Gateway National Recreation Area

GRI Ancillary Map Information Document

Produced to accompany the Geologic Resources Inventory (GRI) Digital Geologic Data for Gateway National Recreation Area

gate_geology.pdf

Version: 9/12/2016
# Geologic Resources Inventory Map Document for Gateway National Recreation Area

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This document has been developed to accompany the digital geologic-GIS data developed by the Geologic Resources Inventory (GRI) program for Gateway National Recreation Area, New York and New Jersey (GATE).

Attempts have been made to reproduce all aspects of the original source products, including the geologic units and their descriptions, geologic cross sections, the geologic report, references and all other pertinent images and information contained in the original publication.

This document contains the following information:

1). **About the NPS Geologic Resources Inventory Program** – A brief summary of the Geologic Resources Inventory (GRI) Program and its products. Included are web links to the GRI GIS data model, and to the GRI products page where digital geologic-GIS datasets, scoping reports and geology reports are available for download. In addition, web links to the NPS Data Store and GRI program home page, as well as contact information for the GRI coordinator, are also present.

2). **GRI Digital Maps and Source Citations** – A listing of all GRI digital geologic-GIS maps produced for this project along with sources used in their completion. In addition, a brief explanation of how each source map was used is provided.

3). **Index Map of Geomorphological Data** - Index map showing geologic data coverage.
   
   a) **Large Scale Data Index Map** - Index map showing large scale (1:24,000) data coverage.
   
   b) **Small Scale Data Index Map** - Index map showing small scale (1:100,000 and 1:250,000) data coverage.

4). **Surficial Map**
   
   a) **Surficial Map Unit List** – A listing of all surficial map units present on the geologic map.
   
   b) **Surficial Map Unit Descriptions** – Descriptions for all surficial map units that are present on the geologic map.
c) Ancillary Source Map Information – Additional source map information. For each source map this may include a stratigraphic column, index map, map legend and/or map notes.

d) Surficial Cross Sections - Large and small scale cross section graphics for surficial maps.

5). Bedrock Map

a) Bedrock Map Unit List – A listing of all bedrock map units present on the geologic map.

b) Bedrock Map Unit Descriptions – Descriptions for all bedrock map units that are present on the geologic map.

c) Ancillary Source Map Information – Additional source map information. For each source map this may include a stratigraphic column, index map, map legend and/or map notes.

d) Bedrock Cross Sections - Large and small scale cross section graphics for bedrock maps.


National Park Service (NPS) Geologic Resources Inventory (GRI) Program staff have assembled the digital geologic-GIS data that accompanies this document.

For information about the status of GRI digital geologic-GIS data for a park contact:

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For information about using GRI digital geologic-GIS data contact:

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About the NPS Geologic Resources Inventory Program

Background

Recognizing the interrelationships between the physical (geology, air, and water) and biological (plants and animals) components of the Earth is vital to understanding, managing, and protecting natural resources. The Geologic Resources Inventory (GRI) helps make this connection by providing information on the role of geology and geologic resource management in parks.

Geologic resources for management consideration include both the processes that act upon the Earth and the features formed as a result of these processes. Geologic processes include: erosion and sedimentation; seismic, volcanic, and geothermal activity; glaciation, rockfalls, landslides, and shoreline change. Geologic features include mountains, canyons, natural arches and bridges, minerals, rocks, fossils, cave and karst systems, beaches, dunes, glaciers, volcanoes, and faults.

The Geologic Resources Inventory aims to raise awareness of geology and the role it plays in the environment, and to provide natural resource managers and staff, park planners, interpreters, researchers, and other NPS personnel with information that can help them make informed management decisions.

The GRI team, working closely with the Colorado State University (CSU) Department of Geosciences and a variety of other partners, provides more than 270 parks with a geologic scoping meeting, digital geologic-GIS map data, and a park-specific geologic report.

Products

Scoping Meetings: These park-specific meetings bring together local geologic experts and park staff to inventory and review available geologic data and discuss geologic resource management issues. A summary document is prepared for each meeting that identifies a plan to provide digital map data for the park.

Digital Geologic Maps: Digital geologic maps reproduce all aspects of traditional paper maps, including notes, legend, and cross sections. Bedrock, surficial, and special purpose maps such as coastal or geologic hazard maps may be used by the GRI to create digital Geographic Information Systems (GIS) data and meet park needs. These digital GIS data allow geologic information to be easily viewed and analyzed in conjunction with a wide range of other resource management information data.

For detailed information regarding GIS parameters such as data attribute field definitions, attribute field codes, value definitions, and rules that govern relationships found in the data, refer to the NPS Geology-GIS Data Model document available at: http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm

Geologic Reports: Park-specific geologic reports identify geologic resource management issues as well as features and processes that are important to park ecosystems. In addition, these reports present a brief geologic history of the park and address specific properties of geologic units present in the park.

For a complete listing of Geologic Resource Inventory products and direct links to the download site visit the GRI publications webpage http://www.nature.nps.gov/geology/inventory/gre_publications.cfm

GRI geologic-GIS data is also available online at the NPS Data Store Search Application: http://irma.nps.gov/App/Reference/Search. To find GRI data for a specific park or parks select the appropriate park
(s), enter “GRI” as a Search Text term, and then select the Search Button.

For more information about the Geologic Resources Inventory Program visit the GRI webpage: http://www.nature.nps.gov/geology/inventory, or contact:

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The Geologic Resources Inventory (GRI) program is funded by the National Park Service (NPS) Inventory and Monitoring (I&M) Division.
GRI Digital Maps and Source Map Citations

The GRI digital geologic-GIS maps for Gateway National Recreation Area, New York and New Jersey (GATE):

**Large Scale Geologic Maps:**

**Digital Surficial Geologic Map of the Sandy Hook and Long Branch Quadrangles and Vicinity, New Jersey (GRI MapCode SHSF)**


**Digital Bedrock Geologic Map of the Sandy Hook and Long Branch Quadrangles, New Jersey (GRI MapCode SHBR)**


**Small Scale Geologic Maps:**

**Digital Surficial Geologic Map of Gateway National Recreation Area and Vicinity, New Jersey and New York (GRI MapCode GWSF)**

Digital Bedrock Geologic Map of Gateway National Recreation Area and Vicinity, New Jersey and New York (GRI MapCode GWBR)


Additional information pertaining to each source map is also presented in the GRI Source Map Information (GATEMAP) table included with the GRI geology-GIS data.
Index Maps

Large Scale Data Index Map

Index maps showing extent of geologic data coverage:

Map graphic produced by the James Winter (Colorado State University).
Small Scale Data Index Map

Gateway NRA and New York Harbor Islands Small Scale Data Index Map

Map graphic produced by the James Winter (Colorado State University).
Surficial Map

Surficial Map Unit List

The surficial geologic units present in the digital geologic-GIS data produced for Gateway National Recreation Area, New York and New Jersey (GATE) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Qaf - Artificial fill). Units are generally listed from youngest to oldest. No description for water is provided. Information about each geologic unit is also presented in the GRI Geologic Unit Information (GWSFUNIT) table included with the GRI geology-GIS data. Some source unit symbols, names and/or ages may have been changed in this document and in the GRI digital geologic-GIS data. This was done if a unit was considered to be the same unit as one or more units on other source maps used for this project, and these unit symbols, names and/or ages differed. In this case a single unit symbol and name, and the unit’s now recognized age, was adopted. Unit symbols, names and/or ages in a unit descriptions, or on a correlation of map units or other source map figure were not edited. If a unit symbol, name or age was changed by the GRI, the unit’s source map symbol, name and/or age appears with the unit’s source map description.

Cenozoic Era

Quaternary Period
Qaf - Artificial fill
Qaft - Trash fill
Qb - Beach and nearshore marine sand
Qbi - Barrier Island
Qm - Estuarine and salt-marsh deposits
Qal - Alluvium
Qs - Swamp and Marsh Deposits
Qcal - Colluvium and Alluvium
Qe - Eolian deposits
Qhkl - Glacial Lake Hackensack, lake-bottom deposits
Qbn - Glacial Lake Bayonne deposits, sand and gravel (deltaic deposits)
Qbnl - Glacial Lake Bayonne deposits, silt, clay and fine sand (lake-bottom deposits)
Qbnf - Glacial Lake Bayonne deposits, lacustrine-fan deposits
Qls - Lacustrine sand
Qrw - Rahway Outwash
Qrt - Raritan terrace deposits
Qld - Lacustrine delta
Qk - Kame deposits
Qt - Rahway Till, continuous
Qtt - Rahway Till, discontinuous
Qty - Rahway Till, yellow phase
Qpt - Lower Passaic terrace
Qwf - Late Wisconsinan glaciofluvial deposits
Qwflv - Late Wisconsinan glaciofluvial plain deposits
Qwlb - Late Wisconsinan glacial lake-bottom deposits
Qez - Elizabeth River deposits
Ql - Uncorrelated glacial-lake deposits
Qsp - Pre-advance stratified sediment
Qic - Ice-contact deposits
Qwb - Glacial Lake Woodbridge deposits
Qab - Glacial Lake Ashbrook deposits, sand, pebbly sand and minor pebble-to-cobble gravel
Qabl - Glacial Lake Ashbrook deposits, silt, clay and fine sand
Qsu - Uncorrelated sand and gravel deposits
**Surficial Map Unit Descriptions**

Descriptions of all surficial geologic map units, generally listed from youngest to oldest, are presented below.

**Qaf - Artificial fill (Holocene)**

**Artificial Fill (Holocene)**
Sand, silt, clay, gravel; brown, gray, yellowish brown; may include demolition debris (concrete, brick, asphalt, glass) and trash. As much as 20 feet thick. In road and railroad embankments and made land. Many small areas of fill in urban areas are not shown. *(GRI Source Map ID 2584)* *(Surficial Geology of the Sandy Hook Quadrangle (OFM 39))*.

**Artificial Fill (Holocene)**
Sand, silt, clay, gravel; brown, gray, yellowish brown; may include demolition debris (concrete, brick, asphalt, glass) and trash. As much as 50 feet thick. In road and railroad embankments, solid-waste landfills, and made land. Many small areas of fill in urban areas are not shown. *(GRI Source Map ID 47707)* *(Surficial Geology of the Long Branch Quadrangle (OFM 38))*.

**af - Artificial fill (Holocene)**
Artificially emplaced sand, grave, silt, clay, and rock; and man-made materials including cinders, ash, brick, concrete, wood, slag, metal, glass, and trash. color variable but generally dark brown, gray, or black. As much as 40 feet thick but generally less than 20 feet thick. Mapped only where it forms
distinct landforms such as highway and railroad embankments, or where it covers salt-marsh deposits. The extent of fill is based on aerial photographs taken in 1979 and 1986. The extent of fill over salt-marsh deposits is based, in part, on the position of shorelines and salt marshes shown on maps by Douglas (1841), Vermuele (1897), and Merrill and others (1902). Fill is also present in all urban areas as thin layer (generally less than 10 feet thick) or fill or mixed fill and natural material overlying the mapped surficial material. *(GRI Source Map ID 2585) (Surficial Geology of the Jersey City Quadrangle (OFM20)).*

**af - Artificial Fill (Holocene)**

Excavated sand, silt, clay, gravel, rock, and till, and man-made materials (bricks, cinders, ash, slag, glass, construction materials and minor amounts of trash). Color is variable, but generally gray to black. In railroad and road embankments, and made land. As much as 50 feet thick but generally less than 20 feet thick. Mapped only where it forms distinct landforms, or where it covers salt-marsh deposits and large floodplains. The extent of fill is based on aerial photographs taken in 1979 and 1986. The extent of fill over salt-marsh deposits and floodplains is based, in part, on the position of shorelines, salt marshes, and alluvial deposits shown on maps in Darton and others (1908) and Ries and Kummel (1904). Fill also occurs in all urban areas, and in most former clay and sand pits, as a thin layer (generally less than 10 feet thick) of fill, or mixed fill and natural material, overlying the mapped surficial material. *(GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).*

**Artificial Fill (Holocene)**

Artificially emplaced sand, clay, silt, and rock; and man-made materials including cinders, ash, brick, concrete, wood, slag, metal, glass, and trash. Color variable but generally dark brown, gray, or black. As much as 40 feet thick but generally less than 20 feet thick. Mapped only where it covers salt-marsh, alluvial, or swamp deposits. Fill is also present in all urban areas as a layer generally less than 10 feet thick, except in highway and railroad fills, where it may be as much as 40 feet thick. The extent of fill is based, in part, on the position of shorelines and salt marshes shown in Salisbury (1895), N. J. Geological Survey (1889), and Merrill and others (1902). *(GRI Source Map ID 55336) (Surficial Geology of the Elizabeth Quadrangle (OFM 42)).*

**af - Artificial Fill (Holocene)**

No unit description available. *(GRI Source Map ID 1574) (Surficial Geologic Map of New York, Lower Hudson Sheet)).*

**Qaft - Trash fill (Holocene)**

Trash and construction materials mixed and covered with excavated clay, silt, sand, gravel, rock, and till. As much as 50 feet thick. *(GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).*

**Qb - Beach and nearshore marine sand (Holocene)**

Sand, very pale brown to light gray; and pebble gravel. As much as 150 feet thick but generally less than 20 feet thick. Silt and clay, dark gray to black, as much as 10 feet thick, overlie the sand and gravel in Sandy Hook Bay. Deposited during Holocene sea-level rise. Underlain in places by estuarine deposits. *(GRI Source Map ID 2584) (Surficial Geology of the Sandy Hook Quadrangle (OFM 39)).*

**Qbs - Beach and Nearshore Marine Sand (Holocene)**

Sand, very pale brown to light gray; and pebble gravel. As much as 100 feet thick but generally less than 20 feet thick. Deposited during Holocene sea-level rise. Underlain by estuarine deposits in places. *(GRI
Qb - Beach Deposits (Holocene)
Sand and pebble gravel. As much as 15 feet thick (estimated). (GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).

Qbs - Beach and Nearshore Marine Sand (Holocene)
Sand and pebble gravel, very pale brown to light gray. As much as 50 feet thick but generally less than 20 feet thick. (GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).

Qbi - Barrier island (Quaternary)
Sand and gravel deposit as barrier island, south shore of Long Island, May have associated dunes, thickness variable. (GRI Source Map ID 1574) (Surficial Geologic Map of New York, Lower Hudson Sheet).

Qm - Estuarine and salt-marsh deposits (Holocene and Pleistocene (late Wisconsinan))
Qmm - Estuarine Deposits (Holocene)
Salt-marsh peat, organic silt and clay; dark brown to black; sand and minor pebble gravel; very pale brown, white, gray. As much as 100 feet thick. Deposited during Holocene sea-level rise. Commonly underlain by lower terrace deposits. (GRI Source Map ID 2584) (Surficial Geology of the Sandy Hook Quadrangle (OFM 39)).

Qm - Estuarine and Salt-Marsh Deposits (Holocene)
Organic silt and clay, and salt-marsh peat, with some sand; black, dark brown, and dark gray. Contains some shells. As much as 40 feet thick, but generally less than 20 feet thick, in the Newark Bay-Kearny area. (GRI Source Map ID 2585) (Surficial Geology of the Jersey City Quadrangle (OFM20)).

Qmm - Estuarine Deposits (Holocene)
Salt-marsh peat, organic silt and clay; dark brown to black; sand and minor pebble gravel; very pale brown, white, gray. As much as 100 feet thick. Deposited during Holocene sea-level rise. Commonly underlain by lower terrace deposits. (GRI Source Map ID 47707) (Surficial Geology of the Long Branch Quadrangle (OFM 38)).

Qm - Estuarine and Salt-Marsh Deposits (Holocene)
Organic silt and clay, and peat, with some sand and fine gravel; black, dark-brown, and dark-gray. As much as 25 feet thick. (GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).

Qm - Estuarine and Salt-Marsh Deposits (Holocene)
Peat and organic clay and silt, brown to dark gray; minor sand and shells. Locally, at base, may include alluvial sand and gravel deposited before marine inundation. As much as 100 feet thick. (GRI Source Map ID 55336) (Surficial Geology of the Elizabeth Quadrangle (OFM 42)).

Qmm - Salt-Marsh and Estuarine Deposits (Holocene)
Silt, sand, peat, clay, minor pebble gravel; brown, dark-brown, gray, black. As much as 300 feet thick in the Hudson valley, 100 feet thick elsewhere. (GRI Source Map ID 74858) (Surficial Geology of New
Qal - Alluvium (Holocene and Pleistocene (late Wisconsinan))

Qal - Alluvium (Holocene and late Pleistocene)
Sand, silt, clay, peat; yellowish brown, dark brown, gray; and pebble gravel. Abundant organic matter. Sand is chiefly quartz, with some glauconite and mica. Gravel is quartz and quartzite with minor ironstone. As much as 15 feet thick. Deposited in floodplains, channels, and ground-water seepage areas. (GRI Source Map ID 2584) (Surficial Geology of the Sandy Hook Quadrangle (OFM 39)).

Qal - Alluvium (Holocene and late Pleistocene)
Sand, silt, clay, peat; yellowish brown, dark brown, gray; and pebble gravel. Abundant organic matter. Sand is chiefly quartz, with some glauconite and mica. Gravel is quartz and quartzite with minor ironstone. As much as 15 feet thick. Deposited in floodplains, channels, and ground-water seepage areas. (GRI Source Map ID 47707) (Surficial Geology of the Long Branch Quadrangle (OFM 38)).

Qal - Alluvium (Holocene and Pleistocene)
Sand, silt, clay, pebble gravel; minor cobble gravel. Contains variable amounts of organic matter. Fine sediment is reddish-brown to dark brown. Gravel and sand composition similar to that of surficial deposits and outcropping bedrock in the drainage basin. Fine sediment is deposited as overbank material on the floodplain and may be as much as 15 feet thick. It generally overlies sand and gravel deposited in the stream channel. The gravel is generally less than 5 feet thick. (GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).

Qal - Alluvium (Holocene and Pleistocene)
Sand, silt, clay, pebble gravel; dark-brown, gray, reddish-brown. As much as 30 feet thick. Many small deposits along streams and in valley bottoms in urban areas, now covered by fill, are not mapped. (GRI Source Map ID 55336) (Surficial Geology of the Elizabeth Quadrangle (OFM 42)).

Qal - Alluvium (Holocene)
Sand, silt, minor gravel and clay; dark-brown to gray. As much as 20 feet thick. In subsurface only, beneath unit Qm. Inferred from records of test borings (table 1). (GRI Source Map ID 2585) (Surficial Geology of the Jersey City Quadrangle (OFM 20)).

Qal - Alluvium (Holocene and Pleistocene)
Sand, gravel, silt, minor clay and peat; reddish brown, yellowish brown, brown, gray. As much as 20 feet thick. (GRI Source Map ID 2585) (Surficial Geology of the Jersey City Quadrangle (OFM 20)).

Qs - Swamp and marsh deposits (Holocene and Pleistocene (late Wisconsinan))

Qs - Swamp and Marsh Deposits (Holocene and late Pleistocene)
Freshwater peat and organic silt, sand, and clay; dark brown to black. As much as 10 feet thick. (GRI Source Map ID 2584) (Surficial Geology of the Sandy Hook Quadrangle (OFM 39)).

Qs - Swamp and Marsh Deposits (Holocene and late Pleistocene)
Freshwater peat and organic silt, sand, and clay; dark brown to black. As much as 10 feet thick. (GRI Source Map ID 47707) (Surficial Geology of the Long Branch Quadrangle (OFM 38)).

Qs - Swamp and Marsh Deposits (Holocene and late Pleistocene)
Gray to brown organic silt and clay, overlain by dark-brown to black peat. As much as 15 feet thick (estimated). (GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).

**Qs - Swamp Deposits (Holocene and late Pleistocene)**
Organic silt and clay, and peat. As much as 10 feet thick (estimated). The deposits are inferred from historical maps (N. J. Geological Survey, 1889) and are now entirely covered by fill. (GRI Source Map ID 55336) (Surficial Geology of the Elizabeth Quadrangle (OFM 42)).

**pm - Swamp deposits (Holocene and Pleistocene)**
Peat-muck, organic silt and sand in poorly drained areas, un-oxidized, may be overlying marl and lake silts, potential land instability, thickness generally 2-20 meters. (GRI Source Map ID 1574) (Surficial Geologic Map of New York, Lower Hudson Sheet).

**Qs - Swamp and Marsh Deposits (late Pleistocene and Holocene)**
Peat and organic clay, silt, and minor sand; gray, brown, black. As much as 40 feet thick. (GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).

**Qcal - Colluvium and alluvium (Holocene and late Pleistocene)**

**Qcal - Colluvium and Alluvium (Holocene and late Pleistocene)**
Interbedded alluvium and colluvium in headwater valleys. As much as 15 feet thick. (GRI Source Map ID 2584) (Surficial Geology of the Sandy Hook Quadrangle (OFM 39)).

**Qcal - Colluvium and Alluvium (Holocene and late Pleistocene)**
Interbedded alluvium and colluvium in headwater valleys. As much as 15 feet thick. (GRI Source Map ID 47707) (Surficial Geology of the Long Branch Quadrangle (OFM 38)).

**Qcal - Alluvium and Colluvium (Holocene and late Pleistocene)**
Interbedded alluvium as in unit Qal and colluvium as in units Qcg, Qcb, Qcd, Qcs, Qcc, Qccb, and Qcl. As much as 20 feet thick. (GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).

**Qe - Eolian deposits (Holocene and Pleistocene (late Wisconsinan))**

**Qe/Qt - Eolian Deposits (Holocene and late Pleistocene?)**
Fine sand, minor silt; very pale brown. As much as 30 feet thick (Salisbury and Peet, 1895) but generally less than 10 feet thick. Extent of deposits is based, in part, on mapping in Merrill and others (1902). In places these deposits may have been removed during urbanization. (GRI Source Map ID 2585) (Surficial Geology of the Jersey City Quadrangle (OFM20)).

**Qe - Eolian Deposits (late Pleistocene and Holocene)**
Fine-to-medium sand, very pale brown to reddish yellow. Sand is chiefly quartz with minor glauconite and mica in places. As much as 20 feet thick. Forms dunes and sand sheets. (GRI Source Map ID 47707) (Surficial Geology of the Long Branch Quadrangle (OFM 38)).

**Qe - Eolian Deposits (Holocene and late Pleistocene?)**
Fine sand, minor silt; very pale brown. As much as 10 feet thick (Russell, 1880; Salisbury and Peet, 1895). Extent of deposits based, in part, on mapping in Merrill and others (1902). In places these deposits may have been removed during urbanization. (GRI Source Map ID 55336) (Surficial Geology of the Elizabeth Quadrangle (OFM 42)).
Qe - Eolian deposits (late Pleistocene, locally of early to middle Pleistocene and Pliocene age on uplands)
Windblown fine sand and silt; very pale brown, yellowish brown. As much as 15 feet thick. *(GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).*

Qhkl - Glacial Lake Hackensack, lake-bottom deposits (Pleistocene (late Wisconsinan))
Silt, clay, fine sand; gray to reddish-brown, varved to thinly-layered. As much as 30 feet thick. In subsurface only (sections AA’, DD’). Lower contact is an approximate timeline marking the estimated position of the lake-bottom surface when Lake Bayonne lowered to the Lake Hackensack level. It does not represent a physical discontinuity. *(GRI Source Map ID 2585) (Surficial Geology of the Jersey City Quadrangle (OFM20)).*

**Glacial Lake Bayonne Deposits**
Deltaic, lake-bottom, and lacustrine-fan deposits on both sides of the Palisades Ridge. Deltaic deposits are of indistinct form and include low sandy terraces rising to about 30 to 40 feet above sea level at the west base of the Palisades Ridge in Jersey City, and low sandy islands (including Ellis and Liberty Islands) rising to about 30 feet above sea level along the west shore of the Hudson from Constable Hook to Hoboken. Lake-bottom sediment is continuous beneath units Qm and Qhkl in the Newark Bay-Kearny lowland and generally present beneath unit Qm between the Palisades and Hudson River. It is also present, in places, beneath distal parts of deltaic deposits (section AA’, BB’, EE’). Lacustrine-fan sediment is inferred from records of test borings and occurs sparsely between the Palisades and the Hudson River. Some of the mapped deltaic deposits may include lacustrine-fan sediment in the subsurface. *(GRI Source Map ID 2585) (Surficial Geology of the Jersey City Quadrangle (OFM20)).*

Deltaic, lake-bottom, and lacustrine-fan deposits. Deltaic deposits (Qbn) include the delta in downtown Newark and other low hills or terraces of sand and gravel of indistinct form within the Lake Bayonne basin. The deltaic deposits mapped in Newark Airport and to the north are former islands in the salt marsh that rose to elevations between 20 and 30 feet (N. J. Geological Survey, 1889). They are now graded away and covered by fill; their extent and composition is from N. J. Geological Survey (1889) and Merrill and others (1902). Lake-bottom sediment (Qbnl) is nearly continuous beneath units Qm and Qpt and locally extends beneath the distal parts of deltaic deposits. It may also occur locally beneath readvance till in the northern and eastern parts of Elizabeth. Lacustrine-fan deposits (Qbnf) are inferred from records of test borings and occur in places at the bottom of the Newark-Harrison valley fill. Some of the deltaic deposits also include lacustrine-fan sediment in the subsurface. *(GRI Source Map ID 55336) (Surficial Geology of the Elizabeth Quadrangle (OFM 42)).*

Include lake-bottom deposits (Qbnl), and some minor lacustrine-fan deposits (Qbn) beneath marsh deposits in the Woodbridge Creek, Arthur Kill, and lower Rahway valleys (sections A-A’, B-B’), and some outcropping lake-bottom deposits near Port Rending. A deltaic deposit mapped by Darton and others (1908) north of Perth Amboy (the "Maurer delta", indicated as (Qbn) on the map) has been mined away. *(GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).*
Qbn - Glacial Lake Bayonne deposits, sand and gravel (deltaic deposits) (Pleistocene (late Wisconsinan))

Qbn - Deltaic deposits (Pleistocene)
Sand, reddish-yellow, light reddish-brown, gray; some pebble gravel; minor cobble gravel. Sediment is generally well-sorted and stratified. Gravel clasts are chiefly red and gray sandstone and mudstone; with lesser amounts of gneiss, diabase, quartz, quartzite, serpentinite, and schist. Sand is chiefly quartz, feldspar, and red and gray mudstone fragments; with lesser amounts of mica and gneiss, diabase, and schist fragments. As much as 100 feet thick. (GRI Source Map ID 2585) (Surficial Geology of the Jersey City Quadrangle (OFM20)).

Qbn - Deltaic deposits (Pleistocene)
Fine-to-coarse sand, reddish-brown, light reddish-brown, gray; some pebble gravel; minor cobble gravel. Well-sorted and stratified, with planar to cross-bedding in fluvial topset beds of pebbly sand and pebble-to-cobble gravel in the upper 10 to 15 feet of the Newark delta; and dipping planar to ripple-crossbedded foreset and bottomset beds, which may be locally deformed by collapse, in the rest of the deposits. As much as 100 feet thick. (GRI Source Map ID 55336) (Surficial Geology of the Elizabeth Quadrangle (OFM 42)).

Qbn - Sand and gravel (Pleistocene (late Wisconsinan))
Sand and gravel. As much as 30 feet thick. (GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).

Qbnl - Glacial Lake Bayonne deposits, silt, clay and fine sand (lake-bottom deposits) (Pleistocene (late Wisconsinan))

Qbnl - Lake-bottom deposits (Pleistocene)
Silt, clay, and fine sand; gray to reddish-brown. Well sorted and stratified. As much as 150 feet thick. In subsurface only (all sections). (GRI Source Map ID 2585) (Surficial Geology of the Jersey City Quadrangle (OFM20)).

Qbnl - Glacial Lake Bayonne Deposits (Pleistocene)
Silt, clay, fine sand. As much as 40 feet thick. (GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).

Qbnl - Lake-bottom deposits (Pleistocene)
Silt, clay, and fine sand; gray to reddish-brown. Well sorted and thinly layered to varved. As much as 200 feet thick. In subsurface only (all sections). (GRI Source Map ID 55336) (Surficial Geology of the Elizabeth Quadrangle (OFM 42)).

