the Pensauken include a full or immature suite similar to the heavy-mineral assemblage in the Bridgeton. In the opaque suite, however, magnetite is much more abundant and widespread in the Pensauken that it is in the Bridgeton.

X-ray studies of the clay-silt fraction of the Pensauken surface and near-surface sand also reveal an important difference in mineralogy as compared with that of the Bridgeton sand. Gibbsite, which is so abundant in the upper several feet of the Bridgeton sand, is absent or sparse within much of the Pensauken Formation. The general absence or small concentration of gibbsite in the upper sand of the Pensauken was noted in all the outcrops shown in figures 16 through 20, which include the sections sampled near the type locality of this unit at Palmyra, N.J.

The clasts in the Pensauken indicate derivation in large part from the very feldspathic rocks of the Piedmont province, as evidenced by the large amount of plagioclase in the Pensauken both in New Jersey and in the Delmarva Peninsula. Contribution of sediment from the Bridgeton (mainly reworked ironstone) and other Coastal Plain formations (mainly glauconitic sand), although significant, was probably small in comparison with "new" sediment derived from the crystalline rocks of the Piedmont.

VECTORAL PROPERTIES

The sand of the Pensauken Formation is exceptionally well cross stratified. (See figs. 18–20.) The azimuths of crossbedding directions were measured at several localities in the upper valley (fig. 23). Most of the crossbedding data from the Delaware part of the Delmarva Peninsula came from a report by Jordan (1964). Figure 24 is a plot of the moving averages of the crossbedding azimuths in this unit and clearly shows a more southerly trend than in the Bridgeton sediments of southern New Jersey.

AGE

As stated earlier, all previous investigations except for ours (Owens and Minard, 1975) considered the Pensauken to be Pleistocene in age. All the dating of this unit is based upon poorly preserved leaves (Berry and Hawkins, 1935) and poorly described flora (Hollick, 1899). The stratigraphic position of these fossil localities, all in New Jersey, is uncertain. Our definition of the Pensauken includes the extensive surface sand and gravelly sand of the northern Delmarva Peninsula. In the southern limit in this peninsula, beds of Pensauken lithology interfinger with thick black-clay beds. Pollen and spores obtained from the black clay show that the pollen assemblage is

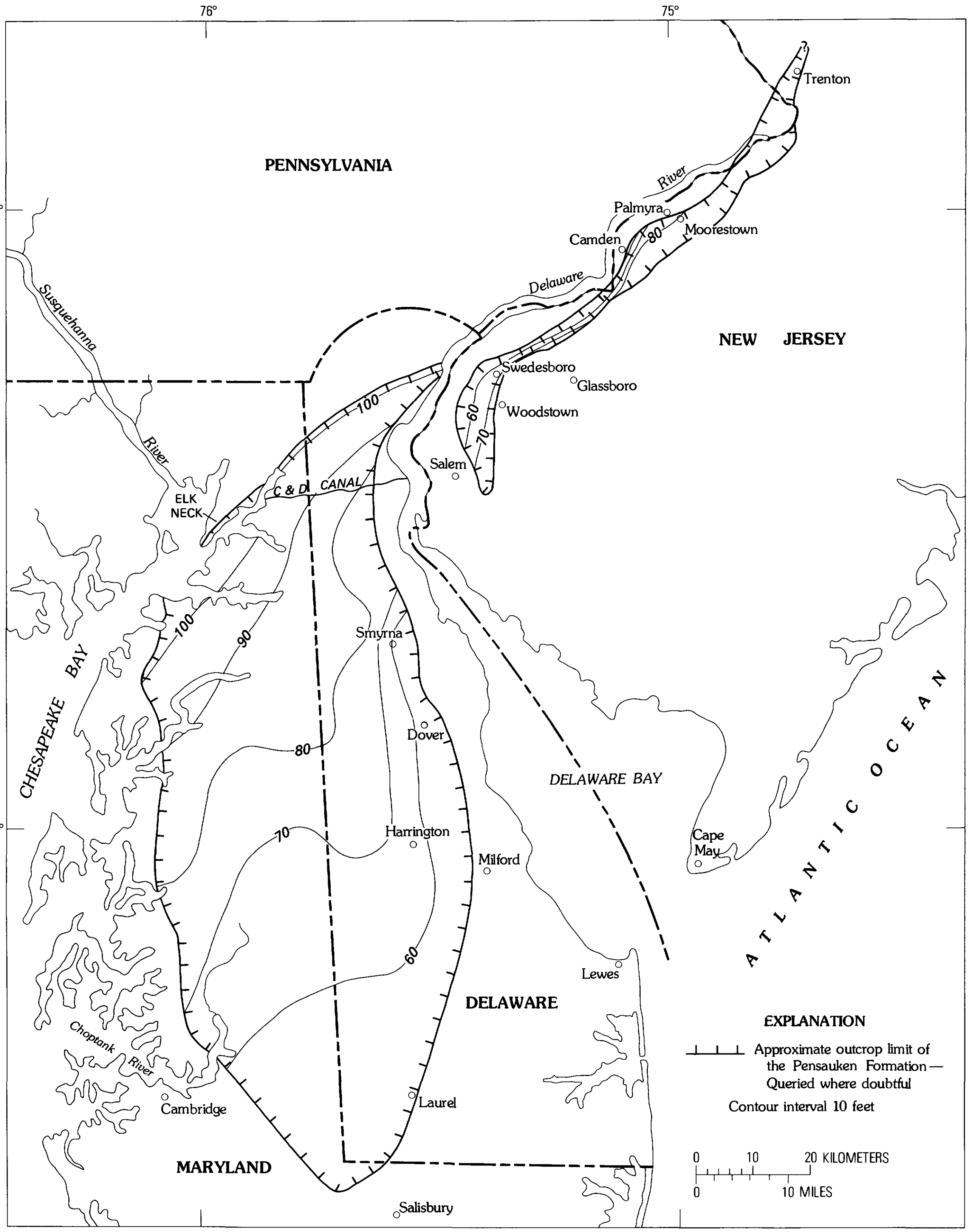

FIGURE 21.—Contour map showing configuration of the surface of the Pensauken Formation.

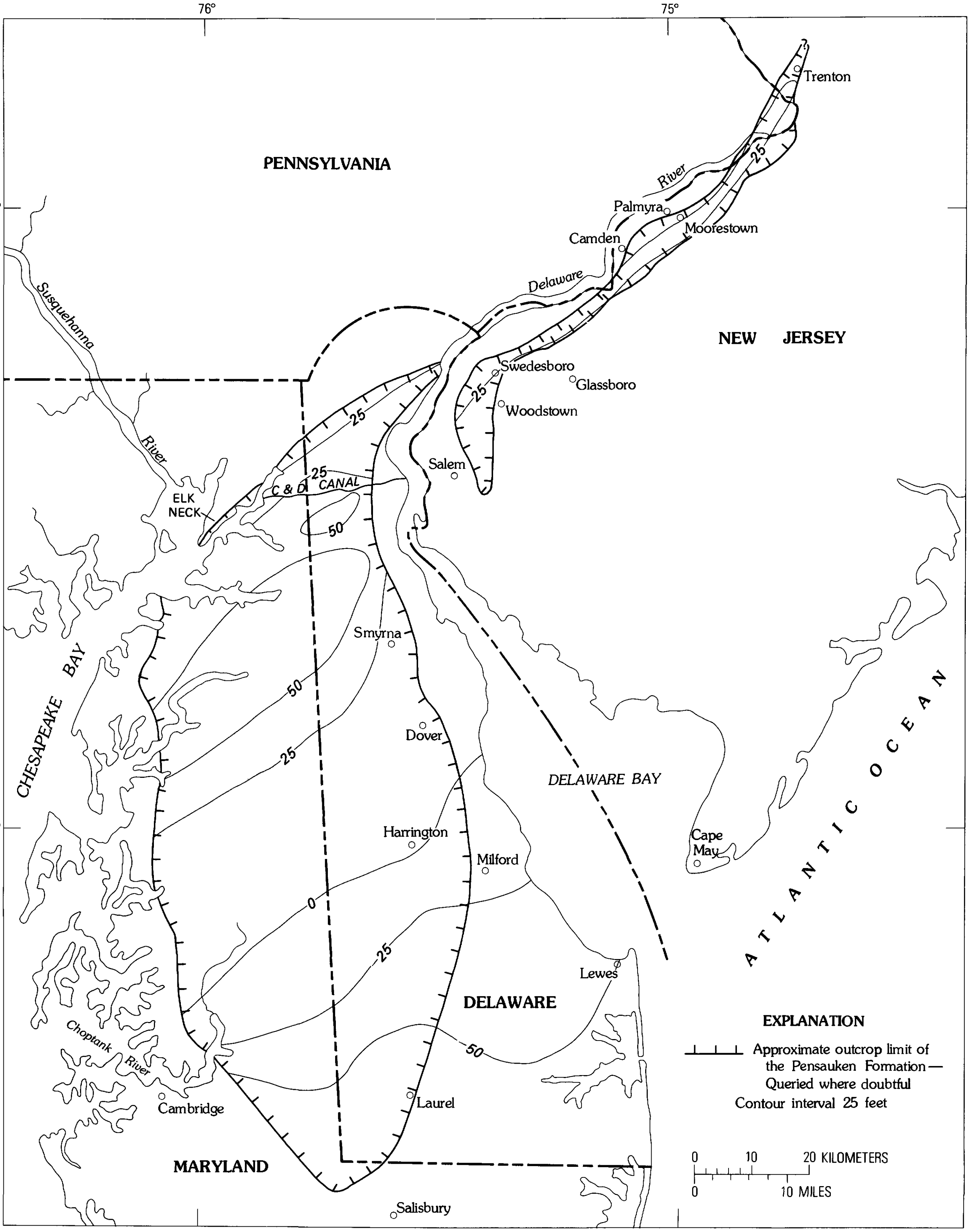

FIGURE 22.—Contour map showing configuration of the base of the Pensauken Formation. Contour interval is in feet. Note low or saddle in base of formation east of Elk Neck.

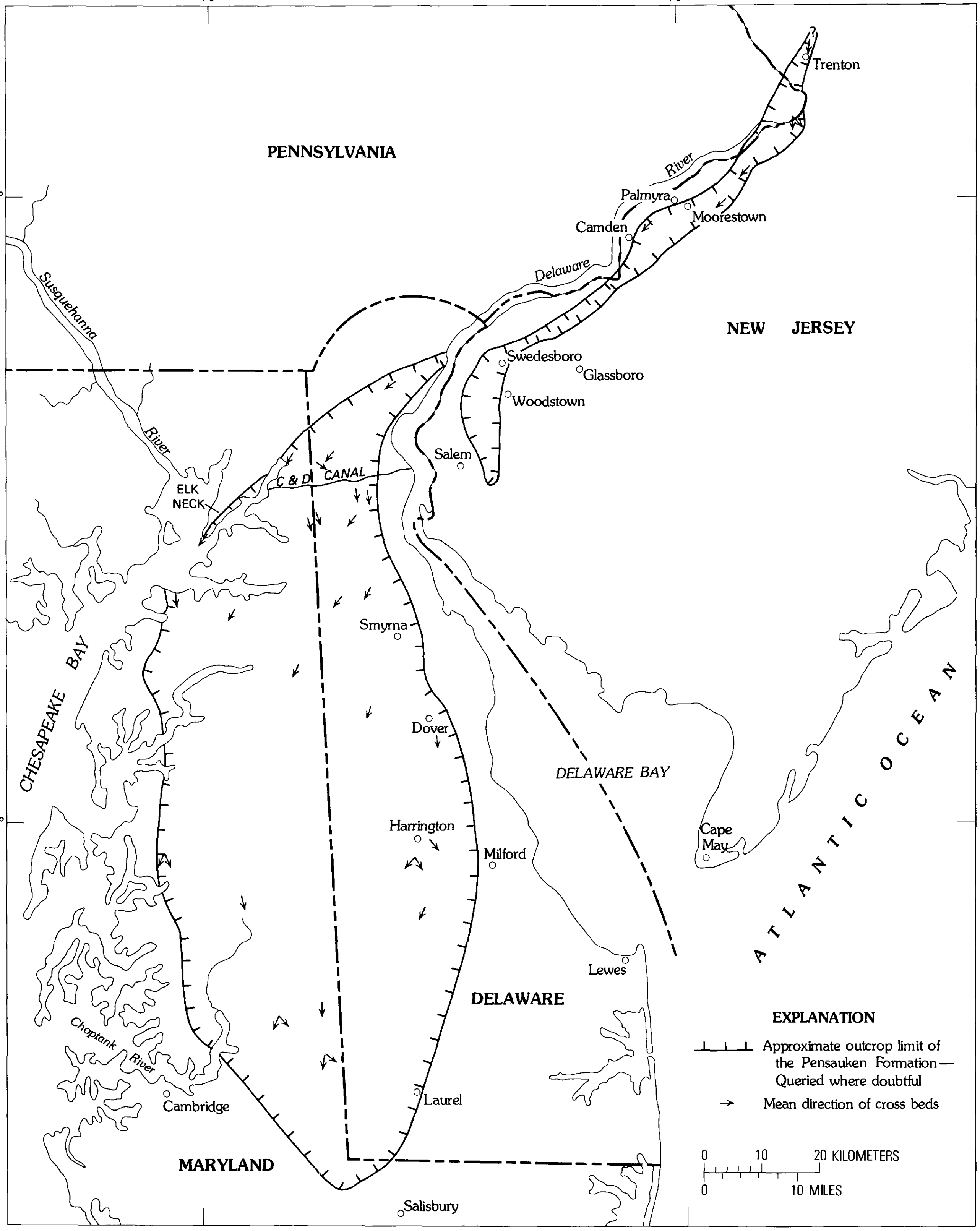

FIGURE 23.—Mean direction of crossbeds in Pensauken Formation.

