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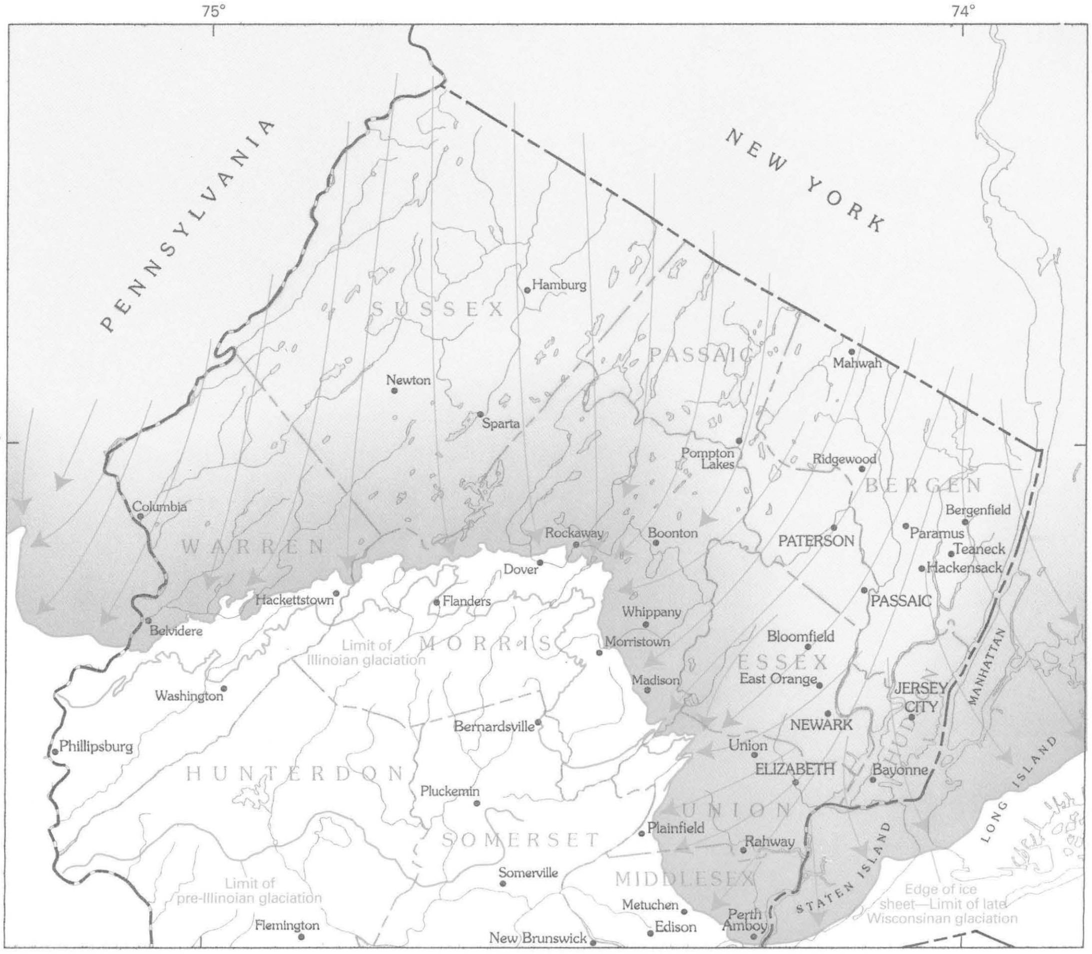
Surficial Geologic Map of Northern New Jersey

By Byron D. Stone, Scott D. Stanford, and Ron W. Witte

Miscellaneous Investigations Series Map I–2540–C



Maximum extent of ice-sheet advance during the three Quaternary glaciations of northern New Jersey. The ice sheets were thicker in the large valleys of eastern and western New Jersey and thinner in the central highlands. These differences produced the lobate shape of the edge of the late Wisconsinan ice sheet, the most recent glaciation. The maximum thickness of this ice sheet was about 1200 m (4000 ft), in the northeastern part of the State. Arrows show ice-flow directions.

Stone and others—Surficial geologic map of northern New Jersey   Scale 1:100,000   Map I–2540–C

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By Byron D. Stone,[1] Scott D. Stanford,[2] and Ron W. Witte[2]

Pamphlet to accompany
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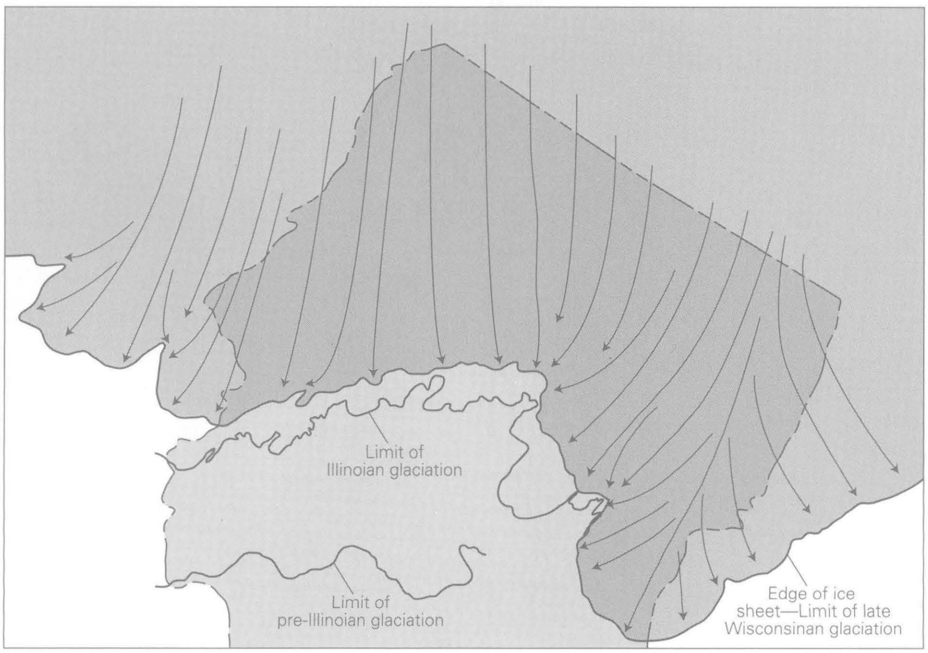

[1]U.S. Geological Survey
[2]New Jersey Geological Survey

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COVER: Maximum extent of ice-sheet advance during the three Quaternary glaciations of northern New Jersey. The ice sheets were thicker in the large valleys of eastern and western New Jersey and thinner in the central highlands. These differences produced the lobate shape of the edge of the late Wisconsinan ice sheet, the most recent glaciation. The maximum thickness of this ice sheet was about 1200 m (4000 ft), in the northeastern part of the State. Arrows show ice-flow directions.

CONTENTS

Description of Map and Subsurface Units

—continued on next page

CONTENTS—continued

Stratotype Sections for Proposed Lithostratigraphic Units of Quaternary Age in Northern New Jersey

DESCRIPTION OF MAP AND SUBSURFACE UNITS

INTRODUCTION

The surficial geologic map (sheet 1), explanatory figures 1–10 (sheet 2), and cross sections (sheet 3) show the distribution of surficial materials that overlie nonweathered bedrock and coastal plain deposits in northern New Jersey. Areas of bedrock outcrops and shallow bedrock are shown by map units and patterns, and the altitude of the surface of bedrock or coastal plain deposits in selected lowlands, large valleys, and upland valleys is shown by contour lines. The surficial geologic map differentiates surficial materials of late Tertiary to Quaternary age on the basis of lithologic characteristics, stratigraphic relations, and age, as shown in the correlation of map and subsurface units (sheet 1) and described in the description of map units. Constructional geomorphic features composed of thick surficial deposits, such as end moraines and drumlins, are distinguished as map units or by map symbols. Ancillary figures provide additional information about bedrock physiography (fig. 1a), bedrock geology (fig. 2), limits of glaciations, end moraines, glacial lakes, and late Wisconsinan retreatal ice-margin positions (fig. 3), till deposits (fig. 4), meltwater deposits (fig. 5), and ice-flow directions (fig. 6).

Surficial materials in northern New Jersey are nonlithified deposits of glacial, meltwater, alluvial, colluvial, eolian, swamp and marsh, and estuarine origin, and residual products of bedrock weathering, which include saprolite, residuum, and rock rubble. Surficial materials are known also as unconsolidated soils, which include coarse-grained soils, fine-grained soils, or organic fine-grained soils as described by engineering classifications. These materials underlie and are the parent materials of modern pedogenic soils that have developed in them at the land surface. Materials in different map units are distinguished lithologically by grain size, mineralogy, and structure. Deposits of glacial origin consist of tills and moraines, which were laid directly by moving or melting ice. They are subdivided on the basis of grain-size characteristics, origin, and age. Glacial deposits are related to three glaciations of New Jersey, from oldest to youngest: pre-Illinoian, Illinoian, and late Wisconsinan. Till deposits consist of nonsorted sediments deposited from ice, and are divided into six formations related to the three glaciations. Tills of Illinoian and late Wisconsinan age are distinguished by grain size and composition. End moraines, composed chiefly of till at the surface, are distinguished as map units. Deposits of meltwater origin, which are sorted and stratified, are divided into three formations related to the three glaciations. Meltwater deposits of Illinoian and late Wisconsinan age are divided into two groups, glacial-stream and glacial-lake deposits. These meltwater deposits are further subdivided into map units on the basis of their distribution in different depositional basins and the relations of sedimentary facies within the depositional basins. The correlation of map and subsurface units (sheet 1) shows the relative ages of numerous meltwater stream and lake deposits that accumulated at the glacier margin in local depositional basins during retreat of the ice sheets. In deposits of large glacial lakes and selected small glacial lakes and ponds, map overprint patterns show the distribution of fine-grained lake-bottom sediments (dashed-line pattern), and sand and gravel deposits of delta topset beds and tributary glacial-stream deposits (dot pattern). Map unit descriptions provide details about glacial-lake dams and spillways, and drainage of the lakes. Postglacial alluvial deposits of Holocene age underlie modern flood plains and stream terraces, and are differentiated on the basis of weathering characteristics, stratigraphic relations, and topographic position. Colluvial deposits, which accumulated on hillslopes, are divided on the basis of lithologic characteristics related to upslope bedrock units from which they derived. Eolian deposits are shown as a unit where their thickness is greater than 1 m, and as a pattern where they are continuous but less than l m thick. Eolian deposits are composed of silt to fine sand and are mixed within the surface soil horizons throughout the area. Postglacial organic sediments in swamp and marsh deposits and in tidal marsh and estuarine deposits underlie modern wetland areas. Residual materials are produced from weathering of bedrock and are distinguished by grain size, structure, and mineral composition, as related to the bedrock units from which they derived.

Knowledge of the distribution and thickness of surficial deposits and of the bedrock surface topography is necessary for studies of water resources, water contamination, minerals and construction aggregate resources, foundation design for structures and transportation corridors, and effective land-management decisions. This map provides the basic near-surface geologic data required for such studies.

BEDROCK SURFACE TOPOGRAPHY

Relief on the surface of bedrock or coastal plain deposits in northern New Jersey reflects relative resistance of highly variable rock units to erosion. Many earth surface processes have contributed to the shaping of the bedrock surface, including long periods of preglacial and interglacial fluvial erosion, rock weathering, slope and marine erosion, and postglacial fluvial erosion. Glacial scour and plucking during three glaciations, as well as meltwater fluvial erosion, profoundly modified the preglacial and interglacial bedrock surface.

Bedrock-surface data were derived from reconnaissance and detailed geologic mapping and include rock outcrop areas, areas of thin surficial materials, and subsurface data that measure or constrain the thickness of overlying surficial materials. More than 3000 subsurface data records were examined, chiefly water-well completion reports from drillers for private water wells (see examples in Stanford, 1989, 1993, and in Witte and Stanford, 1995). The data also include extensive test-boring reports from the urbanized eastern part of the map area (see examples in Parrillo, 1959, and Lovegreen, 1974) as well as stratigraphic test holes completed as part of the geologic mapping studies and concurrent water resources studies (see examples in Harte and others, 1986). Geophysical data, including seismic and microgravity surveys, were used in areas where drill hole data were sparse (see examples in Canace and Hutchinson, 1988, and Ghatge and Hall, 1991). The locations and density of most of the drill-hole data points for the subsurface contours are shown on maps in the cited references.

Rock lithology and structure have exerted a strong control on bedrock outcrop patterns and bedrock surface topography. The relief, linearity, and local features of the bedrock surface reflect this lithologic and structural control as well as resistance to glacial erosion. The map modifies previous bedrock-surface topographic maps by including smoothed and U-shaped contours, wider valley reaches, and local closed-basin contours, reflecting glacial erosion and overdeepening of pre-existing valleys.

The extensive areas of bedrock outcrops and shallow rock divide the map area into two parts. North of the terminal moraine, the late Wisconsinan glaciation removed older surficial materials and produced an upland landscape dominated by outcrops of hard, polished rock and extensive areas of shallow rock discontinuously covered by thin till deposits. South of the terminal moraine, uplands are covered by residual materials derived from lengthy weathering of bedrock, and by thick colluvial deposits and older glacial till deposits. The overall effect of multiple glaciations was to remove weathered rock materials from the rock surface and to deepen and widen valleys in nonresistant rocks. These processes locally produced overdeepened basins bounded by closed contours, which are characteristic of glacially eroded landscapes.

The bedrock-surface topography appears to represent a complex, palimpsest geomorphic surface originally dissected by preglacial or interglacial fluvial systems, with subsequent extensive modification of valleys and interfluves by glacial erosion during multiple glacial advances across the area. The most striking features are the numerous overdeepened (closed) basins, which were created by glacial abrasive scour, shearing, and plucking, and by local subglacial meltwater erosion of nonresistant rocks. The trends of buried-valley segments and closed basins are probably related to the courses of preglacial and interglacial river systems of various ages that eroded relatively nonresistant rock types or fractured rock. In most buried basins, however, the altitude of the basin floor is 15.2 to 30.5 m (50–100 ft) or more below the lowest downslope point on the basin divide, indicating that the present overdeepened basin is not a remnant of a previous fluvially graded valley. Beneath the Hudson River the -76.2-m (-250 ft) contour outlines an overdeepened basin that extends to below -91.4 m (-300 ft). Basins in the Newark-Hackensack lowland are closed below -6.1 m (-20 ft), and are especially noteworthy where several extend to altitudes below -76.2 m (-250 ft). Other significant closed basins are in the following locations (east to west): west of the Watchung Mountains near Pompton Plains; in the Pequannock River valley at Green Pond Mountain; in the Green Pond–Rockaway River valley north and west of Wharton; in the Black Creek valley west of Vernon; in the Wallkill River valley north and west of Ogdensburg; beneath Culvers Lake; northwest of Balesville; in the Pequest River valley near Bear Swamp and Great Meadows; and in the Delaware River valley northwest of Belvidere. Bedrock-surface closure in all of these overdeepened basins generally is 15.2 to 30.5 m (50–100 ft), with a maximum of about 76.2 m (250 ft). The position and shape of most of these areas of deep glacial scour are related to the coincident strike direction of nonresistant rock units and to the glacial-flow direction, especially in the axial parts of valley ice lobes that developed during deglaciation of the area (Stone and others, 1995b; this report, figs. 2, 3, and 6).

MAP AND SUBSURFACE UNITS

Map units include surficial materials more than 1 m (3.3 ft) thick that overlie bedrock and coastal plain deposits; color designations, in parentheses, are based on naturally moist samples (Munsell Color Company, 1975). A veneer of colluvium less than 1 m (3.3 ft) thick covers most slopes and is not mapped; a discontinuous veneer of eolian fine sand to silt is present locally, but is not mapped. Descriptions of soils characteristics are based on data from the cited references for the Engineering Soil Survey of New Jersey, Engineering Bulletin Series; on Tedrow (1986); and on county soil surveys of the U.S. Department of Agriculture, Soil Conservation Service (presently the Natural Resources Conservation Service).

HOLOCENE AND LATE WISCONSINAN ARTIFICIAL FILL, ALLUVIAL, SWAMP, MARSH, ESTUARINE, TALUS, AND EOLIAN DEPOSITS

a — **Artificial fill**—Earth and manmade materials that have been artificially emplaced, including gravel, sand, silt, clay, trash, cinders, ash, and garbage; where extensive is shown by pattern printed over map unit of underlying material (see list of map and subsurface units on sheet 1). Thickness 1.8 to 35.0 m (6–115 ft). Not shown where less than 3.0 m (10 ft) thick in urban areas and where less than 3.0 m (10 ft) thick beneath highway and railroad beds

am — **Artificial fill (mine and quarry tailings)**—Earth materials, including blocks of waste rock and sand, gravel, silt, and minor clay derived from crushed or pulverized rock, that have been artificially emplaced. Thickness as much as 15.2 m (50 ft)

Qal — **Alluvium**—Sand, gravel, silt, minor clay, and some organic material, deposited by modern streams. In flood plains of major rivers, alluvium commonly consists of poorly sorted gravel and sand at the base, overlain by laminated and thinly bedded sand, silt, and clay; sand is moderately to poorly sorted. Thickness 1.8 to 9.1 m (6–30 ft). Along smaller streams alluvium is composed of sand and gravel derived from adjacent glacial, meltwater, colluvial, or weathered-bedrock materials; sand and gravel are poorly sorted; thickness generally is less than 4.0 m (13 ft). In the area of late Wisconsinan glacial deposits, alluvium locally includes and grades laterally into swamp and marsh deposits. In the areas of older glacial deposits, colluvium, and weathered-bedrock materials, alluvium locally grades into or intertongues with colluvium

Qaf — **Alluvial-fan deposits**—Sand, gravel, minor silt, and minor organic material; sand and gravel are poorly sorted; fans commonly are dissected by modern stream alluvium. Thickness as much as 12.2 m (40 ft)

Qcal — **Colluvium and alluvium, undifferentiated**—Silt, sand, and gravel, thinly bedded; discontinuously overlies and is interbedded with very poorly sorted colluvium; sand and gravel are poorly sorted. Unit includes lag accumulations of blocks and cobbles on eroded colluvial surfaces or locally on weathered-bedrock surfaces. Thickness 0.3 to 6.1 m (1–20 ft)

Qmt — **Moonachie terrace deposits**—Coarse to fine sand, with minor pebbly sand and silt and clay; sand beds are moderately sorted. Unit contains fragments of leaves and woody stems (Salisbury, 1902). Surface altitudes slope from 4 m (13 ft) to sea level; thickness 0.3 to 5.2 m (1–17 ft)

Qpt — **Passaic terrace deposits**—Sand and pebble gravel, moderately sorted. Surface altitudes slope from

18 m (60 ft) to sea level; thickness 0.3 to 10.7 m (1–35 ft)

Qst **Stream terrace deposits**—Sand, with lesser amounts of gravel and silt; includes sediment derived from adjacent glacial, meltwater, weathered-bedrock, or colluvial materials; sand is moderately sorted. Unit occurs in terraces adjacent to flood plains of major rivers or in broad plains in lowland areas; deposited by meteoric (nonglacial meltwater) streams. Thickness 0.3 to 6.1 m (1–20 ft)

Qpb **Pine Brook terrace deposits**—Sand and pebbly sand, and sand and gravel; sand and gravel component is moderately to poorly sorted. Surface altitudes slope from 67 m to 52 m (220–170 ft); thickness 1.8 to 9.1 m (6–30 ft)

Qor **Oradell terrace deposits**—Coarse sand and pebbly sand, moderately sorted; surface altitudes slope from 12 m to 9 m (40–30 ft); as much as 6.1 m (20 ft) thick

Qrt **Raritan terrace deposits**—Sand and gravel, sand, and silt in the lower terrace along the lower reach of the Raritan River; sand beds are poorly sorted; clasts are composed of gneiss, sandstone, mudstone, quartzite, and chert, and are generally nonweathered. Surface altitudes slope from 14 m to 6 m (45–20 ft). Thickness 1.8 to 9.1 m (6–30 ft)

Qml **Millstone terrace deposits**—Sand and gravel, sand, and silt; clasts are quartz, siltstone, sandstone, quartzite, gneiss, ironstone, and diabase; gneiss clasts are generally nonweathered. Surface altitudes range from 14 m to 12 m (45–40 ft); thickness as much as 12.2 m (40 ft). Unit includes some meltwater sediments

Qm **Tidal marsh and estuarine deposits**—Peat and muck, as much as 3.0 m (10 ft) thick, overlying and interbedded with laminated and thinly bedded fine sand and silt, as much as 76.2 m (250 ft) thick in the Hudson River estuary, and as much as 30.5 m (100 ft) thick in other valleys. Peat is decomposed, fibrous or matted, herbaceous and silty herbaceous material. Muck is organic, clayey silt

Qs **Swamp and freshwater marsh deposits**—Peat and muck interbedded with and overlying laminated silt, clay, minor sand, and locally marl and diatomaceous earth. Peat is decomposed, fibrous or granular, woody or herbaceous material. Muck is organic, clayey or sandy silt. Thickness, including basal silt and clay, generally less than 5.5 m (18 ft); organic materials are as much as 8.2 m (27 ft) thick, generally less than 3.7 m (12 ft) thick; marl generally is less than 4.6 m (15 ft) thick (Waksman and others, 1943)

Qta **Talus deposits**—Angular blocks accumulated by rockfall and creep at the base of bedrock cliffs and steep hillslopes. Thickness generally is less than 6.1 m (20 ft)

Qse **Eolian deposits**—Light-brown (7.5*YR* 6/4) to light-reddish-brown (5*YR* 6/4) very fine to medium sand and minor silt in continuous sheet deposits that mantle underlying materials. Occurs locally in dunes. Thickness 1 to 4 m (3.3–13 ft). Where continuous but less than 1 m thick, eolian silt and fine sand is shown by a pattern (see explanation of map symbols on sheet 1)

LATE WISCONSINAN GLACIAL MELTWATER DEPOSITS

Rockaway Formation—Light-gray (10*YR* 7/1) to very pale brown (10*YR* 7/3-4) to pale-yellow (2.5*Y* 7/4), or light-brown (7.5*YR* 6/4) to reddish-brown (2.5*YR* 5/4) sand, silt, and gravel (fig. 8, on sheet 2), stratified, poorly to well sorted; and reddish-brown (2.5*YR* 5/4) or dark-gray (10*YR* 4/1) silt and clay, stratified, moderately sorted. Color and mineralogic composition of the deposits are similar to the color and composition of underlying and northerly adjacent till and bedrock units. Gravel composition is polymict; gravel clasts are subrounded to well rounded and generally nonweathered; some coarse gravel clasts are striated. Sand composition is highly variable, from lithic coarse sand to sublithic or subarkosic fine sand; grains generally are nonweathered. The stratified sediments were deposited chiefly by glacial meltwater, and are divided into two groups of map units based on their sedimentary facies: glacial-stream units and glacial-lake units. Deposits of glacial-stream units contain three glaciofluvial facies. Deposits of glacial-lake units contain glaciodeltaic sediments, which include glaciofluvial facies in topset sediments, delta foreset and bottomset facies, glaciolacustrine fan facies, and lake-bottom facies.