Qbnf - Lacustrine-fan deposits (Pleistocene (late Wisconsinan))

Qbnf - Lacustrine-fan deposits (Pleistocene (late Wisconsinan stage))
Sand, minor silt; reddish-brown to gray; and gravel. Sediment is moderately- to well-sorted, stratified. Sand and gravel composition likely similar to Qbn. As much as 100 feet thick. In subsurface only (sections AA’, CC’, EE’). (GRI Source Map ID 2585) (Surficial Geology of the Jersey City Quadrangle (OFM20)).

Qbnf - Lacustrine-fan Deposits (Pleistocene (late Wisconsinan))
Fine to coarse sand, minor silt; reddish-brown to gray; and pebble-to-cobble gravel. Moderately to well-
sorted, stratified. As much as 100 feet thick. In subsurface only (BB' and DD'). *(GRI Source Map ID 55336) (Surficial Geology of the Elizabeth Quadrangle (OFM 42)).*

**Qls - Lacustrine sand (Quaternary)**

Sand deposits associated with large bodies of water, generally a near-shore deposit or near a sand source, well sorted, stratified, generally quartz sand, thickness variable (2-20 meters). *(GRI Source Map ID 1574) (Surficial Geologic Map of New York, Lower Hudson Sheet)).*

**Qrw - Rahway Outwash (Pleistocene (late Wisconsinan))**

Qrw- Rahway Outwash (Pleistocene (late Wisconsinan))

Sand, pebble to cobble gravel, minor silt. As much as 45 feet thick. *(GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).*

**og - Outwash sand and gravel (Pleistocene (late Wisconsinan))**

Coarse to fine gravel with sand, proglacial fluvial deposition, well rounded and stratified, generally finer texture away from ice border, thickness variable (2-20 meters). *(GRI Source Map ID 1574) (Surficial Geologic Map of New York, Lower Hudson Sheet)).*

**Qrt - Raritan terrace deposits (Pleistocene (late Wisconsinan))**

Sand, silt, pebble gravel, minor clay and cobble gravel. Fine sediment is gray, brown, and reddish-brown. Sand is predominantly quartz, with some shale fragments and feldspar, and minor glauconite and mica. Gravel is predominately quartz and quartzite; with some red and gray mudstone and shale; and minor chert, gneiss, and sandstone. As much as 40 feet thick. Deposit is on grade with the Plainfield outwash upstream in the Raritan valley and so is, in part, of late Wisconsinan age. It includes both glacially-derived sediment from bedrock to the north and east of the Raritan basin, and nonglacial sediment from bedrock, Coastal plain formation, and surficial deposits with the basin. *(GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).*

*Note: This unit appears on OFM 28 but is not present in the map extent extracted from this publication by the GRI.*

**Qld - Lacustrine delta (Quaternary)**

Coarse to fine gravel and sand, stratified, generally well sorted, deposited at a lake shoreline, thickness variable (3-15 meters). *(GRI Source Map ID 1574) (Surficial Geologic Map of New York, Lower Hudson Sheet)).*

**Qk - Kame deposits (Quaternary)**

Includes kames, eskers, kame terraces, kame deltas, coarse to fine gravel and/or sand, deposition adjacent to ice, lateral variability in sorting, coarseness and thickness, locally firmly cemented with calcareous cement, thickness variable (10-30 meters). *(GRI Source Map ID 1574) (Surficial Geologic Map of New York, Lower Hudson Sheet)).*
Qt - Rahway Till, continuous (Pleistocene (late Wisconsinan))

Qt/Qtt - Rahway Till (Pleistocene)
Reddish-brown to reddish-yellow silty sand to sandy silt, containing some to many subrounded and subangular pebbles and cobbles and few subrounded boulders. Poorly sorted, non stratified, generally compact below the soil zone. As much as 50 feet thick. Gravel includes, in approximate order of abundance, red and gray mudstone and sandstone, gneiss, diabase (on and east of the Palisades Ridge), conglomerate, quartzite, and quartz. Sand is chiefly quartz, feldspar, and red and gray mudstone fragments; with lesser amounts of gneiss and diabase fragments. The clasts are derived from bedrock and preglacial surficial deposits to the north and northwest along the line of ice flow. Unit Qtt delineates areas where Qt is discontinuous and generally less than 10 feet thick. The extent of unit Qtt is based, in part, on Salisbury and Peet (1895) and Merrill and others (1902). *(GRI Source Map ID 2585) (Surficial Geology of the Jersey City Quadrangle (OFM20)).

Qt/Qtt - Rahway Till (Pleistocene)
Reddish-brown clayey, silty-sand to clayey, sandy-silt with some to many subrounded and subangular pebbles and cobbles and very few subrounded boulders. Gravel includes, in approximate order of abundance, red and gray mudstone and sandstone, quartz, gneiss, conglomerate, and basalt *(table 2). Boulders are chiefly gneiss and quartzite. The clasts arc derived from bedrock and preglacial surficial deposits to the north and northeast, along the line of ice flow. The quartz pebbles are eroded from the Pensauken Formation, which formerly covered the entire quadrangle. Where till overlies Cretaceous deposits, it includes blocks, deformed layers, and pebble-sized pieces of gray clay, white to yellow kaolinitic quartz sand, and brown ironstone eroded from the Cretaceous formations. Where it overlies Pensauken Formation, it may include lenses and blocks of yellow arkosic sand and quartz gravel. The till includes both compact, matrix-supported zones, which may have a weak subhorizontal fissility; and noncompact sandy or gravelly zones that may be weakly stratified in places. As much as 50 feet thick; generally 10 to 30 feet thick. Qt delineates areas where till is continuous and generally more than 10 feet thick. Qtt delineates areas where till is discontinuous and generally thinner. *(GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).

Qr - Rahway Till (Pleistocene)
Reddish-brown to light-reddish-brown silty sand to sandy clayey silt containing some to many subrounded and subangular pebbles and cobbles and a few subrounded boulders. Poorly sorted, nonnutritive, generally compact below the soil zone. May include thin, discontinuous beds and lenses of sorted sand and gravel. As much as 90 feet thick but generally less than 20 feet thick. *(GRI Source Map ID 55336) (Surficial Geology of the Elizabeth Quadrangle (OFM 42)).

t - Till (Pleistocene (late Wisconsinan))
Variable texture (e.g. clay, silt-clay, boulder clay), usually poorly sorted diamict, deposition beneath glacier ice, relatively impermeable (loamy matrix), variable clast content - ranging from abundant well-rounded diverse lithologies in valley tills to relatively angular, more limited lithologies in upland tills, tends to be sandy in areas underlain by gneiss or sandstone, potential land instability on steep slopes, thickness variable (1-50 meters). *(GRI Source Map ID 1574) (Surficial Geologic Map of New York, Lower Hudson Sheet).

Qwtr - Rahway Till (late Pleistocene, late Wisconsinan)
Clayey silt to sandy silt with some to many pebbles and cobbles and few boulders; reddish brown, reddish yellow, yellowish brown, brown. As much as 100 feet thick, generally less than 40 feet thick. *(GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).
Qt - Rahway Till, discontinuous (Pleistocene (late Wisconsinan))

Qt/Qtt - Rahway Till (Pleistocene)
Reddish-brown to reddish-yellow silty sand to sandy silt, containing some to many subrounded and subangular pebbles and cobbles and few subrounded boulders. Poorly sorted, non stratified, generally compact below the soil zone. As much as 50 feet thick. Gravel includes, in approximate order of abundance, red and gray mudstone and sandstone, gneiss, diabase (on and east of the Palisades Ridge), conglomerate, quartzite, and quartz. Sand is chiefly quartz, feldspar, and red and gray mudstone fragments; with lesser amounts of gneiss and diabase fragments. The clasts are derived from bedrock and preglacial surficial deposits to the north and northwest along the line of ice flow. As much as 50 feet thick. Gravel includes, in approximate order of abundance, red and gray mudstone and sandstone, gneiss, diabase (on and east of the Palisades Ridge), conglomerate, quartzite, and quartz. Sand is chiefly quartz, feldspar, and red and gray mudstone fragments; with lesser amounts of gneiss and diabase fragments. The clasts are derived from bedrock and preglacial surficial deposits to the north and northwest along the line of ice flow. Unit Qtt delineates areas where Qt is discontinuous and generally less than 10 feet thick. The extent of unit Qtt is based, in part, on Salisbury and Peet (1895) and Merrill and others (1902). (GRI Source Map ID 2585) (Surficial Geology of the Jersey City Quadrangle (OFM20)).

Qt/Qtt - Rahway Till (Pleistocene)
Reddish-brown clayey, silty-sand to clayey, sandy-silt with some to many subrounded and subangular pebbles and cobbles and very few subrounded boulders. Gravel includes, in approximate order of abundance, red and gray mudstone and sandstone, quartz, gneiss, conglomerate, and basalt (table 2). Boulders are chiefly gneiss and quartzite. The clasts arc derived from bedrock and preglacial surficial deposits to the north and northeast, along the line of ice flow. The quartz pebbles are eroded from the Pensauken Formation, which formerly covered the entire quadrangle. Where till overlies Cretaceous deposits, it includes blocks, deformed layers, and pebble-sized pieces of gray clay, white to yellow kaolinitic quartz sand, and brown ironstone eroded from the Cretaceous formations. Where it overlies Pensauken Formation, it may include lenses and blocks of yellow arkosic sand and quartz gravel. The till includes both compact, matrix-supported zones, which may have a weak subhorizontal fissility; and noncompact sandy or gravelly zones that may be weakly stratified in places. As much as 50 feet thick; generally 10 to 30 feet thick. Qtt delineates areas where till is continuous and generally more than 10 feet thick. Qtt delineates areas where till is discontinuous and generally thinner. (GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).

Qty - Rahway Till, yellow phase (Pleistocene (late Wisconsinan))
Till as above, except that fine sediment is a reddish-yellow to yellow sandy silt to silt; and diabase and serpentinite clasts are more abundant. Incorporates weathered diabase of the Palisades Ridge and weathered serpentinite in Hoboken. Gradational contact with unit Qt. As much as 20 feet thick. (GRI Source Map ID 2585) (Surficial Geology of the Jersey City Quadrangle (OFM20)).

Qpt - Lower Passaic terrace (Pleistocene (late Wisconsinan))
Qpt - Lower Passaic Terrace (Holocene and Pleistocene?)
Fine-to-coarse sand and some silt, light reddish-brown, light-gray, very pale brown; some pebble gravel. Moderately to well-sorted; stratified. As much as 40 feet thick. (GRI Source Map ID 55336) (Surficial Geology of the Elizabeth Quadrangle (OFM 42)).

Qst1 - Lower Postglacial Stream Deposits (Holocene and latest Pleistocene)
Deposits forming stream terraces with surfaces 5 to 15 feet above the modern floodplain. (GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).
Qwf - Late Wisconsinan glaciofluvial deposits (late Pleistocene, late Wisconsinan)
Sand and pebble-to-cobble gravel, minor silt; yellowish brown to reddish brown. As much as 50 feet thick. *(GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).*

Qwfv - Late Wisconsinan glaciofluvial plain deposits (late Pleistocene, late Wisconsinan)
Sand, pebble-to-cobble gravel, minor silt; yellowish brown to reddish brown. As much as 80 feet thick. *(GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).*

Qwlb - Late Wisconsinan glacial lake-bottom deposits (late Pleistocene, late Wisconsinan)
Silt, clay, fine sand; gray, brown, yellowish brown, reddish brown. As much as 200 feet thick. *(GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).*

Qez - Elizabeth River deposits (Pleistocene (late Wisconsinan))
Fine to coarse sand, minor silt; reddish-brown, light reddish-brown, gray; and pebble-to-coarse-cobble gravel. Moderately to well-sorted, plane- to cross-bedded with possible inclined planar foreset and ripple-cross-bedded bottomset beds in lacustrine parts of the deposit. As much as 150 feet thick. *(GRI Source Map ID 55336) (Surficial Geology of the Elizabeth Quadrangle (OFM 42)).*

Ql - Uncorrelated glacial-lake deposits (Pleistocene (late Wisconsinan))
Fine-to-coarse sand, minor silt, reddish-brown to light reddish-brown; pebble-to-coarse-cobble gravel; and sandy silty diamicton. Moderately to well-sorted, stratified. As much as 100 feet thick. *(GRI Source Map ID 55336) (Surficial Geology of the Elizabeth Quadrangle (OFM 42)).*

Qsp - Pre-advance stratified sediment (Pleistocene (late Wisconsinan))
Sand, gravel, some silt and clay; reddish-brown to gray. As much as 50 feet thick. In subsurface only, beneath till (wells 155, 160, 167, 171, 172, section CC'). *(GRI Source Map ID 55336) (Surficial Geology of the Elizabeth Quadrangle (OFM 42)).*

Qic - Ice-contact deposits (Pleistocene (late Wisconsinan))
Pebble-to-cobble gravel and pebbly sand, reddish-brown, poorly-to-moderately sorted, weakly stratified to massive. Strata may be steeply dipping or deformed. Contains beds and lenses of till and deformed Cretaceous sand and clay. As much as 40 feet thick (estimated). Forms two hills in Carteret and Woodbridge; these hills may contain or consist largely of Cretaceous sediment. They may have been deposited in ice-walled basins or by ice-push at recessional ice margins. *(GRI Source Map ID 47711) (
Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).

Qwic - Ice-Contact Deposits (late Pleistocene, late Wisconsinan)
Silt, clay, fine sand; gray, brown, yellowish brown, reddish brown. As much as 200 feet thick. (GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).

Glacial Lake Woodbridge Deposits
Includes deltaic and lacustrine-fan deposits (Qwb) in the South Branch valley. Small lake-bottom deposits may underlie alluvium in this valley, especially in the floodplain south of Menlo Park, but do not crop out. (GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).

Qwb - Glacial Lake Woodbridge deposits (Pleistocene (late Wisconsinan))
Qwb - Sand, pebbly sand, minor pebble-to-cobble gravel. (Pleistocene (late Wisconsinan))
As much as 30 feet thick (estimated). (GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).

Qwb - Glacial Lake Woodbridge deposits (Pleistocene (late Wisconsinan))
Fine-to-coarse sand, minor silt, reddish-brown to light reddish-brown; pebble-to-coarse-cobble gravel; and sandy silty diamicton. Moderately to well-sorted, stratified. As much as 100 feet thick. (GRI Source Map ID 55336) (Surficial Geology of the Elizabeth Quadrangle (OFM 42)).

Qwb - Glacial Lake Woodbridge deposits (Pleistocene (late Wisconsinan))
Qwb - Sand, pebbly sand, minor pebble-to-cobble gravel. (Pleistocene (late Wisconsinan))
As much as 70 feet thick (estimated). (GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).

Note: This unit appears on OFM 28 but is not present in the map extent extracted from this publication by the GRI.

Qabl - Glacial Lake Ashbrook deposits, silt, clay and fine sand (Pleistocene (late Wisconsinan))
Qabl - Silt, clay, fine sand. (Pleistocene (late Wisconsinan))
As much as 50 feet thick (estimated). (GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).

Glacial Lake Ashbrook Deposits
Includes deltaic and lacustrine-fan deposits (Qab), and lake-bottom deposits (Qabl). In addition to their outcrop, lake-bottom deposits may underlie swamp and alluvial deposits in Ash Brook swamp. (GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).

Qab - Glacial Lake Ashbrook deposits, sand, pebbly sand and minor pebble-to-cobble gravel (Pleistocene (late Wisconsinan))
Qab - Sand, pebbly sand, minor pebble-to-cobble gravel. (Pleistocene (late Wisconsinan))
As much as 70 feet thick (estimated). (GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).
Qsu - Uncorrelated sand and gravel deposits (Pleistocene (late Wisconsinan))

Sand, pebbly sand, minor pebble-to-cobble gravel. As much as 20 feet thick. Include small deltaic deposits laid down in glacial ponds on uplands above the levels of lake Ashbrook, Woodbridge, and Bayonne; and overridden sand and gravel deposits beneath till (section C-C'). These overridden sediments are also most probably deltaic deposits laid down in lakes pounded in front of advancing ice. (GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).

Qpf - Plainfield outwash (Pleistocene (late Wisconsinan))

Pebbly sand, minor pebble-to-cobble gravel. May include lacustrine sand and silt in the subsurface. Total thickness as much as 60 feet. Crops out as a plain west of Metuchen and occurs in preglacial valleys beneath the terminal moraine northeast of Metuchen (section C-C') and west of Potters (wells 4-7). (GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).

Qmt - Metuchen outwash (Pleistocene (late Wisconsinan))

Pebble-to-cobble gravel and pebbly sand. As much as 40 feet thick (estimated). Forms a river plain leading from the terminal moraine down the Mill Brook valley. (GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).

Qpa - Perth Amboy outwash (Pleistocene (late Wisconsinan))

Pebble-to-cobble gravel and pebbly sand. As much as 70 feet thick (estimated). Crops out as a plain leading from the terminal moraine at Perth Amboy and occurs beneath the moraine to the north (wells 151, 157-159, 343). (GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).

Note: This unit appears on OFM 28 but is not present in the map extent extracted from this publication by the GRI.
**Qtm - Till of the terminal moraine (Pleistocene (late Wisconsinan))**

Till, forming knoll, ridge, and basin topography of the terminal moraine. As much as 130 feet thick. *(GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).*

**tm - Till moraine (Pleistocene (late Wisconsinan))**

More variably sorted than till, generally more permeable than till, deposition adjacent to ice, more variably drained, may include ablation till, thickness variable (10-30 meters). *(GRI Source Map ID 1574) (Surficial Geologic Map of New York, Lower Hudson Sheet)).*

**Qwmtr - Late Wisconsinan Terminal Moraine Deposits, Rahway Till (Pleistocene (late Wisconsinan))**

Rahway Till as in unit Qt forming morainic ridges and knolls. As much as 200 feet thick. *(GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).*

**Qsw - Weathered shale (Pleistocene)**

Poorly sorted, non stratified to weakly stratified, reddish-brown to yellowish-red silty clay to clayey silt with some to many angular to subangular chips of red (and minor gray) shale. Derived from mechanical and chemical decomposition of shale of the Passaic Formation of Triassic and Jurassic age. Where Pensauken Formation overlies or is upslope from weathered shale, material may include some white to yellow quartz pebbles and yellow sand derived from cryoturbation or bioturbation of the overlying or colluviated Pensauken sediment. Generally less than 10 feet thick. *(GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).*

**Qws - Weathered Shale, Mudstone, and Sandstone (Pleistocene)**

Silty sand to silty clay with shale, mudstone, or sandstone fragments; reddish brown, yellow, light gray. As much as 10 feet thick on shale and mudstone, 30 feet thick on sandstone. *(GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).*

**Qtl - Lower stream terrace deposits (late Pleistocene)**

Sand and minor silt; yellow, yellowish brown, reddish yellow; and pebble gravel. Sand is chiefly quartz with some glauconite and mica. Gravel is quartz and quartzite with minor ironstone. As much as 50 feet thick. Form stream terraces with surfaces 5 to 20 feet above the modern floodplain. *(GRI Source Map ID 2584) (Surficial Geology of the Sandy Hook Quadrangle (OFM 39)).*

**Qtl - Lower stream terrace deposits (late Pleistocene)**

Sand and minor silt; yellow, yellowish brown, reddish yellow; and pebble gravel. Sand is chiefly quartz with some glauconite and mica. Gravel is quartz and quartzite with minor ironstone. As much as 30 feet thick. Forms stream terraces with surfaces 5 to 20 feet above the modern floodplain. *(GRI Source Map ID 47707) (Surficial Geology of the Long Branch Quadrangle (OFM 38)).*

**Qtl - Lower stream terrace deposits (late Pleistocene, late Wisconsinan)**

Sand, pebble gravel, minor silt and cobble gravel; reddish brown, yellowish brown, reddish yellow. As much as 30 feet thick. *(GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).*
Qcl - Lower colluvium (late Pleistocene)

Qcl - Lower Colluvium (late Pleistocene)
Sand, silt, minor clay; yellow, yellowish brown, reddish yellow, light gray; some quartz and ironstone pebbles. As much as 20 feet thick, generally less than 10 feet thick. Forms aprons graded to lower terraces or the modern floodplain. (GRI Source Map ID 2584) (Surficial Geology of the Sandy Hook Quadrangle (OFM 39)).

Qcl - Lower Colluvium (late Pleistocene)
Sand, silt, minor clay; yellow, yellowish brown, reddish yellow, light gray; some quartz and ironstone pebbles. As much as 20 feet thick, generally less than 10 feet thick. Forms aprons graded to lower terraces or the modern floodplain. (GRI Source Map ID 47707) (Surficial Geology of the Long Branch Quadrangle (OFM 38)).

Qcl - Lower Colluvium (late Pleistocene)
Sand, silt, minor clay and pebble gravel; yellow, yellowish brown, reddish yellow, light gray. As much as 20 feet thick, generally less than 10 feet thick. (GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).

Cape May Formation

Qcm2 - Cape May Formation, unit 2 (late Pleistocene)

Qcm2 - Cape May Formation, Unit 2 (late Pleistocene)
Sand, minor silt and clay; very pale brown, yellow, white, olive yellow; and pebble gravel. Sand is chiefly quartz with minor glauconite and mica; gravel is quartz and quartzite. As much as 50 feet thick. Forms a shore-facing terrace with surface elevation between 15 and 40 feet. Deposited in beach and estuarine settings during the Sangamon sea-level highstand between 120,000 and 130,000 years ago. (GRI Source Map ID 2584) (Surficial Geology of the Sandy Hook Quadrangle (OFM 39)).

Qcm2 - Cape May Formation, Unit 2 - Unit 6 Surficial Geology of the Long Branch Quadrangle, Monmouth County, New Jersey (late Pleistocene)
Sand, minor silt and clay; very pale brown, yellow, white, olive yellow; and pebble gravel. Sand is chiefly quartz with minor glauconite and mica; gravel is quartz and quartzite. As much as 50 feet thick. Forms a shore-facing terrace with surface elevation between 15 and 40 feet. Deposited in beach and estuarine settings during the Sangamon sea-level highstand between 120,000 and 130,000 years ago. (GRI Source Map ID 47707) (Surficial Geology of the Long Branch Quadrangle (OFM 38)).

Qcm2 - Cape May Formation, Unit 2 (late Pleistocene)
Sand, pebble gravel, minor silt, clay, peat, and cobble gravel; very pale brown, yellow, reddish yellow, white, olive yellow, gray. As much as 200 feet thick on the Cape May peninsula, generally less than 50 feet thick elsewhere. (GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).

Qcm1 - Cape May Formation, unit 1 (middle? Pleistocene)

Qcm1 - Cape May Formation, Unit 1 (middle? Pleistocene)
Sand, minor silt and clay; very pale brown, yellow, reddish yellow; and pebble gravel. Sand is chiefly quartz, with minor glauconite and mica; gravel is quartz and quartzite. As much as 30 feet thick. Forms a shore-fronting marine terrace with surface elevation between 50 and 75 feet. Deposited in beach and estuarine settings during a middle? Pleistocene sea-level highstand. (GRI Source Map ID 47707) (Surficial Geology of the Long Branch Quadrangle (OFM 38)).
Qcm1 - Cape May Formation, Unit 1 (early to middle? Pleistocene)
Sand, minor silt, clay, and pebble gravel; very pale brown, yellow, reddish yellow. As much as 50 feet thick. *(GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).*

Qtu - Upper stream terrace deposits (middle Pleistocene)
Qtu - Upper Terrace Deposits (middle Pleistocene)
Sand, minor silt; yellow, reddish yellow; and pebble gravel. Sand is chiefly quartz; glauconite and mica are generally less abundant than in the lower terrace deposits and alluvium. Gravel is quartz, quartzite, and minor ironstone. As much as 20 feet thick. Form terraces with surfaces 20 to 50 feet above the modern floodplain. *(GRI Source Map ID 2584) (Surficial Geology of the Sandy Hook Quadrangle (OFM 39)).

Qtu - Upper Terrace Deposits - Unit 6 Surficial Geology of the Long Branch Quadrangle, Monmouth County, New Jersey (middle Pleistocene)
Sand, minor silt; yellow, reddish yellow; and pebble gravel. Sand is chiefly quartz; glauconite and mica are generally less abundant than in the lower terrace deposits and alluvium. Gravel is quartz, quartzite, and minor ironstone. As much as 20 feet thick. Forms terraces with surfaces 20 to 50 feet above the modern floodplain. *(GRI Source Map ID 47707) (Surficial Geology of the Long Branch Quadrangle (OFM 38)).

Qtu - Upper Stream Terrace Deposits (middle to late Pleistocene)
Sand and pebble gravel, minor silt and cobble gravel; yellow, reddish yellow, yellowish brown. As much as 20 feet thick. *(GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).

Qcu - Upper colluvium (middle Pleistocene)
Qcu - Upper Colluvium (middle Pleistocene)
Sand, silt, minor clay; pale brown, yellow, reddish yellow; some quartz, quartzite and ironstone pebbles. As much as 20 feet thick. Forms aprons graded to upper terraces. *(GRI Source Map ID 2584) (Surficial Geology of the Sandy Hook Quadrangle (OFM 39)).

Qcu - Upper Colluvium (middle Pleistocene)
Sand, silt, minor clay; pale brown, yellow, reddish yellow; some quartz, quartzite and ironstone pebbles. As much as 20 feet thick. Forms aprons graded to upper terraces. *(GRI Source Map ID 47707) (Surficial Geology of the Long Branch Quadrangle (OFM 38)).

Qcu - Upper Colluvium (middle Pleistocene)
Sand, silt, minor clay and pebble gravel; pale brown, yellow, reddish yellow. As much as 20 feet thick. *(GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).

QTgl - Upland gravel, lower phase (late Pliocene to middle Pleistocene)
TQg - Upland Gravel, Lower Phase (late Pliocene-middle Pleistocene)
Sand, minor silt; yellow to reddish yellow; and pebble gravel. Sand is chiefly quartz with minor glauconite and mica; gravel is quartz and quartzite. As much as 10 feet thick. Caps lower uplands and interfluves. *(GRI Source Map ID 2584) (Surficial Geology of the Sandy Hook Quadrangle (OFM 39)).
TQg - Upland Gravel, Lower Phase (late Pliocene-middle Pleistocene)
Sand, minor silt; yellow to reddish yellow; and pebble gravel. Sand is chiefly quartz with minor glauconite and mica; gravel is quartz and quartzite. As much as 20 feet thick. Caps lower uplands and interfluvues. (GRI Source Map ID 47707) (Surficial Geology of the Long Branch Quadrangle (OFM 38)).

Tog - Upland Gravel, Lower Phase (late Pliocene-middle Pleistocene)
Sand, clayey sand, and pebble gravel, minor silt; yellow to reddish yellow. As much as 20 feet thick. (GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).

QTg - Upland gravel (Pliocene to early Pleistocene)
Tg - Upland Gravel (Pliocene-early Pleistocene)
Sand, yellow to reddish yellow, and pebble gravel; minor fine-cobble gravel. Sand is chiefly quartz, with minor glauconite in places; gravel is quartz and quartzite with minor weathered chert. Locally iron-cemented. As much as 20 feet thick. In erosional remnants on hilltops and interfluvues. (GRI Source Map ID 47707) (Surficial Geology of the Long Branch Quadrangle (OFM 38)).

Tg - Upland Gravel (Pliocene-early Pleistocene)
Sand, clayey sand, pebble gravel, minor cobble gravel; yellow to reddish yellow. Locally iron-cemented. As much as 20 feet thick. (GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).

QTuc - Upland colluvium (Pliocene-early Pleistocene)
Sand, clayey sand, pebble gravel, minor silt; white, yellow, reddish yellow. As much as 15 feet thick. (GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).

Tp - Pensauken Formation (Pliocene)
Tp - Pensauken Formation (Pliocene)
Sand, pebbly sand, and minor pebble-to-cobble gravel, reddish-yellow to yellow. Sand is predominantly quartz; with some feldspar; and minor red shale, mica, and glauconite. Some of the feldspar in the sand is weathered to clay. Gravel is predominantly white to light gray (stained reddish-yellow to yellow) quartz and quartzite; with some chert, red to gray mudstone and sandstone; and minor ironstone (from Coastal Plain formations), gneiss, schist, and diabase. All the clasts except quartz, quartzite, chert, and ironstone generally have thick weathering rinds or are fully decomposed. Cobble gravel channel deposits are restricted to the basal few feet of the deposit and contain abundant clasts of quartzite, sandstone, and mudstone, and scattered clasts of gneiss, schist, and diabase. Tabular, planar cross-bedded sand with minor pebble gravel dominates the deposit above the basal gravel. The pebble gravel is chiefly quartz and quartzite with some chert and minor mudstone.