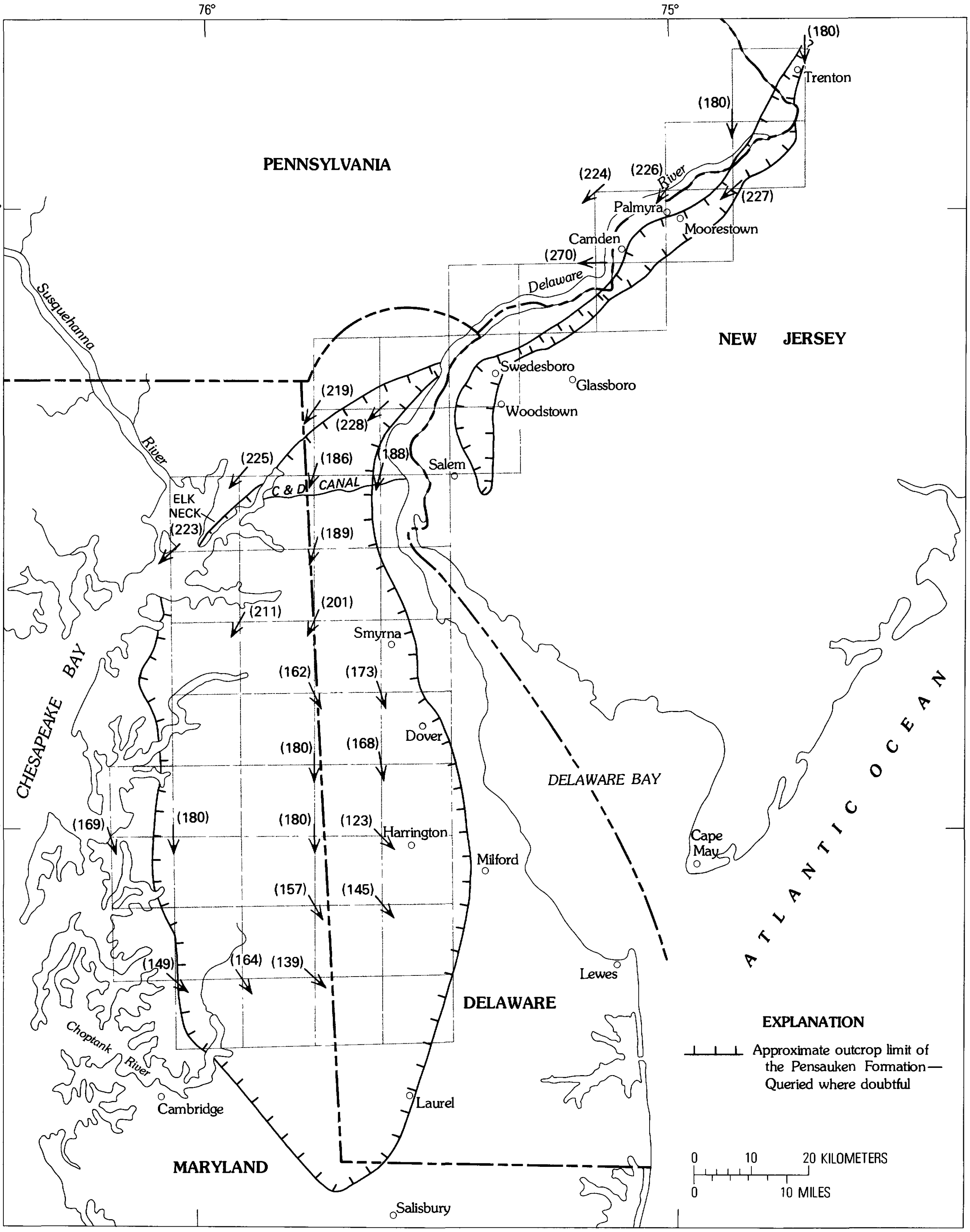

FIGURE 24.—Plot of moving averages of crossbedding orientation in the Pensauken Formation. The method used to construct this plot is the same as that described in figure 14.

dominated by pine (*Pinus*), hickory (*Carya*), and oak (*Quercus*). Locally, the Asian walnut (*Pterocarya*) is very abundant. The presence of *Pterocarya* indicates a Tertiary age for this unit (L. A. Sirkin, written commun., 1974).

South of Salisbury, Md., the Pensauken grades into the very carbonaceous fossiliferous beds of the "Yorktown and Cohansey (?)" Formations as used by Rasmussen and Slaughter in 1955. The macro- and microfossils in these beds have been dated as late Miocene (B. W. Blackwelder and J. E. Hazel, written commun., 1974). The Pensauken is, therefore, of late Miocene age. Stratigraphic relationships, as we have outlined, indicate that the Pensauken is younger than the Bridgeton, and, therefore, by inference, the Bridgeton is also at least this age or older.

MODE OF DEPOSITION AND ORIGIN

The body geometry and bedding characteristics of that part of the Pensauken covered in this report are similar to those of the Bridgeton, suggesting that this part of the Pensauken and the Bridgeton were formed in a similar fluviatile environment. If this interpretation is correct, then the Pensauken as far southwest as the northern Delmarva Peninsula formed in a series of shifting downcutting channels similar to those described herein for the emplacement of the Bridgeton gravelly plain. In the Pensauken, however, the channels downcut progressively to the southeast and east (shown schematically in fig. 25), whereas those in the Bridgeton downcut to the southwest (fig. 15). The emplacement of this gravelly plain, therefore, contributed to the formation of the Delmarva lowland between the much higher Coastal Plain highlands to the northeast in New Jersey and to the west in southern Maryland. No evidence precisely establishes the age of the Pensauken within the area discussed in this report. As will be detailed in a companion report (Owens and Denny, 1978), however, the age of this unit to the south appears to be latest Miocene, not Pleistocene. Such an age has at least two very favorable aspects. First, it helps explain the weathering found throughout almost the entire unit (these beds had more time to be oxidized subaerially); secondly, it provides clues to the effects of the emergence of nearly half of the northern Atlantic Coastal Plain after the initial early(?) Miocene submergence of much of this region. Apparently the uplift of the northern Atlantic Coastal Plain was accompanied by reactivation of the Salisbury Embayment structure (essentially a downwarp; the gravels of Miocene age were transported and in part deposited in this very large continental sag or syncline). The Pensauken gravels represent one tectonic episode in the massive epeirogenic movement of the eastern continental block.

"TRENTON GRAVEL"

The name "Trenton gravel" was proposed by Lewis (1880) to apply to "the newest and last gravels found in the lower Delaware valley."

This very gravelly sand crops out in a large area in the present Delaware River valley, particularly near Trenton. It is below the general level of the Beacon Hill, the Bridgeton, and the Pensauken, and is the youngest sequence in the lowland physiographic subprovince (fig. 3).

Lithologically, this sand is distinct from all the previously described units, being an overall gray or pale reddish brown rather than the yellow or dark reddish brown of the Beacon Hill, the Bridgeton, and the Pensauken. Other lithic characteristics can also be used to separate the units, and these will be discussed shortly. Collectively, these low-lying gravels were grouped into the Cape May Formation by Salisbury and Knapp (1917), even though Fuller (1914) had noted these deposits at two distinct levels—6 m (20 ft) and 12–18 m (40–60 ft). Subsequent investigators of these sediments, notably MacClintock and Richards (1936), Peltier (1959), and Owens and Minard (1975), concurred with Fuller's conclusion that the low-lying "Trenton" gravelly deposits could be divided into two lithic units. Although the deposits are roughly at the levels suggested by Fuller (1914), the sediments at both levels are lithically very similar (the Bridgeton-Pensauken lithic problem repeated).

We have given these deposits provisional locality names; the higher level deposits mapped as "Graywacke 2" (Owens and Minard, 1975) will be discussed under the heading Spring Lake beds, whereas the lower lying beds mapped as "Graywacke 1" will be discussed as the Van Sciver Lake beds. Figure 26 shows the location of profiles across the Delaware River from north of Trenton. Figure 27 is our interpretation of the published (Greenman and others, 1961) and unpublished data from borings from Scudders Falls on the north (Profile I) to the Cape May peninsula on the south (Profile IX). The profiles show the distribution of post-Pensauken beds within the Delaware River valley.

SPRING LAKE BEDS ("GRAYWACKE 2")

DISTRIBUTION AND LITHOLOGY

Deposits having surface altitudes of 10.4–21 m (35–70 ft) are present in the upper reaches (fig. 3) of the lowland subprovince between Trenton, N.J., and Philadelphia, Pa. (figs. 27–30, Profiles I–IX). Most of these deposits are within the Delaware River valley except at Trenton, where they trend away from this valley to the northeast up the valley of Assunpink Creek. (See geologic map of Trenton area, Owens and Minard, 1975.)

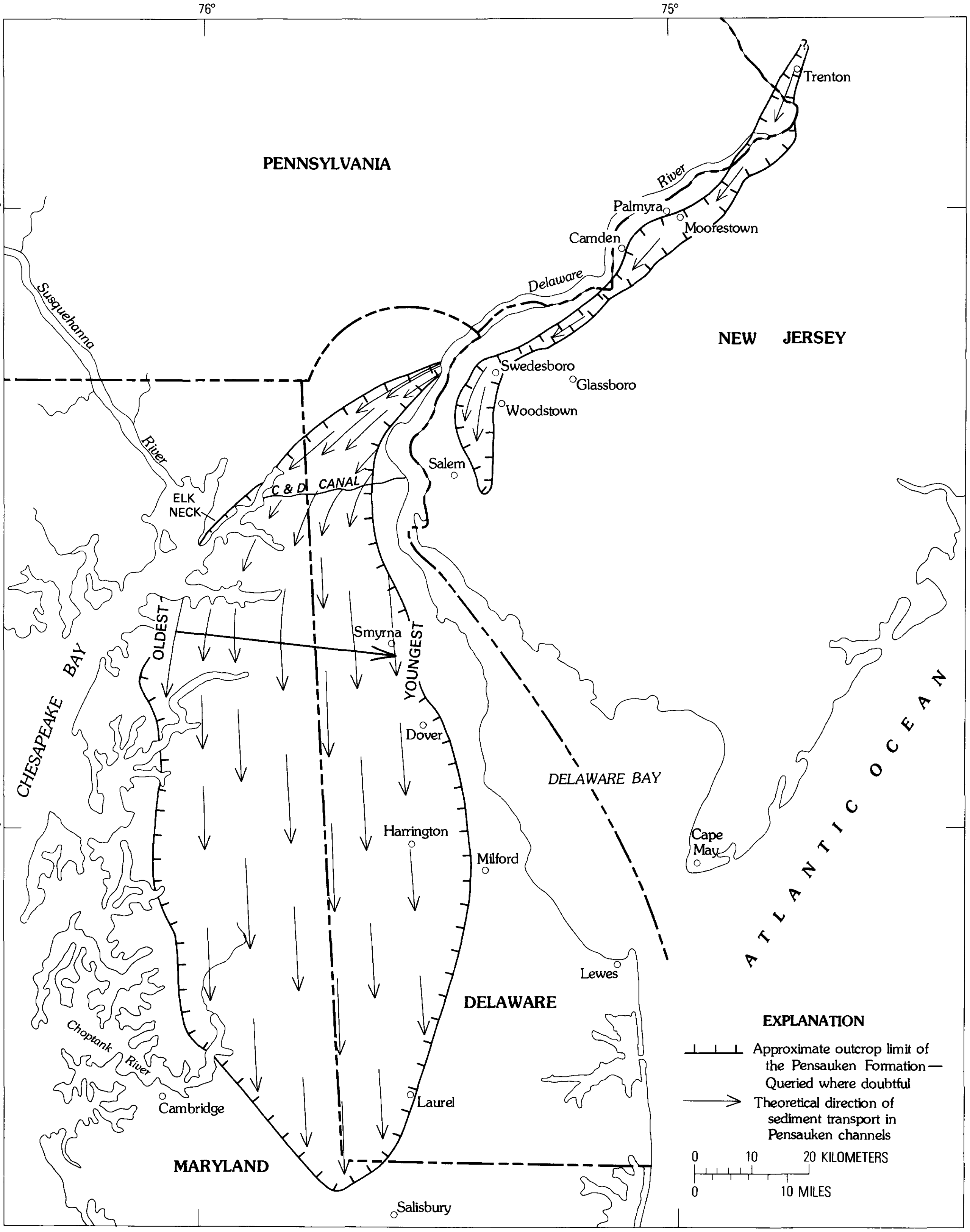

FIGURE 25.—Schematic diagram of paleocurrent trends during the deposition of the Pensauken Formation.