Stratified meltwater deposits are subdivided into map units on the basis of the distribution, stratigraphic relations, and altitudes of facies in different depositional basins. Map units show the extent of sediments in each glacial-stream deposit or sediments deposited in or graded to each glacial lake or related series of lakes. Most map units contain multiple ice-marginal or near-ice-marginal meltwater deposits, known regionally as morphosequences (Koteff and Pessl, 1981). Each morphosequence typically consists of a progression of landforms and sedimentary facies, grading from ice-contact landforms underlain by coarse-grained facies at the head of the deposit, to depositional, noncollapsed landforms underlain by finer grained facies in distal parts of the deposit. The heads of ice-marginal deposits are coarse grained, locally containing boulders and lenses of poorly sorted sediments, and they characteristically have a zone of collapsed and deformed bedding along ice-contact slopes.

Soils in sand and gravel deposits are inceptisols having B horizons 0.3 to 0.8 m (13–30 in.) thick that overlie C horizons in sediments lightly oxidized as deep as 1.5 m (60 in.). Soils in silt and clay deposits are inceptisols having B horizons 0.5 to 0.8 m (18–30 in.) thick that overlie nonoxidized sediments

Deposits of glacial streams

Interbedded sand and gravel, moderately to poorly sorted, horizontally stratified. Deposits grade from (1) coarse gravel facies in ice-proximal heads of units, to (2) sand and gravel facies, to (3) pebbly coarse sand facies in distal parts of some units. The coarse gravel facies consists of massive cobble gravel beds that have a poorly sorted sand matrix; beds of small boulders are common. Coarse gravel beds generally are less than 1 m (3.3 ft) thick; beds composed of finer grained sediment are rare. The sand and gravel facies is most prevalent; it consists of pebble- and cobble-gravel beds interbedded with beds of medium to coarse sand. Cobble-gravel beds are massive or planar bedded, poorly to moderately sorted, and have local imbrication of clasts; pebble- or cobble-gravel beds also contain planar-tabular and trough crossbeds. Gravel beds are 0.2 to 1.5 m (0.7–5 ft) thick. Sand beds are chiefly coarse sand with pebbles and granules, poorly sorted, in trough and planar-tabular crossbeds. Medium- and fine-sand ripple cross-laminated beds are minor constituents. The pebbly coarse sand facies consists chiefly of coarse sand with pebbles in trough and planar-tabular crossbeds, and in planar beds. Thin beds of pebble gravel are minor constituents. Glacial-stream deposits originated as outwash deposits that accumulated in promorainal or ice-marginal outwash plains across wide valley areas, and as valley-train deposits, which are preserved as erosional terrace deposits that do not extend to ice-marginal heads of outwash. The outwash-plain and valley-train terrace deposits have smooth downstream surface profiles. Glacial-stream deposits overlie older glacial-lake deposits in discontinuous local basins north of the terminal moraine, and overlie older alluvial deposits south of the terminal moraine; distal terrace deposits contain sediments locally derived from nonglacial sources. Glacial-stream deposits generally are 1.8 to 15.2 m (6–50 ft) thick, and locally as much as 30.5 m (100 ft) thick

Qrsr **Saddle River outwash deposit**—Sand and gravel, minor coarse gravel, and sand and pebbly sand of valley outwash deposit and outwash terrace; surface altitudes slope from 85 m to 46 m (280–150 ft); as much as 15.2 m (50 ft) thick in outwash and 1.8 to 6.1 m (6–20 ft) thick in terraces

Qrps **Pascack outwash deposits**—Coarse gravel of valley outwash deposit; surface altitudes slope from 67 m to 46 m (220–150 ft); as much as 12.2 m (40 ft) thick

Qrdl **Delaware terrace deposits**—Sand and gravel and pebbly sand; surface altitudes slope from 98 m to 46 m (320–150 ft); as much as 12.2 m (40 ft) thick. Aggradation of sediments occurred proglacially in front of the advancing ice sheet in the upper Delaware River basin, and downstream from the Foul Rift moraine deposit (unit Qkfm) during maximum glacial extent. Meltwater deposition in terraces continued during ice-margin retreat in the Wallkill and Delaware drainage basins in New York

Qrwq **Wanaque outwash deposits**—Coarse gravel and sand-and-gravel of at least four ice-marginal deposits in the Wanaque River valley, and outwash deposits in four tributary valleys; surface altitudes slope from 183 m to 61 m (600–200 ft); as much as 15.2 m (50 ft) thick. Unit includes as much as 30.4 m (100 ft) of deltaic and lacustrine sand to fine sand and silt in the subsurface at and south of Wanaque-Midvale

Qrbf **Big Flat Brook outwash deposit**—Gravel and sand-and-gravel of valley outwash deposits; surface altitudes slope from 239 m to 158 m (785–520 ft); as much as 21.3 m (70 ft) thick

Qrpn **Pequannock terrace deposits**—Coarse gravel with boulders, and sand and gravel, and minor pebbly sand; surface altitudes slope from 341 m to 61 m (1120–200 ft); as much as 15.2 m (50 ft) thick. Deposited in the Pequannock River valley and in several tributary valleys on the north side of the river after the ice margin retreated north of the Riverdale area

Qrpp **Pompton Plains outwash deposit**—Sand and gravel, minor coarse gravel, and pebbly sand; surface altitudes slope from 70 m to 53 m (230–175 ft); thickness about 15.2 m (50 ft) at head of deposit and 1.8 to 12.2 m (6–40 ft) in central part

Qrbd **Brookdale terrace deposits**—Sand and gravel; surface altitudes slope from 49 m to 40 m (160–130 ft); generally less than 6.1 m (20 ft) thick. Deposited by meltwater draining from the Great Notch spillway of glacial Lake Passaic

Qrbc **Blairs Creek outwash deposits**—Sand and gravel and minor coarse gravel of valley outwash deposits as much as 12.2 m (40 ft) thick, and minor ice-marginal deltas as much as 9.1 m (30 ft) thick. Surface altitudes slope from 283 m to 270 m (930–885 ft)

Qrvc **Vancampens outwash deposit**—Sand and gravel of valley outwash deposits; surface altitudes slope from 229 m to 122 m (750–400 ft); as much as 18.3 m (60 ft) thick. Unit includes minor deltaic sand and gravel as much as 18.3 m (60 ft) thick in subsurface at the confluence of Vancampens Brook and the Delaware River

Qrrh **Rahway River outwash deposits**—Sand and gravel of multiple valley outwash deposits; surface altitudes slope from 116 m to 6.1 m (380–20 ft); as much as 9.1 m (30 ft) thick in West Branch valley and 15.2 m (50 ft) thick in East Branch valley. Unit includes terrace deposits south of Maplewood, 0.9 to 3.0 m (3–10 ft) thick

Qrmc **Musconetcong terrace deposits**—Coarse gravel, sand and gravel, and pebbly sand; surface altitudes slope from 145 m to 55 m (475–180 ft); as much as 15.2 m (50 ft) thick

Qrrk **Rockaway River terrace deposits**—Coarse gravel, sand and gravel, and pebbly sand; surface altitudes slope from 213 m to 152 m (700–500 ft); as much as 15.2 m (50 ft) thick. Deposited in the Rockaway River valley and in three tributary valleys on the north side of the Rockaway River valley after draining of glacial lakes Dover and Denville

Qrlr **Lubbers Run outwash deposit**—Sand and gravel and minor pebbly sand of at least four ice-marginal deposits; surface altitudes slope from 258 m to 189 m (845–620 ft); as much as 12.2 m (40 ft) thick. Unit includes deltaic and lacustrine sand in the subsurface beneath Lake Lackawanna, as much as 24.4 m (80 ft) thick

Qrbb **Beaver Brook outwash deposits**—Sand and gravel of valley outwash deposits; surface altitudes slope from 137 m to 107 m (450–350 ft); as much as 27.4 m (90 ft) thick. Unit includes minor deltaic sand and gravel and lacustrine sand and silt in the subsurface north of Sarepta, laid down in small, short-lived sediment-dammed lakes

Qrhc **Hackettstown outwash deposit**—Sand and gravel and pebbly sand of promorainal outwash deposit; surface altitudes slope from 186 m to 146 m (610–480 ft); as much as 15.2 m (50 ft) thick

Qrpf **Plainfield outwash deposit**—Pebbly sand and sand and gravel of promorainal outwash deposit; surface altitudes slope from 62 m to 12 m (205–40 ft); as much as 24.4 m (80 ft) thick. Unit includes subsurface lacustrine sand in the South Plainfield area, as much as 12.2 m (40 ft) thick

Qrmt **Metuchen outwash deposit**—Pebble gravel and sand, and minor sand and gravel of promorainal outwash; surface altitudes slope from 37 m to 18 m (120–60 ft); as much as 24.4 m (80 ft) thick

Qrbl **Belvidere outwash deposits**—Cobble gravel underlying and interbedded with till of the Foul Rift moraine deposit (unit Qkfm), and coarse gravel and sand-and-gravel of valley outwash deposit; surface altitudes slope from 111 m to 91 m (365–300 ft); as much as 30.5 m (100 ft) thick

Qrpa **Perth Amboy outwash deposit**—Sand and gravel and pebbly sand of promorainal outwash deposit; surface altitudes slope from 9.1 m to 0 m (30–0 ft); as much as 12.2 m (40 ft) thick. Deposit extends beneath estuarine sediments (unit Qm) in the Raritan River estuary

Qrfl **Florham outwash deposit**—Subsurface unit (sections *D–D′* and *J–J′*). Sand and gravel and coarse sand of proglacial outwash deposits. Unit may include nonglacial alluvial sediments. Altitudes of top of unit slope from 50 m to 30 m (165–100 ft); as much as 38.1 m (125 ft) thick. Proglacial deposition occurred in front of the advancing ice margin in the upper Passaic basin; deposition ceased when glacial ice dammed the basin at Millburn and impounded the Chatham phase of glacial Lake Passaic

Qrtu **Terrace and meltwater fan deposits, undifferentiated and not correlated**—Sand-and-gravel and pebbly sand, and coarse gravel; as much as 15.2 m (50 ft) thick

Deposits of glacial lakes

Sand, sand and gravel, and silty sand in deltaic, glaciolacustrine fan and ice-channel deposits; and fine sand, silt, and clay in lake-bottom deposits. Deltaic deposits have sand and gravel glaciofluvial topset beds, 0.6 to 6.1 m (2–20 ft) thick (dot pattern on map), which overlie delta foreset and bottomset facies. Foreset facies include (1) the sand and gravel foreset facies, consisting of gravel, pebbly sand, and coarse sand, poorly to moderately sorted, in sets of thin beds that are 2.0 to 10.1 m (6.5–33 ft) thick and that dip 25° to 35°; and (2) the sandy foreset facies, consisting of fine to medium sand, moderately sorted, in interbedded parallel-laminated and ripple cross-laminated sets of beds that are 2.0 to 5.2 m (6.5–17 ft) thick and that dip less than 25°; draped laminations of silt and clay are common in lower beds. Delta bottomset facies are (1) the sand and gravel bottomset facies, consisting of coarse pebbly sand in planar-tabular crossbeds and parallel-bedded fine sand, silt, and clay, in sets of beds that dip less than 5°; and (2) the sandy bottomset facies, consisting of fine sand, silt, and clay, in ripple cross-laminated and parallel-laminated beds that dip less than 5°. The total thickness of deltaic sediments is 6.1 to 45.7 m (20–150 ft). Ice-marginal deltas contain sand and gravel and sandy foreset and bottomset facies; some of these deltas are connected to tributary eskers or ice-channel ridges, which contain sand, coarse gravel, and surface boulders. Fluviodeltas include glacial-stream deposits (dot pattern on map) that extend down tributary valleys to the delta plain, which is underlain by sand and gravel topset sediments, and sandy foreset and bottomset facies. Glaciolacustrine fans typically are low ridges or knolls that contain sand and gravel and sandy foreset and bottomset facies, and minor till, flowtill, and fine-grained lake-bottom sediments; some fans are connected to ice-channel ridges, which contain thick sets of sand and gravel and sandy foreset beds. Lake-bottom deposits (dashed-line pattern on map) contain two facies: (1) the sandy facies, consisting of fine sand to silt in parallel-laminated and minor ripple cross-laminated sets of beds; and (2) the silt-clay facies, consisting of silt-to-very fine sand, and clay in parallel laminations, microlaminations, and minor ripple cross-laminations; deposits with laminations of variable thickness have clay laminae less than 2 mm (0.08 in.) thick; varve deposits of this facies consist of couplets of microlaminated silt-to-very fine sand, and massive clay; couplets are 0.4 to 10 cm (0.2–4 in.) thick; vertical sequences of varves show little variation in couplet thickness. Total thickness of lake-bottom sediments is 3.0 to 61.0 m (10–200 ft).

Deposits of major glacial lakes include multiple ice-marginal deltas and fluviodeltas, minor glaciolacustrine fans, and extensive lake-bottom deposits that contain varve deposits. Deltas commonly have lobate distal delta-plain and foreset-slope margins that grade into flat lake-bottom deposits. The lake basins are in northward-draining valleys that were dammed by the ice margin, or in basins dammed by slightly older stratified deposits or moraines. Spillways over bedrock or till on the lowest points of the basin divides are preserved. Altitudes of delta plains and topset-foreset contacts of deltas in large glacial lakes rise to the north-northeast, reflecting postglacial isostatic tilting (rise) of 0.4 to 0.7 m/km (2–3.5 ft/mi) in that direction. Deposits and altitudes of delta plains of some major lakes lower to the north and are related to successively lowering lake stages, the levels of which were controlled by deglaciation of consecutively lower lake spillways. Deposits and lowering delta-plain altitudes of some other major lakes are related to lake phases, the levels of which lowered due to erosion of sediment dams.

Deposits of small glacial lakes and ponds include few ice-marginal deltas and glaciolacustrine fans; sandy lake-bottom deposits underlie the distal parts of some deltas and are at the surface only locally. The dot pattern and the dashed-line pattern, respectively, are shown in selected units on the map. The lake basins are in the upper parts of northward-draining valleys that were dammed by the ice margin, or in basins that were dammed by slightly older stratified deposits or moraines. Spillways over till are preserved. In some valleys, deltas at lowering altitudes were built into a lowering series of small lakes; multiple lake stages in these valleys are not differentiated. In some narrow valleys, delta-plain altitudes indicate that water at successively higher lake levels was impounded behind dams composed of thick deltaic sediments; these higher lake-level stages are not differentiated. Deposits of small glacial lakes also include coarse deltaic sediments in hummocky ice-contact deposits which form ridges that are topographically above adjacent deltaic deposits. The deposits accumulated in small lakes in channels in stagnant ice; lake spillways were over ice or supraglacial sediment. Other deposits that include similar ice-contact deltaic sediments, or glaciofluvial, debris-flow, or glacially deformed sediments, are in transverse ridges on top of sediments of slightly older deltaic deposits. The sediments in many of these ridges are deformed and they contain some compact till and probable flowtill. These sediments were deposited in ice-contact ponds, or in alluvial fans or colluvial ramparts; some of the deposits subsequently were glacially eroded and transported in ice-pushed ridges. The extent of the major and selected small glacial lakes is shown in figure 3

Deposits of major glacial lakes

CENTRAL AND EASTERN HIGHLANDS

Qrbt **Glacial Lake Bearfort deposits**—Unit includes deposits of two lake stages, undifferentiated. Consists of three ice-marginal deltas, as much as 33.5 m (110 ft) thick, and lake-bottom silt and fine sand that is extensive beneath swamp deposits, as much as 15.2 m (50 ft) thick. Delta-plain altitudes lower from 351 m to 335 m (1150–1100 ft); spillway altitudes are 349 m and 332 m (1145 ft and 1090 ft). The lake basin occupied the northward-draining valley of Long House Creek (northwest of Greenwood Lake); the initial spillway is on the Wallkill River–Pequannock River drainage divide, and the lower spillway is on the Wallkill River-Wanaque River divide. The lake lowered and drained when the ice margin retreated and uncovered lower spillways into the Wallkill River valley in New York

Qrwy **Glacial Lake Wawayanda deposits**—Unit includes deposits of six lake stages in four basins, undifferentiated. Consists of six ice-marginal deltas, as much as 15.2 m (50 ft) thick, and lake-bottom silt and fine sand as thick as 18.3 m (60 ft). Delta-plain altitudes lower from 381 m to 244 m (1250–800 ft); spillway altitudes are 379 m, 375 m, 354 m, 351 m, 344 m, and 235 m (1245 ft, 1230 ft, 1160 ft, 1150 ft, 1130 ft, and 770 ft). Four separate glacial lakes occupied north-draining valleys on Wawayanda Mountain; lake spillways are across local drainage divides into the Mossman Brook drainage and glacial Lake Bearfort (unit Qrbt); the lowest spillway is westward into glacial Lake Wallkill (unit Qrw). The lowest lake lowered to the level of glacial Lake Wallkill when the ice margin retreated off the north end of Wawayanda Mountain in New York

Qrgr **Glacial Lake Greenwood deposits**—Unit includes deposits of three lake stages, undifferentiated. Consists of seven ice-marginal deltas, as much as 36.6 m (120 ft) thick; glaciolacustrine fans, as much as 9.1 m (30 ft) thick; and lake-bottom silt, fine sand, and clay, as much as 39.6 m (130 ft) thick. Delta-plain altitudes lower from 259 m to 198 m (850–650 ft); spillway altitudes are 258 m, 219 m, and 197 m (845 ft, 720 ft, and 645 ft). The lake basins occupied the north-draining valley of Belcher Creek; the initial lake spillway is on the Wanaque River–Pequannock River divide; lower spillways are on local divides to the east into the Wanaque basin. The glacial lakes lowered to the approximate level of present Greenwood Lake when the ice margin retreated north of the Wanaque River valley in the Cooper area

Qrgp **Glacial Lake Green Pond deposits**—Unit includes deposits of two lake stages, undifferentiated. Consists of one ice-marginal delta, as much as 45.7 m (150 ft) thick, and glaciolacustrine fans as much as 30.5 m (100 ft) thick. Delta-plain altitude of 323 m (1060 ft) is related to spillway altitude of 320 m (1050 ft); lower spillway is at 277 m (910 ft). The lake basin occupied a deep, north-draining valley on the south side of the Pequannock River valley; the spillways are on the preglacial Pequannock River–Rockaway River divide. The lake drained when the ice margin retreated north of the Pequannock River valley in the Newfoundland area

Qrsp **Glacial Lake Sparta deposits**—Unit includes five lake stages, undifferentiated. Consists of seven ice-marginal deltas, as much as 19.8 m (65 ft) thick, and minor glaciolacustrine fans; and lake-bottom sand, silt, and clay, extensive beneath swamp deposits, as much as 30.5 m (100 ft) thick. Delta-plain altitudes lower from 259 m to 200 m (850–655 ft); spillway altitudes are 258 m, 251 m, 245 m, 213 m, and 198 m (845 ft, 825 ft, 805 ft, 700 ft, and 650 ft). The lake basin occupied the Wallkill River valley south of the Franklin area, and the five lake stages are related to the uncovering of successively lowering spillways on the Pequest River–Paulins Kill and Wallkill River drainage divides. The lake lowered to the level of glacial Lake North Church (unit Qrnc) when the ice margin retreated north of the Pimple Hills in the Franklin Pond area

Qrhp **Glacial Lake Hopatcong deposits**—Five ice-marginal deltas, as much as 21.3 m (70 ft) thick; glaciolacustrine fans as much as 9.1 m (30 ft) thick; and lake-bottom silt, sand, and clay, as much as 30.5 m (100 ft) thick. Delta-plain altitudes rise from 280 m to 287 m (920–940 ft); spillway altitude is 279 m (915 ft). The lake basin occupied the upper Musconetcong River valley, which was dammed by the Budd Lake moraine (unit Qnbm); the spillway was over the moraine. The glacial lake lowered to a low level in the Lake Hopatcong basin following erosion of the moraine dam; the elevation of present Lake Hopatcong is controlled by a dam

Qrdn **Glacial Lake Denville deposits**—Three ice-marginal deltas, as much as 30.5 m (100 ft) thick; glaciolacustrine fans as much as 9.1 m (30 ft) thick; and lake-bottom silt, fine sand, and minor clay, as much as 45.7 m (150 ft) thick. Deposits are locally overlain by Netcong Till of the Budd Lake moraine deposit (unit Qnbm, section *D–D'*). Delta-plain altitudes rise from 162 m to 165 m

(530–540 ft); spillway altitude is 160 m (525 ft). The glacial lake basin occupied part of the Rockaway River valley that was dammed by the ice margin and by moraine deposits (unit Qnmm), which filled a preglacial valley reach between the Parsippany and Denville areas; the lake spillway is on the Rockaway River–Whippany River drainage divide in the Tabor area. The lake drained when the ice margin retreated north of the gap between Powerville and Boonton

Qrpy **Glacial Lake Picatinny deposits**—Unit includes deposits of two lake stages, undifferentiated. Consists of three ice-marginal deltas, as much as 45.7 m (150 ft) thick; glaciolacustrine fans as much as 18.3 m (60 ft) thick; and lake-bottom silt, sand, and clay, as much as 45.7 m (150 ft) thick. Delta-plain altitudes lower from 219 m to 210 m (720–690 ft); spillway altitudes are 218 m and 210 m (715 ft and 690 ft). The lake basin occupied two separate basins in the valley of Green Pond Brook, which were dammed by the Budd Lake moraine (unit Qnbm) and by till; spillways were over the moraine and sediment dams. The glacial lakes lowered when the sediment dams were eroded, but younger lakes, such as present Lake Picatinny, persisted in the basins

Qrd **Glacial Lake Dover deposits**—Unit includes deposits of two separate lakes, undifferentiated. Consists of three ice-marginal deltas, as much as 15.2 m (50 ft) thick; and lake-bottom silt, fine sand, and minor clay, as much as 30.5 m (100 ft) thick. Delta-plain altitudes lower from 195 m to 177 m (640–580 ft); spillway altitudes are 195 m and 177 m (640 ft and 580 ft). The lake basins occupied segments of the Rockaway River valley and a tributary valley that were dammed by the glacier margin; the lake spillways are on tributary drainage divides. The lakes drained when the ice margin retreated north of the Rockaway area

Qrsc **Glacial Lake Succasunna deposits**—Unit consists of two ice-marginal deltas and one fluviodelta, as much as 45.7 m (150 ft) thick; glaciolacustrine fans in the subsurface; and lake-bottom fine sand, silt, and minor clay as much as 45.7 m (150 ft) thick. Deposits locally overlain by Netcong Till of the Budd Lake moraine deposit (unit Qnbm, sections *D–D′* and *I–I′*). Delta-plain altitudes rise from 210 m to 223 m (690–730 ft); spillway altitude is 206 m (675 ft). Unit includes deltaic deposits with aggraded topset-plain altitudes that rise from 216 m to 223 m (710–730 ft) and that are graded to a small lake with a local spillway at 216 m (710 ft) in the Drakes Brook drainage west of the Succasunna area. The lake basins occupied preglacial, north-draining tributary valleys of the Rockaway River valley; the lake spillway is across bedrock on the preglacial basin drainage divide near Milltown. Meltwater deposition ceased when the ice margin retreated north of the Rockaway River valley in the Wharton area. The lake basin is filled with sediment and the present-surface drainage basin drains south from the Budd Lake moraine

Qrb **Glacial Lake Budd deposits**—One ice-marginal delta, as much as 15.2 m (50 ft) thick, and lake-bottom sand beneath Budd Lake about 16.8 m (55 ft) thick. Delta-plain altitude is 287 m (940 ft); spillway altitude is 285 m (935 ft). The glacial-lake basin occupied a north-draining valley beneath Budd Lake; the lake spillway is on the Wills Brook–South Branch Raritan River drainage divide. Glacial Lake Budd lowered to the level of Budd Lake following erosion of the spillway and isostatic tilting of the basin

KITTATINNY VALLEY, BASINS OF PEQUEST AND MUSCONETCONG RIVERS AND POHATCONG CREEK, AND WESTERN HIGHLANDS

Qrw **Glacial Lake Wallkill deposits, Augusta stage**—Unit consists of nine ice-marginal deltas and four fluviodeltas, as much as 45.7 m (150 ft) thick; multiple glaciolacustrine fans in five local basins, as much as 30.5 m (100 ft) thick; and lake-bottom silt and clay, extensive beneath swamp deposits, as much as 30.5 m (100 ft) thick. Delta-plain altitudes rise from 160 m to 165 m (525–540 ft); spillway altitude is 151 m (495 ft). The glacial lake basin occupied the north-draining Wallkill River valley and tributary valleys; the lake spillway channel is on the Paulins Kill–Wallkill River drainage divide at Augusta. Lower stages of glacial Lake Wallkill were controlled initially by spillways over the Hudson River drainage divide between Goshen and Neelytown, N.Y.