Salisbury and Knapp (1917) defined and mapped the Pensauken Formation. Owens and Minard (1979) reassigned the Pensauken deposits north of Trenton to the Bridgeton Formation (a higher fluvial sand and gravel in southern New Jersey), based on projection of the elevations of the deposits from their type areas in southern New Jersey. This usage was followed by Martino (1981) and Stanford (1993, 1995). However, the deposits north of Trenton are continuous in both extent and elevation with those at the Pensauken type locality, so the original nomenclature is used here. The age of the Pensauken is not firmly established. Berry and Hawkins (1935) describe plant fossils from the New Brunswick area that they consider to be of early Pleistocene age. Owens and Minard (1979) assign a late Miocene age based on correlation to units in the Delmarva Peninsula. Pollen from the Pensauken near Plainsboro,
New Jersey (about 18 miles southwest of Metuchen), include a few pre-Pleistocene species, suggesting a Pliocene age (G. Brenner, written communication, 1991). This age is also consistent with the geomorphic and stratigraphic relation of the Pensauken to late Pliocene or early Pleistocene till and middle to late Miocene marine and fluviatile deposits (Standford, 1993). (GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).

**Tp - Pensauken Formation (Pliocene)**
Sand, clayey sand, pebble gravel, minor silt, clay, and cobble gravel; yellow, reddish yellow, white. Sand typically includes weathered feldspar. Locally iron-cemented. As much as 140 feet thick. (GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).

**Tpg - Pensauken Formation, glauconitic phase (Pliocene)**
Sand, clayey sand, and pebble gravel, minor silt and clay; reddish yellow to yellowish brown. Sand typically includes glauconite. As much as 40 feet thick. (GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).

**Tbh - Beacon Hill gravel (late Miocene)**
Sand, clayey sand, pebble gravel, minor cobble gravel; reddish yellow to yellow. Locally iron-cemented. Feldspathic gravel clasts and sand are weathered to clay. As much as 30 feet thick. (GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).

**TKr - Weathered bedrock (Cretaceous(?) to Tertiary)**

**Qwcp - Weathered Coastal Plain Formations (Cretaceous(?) to Tertiary)**
Exposed sand and clay of Coastal Plain bedrock formations. May be overlain by thin, patchy alluvium and colluvium. Quartz and ironstone pebbles left from erosion of surficial deposits may be present on the surface and in the upper several feet of the formation. (GRI Source Map ID 2584) (Surficial Geology of the Sandy Hook Quadrangle (OFM 39)).

**Qwcp - Weathered Coastal Plain Formations (Cretaceous?) to Tertiary**
Exposed sand and clay of Coastal Plain bedrock formations. May be overlain by thin, patchy alluvium and colluvium. Quartz and ironstone pebbles left from erosion of surficial deposits may be present on the surface and in the upper several feet of the formation. (GRI Source Map ID 47707) (Surficial Geology of the Long Branch Quadrangle (OFM 38)).

**K - Cretaceous Deposits (Cretaceous)**
Gray, white, yellow, pink, red clay and fine-to-coarse quartz sand, minor quartz granule gravel. May contain mica, lignite, and ironstone. Massive to laminated; clays may be jointed. Sand may include white kaolinite clay from decomposition of feldspar. Exposed in former clay and sand pits, where it is generally overlain by fill or regraded natural material. (GRI Source Map ID 47711) (Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)).

**Qwcp - Weathered coastal plain deposits (Chiefly Pleistocene, locally Miocene and Pliocene)**
Exposed sand and clay of Coastal Plain bedrock formations. Includes thin, patchy alluvium and colluvium, and pebbles left from erosion of surficial deposits. (GRI Source Map ID 74858) (Surficial Geology of New Jersey (DGS 07-2)).
r - Bedrock
Large and/or former bedrock outcrops. May be partly covered by fill or construction, or no longer exposed. See GIS data for more information. (GRI Source Map ID 55336) (Surficial Geology of the Elizabeth Quadrangle (OFM 42)).

r - Bedrock
Large and/or former bedrock outcrops. May be partly covered by fill or structures, or no longer exposed. See GIS data for more information. (GRI Source Map ID 2585) (Surficial Geology of the Jersey City Quadrangle (OFM20)).

Ancillary Source Map Information

Large Scale Sources

Surficial Geology of the Elizabeth Quadrangle (OFM 42)

Ancillary Map Notes

Introduction

Surficial deposits in the Elizabeth quadrangle include artificial fill, alluvial, estuarine, and windblown (eolian) sediments of postglacial age, and glacial sediments that are of late Wisconsin age. The postglacial deposits are generally less than 20 feet thick. The glacial sediments include stratified sand, gravel, silt, and clay deposited in glacial lakes and by glacial streams, and till deposited by glacial ice. The stratified glacial sediments are as much as 300 feet thick. Till is as much as 90 feet thick.

The surficial deposits are delineated on the accompanying map and cross sections and are described below. The glacial and postglacial events they record are also discussed below. A brief summary of the hydrologic and engineering characteristics of the deposits is also provided below. Well and test-boring data used to draw bedrock-surface contours and to infer the subsurface distribution of the deposits are plotted on the map, and selected logs are listed in Appendix 1. Table 2 provides the composition of gravel clasts in the glacial deposits. Table 1 summarizes penetration-test data for the surficial materials. Figure 1 shows the extent of glacial lakes and ice margins in the quadrangle and adjacent areas. The chronologic relationships of the deposits are shown in the "Correlation of Map Units".

Hydrologic and Engineering Characteristics

Surficial deposits in the Elizabeth quadrangle convey water from the surface into the underlying bedrock and adjoining surface-water bodies. They also provide support for foundations. and are the materials excavated for underground structures, road and railroad cuts, and shipping channels. Before the 1930s they were ruined for clay, sand, and gravel at a few places (Merrill and others, 1902). Urbanization precludes extraction now, although sand, silt, and clay dredged from Newark Bay, the Arthur Kill, and the Kill van Kull, if sufficiently free from contamination, may be usable for fill or landfill cover.

Hydraulic conductivities of the surficial deposits can be estimated from statewide glacial aquifer-test data on file at the N. J. Geological Survey (www.state.NJ.us/geonjgs/ geodataidgs02-I) and published aquifer-test and laboratory data summarized by Stanford and Witte (in press). Sand and gravel deposits (units...
Qbn, Qwb, Qez, Qbnf, Qpt, and parts of Qat) are highly permeable, with estimated hydraulic conductivities between 101 and 103 feet per day (ft/d). Silt and clay lake-bottom deposits (parts of units Qbnl mid QI) are of low permeability, with estimated hydraulic conductivities of 10-5 to 10-3 ft/d. Fine sand and silt in lake-bottom, alluvial, and estuarine deposits (parts of units Qbnl, QI, Qpt, Qm, and Qat) and sandy silt till (unit Qt) are somewhat more permeable, with estimated hydraulic conductivities of 10-3 to 10-1 ft/d. Estuarine and salt-marsh deposits (Qm) and fill (af) have variable hydraulic conductivities that depend on the clay and silt content of the material. Sandy tidal-channel sediments, salt-marsh peats with little mineral soil, and fill composed of sand, cinders, gravel, demolition debris, slag, and trash, may be highly permeable.

The strength of the surficial materials depends on their grain size, compaction, and water content. Estuarine, salt-marsh, and alluvial deposits (units Qm and Qat) are of low strength because they have not been subject to water or sediment loads greater than those at present, and have been continuously saturated or moist, and so are not compact. They also may contain significant amounts of organic matter, which is weaker than mineral soil. Standard Penetration Test (SPT) data from test borings (Table 1) can be used to assess the compaction and strength of surficial deposits. These tests report the number of blows of a 140-pound hammer falling 30 inches that are required to drive a sampling tube 12 inches into the test material. For unit Qm they show a range of 0-38, with a mean of 3 and a standard deviation of 4 (647 tests). Forty-six percent of the tests had values of zero, indicating that the weight of the hammer or drilling rods alone was sufficient to drive the sampling tube the required distance. For unit Qal, the SPT values range from 0-89, with a mean of 24 and a standard deviation of 14 (221 tests), with 2 percent having values of zero. Construction on these materials generally requires the use of pilings to transfer loads to the underlying bedrock or till, or the excavation of the natural material and replacement with engineered fill of greater strength. The lake-bottom deposits are similarly of low strength because they have been continuously saturated from the time of deposition, except for the upper parts, which were exposed and desiccated when the glacial lakes drained. The desiccated layer, which is as much as 20 feet thick, but is not everywhere present, is more compact than the underlying lake-bottom material. SPT data show an overall mean of 14 and a standard deviation of 14 (1559 tests) for lake-bottom sediment, with 11 percent having a value of zero. The desiccated layer yields blow counts generally between 20 and 50, with some rare values as large as 150.

Sand and gravel (units Qbn, Qbnf, Qwb, Qez, Qpt) are coarser-grained and, where they crop out, better-drained than the lake-bottom and postglacial deposits and thus are of greater strength. SPT values for these sands range from 2 to 139, with a mean of 27 and a standard deviation of 17 (573 tests). Most till (Qt) in the quadrangle was deposited beneath glacial ice and so has been consolidated by the weight of the ice. SPT values for till range from 3 to 330, with a mean of 67 and a standard deviation of 58 (723 tests). In till, low SPT values are typically recorded within 10 feet of the land surface, where soil processes and bioturbation have disaggregated the matrix of the till. In many cases, in till at depths greater than 10 feet, blows were stopped at 50 or 100 for penetrations of less than 6 inches. Thus, till is generally the surface of refusal for driven pilings. Artificial fill consists of a variety of materials, including uncompacted trash and demolition debris, and compacted engineered fills composed of sand, silt, and gravel. SPT values for fill range widely from 0 to 191, with a mean of 18 and a standard deviation of 19 (737 tests), with 1.2 percent having a value of zero.

Data on the density, grain size, and Atterberg limits for the surficial materials are provided by Rogers and others (1951, 1952).

**Postglacial Deposits**

These include man-made fill (af), sediment deposited in estuaries and salt marshes (Qm), in freshwater swamps (Qs), in river flood plains and channels (Qal, Qpt), and windblown sediment blanketing parts of the west slope of the Palisades Ridge (Qe). They were all deposited after glacial retreat.
After glacial lake Bayonne drained to the Hackensack level (see below), the Passaic River, which likely included meltwater fed from the glacier to the north, cut a channel through the deltaic sand at and north of downtown Newark. This sediment was redeposited downstream as a broad terrace (Qpt) on the former Lake Bayonne lake-bottom. The Ironbound section of Newark (east of Route 21 and north of Interstate 78) is located on this terrace. This deposit may include some shallow-water deltaic sediment deposited in Lake Hackensack. Draining of Lake Hackensack caused the Passaic to cut its channel into the terrace and to deposit sandy alluvium (included in unit Qal) on the bottom of drained Lake Bayonne-Hackensack. This alluvial sand is now covered by salt-marsh deposits and fill in the Newark Bay-Newark Airport area. The Elizabeth River and its tributaries likewise cut channels and floodplains (included in unit Qal) into the glacial deposits after Lake Woodbridge drained and the Elizabeth River glaciofluvial deposit became inactive. At the same time, westerly winds blew fine sand and silt from the unvegetated former lake bottom in the Newark Bay area and deposited this sediment as a sheet along the base of the west slope of the Palisades Ridge (Qe). Some of the sand beneath the salt-marsh deposits may also be windblown.

Deposition of the alluvial sediments in the Newark Bay and Arthur Kill areas, and along the lower reaches of the Elizabeth and Passaic Rivers, was gradually replaced by estuarine and salt-marsh sedimentation (Qm) as sea level rose and flooded the former lake plains. Most of the salt-marsh sediment in the Newark Bay-Arthur Kill area has been deposited within roughly the past 3000 years (Newman and others, 1969).

Landfilling on the marsh and alluvial deposits began shortly after permanent European settlement in the 1600s. The earliest fills were likely along the Newark and Elizabeth waterfronts. Large-scale filling for railroad and industrial facilities and trash disposal occurred during the latter part of the nineteenth century and early twentieth century. The period between 1920 and 1970 saw continued filling for Newark Airport and the Port Newark-Port Elizabeth marine terminals. Virtually all of the original salt marsh, and some areas of formerly open water in Newark Bay, have been filled.

**Glacial Deposits**

These include till—a poorly sorted, non stratified sediment containing gravel clasts and boulders, deposited directly from glacial ice (Qr) and sorted, stratified sediments. The stratified sediments include sand and gravel laid down by glacial meltwater in river plains (Qez), in glacial-lake deltas (Qwb, Qbn, possibly Qsp) and in glacial-lake fans (Qbnf), and varved silt, clay, and fine sand deposited on the bottoms of glacial lakes (Qnbl, Ql).

Before these deposits were laid down the underlying bedrock surface was shaped by glacial erosion. The bedrock surface (plotted at 50-foot contour interval on the geologic map) shows elongate northeast-southwest-trending troughs that descend to nearly 300 feet below sea level in the Newark-Harrison area, and to more than 100 feet below sea level in the Newark Bay area. To the south these troughs shallow and grade into a gently rolling bedrock surface less deeply scoured. The troughs are closed to an elevation of just below sea level, indicating that they are products of glacial scour, not filled preglacial valleys. Their southward shallowing may reflect reduced erosive capacity of the glacial ice as it thinned and spread upon exiting the higher-relief topography farther north in the Hackensack River Valley.

The bedrock valley extending westward from the Weequahic Lake area is the eastern end of the Kenilworth valley of Nemickas (1974), which is a tributary of the preglacial Raritan valley (Stanford, 1993). This is thus a preglacial fluvial valley only slightly modified by glacial erosion. Indeed, stratified sediments (Qsp) preserved beneath till in the Hillside-Irvington area are situated in a tributary valley that may have been dammed to form a lake basin during glacial advance. The bedrock surface beneath these deposits thus was not eroded during the most recent glaciation.
The upland in the northwestern sector of the quadrangle is underlain by glacially streamlined sandstone and siltstone bedrock. Till is generally thin over most of this area, indicating that the topography is the product primarily of glacial erosion. However, borings in the southern part of the upland along the Newark-Hillside-Irvington border record till as much as 80 feet thick, indicating that some of the ridges here may be drumlins formed by deposition of till.

Late Wisconsinan ice reached its southernmost position at Perth Amboy, about 12 miles south of Elizabeth (fig. 1), about 21,000 yrs B. P. (years before present), based on radiocarbon dates of organic material at the bottom of postglacial bogs in western New Jersey (Harmon, 1968; Cotter and others, 1986) and on organic sediments beneath till on Long Island (Sirkin, 1986). A continuous terminal moraine was deposited at the position of maximum advance (fig. 1). As the ice front retreated, a series of glacial lakes formed, dammed to the south by the moraine (Stanford and Harper, 1991). One of these, Lake Bayonne, occupied the Arthur Kill, Newark Bay, and upper New York Bay lowlands, and had an outlet over the moraine at Perth Amboy (fig. 1). This outlet was gradually lowered by erosion, and therefore the level of Lake Bayonne steadily declined. In the Elizabeth quadrangle a delta deposited in Lake Bayonne at Newark has a top elevation of about 30 feet above sea level. Adjusting for postglacial rebound of Earth’s surface in response to release of the weight of the glacier, this altitude indicates the spillway at Perth Amboy had been eroded to about 25 feet below sea level (using the rebound rate of 3.5 feet per mile to the north from Stanford and Harper, 1991). Deposits in Lake Bayonne include deltaic sand and gravel (Qbn), lacustrine-fan sand and gravel (Qbnf), and lake-bottom silt, clay, and fine sand (Qbnn).

Continued erosion of the outlet at Perth Amboy, and along the Arthur Kill to the north, uncovered diabase bedrock at an elevation of 30 feet below sea level in the Arthur Kill about 4 miles south of Elizabeth. The diabase halted further downcutting and formed the stable spillway for Lake Hackensack (fig. 1). An auxiliary spillway was also established across diabase in the Kill van Kull near the Bayonne bridge (fig. 1). In the Elizabeth quadrangle, Lake Hackensack occupied the lowest parts of the Newark Bay lowland, although there was little accumulation of additional sediment on top of the Lake Bayonne deposits in this area because the ice margin at the time was more than 10 miles north of quadrangle. The lake drained eastward into the Hudson Valley when the retreating ice front uncovered Sparkill Gap, a deep gap through the Palisades Ridge, about 24 miles north of Newark.

The Elizabeth quadrangle includes a small area of deltaic and lacustrine-fan sand and gravel (Qwb) deposited in association with glacial Lake Woodbridge, which occupied the southwestern part of the Rahway River basin and was dammed on the east by the glacier margin. The deposit in the Elizabeth quadrangle was actually laid down in a local pond dammed between a Lake Woodbridge delta in Kenilworth and the eastward-retreating ice margin in the valley of the West Branch of the Elizabeth River (Stanford, 1991). Two deposits of lacustrine silt (Ql) were laid down in similarly-dammed tributary valleys to the south.

When the retreating ice margin uncovered the Elizabeth River Valley these local ponds drained. Meltwater draining down the valley deposited a fluvial plain (Qez) with an ice-contact head at the west end of Weequahic Lake. The valley fill beneath the northern part of this plain may contain lacustrine sand that filled a small glacial lake before fluvial drainage was established. Likewise, deposits forming the knobby topography in the Weequahic Lake area, east of the head of the fluvial plain, were also laid down in a lake. This lake may have been dammed by the ice-contact slope at the head of the plain and by ice blocks remaining in the area as the main glacier margin retreated eastward. The downstream end of the plain, at Elizabethport, drained into Lake Bayonne at an elevation of about 10 feet. The east edge of the plain is not confined by a valley side today and may have been walled by the glacier margin (margin M1 in fig. 1). Stratified deposits beneath the till in this area (wells 197, 198, 199, 236, 238, 246) suggest that the ice front readvanced approximately 1 mile to this position, which corresponds to the head of the plain at Weequahic Lake.
Table 1 - Standard Penetration Test Data

<table>
<thead>
<tr>
<th>Map Units</th>
<th>Range of SPT Values</th>
<th>Mean ± Standard Deviation</th>
<th>Percentage of Zero Values</th>
<th>Number of Borings</th>
<th>Number of Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>af</td>
<td>0-191</td>
<td>17.8±19.2</td>
<td>1.2%</td>
<td>223</td>
<td>737</td>
</tr>
<tr>
<td>Qm</td>
<td>0-38</td>
<td>2.8±4.5</td>
<td>45.9%</td>
<td>218</td>
<td>647</td>
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<tr>
<td>Qal</td>
<td>0-89</td>
<td>24.0±13.9</td>
<td>1.8%</td>
<td>67</td>
<td>221</td>
</tr>
<tr>
<td>Qbn, Qbnc, Qwb, Qzn, Qpt</td>
<td>2-139</td>
<td>27.3±17.3</td>
<td>0%</td>
<td>79</td>
<td>573</td>
</tr>
<tr>
<td>Qbnl</td>
<td>0-157</td>
<td>13.7±13.9</td>
<td>11.4%</td>
<td>224</td>
<td>1559</td>
</tr>
<tr>
<td>Qt</td>
<td>3-330</td>
<td>67.4±57.8</td>
<td>0%</td>
<td>247</td>
<td>723</td>
</tr>
</tbody>
</table>

Table 1.--Standard Penetration-Test (SPT) data for surficial materials in the Elizabeth quadrangle.

Extracted from: Surficial Geology of the Elizabeth Quadrangle (OFM 42)
### Table 2 - Pebble Count and Compositions

<table>
<thead>
<tr>
<th>Site</th>
<th>Unit</th>
<th>Number of pebbles</th>
<th>Percentage of pebbles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>red sandstone and shale</td>
<td>gray sandstone and shale</td>
</tr>
<tr>
<td>1</td>
<td>Qbn</td>
<td>130</td>
<td>77</td>
</tr>
<tr>
<td>2</td>
<td>Qbn</td>
<td>144</td>
<td>69</td>
</tr>
<tr>
<td>3</td>
<td>Qt</td>
<td>93</td>
<td>97</td>
</tr>
<tr>
<td>4</td>
<td>Qez</td>
<td>123</td>
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<td>5</td>
<td>Qez</td>
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<td>85</td>
</tr>
<tr>
<td>8</td>
<td>Qt</td>
<td>115</td>
<td>87</td>
</tr>
</tbody>
</table>

1Passaic Formation.
2Primarily Passaic and Lockatong Formations, with some Paleozoic clasts.
3Purple to red-brown quartzite conglomerate from the Green Pond and Skunnemunk Formations.
4Proterozoic gneiss from the Hudson Highlands.
5White to yellow-stained quartz and quartzite.
6Either from the Shawangunk Formation or the Pensauken Formation.

Extracted from: [Surficial Geology of the Elizabeth Quadrangle (OFM 42)](http://example.com)
Figure 1 - Glacial Extents

Figure 1.--Ice margins, glacial-lake spillways, and maximum extent of glacial lakes in the Elizabeth quadrangle and vicinity. Arrows show route of drainage from spillways. Ice margins include: M1= last ice margin before deposition of glacial Lake Woodbridge deposits ends. M2=ice margin during deposition of the Elizabeth River glaciofluvial plain. This margin may mark the limit of a readvance from a position about 1 mile to the northeast. M3= last ice margin before lake in Weequahic Park area lowers to Lake Bayonne level. M4=ice margin during deposition of the Newark delta.

Extracted from: Surficial Geology of the Elizabeth Quadrangle (OFM 42)
Correlation of Map Units

Extracted from: Surficial Geology of the Elizabeth Quadrangle (OFM 42)
# Appendix 1 - Selected Well and Boring Logs

<table>
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<th>Description</th>
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</tr>
<tr>
<td>2</td>
<td>19.8</td>
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<td>sandstone (d)</td>
</tr>
<tr>
<td>2</td>
<td>19.8</td>
<td>sandstone (e)</td>
</tr>
<tr>
<td>2</td>
<td>19.8</td>
<td>sandstone (f)</td>
</tr>
<tr>
<td>2</td>
<td>19.8</td>
<td>sandstone (g)</td>
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<td>sandstone (j)</td>
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<td>sandstone (k)</td>
</tr>
<tr>
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<td>sandstone (l)</td>
</tr>
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<td>sandstone (m)</td>
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<td>sandstone (s)</td>
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<td>sandstone (t)</td>
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<td>19.8</td>
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<tr>
<td>2</td>
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<td>sandstone (z)</td>
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*Extracted from: Surficial Geology of the Elizabeth Quadrangle (OFM 42)
<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
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<tbody>
<tr>
<td>118</td>
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<tr>
<td>119</td>
<td>Dolomite</td>
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<tr>
<td>120</td>
<td>Limestone</td>
</tr>
<tr>
<td>121</td>
<td>Sandstone</td>
</tr>
<tr>
<td>122</td>
<td>Mudstone</td>
</tr>
<tr>
<td>123</td>
<td>Quartzite</td>
</tr>
<tr>
<td>124</td>
<td>Tuff</td>
</tr>
<tr>
<td>125</td>
<td>Basalt</td>
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Extracted from: Surficial Geology of the Elizabeth Quadrangle (OFM 42)
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<tr>
<th>Soil Group</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
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<tr>
<td>A2</td>
<td>Clayey fine sand (0)</td>
</tr>
<tr>
<td>A3</td>
<td>Clay (0)</td>
</tr>
<tr>
<td>A4</td>
<td>Clayey silt (0)</td>
</tr>
<tr>
<td>A5</td>
<td>Silt (0)</td>
</tr>
<tr>
<td>A6</td>
<td>Silty clay (0)</td>
</tr>
<tr>
<td>A7</td>
<td>Clayey silt clay (0)</td>
</tr>
<tr>
<td>A8</td>
<td>Silt clay (0)</td>
</tr>
<tr>
<td>A9</td>
<td>Clayey silt silt (0)</td>
</tr>
<tr>
<td>B1</td>
<td>Fine sand (0)</td>
</tr>
<tr>
<td>B2</td>
<td>Silt (0)</td>
</tr>
<tr>
<td>B3</td>
<td>Clayey silt (0)</td>
</tr>
<tr>
<td>B4</td>
<td>Silt clay (0)</td>
</tr>
<tr>
<td>B5</td>
<td>Clayey silt clay (0)</td>
</tr>
<tr>
<td>B6</td>
<td>Clayey silt silt (0)</td>
</tr>
<tr>
<td>B7</td>
<td>Silt clay clay (0)</td>
</tr>
<tr>
<td>B8</td>
<td>Clayey silt clay clay (0)</td>
</tr>
<tr>
<td>B9</td>
<td>Clayey silt silt silt (0)</td>
</tr>
</tbody>
</table>

Extracted from: Surficial Geology of the Elizabeth Quadrangle (OFM 42)
<table>
<thead>
<tr>
<th>Depth</th>
<th>Surficial Geology of the Elizabeth Quadrangle (OFM 42)</th>
<th>Description</th>
</tr>
</thead>
</table>

### Depth 20 feet
- **Description:**
  - Unconsolidated sediments including sands, gravels, and cobbles. The sediments are composed of a mixture of sand, silt, clay, and organic material. The sediments are characterized by a high degree of bioturbation, indicating extensive root development and burrowing activity. The sediments contain a variety of plant debris, including leaves, twigs, and roots. The sediments are typically well stratified, with distinct layers of different colors and textures.
  - **Reference:** Surficial Geology of the Elizabeth Quadrangle (OFM 42)

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- **Description:**
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  - **Reference:** Surficial Geology of the Elizabeth Quadrangle (OFM 42)
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<tr>
<th>Layer Number</th>
<th>Description</th>
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<tr>
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<tr>
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<tr>
<td>103</td>
<td>Volcanic Ash</td>
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<td>Volcanic ash, breccia</td>
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<tr>
<td>104</td>
<td>Clastic Sed</td>
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<tr>
<td>105</td>
<td>Mafic Volcanic</td>
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<td>Mafic volcanic rocks</td>
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</tbody>
</table>

**Extracted from:** Surficial Geology of the Elizabeth Quadrangle (OFM 42)
Map Location

LOCATION IN NEW JERSEY

Extracted from: Surficial Geology of the Elizabeth Quadrangle (OFM 42)
Explanation of Map Symbols

- **Contact**—Solid where well-defined by landforms; dashed where approximate, gradational, or featheredged. Some contacts are modified from Salisbury (1895), Merrill and others (1902), and unpublished manuscript maps of R. D. Salisbury and C. E. Peet on file at the N.J. Geological Survey.

- **Striation**—Observation at dot. Data from Salisbury and Peet (1895).

- **Elevation of bedrock surface in well or boring**—Data from Parrillo (1959). “Less-than” sign (<) indicates bottom of boring did not reach bedrock.

- **Elevation of bedrock surface in well or boring**—Data from Lovegreen (1974). Values are inferred from a bedrock topography map with a contour interval of 20 feet.

- **Elevation of bedrock surface from seismic reflection survey**—Data from Jeffrey Waldner and David Hall, N. J. Geological Survey, 1997.

- **Elevation of bedrock surface in well or boring**—Data from Nemickas (1974).

- **Elevation of bedrock surface in well or boring**—Data from Herpers and Barksdale (1951).

- **Elevation of bedrock surface in well or boring**—Data from files of the N. J. Geological Survey. Elevations in the Newark Bay-Port Newark-Port Elizabeth area are referenced to mean low water, which is 2.3 feet below mean sea level. Elevations elsewhere are referenced to base map datum.

- **Well with log in table 1**—Location judged to be accurate to within 100 feet. Elevation of bedrock surface, datum as above, in parentheses.

- **Well with log in table 1**—Location judged to be accurate to within 500 feet. Elevation of bedrock surface, datum as above, in parentheses.

- **Elevation of bedrock surface**—Contour interval 50 feet.

- **Large bedrock outcrop**—May be partly covered by fill or construction.

- **Former bedrock outcrop**—Shown on unpublished manuscript maps by C. E. Peet, R. D. Salisbury, and H. B. Kummel (on file at the N. J. Geological Survey) but no longer exposed.

- **Well with log in table 1**—On sections, projected to line of section.

- **Depth to bedrock in well or boring**—On sections, projected to line of section. Dot indicates bedrock surface penetrated, no dot indicates bedrock not reached.

- **Unit to left of slash overlies unit to right**—Shows extent of material underlying thin eolian deposits.