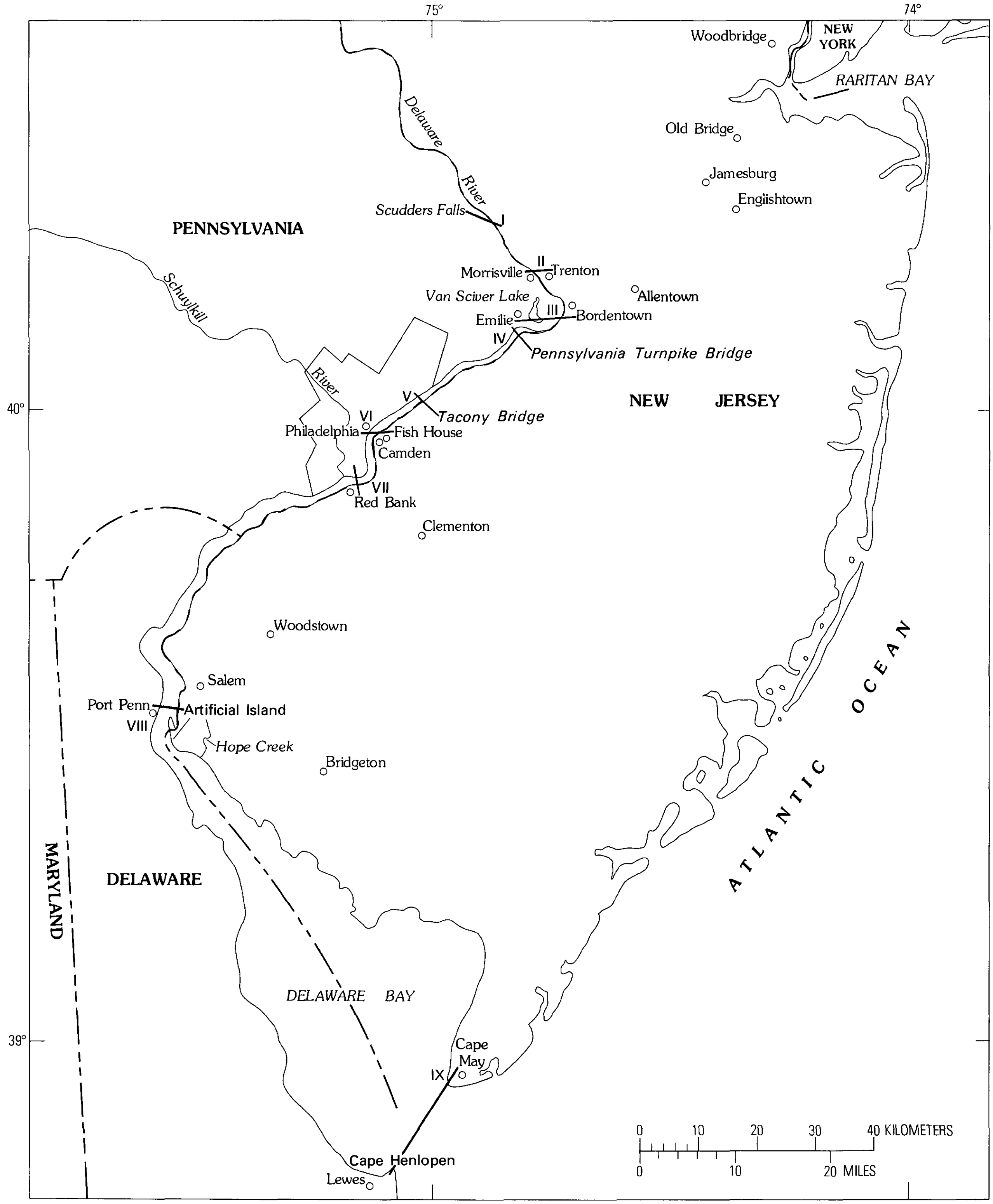

FIGURE 26.—Location of profiles (shown as heavy line) drawn across Delaware River valley (fig. 3). Data used to construct profiles came from many published and unpublished sources but largely from Greenman and others (1961).

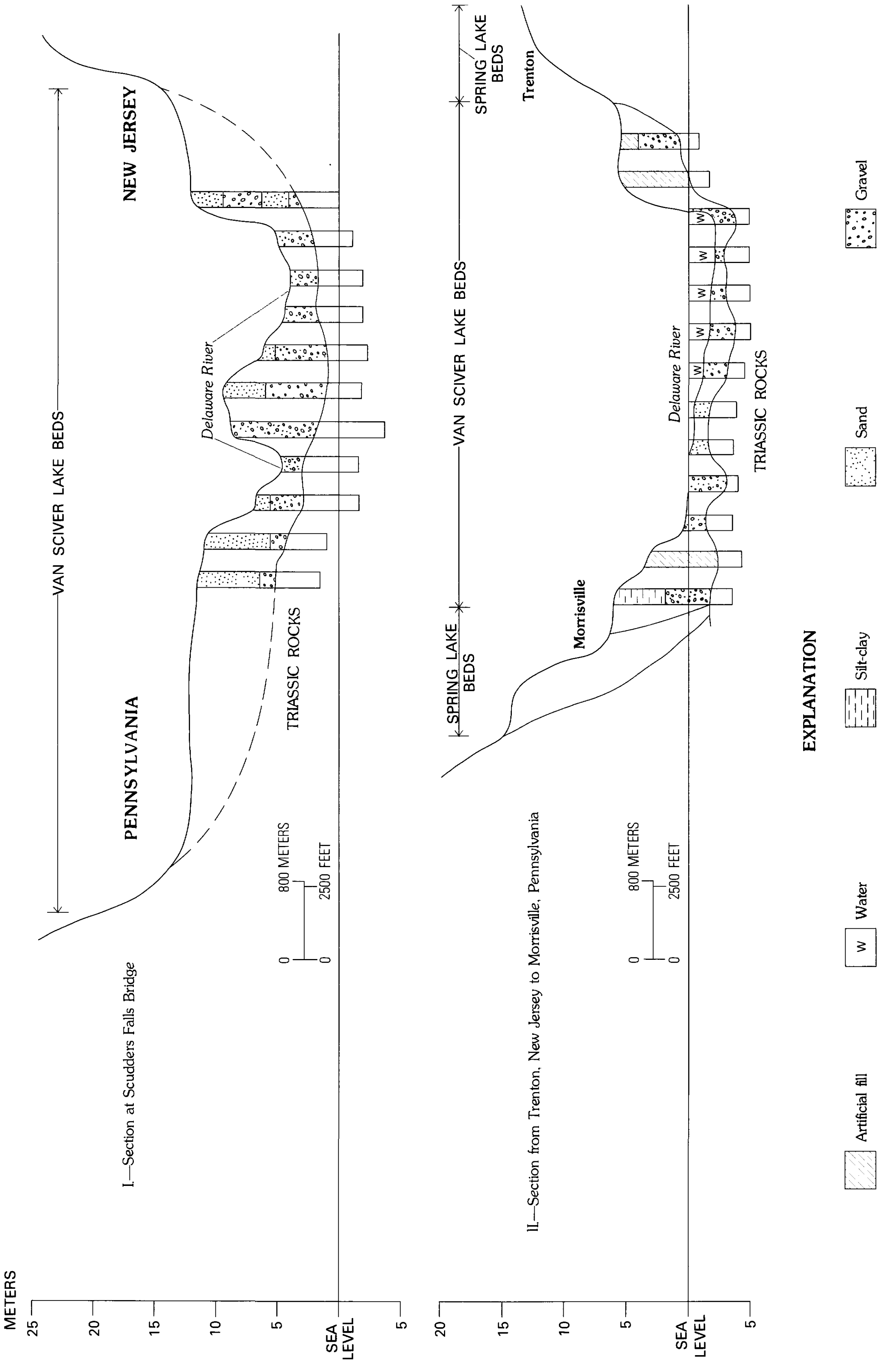

FIGURE 27.—Cross sections showing stratigraphic relations of surficial deposits at locations shown in figure 26. Profiles I and II. Beds at Spring Lake include Fish House Clay and Philadelphia Blue Clay of others. Beds at Van Sciver Lake include the Cape May Formation of Salisbury and Knapp (1917) and Gill (1962). This information applies to figures 27–30.

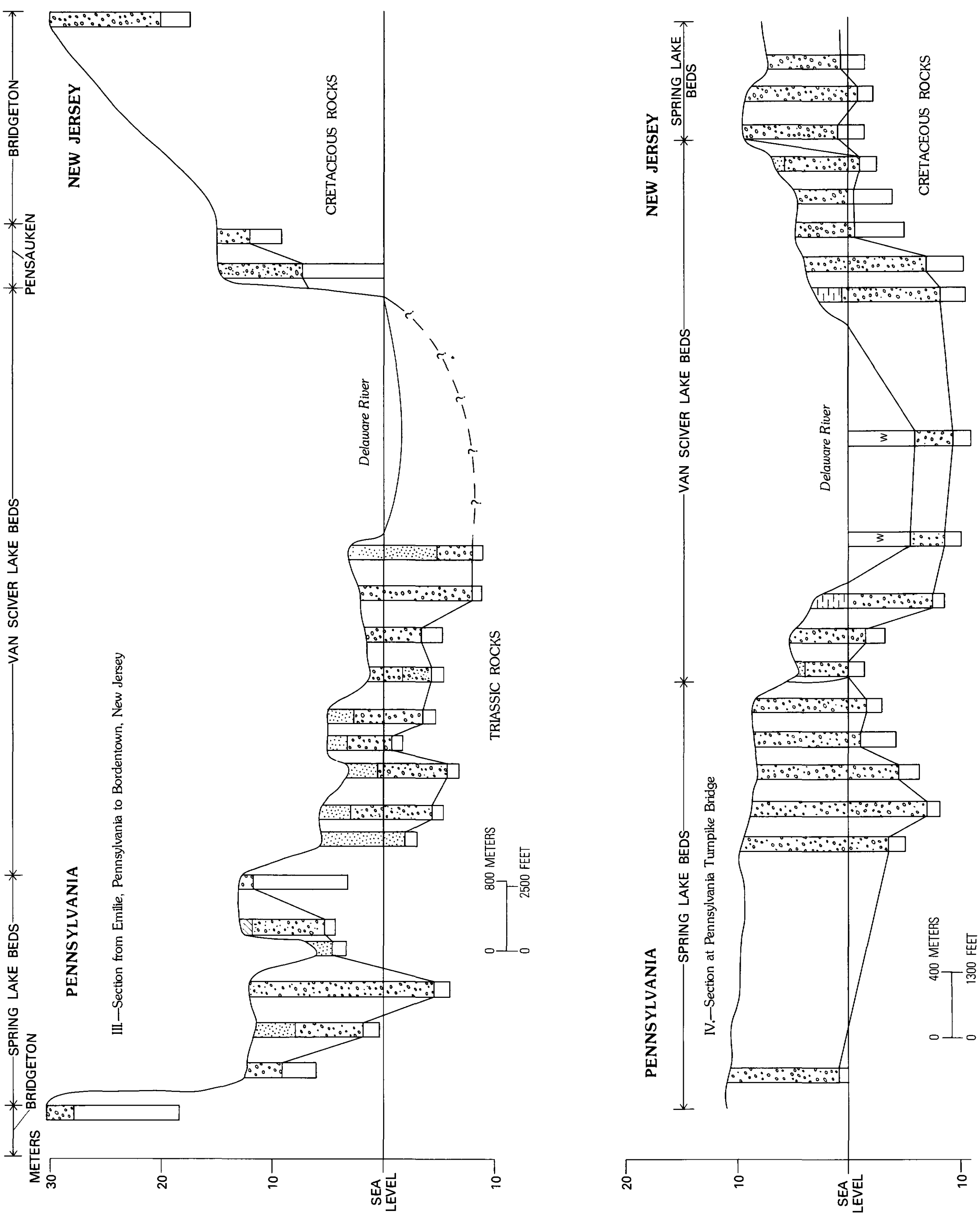

FIGURE 28.—Cross sections showing stratigraphic relations of surficial deposits at locations shown in figure 26. Profiles III and IV. See figure 27 for explanation.