Qrma **Glacial Lake McAfee deposits**—Three ice-marginal deltas, as much as 39.6 m (130 ft) thick; glaciolacustrine fans as much as 9.1 m (30 ft) thick; and lake-bottom silt and fine sand as much as 54.9 m (180 ft) thick. Delta-plain altitudes rise from 166 m to 171 m (545–560 ft); spillway altitude is 165 m (540 ft). The lake basin occupied the upper Black Creek valley, which was dammed by deposits of glacial Lake Hamburg (unit Qrhm); the spillway drained south over bedrock. The lake lowered to the level of glacial Lake Wallkill (unit Qrw) when the sediment dam was eroded

Qrhm **Glacial Lake Hamburg deposits**—One ice-marginal delta, as much as 54.9 m (180 ft) thick; glaciolacustrine fans, as much as 30.5 m (100 ft) thick; and lake-bottom silt, clay, and fine sand, as much as 30.5 m (100 ft) thick. Delta-plain altitude is 171 m (560 ft); spillway altitude is 168 m (550 ft). The lake basin occupied the lower reaches of the north-draining Beaver Run and upper Wallkill River valleys; the lake spillway is on the Beaver Run–Papakating Creek drainage divide. Glacial Lake Hamburg lowered to the level of glacial Lake Wallkill (unit Qrw) when the ice margin retreated north of the Wallkill River valley in the Martins area

Qrwf

Glacial Lake Wallkill deposits, Frankford Plains phase—Unit includes deposits of two lake stages, undifferentiated. Consists of three ice-marginal deltas and one fluviodelta, as much as 18.3 m (60 ft) thick; multiple glaciolacustrine fans; and lake-bottom sand, silt, and clay as much as 22.9 m (75 ft) thick. Delta-plain altitudes lower from 163 m to 160 m (535–525 ft); altitudes of spillways are 161 m and 152 m (529 ft and 500 ft). The lake basin occupied the Papakating Creek valley and spillways were over the Augusta moraine (unit Qkam) and deltaic deposits (unit Qrup) in the upper Paulins Kill valley. The Frankford Plains phase persisted during erosional lowering of the spillway to the formation of the Augusta spillway channel over bedrock at altitude 151 m (495 ft), which is the stable spillway of glacial Lake Wallkill, Augusta stage

Qrbr

Glacial Lake Beaver Run deposits—Unit includes deposits of two lake stages, undifferentiated. Consists of three ice-marginal deltas, as much as 16.8 m (55 ft) thick; and lake-bottom sand, silt, and clay as much as 21.3 m (70 ft) thick. Delta-plain altitudes lower from 180 m to 177 m (590–580 ft); spillway altitudes are 178 m and 175 m (585 ft and 575 ft). The lake basin occupied the lowland northeast of the Lafayette area, which is in the upper Paulins Kill and Beaver Run drainage basins. Spillways are over till and older meltwater deposits. The lake lowered to the level of glacial Lake Hamburg when the ice margin retreated north of the Beaver Run valley into the Wallkill River valley

Qrnc

Glacial Lake North Church deposits—Unit includes deposits of three lake stages, undifferentiated. Consists of two ice-marginal deltas, as much as 45.7 m (150 ft) thick; glaciolacustrine fans as much as 61.0 m (200 ft) thick; and lake-bottom silt, clay, and fine sand as much as 24.4 m (80 ft) thick. Delta-plain altitudes lower from 195 m to 189 m (640–620 ft); spillway altitudes are 192 m, 186 m, and 180 m (630 ft, 610 ft, and 590 ft). The lake basin occupied the upper Wallkill River valley, which was dammed by deposits of glacial Lake Newton (unit Qrn); the higher spillways were over stratified deposits (unit Qrn), which eroded and lowered the spillway from 192 m to 186 m (630–610 ft) during deposition in the lake. The lower spillway drained west over bedrock on the Wallkill River–Beaver Run drainage divide. The lake lowered to the level of glacial Lake Hamburg (unit Qrhm) when the ice margin retreated north of the Hamburg area

Qro

Glacial Lake Owassa deposits—Unit includes deposits of two lake stages, undifferentiated. Consists of two ice-marginal deltas, as much as 15.2 m (50 ft) thick; minor glaciolacustrine fans; and lake-bottom sand, silt, and clay as much as 24.4 m (80 ft) thick. Delta-plain altitude of the higher lake stage is 271 m (890 ft); spillway altitudes are 270 m and 267 m (885 ft and 875 ft). The glacial lake basin occupied a glacially overdeepened basin underlain by till in the Culvers Lake–Lake Owassa area. Spillways are over the Culvers Creek–Trout Brook drainage divide. The lake persisted until the till in the sediment dam at the south end of Culvers Lake was eroded and the lake drained into Culvers Creek valley

Qrn

Glacial Lake Newton deposits—Five ice-marginal deltas, as much as 24.4 m (80 ft) thick; minor glaciolacustrine fans; and lake-bottom silt and clay, extensive beneath swamp deposits, as much as 30.5 m (100 ft) thick. Delta-plain and aggraded delta-plain altitudes rise from 189 m to 204 m (620–670 ft); the spillway altitude is 181 m (595 ft). The lake basin occupied the lowland north of the Newton area and in the Germany Flats area in the Paulins Kill drainage basin; the spillway is over rock on the Pequest River–Paulins Kill drainage divide. Meltwater deposition in the lake ceased after the ice margin retreated into the glacial Lake North Church basin (unit Qrnc) and into glacial Lake Beaver Run (unit Qrbr) and a small unnamed lake in the upper Paulins Kill drainage basin

Qrsw

Glacial Lake Swartswood deposits—Unit includes deposits of two lake stages, undifferentiated. Consists of four fluviodeltas, as much as 18.3 m (60 ft) thick; and lake-bottom sand, silt, and clay as much as 22.9 m (75 ft) thick. Delta-plain altitudes lower from 163 m to 152 m (535–500 ft); the higher spillway altitude is 162 m (530 ft). The lake basin occupied a glacially overdeepened rock basin in a tributary valley of Paulins Kill northeast of the Middleville area. The higher spillway is over rock on a local drainage divide and the lower spillway was eroded in till at the south end of the basin

Qrbs

Glacial Lake Big Springs deposits—Unit includes deposits in local lake basins, undifferentiated. Consists of five ice-marginal deltas, as much as 16.8 m (55 ft) thick; and lake-bottom silt, sand, and clay, extensive beneath swamp deposits, as much as 15.2 m (50 ft) thick. Delta-plain altitudes lower from 197 m to 186 m (645–610 ft). The lake basins occupied scoured rock basins northeast of the Huntsburg area in the upper Pequest River valley; spillways are over rock on local drainage divides at altitudes of 195 m and 183 m (640 ft and 600 ft), and over older meltwater deposits (unit Qrpq) at an altitude of about 186 m (610 ft). Meltwater deposition ceased after the ice margin retreated north into the Pequest River valley

Qrpk

Glacial Lake Paulins Kill deposits—Unit includes deposits of two lake stages, undifferentiated. Consists of five ice-marginal deltas, as much as 18.3 m (60 ft) thick; and lake-bottom silt, clay, and fine sand as much as 21.3 m (70 ft) thick. Delta-plain altitudes lower from 122 m to 116 m (400–380 ft); spillway altitudes are 119 m and 113 m (390 ft and 370 ft). The lake occupied the lower part of the Paulins Kill valley; spillways were over drift and ice dams at or near the area of confluence of the Delaware River and Paulins Kill. The lake drained when the lower dam was eroded and base level lowered to surfaces controlled by outwash deposits (unit Qrcl) in the Delaware River valley

Qrpq **Glacial Lake Pequest deposits**—Unit includes deposits of two lake stages, undifferentiated. Consists of 16 ice-marginal deltas, as much as 51.8 m (170 ft) thick; glaciolacustrine fans as much as 9.1 m (30 ft) thick; and lake-bottom silt, sand, and clay as much as 67.1 m (220 ft) thick. Delta-plain altitude for the higher stage is 174 m (570 ft); delta-plain altitudes for the lower stage rise from 171 m to 186 m (560–610 ft); spillway altitudes are 172 m and 166 m (565 and 545 ft). The lake basin occupied the Pequest River valley, which was dammed by the Townsbury moraine (unit Qktm) and deltaic deposits (unit Qrpq); the spillways are over the moraine dam and adjacent deltaic deposits. Glacial Lake Pequest drained in a series of lowering levels, which are not differentiated, when the sediment dams eroded

Qroxb **Glacial Lake Oxford deposits, Buckhorn stage**—Five ice-marginal deltas, as much as 27.4 m (90 ft) thick; and lake-bottom sand, silt, and clay as much as 19.8 m (65 ft) thick. Delta-plain altitudes rise from 146 m to 152 m (480–500 ft); spillway altitude is 139 m (455 ft). The glacial lake occupied two basins in the lower Pequest River valley, which were dammed by ice in the Delaware River valley; the lake spillway is on the Pophandusing Brook–Buckhorn Creek drainage divide. The Buckhorn stage of glacial Lake Oxford drained when the ice margin retreated westward into the Delaware River valley

Qroxp **Glacial Lake Oxford deposits, Pophandusing stage**—One ice-marginal delta, as much as 24.4 m (80 ft) thick; and lake-bottom sand, silt, and clay in the subsurface. Altitude of collapsed deltaic deposits is 178 m (585 ft); estimated spillway altitude is 178 m (585 ft). North of the Oxford area, the glacial lake basin occupied the Furnace Brook valley, which was dammed by ice in the Delaware River valley. The lake spillway is in a quarried area on the Pequest River–Pophandusing Brook drainage divide. The Pophandusing stage of glacial Lake Oxford lowered to the Buckhorn stage (unit Qroxb) when the ice margin retreated in the lower Pequest River valley to the Bridgeville area

DELAWARE RIVER BASIN

Qrmb **Glacial Lake Millbrook deposits**—Three ice-marginal deltas, extensively collapsed and as much as 18.3 m (60 ft) thick; minor glaciolacustrine fans; and lake-bottom sand, silt, and clay as much as 24.4 m (80 ft) thick. Delta-plain altitudes rise from 195 m to 207 m (640–680 ft); spillway altitude is 192 m (630 ft). The lake basin occupied the Mill Brook and Clove Brook valleys southwest of Duttonville; the spillway is over Shimers Brook deposits (unit Qrsb), east of Millville. The lake drained into the Minisink Valley after the ice margin retreated north of Wallpack Ridge near the Duttonville area

BASINS OF UPPER PASSAIC AND RAMAPO RIVERS AND UPPER HOHOKUS BROOK

Qrpg **Glacial Lake Passaic deposits, Great Notch stage**—One ice-marginal delta and four fluviodeltas, as much as 24.4 m (80 ft) thick; and lake-bottom silt, sand, and clay as much as 6.1 m (20 ft) thick. Delta-plain altitudes rise from 98 m to 107 m (320–350 ft); spillway altitude is 93 m (305 ft). The lake basin occupied the central Passaic and lower Pompton River valleys, which were dammed by the ice margin; the spillway is over the divide on First Watchung Mountain (Orange Mountain). The Great Notch stage of glacial Lake Passaic drained when the ice margin retreated north of First Watchung Mountain

Qrwp **Glacial Lake Whippany deposits**—One fluviodelta, as much as 45.7 m (150 ft) thick; and lake-bottom silt, sand, and clay, extensive beneath alluvium, as much as 15.2 m (50 ft) thick. Delta-plain altitude is 116 m (380 ft). The lake basin occupied the upper Whippany River valley, which was dammed by glacial Lake Passaic, Moggy Hollow stage deposits (unit Qrpm); the spillway was over the dam deposits, at an altitude of about 113 m (372 ft). Glacial Lake Whippany lowered to the level of the Moggy Hollow stage of glacial Lake Passaic when the ice margin retreated to the Cedar Knolls area

Qrpm **Glacial Lake Passaic deposits, Moggy Hollow stage**—Sixteen ice-marginal deltas and four fluviodeltas, as much as 45.7 m (150 ft) thick; 12 glaciolacustrine fans and two ice-channel deposits, as much as 18.3 m (60 ft) thick; eight nearshore spit deposits, chiefly pebble sand and gravel, 1.8 to 4.0 m (6–13 ft) thick; and lake-bottom sand, silt, and clay, as much as 45.7 m (150 ft) thick. Lake-bottom varve deposits (couplets 0.6 to 10 cm [0.25–4 in.] thick) are as much as 61.0 m (200 ft) thick. Delta-plain altitudes rise from 110 m to 125 m (360–410 ft); spillway altitude is 103 m (339 ft). The glacial lake basin occupied the valley of the lower Pompton and central Passaic Rivers, which was dammed by the Perth Amboy moraine (unit Qram). The lake spillway is over the Passaic River–Raritan River drainage divide, north of Pluckemin. The level of the Moggy Hollow stage lowered to the level of the Great Notch stage when the ice margin retreated north of the Great Notch stage spillway in the West Paterson area

Qrpc **Glacial Lake Passaic deposits, Chatham phase**—Subsurface unit (sections *D–D′*, *J–J′*). Consists of glaciolacustrine fan deposits, as much as 41.1 m (135 ft) thick; and lake-bottom sand, silt, and clay as much as 21.3 m (70 ft) thick. Altitudes of tops of deposits range from 79 m to 30 m (260–100 ft). The lake basin occupied the central Passaic River valley during advance of the ice sheet. The valley was dammed by the ice margin and by lower parts of the Perth Amboy moraine (unit Qram); lake spillways were through the gap in Second and First Watchung Mountains south and east of the Summit area at altitudes ranging from about 43 m to 82 m (140–270 ft). The lake level of the Chatham phase rose to the Moggy Hollow-stage level when the ice margin advanced to the Summit area and blocked the earlier spillways

HACKENSACK, RAHWAY, LOWER PASSAIC, AND LOWER RARITAN RIVER BASINS

Qrhr **Glacial Lake Hackensack and Lake Hackensack deposits, Oradell stage**—Unit includes meltwater lake-bottom sediments in lower parts of deposits and meteoric (nonglacial Lake Hackensack) sediments in upper parts. Contains minor sand, and varve deposits (couplets in upper varve deposits average 0.5 cm [0.2 in.] thick; Reeds, 1926). The lake basin occupied a lowland on top of lake-bottom sediments of the Kill Van Kull stage of glacial Lake Hackensack (unit Qrhk) in the Hackensack River valley and the northern part of the Meadowlands area. The initial lake spillway was at the north end of the lake in the area of the Hackensack River–Sparkill Creek drainage divide at present altitude of about 9 m (30 ft); subsequently, the lake drained through the Oradell terrace deposit (unit Qor). Lake Hackensack became shallower, filled with sediment and drained to the south when isostatic rebound raised the north end of the lake basin

Qrhk **Glacial Lake Hackensack deposits, Kill Van Kull stage**—Nine ice-marginal deltas and four fluviodeltas, as much as 21.3 m (70 ft) thick; local glaciolacustrine fans in the subsurface, as thick as 15.2 m (50 ft); and lake-bottom varve deposits (couplets 0.6 to 4 cm [0.25–1.6 in.] thick) as much as 61.0 m (200 ft) thick. Delta-plain altitudes rise from 6 m to 21 m (20–70 ft); altitudes of spillways over bedrock are -9 m (-30 ft) at Arthur Kill, and -6 m (-20 ft) at Kill Van Kull. The lake basin occupied a glacially overdeepened bedrock basin; bedrock spillways were approximately accordant when adjusted for isostatic tilt. The Kill Van Kull stage drained eastward into glacial Lake Hudson (fig. 3), and lowered to the level of the Oradell stage when the ice margin retreated north of Sparkill Gap in New York

Qrtn **Glacial Lake Tenakill deposits**—Four ice-marginal deltas, as much as 30.5 m (100 ft) thick; glaciolacustrine fans as much as 9.1 m (30 ft) thick; and lake-bottom silt, sand, and clay as much as 21.3 m (70 ft) thick. Delta-plain altitudes rise from 17 m to 20 m (55–65 ft); spillway altitude is 17 m (55 ft). The lake basin occupied the Tenakill Brook valley, which was dammed by deposits of glacial Lake Hackensack and the Highwood deposits (units Qrhk, Qrhh); the spillway was over the sediment dam. The lake lowered to the level of glacial Lake Hackensack, Kill Van Kull stage, when the ice margin retreated north of the Closter area

Qrpr **Glacial Lake Paramus deposits**—Six ice-marginal deltas and four fluviodeltas, as much as 24.4 m (80 ft) thick; glaciolacustrine fans as much as 6.1 m (20 ft) thick; and lake-bottom silt, sand, and clay as much as 21.3 m (70 ft) thick. Delta-plain altitudes rise from 18 m to 23 m (60–75 ft); spillway altitude is 15 m (50 ft). The lake basin occupied the lower Saddle River valley and part of the Passaic River valley; the latter was dammed by Delawanna deposits (unit Qrdw), and the spillway was over the sediment dam. The lake lowered to the level of glacial Lake Hackensack, Kill Van Kull stage (unit Qrhk) when the sediment dam eroded

Qrtk **Glacial Lake Teaneck deposits**—Two ice-marginal deltas, as much as 12.2 m (40 ft) thick; and lake-bottom silt and fine sand as much as 9.1 m (30 ft) thick. Delta-plain altitude is 34 m (110 ft); the spillway altitude is 32 m (105 ft). The lake basin occupied the north-draining Hirshfeld Brook valley; the spillway is on a local drainage divide. The lake lowered to the level of glacial Lake Hackensack, Kill Van Kull stage (unit Qrhk), when the ice margin retreated north of the Bergenfield area

Qrwt **Glacial Lake Watsessing deposits**—Unit includes deposits of four lake stages, undifferentiated. Consists of three ice-marginal deltas, as much as 18.3 m (60 ft) thick; and lake-bottom silt, fine sand, and clay as much as 15.2 m (50 ft) thick. Delta-plain altitudes lower from 56 m to 37 m (185–120 ft); spillway altitudes are 55 m, 52 m, 37 m, and 30 m (180 ft, 170 ft, 120 ft, and 100 ft). The lake basin occupied the Second River valley; lake spillways are on the Second River-Elizabeth River drainage divide. The lake drained when the ice margin retreated northeast of the Belleville area

Qrwo **Glacial Lake Woodbridge deposits**—Three ice-marginal deltas, as much as 39.6 m (130 ft) thick; glaciolacustrine fans as much as 21.3 m (70 ft) thick; and lake-bottom silt, clay, and fine sand as much as 18.3 m (60 ft) thick. Delta-plain altitudes rise from 30 m to 37 m (100–120 ft); the spillway altitude is 18 m (60 ft). The lake basin occupied the southern part of the Rahway River basin; the lake spillway is on the Rahway River–Woodbridge Creek drainage divide. The lake drained when the ice margin retreated north of the Rahway area

Qrab **Glacial Lake Ashbrook deposits**—Unit includes deposits of two lake stages, undifferentiated. Consists of two ice-marginal deltas and one fluviodelta, as much as 18.3 m (60 ft) thick; and lake-bottom silt, clay, and fine sand as much as 24.4 m (80 ft) thick. Delta-plain altitudes are 26 m (85 ft); spillway altitudes are 26 m and 23 m (85 ft and 75 ft). The lake basin occupied the Robinsons Branch valley; the initial spillway is on the Rahway River–Raritan River drainage divide over the Perth Amboy moraine (unit Qram); the lower spillway is on the Robinsons Branch–South Branch Rahway River divide. The lake level lowered to the glacial Lake Woodbridge level (unit Qrwo) when the ice margin retreated north of the Middlesex Reservoir area

Qrhd **Glacial Lake Hudson deposits**—Subsurface unit (section *A–A'*). Consists of glaciolacustrine fans as much as 24.4 m (80 ft) thick; and lake-bottom silt, clay, and minor fine sand as much as 36.6 m (120 ft) thick. The lake basin occupied the glacially overdeepened Hudson River valley, which was dammed by the terminal moraine at The Narrows; the spillway was over bedrock at an altitude of -9.1 m (-30 ft) at Hell Gate in the East River (fig. 3). The lake lowered as the moraine dam was eroded below -21 m (-70 ft); the lake sediments are overlain by estuarine sediments related to postglacial sea-level rise

Qrbn **Glacial Lake Bayonne deposits**—Unit includes lake-bottom and deltaic deposits of a high lake stage, undifferentiated. Consists of four ice-marginal deltas, as much as 45.7 m (150 ft) thick; and lake-bottom silt, sand, and clay as much as 82.3 m (270 ft) thick. Delta-plain altitudes rise from 6 m to 9 m (20–30 ft). The lake basin occupied the lowlands in the area of Arthur Kill, Kill Van Kull, Newark Bay, Upper New York Bay, and the East River, which were dammed by the Perth Amboy moraine (unit Qram) and the terminal moraine in New York at The Narrows (fig. 3); the higher spillway was across the moraine at an altitude of about 9 m (30 ft) at Richmond Valley on southwestern Staten Island, N.Y.; the lower lake spillway eroded across the moraine at Perth Amboy at the present altitude of about -9 m (-30 ft). Glacial Lake Bayonne lowered to the level of glacial Lake Hackensack, Kill Van Kull stage, when the ice margin retreated to the Secaucus area. In the Hudson and East River valleys, Lake Bayonne lowered to the level of glacial Lake Hudson when the ice margin retreated north of western Long Island

Deposits of small glacial lakes and ponds

Qrlu **Small glacial lake deposits, undifferentiated and not correlated**—Minor deltaic deposits of sand and gravel, generally less than 15.2 m (50 ft) thick

Qriu **Ice-contact deposits, undifferentiated and not correlated**—Sand and gravel, coarse gravel, and minor sandy flowtill or ablation till at the surface. Deposits are in hummocky hills and ridges, locally transverse to ice-flow direction. Generally less than 45.7 m (150 ft) thick