Extracted from: Surficial Geology of the Elizabeth Quadrangle (OFM 42)

References


Extracted from: Surficial Geology of the Elizabeth Quadrangle (OFM 42)

Surficial Geology of the Sandy Hook Quadrangle (OFM 39)


Map Location

Extracted from: Surficial Geology of the Sandy Hook Quadrangle (OFM 39)
Explanation of Map Symbols

Contact--Contacts of alluvium, beach deposits, and estuarine deposits are well-defined by landforms and are drawn from 1:12,000-scale aerial stereophotographs. Contacts of other units are approximately located based on both landforms and field observation points.

- Material observed in hand-auger hole, exposure, or excavation.


Extracted from: Surficial Geology of the Sandy Hook Quadrangle (OFM 39)

Surficial Geology of the Long Branch Quadrangle (OFM 39)


Map Location
Introduction

Surficial materials in the Perth Amboy and Arthur Kill quadrangles consist of glacial, stream, wetland, and weathered bedrock sediment. The glacial sediment includes sand, gravel, silt, and clay laid down by meltwater in glacial ice as a sheet on the bedrock surface and in the terminal moraine. The sand, gravel, silt, and clay, known collectively as stratified drift, are as much as 70 feet thick. Till is as much as 130 feet thick. The stream sediment included sand, gravel, and silt deposited in floodplains, stream terraces, and former river plains. It is as much as 40 feet thick. The wetland sediment included peat and organic silt and clay deposited in freshwater swamps and saltwater marshes and estuaries. It is as much as 100 feet thick. The weathered bedrock consists of silty clay and shale fragments formed by chemical and mechanical decomposition of shale bedrock of Triassic and Jurassic age. It is generally less than 10 feet thick.

The accompanying map and sections show the surface extent and subsurface relations of these deposits. Figure 1 shows the extent of glacial lakes and river plains, the terminal moraine, and
recessional ice margins. Table 1 lists water-well and test-boring logs used to plot bedrock-surface topography and to infer the subsurface distribution of deposits. Table 2 lists the composition of pebbles in the glacial deposits. The correlation chart shows the temporal relationships and age of deposits.

**Postglacial Deposits**

These include artificial fill, stream, wetland, and beach sediment deposited since retreat of the late Wisconsinan glacier. Alluvial and swamp deposits began to accumulate shortly after deglaciation. Estuarine and salt-marsh deposits began to accumulate as rising sea level entered the Raritan Valley. This occurred as early as 11,500 radiocarbon years before present (yrs B. P.) as indicated by a radiocarbon date of 11,420±560 yrs B. P. (GX-21687) on organic clay at the base of the estuarine deposit at a depth of 98-100 feet in a boring adjacent to boring 139 (Table 1) (Lippincou. Jacobs, and Gouda. Inc., 1995. boring B2).

**Glacial Deposits**

These include till and stratified drift deposited by ice and meltwater during the late Wisconsinan glaciation. The till is a reddish-brown, nonstratified poorly-sorted sediment consisting of pebbles, cobbles, and a few boulders scattered in a compact matrix of mixed silt, sand, and clay. It is deposited by glacial ice. Stratified drift includes reddish-brown, to gray, moderately- to well-sorted, cross- to plane-bedded sand and gravel deposited in deltas and fans in glacial lakes and in glacial river plains; and reddish-brown to gray, well-sorted, laminated to varved silt, clay, and fine sand deposited on the bottoms of glacial lakes. The sand fraction in both till and stratified drift is predominantly quartz and red and gray shale fragments. The composition of pebbles in these deposits is provided in Table 2.

Late Wisconsinan ice advanced southerly to southwesterly across the map area to the southern edge of the terminal moraine. As the glacier advanced, it overrode sand and gravel laid down in lakes and river plains in valleys in front of the ice margin. Records of wells and borings indicate that these deposits are preserved beneath till in a few places, chiefly where valleys drained toward the advancing glacier. These include the preglacial valley in the northwestern pan of the map area (units Qpf and Qsu in wells 4-7, 80, 82, 83, 85), the preglacial valley extending from Metuchen to the Rahway area (units Qpf and Qsu, section C-C'; wells 42, 47, 93, 203, 208-210, 221, 331), and in the lowland between the Arthur Kill and Woodbridge Creek (wells 179-182, 237-239, 241, 242, 244-246, 249, 256, 305, 309, 311). Ice also overrode fluvial sand and gravel at Perth Amboy (unit Qpa, section B-B'; wells 134-137, 151, 158, 159, 343).

Ice also overrode, eroded, and deformed unconsolidated Cretaceous deposits and Pensauken Formation sediment at and south of Carteret, Woodbridge, and Metuchen (K and Tp on sections A-A', B-B'). Folded Cretaceous sand and clay, and, in places, Pensauken sand and gravel, were formerly well exposed in the clay pits at Woodbridge, Perth Amboy, and Fords (Ries and others, 1904) and were also observed in several excavations between 1987 and 1995. The two hills mapped as ice-contact deposits (Qic) in Woodbridge and Carteret may contain, or consist largely of, deformed Cretaceous sediment.

North of the Cretaceous outcrop belt the ice advanced across red shale bedrock. Glacial erosion of bedrock in the preglacial valleys was minimal because the valleys were sediment-filled. On low uplands between the valleys, though, ice eroded rock and deposited till to form low, smoothed ridges with a rough northeast-southwest trend parallel to both ice now and rock strike.

The terminal moraine (Qtm) was deposited while the ice margin stood at and melted back from its maximum position. The moraine is a broad belt of knolls, ridges, and basins, composed mostly of till extending in an are from Perth Amboy to Scotch Plains. A prominent frontal ridge as much as 100 feet high marks the south edge of the moraine between Metuchen and Fords, but elsewhere it generally has less than 50 feet of relief. The back edge of the moraine is a gradual transition from constructional...
moraine landforms to nonmorainic till. As ice stood at the moraine, meltwater deposited sand and gravel in three glacial river plains (Qpf, Qmt, Qpa).

The ice margin was probably in retreat from the moraine by 20,000 years ago (Stanford and Harper, 1991). The retreating ice margin had roughly the same arc-like orientation as the terminal moraine, and three glacial lakes fanned in basins between the retreating ice front and the moraine (fig. 1).

Lake Ashbrook occupied the Robinsons Branch valley. It was controlled first by a spillway at an elevation of about 90 feet across the terminal moraine at Oak Tree, about half-a-mile west of Oak Tree School, just west of the map boundary (spillway AB1 on fig. 1). Most of the Lake Ashbrook deposits in the map area (Qab, Qabl) were probably deposited in this higher lake stage. As the ice margin retreated a lower spillway at an elevation of about 80 feet was uncovered on the divide between the Robinsons Branch and South Branch of the Rahway valleys, just north of Shore View (spillway AB2 on fig. 1). Lake Ashbrook lowered to the level of Lake Woodbridge when the retreating ice front uncovered the Robinsons Branch valley in the vicinity of the present Middlesex Reservoir.

Lake Woodbridge occupied the South Branch valley and, later, the Robinsons Branch valley and main Rahway valley upstream of Rahway. It was controlled by a spillway at an elevation of about 60 feet on the Rahway-Woodbridge Creek divide near Colonia (WB on fig. 1), and drained when the ice front retreated north of the low upland between the South Branch and Woodbridge Creek valleys between Avenel and Rahway. Deposits in this lake in the map area include deltaic sediment near Iselin (Qwb).

Lake Bayonne occupied the lowland along the Arthur Kill, Woodbridge Creek, and lower Rahway River. It was controlled at first by a spillway across the terminal moraine at Richmond Valley on Staten Island at an elevation of 25-30 feet. This spillway was succeeded by one across the terminal moraine between Perth Amboy and Staten Island (BN on fig. 1), which gradually lowered as the overflow eroded the moraine. Deposits in Lake Bayonne in the map area are primarily lake-bottom silt and clay (Qbnl) and scant deltaic or fan sand and gravel (Qbn). With continued erosion the spillway migrated northward along the present Arthur Kill and stabilized when it uncovered diabase bedrock near Tremley Point at an elevation of -30 feet. This formed the spillway for Lake Hackensack (HK on fig. 1). Only the southern most tip of Lake Hackensack extended into the map area, as shallow water along the Arthur Kill north of Tremley Point. Because the ice margin at this time was about 15 miles northeast of Tremley Point, there was little or no glacial sediment deposited in this lake in the map area.

Lakes in the map area had drained by 18,000 years ago (Stanford and Harper, 1991), although meltwater continued to drain down the Rahway, Raritan, and Arthur Kill valleys for a period after lake drainage. In the Rahway valley this meltwater deposited sand and gravel (Qrw). In the Raritan valley the meltwater, sourced mostly from glacial lake overflows in headwater areas, was combined with nonglacial drainage and deposited nonglacial and reworked glacial sediment (Qrt). This deposition likely spanned most of the period when ice was in the Raritan basin. In the Arthur Kill the meltwater was glacial lake overflow from Lake Hackensack. This drainage carried little sediment and so deepened the channel through the moraine at Perth Amboy and the till plain to the north.

**Preglacial Deposits**

These include sand and gravel deposited by a preglacial river (Tp), weathered shale bedrock (Qsw), and outcropping sand and clay of Cretaceous age (K). The preglacial river, which may have included drainage from the Hudson valley and southern New England, flowed across the region from northeast to southwest between about 5 and 2 million years ago and deposited a broad plain of sand and gravel that covered the entire map area. This river was diverted, possibly by glacial blockage, about 2 million years ago. Local drainage then eroded valleys into and through the former river plain, leaving remnants of the deposit on uplands. These remnants, except for a small area in the southwest corner of the map area, beyond the glacial limit, were then overridden by the late Wisconsinan glacier.
Figure 1 - Glacial Extents

Figure 1.—Glacial lakes, river plains, terminal moraine, and recessional ice margins in the map area. Glacial lakes are identified by the following abbreviations on their shorelines and next to their spillways:

- BN=Bayonne
- WB=Woodbridge
- HK=Hackensack
- AB1=high stage of Ashbrook
- AB2=low stage of Ashbrook.

River-plain abbreviations are:

- PF=Plainfield
- MT=Metuchen
- PA=Perth Amboy
- RT=Raritan.

Recessional ice margins are:

- M1=last ice margin before lowering of Lake Ashbrook to lower stage
- M2=last ice margin before Lake Ashbrook lowers to Lake Woodbridge
- M3=last ice margin before Lake Woodbridge drains eastward into Lake Bayonne.
Correlation of Map Units

Extracted from: Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)
Explanation of Map Symbols

Contact—Solid where well-defined by landforms, long-dashed where approximate, short-dashed where gradational or feather-edged, dotted where excavated or projected under fill.

Limit of excavation—Ticks point into excavation. Dashed where obscured by regrading or filling. Marks extent of former clay, sand, and gravel pits. These areas have a discontinuous layer of artificial fill and displaced and regraded surficial and bedrock materials as much as 20 feet thick. Contacts within these areas show the approximate extent of natural material beneath this man-made layer. Fill is mapped separately only where it has a distinct landform. Extent of pits based, in part, on Ries and others (1904). In places, the base map topography within the excavation has been significantly altered since the date of the topographic survey (1934). Contacts within excavated areas show the location of materials at the time of mapping rather than with respect to the base topography.

af/Gm Unit to left of slash overlies unit to right—Shows extent of natural material beneath large areas of fill. Extent of natural materials is based, in part, on Ries and others (1904) and Darton and others (1908).

(Qbn) Unit formerly present—Unit in parentheses removed by excavation. Shows location of Maurer delta deposited in Lake Bayonne, based on Darton and others (1908).

47 Well or boring with log in table 1—Location accurate to within 100 feet. Elevation of bedrock surface in italics.

74 Well or boring with log in table 1—Location accurate to within 500 feet. Elevation of bedrock surface in italics.

47 Elevation of bedrock surface in well or boring—Data from Nemickas (1974).

47 Elevation of bedrock surface in well or boring—Data from N. J. Geological Survey files.

8 Site of pebble count—Data in table 2.


Elevation of bedrock surface—Contour interval 50 feet. Includes surface of Cretaceous deposits.

Qwb Spillway for glacial lake—Symbol in spillway area, arrow shows direction of drainage, lettering indicates associated deposit.

47 Well or boring—On section, projected to line of section.

47 Depth to bedrock in well or boring—On section, projected to line of section.

Extracted from: Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)
### Table 1 - Selected Well and Boring Logs

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Extracted from: Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (QFM 28)
GATE GRI Map Document 55

2016 NPS Geologic Resources Inventory Program

Extracted from: Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)
GATE GRI Map Document 57

2016 NPS Geologic Resources Inventory Program

Extracted from: Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)
Extracted from: Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)
Extracted from: Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)
### Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)

#### Geologic Unit Descriptions

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#### Reference

Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)
### Table 2 - Pebble Count and Compositions

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1Quartz and quartzite: 1-4% chert.
2Purple to red-brown quartzite-conglomerate of the Green Pond Formation.
3Count in till.
4Count in gravel bed in till.

Extracted from: Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)

### References


Extracted from: Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)

Surficial Geology of the Jersey City Quadrangle (OFM20)


Ancillary Map Notes

Introduction

Surficial deposits in the Jersey City quadrangle include alluvial, estuarine, and windblown (eolian) deposits of postglacial age, and glacial lacustrine deposits and till of late Wisconsinan age. These deposits are delineated on the accompanying map and sections and are described below. The glacial and postglacial events they record are also discussed below. Well and boring data used to draw bedrock-surface contours and to infer the subsurface distribution of the deposits are provided in table 1. The chronologic relationships of the deposits are shown on the correlation chart.

Postglacial Deposits

These include sediment deposited in estuaries and salt marshes (Qm), stream sediment deposited in former channels and floodplains beneath the salt-marsh sediment (Qal), windblown sediment blanketing parts of the west slope of the Palisades Ridge (Qe), and man-made fill (af). They were all deposited after glacial retreat.
After glacial lakes Hackensack and Bayonne drained (see below), streams cut shallow channels and plains into the exposed lake bottoms in places and deposited sandy alluvium (Qal). At the same time, and before return of vegetation stabilized surfaces, westerly winds entrained fine sand and silt from the former lake bottom in the Newark Bay area and deposited this sediment as a sheet along the base of the west slope of the Palisade Ridge (Qe). Faint dunes are visible in Lincoln Park and Holy Name cemetery, but urbanization has destroyed any evidence of dunes elsewhere. Merrill and others (1902) mapped several areas of dunes along the west base of the Palisades Ridge in Jersey City of Bayonne, and Russell (1880) described eolian sand deposits at several locations on the east side of the Palisades Ridge from Constable Hook to Hoboken. No evidence of these deposits remains. Most of those described by Russell (1880) were outcrop areas of glacial-lake sand (unit Qbn, see below), and may have been largely wind-shaped glacial sand deposits rather than transported eolian sediment. Some of the sand beneath the salt-marsh deposits, mapped as alluvium, may also be windblown.

Deposition of the alluvial and windblown sediments gradually ended as seal level rose and marshes covered the former lake plains. The bedrock surface beneath the Hudson valley is lower than that beneath the Newark Bay-Kearny area, and the glacial sediment is not as thick, so the rising sea flooded the Hudson valley long before it flooded the Newark Bay-Kearny lowland. Newman and others (1969) indicate estuarine conditions were present in the Hudson valley as long ago as 12,000 yrs B.P (years before present). In the Hackensack valley just north of the quadrangle, salt-marsh deposition did not begin until about 2000 yrs B.P (Heusser, 1963). Estuarine deposits are as much as 300 feet thick beneath the Hudson (sections A-A’, B-B’, C-C’) but are less than 40 feet thick in the Newark Bay-Kearny area. This marked difference in thickness is attributable to the greater depth of the Hudson valley, and the longer period of estuarine deposition there. Estuarine deposition continues today. Landfilling on the marsh deposits began shortly after permanent European settlement in the 1600s. The earliest areas of fill were likely along the Hudson in Hoboken and adjacent parts of Jersey City. The latter part of the nineteenth century, and early twentieth century, saw large-scale landfilling for railroad and shipping terminals and industrial development. By the 1920s almost all of the salt marsh, and some areas of open water, had been covered by fill. Some filling continues today.

**Glacial Deposits**

These include till—a poorly-sorted, non-stratified sediment containing gravel clasts and boulders, deposited directly from glacial ice (Qt, Qty), and well-sorted, stratified sediments. The stratified sediments include sand and gravel laid down by glacial meltwater in glacial-lake deltas (Qbn) and fans (Qbnf) and varved silt, clay, and fine sand deposited on the bottoms of glacial lakes (Qbnl, Qhkl). All of these deposits are of late Wisconsinan age.

Before these deposits were laid down the underlying bedrock surface was shaped by glacial erosion. The topography of the bedrock surface (plotted at 50-foot contour intervals on the map) shows elongate glacially-scoured troughs that extend to more than 200 feet below sea level in the Newark Bay area and more than 300 feet below sea level beneath the Hudson River. To the south and to the north the bedrock surface in these troughs rises, and the trough forms die out (Parrillo, 1959; Stanford and others, 1990), indicating that they are true glacial-scour features rather than buried fluvial valleys. They are eroded into outcrop belts of weak rock, including shale and arkosic sandstone of the Passaic and Lockatong Formations west of the Palisades ridge, arkosic sandstone of the Stockton Formation along the east base of the Palisades ridge, and schist beneath the Hudson River. Resistant diabase makes up the Palisades Ridge. Parrillo (1959) and Lovegreen (1974) show a buried valley crossing the Palisades Ridge at the Bayonne-Jersey City boundary, but no test boring data verify this valley, and outcrops in the area suggest that no valley is present. The series of bedrock highs along the west bank of the Hudson from Castle Point in Hoboken southward to Bayonne is formed on serpentinite and schist.

During the late Wisconsinan advance, the Jersey City area was on the east side of an ice lobe that was channeled between the Watchung Mountains to the west and the Palisades Ridge to the east, and
centered on the Hackensack valley (Salisbury, 1902; Standford and Harper, 1991). The orientation of
striation, and the composition and distribution of till in the quadrangle, indicate that ice flowed
southeasterly here. Reddish-brown silty sand to sandy silt till (“Rahway till”, Qt), is derived from
mudstone and sandstone bedrock. It forms a nearly continuous blanket on the bedrock surface except in
places on the steep east slope of the Palisades Ridge, where it likely was never deposited, and in the
glacially-scoured troughs in the Hudson and Newark Bay-Kearny lowlands, where it either was never
deposited or was later eroded by subglacial meltwater. In the Hoboken-Jersey City area, east of the
Palisades Ridge, the reddish-brown till grades into a more yellowish, siltier till (“Rahway till, yellow
phase”, Qty) that reflects incorporation of weathered serpentinite and diabase. This yellow till likely
underlies unit Qt in places on the Palisades Ridge, and may be present in the subsurface elsewhere
east of Palisades.

Late Wisconsinan ice reached its southernmost position at Perth Amboy, about 16 miles southwest of
Bayonne, earlier than 20,000 yrs B.P., based on radiocarbon dates of organic material at the bottom of
postglacial bogs in western New Jersey (Harmon, 1968; Cotter and others, 1986), on concretions in
glacial Lake Passaic sediments west of the Watchung Mountains (Stone and others, 1989), and on
organic sediments beneath till on Long Island (Sirkin, 1986). A continuous terminal moraine was
deposited at the position of maximum advance (fig. 1). As the ice front retreated, a series of glacial lakes
formed, damned to the south by the moraine (Stanford and Harper, 1991). One of these, Lake Bayonne,
occupied the Arthur Kill, Newark Bay, and upper New York Bay Lowlands, and had an outlet over the
moraine at Perth Amboy (fig. 1). This outlet was gradually lowered by erosion, and therefore the level of
Lake Bayonne steadily declined. In the Jersey City quadrangle, deltas deposited in Lake Bayonne have
top elevations 20 to 30 feet above sea level. Adjusting for postglacial rebound of Earth’s surface in
response to release of the weight of the glacier, these altitudes indicate the spillway at Perth Amboy had
been eroded to between 0 to 20 feet below sea level (using the rebound rate of 3.5 feet/mile to the north
from Standford and Harper, 1991). Deposits in Lake Bayonne include deltaic sand and gravel (Qbn),
lacustrine-fan sand and gravel (Qbnf), and lake-bottom silt, clay, and fine sand (Qbni).

Continued erosion of the outlet at Perth Amboy, and along the Arthur Kill to the north, uncovered diabase
bedrock at an elevation of 30 feet below sea level in the Arthur Kill about 7 miles north of Perth Amboy.
The diabase halted further downcutting and formed the stable spillway for Lake Hackensack (fig. 1). An
auxiliary spillway was also established across diabase in the Kill van Kull, just west of the quadrangle
boundary (fig. 1). In the Jersey City Quadrangle, Lake Hackensack occupied the lowest parts of the
Newark Bay-Kearny lowland. Some lake-bottom silt and clay (Qhkl) in the northeastern corner of the
map area were deposited in Lake Hackensack. The lake drained eastward into the Hudson Valley when
the retreating ice front uncovered Sparkill Gap, a deep gap through the Palisades Ridge, about 22 miles
north of Hoboken.

In the Hudson Valley, Lake Bayonne lowered to form Lake Hudson when the retreating ice front
uncovered the Hell Gate area in the East River between Manhattan and Queens, about 5 miles east of
Hoboken (fig. 1). This event likely occurred when the ice front was just north of the Hoboken area,
because deltaic sand at the Lake Bayonne level occurs in Hoboken but not north of there. Gneiss
bedrock at Hell Gate formed a stable spillway for Lake Hudson at an elevation of 30 feet below sea level.
In the Jersey City quadrangle the level of Lake Hudson, corrected for rebound, was between 40 and 60
Tunnel (borings 29-32 in table 1) did not encounter any Lake Hudson deposits, and none are mapped in
the quadrangle. This absence is due to either nondeposition or removal of deposits by lake meltwater
floods in the Hudson Valley (Newman and others, 1969; Stanford and Harper, 1991). However, remnants
of lake-bottom sediment deposited in Lake Hudson may be present locally beneath the estuarine
deposits under the Hudson River and Upper New York Bay. Lake Hudson persisted until the moraine
dam at the Narrows, about 6 miles south of Bayonne (fig. 1), was breached. The timing of this event is
uncertain, but breaching may have occurred as long ago as about 15,500 yrs B.P., when large volumes
of meltwater, sourced from glacial lakes in the Great Lakes basin, discharged through the Hudson Valley.
Figure 1. -- Ice margins, glacial-lake spillways, and maximum extent of glacial lakes. Lakes are identified by the following abbreviations on their shorelines: Bn=Bayonne, Hk=Hackensack, Hd=Hudson. Placename abbreviations are: PA=Perth Amboy, AK=Arthur Kill, KK=Kill van Kull, Nr=Narrows, HG=Hell Gate. Recessional ice margins include: M1=last ice margin before Lake Bayonne lowered to the Lake Hudson level in the Hudson valley. Deltas in Lake Bayonne were deposited at Hoboken and on the west side of Jersey City. M2=approximate position of ice margins at maximum extent of Lake Bayonne, before the stable Lake Hackensack level was established.
Correlation of Map Units

Extracted from: Surficial Geology of the Jersey City Quadrangle (OFM20)

Map Location

Extracted from: Surficial Geology of the Jersey City Quadrangle (OFM20)
Explanation of Map Symbols

- **Contact**—Solid where well-defined by landforms; dashed where approximate, gradational, or featheredged; dotted where concealed by fill. Some contacts are modified from Merrill and others (1902), and unpublished manuscript maps of C. E. Peet and R. D. Salisbury on file at the N. J. Geological Survey.

- **Striation**—Observation at dot. Flag indicates data from Salisbury and Peet (1895).

- **Elevation of bedrock surface in well or boring**—Data from Parrillo (1959). "Less-than" sign (<) indicates elevation of bottom of boring that did not reach bedrock.

- **Elevation of bedrock surface in well or boring**—Data from Lovegreen (1974). Values are inferred from a bedrock topography map with a contour interval of 20 feet.

- **Elevation of bedrock surface in well or boring**—Data from files of the N. J. Geological Survey.

- **Well with log in table 1**—Location judged to be accurate within 100 feet. Elevation of bedrock surface in parentheses.

- **Well with log in table 1**—Location judged to be accurate within 500 feet. Elevation of bedrock surface in parentheses.

- **Elevation of bedrock surface**—Contour interval 50 feet. Shown only where depth to bedrock generally exceeds 50 feet.

- **Large bedrock outcrop**—May be partly covered by fill or structures.

- **Former bedrock outcrop**—Outcrop noted on unpublished manuscript maps by C. E. Peet, R. D. Salisbury, and H. B. Kummel (on file at the N. J. Geological Survey) but no longer exposed.

- **Well with log in table 1**—On sections, projected to line of section.

- **Depth to bedrock in well or boring**—On sections, projected to line of section. Dot indicates bedrock surface penetrated, no dot indicates bedrock not reached.

- **Unit to left of slash overlies unit to right**—Shows extent of unit underlying large areas of artificial fill and eolian deposits.

- **Surface water**—On sections only.