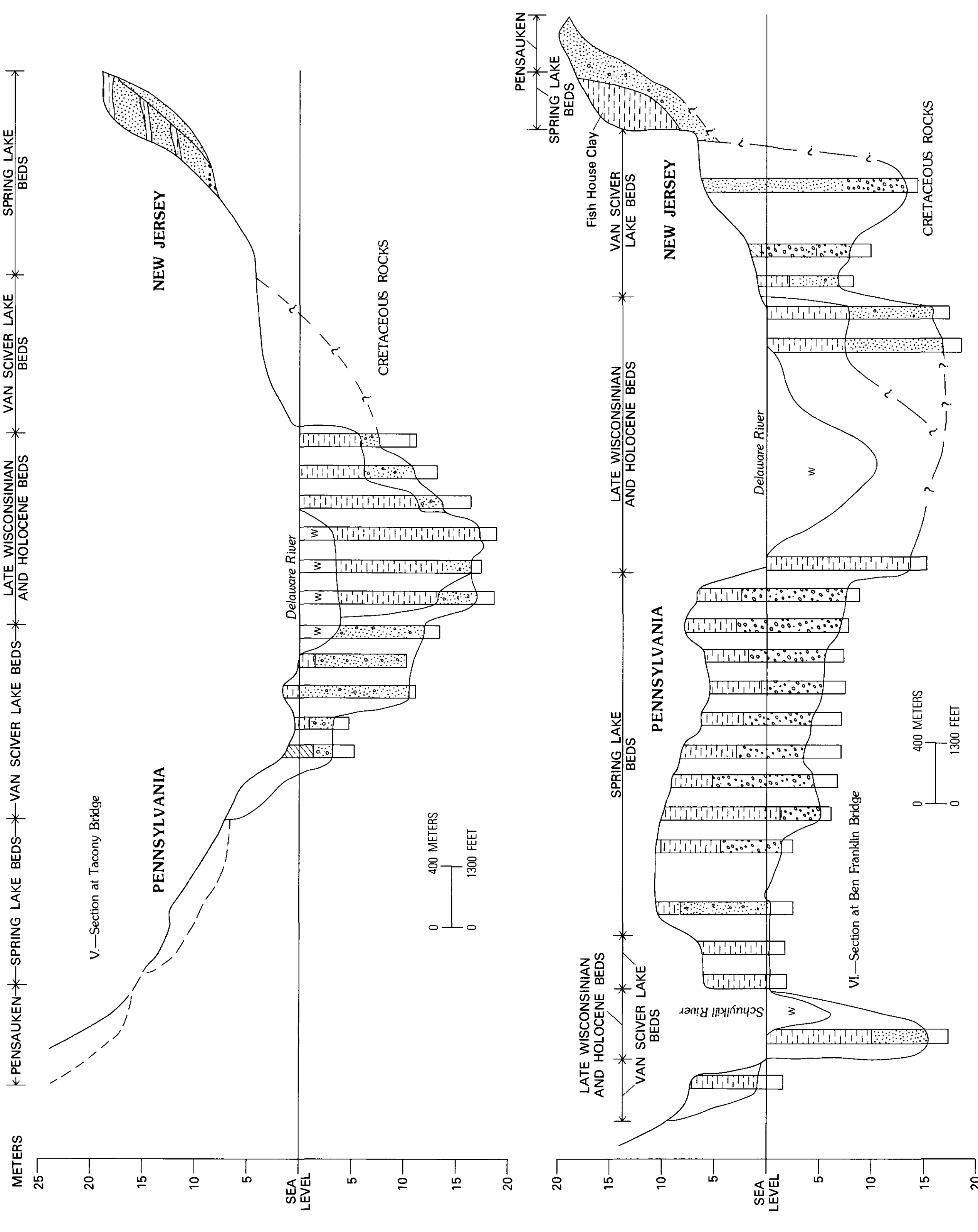

FIGURE 29.—Cross sections showing stratigraphic relations of surficial deposits at locations shown in figure 26. Profiles V and VI. Profile VI modified from Moody and Van Reenan (1967). See figure 30 for explanation.

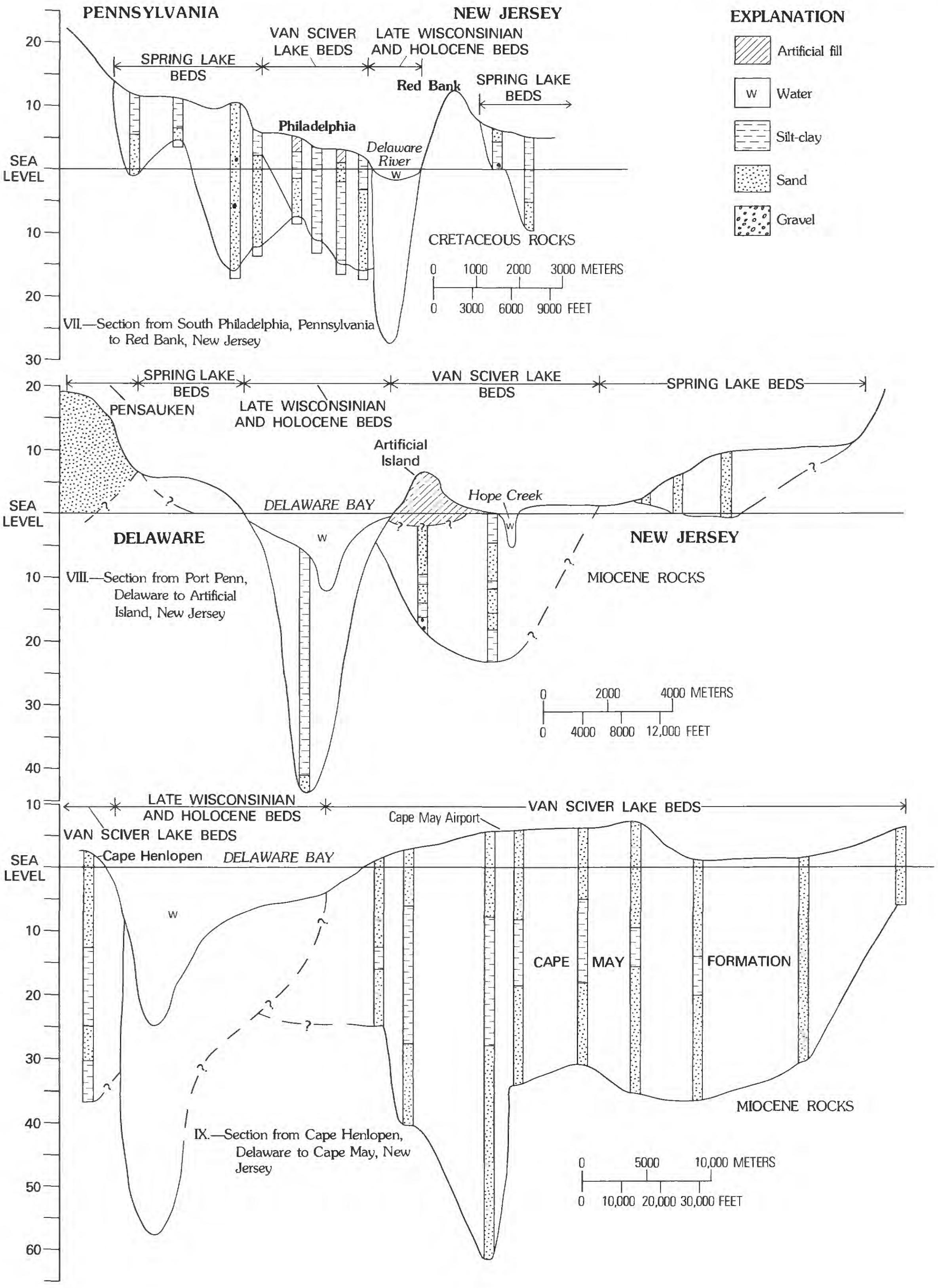

FIGURE 30.—Cross sections showing stratigraphic relations of surficial deposits at locations shown in figure 26. Profiles VII, VIII, and IX. Profiles VII–IX modified from Moody and Van Reenan (1967).

The distribution is very significant because the northwestern part of Assunpink Creek valley is bounded by a high-level (30 m (100 ft) or more) uninterrupted valley wall of sedimentary and metamorphic rocks of the Piedmont province. At least part of the sediment of the Spring Lake beds at Trenton, therefore, was introduced into this region by a large stream flowing from the northeast and not by the Delaware River, a fact noted by Salisbury and Knapp (1917).

Exposures of this unit within Assunpink Valley are far and widely scattered; locally, they may be seen along the creek, in the bluffs along Spring Lake where the Delaware River cuts across the valley fill of the creek, and in railroad and roadcuts in and north of Trenton. Within this valley, the fill is as much as 18 m (60 ft) thick but is commonly much less. Typically, this formation consists of two lithologies—a lower yellow-brown gravelly sand, similar to the Pensauken discussed previously, and an upper pale-reddish-gray to pale-gray gravelly sand. The contact between the two units is sharp, and commonly a gravel layer is found along the contact. The thickness of each bed varies from locality to locality, but the reddish-gray beds are typically the thickest. Salisbury and Knapp (1917) and later MacClintock and Johnson (1956) considered the upper bed to be the Cape May Formation and the lower bed, the Pensauken Formation. We do not agree with these interpretations.

Across the Delaware River in Pennsylvania, sediments in a long, narrow band are similar to and are at generally the same altitude, nearly 21 m (70 ft), as those in the Assunpink Valley (Owens and Minard, 1975). These deposits are typically very gravelly (fig. 31*A*). In fact, boulders as much as 14 m (5 ft) across are common in many of the pits in this unit. Somewhat farther downvalley, between Florence and Burlington, N.J., these deposits are much sandier (fig. 31*B*).

Between Burlington and Palmyra, the width of the post-Pensauken valley is less than 3 km (2 miles), and deposits referrable to the Spring Lake beds are absent, possibly having been removed during the emplacement of younger deposits. At Palmyra, the Pensauken (fig. 32) is overlain by a channel-shaped deposit of interstratified thin beds of cross-stratified sand and grayish-green clay (fig. 28, Profile III). These beds, the interstratified sand and clay, are downvalley equivalents of the Spring Lake beds. A coarse gravelly sand is present at the base of the channel (fig. 28). The clay that crops out near the surface is dark red, suggesting deep subaerial oxidation of these deposits.

To the southwest, the post-Pensauken valley broadens again, and near Philadelphia, it is approximately 6.5 km (4 miles) wide. Deposits that appear to be correlative with those at Spring Lake occur on both sides of the Delaware River at altitudes of 12 to 18 m (40 to 60 ft). The largest area underlain by these deposits in this region is at Philadelphia, where the deposits are referred to as the

FIGURE 31.—*A*. Coarse-gravel facies of Spring Lake beds. Pit is at Penn Valley, Pa. *B*. Sand facies of Spring Lake beds 1.9 km (1.2 miles) northeast of Burlington, N.J., just north of U.S. Route 130.