CENTRAL AND EASTERN HIGHLANDS

Qrhw **Hewitt deposits**—Deltaic deposits in four lake basins, as much as 30.5 m (100 ft) thick. Delta surface altitudes range from 213 m to 114 m (700–375 ft); spillway altitudes range from 210 m to 113 m (690–370 ft). Lake basins occupied north-draining tributary valleys south of the Wanaque River valley. Higher spillways drained south across local drainage divides; lower spillways drained east over local divides. The lowest lakes drained when the ice margin retreated north of the Wanaque River valley

Qrrd **Rudeville deposits**—Deltaic deposits in three lake basins, as much as 24.4 m (80 ft) thick. Delta-plain and collapsed-delta surface altitudes range from 213 m to 191 m (700–625 ft); spillway altitudes range from 207 m to 192 m (680–630 ft). Lake basins occupied three separate north-draining valleys along the base of Hamburg Mountain; the spillways drained south over local divides. The lowest lakes drained when the ice margin retreated north of each valley

Qruv **Union Valley deposits**—Three ice-marginal deltas, as much as 21.3 m (70 ft) thick. Aggraded alluvial-surface altitudes rise from 229 m to 268 m (750–880 ft). The lake basins occupied the Kanouse Brook valley, which was dammed by deposits of glacial Lake Green Pond (unit Qrgp); the highest spillway was over the sediment dam at an altitude of about 226 m (740 ft). Meltwater deposition ceased when the ice margin retreated northward into the basin of glacial Lake Greenwood (unit Qrgr)

Qrws **West Brook deposits**—Deltaic deposits in nine lake basins, locally highly collapsed and containing poorly sorted sediments, as much as 36.6 m (120 ft) thick. Delta-plain or collapsed-delta surface altitudes range from 306 m to 108 m (1005–355 ft); spillway altitudes range from 305 m to 107 m (1000–350 ft). Lake basins are in tributary valleys on the south side of West Brook valley. Higher spillways drained south over the West Brook divide; lower spillways drained east over local divides in the West Brook valley. The lowest lakes drained when the ice margin retreated north of the West Brook valley

Qrmp **Macopin deposits**—Deltaic deposits in six lake basins. Deposits locally are highly collapsed and contain poorly sorted sediments; total thickness is as much as 61.0 m (200 ft). Delta-plain or collapsed-delta surface altitudes range from 259 m to 126 m (850–415 ft); spillway altitudes range from 259 m to 125 m (850–410 ft). Lake basins are chiefly in southerly tributary valleys of the Pequannock River basin and in one valley in the Rockaway River basin. Higher spillways are on the Rockaway-Pequannock drainage divide; lower spillways are on local divides in the Pequannock River valley. The lowest lake drained as the ice margin retreated north of the Riverdale area

Qrbv

Berkshire Valley deposits—Five ice-marginal deltas and one fluviodelta, as much as 61.0 m (200 ft) thick; minor glaciolacustrine fans; and lake-bottom sand and silt in the subsurface, as much as 36.6 m (120 ft) thick. Delta-plain altitudes rise from 213 m to 264 m (700–865 ft). Lake basins occupied the upper Rockaway River valley, which was dammed by the Budd Lake moraine (unit Qnbm) and successive Berkshire Valley deposits. The initial spillway was over the moraine dam; spillways for successively higher lakes were over aggraded deltaic deposits (unit Qrbv). Meltwater deposition ceased when the ice margin retreated north of the Newfoundland area

Qrsk

Stockholm deposits—Deltaic deposits in four lake basins, locally highly collapsed and containing minor poorly sorted sediments, as much as 42.7 m (140 ft) thick; and lake-bottom silt and fine sand beneath swamp deposits. Collapsed-delta surface altitudes range from 349 m to 312 m (1145–1025 ft); spillway altitudes range from 351 m to 311 m (1150–1020 ft). Lake basins occupied four separate tributary valleys on the south side of the Pequannock River valley. Higher spillways drained south over the Rockaway-Pequannock divide and local divides; lower spillways drained east over local divides in the Pequannock basin. The lowest lakes drained when the ice margin retreated north of the Pequannock River valley

Qrsm

Sussex Mills deposits—Deltaic deposits of two lake stages, undifferentiated, as much as 16.8 m (55 ft) thick; and lake-bottom sand and silt in the subsurface, as much as 12.2 m (40 ft) thick. Delta-plain altitudes lower from 251 m to 223 m (825–730 ft); spillway altitudes are 248 m and 221 m (815 ft and 725 ft). The lake basins occupied a tributary valley of the Pequest River; spillways are over local drainage divides. Meltwater deposition ceased after the ice margin retreated north of the Sussex Mills area and the lower lake drained into the Pequest River valley

Qrbg

Bowling Green deposits—Deltaic deposits, locally highly collapsed and containing minor poorly sorted sediments, as much as 36.6 m (120 ft) thick. Delta surface altitudes lower from 358 m to 300 m (1175–985 ft); spillway altitudes are 357 m and 299 m (1170 ft and 980 ft). The lake basin occupied a north-draining valley on the north side of Bowling Green Mountain; the higher spillway is on the Rockaway River–Musconetcong River divide; the lower spillway drained eastward across a local divide. The lower lake drained when the ice margin retreated north of the valley

Qrsn

Shawnee deposits—Deltaic deposits in three lake basins, as much as 18.3 m (60 ft) thick. Collapsed-delta surface altitudes range from 331 m to 290 m (1085–950 ft); spillway altitudes range from 332 m to 290 m (1090–950 ft). The lake basins occupied separate tributary valleys on the east side of the Beaver Brook valley. Higher spillways drained east over the Rockaway River–Musconetcong River divide; lower spillways drained south across local divides. The lowest lakes drained or lowered to the level of glacial Lake Hopatcong (unit Qrhp) when the ice margin retreated north of the Lake Shawnee area

Qrwb

Wills Brook deposits—Deltaic deposits of three lake stages, undifferentiated, as much as 16.8 m (55 ft) thick, and ice-channel deposits. Delta-plain altitudes lower from 259 m to 238 m (850–780 ft); spillway altitudes are 259 m and 236 m (850 ft and 775 ft). The lake basin occupied the lower Wills Brook drainage basin; lake spillways are in eroded till over a local drainage divide. The lower lake stage drained when the ice margin retreated to the Waterloo area, where deposition continued in ice channels

Qrwl

Waterloo deposits—Cobble gravel of glacial outwash deposits underlying till of the Budd Lake moraine (unit Qnbm), 6.1 to 22.9 m (20–75 ft) thick. Unit includes subsurface deltaic sand and minor silty sand, as much as 30.5 m (100 ft) thick

KITTATINNY VALLEY, BASINS OF PEQUEST AND MUSCONETCONG RIVERS AND POHATCONG CREEK, AND WESTERN HIGHLANDS

Qrwn

Wantage deposits—Deltaic deposits of two lake stages, undifferentiated, as much as 30.5 m (100 ft) thick. Delta-plain altitudes lower from 201 m to 189 m (660–620 ft); spillway altitudes are 198 m and 184 m (650 ft and 605 ft). The lake basin occupied a tributary valley of the Wallkill River; lake spillways are across local drainage divides. The lakes drained when the ice margin retreated north into New York

Qrwbp

West Branch Papakating deposits—Deltaic deposits of four lake stages, undifferentiated. Ice-marginal deltas and fluviodeltas as much as 12.2 m (40 ft) thick; and lake-bottom sand and silt in the subsurface as much as 12.2 m (40 ft) thick. Delta-plain altitudes lower from 250 m to 203 m (820–665 ft); spillway altitudes are 242 m, 230 m, 215 m, and 203 m (795 ft, 755 ft, 705 ft, and 665 ft). The lake basins occupied tributary valleys in the West Branch Papakating Creek drainage basin; spillways are over local drainage divides

Qrup

Paulinskill deposits—Ten ice-marginal deltas, as much as 18.3 m (60 ft) thick; minor glaciolacustrine fans; and lake-bottom sand, silt, and clay in the subsurface, as much as 12.2 m (40 ft) thick. Delta-plain altitudes rise from 146 m to 177 m (480–580 ft). The lake basins occupied the main part of the upper Paulins Kill valley, which was dammed at the south end by older deltaic deposits (unit Qrpk) and locally by successive, aggraded deltaic deposits (unit Qrup)

Qrpl

Plymouth Pond deposits—Deltaic and minor glaciolacustrine fan deposits of multiple lake stages, undifferentiated, as much as 15.2 m (50 ft) thick; and lake-bottom sand and silt in the subsurface, as much as 12.2 m (40 ft) thick. Delta-plain altitudes range from 299 m to 287 m (980–940 ft). The lake basins occupied several tributary valleys to the Paulins Kill valley; spillways are over local drainage divides

Qrupq **Pequest deposits**—Four ice-marginal deltas, as much as 25.9 m (85 ft) thick; minor glaciolacustrine fans; and lake-bottom sand and silt in the subsurface, as much as 19.8 m (65 ft) thick. Delta-plain altitudes rise from 171 m to 190 m (560–625 ft). The lake basins occupied the upper part of the Pequest River valley, which was dammed initially by glacial Lake Pequest deposits (unit Qrpq). Lake spillways were over the sediment dam. Meltwater deposition in these lakes ceased when the ice margin retreated north into the glacial Lake Newton basin (unit Qrn)

Qran **Andover deposits**—Deltaic, glaciolacustrine fan, and ice-channel deposits of two lake stages, undifferentiated, as much as 15.2 m (50 ft) thick; and lake-bottom sand and silt in the subsurface, as much as 12.2 m (40 ft) thick. Delta-plain and collapsed-delta surface altitudes lower from 215 m to 198 m (705–650 ft); spillway altitudes are 218 m and 197 m (715 ft and 645 ft). The lake basins occupied a tributary valley of the Pequest River valley; spillways are over local drainage divides. The lower lake drained into the upper Pequest River valley when the ice margin retreated north of the Andover area

Qrml **Mountain Lake deposits**—One ice-marginal delta, as much as 35.1 m (115 ft) thick; and lake-bottom sand, silt, and clay as much as 15.2 m (50 ft) thick. Delta-plain altitude is 162 m (530 ft). The lake basin occupied the Mountain Lake Brook drainage basin, which was dammed by the Mountain Lake moraine (unit Qnlm). The lake spillway over the moraine was at about 158 m (520 ft) altitude. Meltwater deposition in the lake ceased when the ice margin retreated north of Jenny Jump Mountain

DELAWARE RIVER BASIN

Qrmn **Minisink deposits**—Unit consists of five ice-marginal deltas with aggraded glaciofluvial deposits, and multiple fluviodeltas, as much as 30.5 m (100 ft) thick; and lake-bottom sand, silt, and clay in the subsurface, as much as 22.9 m (75 ft) thick. Delta-plain and aggraded alluvial surface altitudes rise from 128 m to 160 m (420–525 ft). The lake basins occupied the Delaware River valley north of Delaware Water Gap, which was dammed initially by Columbia deposits (unit Qrcl). The lowest lake spillway was over the sediment dam; spillways for successively higher lakes were over aggraded deltaic deposits (unit Qrmn). Meltwater deposition of deltaic deposits ceased after the ice margin retreated north of the confluence of the Delaware and Neversink Rivers, at the northernmost tip of New Jersey

Qrsb **Shimers Brook deposits**—Deltaic deposits of two lake stages, undifferentiated, as much as 30.5 m (100 ft) thick; and lake-bottom sand and fine sand in the subsurface, as much as 15.2 m (50 ft) thick. Delta-plain altitudes lower from 207 m to 195 m (680–640 ft); spillway altitudes are 204 m and 191 m (670 ft and 625 ft). The lake basin occupied the north-draining Shimers Brook valley, which was dammed by Flatbrook deposits and high ice-channel deposits (units Qrf, Qriu); lake spillways are across Flatbrook deposits and a local drainage divide. The lower lake stage lowered to the level of glacial Lake Millbrook (unit Qrmb) when the ice margin retreated north of the Millville area

Qrwh **White Brook deposits**—Deltaic deposits of two lake stages, undifferentiated, as much as 12.2 m (40 ft) thick; and lake-bottom sand and silt as much as 15.2 m (50 ft) thick. Delta-plain altitudes lower from 221 m to 209 m (725–685 ft); spillway altitudes are 219 m and 209 m (720 ft and 685 ft). The lake basin occupied the White Brook valley; spillways are across local drainage divides between the Flat Brook, White Brook, and Delaware River basins. The lake drained after the ice margin retreated north of the confluence of White Brook and the Delaware River

Qrf **Flatbrook deposits**—Multiple ice-marginal deltas with aggraded glaciofluvial deposits, as much as 24.4 m (80 ft) thick; and lake-bottom sand, silt, and clay in the subsurface, as much as 15.2 m (50 ft) thick. Delta-plain and aggraded alluvial surface altitudes rise from 128 m to 232 m (420–760 ft). Lake basins occupied a series of basins that were dammed by ice blocks and drift at Wallpack Bend in the Delaware River valley; the lowest spillway was over Minisink deposits (unit Qrmn) in the area of the confluence of Flat Brook and the Delaware River

Qrcl **Columbia deposits**—Unit consists of multiple ice-marginal deltas with aggraded glaciofluvial deposits, fluviodeltas, and minor alluvial terrace deposits as much as 30.5 m (100 ft) thick; and lake-bottom sand, silt, and clay in the subsurface, as much as 18.3 m (60 ft) thick. Delta-plain and aggraded alluvial surface altitudes rise from 99 m to 149 m (325–490 ft). The lake basins occupied a valley reach that was dammed by ice blocks and drift between the area of Manunka Chunk and the Delaware Water Gap; the lowest spillway was over Belvidere outwash deposits (unit Qrbl). Meltwater deposition ceased when the ice margin retreated north of the Delaware Water Gap

Qrbe **Bridgeville deposits**—Multiple ice-marginal deltas as much as 18.3 m (60 ft) thick; and lake-bottom sand and silt in the subsurface, as much as 12.2 m (40 ft) thick. Delta-plain altitudes rise from 98 m to 111 m (320–365 ft). The lake basin occupied the Delaware River valley in the Belvidere area and the lower reaches of the Beaver Brook and Pequest River valleys near the Bridgeville area, which were dammed by the Foul Rift moraine, Belvidere outwash deposits (units Qkfm and Qrbl), and ice. Lake spillways were over the sediment dams

BASINS OF UPPER PASSAIC AND RAMAPO RIVERS AND UPPER HOHOKUS BROOK

Qrv **Ramapo Valley deposits**—Five ice-marginal deltas and two fluviodeltas, as much as 50.3 m (165 ft) thick; and lake-bottom sand and silt in the subsurface as much as 6.1 m (20 ft) thick. Delta-plain altitudes rise from 76 m to 91 m (250–300 ft). The lake basin occupied the middle and upper (in New Jersey) Ramapo River valley, which was dammed by Ramapo deposits (unit Qrrm); the lowest spillway was over Ramapo deposits. Meltwater deposition in these lakes ceased when the ice margin retreated into New York

Qrrm **Ramapo deposits**—Multiple ice-marginal deltas, as much as 38.1 m (125 ft) thick; and lake-bottom sand in the subsurface, as much as 9.1 m (30 ft) thick. Delta-plain altitudes rise from 61 m to 69 m (200–225 ft). The lake basin occupied the lower Ramapo drainage basin, which was dammed by Pompton Plains outwash deposits (unit Qrpp); the spillway was over the sediment dam. Meltwater deposition ceased when the ice margin retreated north of the Oakland area

Qrfr **Franklin Lakes deposits**—Deltaic, ice-channel, and esker deposits of three lake stages, undifferentiated, as much as 42.7 m (140 ft) thick. Delta-plain altitudes lower from 146 m to 119 m (480–390 ft); the highest spillway altitude is 133 m (435 ft). The glacial lake basins are in the Pond Brook tributary valley of the Ramapo River basin; the highest spillway is through the gap in Preakness Mountain south of Franklin Lake; lower spillways were over ice and drift in the Ramapo River valley. The lakes drained when the ice margin retreated north of the Oakland area

Qrprk **Preakness deposits**—Multiple coarse-grained deltaic deposits, as much as 54.9 m (180 ft) thick. Surface altitudes range from 134 m to 143 m (440–470 ft). Meltwater deposition ceased when the surrounding stagnant ice melted and the local lake level lowered to the level of glacial Lake Passaic, Moggy Hollow stage (unit Qrpm)

HACKENSACK, RAHWAY, LOWER PASSAIC, AND LOWER RARITAN RIVER BASINS

Qrtp **Tappan deposits**—Sand and gravel, coarse gravel, and sandy flowtill or ablation till at the surface; and sand and sand-and-gravel in the subsurface, as much as 30.5 m (100 ft) thick. Surface altitudes range from 24 m to 40 m (80–130 ft)

Qrnw **Norwood deposits**—Sand and gravel, as much as 18.3 m (60 ft) thick. Surface altitudes range from 21 m to 40 m (70–130 ft). Meltwater deposition ceased when the ice margin retreated north of the Norwood area

Qrmh **Mahwah deposits**—Deltaic, ice-channel, and esker deposits of two lake stages, undifferentiated, as much as 45.7 m (150 ft) thick. Delta-plain altitudes lower from 110 m to 101 m (360–330 ft); spillway altitudes are 105 m and 99 m (345 ft and 325 ft). The lake basins occupied the north-draining Masonicus Brook basin; the higher spillway is across Hohokus deposits (unit Qrho). The lower lake drained when the ice margin retreated north of the West Mahwah area

Qrms **Musquapsink deposits**—One ice-marginal delta, as much as 33.5 m (110 ft) thick; minor glaciolacustrine fans; and lake-bottom sand and silt in the subsurface, as much as 9.1 m (30 ft) thick. Delta-plain altitude is 21 m (70 ft). The lake basin occupied the Musquapsink Brook valley, which was dammed by glacial Lake Paramus deposits (unit Qrpr); the highest lake spillway was over the sediment dam at an altitude of about 21 m (70 ft). The lake level lowered to the level of glacial Lake Hackensack, Kill Van Kull stage (unit Qrhk), when the ice margin retreated north of the Westwood area

Qrho **Hohokus deposits**—Deltaic, extensive esker, and minor ice-channel deposits of five lake stages, undifferentiated, as much as 30.5 m (100 ft) thick. Delta-plain altitudes lower from 137 m to 73 m (450–240 ft); spillway altitudes lower from 136 m to 70 m (445–230 ft). The lake basins occupied tributary valleys of the Hohokus Brook and Goffle Brook valleys; lake spillways are across local drainage divides. The lowest lake drained when till in the lowest dam in the Ridgewood area was eroded

Qrhh **Highwood deposits**—Sand-and-gravel and coarse gravel at the surface; and sand and sand-and-gravel in the subsurface; total thickness as much as 18.3 m (60 ft). Surface altitudes range from 27 m to 37 m (90–120 ft). Meltwater deposition ceased when the ice margin retreated north of the Tenafly area

Qrdw **Delawanna deposits**—Deltaic deposits in three lake basins, as much as 24.4 m (80 ft) thick. Delta-plain altitudes range from 37 m to 15 m (120–50 ft); spillway altitudes range from 37 m to 12 m (120–40 ft). The lake basins are in tributary valleys chiefly on the west side of the Passaic River valley; spillways are over local divides or over sediment dams in the Passaic Valley. The lowest lake drained when the sediment dam eroded

Qrsh **Sandy Hill deposits**—Deltaic and glaciolacustrine fan deposits of two lake stages, undifferentiated;

as much as 18 m (60 ft) thick. Delta-plain altitudes lower from 44 m to 34 m (145–110 ft); spillway altitudes are 43 m and 29 m (140 ft and 95 ft). The lake basin is in a tributary basin of the Passaic River valley; lake spillways are across local drainage divides. The lower lake drained when the ice margin retreated north of the Paterson area

Qrhn **Haledon deposits**—Deltaic and ice-channel deposits, as much as 15.2 m (50 ft) thick. Surface altitudes range from 85 m to 61 m (280–200 ft). The lake basin occupied the lower part of the Molly Ann Brook drainage basin; lake spillways were along the ice margin on the north side of First Watchung Mountain (Garrett Mountain). The lake drained when the ice margin retreated north of Garrett Mountain

Qrbm **Bloomfield deposits**—Sand and gravel, coarse gravel, and till at the surface; total thickness as much as 39.6 m (130 ft). Surface altitudes range from 43 m to 55 m (140–180 ft). Meltwater deposition ceased when the ice margin retreated north of the Belleville area

Qrv **Verona deposits**—Deltaic deposit, as much as 37 m (120 ft) thick; minor glaciolacustrine fan deposits; and minor lake-bottom silt and fine sand in the subsurface. Delta-plain altitude is 128 m (420 ft); spillway altitude is 125 m (410 ft). The lake occupied the north-draining valley of the Peckman River; the spillway is on the Peckman River–Rahway River divide. The lake lowered to the level of glacial Lake Passaic, Moggy Hollow stage (unit Qrpm), when the ice margin retreated north of the Cedar Grove area

Qrez **Elizabeth deposits**—Deltaic deposits, as much as 30.5 m (100 ft) thick; terrace deposits; and lake-bottom sand and silt in the subsurface, as much as 15.2 m (50 ft) thick. Delta-plain altitudes rise from 9 m to 21 m (30–70 ft); the spillway altitude was 8 m (25 ft). The lake basin occupied a northeast-trending glacially eroded trough north of the Elizabeth River; the lake spillway was over till, subsequently eroded. The lake drained to the level of glacial Lake Bayonne (unit Qrbn) when the ice margin retreated north of the Weequahic Lake area

Qrgh **Galloping Hills deposits**—Sand and gravel at the surface; and sand and sand-and-gravel in the subsurface; total thickness as much as 61.0 m (200 ft); unit includes esker deposits. Surface altitudes range from 43 m to 49 m (140–160 ft). Meltwater deposition ceased when the ice margin retreated to the Union area

Qrnm **Nomahegan deposits**—Multiple ice-marginal deltas in two lake basins, as much as 30.5 m (100 ft) thick. Delta-plain and collapsed-delta surface altitudes are 43 m and 27 m (140 ft and 90 ft). The lake basins occupied a tributary valley to the Rahway River valley that was dammed by the Perth Amboy moraine (unit Qram); spillways are over the moraine dam and till at altitudes of 41 m and 34 m (135 ft and 110 ft). The lakes lowered to the level of glacial Lake Woodbridge (unit Qrwo) when the ice margin retreated east of the Garwood area

Qrsu **Summit deposits**—Four ice-marginal deltas in two lake basins, as much as 30.5 m (100 ft) thick. Delta-plain and collapsed-delta surface altitudes are 119 m and 94 m (390 ft and 310 ft). The lake basins occupied two upland basins that were dammed by the Perth Amboy moraine (unit Qram); spillways are over the moraine at altitudes of 113 m and 94 m (370 ft and 310 ft). The lower lake lowered to the level of glacial Lake Woodbridge (unit Qrwo) when the ice margin retreated east of the Milburn area