Extracted from: [Surficial Geology of the Jersey City Quadrangle (OFM20)](file:///C:/users/user/Downloads/01-Geologic-Map/01-Geologic-Map.pdf)
### Table 1 - Selected Well and Boring Logs

<table>
<thead>
<tr>
<th>Well No.</th>
<th>Identifier</th>
<th>Depth (feet below land or water surface)</th>
<th>Lithologic Log Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>N 26-13-764</td>
<td>0-6</td>
<td>mud (Qms)</td>
<td>sand and fill (af)</td>
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<tr>
<td>9-15</td>
<td>fine sand and clay (Qfcl)</td>
<td>meadow mud (Qm)</td>
<td></td>
</tr>
<tr>
<td>15-23</td>
<td>gray sand (Qs)</td>
<td>sand (Qs)</td>
<td></td>
</tr>
<tr>
<td>23-54</td>
<td>light yellow clay and sand (Qclt)</td>
<td>sand and clay (Qfcl)</td>
<td></td>
</tr>
<tr>
<td>N-100</td>
<td>light brown clay (Qbet)</td>
<td>fine sand (Qfbs)</td>
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</tr>
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<td>N 26-13-765</td>
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<td>mud (Qms)</td>
<td>sand and fill (af)</td>
</tr>
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<td>6-11</td>
<td>gray sand (Qs)</td>
<td>meadow mud (Qm)</td>
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</tr>
<tr>
<td>11-29</td>
<td>sand and clay (Qfcl)</td>
<td>sand and clay (Qfcl)</td>
<td></td>
</tr>
<tr>
<td>29-55</td>
<td>light brown very soft clay (Qms)</td>
<td>gravelly clay (Qfcl)</td>
<td></td>
</tr>
<tr>
<td>53-74</td>
<td>red clay (Qmcr)</td>
<td>gravelly clay (Qfcl)</td>
<td></td>
</tr>
<tr>
<td>74-76</td>
<td>soft shale</td>
<td>gravelly clay (Qfcl)</td>
<td></td>
</tr>
<tr>
<td>N 26-13-759</td>
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<td>mud (Qms)</td>
<td>sand and fill (af)</td>
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<td>4-16</td>
<td>gray sand (Qs)</td>
<td>meadow mud (Qm)</td>
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<tr>
<td>16-41</td>
<td>blue clay and sand (Qms)</td>
<td>sand and clay (Qfcl)</td>
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<td>41-81</td>
<td>light brown clay (Qbet)</td>
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<tr>
<td>81-84</td>
<td>fine brown sand (Qfb)</td>
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<td>sand and fill (af)</td>
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<td>9-13</td>
<td>sand and gravel (Qfgr)</td>
<td>meadow mud (Qm)</td>
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<tr>
<td>13-20</td>
<td>coarse sand and gravel (Qfgr)</td>
<td>sand and gravel, quicksand at bottom (Qms)</td>
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<td>20-26</td>
<td>fine sand (Qs)</td>
<td>fine sandy clay, including some gravel (Qfcl)</td>
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<tr>
<td>26-31</td>
<td>blue clay and sand (Qms)</td>
<td>gravelly clay (Qfcl)</td>
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<tr>
<td>31-35</td>
<td>brown clay and sand (Qmcr)</td>
<td>gravelly clay (Qfcl)</td>
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<tr>
<td>35-61</td>
<td>fine brown sand (Qfb)</td>
<td>gravelly clay (Qfcl)</td>
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<td>N 26-13-858</td>
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<td>sand and fill (af)</td>
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<td>5-16</td>
<td>gray sand (Qs)</td>
<td>meadow mud (Qm)</td>
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<td>16-19</td>
<td>fine sand, clay (Qms)</td>
<td>sand and clay (Qfcl)</td>
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<td>19-22</td>
<td>medium sand and clay (Qms)</td>
<td>sand and clay (Qfcl)</td>
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<tr>
<td>22-58</td>
<td>soft sand and clay (Qmcr)</td>
<td>sand and clay (Qfcl)</td>
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<td>58-77</td>
<td>compact clay (Qmcr)</td>
<td>sand and clay (Qfcl)</td>
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<td>32-40</td>
<td>blue and red clay (Qmcr)</td>
<td>meadow mud (Qm)</td>
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<td>40-50</td>
<td>red clay (Qmcr)</td>
<td>meadow mud (Qm)</td>
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<td>red clay with some fine sand (Qmcr)</td>
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<tr>
<td>60-64</td>
<td>hard red clay mixed with small pebbles and stones (Qmcr)</td>
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<td>64-68</td>
<td>water</td>
<td>meadow mud (Qm)</td>
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<td>N 26-13-797</td>
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<td>cinder fill (af)</td>
<td>gray organic silt clay (Qmcs)</td>
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<td>4-14</td>
<td>swamp mud (Qms)</td>
<td>gray organic silt clay (Qmcs)</td>
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<td>14-34</td>
<td>gray sand (Qs)</td>
<td>gray organic silt clay (Qmcs)</td>
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<tr>
<td>34-114</td>
<td>red clay (Qmcr)</td>
<td>gray organic silt clay (Qmcs)</td>
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<td>114-126</td>
<td>red shale</td>
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<tr>
<td>126-127</td>
<td>gray sandstone</td>
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<td>127-141</td>
<td>red shale</td>
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<td>N 26-12-121</td>
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<td>water</td>
<td>gray organic silt clay (Qmcs)</td>
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<tr>
<td>14-20</td>
<td>sand and gravel (Qfgr)</td>
<td>gray organic silt clay (Qmcs)</td>
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<tr>
<td>20-32</td>
<td>sand and clay (Qfcl)</td>
<td>gray organic silt clay (Qmcs)</td>
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<tr>
<td>32-65</td>
<td>sand and gravel (Qfgr)</td>
<td>gray organic silt clay (Qmcs)</td>
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</tr>
<tr>
<td>65-76</td>
<td>water</td>
<td>gray organic silt clay (Qmcs)</td>
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Extracted from: [Surficial Geology of the Jersey City Quadrangle (OFM20)](https://example.com/surficial-geology-2020)
<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
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<tbody>
<tr>
<td>23 NIGIS files</td>
<td>0.24 fill (al) 0.28-158 gray organic silty clay (Qm) 0.28-158 gray silty medium-to-fine sand, some gravel and boulders (Qm) 0.165-175 cemented till (probably conglomerate bedrock)</td>
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<td>22 NIGIS files</td>
<td>0.28-108 gray organic silty clay (Qm) 0.108-130 gray fine-to-medium sand, trace silt and gravel (Qm) 0.130-138 gray medium-to-fine sand, some gravel and boulders, trace silt (Qm) 0.138-148 cemented silt (probable conglomerate bedrock)</td>
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<tr>
<td>23 NIGIS files</td>
<td>0.30-36 gray organic silty clay (Qm) 0.30-36 red-brown to brown-gray fine-to-medium sand, some silt (Qm) 0.78-85 brown-gray, mid-brown, black coarse-to-fine sand, some silt, gravel (Qm) 0.85-91 cemented silt (probable conglomerate bedrock)</td>
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<tr>
<td>24 NIGIS files</td>
<td>0.18-21 gray organic silty clay (Qm) 0.41-45 dark gray fine-to-coarse sand, some gravel and organic silty clay (Qm over QmQ or Qm) 0.45-51 boulders and cemented silt (Qm or QmQ)</td>
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<tr>
<td>25 NIGIS files</td>
<td>0.04-9 water 0.24-98 gray organic silty clay (Qm) 0.185-118 gray and brown silty fine sand (QmQ) 0.118-130 cemented till (probable conglomerate bedrock)</td>
</tr>
<tr>
<td>26 NIGIS files</td>
<td>0.00-10 fill (al) 0.09-13 gray organic silty clay (Qm) 0.09-13 red-brown clayey fine-to-coarse sand, some gravel and boulders (Qm) 0.61-74 cemented silt (probable conglomerate bedrock)</td>
</tr>
<tr>
<td>27 NIGIS files</td>
<td>0.04 fill (al) 0.04-76 gray organic silty clay (Qm) 0.78-113 gray fine sand, some silt, becoming black and silty with trace wood before till fine (Qm) 0.113-124 till (Qm) 0.124-150 cemented till (probable conglomerate bedrock) 0.150-153 cemented silt (probable conglomerate bedrock)</td>
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<td>28 NIGIS files</td>
<td>0.25 fill (QmQ) 0.23-220 gray sand and gravel (QmQ)</td>
</tr>
<tr>
<td>N 26-26-124</td>
<td>0.05 water 0.35-159 gray organic silty clay (Qm) 0.159-171 rock 0.171 N 26-26-124</td>
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</table>

Extracted from: Surficial Geology of the Jersey City Quadrangle (OFM20)
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<th>Layer</th>
<th>Description</th>
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<tbody>
<tr>
<td>50</td>
<td>0-17: water</td>
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<tr>
<td></td>
<td>17-24: black organic silty clay (Qm)</td>
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<td></td>
<td>24-25: mica silty</td>
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<td>10-50: gray organic silty clay, trace shells (Qm)</td>
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<tr>
<td></td>
<td>50-60: gray sand, trace gravel, trace silt (Qm)</td>
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<tr>
<td></td>
<td>60-61: red-brown clayey silt (Qb or Qs)</td>
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<tr>
<td>52</td>
<td>0-7: cinder fill (af)</td>
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<td></td>
<td>7-55: dark gray organic clay and silt, trace shells (Qm)</td>
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<td></td>
<td>55-60: medium-to-fine gray sand, gray silt and clay, trace gravel (Qm)</td>
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<tr>
<td></td>
<td>60-61: brown clayey silt (Qs or Qfs)</td>
</tr>
<tr>
<td>53</td>
<td>0-17: fill (af)</td>
</tr>
<tr>
<td></td>
<td>17-30: gray organic silty clay (Qm)</td>
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<td></td>
<td>30-41: gray sand, trace gravel, trace silt (Qm)</td>
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<tr>
<td></td>
<td>41-61: red-brown clayey silt (Qs or Qfs)</td>
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<tr>
<td>54</td>
<td>0-5: fill (af)</td>
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<td>5-20: organic silty clay, trace shells (Qm)</td>
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<td></td>
<td>20-22: dark brown peat (Qm)</td>
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<td></td>
<td>22-36: gray brown silt and clay and fine sand, light gravel (Qm)</td>
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<td>0-15: fill (af)</td>
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<td>15-62: gray organic silty clay, shells (Qm)</td>
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<td></td>
<td>62-71: varved gray and brown silt and clay (Qm)</td>
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<tr>
<td>56</td>
<td>0-15: cinder fill (af)</td>
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<tr>
<td></td>
<td>15-25: organic clay and dark brown peat (Qm)</td>
</tr>
<tr>
<td></td>
<td>25-30: fine gray sand, trace silt (Qs)</td>
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<tr>
<td></td>
<td>30-40: gravel and coarse-to-fine sand, some silt and clay (Qm)</td>
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<tr>
<td></td>
<td>40-41: varved brown silt and clay, fine sand peat (Qm)</td>
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<tr>
<td>57</td>
<td>0-15: fill (af)</td>
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<tr>
<td></td>
<td>15-30: gray organic silty clay, shells (Qm)</td>
</tr>
<tr>
<td></td>
<td>30-40: sand, trace silt (Qm)</td>
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<td></td>
<td>40-41: brown silt and clay, veins of fine- to medium sand (Qm)</td>
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<td>58</td>
<td>0-20: fill (af)</td>
</tr>
<tr>
<td></td>
<td>20-25: gray organic silt and clay with shells (Qm)</td>
</tr>
<tr>
<td></td>
<td>25-35: gray and brown sand, some gravel (Qs)</td>
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<td></td>
<td>35-80: varved reddish-brown clay and silt (Qbfs)</td>
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<td></td>
<td>80-100: sand, gravel, cobbles, rock fragments (Qm)</td>
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<td>59</td>
<td>0-6: water</td>
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<tr>
<td></td>
<td>6-12: mud (Qm)</td>
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<tr>
<td></td>
<td>12-25: sand and black sand (Qm)</td>
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<td>25-39: fine sand and clay (Qnfs)</td>
</tr>
<tr>
<td></td>
<td>39-46: coarse, compact sand (Qb or Qs)</td>
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<tr>
<td></td>
<td>46-49: clay and sandstone (Qs)</td>
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<td>49-50: fine sand (Qs)</td>
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<tr>
<td></td>
<td>50-59: boulders (Qs)</td>
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<td></td>
<td>59-61: clay and gravel (Qs)</td>
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<tr>
<td></td>
<td>61-82: red sandstone</td>
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<tr>
<td>60</td>
<td>0-10: water (horizons made before filling)</td>
</tr>
<tr>
<td></td>
<td>10-40: sand and mud (Qm)</td>
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<tr>
<td></td>
<td>40-47: clay and boulders (Qm or Qs)</td>
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<tr>
<td></td>
<td>47-48: sand (Qm or Qs)</td>
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<tr>
<td></td>
<td>48-49: clay (Qm or Qs)</td>
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<td></td>
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<td>52-53: gravel (Qm or Qs)</td>
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<td></td>
<td>53-60: clay (Qm or Qs)</td>
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<tr>
<td></td>
<td>60-61: coarse gravel and sand (Qm or Qs)</td>
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<td>61-80: Hudson silt</td>
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Extracted from: Surficial Geology of the Jersey City Quadrangle (OFM20)
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<tr>
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<td>0-10 fill (cl)</td>
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<td>26-5744</td>
<td>0-11 sand (Qs)</td>
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<td>26-6687</td>
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<td>26-7005</td>
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<td>26-4500</td>
<td>0-20 stagnant water (Qs)</td>
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Extracted from: Surficial Geology of the Jersey City Quadrangle (OFM20)
### Surficial Geology of the Jersey City Quadrangle (OFM20)

<table>
<thead>
<tr>
<th>Well</th>
<th>Depth</th>
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<td>fill (af over Qtn)</td>
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<td>fill (af)</td>
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<td>red sand and clay (Qtn)</td>
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<td>37-44</td>
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<td>red sand, some clay (Qtn)</td>
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<td>gravel (Qtn)</td>
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<td>Well 9a</td>
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<td>40-70</td>
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<td>rock</td>
<td>rock</td>
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**Extracted from:** Surficial Geology of the Jersey City Quadrangle (OFM20)
| 100 NGIS Films | 0-11 | cinders, brick, silt, wood (ad) | 11-26 | cinders, brick, silt, and layers of gray sand (Qgr) |
| 100 NGIS Films | 0-13 | cinders, wood, glass, brick filling (ad) | 13-22 | cinders, brick, silt, and layers of gray sand (Qgr) |
| 100 NGIS Films | 0-18 | fine to medium-grained brown sand with a trace of clay (Qgr) | 18-40 | fine to medium-grained brown sand with a trace of clay (Qgr) |
| 100 NGIS Films | 0-24 | fine to medium-grained brown sand with a trace of clay (Qgr) | 24-52 | fine to medium-grained brown sand with a trace of clay (Qgr) |
| 100 NGIS Films | 0-30 | fine to medium-grained brown sand with a trace of clay (Qgr) | 30-60 | fine to medium-grained brown sand with a trace of clay (Qgr) |
| 100 NGIS Films | 0-36 | fine to medium-grained brown sand with a trace of clay (Qgr) | 36-72 | fine to medium-grained brown sand with a trace of clay (Qgr) |
| 100 NGIS Films | 0-46 | fine to medium-grained brown sand with a trace of clay (Qgr) | 46-92 | fine to medium-grained brown sand with a trace of clay (Qgr) |
| 100 NGIS Films | 0-50 | fine to medium-grained brown sand with a trace of clay (Qgr) | 50-100 | fine to medium-grained brown sand with a trace of clay (Qgr) |

Extracted from: Surficial Geology of the Jersey City Quadrangle (QFM20)
<table>
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Extracted from: Surficial Geology of the Jersey City Quadrangle (OFM20)
### References


Douglas. E. F., 1841, Topographical map of Jersey City, Hoboken, and the adjacent county, describing minutely the course of rivers, brooks, the township and original patent lines, railways, turnpike carriage, and bridle roads, the present farm boundaries with the names of their proprietors, a correct plan of public

Extracted from: Surficial Geology of the Jersey City Quadrangle (OFM20)
grounds and gentlemen's country seats, the position of farm houses, forests, swamps, and marshes, showing a complete view of the face of the county: published by the author, on file at the N. J. State Archives.


Lippincott, Jacobs, and Gouda, Inc., 1995a, Geotechnical investigation, proposed Jersey City Medical Center: prepared for Jersey City Medical Center.

Lippincott, Jacobs, and Gouda, Inc., 1995b, Preliminary geotechnical investigation, Community Mental Health, Liberty Health Systems distribution center: prepared for Jersey City Medical Center.


Extracted from: Surficial Geology of the Jersey City Quadrangle (OFM20)

Small Scale Sources
Surficial Geologic Map of New York, Lower Hudson Sheet (Map and Chart Series 40)

Index Map

Extracted from: Surficial Geologic Map of New York, Lower Hudson Sheet (Map and Chart Series 40)
Figure 1 - Generalized Ice Margins

Extracted from: Surficial Geologic Map of New York, Lower Hudson Sheet (Map and Chart Series 40)

Geomorphic History of Southeastern New York

The Lower Hudson Sheet of the New York State Surficial Geologic Map includes parts of five physiographic provinces - the Appalachian Uplands, the Hudson-Mohawk Lowlands, the New England Uplands, the Triassic Lowland, and the Atlantic Coastal Lowlands. The bedrock geology varies widely among the different provinces. The bedrock beneath the Appalachian Uplands comprises sandstone, shale and limestone beds of Silurian and Devonian age that dip gently to the southwest. Beneath the Hudson-Mohawk Lowlands are beds of Ordovician shale, sandstone and limestone. The New England Uplands are composed of diverse group of sedimentary rocks (shale, graywacke and limestone) and a suite of metamorphic rocks (phyllite, schist, quartzite and marble). The Triassic Lowland in Rockland County, is developed on shale, sandstone and diabase beds of Triassic and Jurassic ages. The Atlantic Coastal Lowlands lie upon a thick mantle of glacier-derived sediments that are draped over cuestas of Cretaceous sedimentary rocks.

The landscapes in southeastern New York have a pronounced glacial imprint. Upland and valley regions alike were reshaped by glacial erosion and deposition during both glacier advance and retreat. However, this imprint is not uniform across southeastern New York. The effects are greater in the Hudson Valley and Atlantic Coastal Plain where weaker, more easily eroded strata are present.

New York State was subjected to glaciation several times during the Pleistocene Epoch. Each
successive glacial episode masked or destroyed completely the geologic record of the previous one. Glacial deposits found in the area of this Lower Hudson Sheet were derived almost entirely from Late Wisconsinan (Woodfordian) glaciation, an expansion of the ice sheet that began about 28,000 years ago and culminated perhaps 21,750 years ago on Long Island. As this Late Wisconsinan (Woodfordian) glacier advanced over the landscape the glacier incorporated and transported large quantities of rock and soil. Its erosive power was enhanced in the Hudson Valley region by the parallelism of the valley and glacier flow and uplands, as in the southern Catskill Mountains, where thinner ice prevailed. On long Island a record of multiple glaciation was discovered along the north shore near Port Washington. Here, deformed masses of stratified clay, peat and oyster reef beds of pre-Woodfordian age are interbedded with Woodfordian outwash. Radiocarbon dates from the organic beds range from more than 42,800 to 21,750 yr B.P. and pollen analysis suggests a relatively warm climate developed and then ameliorated during this mid-Wisconsinan warm interval. A till beneath the organics, the Montauk Till, is assigned an early Wisconsinan age (Altonian) and the Roslyn Till (Woodfordian) caps the organics section.

Three major lobes of the Woodfordian glacier deposited moraines on Long Island. On western Long Island, deposition of the Harbor Hill Moraine was controlled by the Hudson-Champlain Lobe, with ice advancing to southern Staten Island. In central Long Island the deposition of the Ronkonkoma Moraine was controlled by the Connecticut Lobe. The deposition of moraines on eastern Long Island was controlled by eastern Connecticut-western Rhode Island Lobe.

After formation of the complex of moraines on Long Island the Woodfordian glacier began its sporadic retreat northward to Canada, a process that produced a series of proglacial lakes and recessional moraines. Because the ice was thinner over the upland regions they were deglaciated before adjacent lowland areas. In southeastern New York, for example, the Taconic Mountains, Shawangunk Mountains, southern Catskill Mountains and the Hudson Highlands emerged through the Taconic Mountains, Shawangunk Mountains, southern Catskill Mountains and the Hudson Highlands emerged through the thinning ice while a tongue of glacial ice remained active with the lower Hudson Valley. Recessional moraines, indicated in Figure 1, formed where the margin of the glacier remained stationary temporarily deposits of drift in the valleys are thicker (up to 100's of meters) than drift in the uplands (generally less than 5 meters).

During the retreat of the Hudson-Champlain Glacial Lobe, Glacial Lake Hudson formed in the lower Hudson Valley between the terminal moraine and the glacier margin. This lake gradually enlarged as the ice front receded northward to the Hudson Highlands. With further retreat of the ice this lake continued to enlarge throughout the mid- and upper Hudson Valley where it is known as Glacial Lake Albany. The location of the outflow channel is an enigma of these lakes. Although theories abound, it has not been determined whether outflow was south across the terminal moraine or across a bedrock divide into another drainage basin (e.g. Sparkill Gap).

The existence of Glacial Lake Hudson and Albany has been deduced from the materials deposited in the lake and by recognition of its shoreline features. Deltas of sand and gravel developed where streams entered the lake. Examples of such deltas can be observed in Westchester County along the Peekskill Hollow Creek; in Orange County on Moodna Creek; in Dutchess County on Crum Elbow Creek; and in Ulster county along the Esopus Creek. The dam for Lakes Hudson and Albany remained intact for 5000-8000 years. When the dam failed Lake Albany drained, leaving lacustrine deposits as evidence of its former existence.

Two recessional moraines occur in the Wallkill Valley, which is west of the Hudson River and north of the Hudson Highlands. The older Pellets Island Moraine was deposited against the Hudson Highlands. North of this the Wallkill Moraine extends westward into the Minisink Valley and Catskill Mountains. East of the Hudson River the Shenandoah and Poughkeepsie Moraines correlate with the Pellets Island and Wallkill Moraines, respectively. The younger Red Hook and Pine Plains Moraines may be correlative with Rosendale readvance ice margins in the northern Wallkill Valley.
The Wisconsinan glacier receded from New York State about 12,000 years ago. After deglaciation the landforms of New York have been reshaped only moderately by postglacial processes, mainly along the floodplains of streams and the adjacent valley walls.

Extracted from: Surficial Geologic Map of New York, Lower Hudson Sheet (Map and Chart Series 40)

References and Reference Map

Surficial Geology of New Jersey (DGS 07-2)


Note: Only cross section graphics are included in this Digital Geodata Series map. Graphical map elements such as legends, correlations, indexes, etc. are not present.

Surficial Cross Sections

The cross sections present in the GRI digital geologic-GIS data produced for Gateway National Recreation Area, New York and New Jersey (GATE) are presented below. Note that some cross section abbreviations (e.g., A-A’) may have been changed from their source map abbreviation in the GRI data so that each cross section abbreviation in the GRI data is unique. Cross section graphics were scanned at a high resolution and can be viewed in more detail by zooming in (if viewing the digital format of this document).

Large Scale Maps (1:24,000)

Cross Section A-A’

Extracted from: Surficial Geology of the Jersey City Quadrangle (OFM20)
Cross Section B-B'

Extracted from: Surficial Geology of the Elizabeth Quadrangle (OFM 42)

Note: this cross section is labeled A-A' on the source map.

Cross Section C-C'

Extracted from: Surficial Geology of the Jersey City Quadrangle (OFM20)

Note: this cross section is labeled B-B' on the source map.

Cross Section D-D'

Extracted from: Surficial Geology of the Elizabeth Quadrangle (OFM 42)
Note: this cross section is labeled B-B’ on the source map.

Cross Section E-E’

Extracted from: Surficial Geology of the Jersey City Quadrangle (OFM20)

Note: this cross section is labeled C-C’ on the source map.

Cross Section F-F’

Extracted from: Surficial Geology of the Elizabeth Quadrangle (OFM 42)

Note: this cross section is labeled C-C’ on the source map.

Cross Section G-G’

Extracted from: Surficial Geology of the Elizabeth Quadrangle (OFM 42)

Note: this cross section is labeled D-D’ on the source map.
Cross Section H-H'

Extracted from: Surficial Geology of the Elizabeth Quadrangle (OFM 42)

Note: this cross section is labeled E-E’ on the source map.

Cross Section I-I'

Extracted from: Surficial Geology of the Jersey City Quadrangle (OFM20)

Note: this cross section is labeled D-D’ on the source map.

Cross Section J-J'

Extracted from: Surficial Geology of the Jersey City Quadrangle (OFM20)

Note: this cross section is labeled E-E’ on the source map.
Cross Section K-K'

Extracted from: Surficial Geology of the Perth Amboy and Arthur Kill Quadrangles (OFM 28)

Note: this cross section is labeled A-A’ on the source map.

Small Scale Maps (1:100,000 and 1:250,000)

Cross Section C-C'

Extracted from: Surficial Geology of New Jersey (DGS 07-2)

Cross Section D-D'

Extracted from: Surficial Geology of New Jersey (DGS 07-2)

Cross Section K-K'

Extracted from: Surficial Geology of New Jersey (DGS 07-2)
Bedrock Map

Bedrock Map Unit List

The bedrock geologic units present in the digital geologic-GIS data produced for Gateway National Recreation Area, New York and New Jersey (GATE) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Qtm - Tidal-marsh deposits). Units are generally listed from youngest to oldest. No description for water is provided. Information about each geologic unit is also presented in the GRI Geologic Unit Information (GWBRUNIT) table included with the GRI geology-GIS data. Some source unit symbols, names and/or ages may have been changed in this document and in the GRI digital geologic-GIS data. This was done if a unit was considered to be the same unit as one or more units on other source maps used for this project, and these unit symbols, names and/or ages differed. In this case a single unit symbol and name, and the unit's now recognized age, was adopted. Unit symbols, names and/or ages in a unit descriptions, or on a correlation of map units or other source map figure were not edited. If a unit symbol, name or age was changed by the GRI, the unit's source map symbol, name and/or age appears with the unit's source map description.

Cenozoic Era

Quaternary Period
- Qtm - Tidal-marsh deposits
- Qga - Glacial and alluvial deposits
- Qal - Alluvium
- Qbs - Beach sand
- Qfc - Foraminiferal clay
- Qgs - Glauconitic sand

Tertiary Period
- Tch - Cohansey Formation
- Tkw - Kirkwood Formation
- Tkl - Kirkwood Formation, lower member
- Tsr - Shark River Formation
- Tmq - Manasquan Formation
- Tvt - Vincentown Formation
- Thl - Hornerstown Formation

Mesozoic Era

Cretaceous Period
- Kbr - Cretaceous bedrock (Cretaceous?)
- Km - Monmouth Group, Matawan Group and Magothy Formation, undivided
- Kt - Tinton Formation
- Krs - Red Bank Formation, Shrewsbury Member
- Krsh - Red Bank Formation, Sandy Hook Member
- Kns - Navesink Formation
- Kml - Mount Laurel Formation
- Kw - Wenonah Formation
- Kmt - Marshalltown Formation
- Ket - Englishtown Formation
- Kwb - Woodbury Formation
- Kmv - Merchantville Formation
- Kcq - Cheesequake Formation
- Kmg - Magothy Formation
Jurassic and Triassic Period

**Kr** - Raritan Formation, undivided

**Krw** - Raritan Formation, Woodbridge Clay Member

**Krf** - Raritan Formation, Farrington Sand Member

**Kp** - Potomac Formation

Triassic Period

**Ttrgp** - Passaic Formation, undivided

**JTRpms** - Passaic Formation, mudstone facies

**JTRps** - Passaic Formation, sandstone and siltstone facies

**Triassic Period**

**Trpg** - Passaic Formation, gray bed

**TRb** - Brunswick Formation

**TRp** - Palisade Diabase sill

**TRI** - Lockatong Formation

**TRla** - Lockatong Formation, arkosic sandstone facies

**TRS** - Stockton Formation

Paleozoic Era

Ordovician Period

**Ohr** - Harrison Gneiss

Cambrian to Ordovician Periods

**OCi** - Inwood Marble

Neoproterozoic to Ordovician Periods

**OZs** - Serpentinite

**OZm** - Manhattan Formation

Bedrock Map Unit Descriptions

Descriptions of all bedrock geologic map units, generally listed from youngest to oldest, are presented below.

**Qtm** - Tidal-marsh deposits (Pleistocene and Recent)

Tidal-marsh sediments include deposits in swamplike areas near the mouths of streams and on the islands in the Navesink River estuary that are subject to tidal flooding. They consist largely of organic-rich saturated muds containing minor amounts of sand, and are characterized by aquatic plant growths. Some fill has been placed on these deposits; but because of their limited extent, the fills have not been mapped separately. *(GRI Source Map ID 2583) (Geology of the Sandy Hook Quadrangle (Bulletin 1276)).*

**Qga** - Glacial and alluvial deposits (Quaternary)

Underlying bedrock geology unknown. *(GRI Source Map ID 7288) (Geologic Map of New York, Lower Hudson Sheet)).*
Qal - Alluvium (Pleistocene and Recent)

Deposits in and along present streams and accumulations at the bases of some steep slopes are mapped as Recent alluvium. The deposits are derived mainly from the underlying and nearby formations and therefore reflect the local lithologies. The Recent deposits are composed largely of sand and gravel, but they contain silt, clay, and peat. The deposits are generally small in areal extent and thin (5-10 ft thick), but locally are as thick as 20 feet. (GRI Source Map ID 2583) (Geology of the Sandy Hook Quadrangle (Bulletin 1276)).

Qbs - Beach sand (Pleistocene and Recent)

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

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

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

Sandy Hook has lengthened appreciably during the past half century. Comparison of the "Geologic Map of New Jersey" (Lewis and Kümmel, 1912) with the U.S. Geological Survey, Sandy Hook 72-minute quadrangle (revised 1954) indicates an increase in length of about 4,000 feet during that time interval. Aerial photographs (fig. 9) show that during the 21 years between 1940 and 1961, the spit was extended northward about 1,000 feet, and an area of about 65 acres was added to the end of Sandy Hook. Some of this growth was at the expense of the spit elsewhere, particularly along the open-ocean front. Yasso (1965, p. 704) reports a considerable loss of sand at Spiral Beach (fig. 10) and also from the crescentric beach at the lower right of photograph B (fig. 9) during a storm in March 1962. A comparison of the outlines of approximately the northern third of the spit, as recorded on the vertical aerial photographs in 1940 and 1961, is shown in figure 10. It seems that more sand has been added to some parts of the spit than has been removed from others. Therefore, some sand must have been obtained from farther south and possibly some from the ocean bottom. Groins, along the northern part of the spit, and a large seawall, along the barrier bar and southern part of the spit, have been constructed to curtail the loss of sand from the open ocean side of Sandy Hook. (GRI Source Map ID 2583) (Geology of the Sandy Hook Quadrangle (Bulletin 1276)).

Qfc - Foraminiferal clay (Pleistocene and Recent)

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

The foraminiferal clay is composed of medium- to dark-gray or dark-greenish-gray glauconitic silt and clay, containing as much as 26 percent very fine to medium quartz sand (table 1). Glaucinite occurs as rounded dusky-green and moderate-green silt to fine sand. Colorless and green chloritized mica and sand-sized clusters of pyrite crystals are present. Some samples contain much fresh, dusky-brown plant matter, and several samples initially had faint to strong odors of hydrogen sulfide. Kaolinite, chlorite, and mica are the major clay minerals. (GRI Source Map ID 2583) (Geology of the Sandy Hook Quadrangle (Bulletin 1276)).