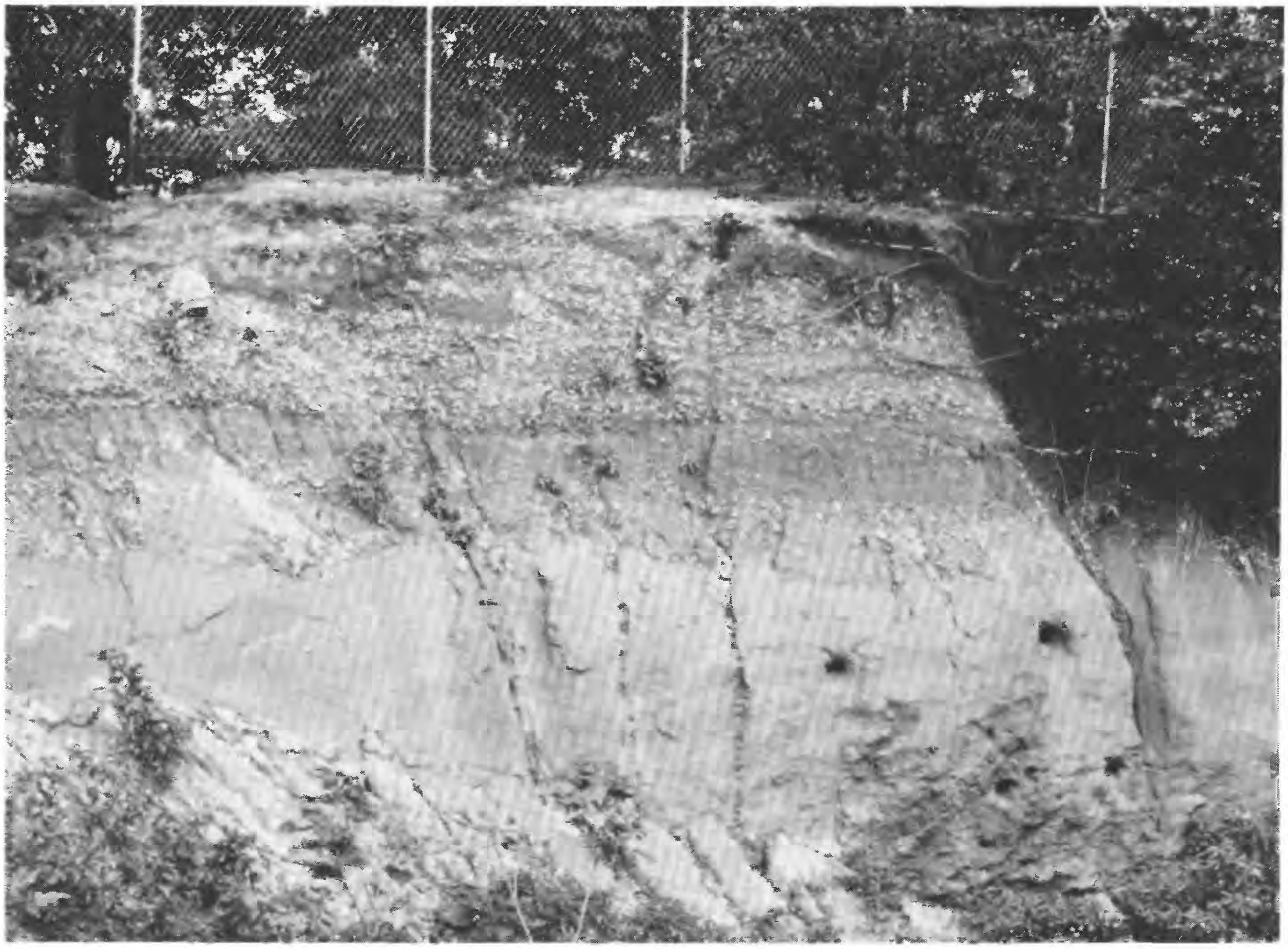

FIGURE 32.—Basal gravel of Spring Lake beds overlying Pensauken Formation at Palmyra, N.J. Pit is just west of junction of U.S. Route 130 and U.S. Route 73.

"Philadelphia blue clay." In New Jersey, a small perched terrace near Camden was once extensively mined and referred to as the "Fish House Clay" (fig. 29, Profile VI). Although the "Philadelphia blue clay" is more widespread than its probable New Jersey equivalent, the "Fish House Clay," the latter unit is better known, primarily because of the very detailed study of this deposit by Woolman (1897) (see fig. 29, Profile VI). The pits that exposed the "Fish House Clay" have been abandoned and built over. Part of the deposit remains as indicated by the log from an augered hole along the abandoned pit edge (fig. 33). The bulk of the deposit is primarily fine clasts, silt and clay, green or grayish green, and deeply weathered near the surface. The clay is about 9 m (30 ft) thick and overlies beds resembling the Pensauken. Similar thick clay-silt layers, overlying Pensauken-type deposits, also occur in the Philadelphia area (Strock, 1929; Greenman and others, 1961).

Downvalley from here, data regarding the Spring Lake beds are very sparse, largely because of poor exposures and few detailed studies of the wells that have been drilled in this area, or lack of drilling by ourselves. Correlations, therefore, are speculative between Philadelphia and lower Delaware Bay.

In the Port Penn, Del., area (fig. 30, Profile VIII), sediments having surface altitudes of 6 to 9 m (20 to 30 ft) above sea level occur along the edges of the Delaware River. These sediments are interpreted to be remnants of the Spring Lake beds. Farther south, in the lower Delaware Bay, similar deposits are present, at least on the west side of the bay. There, deposits are separated from the lower lying deposits by an intermittent scarp that has a toe almost 6 m (20 ft) above sea level. Apparently, Spring Lake beds were present throughout the present Delaware River valley but have been extensively stripped away in many parts of the valley.

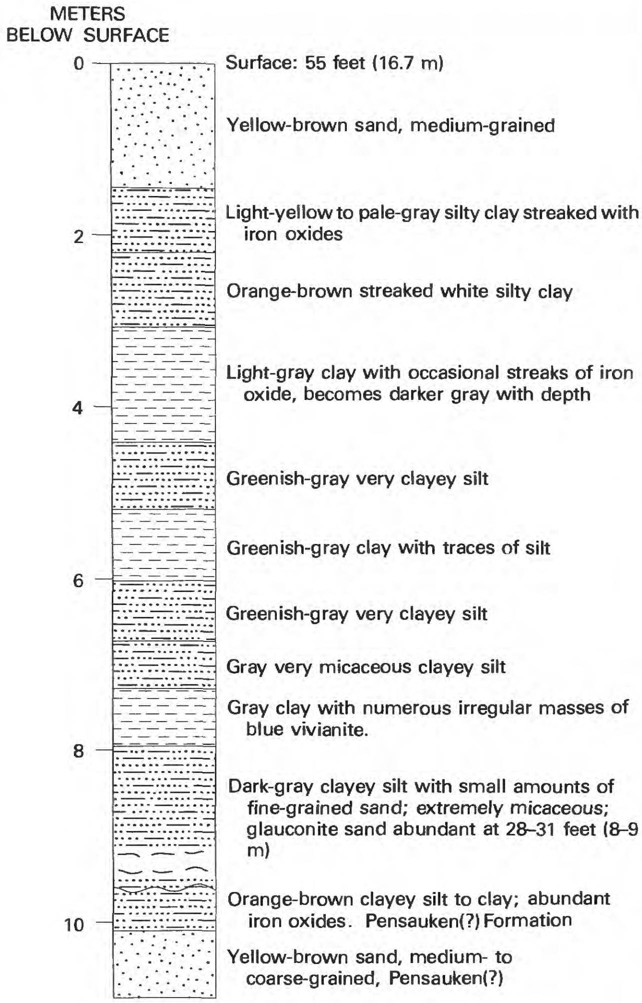

FIGURE 33.—Log of auger hole in "Fish House Clay" on east side of River Road, Camden, N.J. For precise location and description of clay pit, see Woolman (1897).

PETROLOGY

The Spring Lake beds are characterized by marked textural changes downvalley. At Trenton, the beds are a very gravelly graywacke sand. Gravel diminishes in both size and concentration downvalley, and the unit is mostly interbedded sand and clay-silt. Clay-silt is particularly thick in the upper beds near Philadelphia. The sand also shows a downvalley change in composition. At Trenton, the sand has large concentrations of feldspar. Downvalley, the feldspar content decreases and the sand is mostly quartz. This change is possibly the result of two factors. One factor is that the rock fragments are less durable than quartz during transport downstream. The other factor is that the Delaware passes through a vast width of quartz-sand surface beds (Cohansey Sand and Kirkwood Formation) that would contribute large amounts of quartz to the Van Sciver beds, causing a marked change in quartz content from the upper to the lower valley. Heavy-mineral assemblages in the beds follow much the same pattern. In the upper valley, the beds have large concentrations of hornblende and pyroxene (immature assemblage). Downstream, the concentrations of these two mineral types decline markedly, producing a more mature heavy-mineral assemblage after the change from a graywacke to an orthoquartzite in the lower valley.

The clay assemblages in this unit also are less mature than the assemblages in the older units, as shown by the large concentrations of chlorite and montmorillonite in both the clay-silt beds and the clay-silt matrix of the sand. Montmorillonite and chlorite are unstable in zones of intensive subaerial oxidation. The presence of these minerals in the interstices of sands indicates that the beds are not extensively weathered.

AGE

In contrast to the older formations, the Spring Lake beds have floral and faunal remains. In the middle upper valley near Camden, N.J., marine and freshwater diatoms, sponge spicules, freshwater clams, and vertebrate remains (horse, *Equis complicatus*, and unnamed wolf vertebrate) have been reported from these beds (Woolman, 1890; 1897; Pilsbry, 1897; Richards, 1932). In the lower Delaware Bay region and along the coast in the Delmarva Peninsula, the Spring Lake beds apparently interfinger with the estuarine beds and then, farther seaward, with the marginal marine facies of the Omar Formation, which has been dated radiometrically at about 107,000 years, or Sangamon (B. Szabo, written commun., 1975). The beds at Spring Lake, therefore, are Sangamonian in age.

Palynologic studies were made on the dark clayey beds at Fish House. As suggested by the marine fauna, the overall assemblage is dominated by a warm-temperate flora (oak-hickory-birch) and small amounts locally of cool elements (spruce and hemlock), particularly near the base (L. A. Sirkin, written commun., 1976). The exotic pollen types, *Pterocarya*, *Englehardtia*, and others, presumably Tertiary forms, are absent; hence, the Spring Lake beds contain a modern flora (Quaternary forms).

MODE OF DEPOSITION

The Spring Lake beds have many sedimentary characteristics not observed in the older alluvial units of this area. The unit grades from a coarse gravel in the upper part of the Delaware Valley at Trenton, N.J., to a sand at Burlington, N.J., and finally to a clayey silt at Philadelphia. This textural change takes place within the relatively short distance of 32 km (20 miles). In contrast, the older units, particularly the Bridgeton and Pensauken, are largely sand and coarser fragments throughout most of their outcrop area—about 160 km (100 miles) in both units.

The general arrangement of the various lithofacies in the Spring Lake beds resembles, in most respects, the depositional environments existing today in the Delaware River valley, particularly between Trenton and Philadelphia. At present, the Delaware River upstream from Trenton is flowing on bedrock and has a relatively steep gradient. Below Trenton, the gradient is low, and the river is tidal. Above Trenton, the stream is mostly transporting sand and gravel as bedload, whereas below Trenton, most of this bedload is deposited because of a reduction in gradient, and only the clay-silt clasts are transported in suspension downstream. The depositional environments in this modern analog, therefore, would be fluviatile above Trenton, deltaic at Trenton just below the Fall Line, and estuarine where the sand is deposited (clayey) from Philadelphia downstream.

The presence of thick clayey estuarine deposits well into the upper part of Spring Lake depositional valley represents a marked change in environmental conditions when this valley is compared with the depositional valleys of the older formations in which sand dominated throughout.

The Spring Lake beds, particularly at Trenton, are markedly different in physical appearance from those in the older gravelly units. Overall they are gray to pale reddish brown and lack the widespread cementation and staining by iron oxide found in the older, higher level units. The similarity of the clay-mineral assemblages in both the matrix of the sand and gravel and in the clay-silt strata of the Spring Lake beds suggests that these beds have not been weathered extensively. Certainly the degree of subaerial oxidation in this unit is considerably less than that found in the older formations. Several previous investigators recognized the similarity between the sediments of the Spring Lake beds and those in the morainal deposits to the north. Because of this similarity, many have considered the "Trenton gravel," including the beds at Spring Lake, to be Wisconsinan in age (Peltier, 1959). Radiocarbon dating in the lower valley and the possibility that the Spring Lake beds may be the fluviatile equivalent of the fossiliferous Omar Formation at the coast, however, make such an interpretation unlikely. In our study of the coastal deposits in the central Delmarva Peninsula, we would correlate this unit with the Omar beds (Sangamonian age) of that region. If the Spring Lake beds are Sangamonian in age, they probably represent in part reworked debris from morainal deposits older than Wisconsinan, that is, Illinoian, or perhaps older.

The fossil evidence (marine diatoms, Woolman, 1897) supports at least a partial estuarine origin for the clayey beds as far upvalley as Philadelphia. The presence of fresh-water mussels (Woolman, 1897) near the base of the clay, then more marine diatoms in the upper part of the clay, suggests the gradual encroachment of marine conditions up the valley during deposition of this unit. This relationship suggests that the deposits accumulated during a rise in sea level (transgression). Microfloral remains (principally oak-hickory-dominated pollen assemblages) in the clay indicate that the climate was mild during this transgression, thus attesting to a nonglacial time of accumulation.

Figure 34 shows the direction of sediment transport during the deposition of this unit. There is no evidence that beds of this age are present in southern New Jersey; they are, however, found along the west side of Delaware Bay.