LATE WISCONSINAN TILLS AND MORAINE DEPOSITS

Tills—Sandy, sandy-to-silty, and silty-to-clayey deposits, consisting of a very poorly sorted matrix of sand, silt, and clay (fig. 7) containing commonly 5 to 50 percent (by volume) pebbles, cobbles, and boulders. Generally nonstratified and homogeneous; chiefly compact but locally loose. Gravel clasts are subangular to subrounded; some have been glacially faceted and striated; most gravel clasts and sand grains are nonweathered; many gravel clasts have thin silt caps that adhere to their upper surfaces. Gravel composed of local bedrock constitutes 50 to 90 percent of clasts. The distinguishing color, grain size, and composition of three till formations (units Qr, Qn, and Qk) are related to the underlying bedrock source and local ice-flow directions (compare fig. 2 with fig. 6). Till deposits of these units include two facies: (1) a compact, nonlayered till with subhorizontal fissility and subvertical joints, few thin lenses of sorted silt and fine sand, and gravel clasts with long-axis fabrics generally oriented in the direction of glacier flow; this till facies is subglacial till of lodgement or meltout origin; it is overlain locally by (2) a noncompact, sandier, locally layered till, containing as much as 50 percent gravel clasts, locally very bouldery, with few beds of sorted and stratified sand, silt, and clay; this till facies is chiefly a supraglacial till of meltout or local flowtill origin, which may contain other supraglacial materials, colluvium, or solifluction debris. The compact till is present beneath hillslopes that faced the direction of glacier flow, in small drumlins, and at the surface of large drumlins, as a smooth till-sheet deposit in wide lowland areas, and in some moraines; thickness is 0.9 to 24.4 m (3–80 ft). Compact till also is present locally in areas of numerous bedrock outcrops, where it is generally less than 3.0 m (10 ft) thick. The loose bouldery till forms a thin, discontinuous veneer overlying the compact till and bedrock; it forms small recessional moraines in the Highlands in which it is more than 3.0 m (10 ft) thick. Till generally overlies bedrock and underlies stratified meltwater deposits in valleys. In some large valleys near the terminal moraine, the morainal till overlies older stratified deposits (sections *D–D′*, *I–I′*, *J–J′*, and *K–K′*). Till units include thin surface colluvium and small deposits of stratified meltwater sediments locally. Soils chiefly are alfisols with argillic B horizons, 0.2 to 0.6 m (8–24 in.) thick, overlying Bx fragipan horizons, 0.4 to 1 m (15–40 in.) thick, which overlie the C horizon in slightly weathered till, oxidized as deep as 2 m (6.6 ft). In shallow-rock areas or in tills with abundant gravel, soils are inceptisols with cambic B horizons, 0.2 to 0.6 m (8–24 in.) thick, above Bx fragipan horizons in slightly weathered till

Qr

Rahway Till—Dark-reddish-brown (2.5*YR* 3/4) to reddish-brown (5*YR* 5/4) to dark-brown (7.5*YR* 4/4) to yellowish-brown (10*YR* 5/4) sandy-to-silty-to-clayey till (fig. 7), containing commonly 5 to 20 percent pebbles, cobbles, and boulders of gneiss, sandstone, basalt, and quartzite. In areas underlain by shale and sandstone (figs. 2 and 4), the matrix contains abundant shale and siltstone fragments and reddish-brown silt and clay. Till is noncalcareous and chiefly compact, with a firm to hard consistency; gravel clasts are generally nonweathered, subangular to subrounded; gravel clasts of fine-grained sandstone commonly are striated; and rounded gravel clasts are abundant locally (fig. 8). Deposit contains few thin lenses of stratified gravel, sand, and silt; minor iron-manganese stain is on joint faces locally. Thickness generally is 3.0 to 9.1 m (10–30 ft), locally as much as 36.6 m (120 ft) (section *D–D'*); as much as 15.2 m (50 ft) in small drumlins. Unit includes brown (7.5*YR* 4/4) to strong brown (7.5*YR* 5/6) silty till, containing 5 to 35 percent pebbles, cobbles, and boulders of basalt or diabase, sandstone, gneiss, and quartzite. In areas underlain by basalt or diabase, and on sandstone and serpentinite bedrock east of the Palisades (fig. 4), till is compact to loose, of very soft to firm consistency, locally exhibiting subhorizontal fissility. Thickness generally is less than 1.8 m (6 ft)

Qn
Qnu

Netcong Till—Light-gray (10*YR* 7/2) to pale-brown (10*YR* 6/3) to dark-yellow-brown (10*YR* 4/4) to brown (10*YR* 5/3), sandy till and some silty till (fig. 7), containing commonly 5 to 30 percent pebbles, cobbles, and boulders of gneiss, quartzite, carbonate rock, and sandstone. In areas underlain by gneiss (figs. 2 and 4), matrix contains quartz, feldspar, nonweathered heavy minerals and micas; matrix silt-clay fraction is gray, noncalcareous, chiefly compact, and of firm to hard consistency. Gravel clasts generally are nonweathered, except for some gneiss clasts that have thin weathering rinds; some gneiss clasts in till in the southern part of the area are thoroughly weathered; some scarce carbonate rock clasts are thoroughly weathered. Unit includes reddish-brown (5*YR* 4/3) to pale-brown (10*YR* 6/3) silty till and minor clayey till, containing quartzite and gneiss clasts; in areas underlain by shale near Green Pond Mountain (fig. 4); it is noncalcareous and compact. Till is strong brown (7.5*YR* 5/6) locally where it contains weathered and iron-manganese-stained gravel clasts and sand grains. Thickness of compact till generally is 3.0 to 6.1 m (10–20 ft). Unit includes loose sandy till (unit Qnu; see fig. 7), containing 10 to 40 percent pebbles and cobbles and locally very numerous boulders of gneiss; the sandy till is locally layered and contains few thin beds of sorted and stratified gravel, sand, silt, and clay; thickness is 3.0 to 12.2 m (10–40 ft). The loose sandy till underlies areas of hummocky topography in the Highlands and small recessional moraines (units Qnsm, Qnpm, and Qncm) in which it is more than 3.0 m (10 ft) thick

Qk

Kittatinny Mountain Till—Silty-to-sandy tills, noncalcareous and locally calcareous, containing clasts and matrix derived from shale, sandstone, quartzite, conglomerate, and carbonate rocks (figs. 2 and 4); matrix contains nonweathered quartz, feldspar, shale and siltstone fragments, heavy minerals, and dolostone and limestone fragments locally. Matrix silt-clay fraction is gray, chiefly compact, and of firm to hard consistency; gravel clasts are generally nonweathered. Three varieties of till are recognized:

(1) Light-olive-brown (2.5*Y* 5/4) to reddish-brown (5*YR* 4/3) silty-to-sandy till, containing pebbles and cobbles of quartzite, sandstone, and shale, and boulders of quartzite; in areas underlain by quartzite, shale, and sandstone on Kittatinny Mountain the till is noncalcareous and compact. Thickness is as much as 45.7 m (150 ft)

(2) Olive-gray (5*Y* 5/2) to olive-brown (2.5*Y* 5/4) to dark-grayish-brown (10*YR* 3/2) silty till, containing chips, pebbles, and cobbles of shale, slate, brown and gray sandstone, and quartzite. Matrix contains sand-sized grains of shale in areas underlain by shale and slate in the western part of the Kittatinny Valley (the lowlands east of Kittatinny Mountain); it is noncalcareous and compact. Thickness reportedly is as much as 30.5 m (100 ft)

(3) Light-olive-brown (2.5*YR* 5/4) silty till containing pebbles, cobbles, and boulders of carbonate rock, gneiss, sandstone, and shale. In eastern part of Kittatinny Valley, matrix is compact and contains sand-sized grains of shale; it is calcareous but reacts weakly to dilute hydrochloric acid. Calcareous till is leached to a depth of about 0.6 m (24 in.). Thickness generally is less than 3.0 m (10 ft)

Moraine deposits—Composed chiefly of till, and commonly more than 15.2 m (50 ft) thick; characterized by hummocky or ridge-and-kettle topography, or local transverse ridges. Two classes of moraines are recognized: (1) recessional moraines, and (2) segments of the late Wisconsinan terminal moraine. Recessional moraines consist chiefly of loose to poorly compact, stony till, and minor stratified gravel, sand, and silt in discontinuous, bouldery, transverse ridges; surface morphology consists of ridge-and-kettle and knob-and-kettle topography. Hillslopes in the outer (southerly) parts of some moraines are relatively steep, and slopes in inner (northerly) parts of moraines are moderate. Recessional moraine deposits are as much as 22.9 m (75 ft) thick, and they commonly overlie promorainal meltwater deposits of the Rockaway Formation (sections *A–A'*, *B–B'*, and *H–H'*). Segments of the late Wisconsinan terminal moraine are chiefly compact till, and include local glacially transported lenses and blocks of stratified gravel, sand, silt, and clay; the moraine also contains loose, stony till, flowtill and colluvial deposits, local boulder accumulations, and minor meltwater sediments. Ridge-and-kettle and hummocky surface morphology is common. Terminal moraine deposits overlie promorainal meltwater deposits of the Rockaway Formation in some valleys (sections *D–D′*, *G–G′*, *I–I′*, *J–J′*, and *K–K′*); they overlie bedrock and underlie meltwater deposits in other valleys and in upland areas (sections *D–D′* and *H–H′*). Terminal moraine deposits are as much as 68.6 m (225 ft) thick

Recessional Moraines

Qncm **Cherry Ridge moraine deposit**—Netcong Till; as much as 18.3 m (60 ft) thick

Qnpm **Mud Pond moraine deposit**—Netcong Till; as much as 24.4 m (80 ft) thick

Qnsm **Silver Lake moraine deposit**—Netcong Till; as much as 18.3 m (60 ft) thick

Qklm **Libertyville moraine deposit**—Kittatinny Mountain Till; as much as 13.7 m (45 ft) thick

Qkmu **Moraine deposits, undifferentiated and not correlated**—Kittatinny Mountain Till; in small areas; as much as 9.1 m (30 ft) thick

Qkvm **Millville moraine deposit**—Kittatinny Mountain Till; as much as 9.1 m (30 ft) thick

Qksm **Steeny Kill Lake moraine deposit**—Kittatinny Mountain Till; as much as 13.7 m (45 ft) thick

Qkmm **Montague moraine deposit**—Kittatinny Mountain Till; as much as 19.8 m (65 ft) thick

Qkam **Augusta moraine deposit**—Kittatinny Mountain Till; as much as 19.8 m (65 ft) thick

Qkdm **Dingmans Ferry moraine deposit**—Kittatinny Mountain Till; as much as 19.8 m (65 ft) thick

Qkom / Qnom **Ogdensburg-Culvers Gap moraine deposit**—Kittatinny Mountain Till and Netcong Till; as much as 22.9 m (75 ft) thick

Qkgm **Franklin Grove moraine deposit**—Kittatinny Mountain Till; as much as 13.7 m (45 ft) thick

Segments of the Terminal Moraine

Qram **Perth Amboy moraine deposit**—Rahway Till; contains local glacially transported lenses and blocks of Cretaceous clay and sand; average thickness is about 21.3 m (70 ft); locally as thick as 61.0 m (200 ft)

Qnmm / Qrmm **Madison moraine deposit**—Rahway Till and Netcong Till; contains local glacially transported lenses and blocks of stratified sediments; includes local surface sand and gravel; average thickness is about 45.7 m (150 ft)

Qnlm **Mountain Lake moraine deposit**—Netcong Till; average thickness is about 24.4 m (80 ft)

Qnbm **Budd Lake moraine deposit**—Netcong Till; locally overlies stratified sediments of the Rockaway Formation and Lamington Formation, and Flanders Till; includes local surface sand and gravel. Average thickness is about 24.4 m (80 ft); locally as thick as 68.6 m (225 ft) (section *D–D′*)

Qktm / Qntm **Townsbury moraine deposit**—Kittatinny Mountain Till and Netcong Till; average thickness is about 24.4 m (80 ft)

Qkfm **Foul Rift moraine deposit**—Kittatinny Mountain Till; average thickness is about 15.2 m (50 ft)

MIDDLE WISCONSINAN TO PRE-ILLINOIAN ALLUVIAL DEPOSITS

Qw **Wharton alluvial deposits**—Subsurface unit (sections *D–D′* and *I–I′*). Sand and gravel alluvial deposits, probably including proglacial outwash deposits of the Lamington Formation (Illinoian) at the base; as much as 9.1 m (30 ft) thick

Qof **Fan deposits**—Sand, gravel, and minor silt; sand and gravel is poorly sorted. Gravel clasts are angular to subangular; gneiss clasts have weathering rinds 0.2 to 1 cm (0.1–0.4 in.) thick. Thickness of unit as much as 12.2 m (40 ft)

Qrto **Raritan upper terrace deposit**—Sand and gravel, and sand, silt, and clay in upper terrace along the Raritan River; sand and gravel is poorly sorted; clasts are gneiss, sandstone, quartzite, and chert; gneiss clasts have weathering rinds 0.2 to 1 cm (0.1–0.4 in.) thick. Surface altitudes slope from 61 m to 6 m (200–20 ft); unit is as much as 15.2 m (50 ft) thick. Ground-ice involutions deform surface sediments in several localities

ILLINOIAN GLACIAL MELTWATER DEPOSITS

Lamington Formation—Light-gray (10*YR* 7/1) to very pale brown (10*YR* 7/3-4) to pale-yellow (2.5*Y* 7/4), or light-brown (7.5*YR* 6/4) to reddish-brown (2.5*YR* 5/4) gravel, sand, and silt (fig. 8), stratified, poorly to well sorted; and reddish-brown (2.5*YR* 5/4) or dark-gray (10*YR* 4/1) silt and clay, stratified, moderately sorted. Color and mineralogic composition of the deposits are similar to the color and composition of underlying and northerly adjacent till and bedrock units. Gravel is polymict; gravel clasts are subrounded to well rounded, and variably weathered; many clasts have weathering rinds 0.2 to 1 cm (0.1–0.4 in.) thick, and many clasts are friable and disintegrated. Sand grains are generally nonweathered beneath the soil. Sand composition is highly variable, from lithic coarse sand to sublithic to subarkosic fine sand. The stratified sediments were deposited chiefly by glacial meltwater, and are divided into two groups of map units based on their sedimentary facies. Deposits of glacial-stream units contain three glaciofluvial facies. Deposits of glacial-lake units contain glacial deltaic sediments, which include glaciofluvial facies in topset sediments, delta foreset and bottomset facies, glaciolacustrine fan sediments, and lake-bottom facies. Stratified meltwater deposits are subdivided into map units on the basis of the distribution and altitudes of facies in different depositional basins, and on the basis of the position and facies relations of related alluvial, deltaic, fan, and lake-bottom deposits within the depositional basin of each unit. Soils in sand and gravel deposits are inceptisols with B horizons as thick as 0.9 m (34 in.), which overlie C horizons in sediments oxidized to more than 1.5 m (60 in.); gravel clasts have silt caps in the C horizon and in the upper part of the deposits. Soils in eolian sand, congelliturbate, colluvium, or solifluction deposits that are as much as 6.1 m (20 ft) thick and that overlie sand and gravel deposits contain ventifacts, and are alfisols with argillic B horizons, 0.6 to 0.9 m (22–34 in.) thick, which overlie the C horizon in oxidized sediments. Some of the stratified sediments of this unit were correlated in the northern belt of deposits of the Jerseyan drift of Salisbury (1902, *in* Bayley and others, 1914). Salisbury noted that stratified drift of the northern belt of drift was more extensive and less eroded than the deposits of the southern belt of the Jerseyan drift. This conclusion is supported by studies of clast weathering (MacClintock, 1940) and soil development

Deposits of glacial streams

Interbedded sand and gravel, moderately to poorly sorted, horizontally stratified. Deposits grade from (1) coarse gravel facies in ice-proximal heads of units, to (2) sand and gravel facies, to (3) pebbly coarse sand facies in distal parts of some units. Scattered boulders are common in ice-proximal parts of some deposits. The sand and gravel facies is most prevalent at the surface of the deposits; it consists of pebble- and cobble-gravel beds interbedded with beds of medium to coarse sand, and a few beds of fine sand or silt. Glacial-stream deposits originated as outwash deposits that accumulated in promorainal or ice-marginal outwash plains across wide valley areas, and as valley-train deposits, which are preserved as erosional terrace deposits that do not extend to ice-marginal heads of outwash; distal terrace deposits contain sediments locally derived from nonglacial sources. Glacial-stream deposits generally are 1.8 to 15.2 m (6–50 ft) thick, and locally are reported to be as thick as 30.5 m (100 ft)

Qld **Drakes Brook outwash deposit**—Sand and gravel, and coarse gravel of promorainal outwash and terrace deposits, as much as 30.5 m (100 ft) thick. Surface altitudes slope from 201 m to 198 m (660–650 ft)

Qlbr **Brainards outwash deposit**—Sand and gravel of terrace deposit; as much as 12.2 m (40 ft) thick. Surface altitudes in discontinuous terrace slope from 99 m to 67 m (325–220 ft). Unit includes local sand and gravel deposits with surface altitudes ranging from 122 m to 146 m (400–480 ft)

Deposits of glacial lakes

Sand, sand and gravel, and silty sand in deltaic, glaciolacustrine fan and ice-channel deposits; and fine sand, silt, and clay in lake-bottom deposits. Ice-marginal deltaic deposits have interbedded sand and gravel glaciofluvial topset beds 0.6 to 6.1 m (2–20 ft) thick; sandy colluvium, flowtill, or till is along some eroded ice-contact slopes. Coarse foreset and bottomset facies reportedly underlie topset beds. Total thickness of deltaic sediments is 6.1 to 45.7 m (20–150 ft). Glaciolacustrine fans are low ridges or knolls that contain sand-and-gravel and sand deposits, and minor till, flowtill, and fine-grained lake-bottom sediments. Lake-bottom deposits reportedly are clayey sand. Deposits of glacial lakes include ice-marginal deltas (glaciofluvial sediments shown by dot pattern) and lake-bottom deposits (dashed-line pattern); deltas generally have preserved flat tops, but slopes have been modified by erosion. The lake basins are in northward-draining valleys that were dammed by the ice margin. The spillway over bedrock for one lake is preserved (unit Qli). Ice-margin-position lines (fig. 3) show the extent of some ice dams. Deposits of small glacial lakes contain coarse deltaic sediments in hummocky ice-contact deposits, which form ridges that are topographically above adjacent deltaic deposits; ice-contact slopes have been erosionally modified. The deposits accumulated in small ponds in channels in stagnant ice; lake spillways were over ice or supraglacial sediment. The sediments in these ridges contain probable flowtill. The extent of Illinoian glacial Lake Shongum is indicated in figure 3

Qlh **Harmony Station deposits**—Deltaic deposits of two lake stages, undifferentiated, as much as 21.3 m (70 ft) thick. Delta-plain altitudes are 148 m and 130 m (485 ft and 425 ft). Lake spillways were across glacial ice in the Delaware River valley and local drainage divides. The lake basin occupied a tributary drainage basin which was dammed by the ice margin that extended through the water gap in Marble Mountain. The lake drained after ice in the gap melted and southward drainage was reestablished down the main part of the Delaware River valley

Qli **Glacial Lake Ironia deposits**—Two ice-marginal deltas, as much as 45.7 m (150 ft) thick; and lake-bottom sand, silt, and clay in the subsurface as much as 9.1 m (30 ft) thick. Delta-plain altitudes rise from 210 m to 213 m (690–700 ft); spillway altitude is 207 m (680 ft). The lake basin occupied a preglacial, north-draining tributary valley of the Rockaway River valley that was dammed by the ice margin; the lake spillway is across bedrock on the preglacial-basin drainage divide near the Milltown area. Meltwater deposition in the lake ceased when the ice margin retreated north of the Rockaway River valley in the Wharton area

Qls **Glacial Lake Shongum deposits**—Unit includes deposits of multiple lake stages, undifferentiated. Six ice-marginal deltas, as much as 45.7 m (150 ft) thick; and lake-bottom silt and fine sand as much as 24.4 m (80 ft) thick. Delta surface altitudes lower from 262 m to 195 m (860–640 ft); highest spillway altitude is 259 m (850 ft); altitudes of lower spillways are uncertain. The lake basin occupied the Mill Brook valley and an adjacent valley to the east that were dammed by the ice margin; the highest spillway was on the Rockaway River–Whippany River drainage divide, and lower spillways were eastward over local divides in the Rockaway River basin. The lake drained when the ice margin retreated north of the Rockaway area

Qlbn **Bernardsville deposits**—Two ice-marginal deltas, as much as 24.4 m (80 ft) thick; and lake-bottom fine sand and silt as much as 9.1 m (30 ft) thick. Delta-plain altitude is 140 m (460 ft). Unit includes minor sand and gravel deposits with surface altitude of 107 m (350 ft). The lake basin occupied a small tributary valley on the Passaic River–Raritan River drainage divide that was dammed by the ice margin; the spillway was over bedrock on the divide. The lake lowered to a lake level controlled by a spillway at Moggy Hollow or near Summit when the ice margin retreated north of the Basking Ridge area

Qla — **Allamatong deposit**—Deltaic deposits with sand and gravel topset beds in two ice-contact ridges, as much as 48.8 m (160 ft) thick. Surface altitude is 226 m (740 ft)

Ql — **Lamington Formation, undifferentiated**—Minor sand and gravel, and sand

ILLINOIAN TILLS AND MORAINE DEPOSITS

Tills—Silty-to-sandy and silty-to-clayey deposits consisting of a very poorly sorted matrix of sand, silt, and clay (fig. 7) containing commonly 5 to 20 percent (by volume) pebbles, cobbles, and few boulders. Generally nonstratified and homogeneous; generally very compact; hard to very hard consistency. Gravel clasts are subangular to subrounded; some have been glacially faceted and striated; many clasts have thin silt caps that adhere to their upper surfaces. Gravel clasts from local bedrock units constitute 50 to 90 percent of clasts. The distinguishing color, grain size, and composition of two till formations (units Qb and Qf) are related to the underlying bedrock source and local ice-flow directions (figs. 2 and 4). Till deposits of these units have well-developed subhorizontal fissility and subvertical joints, few thin lenses of sorted silt and fine sand, and gravel clasts with long-axis fabrics oriented in the direction of glacier flow; this till facies is a subglacial till of lodgement or meltout origin. The upper 3.0 to 5.2 m (10–17 ft) of till is weathered, characterized by a pervasive stain of matrix by oxidized iron (in the Flanders Till), and brown to black iron-manganese stain on clasts and sand grains, and on joint faces. Gravel clasts of gneiss in the weathered zone have weathering rinds 0.2 to 1 cm (0.1–0.4 in.) thick; gravel clasts of carbonate rock are entirely decomposed to depths of 3.0 m (10 ft); quartzite, shale, and sandstone clasts are generally fresh or have thin weathering rinds. South of the area of late Wisconsinan glaciation, compact tills are present beneath hillslopes that faced the direction of glacier flow, as local patches of thin till, and in one moraine; thickness is generally less than 6.1 m (20 ft). Soils are alfisols with argillic B horizons, 0.8 to 1.3 m (30–51 in.) thick, including or overlying Bx fragipan horizons that overlie the C horizon in weathered till, oxidized as deep as 8.0 m (26.2 ft). Compact and weathered Bergen and Flanders Tills are inferred to underlie tills of late Wisconsinan age (sections *A–A′*, *B–B′*, and *C–C′*) in large drumlins in the northern part of the map area; thickness of the Illinoian tills is 3.0 to 65.5 m (10–215 ft), and commonly greater than 24.4 m (80 ft) in drumlins.