Qgs - Glaucinitic sand (Pleistocene and Recent)

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

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

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

The deposits underlie the hill slopes below 100 feet altitude, valley bottoms bordering streams, and the broad, flat areas bordering Sandy Hook Bay and the south side of Navesink River. Exposures are limited mainly to pit walls and cutbanks. One pit is located south of Route 35 at the west edge of the quadrangle; one just east of Route 35, southeast of the junction with Mountain Hill Road; and one along the south side of McClees Creek, just north of Cooper Road. The distribution of the deposits was determined largely from small outcrops and by angering. (GRI Source Map ID 2583) (Geology of the Sandy Hook Quadrangle (Bulletin 1276)).

Tch - Cohansey Formation (middle Miocene)

Tch - Cohansey Formation (Miocene? and Pliocene?)

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

About 1 percent clay is present as a coating on sand grains or, locally, as pinkish- or yellowish-gray thin layers near the base of the sand. Weathered feldspar is present in small amounts, and ilmenite is abundant (2-3 percent by weight), particularly in the base. Scattered grains of mica, chiefly colorless, but some black, are also present. Quartz grains are chiefly subangular to subrounded, but some are well rounded and frosted; a few abraded quartz crystals are present. The upper part of the Cohansey contains many small pebbles, most of which are less than 1 inch in diameter. A few pebbles are larger, and one cobble 8 inches long was found. The pebbles are mainly of quartz but some are of chert or sandstone, and a few are from metamorphic rocks. Most of the upper gravel layers are firmly cemented by iron oxide into resistant ledges, which probably are responsible for the high hills and considerable relief in this quadrangle. Cemented layers are also locally present throughout the entire formation and may include layers of clean loose sand.

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

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

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

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

The Cohansey is the unit that covers most of the emerged Coastal Plain in New Jersey. It is presently considered to be of Miocene (?) and Pliocene (?) age and is the youngest Tertiary Formation in the Sandy Hook quadrangle. To the southwest, it is underlain by the Kirkwood Formation of Miocene age, but the Kirkwood is absent in the Sandy Hook quadrangle; and although a few local thin beds in the base of the Cohansey resemble the Kirkwood, they are included in the Cohansey here. The formation ranges in thickness from several feet to as much as 66 feet.

The Cohansey underlies the upper slopes and tops of the highest hills in the southeastern part of the quadrangle. Excellent exposures are present in the large pits along Route 36, south of Hilton, and in the
side of the hill (alt 266 ft.), 0.7 mile east of these pits. Other exposures are in small pits in the hilltops south of Waterwitch and Highlands; in the upper part of the bluff at Waterwitch; in the bluff just northwest of Hart horizontal control station along the north side, of Navesink River; and in the pits in the hilltop along Monmouth Avenue west of Navesink. *(GRI Source Map ID 2583) *(Geology of the Sandy Hook Quadrangle (Bulletin 1276)).

**Tch - Cohansey Formation (Miocene?)**
Fine-to-coarse quartz sand, with thin beds of very coarse sand to very fine pebbles; very pale brown, white, yellow, light gray. Weakly horizontally bedded to cross-bedded. Sand and very fine pebbles consist of quartz with minor (<5%) quartzite and chert. Coarse-sand beds are locally iron-cemented. As much as 30 feet thick in the Long Branch quadrangle. In hilltop erosional remnants above 140-160 feet in elevation in the southwest corner of the quadrangle. Latest middle Miocene in age, based on pollen (Owens and others, 1988, 1998). Unconformably overlies the Kirkwood Formation. *(GRI Source Map ID 75557) *(Bedrock Geology of the Long Branch Quadrangle (OFM 78)).

**Tch - Cohansey Formation (middle Miocene, Serravallian)**
Sand, white to yellow with local gravel and clay. Locally stained red or orange brown by iron oxides and (or) cemented into large blocks of ironstone. Unweathered clay is typically dark gray, but commonly weathers white where interbedded with thin beds of ironstone. Unit is a complex of interfingering marine and nonmarine facies. Sand is typically medium grained and moderately sorted although it ranges from fine to very coarse grained and from poorly to wellsorted. Sand consists of quartz and siliceous rock fragments. Some beds are locally micaceous, and in the Lakehurst area, Ocean County, some beds have high concentrations of “black” sand (pseudorutile) that was once extensively mined. In general, the sand is crossbedded, although the style of cross bedding varies significantly with the paleoenvironment. Trough crossbedding predominates, especially in the nonmarine channel fill deposits, and the scale of the crossbeds varies from small to large. In some areas, planar bedding is well developed in sections that have abundant marine burrows (mostly the clay-lined trace fossil Ophiomorpha nodosa). Such marine-influenced beds (largely foreshore deposits) occur on the central sheet west of Asbury Park, near Adelphia, Monmouth County, north of th Lakehurst Naval Air Station, Ocean County, and at Juliustown, Burlington County (Owens and Sohl, 1969), and on the southern sheet as far north as Salem, Salem County. Gravel beds occur locally, especially in updip areas such as near New Egypt, Ocean County, in the Atlantic Highlands and in the highlands west of Barneget, Ocean County, in the southern part of the central sheet and in mixed marin and nonmarine facies in the northeastern part of the southern sheet where gravel occurs in well-defined channels. Most of the gravel is 1.3 to 2.5 cm (0.5-1.0 in) in diameter, but pieces as long as 10 cm (4 in) are present. The gravel is composed of quartz with small amounts of black chert and quartzite. Clay commonly occurs as discrete, thin, discontinuous beds, is dark gray where unweathered, white or red where weathered. Lesser, thin laminated clay strata also are present. Locally, as near Lakehurst, thick, dark-gray, very lignitic clay was uncovered during the mining of ilmenite and is informally called the Legler lignite (Rachele, 1976). An extensive, well-preserved leaf flora was collected from a thick clay lens in a pit near Millville, Cumberland County. The leaf flora was dominated by Alangium sp., a tree no longer growing in eastern North America (J.A. Wolfe, written commun., 1992). *(GRI Source Map ID 7285) *(Bedrock Geology of New Jersey (DGS 04-6)).

**Tkw - Kirkwood Formation (early Miocene)**
Very-fine-to-fine quartz sand, minor medium-to-coarse sand and very fine pebbles, with thin beds of silt and clay; very pale brown, white, yellow, light gray. Sand is unstratified to horizontally bedded. Silt and clay are interlaminated or thinly interbedded with very fine-to-fine sand. Sand consists of quartz with minor mica and a trace (<1%) of glauconite in places in the lowermost several feet of the formation. As much as 75 feet thick. Early Miocene in age based on diatoms (Woolman, 1895; Sugarman and Owens, 1994), foraminifera (Miller and others, 2006), and strontium-isotope ratios (Sugarman and others, 1993). Unconformably overlies the Manasquan and Vincentown Formations. *(GRI Source Map ID 75557)*
Tkl - Kirkwood Formation, lower Member (Tertiary)

Sand and clay. Upper sand facies: sand, typically fine- to medium-grained, massive to thick-bedded, locally crossbedded, light-yellow to white, locally very micaceous and extensively stained by iron oxides in near-surface beds. The thick bedded strata commonly consist of interbedded fine-grained, micaceous sand and gravelly, coarse- to fine-grained sand. Some beds are intensely burrowed. Trough crossbedded strata with high concentrations of ilmenite and a few burrows are most commonly seen in the Lakewood quadrangle. Lower clay facies: clay and clay-silt, massive to thin-bedded, dark-gray, micaceous, contains wood fragments, flattened lignitized twigs, and other plant debris. Locally, the clay has irregularly shaped sand pockets, which may represent some type of burrow. In the least weathered beds, the sand of the upper sand facies is principally quartz and muscovite with lesser amounts of feldspar. The light-mineral fraction of the dark-colored clay has significantly more feldspar (10-15 percent) and rock fragments (10-15 percent) than the upper sand facies, where the feldspar was probably leached during weathering. The basal beds have a reworked zone 0.3 to 1.2 m (1-4 ft) thick that contains fine- to very coarse grained sand and, locally, gravel. These beds are very glauconitic and less commonly contain wood fragments. Reworked zones are present throughout the lower member. The lower member consists of a lower fine-grained, clayey, dark-colored, micaceous sand (transgressive) and an upper massive or thick-bedded to crossbedded, light-colored sand (regressive). The lower, dark clayey unit was formerly called the Asbury Park Member. The clay-silt was previously called the Asbury Clay by Kümmel and Knapp (1904).

The upper sand facies has been observed only in pits and roadcuts. It is poorly exposed because of its sandy nature. In the central sheet, the lower clay facies is exposed in pits north of Farmingdale, Monmouth County; in a few cuts along the Manasquan River, north of Farmingdale; and along the Shark River, northeast of Farmingdale. In the southern sheet, the lower clay facies is exposed only where the Coastal Plain was deeply entrenched and stripped away. In the southwestern most part of the southern sheet, for example, the Cohansay Formation and much of the upper sand facies were stripped away by successive entrencheds of the Delaware River.

On the central sheet, the lower member ranges in thickness from 20 to 30 m (66-98 ft) along strike, but thickens to over 60 m (197 ft) to the southeast. On the southern sheet, the unit ranges in thickness from 15 to 25 m (49-82 ft). The age of the lower member is based on the presence of the diatom *Actinoptychus heliopelta*, which was recovered from an exposure southwest of Farmingdale near Oak Glen, Monmouth County (Goldstein, 1974). This diatom places the lower member in the lower part of the ECDZ 1 of Andrews (1987), indicative of an early Miocene (Burdigalian) age (Andrews, 1988). Sugarman and others (1993) report strontium-isotope ages of 22.6 to 20.8 Ma, thereby extending the age of the unit to Aquitanian. *(GRI Source Map ID 7285)* *(Bedrock Geology of New Jersey (DGS 04-6))*.

Tsr - Shark River Formation (Tertiary)

Glaucite sand, silt, and clay, medium- to coarse-grained, light-brown to medium-gray, locally indurated at top and noncalcareous throughout. Mollusk impressions (mainly *Venericardia perantiqua*) were observed in the Farmingdale quadrangle. The Shark River is exposed only at a few localities in the central sheet near Farmingdale, Monmouth County, along the Manasquan and Shark Rivers and in several tributaries to Deal Lake near Asbury Park in the Asbury Park quadrangle (Sugarman and Owens, 1994). Most outcrops are small, less than 3 m (10 ft) in height. The contact with the underlying Manasquan Formation was not observed. The Shark River is about 18 m (59 ft) thick and consists of two fining-upward cycles: a glauconite sand is present at the base and a clay or silt is present at the top of
each cycle. Calcareous nanofossils in subsurface Shark River sections indicate Zones NP 14 through NP 18 (Martini, 1971) (middle Eocene and early late Eocene). (GRI Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).

Tmq - Manasquan Formation (early Eocene)

Tmq - Manasquan Formation (Eocene)
Glaucolithic (15-30%) clayey-silty very-fine-to-fine sand to fine-sandy clayey silt; olive and olive-gray where unweathered, olive-brown to brown where weathered; unstratified. As much as 80 feet thick. Early Eocene in age based on calcareous nanofossils (Sugarman and others, 1995; Owens and others, 1998; Miller and others, 2006) and foraminifera (Miller and others, 2006). Described by drillers as "green sand" or "green clay". Unconformably overlies the Vincentown Formation. (Bedrock Geology of New Jersey (DGS 04-6)).

Tmq - Manasquan Formation (lower Eocene, Ypresian) - Consists of several lithologies. In the northern part of the central sheet, unit consists of a lower, clayey, quartz-glaucolithic sand, which is exposed intermittently along the Manasquan River near Farmingdale, Monmouth County, and an upper, fine-grained quartz sand or silt, which is exposed along Hog Swamp Brook west of Deal, Monmouth County. The Farmingdale Member and the Deal Member (of Enright, 1969) are not used on this map because they are not continuous through the outcrop belt or in the subsurface. The formation is best exposed in the central sheet from the Fort Dix Military Reservation, Burlington County, southwestward to the Medford Lakes quadrangle. Here the lower part of the formation consists of 5 m (16 ft) of medium- to coarse-grained, massive, dark-grayish-green, glauconite-quartz sand. The lowest 1 m (3 ft) mostly contains calcareous debris and phosphatized internal fossil molds reworked from the underlying Vincentown Formation. The upper part of the formation is approximately 8 m (26 ft) thick and is mostly a very clayey, blue-green to pale-gray, quartz-glaucolithic (about 20 percent glauconite) sand. Locally, the glauconite content of this interval is variable, and the unit becomes almost a bluegreen clay-silt, especially near Pemberton, Burlington County (Owens and Minard, 1964a). Casts and molds of mollusks (especially Venericardia perantiqua) occur in outcrop. The age of the formation was determined from microfauna in unweathered subsurface beds. Calcareous nanofossils indicates upper Zone NP 9 to mid Zone NP 14 (early Eocene). (GRI Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).

Tvt - Vincentown Formation (late Paleocene)

Tvt - Vincentown Formation (Paleocene)
The Vincentown is thick- to massive-bedded medium glauconitic (15 percent) quartz sand. It is typically light greenish to yellowish gray, but locally, is oxidized to mottled moderate red and moderate olive brown. Some iron oxide cementation is present at or near the base of weathered sections. One- to two-inch pods of nearly pure glauconite sand occur near the base. Glaucolithic constitutes nearly half the sand fraction in the basal few feet. Grain size ranges from clay to coarse sand, but generally more than half is medium sand (table 1). Coarse grains constitute only a few percent; these are mainly quartz, but they include a few grains of glauconite. Quartz grains are generally sub-angular to subrounded, but many angular and some rounded grains are present; glauconite grains are botryoidal. Muscovite and green chloritized mica are present. Much of the sand is fairly loose and clean, but in some outcrops as much as 25 percent clay and silt are present. A small amount of feldspar is present as light-gray weathered grains. In the clay-sized fraction, kaolinite and mica are the common minerals. Characteristic detrital heavy minerals are tourmaline and staurolite. Mica is fairly abundant. Glaucolithic, both detrital and authigenic, is abundant in the heavy-mineral suite.
The contact with the underlying Hornerstown appears gradational. Although the basal few feet are highly glauconite, the underlying Hornerstown is much more so. The contact is placed at the base of the quartzose glauconite sand, and in some outcrops, is marked by clay-ironstone layers. Animal boring or pods, filled by glauconite or quartz sand, are present both above and below the contact. The glauconite-filled borings or pods are chiefly in the base of the Vincentown; the quartz-filled ones, in the upper part of the Hornerstown.

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

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

The Vincentown is of Paleocene age. Before 1928 the formation was thought to be of Late Cretaceous age (Weller, 1907); but faunal evidence by Cooke and Stephenson (1928) suggested the early Tertiary age which has been confirmed by many subsequent workers. It crops out almost continuously in the Coastal Plain in New Jersey and is present in Delaware and Maryland, where it is called the Aquia Formation. The formation ranges in thickness from 0 to 35 feet in the Sandy Hook quadrangle, and is as much as 50 to 60 feet thick in the New Egypt area (Millard and Owens, 1962; Bascom and others, 1909, p.14). The formation underlies steep, middle and upper slopes of the high hills in the southeastern part of the quadrangle and forms a narrow band of outcrop around these hills. The thickest sections are downdip, in the southeast area. The formation thins to zero updip to the northwest, where it is truncated by the overlying Cohansey Sand. The Vincentown is well exposed near the tops of the same bluffs in which the Hornerstown is exposed, in the same pits along Route 36, and in the pit in the hillside about 0.35 mile west of Navesink Light. (GRI Source Map ID 2583) (Geology of the Sandy Hook Quadrangle (Bulletin 1276)).

**Tvt - Vincentown Formation (late Paleocene?)**
Glauconitic (5-20%) silty medium-to-coarse quartz sand, some fine-to-medium sand, some very coarse sand to very fine pebbles; yellow, reddish-yellow, olive-yellow, olive-brown; unstratified to weakly horizontally stratified. Coarse sands are locally iron-cemented into beds and masses as much as 10 feet thick. Lowermost 10-20 feet of the formation is silty fine-to-medium sand, with more glauconite than upsection. Total thickness of formation is 180 feet. Late Paleocene in age, based on foraminifera (Olsson and Wise, 1987; Miller and others, 2006) and calcareous nanofossils (Sugarman and others, 1991). Unconformably overlies the Hornerstown Formation. (GRI Source Map ID 75557) (Bedrock Geology of the Long Branch Quadrangle (OFM 78)).

**Tvt - Vincentown Formation (upper Paleocene, Selandian)**
Sand, quartz, medium-grained, well- to poorly sorted, dusky-yellow to pale-gray; weathers orange brown or red brown, typically very glauconitic and clayey near base; glauconite decreases up section. Feldspar and mica are minor sand constituents. Unit best exposed in the Pemberton, New Egypt, and Mount Holly quadrangles of the central sheet where the overlying formations have been stripped away. The Vincentown Formation is as much as 30 m (98 ft) thick and averages 3 to 15 m (10-49 ft) in its subcrop belt. Where unweathered the unit is generally a shelly sand; where weathered the unit is largely a massive quartz sand. The unweathered sand of the Vincentown is exposed intermittently along the Manasquan River near Farmingdale, Monmouth County. The calcareous nature of the unweathered Vincentown was observed in several coreholes in the vicinity of Farmingdale. The contact with the underlying Hornerstown Formation is disconformable; locally shell beds (bioherms) up to 1.5 m (5 ft)
thick are found along the contact. Shells in the bioherms are typical of a restricted environment and contain the brachiopod *Oleneothyris harlani* (Morton) in the lower beds and the oyster *Pycnodonte dissimilis* in the upper beds. The basal contact and the *Oleneothyris* bioherms are exposed along Crosswicks and Lahaway Creeks and their tributaries. Where bioherms are absent, the basal contact is difficult to place within a sequence of glauconite beds. In general, glauconite beds of the Vincentown are darker gray than glauconite beds of the Hornerstown, and the Vincentown has more quartz sand. Upper beds of the Vincentown are as much as 12 m (39 ft) thick and are mostly silty, dark gray to green-gray, massive, glauconite sand that contains a small percentage of quartz. Calcarenite or coquina, characterized by an abundance of bryozoans, occurs locally along the western belt. These fossiliferous beds, 6 to 7.5 m (20-25 ft) thick, are best exposed along Shingle Run in the New Egypt quadrangle area and in streams that cross the Vincentown outcrop belt in the Pemberton quadrangle.

Calcareous nannofossils, present in some Vincentown outcrops, are from Zones NP 5 (the *Oleneothyris* beds) and NP 9 (late Paleocene). Vincentown sediments are much more fossiliferous in the subsurface and contain Zones NP 5 through NP 9, inclusive. Therefore, the Vincentown corresponds in age with the Aquia Formation of Virginia and Maryland. Numerous studies of the foraminifera of the Vincentown from calcareous beds in the western outcrop belt indicate that the Vincentown includes the planktic foraminifera Zones P3b through P6a (Olsson and others, 1988). A potassium-argon age of 56±18 Ma was determined for basal beds near New Egypt, Ocean County (Owens and Sohl, 1973). (GRI Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).

**Tht - Hornerstown Formation (early Paleocene)**

**Tht - Hornerstown Sand (Paleocene)**

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

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

The contact with the underlying Tinton is distinct and unconformable. In most outcrops, green to olive-gray glauconite of the Hornerstown lies on highly oxidized, iron oxide-crusted, and indurated quartz glauconite sand of the Tinton. Evidence for the unconformity is (1) truncation and overlap, by the Hornerstown, of increasingly older units toward the southwest; (2) reworked material in the base of the Hornerstown; and (3) the irregular, eroded upper surface of the Tinton. No fossils were found within the Hornerstown here, although to the southwest, fossils are present at the base. These fossils have almost certainly been reworked from the underlying formation. They include *Cucullaea vulgaris* (Morton), gastropods, and rarely, *Sphenodiscus lobatus* (Tuomey) (Minard and others, 1964), Weller (1907, p. 155-160) lists about 20 different fossils from the Hornerstown. The author, however, thinks that most of
these are actually from the overlying Vincentown as discussed by Minard and others (1964), and were placed in the Hornerstown by Weller, only with reservation (1907, p. 159).

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

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

The formation underlie middle to upper slopes of the highest hills in the southeastern part of the quadrangle and forms a narrow band of outcrop around these hill. It is well exposed near the tops of several bluffs; one at Waterwitch on Sandy Hook Bay, and those near the horizontal control stations, Lower and Hart, along the north side of the Navesink River. It also is well exposed in several pits, three of which are along Route 36 in the southeastern part of the quadrangle; two of these pits, one on each side of the highway, are south of Hilton, and one is north of the highway, about 0.7 mile east. Other pits in which the Hornerstown is exposed are near the hilltop along Monmouth Avenue, about 1 mile west of the town of Navesink, and one is in the hillside, about 0.35 mile west of Navesink Lighthouse. The formation also crops out in the roadbank along the north side of Navesink Avenue where it joins Route 36, and in the roadbank in the side of the high hill along the north side of Riverside Drive. (GRI Source Map ID 2583) (Geology of the Sandy Hook Quadrangle (Bulletin 1276)).

Tht - Hornerstown Formation (early Paleocene)
Glaucinite (>50%) clay and silty clay; olive, dark green, black where unweathered, olive-brown with brown to reddish-brown mottles where weathered; unstratified. Glaucinite occurs primarily in soft grains of fine-to-medium sand size. Thickness is 25 to 30 feet. Early Paleocene in age, based on foraminifera (Olsson and others, 1997; Landman and others, 2004; Miller and others, 2006) and calcareous nannofossils (Sugarman and others, 1991; Miller and others, 2006). Unconformably overlies the Tinton Formation. (GRI Source Map ID 75557) (Bedrock Geology of the Long Branch Quadrangle (OFM 78)).

Tht - Hornerstown Formation (lower Paleocene, Danian) - Sand, glaucinite, fine- to medium-grained, locally clayey, massive, dark-gray to dusky-green; weathers dusky yellow or red brown, extensively bioturbated, locally has a small amount of quartz at base. Glaucinite grains are typically dark green and have botryoidal shapes. The Hornerstown weathers readily to iron oxide because of its high glauconite content. The Hornerstown in most areas is nearly pure glauconite greensand. The Hornerstown crops out in a narrow belt throughout most of the western outcrop area. In the northern part of the central sheet, it is extensively dissected and occurs as several outliers. Throughout its outcrop belt in the central sheet, the Hornerstown unconformably overlies several formations: the Tinton Formation in the extreme northern area; the Red Bank Formation in the northwestern and west-central areas; and the Navesink Formation in the west-central and southern areas. In the southern sheet, it unconformably overlies the Mount Laurel Formation. The unconformable basal contact locally contains a bed of reworked phosphatic vertebrate and invertebrate fossils. For the most part, however, the basal contact is characterized by an intensely bioturbated zone in which many burrows filled with bright green glauconite sand from the Hornerstown Formation project down into the dark-gray matrix of the underlying Navesink Formation. In a few exposures, a thin layer of medium- to coarse-grained quartz sand separates the Hornerstown from the underlying unit. The Hornerstown is 1.5 to 7 m (5-23 ft) thick.
A Cretaceous age was assigned to this unit by Koch and Olsson (1977) based, in part, on a vertebrate fauna found at Sewell, Gloucester County. However, early Paleocene calcareous nannofossil Zones NP 2-4 were found in a core at Allaire State Park, Monmouth County. This is the only locality in New Jersey where Zone NP 2 was observed; otherwise, the Hornerstown is confined to Zones NP 3 and NP 4. Lowermost Paleocene Zone NP 1 was not identified, and it is thought that the Cretaceous-Tertiary boundary in New Jersey may be unconformable. A complete Cretaceous-Tertiary boundary section was recovered at the Bass River borehole (ODP Leg 174AX). It contained the uppermost Maastrichtian calcareous nannofossil Micula prinsii Zone below a spherule layer and the basal Danian planktonic foraminifer Guembelitria cretacea P0 Zone just above the layer (Olsson and others, 1997). (GRI Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).

**Kbr - Cretaceous bedrock (Cretaceous?)**

No unit description available. (GRI Source Map ID 2583) (Geology of the Sandy Hook Quadrangle (Bulletin 1276)).

**Km - Monmouth Group, Matawan Group and Magothy Formation, undivided (Cretaceous)**

**Km - Manmouth Group, Matawan Group, and Magothy Formation (Upper Cretaceous)**

Silt clay, glauconitic sandy clay, sand, gravel. (GRI Source Map ID 7288) (Geologic Map of New York, Lower Hudson Sheet).

**Km - Magothy Formation (Cretaceous)**

No description provided. (GRI Source Map ID 2583) (Geology of the Sandy Hook Quadrangle (Bulletin 1276)).

**Kt - Tinton Formation (Late Cretaceous (Maestrichtian))**

**Kt - Tinton Formation (Late Cretaceous)**

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

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

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

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

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

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

The Tinton Sand is here mapped and described as a separate formation. Previously, it was described as
the uppermost member of the Red Bank Sand. Cook (1868, p. 261, 268-269) probably was the first to
recognize it as a distinct unit and referred to it as the "Indurated green earth." Weller (1905, p. 159)
states that "for both faunal and stratigraphic reasons the indurated green earth of Cook is separated from
the Red Bank Sand, and is recognized as a distinct formation to which the name Tinton beds is
applied." Weller, however, did not map the unit separately. Mansfield (1922, p1. 3) showed the Tinton as
a separate map unit (as mapped by George Knapp in Mansfield, 1922, p. 4), but still considered it a
member of the Red Bank Sand. This member status continued through the many subsequent reports,
including the New Jersey State geological report by Kümmel (1940, p. 119). Kümmel recognized it as
different from the Red Bank but did not show it separately on the State map. Olsson (1963, p. 653), in
one of the most recent papers describing the Tinton, considered it a separate formation but also did not
show it on a map.

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

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

The Tinton underlies steep, middle to upper slopes of the highest hills in the southeastern part of the quadrangle. It is well exposed in the bluffs at Waterwitch and along the north side of the Navesink River near its mouth, and in the pits along Route 36 south of Hilton. (GRI Source Map ID 2583) (Geology of the Sandy Hook Quadrangle (Bulletin 1276)).

Kt - Tinton Formation (Late Cretaceous)
Glaucnitic (5-30%) silty medium-to-coarse and fine-to-medium quartz sand; reddish-brown, reddish-yellow, yellowish-brown where weathered, grayish-brown, brown, olive-brown where unweathered; unstratified to weakly horizontally stratified. Commonly iron-cemented into beds and masses as much as 15 feet thick. Uppermost 4-6 feet, just below contact with Homerstown Formation, is a brown to olive-gray glauconitic clayey-silty fine sand to fine-sandy silt-clay ("New Egypt Formation" of Landman and others, 2004). Total thickness of Tinton is 30 to 40 feet. Late Cretaceous (late Maestrichtian) in age based on foraminifera, nanofossils, and ammonites (Landman and others, 2004) and strontium-isotope ratios (Sugarman and others, 1995). Overlies the Shrewsbury Member of the Red Bank Formation. Contact with Shrewsbury is not exposed in the Long Branch quadrangle. It is gradational over several feet in the Sandy Hook quadrangle, north of the Long Branch quadrangle (Minard, 1969), but may be unconformable in the Marlboro quadrangle, west of the Long Branch quadrangle (Sugarman and Owens, 1996). (GRI Source Map ID 75557) (Bedrock Geology of the Long Branch Quadrangle (OFM 78)).

Kt - Tinton Formation (Upper Cretaceous, upper Maastrichtian)
Sand, quartz, and glauconite in varying proportions, very clayey and locally indurated by siderite into hard, massive ledges. Sand is dark gray to dark yellow where unweathered; where weathered, siderite changes color of unit to orange brown because of iron oxides, and the formation is stained or cemented in exotic patterns. The Tinton crops out in the northern part of the central sheet from Sandy Hook, Monmouth County, to the northernmost part of the Roosevelt quadrangle, near Perrineville. Unit unconformably overlies the Red Bank Formation in the high hills of the northern Coastal Plain, most notably near Perrineville and Morganville, Monmouth County. In these updip areas, fine gravel, 1 cm (0.4 in) maximum diameter, or large shell concentrations are found along the basal contact. The typical basal bed is a massive, glauconitic (10-35 percent), fine to medium-grained quartz sand with scattered gravel. The massive character of the basal bed is the result of extensive bioturbation. Burrows, filled with glauconite sand of the Tinton, project down into the quartz sand of the underlying Red Bank Formation.