VAN SCIVER LAKE BEDS ("GRAYWACKE 1")

DISTRIBUTION AND LITHOLOGY

In the Delaware Valley at Trenton, a broad terrace as much as 8 km (5 miles) wide has surface altitudes of 3 to 6 m (10 to 20 ft) above sea level (fig. 27, Profile II). The terrace crosscuts the higher level Spring Lake beds, dividing this unit into three separate masses (Owens and Minard, 1975). The lower part of the terrace is underlain by sand and gravelly sand, which have been extensively dug in Pennsylvania, producing a large artificial body of water called Van Sciver Lake. This site was chosen to be representative of these beds, although only one of several lithofacies in this unit is present here. Earlier, this deposit was mapped as "Graywacke 1" (Owens and Minard, 1975).

The distribution of this unit is shown in the cross sections in figures 27–30. In the northernmost section (Profile I), up the Delaware River, the Van Sciver Lake beds have surface altitudes as much as 12 m (40 ft) above sea level, and the base is consistently above sea level. At Trenton (see Profiles II and III), the crosscutting relationship to the Spring Lake beds is shown. The base of the Van Sciver Lake beds deepens gradually down the Delaware Valley (Profiles IV–VIII), and in the vicinity of the Cape May airport, the deepest channel in the unit extends to about 60 m (200 ft) below sea level (Profile IX). The entrenchment into and below the Spring Lake beds is shown in this series of profiles.

Exposures of the Van Sciver Lake beds are few because most of the unit is deeply buried. The best outcrops are in excavations in the upper Delaware River valley, particularly at Van Sciver Lake. For a short time, the beds were exposed in a deep excavation at Artificial Island, N.J. The coarse gravel and sand within this unit are somewhat similar to those in the beds at Spring Lake. In the upper part of the valley near Trenton, the beds are very gravelly (fig. 35). Downvalley at

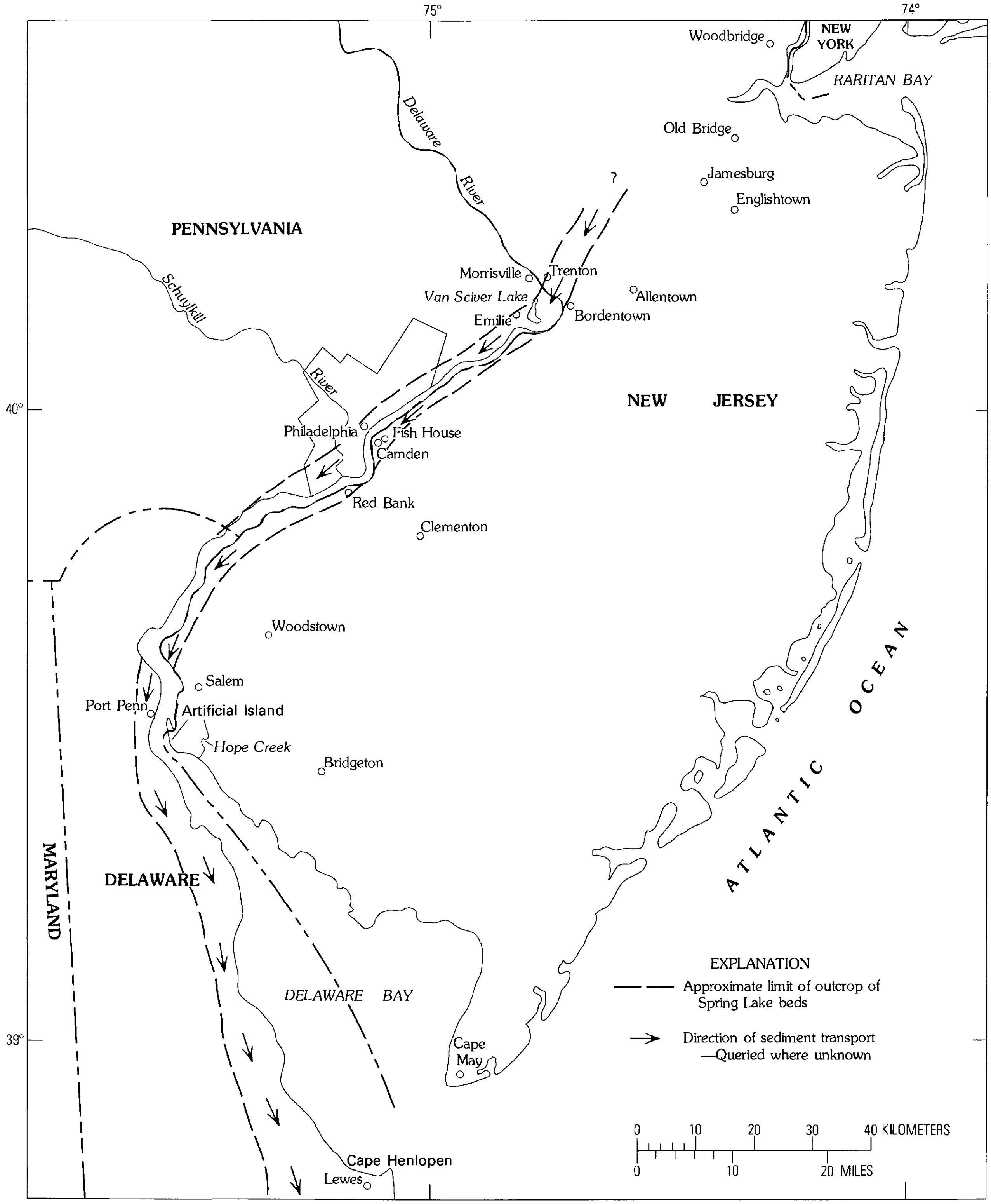

FIGURE 34.—Direction of sediment transport during Spring Lake time. Sediment entered the Trenton area from the northeast and moved down present Delaware Valley to the sea.

FIGURE 35.—Typical lithology in cut banks at Van Sciver Lake 2.7 km (1.7 miles) due south of Morrisville, Pa.

Artificial Island, the gravel content has declined, and the unit is mostly interbedded, thick-bedded clay-silt (fig. 36) and crossbedded sand (fig. 37). Figure 38 is a measured section in the pit, showing the various lithologies in this unit. The interbedding of sand and clay-silt persists to the coast (fig. 30, Profile IX), where, however, the unit is fossiliferous (Gill, 1962). Here we included the Cape May Formation of Gill (1962) in the Van Sciver Lake beds.

Figure 39 shows the direction of sediment transport in this unit within the area of investigation. The sediment in this unit at Trenton was introduced in the Delaware Valley from the northwest, as shown by the map distribution (Owens and Minard, 1975). This direction thus represents a significant change from the direction of sediment input of the older units in the valley. Downvalley from Trenton to Salem, the Van Sciver Lake sediments underlie much of the lower lying parts of the valley. From Salem to Cape May, these sediments appear to be largely restricted to the east side of Delaware Bay.

Because of their restriction to the Delaware Valley and because of poor exposures, no effort was made to study the crossbedding, hence vectoral properties, in this unit.

PETROLOGY

As observed earlier, the sediments in this unit and in the Spring Lake beds are lithologically very similar in outcrop to those in the upper part of the valley. Downvalley samples were available at only a few localities (Artificial Island and Cape May Peninsula, N.J.). The mineralogy of the sediments in this unit therefore is only grossly known.

FIGURE 36.—Massive dark-gray clay-silt underlain by thin coarse gravel bed at base of channel in excavation at Artificial Island, N.J. Vincentown Formation (Paleocene) is exposed at base of bank.

FIGURE 37.—Large-scale high-angle crossbeds in sands near base of excavation at Artificial Island, N.J.

On the Pennsylvania-New Jersey border, at and in the vicinity of Van Sciver Lake and upvalley to Scudders Falls, the sand in this unit is a high-rank graywacke as defined by Krynine (1948). The gravel (fig. 35) also is characterized by a large number of rock types, conspicuous among which is limestone. Mostly, however, the

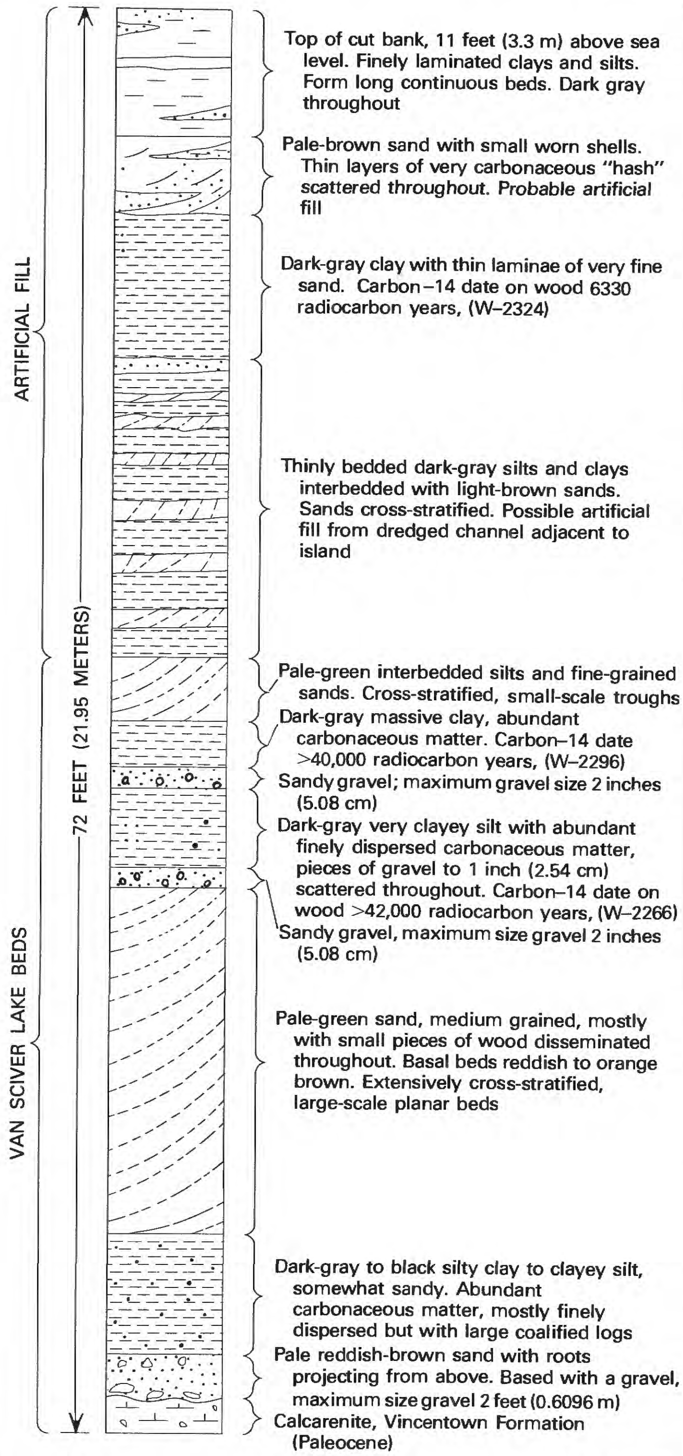

FIGURE 38.—Composite section from deep excavation at Artificial Island, N.J.

calcareous material forms coatings on the more siliceous gravel pieces. At Artificial Island, the sand has a much lower proportion of rock fragments, and the quartz content increases markedly. The interbedded clay-silt has a veried clay-mineral assemblage characterized, as in the Spring Lake beds, by a high concentration of chlorite. On the Cape May Peninsula, the beds assigned to this unit are very quartzose, essentially protoquartzite in composition.

The nonopaque heavy minerals do not vary greatly throughout the valley. At all localities sampled, the nonopaque heavy minerals are immature, containing moderate amounts of hornblende and to a lesser degree, hypersthene.

AGE

The beds at Van Sciver Lake are considered to be Sangamonian in age on the basis of the following facts. The fossils in this unit at Cape May are in part a warm-water assemblage (Richards, 1962). The pollen in the deposits at Artificial Island and in the clay-silt beds at Cape May consists of similar warm-temperate assemblages (L. A. Sirkin, written commun., 1975). Radiocarbon ages run on shells from Cape May were greater than 35,000 radiocarbon years (Richards, 1962). Wood from the undisturbed beds at Artificial Island yielded ages of greater than 40,000 radiocarbon years (W–2266 and 2296). All these data are compatible with deposition during an interglacial period. These facts taken in conjunction with the crosscutting relationship of this unit with Spring Lake beds, also thought to be Sangamonian, suggest a late Sangamonian age for the beds at Van Sciver Lake. These beds would correlate with the Ironshire Formation of the central Delmarva Peninsula (Owens and Denny, 1978).