Qf — **Flanders Till**—Strong brown (7.5*YR* 5/6), pale-brown (10*YR* 6/3), yellow (10*YR* 7/6) to yellowish-brown (10*YR* 5/4-6) silty-to-sandy till (fig. 7), containing 5 to 20 percent pebbles, cobbles, and few boulders of gneiss, and locally gravel clasts of carbonate rock and quartzite, in areas underlain by gneiss, shale, sandstone, or carbonate rocks (figs. 2 and 4); matrix contains quartz, feldspar, shale fragments, and heavy minerals and biotite that have iron-oxide stains; matrix silt-clay fraction is yellowish-brown to gray. Generally noncalcareous, but subsurface till may be calcareous in areas underlain by carbonate rock. Reported compact gray till that forms the bulk of till in large drumlins and areas of thick till in the central and western part of the map area is inferred to be the Flanders Till; the weathered zone in the top of the Flanders Till is truncated by Netcong Till or Kittatinny Mountain Till, which are the surface fills in the drumlins. Thickness is generally less than 6.1 m (20 ft), but is as much as 65.5 m (215 ft) in areas of thick till, including drumlins. The tills of this unit were correlated in the northern belt of till deposits of the Jerseyan drift of Salisbury (1902, *in* Bayley and others, 1914). Salisbury noted that sediments of the northern belt of drift appeared less weathered and eroded than the sediments of the southern belt of the Jerseyan drift. This conclusion was supported by studies of clast weathering (MacClintock, 1940) and soil development

Qb — **Bergen Till**—Brown (7.5*YR* 5/4) to reddish-brown (5*YR* 4/4) to red (2.5*YR* 4/6) silty till and silty-to-clayey till (fig. 7), containing 5 to 20 percent pebbles, cobbles, and few boulders of gneiss, sandstone, and quartzite. In areas underlain by sandstone and shale (figs. 2 and 4), matrix contains abundant shale and siltstone fragments; matrix silt and clay fraction is reddish-brown; noncalcareous. The compact and weathered till is chiefly a subsurface unit that forms the bulk of till in drumlins in Bergen County, where it is as much as 21.3 m (70 ft) thick; the weathered zone in the top of the Bergen Till is truncated by Rahway Till or Netcong Till, which are the surface tills in the drumlins. Weathering features in the Bergen Till are similar to weathering features in the Flanders Till south of the area of late Wisconsinan glaciation

Moraine deposits—Composed chiefly of compact till, more than 15.2 m (50 ft) thick

Qfpm — **Pequest moraine deposit**—Flanders Till; hummocky ridge; is inferred to be a recessional moraine; average thickness about 16.8 m (55 ft)

Qfm — **Flanders moraine deposit**—Flanders Till; scattered surface boulders; elongate, smooth ridge; is inferred to be a segment of the terminal moraine of the Flanders Till; reportedly as much as 36.6 m (120 ft) thick

Qfwm — **Washington moraine deposit**—Flanders Till; scattered surface boulders; elongate, smooth ridge; is inferred to be a segment of the terminal moraine of the Flanders Till; reportedly as much as 30.5 m (100 ft) thick

PRE-ILLINOIAN STRATIFIED DEPOSITS AND TILL

Port Murray Formation

Qps **Stratified deposits**—Reddish-yellow (7.5*YR* 6/6-8) to strong brown (7.5*YR* 5/6-8) sand and pebble-to-cobble gravel; gravel clasts are rounded to subangular; gravel clasts of carbonate rock and gneiss are deeply weathered to fully decomposed to depths of more than 3.0 m (10 ft); gravel clasts of chert and quartzite have thin weathering rinds; some gravel clasts have thin silt caps that adhere to their upper surfaces; gravel clasts of quartzite and quartzite conglomerate have a reddish-yellow iron-oxide stain; a black iron-manganese coating covers some gravel clasts. A weathered zone extends from the surface through the entire deposit and into weathered rock. The stratified deposits were deposited chiefly by glacial meltwater but some also have been eroded and redeposited by alluvial and slope processes. Thickness generally less than 5.2 m (17 ft). Soils are alfisols with argillic B horizons, 0.4 to 1.3 m (15–50 in.) thick, overlying the C horizon in weathered sediment

Qp **Till**—Reddish-yellow (7.5*YR* 6/6-8) to strong brown (7.5*YR* 5/6-8) to yellowish-brown (10*YR* 5/6-8), or reddish-brown (5*YR* 4/3) to weak red (2.4*YR* 4/3) silty-to-sandy and silty-to-clayey till and (or) other very poorly sorted deposits (fig. 7), containing 2 to 10 percent (by volume) pebbles and cobbles of quartzite, gneiss, sandstone, shale, chert, conglomerate, and carbonate rock, and few boulders of quartzite and gneiss; is present in areas underlain by shale, carbonate rock, or gneiss (figs. 2 and 4). Matrix contains quartz, scattered weathered feldspar, few heavy minerals, and weathered shale fragments; matrix silt-clay fraction is brown to strong brown, noncalcareous, compact, and of firm to very hard consistency. Gravel clasts are subangular to rounded; some have been glacially faceted and striated; some clasts have thin silt caps. Gravel clasts from local bedrock units constitute 50 to 90 percent of clasts. Deposits include till and probable disaggregated till, colluvium, and solifluction debris in some areas. The distinguishing grain size and composition of these deposits are related to the underlying bedrock source and inferred ice-flow directions (fig. 6), and possibly to incorporation of large amounts of disaggregated till matrix in some colluvial deposits. Deposits of this unit have well-developed subhorizontal fissility and subvertical joints. Gravel clasts of carbonate rock and gneiss are deeply weathered to entirely decomposed to depths of more than 3.0 m (10 ft); gravel clasts of chert and quartzite have thin weathering rinds; gravel clasts of quartzite and quartzite conglomerate have a reddish-yellow iron-oxide surface stain; many have small surface weathering pits. A weathered zone extends from the surface through the entire deposit and into weathered bedrock; the zone is characterized by relatively high clay content and plasticity, pervasive weathering of matrix minerals and rock fragments, and iron-manganese coatings and clay coatings on joint faces. Deposits are as much as 9.1 m (30 ft) thick. Soils are alfisols in areas underlain by carbonate rock, shale and sandstone; these soils have argillic B horizons, 0.8 to 1.8 m (30–72 in.) thick overlying the C horizon in weathered till, which is oxidized to the base. The sediments of this unit were correlated in the southern belt of till deposits of the Jerseyan drift of Salisbury (1902, *in* Bayley and others, 1914). Salisbury noted that sediments of the southern belt of drift appeared more deeply weathered and eroded than the drift of the northern belt of the Jerseyan drift. This conclusion was supported by studies of clast weathering (MacClintock, 1940)

LATE WISCONSINAN TO MIDDLE PLEISTOCENE COLLUVIAL DEPOSITS

Silty sand, sandy silt, clayey silt, or gravelly sand deposits, consisting of a very poorly to poorly sorted matrix of sand, silt, and clay (fig. 7), commonly containing 5 to 60 percent (by volume) angular rock chips, tabular-shaped pebbles and cobbles, and small boulders; commonly massive to indistinctly layered; locally stratified; compact to loose, of firm to hard consistency; gravel clasts are subangular to angular and weathered; color and grain size are variable, reflecting composition of bedrock on higher slopes; local bedrock constitutes more than 95 percent of gravel clasts; contains few erratic gravel clasts in glaciated areas. Tabular gravel clasts have a strong slope-parallel fabric. Some clasts and aggregates have iron-manganese stain. Materials are gradational on slopes, as follows: (1) from silty sand matrix with angular gravel, less than 2.0 m (6.6 ft) thick, on steep upper slopes, to (2) silty sand matrix with less than 40 percent pebbles and small cobbles, 2.0 to 3.0 m (6.6–10.0 ft) thick, on middle slopes, to (3) compact silty sand matrix with less than 15 percent pebbles, with a platy structure, and locally more than 9.1 m (30 ft) thick, on lower slopes. Colluvium is deposited on slopes by creep; is shown where deposits form a continuous mantle on slopes over saprolite, residuum, or partly weathered bedrock. Units include thin beds and lenses of sorted and stratified sheetwash alluvial sand and gravel, thin bouldery alluvial-fan deposits, sorted blocks and coarse-sand debris-flow deposits, and minor beds of clay and silt. Units also contain massive to indistinctly layered, very poorly sorted, silty, sparsely stony solifluction deposits, and local boulder talus below steep bedrock outcrops. Units include multiple colluvial deposits: surface colluvium generally is composed of lightly weathered clasts; it overlies local older colluvium containing weathered clasts and buried, truncated red soil profiles. Total thickness 3.0 to 21.3 m (10–70 ft). Soils are alfisols with argillic B horizons, 0.6 to 1.0 m (24–40 in.) thick, overlying the C horizon in weathered colluvium

Qcg **Gneiss-clast silty-sand colluvium**—Yellow (10*YR* 7/6) to reddish-yellow (7.5*YR* 6/6), brown (10*YR* 5/3) to yellowish-brown (10*YR* 5/6-8) to strong brown (7.5*YR* 5/6) silty-sand to sandy-silt matrix, containing angular to subangular cobbles and pebbles of gneiss. Matrix is poorly to very poorly sorted, chiefly compact, of firm to hard consistency, and locally cemented with iron-manganese oxides. Locally unit includes angular coarse sand and micaceous silt and clay at depth, laminated to indistinctly layered, poorly sorted, with layering parallel to surface slope, as much as 2.0 m (6.6 ft) thick, of creep or possible solifluction origin. Unit also includes surface concentrations of blocky boulders and subrounded joint-block core stones of partly weathered rock. Thickness of deposits 3.0 to 21.3 m (10–70 ft)

Qcb **Basalt-block colluvium**—Dark-gray (10*YR* 4/1), brown (10*YR* 5/3), yellowish-red (5*YR* 4/6) to reddish-brown (5*YR* 4/4) clayey-silt to silty-clay matrix, containing angular to subangular blocky boulders and cobbles of basalt; poorly sorted, chiefly compact, of firm consistency. Blocky gravel clasts have weathering rinds 0.2 to 1 cm (0.1–0.4 in.) thick. Unit includes local surface bouldery rubble of subrounded joint-block core stones of partly weathered rock. Thickness of deposits 1.8 to 15.2 m (6–50 ft)

Qcd **Diabase-block colluvium**—Reddish-yellow (7.5*YR* 6/6) to brownish-yellow (10*YR* 6/6) sandy silt matrix, containing angular to subangular blocky boulders and cobbles of diabase; poorly sorted, chiefly compact, of firm consistency. Blocky gravel clasts have weathering rinds 0.2 to 1 cm (0.1–0.4 in.) thick. Unit includes local surface bouldery rubble of subrounded joint-block core stones of partly weathered rock. Thickness of deposits 1.8 to 15.2 m (6–50 ft)

Qcs **Sandstone-, siltstone-, conglomerate-, or shale-clast colluvium**—Pale-red (2.5*YR* 6/2) to light-brownish-red (5*YR* 6/3), light-olive-brown (2.5*YR* 5/2), or reddish-brown (2.5-5*YR* 4/4) silty-sand or clayey-silt matrix, containing angular to subangular chips and tabular-shaped pebbles and cobbles of sandstone, siltstone, or shale; poorly sorted, moderately compact, and of firm consistency. Conglomerate-clast colluvium (overprint pattern) contains subrounded, fractured pebbles and cobbles derived from weathered conglomerate. Unit includes minor sand and silt, laminated, poorly sorted, with lamination parallel to surface slope; as much as 1.0 m (3.2 ft) has been subject to creep or possible solifluction. Unit also includes local surface rock rubble composed of partly weathered rock. Thickness of deposits 3.0 to 9.1 m (10–30 ft)

Qccb **Carbonate-clast colluvium**—Gray (10*YR* 5/1), pale-yellow (2.5*Y* 7/4), or yellow (10*YR* 7/6) silt to clayey-silt matrix, containing angular to subangular granule chips, and tabular pebbles and cobbles of carbonate rock and minor chert and shale; poorly sorted, moderately compact, and of soft to firm consistency. Unit includes minor silt, laminated, moderately sorted, with lamination parallel to surface slope; as much as 1.0 m (3.2 ft) has been subject to creep or possible solifluction. Thickness of deposit as much as 4.6 m (15 ft)

QUATERNARY AND TERTIARY SAPROLITE, RESIDUUM, AND ROCK RUBBLE

Silty sandy to clayey silty weathered-rock materials, consisting of a very poorly sorted or nonsorted matrix of sand, silt, and clay, commonly containing 5 to 50 percent (by volume) angular pebbles and cobbles; loose to compact, of firm to hard consistency. Composition of gravel clasts is quartzose, chert, or shale, which is resistant to weathering dissolution; partly weathered gravel clasts of local bedrock are in lower parts of saprolite and residuum and in thin colluvial deposits near the land surface; few erratic gravel clasts are found at the land surface in glaciated areas; local color and grain size of matrix are variable, reflecting composition and degree of weathering of underlying bedrock. Materials are derived from in-place chemical weathering of underlying bedrock, with no appreciable subsequent lateral transport. Materials include: (1) sandy to clayey decomposition residuum, composed of homogeneous matrix and weathered angular gravel clasts, derived from in-place weathering of clastic rock; (2) clayey silty sand to silty clay solution residuum, composed of homogeneous to thinly laminated matrix and gravel clasts of chert and weathered rock, derived from in-place weathering of carbonate rock; and (3) silty sandy to clayey structured saprolite, composed of a quartzose framework that preserves original rock structure and fabric and interstitial clay derived from weathering of feldspar and accessory minerals, derived from crystalline rocks, quartzite, and quartz conglomerate. A zone of structureless saprolite, composed of quartz and clay produced by collapse and minor lateral creep of the original saprolite framework, overlies the structured saprolite. Local weathered-rock rubble, composed of subangular joint blocks of partly weathered rock, overlies partly weathered bedrock in areas of shallow bedrock on some ridge crests. Residuum and saprolite grade downward into partly weathered bedrock through a zone of weathered rock that is altered and iron-manganese-stained along joint planes or bedding, or through alternating zones of rock and saprolite or residuum. Translocated clay fills some fractures in partly weathered rock. Map units include surface deposits of poorly sorted sandy or silty colluvium or solifluction debris on nearly all slopes greater than 3 to 5°, thin alluvium and sheetwash deposits, and debris-flow deposits. Soils are ultisols and alfisols, with argillic B horizons, 0.56 to 1.17 m (22–46 in.) thick, overlying C horizons in weathered rock that reportedly extends to depths of more than 15.2 m (50 ft), or C horizons in saprolite, oxidized as deep as 10.7 m (35 ft)

Qbw **Clayey silty basalt saprolite and rock rubble**—Yellowish-red (5*YR* 4/6) to reddish-brown (5*YR* 4/4) to red (2.5*YR* 4/8) silty clay structureless saprolite, containing 10 to 50 percent angular pebbles and cobbles of partly weathered basalt; nonsorted; gravel clasts have weathering rinds 0.2 to 1 cm (0.1–0.4 in.) thick. Structureless saprolite is as much as 6.1 m (20 ft) thick; overlies silty clay structured saprolite that is generally less than 1.8 m (6 ft) thick. Unit includes local granular to blocky weathered rock rubble with boulders, as much as 3.0 m (10 ft) thick

Qdw **Sandy silty diabase saprolite and rock rubble**—Brown (7.5*YR* 5/4) to strong brown (7.5*YR* 5/8) sandy silty structureless saprolite containing 10 to 50 percent angular pebbles and cobbles of partly weathered diabase; nonsorted; gravel clasts have weathering rinds 0.2 to 1 cm (0.1–0.4 in.) thick; as much as 6.1 m (20 ft) thick, overlying sandy silty structured saprolite, generally less than 1.8 m (6 ft) thick. Unit includes granular to blocky weathered rock rubble with boulders, as much as 3.0 m (10 ft) thick

Qsw **Silty clayey to sandy silty sandstone, siltstone, and shale residuum; silty sandy quartzite and conglomerate saprolite; and rock rubble**—Reddish-brown (5*YR* 4/3–2.5*YR* 4/4) silty clay or sandy silt residuum containing 10 to 50 percent chips and tabular pebbles and cobbles of shale, siltstone, or sandstone; nonsorted; compact. Thickness less than 0.9 m (3 ft) on ridges; as much as 3.0 m (10 ft), including colluvium, at bases of slopes. Unit includes light-olive-brown (2.5*YR* 5/2) silty shale and slate residuum containing 10 to 50 percent shale or slate chips and flat pebbles of shale or slate; nonsorted, compact, and less than 1.8 m (6 ft) thick. Unit also includes local light-gray to white structureless and structured quartzite saprolite, and reddish-brown (2.5*YR* 4/4) silty clay to very pale brown (10*YR* 8/4) sandy structureless and structured conglomerate saprolite (overprint pattern) containing 10 to 50 percent pebbles and cobbles of quartzite and weathered conglomerate; nonsorted; as much as 21.3 m (70 ft) thick. Total unit thickness is as much as 45.7 m (150 ft) thick

QTcpw **Silty sandy to clayey sand, silt, and clay residuum**—Yellow (10*YR* 7/6) to pink (5*YR* 8/3) to white (5*YR* 8/1) to dark-gray (5*YR* 4/1) to pale-brown (10*YR* 6/3) to red (2.5*YR* 4/8) sand, silt, and clay derived from Coastal Plain deposits; thinly bedded to massive, moderately sorted; sand is chiefly quartzose. Surface oxidation of sediments extends to depths of more than 9.1 m (30 ft). On natural slopes the Coastal Plain deposits are discontinuously overlain by a thin sandy silt and gravel colluvium derived from the overlying Pensauken Formation. The colluvium is generally less than 0.9 m (3 ft) thick

QTgw **Silty sandy gneiss saprolite and rock rubble**—Brown (10*YR* 5/3) to yellowish-brown (10*YR* 5/6-8) to strong brown (7.5*YR* 5/6), white (5*YR* 8/1), and red (2.5*YR* 4/8) silty clayey sandy to clayey silty structureless saprolite containing 20 to 60 percent pebbles and cobbles of partly weathered gneiss; nonsorted to very poorly sorted; nonstratified, friable; clasts are angular, with weathering rinds 0.1 to 0.5 cm (0.04–0.2 in.) thick; thickness 1.0 to 3.0 m (3.3–10.0 ft). Overlies partly weathered bedrock on some slopes, and in upland areas overlies yellowish-brown silty sandy structured saprolite, locally micaceous, containing 10 to 30 percent slightly weathered pebble- and cobble-sized core stones and angular quartz; saprolite retains original structures of gneiss, but is friable and noncompact; the distribution of structured saprolite is highly variable, related to different rock types and to very localized zones of different composition or fracture density; zones of saprolite alternate laterally with zones of variably weathered rock; at depth structured saprolite is transitional with underlying weathered bedrock; structured saprolite is as thick as 30.5 m (100 ft). Unit includes extensive but locally discontinuous colluvium, 1.0 to 3.0 m (3.3–10.0 ft) thick, which overlies weathered rock or saprolite on slopes

QTcw **Clayey silty carbonate-rock residuum and rock rubble**—Light-red (2.5*YR* 6/6) to red (2.5*YR* 5/6), reddish-yellow (7.5*YR* 7/8) to strong brown (7.5*YR* 5/6) to yellowish-brown (10*YR* 5/6), or yellow (10*YR* 7/6), locally highly variegated, clayey silty sand to silty clay solution residuum containing generally less than 5 percent angular clasts of chert, and weathered carbonate rock and shale; matrix contains quartz sand grains; nonsorted, moderately compact. Unit includes colluvium and thin alluvial sediments, and local glacial sand, gravel, and boulders in the upper part; as much as 100.6 m (330 ft) thick

COASTAL PLAIN DEPOSITS AND BEDROCK

Tps **Pensauken Formation (Tertiary)**—Reddish-yellow (7.5*YR* 6/6) to yellow (10*YR* 7/6-8) sand and gravel, with few lenses of silt; interbedded planar beds of pebble-cobble gravel and crossbedded medium to coarse sand; gravel and sand are moderately to poorly sorted; gravel clasts are rounded to subrounded, chiefly quartz, quartzite, and chert, and minor gneiss, red and gray sandstone, and siltstone; quartzose gravel clasts have a thin weathering rind and a yellow iron stain; many have small surface weathering pits; gravel clasts of gneiss and some sandstone and siltstone are deeply weathered to fully decomposed to depths of 4.6 m (15 ft); sand is arkosic, consisting of quartz, feldspar, heavy minerals, and mica; nonfossiliferous. Thickness of unit is 2.0 to 8.0 m (6.6–26.2 ft). Surface altitudes slope from 43 m to 34 m (140–110 ft); includes small, thin deposits north of Somerville, with surface altitudes ranging from 49 m to 55 m (160–180 ft). A weathered zone extends from the surface to depths of more than 6.1 m (20 ft); the zone is characterized by pervasive weathering and dissolution of feldspar, heavy minerals, and rock fragments; Liesegang banding and clay caps, bridges, and halos are common, indicating downward translocation of silt, clay, and colloidal-size weathering products; clay minerals include mixed-layer illite and vermiculite, and gibbsite. Soils are alfisols with argillic B horizons, 0.5 to 0.7 m (20–26 in.) thick overlying the C horizon in deeply weathered sediment.

Materials of this unit formerly were included in the Pensauken Formation of Salisbury (1902, *in* Bayley and others, 1914; late Tertiary or early Pleistocene-Jerseyan [glacial] Stage). Salisbury (*in* Bayley and others, 1914), Owens and Minard (1975, 1979), and Martino (1981) interpreted the sediments to be of nonglacial fluvial origin. The deposits in the map area are continuous to the southwest with the extensive Pensauken Formation of Newell and others (2000) and of Owens and Minard (1979), which overlies the Cohansey Formation of middle Miocene age in southern New Jersey (Newell and others, 2000). The Pensauken is entrenched below and is therefore younger than the Bridgeton Formation of probable middle to late Miocene age (Newell and others, 2000). Deposits equivalent to the Pensauken Formation extend through the uplands of Delaware (the Columbia Group of Jordan [1964]) to Maryland, where they are overlain by the Yorktown Formation of early Pliocene age (Owens and Minard, 1979). Thus the Pensauken may range in age from late Miocene to early Pliocene

Bedrock (early Mesozoic to Middle Proterozoic)—Exposed bedrock in quarries, other large excavations, and large natural outcrops; partly weathered along fractures in upper part. Symbol is shown in correlation, in list of map and subsurface units, and in explanation of map symbols, all on sheet 1

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STRATOTYPE SECTIONS FOR PROPOSED LITHOSTRATIGRAPHIC UNITS OF QUATERNARY AGE IN NORTHERN NEW JERSEY

INTRODUCTION

Till and meltwater deposits related to three glaciations of northern New Jersey are shown on the surficial geologic map and in the correlation of map and subsurface units. These glaciogenic deposits are divided into eight lithostratigraphic units of formation rank on the basis of lithic characteristics, such as color, grain size, and sedimentary structures. The deposits also are subdivided by age, based on their weathering and erosional characteristics, geographic location, and radiometric ages. Till deposits, which comprise six formations, are the most extensive and internally homogeneous units. The tills are sheet deposits, consisting of glacially eroded and deposited rock materials that are closely related in composition to underlying and northerly adjacent bedrock units. Meltwater deposits, which are divided into three formations based on their age, are distributed discontinuously across the region, chiefly confined to glacially eroded valleys and lowland basins. These deposits, which consist of sorted and stratified gravel, sand, silt, and clay, are subdivided into informal units of glacial-stream and glacial-lake sediments that were deposited in different basins during retreat of the ice-sheet margins. The proposed formations are, from youngest to oldest: Rockaway Formation, Rahway Till, Netcong Till, Kittatinny Mountain Till, Lamington Formation, Flanders Till, Bergen Till, and Port Murray Formation.