At lower elevations downdip, the Tinton is less weathered, much darker, more glauconitic, and typically indurated. The type locality on Pine Brook at Tinton Falls, Monmouth County, is in this downdip area. At Tinton Falls, 7 to 8 m (23-26 ft) of the Tinton is exposed and has a higher glauconite content than in the updip area. Glauconite at Tinton Falls is light green to pale yellow, and many of the grains have a smooth polished surface that is almost lustrous. Thin sections of the Tinton reveal that many of the grains are oolitic (Owens and Sohl, 1973). X-ray analyses indicate the presence of mixed clay minerals; therefore, the unit is not pure glauconite.

The Tinton Formation at Tinton Falls has scattered molds of calcitic fossils and aragonitic shells. Richards (1958) recorded 30 species of mollusks from the Tinton in this area. Of importance are *Sphenodiscus lobatus*, *Cucullaea (Idonearca) littlei*, and *Scabrotrigonia cerulia*. In New Jersey, *Scabrotrigonia cerulia* is restricted to the Tinton. All three species are common to the upper Maastrichtian *Haustator bilira* Zone of Sohl (in Owens and others, 1977). Strontium-isotope analysis on calcareous shells from the Tinton yielded ages of 66.2 to 65.6 Ma or a late Maastrichtian age (Sugarman and others, 1995). (GRI Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).
Red Bank Sand (Upper Cretaceous)

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

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

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

Excellent exposures also are present in the bluffs along Sandy Hook Bay, from the mouth of Navesink River west to Atlantic Highlands Yacht Harbor. The best and most complete exposure is in the bluff along Bay View Street at Waterwitch, about 300 feet southeast of a slump block. Except for a few feet of the base, the entire 120-foot section is nearly continuously exposed. In addition, four of the overlying formations also are exposed in the top of the bluff. The underlying Navesink Formation can be seen in contact with the lower member of the Red Bank Sand in the roadbank about 800 feet southeast of the bluff exposure. (GRI Source Map ID 2583) (Geology of the Sandy Hook Quadrangle (Bulletin 1276)).

Note: this unit does not appear on source map.

Red Bank Formation (Upper Cretaceous, upper and middle Maastrichtian)
Consists of two thick named lithofacies and one thin unnamed lithofacies. In the northernmost outcrop belt of the central sheet, Olsson (1963) named the upper thick facies the Shrewsbury Member and the lower thick facies the Sandy Hook Member. These lithofacies merge with an unnamed thin, dark-gray, very micaceous, quartz-glaucinite sand to the southwest. This unnamed glauconite lithofacies was mapped in detail in the Roosevelt (Minard, 1964), Allentown (Owens and Minard, 1966), and New Egypt (Minard and Owens, 1962) quadrangles on the central sheet. The Red Bank, like the overlying Tinton, crops out only in the northern part of the central sheet from Sandy Hook, Monmouth County, to near New Egypt, Ocean County. The scale of the map permits showing only the thicker Sandy Hook and Shrewsbury Members. The contact with the underlying Navesink Formation is gradational over several feet. The Sandy Hook Member and the unnamed glauconite member near New Egypt have similar sand and clay mineral compositions.

Smith (in Owens and others, 1977) determined that the Red Bank Formation is of late middle and late Maastrichtian age based primarily on the presence of the ammonite Sphenodiscus lobatus and the planktic foraminfera in the Sandy Hook Member from the Poricy Brook locality, Monmouth County. The concurrence of Rugoglobigerina scotti and Globotruncana contusa place this member well above the base of the Gansserina gansseri Subzone in the upper Maastrichtian. Sugarman and others (1995) assigned a late Maastrichtian CC26 Zone to the unit. Wolfe (1976) assigned pollen from the Sandy Hook
Member to the Maastrichtian CA6/MA-1 Zone. Strontium-isotope age estimates for the Red Bank average 65.8 Ma (Sugarman and others, 1995). (GRI Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).

**Krs - Red Bank Formation, Shrewsbury Member (Late Cretaceous (Maestrichtian))**

**Krs - Red Bank Sand, Shrewsbury Member (Late Cretaceous)**

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

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

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

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

Soil developed on the member is loose and sandy. (GRI Source Map ID 2583) (Geology of the Sandy Hook Quadrangle (Bulletin 1276)).

**Krs - Red Bank Formation, Shrewsbury Member (Late Cretaceous?)**

Fine-to-medium quartz sand, minor medium-to-coarse sand, slightly silty, glauconitic (<5%), and micaceous; reddishyellow, yellow where weathered, light gray and gray where unweathered; unstratified to weakly horizontally bedded; locally iron-cemented. As much as 100 feet thick. Late Cretaceous (late Maestrichtian) in age based on fossils in the underlying Sandy Hook Member; the Shrewsbury Member is unfossiliferous. Grades downward within 2-3 feet to the Red Bank Formation, Sandy Hook Member. On geophysical well logs, transition to Sandy Hook Member is marked by increased gamma-ray intensity and decreased resistance. (GRI Source Map ID 75557) (Bedrock Geology of the Long Branch Quadrangle (OFM 78)).

**Krb - Shrewsbury Member**

Sand, quartz, fine-to-coarse-grained, somewhat clayey and micaceous, mostly massive with local small-scale crossbedding, light-yellow to red or dark-brown, slightly glauconitic at the base. Feldspar is a minor sand constituent. The Shrewsbury is extensively burrowed but is otherwise unfossiliferous. Locally, small “Callianassa”-type burrows are present. Maximum thickness is over 30 m (98 ft) in the
highlands near Matawan. Unit thins southwestward and pinches out near Arneytown, Ocean County. The transition to the underlying Sandy Hook Member occurs within several feet and is characterized by an increase in clay, quartz, silt, mica, and fine pieces of wood downward. (GRI Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).

Krsh - Red Bank Formation, Sandy Hook Member (Late Cretaceous (Maestrichtian))

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

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

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

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

Soil developed on the member is a clayey sand which usually is not very well drained. (GRI Source Map ID 2583) (Geology of the Sandy Hook Quadrangle (Bulletin 1276)).

Krsh - Red Bank Sand, Sandy Hook Member (Late Cretaceous?)

Fine-sandy clayey silt, micaceous, slightly glauconitic (<5%); brown to yellowish-brown where weathered, dark gray, olive-gray where unweathered; unstratified. Calcareous brachiopod, pelecypod, and gastropod fossils are common. As much as 20 feet thick. Late Cretaceous (late Maestrichtian) in age based on calcareous nannofossils (Sugarman and Owens, 1996), foraminifera (Olsson, 1964; Olsson and Wise, 1987; Owens and others, 1977), and strontium-isotope ratios (Sugarman and others, 1995). Grades downward within 2-3 feet into the Navesink Formation. On geophysical well logs, transition to Navesink is marked by increased gamma-ray intensity and slightly decreased resistance. (GRI Source Map ID 75557) (Bedrock Geology of the Long Branch Quadrangle (OFM 78)).

Krbsh - Sandy Hook Member
Sand, quartz, fine-grained, clayey, very micaceous, massive, dark-gray, fossiliferous. Feldspar, muscovite, chlorite, and biotite are minor sand constituents. Well exposed at Poricy Brook in the Long Branch quadrangle. The Sandy Hook is much thinner than the overlying Shrewsbury Member and is a maximum of 10 m (33 ft) thick. (GRI Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).

Kns - Navesink Formation (Late Cretaceous (Maestrichtian))

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

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

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

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

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

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

The type section of the formation is described (Clark, 1894, p. 336-337) from outcrops near the village of Navesink in the Sandy Hook quadrangle and from outcrops along the north bank of the Navesink River in both the Sandy Hook and Long Branch quadrangles. The formation underlies lower and middle slopes of hills in most of the area and is exposed in many places. Several outcrops can be seen in pits along the south side of Route 35 between Middletown and Tindall Roads, in revetments for railroad cars east of...
Garrett Hill on the Naval Reservation, in the west side of the hill on Mountain Hill Road, in the railroad cut at the northwest edge of Middletown, and in roadcuts and pits elsewhere in the southwestern part of the quadrangle. The best exposures are in the bluffs along Sandy Hook Bay east of Atlantic Highlands where the entire thickness of the formation is exposed and the basal contact with the Mount Laurel can be seen. The basal contact can also be seen in a pit on the east side of Route 35 just south of Mountain Hill Road, but the rocks are weathered there. The basal contact also was penetrated in several auger holes. (GRI Source Map ID 2583) (Geology of the Sandy Hook Quadrangle (Bulletin 1276)).

Kns - Navesink Formation (Late Cretaceous)
Glauconitic (20-50%) clayey-silty fine-to-medium quartz sand to fine-sandy clayey silt; dark gray, gray, grayish-brown, olive-gray where unweathered, brown to yellowish-brown where weathered; unstratified. Glauconite occurs chiefly in soft grains of fine-to-medium sand size. Calcareous brachiopod, pelecypod, and gastropod fossils are common. Late Cretaceous (late Maestrichtian) in age based on calcareous nannofossils and foraminifera (Olsson, 1964; Miller and others, 2006), macrofossils (Sohl, 1977), and strontium-isotope ratios (Sugarman and others, 1995). Unconformably overlies the Mount Laurel Formation. Contact with Mount Laurel is commonly marked by a sharp peak in gamma-ray intensity on geophysical well logs, with reduced intensity in the Mount Laurel. (GRI Source Map ID 75557) (Bedrock Geology of the Long Branch Quadrangle (OFM 78)).

Kns - Navesink Formation (Upper Cretaceous, Maastrichtian)
Sand, glauconite, medium-grained, clayey and silty, massive, dark-gray to dark-gray-green, extensively bioturbated, locally contains large calcareous shells; sand-size mica, locally abundant; weathers light brown or red brown. Basal quartz sand is fine- to coarse-grained, pebbly, massive, light-yellow, and somewhat glauconitic, as much as 2 m (7 ft) thick and formed by the reworking of the underlying Mount Laurel Formation (Owens and others, 1977). Exogyra costata and the belemnite Belemnitella americana occur in the basal quartz sand. Crops out in a narrow belt throughout map area. Fresh exposures occur along tributaries of Raccoon Creek near Mullica Hill, Gloucester County. The Navesink is 3 to 7.5 m (10-25 ft) thick. The Navesink and Red Bank deposits represent a transgressive (Navesink)-regressive (Red Bank) cycle of sedimentation (Owens and Sohl, 1969). The cycle is unconformity-bounded at top and bottom. Within the cycle, the formational contact is gradational. The age of the Navesink was determined from both the macrofauna and microfauna. Planktic foraminifera from the lower part of the Navesink are indicative of the Rugotruncana subcircumnodifera subzone of early Maastrichtian age (Smith, in Owens and others, 1977). The upper part contains the mollusks Exogyra costata, Sphenodiscus lobatus, and Pycnodonte vesicularis indicating a middle to late Maastrichtian age. Planktic foraminifera from the upper part represent the Gansserina gansseri Subzone of middle Maastrichtian age (Smith, in Owens and others, 1977). Pollen in the Navesink and Sandy Hook Member of the Red Bank are similar; the Navesink microflora is a CA6/MA-1 Zone in Wolfe's (1976) classification. The Navesink, therefore, ranges from early to late Maastrichtian. Sugarman and others (1995) assigned a middle Maastrichtian Zone CC 25 to the Navesink. (GRI Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).

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

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

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

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

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

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

The Mount Laurel Sand underlies lower slopes of hills and, locally, valley bottoms. A nearly complete section is exposed in the bluff between Atlantic Highlands and Hilton. The upper part is exposed in pits and cutbanks along the south side of Route 35 near Middletown Road and on the east side, south of Mountain Hill Road. The bedded sequence was well exposed beneath surficial deposits in a storm drain ditch in the housing development between Sleepy Hollow and Chapel Hill Roads just south of Highland Road. Both the horizontally and cross-stratified sequence were exposed in the embankment next to the parking lot of the supermarket at the southwest corner of the intersection of Route 35 and Middletown Road (fig. 4). Exposures also were seen in the banks of the small creek behind the supermarket. *(GRI Source Map ID 2583)* *(Geology of the Sandy Hook Quadrangle (Bulletin 1276))*.

**Kml - Mount Laurel Formation (Late Cretaceous)**

Glaucnitic (3-15%) fine-to-medium quartz sand, minor medium-to-coarse sand, with thin interbeds of clay and silt; yellowish-brown where weathered, olive-gray to olive-brown where unweathered. Sand is
unstratified to horizontally bedded to cross-bedded. As much as 50 feet thick in the southern part of the quadrangle; thins to 20 feet to the north. In subsurface only, covered by surficial deposits in the Navesink River estuary and by overlying Coastal Plain formations elsewhere. Late Cretaceous (late Campanian) in age, based on calcareous nanofossils and strontium-isotope ratios (Sugarman and others, 1991; Miller and others, 2006). Grades downward into the Wenonah Formation. On geophysical well logs, transition to Wenonah is generally marked by slightly decreased resistance and increased gamma-ray intensity. (GRI Source Map ID 75557) (Bedrock Geology of the Long Branch Quadrangle (OFM 78)).

**Kml - Mount Laurel Formation (Upper Cretaceous, upper Campanian)**

Sand, quartz, massive to crudely bedded, typically coarsens upward, interbedded with thin clay beds. Glauconite and feldspar are minor sand constituents. Muscovite and biotite are abundant near the base. Lower part of formation is a fine- to medium-grained, clayey, dark-gray, glauconitic (maximum 25 percent) quartz sand. Typically weathers to white or light yellow and locally stained orange brown by iron oxides. Small pebbles scattered throughout, especially in the west-central area. Locally, has small, rounded siderite concretions in the interbedded clay-sand sequence. Granules and gravel are abundant in the upper 1.5 m (5 ft). Upper beds are light gray and weather light brown to reddish brown. The Mount Laurel is 10 m (33 ft) thick from the Roosevelt quadrangle to the Runnemede quadrangle in the central sheet. Thickness varies in the northern part of the map area due, in part, to extensive interfingering of this formation with the underlying Wenonah Formation. Weller (1907) and Kümmel (1940) recognized only about 1.5 m (5 ft) of the Mount Laurel in the north. In this report those beds are assigned to the overlying Navesink Formation. The interbedded sequence, the major facies in the north, ranges to about 4.5 m (15 ft) thick. These interbeds have well-developed large burrows (Martino and Curran, 1990), mainly *Ophiomorpha nodosa*, and less commonly *Rosselia socialis*. The Mount Laurel is gradational into the underlying Wenonah Formation. A transition zone of 1.5 m (5 ft) is marked by an increase in clay, silt, and mica into the Wenonah, especially in the west-central area of the central sheet.

The oyster *Agerostrea falcata* occurs in the lower part of the formation. *Exogyra cancellata* and *Belemnitella americana* are abundant in upper beds in the west-central area of the central sheet (New Egypt quadrangle). The Mount Laurel Formation is of late Campanian age based on the assignment of Zone CC 22b to the formation by Sugarman and others (1995) and the occurrence of *Exogyra cancellata* near Mullica Hill, Gloucester County. (GRI Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).

**Kw - Wenonah Formation (Late Cretaceous (Campanian))**

**Kw - Wenonah Formation (Late Cretaceous)**

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

In the clay-sized fraction quartz, kaolinite, muscovite, chlorite, and carbonaceous matter are common to major constituents. Detrital heavy minerals are abundant and are characterized by both stable and unstable types; zircon, tourmaline, staurolite, garnet, and epidote are particularly representative. At the basal contact the micaceous clayey glauconitic silt and sand of the Wenonah grades down into the non-micaceous glauconite-rich clayey silt and sand of the Marshalltown.
Although the formation is fossiliferous elsewhere (Weller, 1907, p. 91-101), only phosphatic fragments, such as shark teeth, were found here. This fossil deficiency may be attributed partly to the lack of unweathered outcrop.

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

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

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

The formation underlies lower slopes of the hills in the middle part of the land area of the quadrangle. Weathered parts of the formation were seen only in a few temporary excavations and cut-banks. Exposures were present in a 10-foot-high bank near the junction of Thompson and Hamilton Streets in Leonardo and in a roadcut in the small outlier on Middletown Road. (GRI Source Map ID 2583) (Geology of the Sandy Hook Quadrangle (Bulletin 1276)).

**Kw - Wenonah Formation (Late Cretaceous)**

Silty fine-to-very-fine quartz sand to fine-sandy clayey silt, micaceous, slightly glauconitic (<5%); yellow, very pale brown where weathered, gray to pale-olive where unweathered; unstratified. As much as 40 feet thick. In subsurface only, covered by surficial deposits in the Navesink River estuary and by overlying Coastal Plain formations elsewhere. Late Cretaceous (late Campanian) in age based on pollen (Wolfe, 1976) and ammonites (Kennedy and Cobban, 1994). Grades downward into the Marshalltown Formation. On geophysical well logs, transition to Marshalltown is marked by increased gamma-ray intensity. (GRI Source Map ID 75557) (Bedrock Geology of the Long Branch Quadrangle (OFM 78)).

**Kw Wenonah Formation (Upper Cretaceous, upper Campanian)**

Sand, quartz and mica, finegrained, silty and clayey, massive to thick-bedded, dark-gray to medium-gray; weathers light brown to white, extensively bioturbated, very micaceous, locally contains high concentrations of sand-sized lignitized wood and has large burrows of Ophiomorpha nodosa. Feldspar (5-10 percent) is a minor sand constituent. Unit crops out in a narrow belt from Sandy Hook Bay on the central sheet and pinches out southwest of Oldmans Creek, Salem County, on the southern sheet. Isolated outliers of the Wenonah are detached from the main belt in the central sheet area. Thickness is about 10 m (33 ft) in the northern part of the central sheet, 20 m (66 ft) in the southwestern part of the central sheet, and 7.5 m (25 ft) in the southern sheet. The Wenonah is gradational into the underlying Marshalltown Formation. A transition zone of several meters is marked by a decrease in mica and an increase in glauconite sand into the Marshalltown.

Fossil casts are abundant in the Wenonah. Weller (1907) reported *Flemingostrea subpatulata* Hop Brook in the Marlboro quadrangle indicating a late Campanian age. Wolfe (1976) placed the Wenonah microflora in his CA5A assemblage, considered to be of late Campanian age. Kennedy and Cobban (1994) identified ammonites including *Baculites* cf. *B. scotti*, *Didymoceras* n. sp., *Menuites portlocki*,...
Nostoceras (Nostoceras) puzosiforme n. sp., Nostoceras (Nostoceras) aff. N. colubriformus, Paranodonoceras sp., Placenticeras placenta, P. minor n. sp., and Trachyscaphites pulcherrimus. The presence of M. portlocki and T. pulcherrimus indicates late, but not latest, Campanian. (GRI Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).

Kmt - Marshalltown Formation (Late Cretaceous (Campanian))

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

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

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

The formation is very fossiliferous in the southwestern part of the State (Weller, 1907, p. 81-89; Mello and others, 1964; Millard, 1965), but only a few shell fragments in cuttings from an auger hole were found in the Sandy Hook quadrangle. The soil developed on the formation is brown, loamy, and fertile and supports a varied dense vegetative cover.

Within the quadrangle, the Marshalltown is a thin conspicuous marker unit, having a fairly constant thickness ranging between 10 and 12 feet. Most previous workers reported a greater thickness in this vicinity and elsewhere in New Jersey. Clark (in Bascom and others, 1909, p. 12) reported a thickness of 30-35 feet, and Weller (1907, p. 81) and Kümmel (1940, p. 53) reported a thickness of 30-40 feet. These workers were possibly including some of the overlying Wenonah and underlying Englishtown Formations in the Marshalltown. The formation has a nearly continuous outcrop in New Jersey, from Sandy Hook southwest to the Delaware River, and extends across Delaware to at least the east shore of Chesapeake Bay. The Marshalltown underlies the lower slopes of the low hills lying inland from the flat plain bounding Sandy Hook Bay on the south. It is exposed only in the southwestern part of Leonard, in the railroad cut just west of BM 29 and in a low bank on the south side of Route 36. The contact with the underlying Englishtown can be seen in the railroad cut. The areal distribution of the Marshalltown was determined by augering through the alluvium and slope wash which mantle most of the formation. (GRI Source Map ID 2584) (Surficial Geology of the Sandy Hook Quadrangle (OFM 39)).

Kmt - Marshalltown Formation (Late Cretaceous (Campanian))
Glaucinitic (20-50%), slightly micaceous, silty-clayey fine-to medium quartz sand, to fine-sandy clayey silt; olive-gray to olive-brown; unstratified. Thickness is 15 to 20 feet. In subsurface only. Late Cretaceous (middle Campanian) in age based on calcareous nanofossils, foraminifera, mollusks, and strontium-isotope ratios (Sugarman and others, 1995). Unconformably overlies the Englishtown Formation. On geophysical well logs, contact with Englishtown is marked by decreased gamma-ray intensity and slightly increased resistance. (GRI Source Map ID 75557) (Bedrock Geology of the Long Branch Quadrangle (OFM 78)).
Kmt - Marshalltown Formation (Upper Cretaceous, upper and middle Campanian)
Sand, quartz and glauconite, fine- to medium-grained, silty and clayey, massive, dark-gray; weathers light brown or pale red, extensively bioturbated. Very glauconitic in basal few meters; glauconite concentration decreases upward so that in upper part of unit, quartz and glauconite are nearly equal. Feldspar, mica, pyrite, and phosphatic fragments are minor sand constituents. Locally, very micaceous (mostly green chlorite) with sparse carbonized wood fragments. Fine-grained pyrite abundant throughout formation. Local thin, pebbly zones with large fossil impressions occur in the middle of the formation. In the upper part of the formation, quartz increases to about 40 percent. Unit crops out in a narrow belt throughout the map area and forms isolated outliers in the central sheet. Best exposures are along Crosswicks Creek in the Allentown quadrangle. In the southern sheet, the Marshalltown underlies a narrow belt in the uplands and broadens to the southwest. Many Marshalltown exposures occur along Oldmans Creek and its tributaries near Auburn, Gloucester County. The contact with the underlying Englishtown Formation is sharp and unconformable. The basal few centimeters of the Marshalltown contain siderite concentrations, clay balls, and wood fragments reworked from the underlying Englishtown. Many burrows, some filled with glauconite, project downward into the Englishtown for about one meter (3 ft) giving a spotted appearance to the upper part of the Englishtown (Owens and others, 1970). The Marshalltown is the basal transgressive unit of a sedimentation cycle that includes the regressive deposits of the overlying Wenonah and Mount Laurel Formations resembling the overlying Red Bank Formation to Navesink Formation cycle in its asymmetry.

Within the map area, only a few long-ranging megafossils occur in the Moorestown quadrangle (Richards, 1967). To the south, in the type area, Weller (1907) reported diverse molluskan assemblages indicating a Campanian age. More importantly, Olsson (1964) reported the late Campanian foraminifera Globotruncana calcarata Cushman from the upper part of the formation. No G. calcarata were found during our investigations. Wolfe (1976) assigned the pollen assemblage of the Marshalltown to the CA5A Zone considered to be Campanian. The Marshalltown has most recently been assigned to Zone CC 20-21 (Sugarman and others, 1995) of middle and late Campanian age (Perch-Nielsen, 1985). (GRI Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).

Ket - Englishtown Formation (Late Cretaceous (Campanian))

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

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

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

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

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

The Englishtown Formation underlies the flat area bordering Sandy Hook Bay in the west half of the quadrangle, and the low hills and slopes a short distance inland. It is poorly exposed, being largely covered by alluvium and marshes. Exposures of the unit were present in the hill just east of Harmony, but a housing development now covers the outcrop. A few feet of the upper part of the unit are exposed in a small bank on the beach between the Atlantic Highlands Yacht Harbor pier and the tank farm at the mouth of Wagner Branch, and also in the railroad cut at the southwestern part of Leonardo, just west of BM 29. There are also good exposures a short distance west of Harmony in the adjacent Keyport quadrangle. The exposures are in pits in the small hill along the west side of Laurel Avenue slightly more than 0.3 mile south of Route 36. Except for these few exposures, most information was obtained by angling. (GRI Source Map ID 2583) (Geology of the Sandy Hook Quadrangle (Bulletin 1276)).

**Ket - Englishtown Formation - (Late Cretaceous (Campanian))**

Fine-to-medium quartz sand, minor medium-to-coarse sand, with thin interbeds of clay and silt; micaceous and lignitic, with a trace (<1%) of glauconite; white and light gray where weathered, dark gray where unweathered. Sand is unstratified to horizontally bedded to cross-bedded. In subsurface only. As much as 140 feet thick in the eastern part of the quadrangle, thins to 110 feet thick in the west. In the Asbury Park quadrangle to the south of the Long Branch quadrangle, and farther southwest in northern Ocean County, the Englishtown is divided into an upper and lower member based on the presence of a clay-silt facies in the middle of the formation that is distinctive on gamma-ray logs (Nichols, 1977; Sugarman and Owens, 1994; Miller and others, 2006). This facies is not well marked on gamma-ray logs in the Long Branch quadrangle (wells 29-9335, 29-7941, 29-9465, 29-6173, 29-23948, and 29-48307) and so the members are not mapped here. Late Cretaceous (middle to late Campanian) in age, based, based on pollen (Wolfe, 1976), ostracodes (Gohn, 1992), calcareous nannofossils, and strontium-isotope ratios (Miller and others, 2006). Grades downward into the Woodbury Formation. On geophysical well logs, transition to Woodbury is marked by increased gamma-ray intensity and decreased resistance. (GRI Source Map ID 75557) (Bedrock Geology of the Long Branch Quadrangle (OFM 78)).

**Ket - Englishtown Formation (Upper Cretaceous, lower Campanian)**

Sand, quartz, fine- to coarsegrained, gravelly, massive, bioturbated, medium- to dark-gray; weathers light brown, yellow, or reddish brown, locally interbedded with thin to thick beds of dark clay. Abundant carbonaceous matter, with large lignitized logs occur locally, especially in clay strata. Feldspar,
glaucnite, and muscovite are minor sand constituents. Sand is extensively trough crossbedded particularly west of Mount Holly, Burlington County. In a few places in the western outcrop belt, trace fossils are abundant, typically the burrow Ophiomorpha nodosa. Unit is pyritic, especially in the carbonaceous-rich beds where pyrite is finely disseminated grains or pyritic masses as much as 0.6 m (2 ft) in diameter. Lowest part of unit is a massive sand that contains small to large, soft, light-gray siderite concretions. The Englishtown underlies a broad belt throughout the map area and ranges from about 45 m (148 ft) thick in the northern part of the central sheet to 30 m (98 ft) thick in the western part of the central sheet to 15 m (49 ft) in the southern sheet. Best exposures occur along Crosswicks Creek in the Allentown quadrangle and along Oldmans Creek. The basal contact with the underlying Woodbury Formation or Merchantville Formation is transitional over several meters. The age of the Englishtown in outcrop could not be determined directly but was inferred from stratigraphic position and pollen content. Wolfe (1976) designated the microflora of the unit as Zone CA4 and assigned it to the lower Campanian.

Kwb - Woodbury Formation (Late Cretaceous (Campanian))

Kwb - Woodbury Clay (Upper Cretaceous)
Dark-gray micaceous silty clay. Shown in section only. (GRI Source Map ID 2583) (Geology of the Sandy Hook Quadrangle (Bulletin 1276)).

Kwb - Woodbury Formation (Late Cretaceous (Campanian))
Clay, silty clay, with minor thin beds of very fine quartz sand, slightly micaceous and lignitic; dark gray and black where unweathered, yellowish-brown to brown where weathered; unstratified. In subsurface only. As much as 240 feet thick in the eastern part of the quadrangle, thins to 160 feet thick in the central and western parts of the quadrangle. Late Cretaceous (early to middle Campanian) based on pollen (Wolfe, 1976), ostracodes (Gohn, 1992), and calcareous nanofossils (Miller and others, 2006). Grades downward into the Merchantville Formation. On geophysical well logs, transition to the Merchantville is marked by slightly increased gamma-ray intensity. (GRI Source Map ID 75557) (Bedrock Geology of the Long Branch Quadrangle (OFM 78)).

Kwb Woodbury Formation (Cretaceous)
Clay-silt. (GRI Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).