MODE OF DEPOSITION AND ORIGIN

The distribution of sediment in this unit is somewhat similar to that in the Spring Lake beds. Basically, the deposits in the Van Sciver Lake beds are more gravelly in the upper part of the valley and more clayey in the lower part. In addition, the sand changes from immature (graywacke) in the upper part of the valley to mature (protoquartzite) in the lower part. Gill (1962) in his analyses of the beds at Cape May noted that estuarine beds were at the base and marine beds at the top. Such a relationship suggests an initial period of downcutting and then an infilling of the valley, first by sediments laid down under brackish conditions and then by sediments deposited under open-ocean marine conditions. The vertical arrangement of beds indicates a regression followed by a transgression. The regression was of large magnitude, extending to more than 60 m (200 ft) below sea level at the present coast. Sea level then rose to nearly 7.4 m (25 ft) above the present level, or somewhat less than the sea-level rise associated with the beds at Spring Lake (nearly 21 m (70 ft) above present sea level).

If these relationships are valid, then the Van Sciver

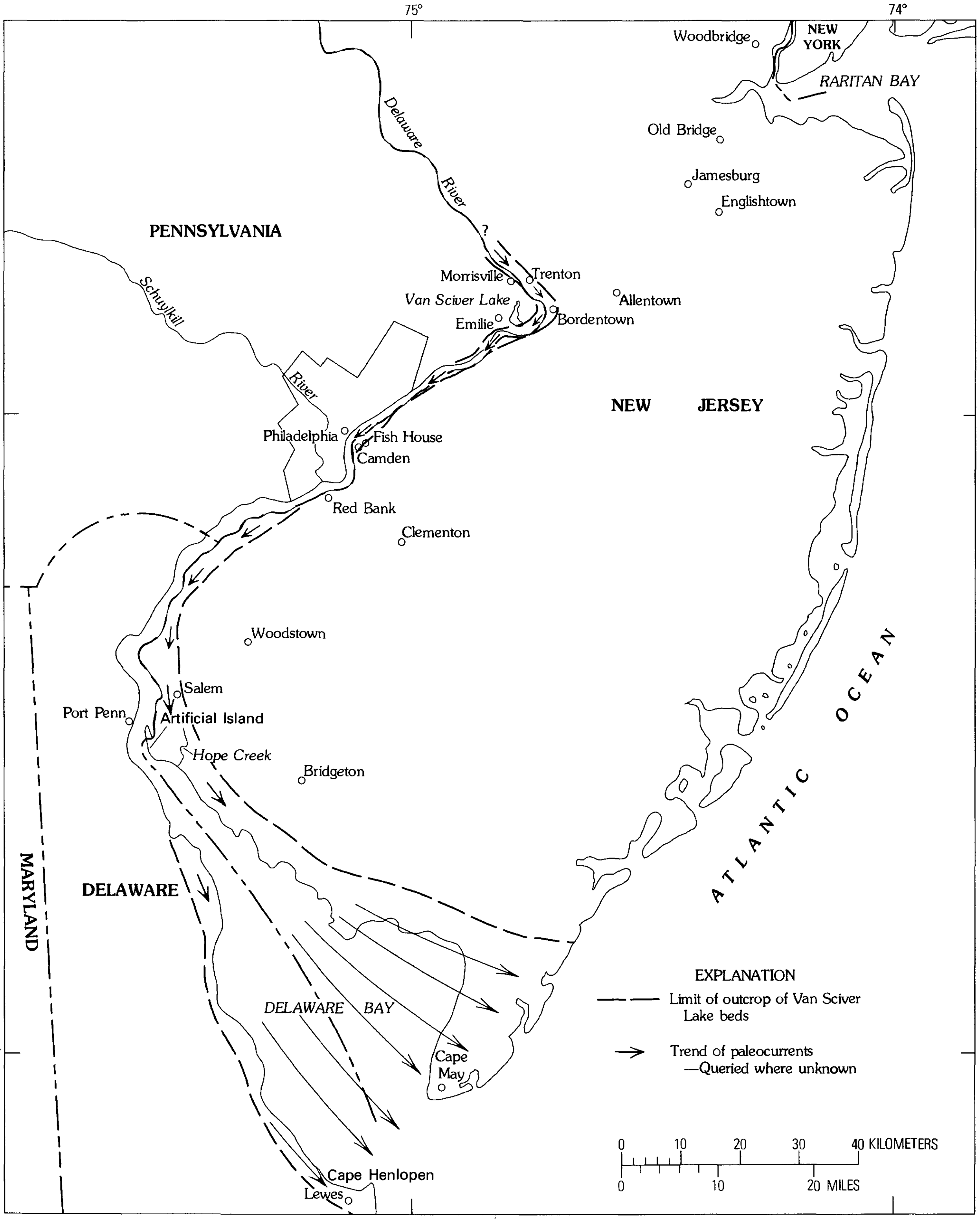

FIGURE 39.—Hypothetical paleocurrent trends in the beds at Van Sciver Lake, Pa.

Lake beds represent a single regressive-transgressive cycle and are not associated with the sedimentary cycle represented by the Spring Lake beds. Open-ocean marine conditions did not extend very far up the Van Sciver Lake beds valley, as evidenced by no marine fossils at Artificial Island, N.J., and none reported in the many borings into this unit even farther up the valley. The marine phase of the Van Sciver Lake beds has a very restricted distribution to the lower Delaware Bay region. The marine incursion up the Delaware Valley was less during Van Sciver Lake time than during Spring Lake time.

SUMMARY

The original plan of our study was to examine the surficial sediments of the "Amboy-Salem" trench or valley along the inner edge of the New Jersey Coastal Plain. As the study progressed, the scope of the investigation had to be enlarged to cover southern New Jersey and the northern half of the Delmarva Peninsula west of Delaware Bay in order to understand the regional stratigraphic relationships within these alluvial sediments.

The "yellow gravels" of Salisbury (1898) were critically analyzed to determine whether mappable units were indeed present, as Salisbury and Knapp (1917) proposed, or whether, as MacClintock and Richards (1936) had proposed, the "yellow gravels" were a single sedimentary complex spanning most of early Pleistocene time. Although the "yellow gravels" are lithologically very similar (largely sand and gravelly sand of arkosic composition), viewed regionally, two distinct gravelly sand sheets were outlined—the older and higher level beds (the Bridgeton), largely in southern New Jersey, and the lower level beds (the Pensauken), mostly in the northern Delmarva Peninsula (fig. 40). These two units occupy part of the Amboy-Salem trench or valley between Trenton and Salem, N.J. Here, the Bridgeton is found typically on hilltops, surrounded by Pensauken in the adjacent valleys. The Pensauken appears to have been deposited in valleys that eroded through the Bridgeton and thus postdates this unit.

This interpretation differs from that of Salisbury and Knapp (1917). In their interpretation, the Bridgeton would have been restricted largely to southern New Jersey, and the Pensauken would have occupied nearly all the Amboy-Salem trench. In this general region, we would restrict the Pensauken to the Swedesboro plain (New Jersey) of Salisbury and Knapp (1917), and the Woodstown plain deposits (New Jersey) to the Bridgeton.

Crossbedding studies within the Bridgeton and Pensauken Formations reveal that both units occupied at least parts of the Amboy-Salem trench northeast of

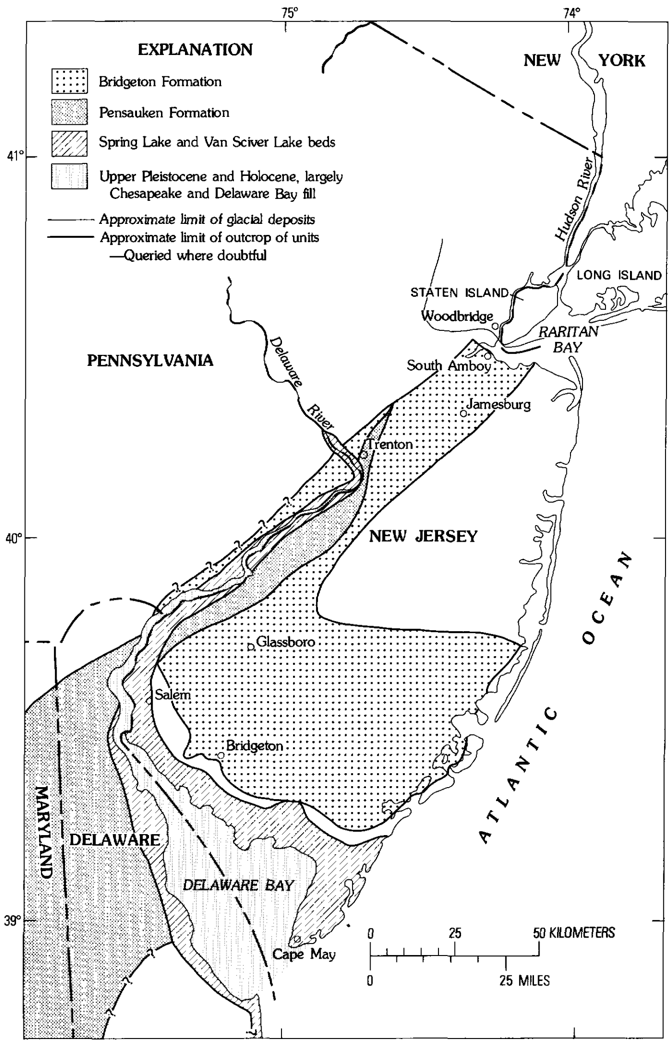

FIGURE 40.—Map showing locations and shapes of the different units in the area of investigation.

Trenton. The Bridgeton sediments were carried into the New Jersey Coastal Plain by a large stream coming from the north (the ancestral Hudson?), but the evidence for the most northeasterly extension of the stream is buried beneath a thick covering of glacial deposits of Pleistocene age. The upvalley distribution of the Pensauken was not investigated, but the deposits discussed by Hale and Howell (1946) and Campbell and Bascom (1933) in the vicinity of Somerville, N.J. or well to the north of the Amboy-Salem trench, may be the Pensauken. In any case, the sediments of both formations occupy the same part of the valley southwest from Trenton to near Clementon, where the crossbedding direction in the Bridgeton sediments turns sharply to the east. Studies of the Bridgeton crossbeds in southern New Jersey reveal that the gravel sheet was constructed by a series of channels downcutting from north to south. Studies of the crossbedding in the Pensauken gravel sheet largely east of Chesapeake Bay reveal that this unit was also constructed by a series of channels downcutting from northeast to southwest, or nearly at a right angle to the downcutting direction of the Bridgeton channels in southern New Jersey. Both these gravel sheets, therefore, were formed by essentially the same mechanism as that proposed by Hack (1955) for the upland gravels sheet of the "ancestral" Potomac River in southern Maryland.

No datable fauna or flora have ever been recovered from the Bridgeton, but, as discussed by Owens and Denny (1978), the Pensauken coarse clasts interfinger with deltaic marginal marine units in the subsurface of the southern half of the Delmarva Peninsula. These marginal marine (deltaic) units (the "Yorktown and Cohansey?" Formations as used by Rasmussen and Slaughter in 1955) have been dated as latest Miocene. In our view, therefore, the Pensauken and thus the Bridgeton are not Pleistocene in age but are considerably older. The Bridgeton is post-Cohansey (the Cohansey of New Jersey, which must be at least Miocene) and is older than the Pensauken (upper Miocene); it must therefore be some part of the Miocene, possibly upper. This greater age is probably the reason for the very weathered appearance and lateritic soil of these two formations.

The "Trenton gravel" of Lewis (1880) is lithologically distinct from the deeply weathered Bridgeton and Pensauken Formations. The sediment in this unit is much fresher and shows comparatively little evidence of subaerial oxidation. A twofold division of the "Trenton gravel" near Trenton is proposed: (a) the Spring Lake beds, at altitudes as great as 21 m (70 ft) above sea level; these deposits were introduced into this area from the northeast and therefore not along the present segment of the Delaware River flowing from the northwest; and (b) the Van Sciver Lake beds, which have surface altitudes at approximately 6 m (20 ft); the sediments in these beds were transported into the Trenton area from the northwest along the present Delaware River. Both these units have similar facies relationships—coarse gravelly sand in the upper part of the valley that grades rapidly downvalley to finer clasts characterized by abundant finely dispersed carbonaceous matter. This downvalley fining of the sediment in these beds is a marked departure in sedimentation pattern from that of the Bridgeton and Pensauken Formations, where sand predominated over vast areas. Certainly, the sheet gravels characteristic of the older formations are absent in the two units of the "Trenton gravel." As interpreted, a rapid sea-level drop initiated downcutting, and both these units were deposited as valley infillings during a subsequent rise in sea level. The deposition of these Sangamonian beds of the "Trenton gravel," therefore, seems to conform with the theory of a late Wisconsinan drop of sea level and the subsequent infilling of the formed river valleys during a Holocene rise in sea level in Chesapeake and Delaware Bays (Owens and others, 1974).