UNITS OF LATE PLEISTOCENE AGE, LATE WISCONSINAN GLACIATION

Three till deposits, of contrasting colors and mineralogic composition related to underlying bedrock types, discontinuously cover northern New Jersey and extend to the terminal moraine or maximum position of the late Wisconsinan ice sheet (figs. 3 and 4). Meltwater glacial-stream deposits extend southward from the late Wisconsinan glacial limit down five valleys across the region. At the glacial limit and north of it, meltwater glacial-stream and glacial-lake sediments constitute 101 additional deposits in various lowland and valley basins. The age of the late Wisconsinan glacial episode is based on the regional and local array of ^{14}C-dated materials (table 1) incorporated within and on top of the glaciogenic deposits. The age range of the deposits is estimated to be 26 to 17.8 ka radiocarbon years (Fullerton, 1986; Stone and Borns, 1986; Stone, 1995), or about 29.6 to 20 ka calendar years (^{14}C calibration of Bard and others, 1993; Stuiver and Reimer, 1993).

RAHWAY TILL

Name and rank—The Rahway Till is proposed as a unit of formation rank, named for the stratotype locality along the Rahway River, in the southern part of the glaciated Newark basin of the Piedmont lowland province (figs. 4 and 6). The lithogenetic term "till" is used in the name to denote the very poorly sorted, nonstratified, compact material deposited directly by or from glacial ice (Dreimanis, 1989).

Type section—The type section for the Rahway Till is designated as the exposure in the cutbank on the east side of the Rahway River, 716 m (2350 ft) east of Walnut Avenue, 305 m (1000 ft) southwest of Centennial Avenue, at about 18.3 m (60 ft) altitude (40°38'42" N. lat, 74°18'05" W. long), City of Cranford, Union County, in the Roselle 7.5-minute quadrangle. The following section at the stratotype locality of the Rahway Till was measured in 1991 by B.D. Stone and S.D. Stanford:

Depth (m)	**Description**
0	Land surface
0–1.5	Covered interval

1.5–4.68 Red (2.5*YR* 4–5/6) till, with a very poorly sorted matrix of sandy silt with clay, containing less than 5 percent large cobbles and boulders and 10 to 15 percent pebbles by volume; sediment appears generally homogeneous and very poorly sorted. Matrix is compact, has low to moderate dry strength, is of firm to hard consistency, has low plasticity, and is noncalcareous; contains abundant sand-size fragments of shale and siltstone, quartz, and minor feldspar. Matrix has a subhorizontal fissility that bounds angular plate- and disk-shaped fragments less than 1 cm (0.4 in.) thick and less than 2 cm (0.8 in.) long; the fissile structure is enhanced in the drier upper part of the exposure and is poorly developed in the lower part; the matrix is fractured subvertically in irregularly spaced areas in the exposure; vertical fractures and fissility fractures do not contain clay or iron-manganese coatings. Gravel clasts less than 8 cm (3.1 in.) long and 5 cm (2.0 in.) wide are common, especially small pebbles less than 2 cm (0.8 in.) wide; clasts are subrounded, and many have one hackly broken face; clasts commonly have a silt-clay cap less than 2 mm (0.08 in.) thick adhering to the upper surface; a few pebbles have a very thin, discontinuous iron-manganese stain on their surface. Scattered boulders are subrounded, with hackly broken faces; the largest boulder is a granitic gneiss erratic, 0.9 m (3 ft) in exposed length, striated on two exposed faces; another red sandstone boulder, 0.4 m (1.3 ft) long, is striated on three faces, and the striae on the top surface trend toward an azimuth of 241° to 260°. Small pebbles having an intermediate axis less than 2 cm (0.8 in.) are numerous; clasts of very fine-grained red sandstone commonly are striated parallel to the long axis of the clasts; a thin, discontinuous black iron-manganese stain coats the top face of some sandstone clasts; long axes of clasts show weak preferred orientation with average plunge toward an azimuth of 231°. Gravel clast rock types include very fine-grained red sandstone, 90 percent; medium-grained gray sandstone, 6 percent; granitic gneiss, 2 percent; basalt, 1 percent; and quartzite, 1 percent

4.68–5.70 Red shale bedrock of the Passaic Formation (Late Triassic–Early Jurassic).

Lithologic characteristics—The Rahway Till typically consists of a dark-reddish-brown (2.5*YR* 3/4) to reddish-brown (5*YR* 5/4) to dark-brown (7.5*YR* 4/4) to yellowish-brown (10*YR* 5/4) silty, to silty sandy, to clayey silty sandy (fig. 7) very poorly sorted (diamict) sediment that contains 5 to 20 percent pebbles, cobbles, and boulders. The matrix generally is compact, homogeneous, has low to moderate plasticity, and is noncalcareous. Sand grains in the matrix and most gravel clasts are subangular to subrounded, and generally nonweathered. The matrix contains abundant sand-size fragments of shale, siltstone, quartz, and minor feldspar, and reddish-brown silt and clay. Locally, the matrix contains a few lenses or laminations of sorted silt and fine sand. The till contains well-rounded gravel clasts in some areas. Many gravel clasts have thin silt caps that adhere to the tops of the clasts. Gravel clasts of red sandstone and siltstone from local bedrock units are dominant rock types in pebble and small cobble sizes, which also include gneiss, quartz, gray sandstone, basalt, and quartzite. Erratic clasts of gneiss and quartzite from the highland areas to the north constitute 50 to 90 percent of large cobbles and boulders. Where the Rahway Till overlies Cretaceous coastal plain deposits in the southeastern part of the area, it includes 5 to 50 percent blocks and lenses of white, red, yellow, and gray clay and quartz sand derived from the Cretaceous deposits, and yellow sand and quartz-pebble gravel derived from the Pensauken Formation. The abundance of gravel clasts and sand content of the matrix decrease in the direction of glacier flow from the gneiss terrane of the Highlands and from the area underlain by sandstone in the northern part of the Newark basin. The long axes of elongate gravel clasts are subhorizontal and have preferred orientations that are parallel to local glacier-flow directions. As shown on the map, the Rahway Till deposit locally includes thin surface colluvium and small deposits of stratified meltwater sediments.

The Rahway Till comprises two facies that are distinguished texturally and structurally. The lower compact facies is a dense, massive till that contains few lenses of sorted silt and fine sand. In naturally dried outcrops, the till exhibits a subhorizontal fissility defined by clayey parting surfaces that vary in spacing from less than 0.5 cm (0.2 in.) to 2.0 cm (0.8 in.). A subvertical system of joints, spaced at more than 5 cm (2 in.), imparts an angular blocky structure to the till. In some exposures, thin, discontinuous dark-brown to black iron-manganese coating stains some joint faces. In shallow surface exposures the till is chiefly compact, firm to very firm, and has moderate dry strength. Gravel clasts have strongly preferred long-axis fabrics oriented in the direction of glacier flow. The compact facies is overlain locally by the noncompact, sandy facies, which is a locally layered till, containing as much as 40 percent gravel clasts and large boulders, and minor beds of sorted and stratified sand, silt, and clay.

The Rahway Till includes a distinctive compositional variety of till in areas underlain by basalt and diabase, or sandstone and serpentinite east of the Palisades. This variety is a reddish-yellow (7.5*YR* 6/6) to brown (7.5*YR* 4/4) to strong brown (7.5*YR* 5/6), or gray (10*YR* 5/1) to grayish-brown (10*YR* 5/2) silty sand to sandy silt till, which contains a brown silt-sand matrix composed of fragments of basalt or diabase. The till contains 5 to 35 percent pebbles, cobbles, and boulders of basalt or diabase, sandstone, gneiss, quartz, and quartzite. The till is compact to loose, locally very firm, and exhibits subhorizontal fissility.

Soils and weathering characteristics—Soils developed in the upper part of till deposits thicker than 1 m (3.3 ft) are alfisols, with argillic B horizons, 0.2 to 0.6 m (8–24 in.) thick, overlying Bx fragipan horizons that are 0.4 to 1.0 m (15–40 in.) thick, which overlie the C horizon in slightly weathered till, oxidized as deep as 2 m (6.6 ft). Clay and iron-manganese coatings are on ped faces in the lower B horizon, and on vertical joint faces in the till below the solum. In areas underlain by shallow rock or in till deposits having abundant gravel in the upper meter, soils are inceptisols having cambic B horizons, 0.2 to 0.6 m (8–24 in.) thick above Bx fragipan horizons in slightly weathered till.

Contact relations—The Rahway Till is the surface till of northeastern New Jersey, where it unconformably overlies bedrock units of Middle Proterozoic to Cretaceous age in the area (figs. 2 and 4). At its type locality, the Rahway overlies locally weathered red shale of the Upper Triassic and Lower Jurassic Passaic Formation. In most exposures, the Rahway was observed to overlie a polished, striated or grooved surface of fresh bedrock. Water-well descriptions commonly refer to distinct subsurface contact relations of the Rahway with underlying fresh bedrock. However, in some areas, a zone of weathered bedrock, 0.5 m (20 in.) to several meters thick, has been reported beneath the Rahway (Nichols, 1968), notably an arkosic sandstone and conglomerate in the northern part of the Newark basin. The Rahway overlies glacially deformed clay and sand of the Cretaceous Raritan Formation, and sand and gravel of the Pensauken Formation in the southeastern part of the area. The Rahway overlies stratified glacial meltwater deposits of the Rockaway Formation in the upper Passaic River drainage basin, and also overlies the heads of the Perth Amboy and Plainfield outwash deposits. In the thick till deposits in large drumlins in the northern part of the Newark basin, the till overlies older, harder, red Bergen Till and older stratified meltwater deposits of the Lamington Formation locally, as reported in water-well records. The contact between the tills was not well exposed during the field mapping; a few exposures indicate that the contact is diffuse or gradational. The surface Rahway Till is generally less than 6.1 m (20 ft) thick and comprises a mixed zone that includes clasts and disseminated matrix materials of the underlying Bergen Till. The Rahway may overlie the Bergen Till beneath the area of the Perth Amboy segment of the terminal moraine.

Boundaries—The top of the Rahway Till is at the land surface in upland areas, and is beneath stratified materials of the Rockaway Formation and younger surface deposits in valleys and lowland areas. The base of the Rahway Till generally rests on hard, glacially eroded and polished bedrock, locally on weathered rock, and on older surficial and Cretaceous deposits in the southeastern part of the map area. To the west, the Rahway extends to a distinct contact with Netcong Till deposits. To the east, the Rahway extends beneath the Hudson River valley.

Extent and surface form—The distribution of the Rahway Till in northern New Jersey is coincident with the distribution of sedimentary, volcanic, and intrusive rocks of the Newark basin, from which it is principally derived. The Rahway extends to the limit of glaciation, marked by the southern edges of the Perth Amboy and Madison segments of the terminal moraine, by local till deposits south of the terminal moraine, and by kettles in promorainal meltwater deposits of the Rockaway Formation. The Rahway Till forms a discontinuous sheet deposit at the land surface, where its surface is truncated in places by meltwater channels and modern stream channels and by slope erosion. In areas of shallow bedrock, the till surface generally conforms to the linear topographic features controlled by underlying bedrock. The till forms a ground moraine in the upper Passaic River basin where it overlies stratified materials. In the area of ground moraine and on small drumlins the till surface is generally smooth, with local topographic features generally having less than 2 m (6.6 ft) of relief. In areas of the Perth Amboy and

Madison segments of the terminal moraine, the surface of the till forms linear and circular features having local relief of 3 to 20 m (10–66 ft).

Thickness—The thickness of the Rahway Till generally is 3.0 to 9.1 m (10–30 ft), locally as much as 36.6 m (120 ft). It is as much as 30.5 m (100 ft) thick in drumlins and other areas of relatively thick till inferred to be products of late Wisconsinan ice advance (fig. 6). The total thickness of deposits in the Perth Amboy segment of the terminal moraine, chiefly Rahway Till, is as much as 56.4 m (185 ft). The till is very thin over bedrock on the crests and glacial-leeside slopes of mountains and hills, especially in areas underlain by basalt and diabase where the till is generally less than 1.8 m (6 ft) thick. The till forms relatively thick wedge-shaped ramps on hillsides that faced advancing ice. In areas of lowland ground moraine the till is 6.1 to 12.2 m (20–40 ft) thick. Till in the subsurface beneath stratified deposits reportedly varies in thickness from 0 to 30.5 m (0–100 ft).

Origin—The Rahway Till is a glacial sediment, deposited directly from glacial ice, and consisting of two facies. The lower compact facies is inferred to be a basal till of lodgement and basal-meltout origin. The overlying noncompact, sandy and gravelly facies is inferred to be a meltout (ablation) till (in the genetic classification of Dreimanis, 1989).

Age and regional correlations—The Rahway Till coincides with the axial part of the Hudson-Champlain lobe of the Laurentide ice sheet. Based on its axial position and on stratigraphic position of tills, moraine segments, and glaciolacustrine deposits in the upper Passaic and Rockaway River basins, the base of the Rahway is inferred to be slightly older than the base of the Netcong and Kittatinny Mountain Tills in areas to the west. The relative ages of inferred ice-marginal recession positions in areas underlain by these tills indicate that the ice sheet remained longest in the Hackensack lowland, and thus the age of the top of the Rahway is slightly younger than the surface of the adjacent Netcong or Kittatinny Mountain Tills. On the basis of radiocarbon-dated materials from beneath or within the till, and in sediments overlying the 'till, we infer that the late Wisconsinan Rahway Till was deposited from about 26 ka to about 17.8 ka radiocarbon years.

The Rahway Till is similar lithically to late Wisconsinan surface till derived from sedimentary and igneous rocks of the Hartford basin in Connecticut and Massachusetts (Stone and others, 1992). Surface tills on Long Island (Sirkin, 1982; Cadwell, 1989), in the central and western parts of northern New Jersey (Netcong Till and Kittatinny Mountain Till of this report), and in adjacent Pennsylvania (Crowl and Sevon, 1980; Braun, 1994) all extend to the terminal moraine or glacial limit of the late Wisconsinan glacial episode, and are thus correlated with the Rahway Till.

NETCONG TILL

Name and rank—The Netcong Till is proposed as a unit of formation rank, named for the stratotype locality near the Borough of Netcong in the central glaciated Highlands province (figs. 4 and 6). The lithogenetic term "till" is used in the name to denote the very poorly sorted, nonstratified, compact material deposited directly by or from glacial ice (Dreimanis, 1989).

Type section—The type section for the Netcong Till is designated as the exposure in a gravel pit 91 m (300 ft) north of the Conrail railroad tracks, 2900 m (9500 ft) east-northeast of the intersection of U.S. Routes 46 and 206 in the Borough of Netcong, at about 277 m (910 ft) altitude (40°54'31" N. lat, 74°40'15" W. long), in Roxbury Township, Morris County, in the Stanhope 7.5-minute quadrangle. The following section at the stratotype locality of the Netcong Till was measured in 1991 by B.D. Stone and S.D. Stanford:

Depth (m) **Description**

0 Land surface

0–0.4 Pale-brown (10*YR* 6/3) till, with a very poorly sorted silty sand matrix containing 5 percent gravel clasts by volume, chiefly small pebbles; matrix is dry, very compact, nonplastic, and noncalcareous; subhorizontal platy fissility is locally developed in the matrix; plates are less than 2 mm (0.08 in.) thick and less than 5 mm (0.2 in.) long; pebbles and cobbles are chiefly gneiss, subangular to subrounded

0.4–1.2 Pale-brown (10*YR* 6/3) till, with a very poorly sorted silty sand matrix containing 10 percent gravel clasts by volume, chiefly small cobbles; matrix is dry, very compact, nonplastic, and noncalcareous; cobbles are chiefly gneiss, subangular to subrounded, 4 to 15 cm (1.6–5.9 in.) long

1.2–3.1 Brownish-yellow (10*YR* 6/6) till, with a very poorly sorted silty sand matrix containing 7 to 10 percent gravel clasts by volume; locally zones within matrix contain 15 to 20 percent gravel clasts by volume. Very dry pieces have moderately high dry strength; moist pieces have moderate dry strength. Matrix has subhorizontal fissility to blocky structure and nonplastic consistency; contains quartz, feldspar, nonweathered heavy minerals, and micas. Matrix silt-clay fraction is gray, noncalcareous, chiefly compact, and of firm to hard consistency. Gravel clasts generally are nonweathered and have thin and discontinuous silt caps; clasts are chiefly gneiss and granitic rock, with some weathered carbonates and crystalline clasts; discontinuous iron-manganese stain is on faces of some gravel clasts. Clasts show weak preferred direction of long axes at type locality, with average plunge toward an azimuth of 212°.

Lithologic characteristics—The Netcong Till typically consists of light-gray (10*YR* 7/2) to pale-brown (10*YR* 6/3) to very pale brown (10*YR* 7/4) sandy to silty-sandy very poorly sorted (diamict) sediment containing 5 to 30 percent pebbles, cobbles, and boulders. The matrix generally is compact, homogeneous, has low to moderate plasticity, and is noncalcareous. Sand grains in the matrix and most gravel clasts are subangular to subrounded, and generally nonweathered. The matrix contains quartz, feldspar, fresh heavy minerals and mica, and gray silt and clay. Locally, the matrix contains a few lenses or laminations of sorted silt and fine sand. The till contains well-rounded gravel clasts in some areas. Many gravel clasts have thin silt caps that adhere to the tops of the clasts. Gravel clasts of gneiss and quartzite from local bedrock units are the dominant rock types in pebble and small cobble sizes, which also include gray to brown mudstone, sandstone, chert, and carbonate rock. Erratic clasts of gneiss and quartzite from the highland areas to the north constitute 50 to 90 percent of large cobbles and boulders. In many localities in the southern part of the area, some gneiss clasts have thin weathering rinds and some are thoroughly weathered; some scarce carbonate rock clasts are thoroughly weathered in noncalcareous till. The long axes of elongate gravel clasts are subhorizontal and have preferred orientations that are parallel to local glacier-flow directions. As shown on the map, the Netcong Till deposit locally includes thin surface colluvium and small deposits of stratified meltwater sediments.

The Netcong Till comprises two facies that are distinguished texturally and structurally. The lower, compact facies is a dense, massive till that contains few lenses of sorted silt and fine sand. In naturally dried outcrops, the till exhibits a subhorizontal fissility defined by silty to clayey parting surfaces that vary in spacing from less than 0.5 cm (0.2 in.) to 2.0 cm (0.8 in.). A less distinct subvertical system of joints, spaced at more than 5 cm (2 in.), imparts an angular blocky structure to parts of the till. In some exposures, thin, discontinuous dark-brown to black iron-manganese coating stains some joint faces. In shallow surface exposures the till is chiefly compact, firm to very firm, and has moderate dry strength. The compact facies is overlain locally by the noncompact, sandy facies, which is a loose, locally layered till, containing as much as 40 percent gravel clasts and large boulders, and minor beds of sorted and stratified gravel, sand, silt, and clay. The noncompact, sandy facies is locally extensive.

The Netcong includes distinctive compositional varieties of till in areas underlain by shale near Green Pond Mountain (fig. 4). The till matrix varies from a reddish-brown (5*YR* 4/3) clayey-silty sand matrix, to pale-brown (10*YR* 6/3) silt-sand matrix containing conspicuous sand- and granule-size shale chips. Gravel clasts are dominantly gneiss and quartzite, with lesser sandstone, siltstone, and shale. On and southeast of mountains underlain by quartzite (Bearfort, Kanouse, Green Pond, Bowling Green, and Copperas), the Netcong Till includes a reddish-brown (5*YR* 5/4) to light-brown (7.5*YR* 6/4) silty sand matrix with subangular to subrounded quartzite and conglomerate gravel clasts. The Netcong Till also includes strong brown (7.5*YR* 5/6) to dark-yellow-brown (10*YR* 4/4) to brown (10*YR* 5/3) silty sand matrix in areas where it contains numerous weathered and iron-manganese-stained gneiss clasts.

Soils and weathering characteristics—Soils developed in the upper part of till deposits thicker than 1 m (3.3 ft) are alfisols, with argillic B horizons, 0.2 to 0.6 m (8–24 in.) thick, overlying Bx fragipan horizons that are 0.4 to 1 m (15–40 in.) thick, which overlie the C horizon in slightly weathered till, oxidized as deep as 2 m (6.6 ft). Clay and iron-manganese coatings are on ped faces in the lower B horizon, and on vertical joint faces in the till below the solum. In areas underlain by shallow rock or in till deposits having abundant gravel in the upper meter, soils are inceptisols having cambic B horizons, 0.2 to 0.6 m (8–24 in.) thick above Bx fragipan horizons in slightly weathered till.

Contact relations—The Netcong Till is the surface till of the Highlands and part of the Newark basin in north-central New Jersey, where it unconformably overlies bedrock units of Middle Proterozoic to Early Jurassic age (figs. 2 and 4). In most exposures, the Netcong was observed to overlie a polished, striated, or grooved surface of fresh bedrock. Water-well descriptions commonly refer to distinct subsurface contact relations of the Netcong with underlying fresh bedrock. However, in some areas, a zone of weathered bedrock, 30.5 m (100 ft) thick, has been reported beneath the Netcong. As much as 4.9 m (16 ft) of saprolite has been observed beneath exposures of Netcong Till. The Netcong overlies stratified glacial meltwater deposits of the Rockaway Formation in the Rockaway and Musconetcong River basins. In the thick till deposits in large drumlins in the northern part of the area, the till overlies older, harder Flanders Till, as reported in water-well records. The contact between the tills was not well exposed during field mapping; a few exposures indicate that the contact is diffuse or gradational. The surface Netcong Till is generally less than 6.1 m (20 ft) thick and comprises a mixed zone that includes clasts and disseminated matrix materials of the underlying Flanders Till.

Boundaries—The top of the Netcong Till is at the land surface in upland areas, and is beneath stratified materials of the Rockaway Formation and younger surface deposits in valleys and lowland areas. The base of the Netcong Till generally rests on hard, glacially eroded and polished bedrock, and locally on weathered rock and stratified meltwater deposits. To the west, the Netcong extends to a gradational contact with the Kittatinny Mountain Till. To the east, the Netcong extends to a distinct contact with the Rahway Till.