Kmv - Merchantville Formation (Late Cretaceous (Campanian))

Kmv - Merchantville Formation (Cretaceous)
Dark-gray, silty, glauconitic quartz sand. Shown in section only. (GRI Source Map ID 2583) (Geology of the Sandy Hook Quadrangle (Bulletin 1276)).

Kmv - Merchantville Formation (Late Cretaceous (Campanian))
Glaucnitic (20-50%) clayey silt to sandy clayey silt, slightly micaceous; olive, dark gray, black where unweathered, olive-brown to yellowish-brown where weathered; unstratified. Thickness is 40 to 60 feet. In subsurface only. Late Cretaceous (early Campanian to Santonian) in age based on ammonites (Owens and others, 1977) and calcareous nanofossils (Miller and others, 2006). The Cheesequake Formation, a glauconitic clayey silt underlying the Merchantville, is mapped in outcrop in northern Monmouth and eastern Middlesex counties (Sugarman and Owens, 1996; Sugarman and others, 2005; Stanford and Sugarman, 2008) and in the subsurface both west and south of the Long Branch quadrangle (Sugarman and Owens, 1994, 1996). Because it is lithically similar to the Merchantville and cannot be easily distinguished from it on geophysical logs, it is not mapped separately here. If present, it is included here within the Merchantville, or uppermost Magothy Formation. (GRI Source Map ID 75557) (Bedrock Geology of New Jersey (DGS 04-6)).
Kmv - Merchantville Formation (Cretaceous)
Glaucite sand to quartz-glaucite sand, clayey and silty. *(GRI Source Map ID 7285)* *(Bedrock Geology of New Jersey (DGS 04-6)).*

Kcq - Cheesequake Formation (Late Cretaceous (Santonian to Campanian))
Clay and clay-silt, micaceous, thin-bedded to laminated, dark-gray; weathers light tan. Contains abundant wood fragments intercalated with light-colored, fine-grained micaceous quartz sand and is rarely crossbedded. Rock fragments and feldspar are minor sand constituents. Small cylindrical burrows occur in the updip area. Abundant, rounded, pale-gray siderite concretions (about 8 cm (3 in) in diameter) occur in thin discontinuous beds. Sand interfingers rapidly within a short distance with extensively bioturbated, dark-gray, very micaceous, somewhat woody clay-silt. The basal clay-silt has extensive cylindrical burrows filled with fine-grained, light- to medium-green botryoidal glauconite. The basal contact with the underlying Magothy Formation is sharp. Reworked siderite concretions and some glauconite and coarse-grained quartz sand are found along the contact within the Cheesequake. Unit exposed only in the South Amboy and Keyport quadrangles. The unit is about 14 m (46 ft) thick. The age of the Cheesequake was determined from pollen (Litwin and others, 1993), which indicates the unit is between the Merchantville Formation microflora (CA2 Zone of Wolfe, 1976, lower Campanian) and the uppermost Magothy microflora (??Pseudoplicapollis cunceata-Semioculopollis verrucosa Zone of Christopher, 1979, upper Santonian). It is probable that the Cheesequake Formation contains the Santonian-Campanian boundary. This unit was not recognized by Petters (1976) who concluded that the Magothy and Merchantville interfingered in the subsurface and the Merchantville was, in part, Santonian. *(GRI Source Map ID 7285)* *(Bedrock Geology of New Jersey (DGS 04-6)).*

Kmg - Magothy Formation (Late Cretaceous (Santonian))

Km - Magothy Formation (Cretaceous)
Dark-and light-gray intercalated clay and quartz sand. Shown in section only. *(GRI Source Map ID 2583)* *(Geology of the Sandy Hook Quadrangle (Bulletin 1276)).*

Kmg - Magothy Formation (Santonian-Coniacian-Turonian (late Cretaceous))
Fine-to-medium quartz sand, some very-fine-to-fine sand and minor medium-to-coarse sand, micaceous, lignitic, and pyrite-bearing in places, with thin interbeds of silt and clay; white to yellow where weathered, light gray to gray where unweathered. Sand is cross-bedded to laminated. As much as 220 feet thick. In subsurface only. Late Cretaceous (Turonian-Santonian) in age, based on pollen (Christopher, 1979, 1982; Miller and others, 2006). Unconformably overlies the Raritan Formation, Woodbridge Clay member. On geophysical well logs, contact with the Woodbridge is marked by increased gamma-ray intensity.

In its outcrop area in eastern Middlesex County the Magothy is divided into 5 members. From bottom to top they include; South Amboy Fire Clay, Old Bridge Sand, Amboy Stoneware Clay, Morgan beds, and Cliffwood beds (Sugarman and others, 2005). The Old Bridge is a thick sand, the other members are interbedded clay-silt and fine sand. These members may extend down dip in the subsurface (Miller and others, 2006). Geophysical well logs in the Long Branch quadrangle (wells 29-21612, 29-23948, 29-21510, 29-9335, 29-7941, 29-9465, and 29-6173) show generally higher gamma-ray intensity and lower resistivity in the uppermost 50 feet of the formation, and again in the lowermost 30-40 feet, than in the middle 100-120 feet. The upper fine-grained beds may correspond to the Amboy Stoneware Clay and Morgan and Cliffwood beds, and the lower fine-grained beds may correspond to the South Amboy Fire
Clay. The middle sand may correspond to the Old Bridge Sand. *(GRI Source Map ID 75557)* *(Bedrock Geology of the Long Branch Quadrangle (OFM 78)).*

**Kmg - Magothy Formation (Upper Cretaceous, middle and lower Santonian)** - Sand, quartz, fine-to-coarse-grained, locally gravelly (especially at the base), white; weathers yellow brown or orange brown, interbedded with thin-bedded clay or dark-gray clay-silt mainly at the top of the formation. Muscovite and feldspar are minor sand constituents. Large wood fragments occur in many clay layers. Clay weathers to gray brown or white. Formation characterized by local vertical and lateral facies changes. The Magothy is best exposed and thick (about 80 m (262 ft)) in the Raritan Bay area. The outcrop belt is widest in the north and narrows to the southwest. The formation is about 25 m (82 ft) thick or less in the southern sheet. The formation is poorly exposed because of its sandy nature and its widespread cover by younger sediments.

The old geologic map of New Jersey *(Lewis and Kümmel, 1910-1912, revised 1950)* showed the Magothy to consist of only one lithology (Cliffwood beds at Cliffwood Beach, Monmouth County). Subsequent pollen studies of the Magothy and the underlying Raritan Formation showed most of the Raritan to be the same age as the Magothy. Wolfe and Pakiser *(1971)* redefined and considerably expanded the Magothy. Kümmel and Knapp *(1904)* had already recognized that the Magothy, as used here, contained a large number of lithologies. At the time of their study, the Magothy was extensively mined for clay and sand and was well exposed. Their subdivisions had economic designations (for example, Amboy stoneware clay). Barksdale and others *(1943)* later gave geographic names to these subdivisions, discussed individually below.

The lower contact of the Magothy in the Delaware River valley is difficult to place because the lower part of the Magothy is lithically similar to the underlying Potomac Formation. The contact is placed at the base of the lowest dark-gray clay in the Magothy. The best faunas from the Magothy were obtained from siderite concretions and slabs in and near Cliffwood Beach representing only the top of the formation. These faunas were discussed in detail by Weller *(1904, 1907)* and supplemented by Sohl *(in Owens and others, 1977)*. The presence of *Ostrea cretacea* in the Cliffwood Beach fauna suggests that the upper part of the Magothy is late Santonian in age. Wolfe and Pakiser *(1971)* and Christopher *(1979, 1982)* discussed the microfloral assemblage in the Magothy. Christopher subdivided the Magothy into three zones: *Complexipollis exigua-Santalacites minor* (oldest), ?*Pseudoplicapollis longiannulata-Plicapollis incisa* (middle), and ?*Pseudoplicapollis cuneata-Semioculopollis verrucosa* (youngest). The oldest zone, originally considered to be as old as Turonian, was subsequently considered to be post-Coniacian *(Christopher, 1982)*. The middle and upper zones are also probably Santonian. Christopher *(1979)* followed the nomenclature for the subdivisions elaborated upon earlier. The Cliffwood and Morgan beds, and, presumably the upper thin-bedded sequence, would include the youngest pollen zone: the Amboy Stoneware Clay Member and perhaps the uppermost part of the Old Bridge Sand Member, the middle pollen zone; and the lower part of the Old Bridge Sand Member and South Amboy Fire Clay Member, the oldest pollen zone. The Magothy is considered herein to be of Santonian age.

**Cliffwood beds** - Typically very sandy, horizontally bedded to crossbedded, mainly small-scale trough crossbeds. Thin layers of dark, fine, carbonaceous matter are interbedded with sand. Carbonaceous units are conspicuously micaceous; the sand is less so. Sand is typically fine to medium grained and locally burrowed. Burrows include the small-diameter *Ophiomorpha nodosa* and some that are not clay lined. Slabs of dark-reddish-brown siderite were common at the base of the bluff at Cliffwood Beach before the outcrop was covered. Some of these slabs had many fossil molds, typically a large number of pelecypods. Lower in the section, between high and low tide level, there is a pale-gray clay-silt about 1.5 m (5 ft) thick with many small reddish-brown siderite concretions. These concretions have many fossils that were described in detail by Weller *(1904)*. The Cliffwood beds are about 7.5 m (25 ft) thick in outcrop. Equivalents of the Cliffwood beds are exposed near the Delaware River between Trenton and Florence, Burlington County. These beds are mainly sand, as are those at Cliffwood Beach, but they tend to have more crossbedding than the typical Cliffwood strata and no burrows or marine fossils. In
addition, beds of quartz gravel are present in the Cliffwood near Riverside, Burlington County.

Morgan beds - Occur only in the northern part of the central sheet. They consist of interbedded, thin, dark-colored clay and fine-grained, light-colored, micaceous sand. Clay is locally more abundant in the Morgan than in the Cliffwood beds. Sand ranges from massive to locally crossbedded and locally has fine organic matter. This unit is exposed only in the South Amboy quadrangle where it is as much as 12 m (39 ft) thick. It grades downward into underlying clay.

Amboy Stoneware Clay Member - Crops out only in the South Amboy quadrangle in the central sheet and is mainly dark-gray, white-weathering, interbedded clay and silt to fine-grained quartz sand. Clay has abundant, fine, carbonaceous matter and fine mica flakes. Small cylindrical burrows are abundant in this unit. Locally, the clay is interbedded with sand and contains large pieces of lignitized, bored (*Teredolites*) logs. Large slabs of pyrite-cemented sand are associated with the woody beds. Amber occurs in some of the wood. Unit is approximately 7.5 m (25 ft) thick, but pinches out along strike. The Amboy Stoneware is disconformable on the underlying sand.

Old Bridge Sand Member - Predominantly a light-colored sand, extensively crossbedded and locally interbedded with dark-gray laminae; clay is highly carbonaceous, woody, in discontinuous beds, especially near the base. The scale of crossbedding varies from small to large. Locally, small burrows are present. Unit is as much as 12 m (39 ft) thick and rests disconformably on the underlying unit.

South Amboy Fire Clay Member - Basal member of the Magothy Formation. Unit resembles the Amboy Stoneware Clay Member, particularly in its lensing character. Unit is best exposed in the central sheet in the South Amboy quadrangle and in the Delaware River valley at the base of the bluffs at Florence. The South Amboy is a dark, massive to finely laminated clay, locally oxidized to white or red. Unit fills large channels and has local concentrations of large, pyrite-encrusted, lignitized logs. Some of the clay is slumped, suggesting post-depositional undercutting during channel migration. The clay is interbedded with fine- to medium-grained, crossbedded sand. The basal contact with the underlying Raritan is well exposed in the Sayre and Fisher Pit in Sayreville, Middlesex County, where the contact is marked by a deeply weathered gravel zone. *(GRI Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).

**Kr - Raritan Formation, undivided (Late Cretaceous (Cenomanian))**

**Kr - Raritan Formation (Upper Cretaceous)**
Clay, silty clay, sand, gravel. *(GRI Source Map ID 7288) (Geologic Map of New York, Lower Hudson Sheet).*

**Kr - Raritan Formation (Upper Cretaceous, upper Cenomanian)**
Consists of an upper clayey silt (Woodbridge Clay Member) and a lower sand (Farrington Sand Member). *(GRI Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).*

**Krw - Raritan Formation, Woodbridge Clay Member (Late Cretaceous (Cenomanian))**
Clay and silt, micaceous, lignitic, and pyrite-bearing; gray and black where unweathered, white to brown when weathered; with minor thin interbeds and laminas of white, yellow, and light gray very-fine-to-fine quartz sand. As much as 110 feet thick. In subsurface only, penetrated by wells 29-9465 and 29-1921. The driller’s log for well 29-2366 in Eatontown reports “weathered bedrock”, with no further information, beneath the Magothy Formation, at a depth of 875-891 feet. This depth is anomalously shallow for the basement surface, suggesting that the material may be weathered clay of either the Woodbridge of South Amboy Fire Clay member of the Magothy. The Woodbridge is Late Cretaceous (late Cenomanian)
in age based on pollen (Christopher, 1979) and ammonites (Cobban and Kennedy, 1990). Grades downward into the Raritan Formation, Farrington Sand member. Transition to the Farrington is marked by decreased gamma-ray intensity on geophysical well logs. (GRI Source Map ID 75557) (Bedrock Geology of the Long Branch Quadrangle (OFM 78)).

**Krf - Raritan Formation, Farrington Sand Member (Late Cretaceous (Cenomanian))**

Fine-to-coarse quartz sand, some coarse-to-very-coarse sand, minor beds of clay and silt; white and yellow where weathered, gray where unweathered. Sands are horizontally bedded to cross-bedded. As much as 60 feet thick. In subsurface only, penetrated in well 29-9465. Late Cretaceous (Cenomanian) in age based on pollen (Christopher, 1979). Unconformably overlies the Potomac Formation. Contact with Potomac is marked by increased gamma-ray intensity on geophysical well logs. (GRI Source Map ID 75557) (Bedrock Geology of the Long Branch Quadrangle (OFM 78)).

**Kp - Potomac Formation (Late Cretaceous (Cenomanian-Albian))**

Fine-to-medium quartz sand, some coarse-to-very-coarse sand, with beds of clay and silt; white, red, yellow where weathered, gray where unweathered. Sands are horizontally bedded to cross-bedded, clays are in beds as much as 8 feet thick. More than 90 feet thick, full thickness not penetrated in the Long Branch quadrangle. In subsurface only, partially penetrated in well 29-9465. Late Cretaceous (Albian-Cenomanian) based on pollen (Sugarman and Owens, 1996; Miller and others, 2006), which indicates that the Potomac in this area corresponds to the Potomac Formation, unit 3, of Doyle and Robbins (1977). (GRI Source Map ID 75557) (Bedrock Geology of the Long Branch Quadrangle (OFM 78)).

**Jd - Jurassic Diabase (Jurassic)**

Concordant to discordant, predominantly sheet-like intrusions of medium- to fine-grained diabase and dikes of fine-grained diabase; dark-greenish-gray to black; subophitic texture. Dense, hard, sparsely fractured rock composed mostly of plagioclase (An_{50-70}), clinopyroxene (mostly augite), and magnetite-ilmenite. Orthopyroxene (Er_{75-80}) is locally abundant in the lower part of the sheets. Accessory minerals include apatite, quartz, alkali feldspar, hornblende, sphene, zircon, and rare olivine. Diabase in the map area was derived primarily from high-titanium, quartz-tholeiite magma. Sedimentary rocks within about 300 m (984 ft) above and 200 m (656 ft) below major diabase sheets are thermally metamorphosed. Red mudstone is typically altered to indurated, bluish-gray hornfels with clots or crystals of tourmaline or cordierite. Gray argillitic siltstone is typically altered to brittle, black, very fine grained hornfels. Sills are 365 to 400 m (1,197-1,312 ft) thick. Dikes range in thickness from 3 to 10 m (10-33 ft) and are many kilometers long. (GRI Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).

**JTRp - Passaic Formation, undivided (Jurassic and Triassic)**

Predominantly red beds consisting of argillaceous siltstone; silty mudstone; argillaceous, very fine grained sandstone; and shale; mostly reddish-brown to brownish-purple, and grayish-red. Upper Triassic gray lake deposits (Trpg) consist of gray to black silty mudstone, gray and greenish- to purplish-gray argillaceous siltstone, black shale, and medium- to dark-gray, argillaceous, fine-grained sandstone and are abundant in the lower half of the Passaic Formation. Red beds occur typically in 3- to 7-m (10- to 23-ft)-thick, cyclic playa-lake-mudflat sequences and fining-upward fluvial sequences. Lamination is commonly indistinct due to burrowing, desiccation, and paleosol formation. Where layering is preserved,
most bedforms are wavy parallel lamination and trough and climbing-ripple cross lamination. Calcite- or dolomite-filled vugs and flattened cavities, mostly 0.5 to 0.2 mm (0.02-0.08 in) across, occur mostly in the lower half. Sand-filled burrows, 2 to 5 mm (0.08-0.2 in) in diameter, are prevalent in the upper two-thirds of the unit. Desiccation cracks, intraformational breccias, and curled silt laminae are abundant in the lower half. Lake cycles, mostly 2 to 5 m (7-16 ft) thick, have a basal, greenish-gray, argillaceous siltstone; a medial, dark-gray to black, pyritic, carbonaceous, fossiliferous, and, in places, calcareous lake-bottom fissile mudstone or siltstone; and an upper thick-bedded, gray to reddish and purplish-gray argillaceous siltstone with desiccation cracks, intraformational breccias, burrows, and mineralized vugs. Gray lakebeds occur in groups of two to five cycles although they also occur as single cycles in some parts of the formation. Several lakebed sequences consisting of one or two thick groups of drab-colored beds as much as 30 m (98 ft) thick or more can be traced over tens of kilometers. Many gray-bed sequences are locally correlated within fault blocks; some can be correlated across major faults or intrusive rock units. Thickness of the formation between Sourland Mountain and Sand Brook syncline is about 3,500 m (11,483 ft). (GRI Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).

**JTRpms - Passaic Formation, mudstone facies (Jurassic and Triassic)**

Sandy mudstone. Only in cross section. (GRI Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).

**JTRps - Passaic Formation, sandstone and siltstone facies (Jurassic and Triassic)**

Sandstone and siltstone. Only in cross section. (GRI Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).

**TRpg - Passaic Formation, gray bed (Triassic)**

Sandstone, siltstone and shale. Only in cross section. (GRI Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).

**TRb - Brunswick Formation (Triassic)**

Sandstone and conglomerate. (GRI Source Map ID 7288) (Geologic Map of New York, Lower Hudson Sheet).

**TRp - Palisade Diabase sill (Triassic)**

No unit description available. (GRI Source Map ID 7288) (Geologic Map of New York, Lower Hudson Sheet).

**TRI - Lockatong Formation (Triassic)**

Predominantly cyclic lacustrine sequences of silty, dolomitic or analcime-bearing argillite; laminated mudstone; silty to calcareous, argillaceous very fine grained sandstone and pyritic siltstone; and minor silty limestone, mostly light- to dark-gray, greenishgray, and black. Grayish-red, grayish-purple, and
dark-brownish-red sequences (TrLa) occur in some places, especially in upper half. Two types of cycles
are recognized: freshwater-lake (detrital) and alkaline-lake (chemical) cycles. Freshwater-lake cycles
average 5.2 m (17 ft) thick. They consist of basal, transgressive, fluvial to lake-margin deposits that are
argillaceous, very fine grained sandstone to coarse siltstone with indistinct lamination, planar or cross
lamination, or are disrupted by convolute bedding, desiccation cracks, root casts, soil-ped casts, and
tubes. Medial lake-bottom deposits are laminated siltstones, silty mudstones, or silty limestones that
are dark gray to black with calcite laminae and grains and lenses, or streaks of pyrite; fossils are
common, including fish scales and articulated fish, conchostracans, plants, spores, and pollen. Upper
regressive lake margin, playa lake, and mudflat deposits are light- to dark-gray silty mudstone to argillitic
siltstone or very fine grained sandstone, mostly thick bedded to massive, with desiccation cracks,
intraformational breccias, faint wavy laminations, burrows, euhehedral pyrite grains, and dolomite or calcite
specks. Alkaline-lake cycles are similar to freshwater-lake cycles, but are thinner, averaging 3 m (10 ft),
have fewer fossils (mainly conchostracans), and commonly have red beds, extensive desiccation
features, and abundant analcime and dolomite specks in the upper parts of cycles. Thickness near
Byram is about 1,070 m (3,510 ft). The formation thins to the southeast and northeast; thickness near
Princeton is less than 700 m (2,297 ft). *(GRI Source Map ID 7285) (Bedrock Geology of New Jersey
(DGS 04-6)).*

**TRLa - Lockatong Formation, arkosic sandstone facies (Triassic)**

Coarse to fine-grained arkosic sandstone. Only in cross section. *(GRI Source Map ID 7285) (Bedrock
Geology of New Jersey (DGS 04-6)).*

**TRs - Stockton Formation (Triassic)**

**Trs - Stockton Formation (Late Triassic)**

Sandstone, mudstone, silty mudstone, argillaceous siltstone, and shale. Only in cross section. *(GRI
Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).*

**Trs - Stockton Formation (Upper Triassic)**

Arkose, conglomerate, and mudstone. *(GRI Source Map ID 7288) (Geologic Map of New York, Lower
Hudson Sheet)).*

**Ohr - Harrison Gneiss (Ordovician)**

Biotite hornblende quartz plagioclase gneiss with accessory garnet and sphene; plagioclase commonly
occurs as augen. *(GRI Source Map ID 7288) (Geologic Map of New York, Lower Hudson Sheet)).*

**OCi - Inwood Marble (Cambrian to Ordovician)**

Dolomite marble, calc-schist, granulite, and quartzite, overlain by calcite marble; grades into underlying
patchy Lowerre Quartzite of Early Cambrian age. *(GRI Source Map ID 7288) (Geologic Map of New
York, Lower Hudson Sheet)).*
OZs - Serpentinite (Neoproterozoic to Ordovician)

Os - Serpentinite (Lower Ordovician)
No unit description available. (GRI Source Map ID 7288) (Geologic Map of New York, Lower Hudson Sheet).

CZs - Serpentinite (Neoproterozoic to Cambrian)
Fine-grained. (GRI Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).

OZm - Manhattan Schist (Neoproterozoic to Ordovician)

Om - Manhattan Formation, undivided (middle Ordovician)
Pelitic schists, amphibolite. (GRI Source Map ID 7288) (Geologic Map of New York, Lower Hudson Sheet).

CZm - Schist and Gneiss (Neoproterozoic to Cambrian)
Medium- to coarse-grained. (GRI Source Map ID 7285) (Bedrock Geology of New Jersey (DGS 04-6)).

Ancillary Source Map Information

Large Scale Sources

Geology of Sandy Hook Quadrangle (Bulletin 1276)


Map Location

Extracted from: Geology of the Sandy Hook Quadrangle (Bulletin 1276)
Columnar Cross Section

Extracted from: Geology of the Sandy Hook Quadrangle (Bulletin 1276)
Report

A complete geologic report, including figures and tables, is included with this publication and can be downloaded and viewed through the USGS publications website: http://pubs.er.usgs.gov/publication/b1276.

Correlation of Map Units

Extracted from: Geology of the Sandy Hook Quadrangle (Bulletin 1276)
Explanation of Map Symbols

Contact
Long dashed where approximately located; short dashed where indefinite; dotted where concealed

Fault bounding slump block
Dashed where approximately located.
U, upthrown side; D, downthrown side

Sand or gravel pit

Auger hole
Some of the numbered auger holes are described in plate 2

Extracted from: Geology of the Sandy Hook Quadrangle (Bulletin 1276)
Logs of Selected Wells (Plate 2)

**References**


Bedrock Geology of the Long Branch Quadrangle (OFM 78)


Correlation

Extracted from: Bedrock Geology of the Long Branch Quadrangle (OFM 78)
Location Map

Extracted from: *Bedrock Geology of the Long Branch Quadrangle (OFM 78)*

Map Symbols

- **▲ ▼** Contact—Approximately located. Solid triangle indicates contact observed in outcrop. Open triangle indicates contact formerly observed, as reported in permanent note collection of the N. J. Geological Survey.

- **●** Formation observed in outcrop or excavation, or penetrated in hand-auger hole.

- **○** Formation formerly observed in outcrop or excavation—Reported in permanent note collection of the N. J. Geological Survey.

- **Formation covered by surficial deposits—Surficial deposits of Quaternary, Pliocene, and late Miocene age continuous and generally more than 5 feet thick.**

- **Well showing formations penetrated—Location accurate to within 200 feet. Identifiers of the form 29-xxxx are N. J. Department of Environmental Protection well permit numbers. Identifiers of the form 25-xxxx are U. S. Geological Survey Ground Water Site Inventory identification numbers. Lithologic and geophysical logs for most of these wells are provided by Gronberg and others (1989). Identifiers of the form 29-xx-xxxx are N. J. Atlas Sheet coordinates of records of wells in the permanent note collection of the N. J. Geological Survey. Identifiers of the form "Healy 3-23-63 B2" provide the date and identification number of test borings drilled by the A. J. Healy Company, with copies on file at the N. J. Geological Survey. Identifier "KPI" indicates a stratigraphic test hole drilled by the U. S. Geological Survey in cooperation with the N. J. Geological Survey and Rutgers University Earth and Planetary Sciences Department in 2008.**

Extracted from: *Bedrock Geology of the Long Branch Quadrangle (OFM 78)*
References


Small Scale Sources

Bedrock Map of New York, Lower Hudson Sheet (Map and Chart Series 15)


Index Map

Extracted from: Bedrock Geology of the Long Branch Quadrangle (OFM 78)

Extracted from: Geologic Map of New York, Lower Hudson Sheet (Map and Chart Series 15)
Map symbols

Extracted from: Geologic Map of New York, Lower Hudson Sheet (Map and Chart Series 15)

Bedrock Geology of New Jersey (DGS 04-6)


Note: Only cross section graphics are included in this Digital Geodata Series map. Graphical map elements such as legends, correlations, indexes, etc. are not present.

Bedrock Cross Sections

The cross sections present in the GRI digital geologic-GIS data produced for Gateway National Recreation Area, New York and New Jersey (GATE) are presented below. Note that some cross section abbreviations (e.g., A-A') may have been changed from their source map abbreviation in the GRI data so that each cross section abbreviation in the GRI data is unique. Cross section graphics were scanned at a high resolution and can be viewed in more detail by zooming in (if viewing the digital format of this document).
Large Scale Maps (1:24,000)
Cross Section L-L'

Extracted from: Geology of the Sandy Hook Quadrangle (Bulletin 1276)

Note: this cross section is labeled A-A’ on the source map.

Cross Section M-M'

Extracted from: Bedrock Geology of the Long Branch Quadrangle (OFM 78)

Note: this cross section is labeled B-B’ on the source map.
Cross Section N-N'

Extracted from: Bedrock Geology of the Long Branch Quadrangle (OFM 78)

Note: this cross section is labeled C-C' on the source map.

Cross Section O-O'

Extracted from: Bedrock Geology of the Long Branch Quadrangle (OFM 78)

Note: this cross section is labeled A-A' on the source map.

Small Scale Maps (1:100,000 and 1:250,000)

Cross Section NB-B'

Extracted from: Bedrock Geology of New Jersey (DGS 04-6)
Cross Section CSE-E'

Extracted from: Bedrock Geology of New Jersey (DGS 04-6)
GRI Digital Data Credits

This document was developed and completed by James Winter (Colorado State University) for the NPS Geologic Resources Division (GRD) Geologic Resources Inventory (GRI) Program. Quality control of this document by James Chappell (Colorado State University).

The information in this document was compiled from GRI source maps, and intended to accompany the digital geologic-GIS map(s) and other digital data for Gateway National Recreation Area, New York and New Jersey (GATE) developed by James Chappell, Derek Witt, Stephanie O'Meara, James Winter and Kari Lanphier (Colorado State University) from initial work by Andrea Croskrey (National Park Service GRD). See the GRI Digital Maps and Source Map Citations section of this document for all sources used by the GRI in the completion of this document and related GRI digital geologic-GIS maps.

GRI finalization by James Chappell (Colorado State University).

GRI program coordination and scoping provided by Bruce Heise and Tim Connors (NPS GRD, Lakewood, Colorado).