The problem, therefore, is what event or events are represented by these two units in the "Trenton gravel." The very heterogeneous character of the sediment in these units suggests the contribution of rocks from many sources. Several other investigators have noted the general similarity of the sediments in these beds at Trenton to those in the glacial deposits of northern New Jersey and have interpreted the "Trenton gravel" to be reworked sediment from these glacial deposits. The higher level deposits (Spring Lake beds) appear to have been introduced into the Trenton area from the northeast by a stream system no longer in existence. Certainly the present stream is too small to account for the quantity and size of the material in the Assunpink Creek valley in the area north of Trenton. In addition, these sediments can be only traced a relatively short distance (11 km; 7 miles) northeast of Trenton and certainly not to the Wisconsinan moraines near New Brunswick, N.J. A possible interpretation is that the Spring Lake beds are reworked sediment from pre-Sangamonian glacial deposits. Although these deposits have been reported (Minard and Rhodehamel, 1969) in New Jersey south of the terminal moraine, they are very poorly known. Downvalley from Trenton, the gravel in this unit decreases, and in the Philadelphia-Camden area it is overlapped by a thick sequence of dark clay-silt (the "Philadelphia blue clay" in Pennsylvania and the "Fish House Clay" in New Jersey). These beds probably are the estuarine facies associated with a Sangamon sea-level rise to about 12 m (40 ft) and perhaps as high as 18 m (60 ft) above sea level during this time. Numerous fossils in these beds support an estuarine origin but could not be used to date the deposits. At the coast, beds of this unit have more marine aspects and contain a warm-temperate flora (the Omar Formation of Owens and Denny, 1978). The fossil assemblage is considered to be probably late Pleistocene in age. Shells within this unit that were dated by the radiocarbon method were too old to yield a finite age (therefore, the unit is probably older than 38,000 years B.P.). This age taken in conjunction with the warm flora, and presumably a warm-water fauna, suggests a Sangamonian or older age.

The Van Sciver Lake beds are lithologically similar to the higher level deposits at Spring Lake but appear to be at consistently lower levels throughout the area of investigation. The sediment in this unit appears to have been introduced into the Trenton area down the present Delaware Valley (northwest) and thus establishes the time when this segment of the river became the major sediment drainageway for the river. Downvalley, these sediments downcut through the Spring Lake beds and ultimately interfinger with marine and marginal marine facies, the Cape May Formation of Gill (1962). The Van Sciver Lake beds are considered to be late Sangamonian in age and equivalent to the Ironshire Formation of the lower Delmarva Peninsula (Owens and Denny, 1978).

Both the Spring Lake and Van Sciver Lake beds represent separate transgressive-regressive cycles. Thus, in the Sangamon, there is evidence of two periods of sea-level drop followed by a rise. Although the Spring Lake beds might be an older Pleistocene unit (Illinoian?), they are probably early Sangamonian in age.

REFERENCES CITED

Allen, J. R. L., 1965, A review of the origin and characteristics of recent alluvial sediments: Sedimentology, v. 5, no. 2, p. 89–191.

Berry, E. W., and Hawkins, A. C., 1935, Flora of the Pensauken Formation in New Jersey: Geol. Soc. America Bull., v. 46, no. 2, p. 245–252.

Bowman, J. R., II, 1969, Petrology of the Pensauken Formation: New Brunswick, N.J., Rutgers Univ., unpub. Ph.D. thesis, 155 p.

Campbell, M. R., 1931, Alluvial fan of Potomac River: Geol. Soc. America Bull., v. 42, no. 1, p. 182.

Campbell, M. R., and Bascom, Florence, 1933, Origin and structure of the Pensauken gravel: Am. Jour. Sci., 5th ser., v. 26, no. 153, p. 300–318.

Fuller, M. L., 1914, The geology of Long Island, N.Y.: U.S. Geol. Survey Prof. Paper 82, 231 p.

Gibson, T. G., 1970, Late Mesozoic-Cenozoic tectonic aspects of the Atlantic coastal margin: Geol. Soc. America Bull., v. 81, no. 6, p. 1813–1822.

Gill, H. E., 1962, Ground-water resources of Cape May County, New Jersey—Salt-water invasion of principal aquifers: New Jersey Dept. Conserv. and Econ. Devel., Div. Water Policy and Supply Spec. Rept. 18, 171 p.

Greenman, D. W., and others, 1961, Ground-water resources of the Coastal Plain area of southeastern Pennsylvania with special reference to the effects of human activities on the quality of water in the Coastal Plain sediments: Pennsylvania Geol. Survey, 4th ser., Bull. W 13, 375 p.

Hack, J. T., 1955, Geology of the Brandywine area and origin of the upland of southern Maryland: U.S. Geol. Survey Prof. Paper 267-A, p. 1–43.

Harms, J. C., and Fahnestock, R. K., 1965, Stratification, bed forms, and flow phenomena (with an example from the Río Grande), *in* Primary sedimentary structures and their hydrodynamic interpretation—A symposium: Soc. Econ. Geologists and Mineralogists Spec. Pub. 12, p. 84–115.

Hazel, J. E., 1971, Paleoclimatology of the Yorktown Formation (upper Miocene and lower Pliocene) of Virginia and North Carolina, *in* Paleoecologie Ostracodes Pau, 1970: Centre Recherches Pau Bull., v. 5 (supp.), p. 361–375.

Hollick, C. A., 1899, The relation between forestry and geology in New Jersey: Am. Naturalist, v. 33, p. 1–14, 109–116; *also pub. as*: New Jersey Geol. Survey Ann. Rept. for 1899, pt. 2, p. 173–201, 1900.

Howell, B. F., and Hale, H. E., II, 1946, Fossiliferous pebbles in "Pensauken gravel" at Princeton, New Jersey: Jour. Geology, v. 54, no. 6, p. 386–390.

Isachsen, Y. W., and Wold, R. J., 1977, Geodetic, geological, and geophysical evidence for Holocene vertical movements in the Adirondack region, New York [abs.]: Geol. Soc. America Abs. with Programs, v. 9, no. 3, p. 278–279.

Jordan, R. R., 1964, Columbia (Pleistocene) sediments of Delaware: Delaware Geol. Survey Bull. 12, 69 p.

Krebs, R. D., and Tedrow, J. C. F., 1958, Genesis of red-yellow podzolic and related soils in New Jersey: Soil Sci., v. 85, no. 1, p. 28–37.

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

Kümmel, H. B., and Knapp, G. N., 1904, Part II, The stratigraphy of the New Jersey clays: New Jersey Geol. Survey Final Rept., v. 6, p. 117–209.

Lewis, H. C., 1880, The Trenton gravel and its relation to the antiquity of man: Acad. Nat. Sci. Philadelphia Proc. 1880, p. 296–309.

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

Lodding, William, 1961, Gibbsite vermiforms in the Pensauken Formation of New Jersey: Am. Mineralogist, v. 46, nos. 3–4, p. 394–401.

MacClintock, Paul, and Johnson, M. E., 1956, Guidebook, Twenty-second Annual Field Conference of Pennsylvania Geologists, Trenton, N.J., September 28–29, 1956: Trenton, N.J., New Jersey Geol. Survey, 62 p.

MacClintock, Paul, and Richards, H. G., 1936, Correlation of late Pleistocene marine and glacial deposits of New Jersey and New York: Geol. Soc. America Bull., v. 47, no. 3, p. 289–338.

McGee, W J, 1888, Three formations of the Middle Atlantic slope: Am. Jour. Sci., 3d ser., v. 35, p. 120–143, 328–330, 367–388, 448–466.

Minard, J. P., 1964, Geology of the Roosevelt quadrangle, New Jersey: U.S. Geol. Survey Geol. Quad. Map GQ–340, scale 1:24,000.

Minard, J. P., and Rhodehamel, E. C., 1969, Quaternary geology of part of northern New Jersey and the Trenton area, Field Trip 3, *in* Subitzky, Seymour, ed., Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook of excursions: New Brunswick, N.J., Rutgers Univ. Press, p. 279–313.

Moody, D. W., and Van Reenan, E. D., 1967, High-resolution subbottom seismic profiles of the Delaware estuary and bay mouth, *in* Geological Survey research 1967: U.S. Geol. Survey Prof. Paper 575–D, p. D247–D252.

Owens, J. P., 1969, Coastal Plain rocks of Harford County, *in* Maryland Geol. Survey, The geology of Harford County, Maryland: Baltimore, Md., Maryland Geol. Survey, p. 77–103, 123–127.

Owens, J. P., and Denny, C. S., 1979, Upper Cenozoic deposits of the central Delmarva Peninsula, Maryland and Delaware: U.S. Geol. Survey Prof. Paper 1067–A.

Owens, J. P., and Minard, J. P., 1960, The geology of the north-central part of the New Jersey coastal plain: Johns Hopkins Univ. Studies Geology, no. 18, Guidebook 1, 45 p.

———1966, Pre-Quaternary geology of the Allentown quadrangle, New Jersey-Pennsylvania: U.S. Geol. Survey Geol. Quad. Map GQ–566, scale 1:24,000.

———1975, Geologic map of the surficial deposits in the Trenton area, New Jersey and Pennsylvania: U.S. Geol. Survey Misc. Geol. Inv. Map I–884.

Owens, J. P., and Sohl, N. F., 1969, Shelf and deltaic paleoenvironments in the Cretaceous-Tertiary formations of the New Jersey Coastal Plain, Field Trip 2, *in* Subitzky, Seymour, ed., Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook of excursions: New Brunswick, N.J., Rutgers Univ. Press, p. 235–278.

Owens, J. P., Stefansson, Karl, and Sirkin, L. A., 1974, Chemical, mineralogic, and palynologic character of the upper Wisconsinan-lower Holocene fill in parts of Hudson, Delaware, and Chesapeake estuaries: Jour. Sed. Petrology, v. 44, no. 2, p. 390–408.

Peltier, L. C., 1959, Late Pleistocene deposits, Chap. 5 *of* Willard, Bradford, Geology and mineral resources of Bucks County, Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Bull. C9, p. 163–184.

Pilsbry, H. A., 1897, Geology of the mussel-bearing clays of Fish House, N.J.: Acad. Nat. Sci. Philadelphia Proc. 1896, p. 567–570.

Potter, P. E., and Pettijohn, F. J., 1963, Paleocurrents and basin analysis: New York, Academic Press, 296 p.

Rachele, L. D., 1974, Palynology of Legler lignite: New York, New York Univ., unpub. thesis, 94 p.

Rasmussen, W. C., and Slaughter, T. H., 1955, The ground-water resources, *in* The water resources of Somerset, Wicomico, and Worcester Counties: Maryland Dept. Geology, Mines and Water Resources, Bull. 16, p. 1–469.

Richards, H. G., 1932, The subway tree; a record of a Pleistocene cypress swamp in Philadelphia: Bartonia, no. 13, p. 1–6.

———1962, Studies on the marine Pleistocene: Am. Philos. Soc. Trans. 1962, v. 52, pt. 3, 141 p.

Salisbury, R. D., 1898, Surface geology; report of progress, 1897: New Jersey Geol. Survey Ann. Rept. 1897, p. 1–22.

———1909, Quaternary system, *in* Bascom, Florence, and others, Description of the Trenton quadrangle [N.J.–Pa.]: U.S. Geol. Survey Geol. Atlas, Folio 167.

Salisbury, R. D., and Knapp, G. N., 1917, The Quaternary formations of southern New Jersey: New Jersey Geol. Survey Final Rept. 8, 218 p.

Salisbury, R. D., and others, 1894, Surface geology; report of progress: New Jersey Geol. Survey Ann. Rept. 1893, p. 33–328.

Schlee, J. S., 1957, Upland gravels of southern Maryland: Geol. Soc. America Bull., v. 68, no. 10, p. 1371–1409.

Schlee, J. S., and Pratt, R. M., 1970, Atlantic Continental Shelf and Slope of the United States—Gravels of the northeastern part: U.S. Geol. Survey Prof. Paper 529–H, 39 p.

Strock, L. W., 1929, A study of the Pensauken Formation: Wagner Free Inst. Sci. Bull., v. 4, nos. 1–2, 10 p.

Woolman, Lewis, 1890, Marine and fresh-water diatoms and sponge spicules from the Delaware River clays of Philadelphia: Acad. Nat. Sci. Philadelphia Proc., 1890, p. 189–191.

———1897, Stratigraphy of the Fish House black clay and associated gravels: New Jersey Geol. Survey Ann. Rept. 1896, p. 201–254.

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