Extent and surface form—The distribution of the Netcong Till in northern New Jersey is coincident with the distribution of granitic gneiss and intrusive rocks of the Highlands, from which it is principally derived. In the northeastern part of the map area, the Netcong overlies local red tills derived from sedimentary, volcanic, and intrusive rocks of the Newark basin. The Netcong extends to the limit of glaciation, marked by the southern edges of the Budd Lake and Mountain Lake segments of the terminal moraine, by local till deposits south of the terminal moraine, and by kettles in promorainal meltwater deposits of the Rockaway Formation. The Netcong Till forms a discontinuous sheet deposit at the land surface, where its surface is truncated by meltwater channels and modern stream channels and by slope erosion. In areas of shallow bedrock, the till surface generally conforms to the linear topographic features controlled by underlying bedrock. On drumlins the till surface is generally smooth, with local topographic features generally having less than 2 m (6.6 ft) of relief. In areas of the Budd Lake and Mountain Lake segments of the terminal moraine, the surface of the till forms linear and circular features having local relief of 3 to 10 m (10–33 ft).

Thickness—The thickness of the compact facies of the Netcong Till generally is 3.0 to 6.1 m (10–20 ft). It is as much as 30.5 m (100 ft) thick in drumlins and other areas of relatively thick till inferred to be products of late Wisconsinan ice advance (fig. 6). The total thickness of deposits of the terminal moraine, locally mostly Netcong Till, is as much as 68.6 m (225 ft). The thickness of the noncompact, sandy till facies, where present, is 0.9 to 3.0 m (3–10 ft). The noncompact facies is as much as 12.2 m (40 ft) thick in unit Qnu. The till is very thin over bedrock on the crests and glacial-leeside slopes of mountains and hills. The till forms relatively thick wedge-shaped ramps on hillsides that faced advancing ice. Till in the subsurface beneath stratified deposits reportedly is as much as 15.2 m (50 ft) thick.

Origin—The Netcong Till is a glacial sediment, deposited directly from glacial ice, and consisting of two facies. The lower compact facies is inferred to be a basal till of lodgement and basal-meltout origin. The overlying noncompact, sandy and gravelly facies is inferred to be a meltout (ablation) till (in the genetic classification of Dreimanis, 1989).

Age and regional correlations—The Netcong Till covers the Highlands province and part of the Newark basin, which were glaciated by the western margin of the Hudson-Champlain lobe of the Laurentide ice sheet (fig. 6). Near its southern edge, the Netcong in the terminal moraine attains an altitude of 335 m

(1100 ft), the highest part of the moraine in New Jersey. Based on altitude of the till deposits and on ice-flow directions, stratigraphic position of tills, moraine segments, and glaciolacustrine deposits in the Rockaway and upper Passaic River valleys, the base of the Netcong is inferred to be slightly younger than the base of the Rahway Till in the lowlands to the east. The relative ages of inferred ice-marginal recession positions (fig. 5) indicate that the ice sheet remained longest in the Hackensack lowland, and thus the age of the youngest Netcong Till deposit is slightly older than the youngest Kittatinny Mountain Till or Rahway Till. On the basis of radiocarbon-dated materials from beneath or within the surface tills of the region, and in sediments overlying the till, we infer that the late Wisconsinan Netcong Till was deposited from about 25 ka to about 18 ka radiocarbon years.

The Netcong Till is similar lithically to late Wisconsinan surface tills derived from metasedimentary and igneous rocks of southern New England (Stone and others, 1992; Stone and Borns, 1986). Surface tills on Long Island (Sirkin, 1982; Cadwell, 1989), in the eastern and western parts of northern New Jersey (Rahway Till and Kittatinny Mountain Till of this report), and adjacent Pennsylvania (Crowl and Sevon, 1980; Braun, 1994) all extend to the terminal moraine or glacial limit of the late Wisconsinan glacial episode, and are thus correlated with the Netcong Till.

KITTATINNY MOUNTAIN TILL

Name and rank—The Kittatinny Mountain Till is proposed as a unit of formation rank, named for the stratotype locality in the eastern piedmont area of Kittatinny Mountain, in the west-central part of the glaciated Kittatinny Valley (figs. 4 and 6). The lithogenetic term "till" is used in the name to denote the very poorly sorted, nonstratified, compact material deposited directly by or from glacial ice (Dreimanis, 1989).

Type section—The type section for the Kittatinny Mountain Till is designated as the borrow-pit excavation 30.5 m (100 ft) west of U.S. Route 206, 274 m (900 ft) north of Layton Road at the village of Tuttles Corner, at about 177 m (580 ft) altitude (41°12'01" N. lat, 74°48'14" W. long), Sussex County, in the Culvers Gap 7.5 minute quadrangle. The following section at the stratotype locality of the Kittatinny Mountain Till was measured in 1991 by R.W. Witte:

Depth (m)	Description
0	Land surface
0–0.05	Soil A horizon; includes thin mat of forest litter
0.05–0.25	Soil B horizon; reddish-brown (5*YR* 5/4) sandy silt matrix containing 3 percent gravel clasts by volume; matrix has low to moderate compaction and is noncalcareous
0.25–2.75	Soil C horizon and soil parent material; reddish-brown (5*YR* 5–4/3) till, with a silty sand matrix containing 7 to 10 percent gravel clasts by volume. Matrix has moderate dry strength and moderate compaction; is nonplastic and noncalcareous. Matrix has poorly developed subvertical fractures; fracture spacing is uneven and varies from one to several centimeters; clay films less than 0.1 mm thick are on fracture surfaces; below depth of 2.2 m (7.2 ft) fracture surfaces also are coated by a black film of ferromanganese oxide. Scattered throughout the outcrop are thin (less than 10 cm (4 in.) thick), irregular lenses of brown (7.5*YR* 5/4), well-sorted fine to medium sand. Most sand lenses have a horizontal orientation, but a few have a subvertical orientation, which is interpreted to be fractures that have filled with sand since dislocation. Carbonate-rock gravel clasts are weathered through the section.

Lithologic characteristics—The Kittatinny Mountain Till consists of three typical varieties: (1) light-olive-brown (2.5*Y* 5/4) to reddish-brown (5*YR* 4/3) silty sandy to sandy till containing pebbles and cobbles of quartzite, sandstone, and shale, and boulders of quartz-pebble conglomerate, in the area of Kittatinny Mountain; (2) olive-gray (5*Y* 5/2) to olive-brown (2.5*Y* 5/4) to dark-grayish-brown (10*YR* 3/2) silty sandy till, containing chips, pebbles, and cobbles of shale, slate, gray sandstone, and quartzite, and boulders of quartzite and conglomerate, in the western part of the Kittatinny Valley; and (3) light-olive-brown (2.5*Y* 5/4) silty calcareous till containing carbonate rock, sandstone, slate, shale, and gneiss pebbles, cobbles, and boulders in valleys underlain by carbonate rock. Each of the three till varieties is very poorly sorted (diamict) sediment containing 5 to 20 percent pebbles, cobbles, and boulders. The matrix generally is compact, homogeneous, and has low to moderate plasticity. Sand grains in the matrix and most gravel clasts are subangular to subrounded and generally nonweathered. The matrix contains sand-size fragments of shale, siltstone, quartzite, quartz, minor feldspar, and reddish-brown silt and clay. Locally, the matrix contains a few lenses or laminations of sorted silt and fine sand. The till contains well-rounded gravel clasts in some areas. Many gravel clasts have thin silt caps that adhere to the tops of the clasts. Gravel clasts of quartzite, sandstone, shale, slate, carbonate rock, and siltstone from local bedrock units are the dominant rock types in pebble and small cobble sizes. Erratic clasts of quartzite and sandstone from the highland areas to the north and carbonate rock from the valleys are the dominant types of large cobbles and boulders. The long axes of elongate gravel clasts are subhorizontal and have preferred orientations that are parallel to local glacier-flow directions. As shown on the map, the Kittatinny Mountain Till locally includes thin surface colluvium and small deposits of stratified meltwater sediments.

The Kittatinny Mountain Till comprises two facies that are distinguished texturally and structurally. The lower compact facies is a dense, massive till that contains a few lenses of sorted silt and fine sand. In naturally dried outcrops, the till has a subhorizontal fissility defined by silty or clayey parting surfaces that vary in spacing from less than 0.5 cm (0.2 in.) to 2.0 cm (0.8 in.). A subvertical system of joints, spaced at more than 5 cm (2 in.), imparts an angular blocky structure to the till. In some exposures, thin, discontinuous, dark-brown to black iron-manganese coating stains some joint faces. In shallow surface exposures the till is chiefly compact, firm to very firm, with moderate dry strength. Gravel clasts have strongly preferred long-axis fabrics oriented in the direction of glacier flow. The compact facies is overlain locally by the noncompact sandy facies, which is a locally layered till, having as much as 40 percent gravel clasts and large boulders, and minor beds of sorted and stratified sand, silt, and clay.

Soils and weathering characteristics—Soils developed in the upper part of Kittatinny Mountain Till deposits thicker than 1 m (3.3 ft) are alfisols, with argillic B horizons, 0.2 to 0.6 m (8–24 in.) thick, overlying Bx fragipan horizons (in some areas), that are

0.4 to 1 m (15–40 in.) thick, which overlie the C horizon in slightly weathered till, oxidized as deep as 2 m (6.6 ft). Clay and iron-manganese coatings are on ped faces in the lower B horizon, and on vertical joint faces in the till below the solum. In areas underlain by shallow rock or in till deposits having abundant gravel in the upper meter, soils are inceptisols having cambic B horizons, 0.2 to 0.6 m (8–24 in.) thick above Bx fragipan horizons in slightly weathered till. The calcareous till variety is leached to a depth of about 0.7 m (28 in.).

Contact relations—The Kittatinny Mountain Till is the surface till of northwestern New Jersey, where it unconformably overlies bedrock units of Middle Proterozoic to Devonian age (figs. 2 and 4). At its type locality, the Kittatinny Mountain Till overlies shale and sandstone of the Silurian Bloomsburg Red Beds. In most exposures, the Kittatinny Mountain Till was observed to overlie a hard, locally grooved surface of fresh bedrock. Water-well descriptions commonly refer to distinct subsurface contact relations of the Kittatinny Mountain Till with underlying fresh bedrock. However, in some areas, a zone of weathered bedrock, 0.5 to 2 m (1.6–6.6 ft) thick, has been reported beneath the till. The Kittatinny Mountain Till overlies stratified glacial meltwater deposits of the Rockaway Formation in the head of the Belvidere outwash deposit beneath the Foul Rift moraine. In the thick till deposits in large drumlins in the northern part of the area, the till overlies older, harder, inferred Flanders Till, as reported in water-well records. The contact between the tills was not well exposed during field mapping; a few exposures indicate that the contact is diffuse or gradational. The surface Kittatinny Mountain Till is generally less than 6.1 m (20 ft) thick and comprises a mixed zone that includes clasts and disseminated matrix materials of the underlying Flanders Till.

Boundaries—The top of the Kittatinny Mountain Till is at the land surface in upland areas, and is beneath stratified materials of the Rockaway Formation and younger surface deposits in valleys and lowland areas. The base of the Kittatinny Mountain Till generally rests on hard, glacially eroded bedrock, and locally on weathered rock. To the west, the Kittatinny Mountain Till extends beneath the Delaware River valley. To the east, the Kittatinny Mountain Till extends to a gradational contact with Netcong Till deposits. The three compositional varieties of the Kittatinny Mountain Till are inferred to have gradational boundaries.

Extent and surface form—The distribution of the Kittatinny Mountain Till in northern New Jersey is coincident with the distribution of sedimentary rocks of the Kittatinny Valley and Kittatinny Mountain area, from which it is principally derived. The Kittatinny Mountain Till extends to the limit of glaciation, marked by the southern edges of the Budd Lake, Townsbury, Mountain Lake, and Foul Rift segments of the terminal moraine, by local till deposits south of the terminal moraine, and by inferred ice-margin positions beneath promorainal meltwater deposits of the Rockaway Formation (fig. 3). The Kittatinny Mountain Till forms a discontinuous sheet deposit at the land surface, where its surface is truncated by meltwater channels and modern stream channels and by slope erosion. In areas of shallow bedrock, its surface form generally is controlled by the linear topographic features of the underlying bedrock. On drumlins the till surface is generally smooth, with local topographic features generally having less than 2 m (6.6 ft) of relief. In some areas of the Budd Lake, Townsbury, Mountain Lake, and Foul Rift segments of the terminal moraine, the surface of the till forms ridges and swales and linear and circular features having local relief of 3 to 10 m (10–33 ft).

Thickness—The thickness of the Kittatinny Mountain Till generally is 3.0 to 9.1 m (10–30 ft). The thickness of the brown, silty to sandy variety is as much as 45.7 m (150 ft). The thickness of the olive-gray silty till is reportedly as much as 18.3 to 30.5 m (60–100 ft) in drumlins and other areas of relatively thick till inferred to be products of late Wisconsinan ice advance. The carbonate till variety is generally less than 3.0 m (10 ft) thick. The till is very thin over bedrock on the crests and glacial-leeside slopes of mountains and hills. The till forms relatively thick wedge-shaped ramps on hillsides that faced advancing ice. Till in the subsurface beneath stratified deposits reportedly varies in thickness from 0 to 29.0 m (0–95 ft).

Origin—The Kittatinny Mountain Till is a glacial sediment, deposited directly from glacial ice, and consisting of two facies. The lower compact facies is inferred to be a basal till of lodgement and basal-meltout origin. The overlying noncompact, sandy and gravelly facies is inferred to be a meltout (ablation) till (in the genetic classification of Dreimanis, 1989). Similar loose, sandy diamict sediment within and on stratified meltwater deposits of the Rockaway Formation is a sediment-flow deposit, or flowtill (Hartshorn, 1958).

Age and regional correlations—The Kittatinny Mountain Till is inferred to have been deposited by the western edge of the Hudson-Champlain lobe of the Laurentide ice sheet, combined with ice flow from the north and from the eastern edge of the Ontario lobe (fig. 6). Based on its distribution and on stratigraphic position of tills, moraine segments, and glaciofluvial and glaciolacustrine deposits to the east, the base of the Kittatinny Mountain Till is inferred to be slightly older than the base of the adjacent Netcong Till. The relative ages of inferred ice-marginal recession positions indicate that valley ice lobes persisted in the large valleys of western New Jersey after the Highlands were deglaciated, and thus the age of the youngest deposit of the Kittatinny Mountain Till is slightly younger than the youngest Netcong Till. On the basis of the regional array of radiocarbon-dated materials from beneath or within the till, and in sediments overlying the till, we infer that the late Wisconsinan Kittatinny Mountain Till was deposited from about 25 ka to about 18 ka radiocarbon years.

The Kittatinny Mountain Till is similar lithically to the late Wisconsinan Olean Till derived from sedimentary rocks of adjacent Pennsylvania (Crowl and Sevon, 1980; Braun, 1994). Surface tills in north-central and northeastern New Jersey (Netcong Till and Rahway Till of this report) extend to the terminal moraine of the late Wisconsinan glacial episode, and are thus correlated with the Kittatinny Mountain Till.

ROCKAWAY FORMATION

Name and rank—The Rockaway Formation is proposed as a unit of formation rank, named for the stratotype locality in the upper Rockaway River basin in the south-central part of the glaciated Highlands province (fig. 6).

Type section—The type section for the Rockaway Formation is designated as the large gravel pit exposure in the Rockaway River valley at the head of Succasunna Plains at the southern edge of the terminal moraine, 244 m (800 ft) east of Dell Avenue, 1798 m (5900 ft) north of U.S. Route 46, at about 226 m (740 ft) altitude (40°53'45" N. lat, 74°36'24" W. long), in Roxbury Township, Morris County, in the Dover 7.5-minute quadrangle. The following section at the stratotype locality of the Rockaway Formation was measured in 1991 by B.D. Stone and S.D. Stanford:

Depth (m)	Description
0	Land surface

0–0.3 Cobble gravel; framework gravel ranges from small to large cobbles; gravel clasts are rounded to well rounded and oblate to elongate in shape; gravel imbrication locally well developed; matrix is reddish-brown (2.5*YR* 5/4), loose, poorly sorted, silty, fine to very coarse sand

0.3–1.03 Pebble-cobble gravel and sand; framework gravel ranges from large pebbles to medium cobbles; very thinly bedded to thin bedded; horizontal-plane beds marked by stone lines at base of beds or by alternating finer and coarser gravel beds

1.03–1.18 Cobble-pebble gravel and sand, indistinctly layered; imbrication locally well developed; light-brown, loose, poorly sorted matrix

1.18–1.52 Pebble-cobble gravel and sand; framework gravel ranges from large pebbles to medium cobbles; very thinly bedded to thin bedded

1.52–1.7 Cobble line; imbrication locally well developed

1.7–1.94 Pebble-cobble gravel; framework gravel ranges from large pebbles to medium cobbles; very thinly bedded to thin bedded

1.94–2.21 Pebble gravel; framework gravel ranges from large pebbles to granular gravel; sand matrix in large pebble gravel is very poorly sorted

2.21–2.32 Cobble line; imbrication locally well developed

2.32–3.44 Pebble-cobble gravel; very thinly bedded to thin bedded; horizontal-plane beds marked by stone lines at base of beds or by alternating finer and coarser gravel beds

3.44–3.90 Cobble gravel; appears well sorted; clasts are 10 to 20 cm (4–8 in.) long, rounded to well rounded, and oblate to elongate in shape; gravel indistinctly layered; imbrication locally well developed; loose, poorly sorted matrix

3.90–5.97 Netcong Till—brown till; silty sand matrix contains scattered clasts of quartzite, gneiss, minor shale and sandstone, and chert; maximum gravel clast 30 cm (11.8 in.) long (exposed part); large clasts are subangular till boulders; cobbles are rounded to subrounded, derived from underlying gravel

5.97–6.91 Pebble gravel, very thinly bedded, and horizontal-plane bedded; framework gravel ranges from large pebbles to granular gravel; sand matrix in large pebble gravel is very poorly sorted, with mode of medium sand and range from fine sand to coarse gravel.

Lithologic characteristics—The Rockaway Formation is highly variable texturally and compositionally. It includes stratified light-gray (10*YR* 7–1) to very pale brown (10*YR* 7/3–4) to pale-yellow (2.5*Y* 7/4), or light-brown (7.5*YR* 6/4) to reddish-brown (2.5*YR* 5/4) sand, silt, and gravel that is loose and poorly to well sorted; and reddish-brown (2.5*YR* 5/4) or dark-gray (10*YR* 4/1) silt and clay that is stratified and poorly to moderately sorted. The color and the mineralogic composition of the deposits generally are similar to the color and composition of underlying and northerly adjacent till and bedrock units. Gravel composition typically is polymict; gravel clasts are subrounded to well rounded, and generally nonweathered; some coarse gravel clasts are striated. Sand composition is highly variable, from lithic coarse sand to sublithic or subarkosic fine sand; grains generally are nonweathered.

Two principal types of deposits, glacial-stream and glacial-lake deposits (fig 5), are recognized within the Rockaway, based on lithic characteristics, local stratigraphic successions, and comparison with modern depositional systems. Deposits of glacial streams consist of horizontally stratified, interbedded sand and gravel, moderately to poorly sorted. Deposits grade from (1) coarse gravel facies in ice-proximal heads of units, to (2) sand and gravel facies, to (3) pebbly coarse sand facies in distal parts of some units. The coarse gravel facies consists of massive cobble-gravel beds that have a poorly sorted sand matrix; beds of small boulders are common. Coarse gravel beds generally are less than 1 m (3.3 ft) thick. Beds composed of finer grained sediment are rare. The sand and gravel facies is most prevalent; it consists of pebble- and cobble-gravel beds interbedded with beds of medium to coarse sand. Cobble-gravel beds are massive or planar bedded, poorly to moderately sorted, and have local imbrication of clasts. Pebble- or cobble-gravel beds also contain planar-tabular and trough crossbeds. Gravel beds are 0.2 to 1.5 m (0.7–5 ft) thick. Sand beds are chiefly coarse sand with pebbles and granules, poorly sorted, in trough and planar-tabular crossbeds. Medium- and fine-sand ripple cross-laminated beds are minor constituents. The pebbly coarse sand facies consists chiefly of coarse sand with pebbles in trough and planar-tabular crossbeds, and in planar beds. Thin beds of pebble gravel are minor constituents.

Deposits of glacial lakes consist of sand, sand and gravel, and silty sand in deltaic, glaciolacustrine fan and ice-channel deposits; and fine sand, silt, and clay in lake-bottom deposits. Deltaic deposits have sand and gravel glaciofluvial topset beds, 0.6 to 6.1 m (2–20 ft) thick, locally as much as 12.2 m (40 ft) thick, which overlie deltaic foreset and bottomset facies. Foreset facies include (1) the sand and gravel foreset facies, consisting of gravel, pebbly sand, and coarse sand, poorly to moderately sorted, in 2.0- to 10.1-m (6.5–33-ft)-thick sets of thin beds which dip 25 to 35°; and (2) the sandy foreset facies, consisting of fine to medium sand, moderately sorted, in interbedded parallel-laminated and ripple cross-laminated sets of beds that are 2.0 to 5.2 m (6.5–17 ft) thick and that dip less than 25°; draped laminations of silt and clay are common in lower beds. Delta bottomset facies are (1) the sand and gravel bottomset facies, consisting of coarse pebbly sand in planar-tabular crossbeds and parallel-bedded fine sand, silt and clay, in sets of beds that dip less than 5°; and (2) the sandy bottomset facies, consisting of fine sand, silt, and clay, in ripple cross-laminated and parallel-laminated beds that dip less than 5°. Lake-bottom deposits contain two facies: (1) the sandy facies, consisting of fine sand to silt in parallel-laminated and minor ripple cross-laminated sets of beds; and (2) the silt-clay facies, consisting of silt-to-very fine sand, and clay in parallel laminations, microlaminations, and minor ripple cross-laminations. Lake-bottom deposits with laminations of variable thickness have clay laminae less than 2 mm (0.08 in.) thick. Lake-bottom varved deposits consist of couplets of microlaminated silt-to-very fine sand, and massive clay; couplets are 0.4 to 10 cm (0.2–4 in.) thick; sequences of couplets show little variation in thickness.

Soils and weathering characteristics—Soils in sand and gravel deposits are inceptisols, or local entisols or alfisols, with B horizons 0.3 to 0.8 m (13–30 in.) thick overlying C horizons in sediments lightly oxidized as deep as 1.5 m (60 in.). Soils in silt and clay deposits are inceptisols with B horizons 0.5 to 0.8 m (18–30 in.) thick overlying nonoxidized sediments.

Contact relations—The Rockaway Formation is the predominant surface unit of sorted and stratified deposits in the valleys and lowlands of northern New Jersey. The Rockaway unconformably overlies the Rahway Till, the Netcong Till, and the Kittatinny Mountain Till. In some valleys, deposits of the Rockaway Formation directly overlie bedrock, weathered rock materials, colluvium, or deposits of the Lamington Formation, Bergen Till, or Flanders Till. At its type locality, the Rockaway Formation overlies glacial meltwater deposits of the Lamington Formation of Illinoian age, and interglacial fluvial deposits of the Wharton deposits. Till deposits of the Rahway Till, Netcong Till, and Kittatinny Mountain Till unconformably overlie locally sheared deposits of the Rockaway Formation in areas of segments of the terminal moraine and in parts of some recessional moraines.

Boundaries—The top of the Rockaway Formation is at the land surface in valleys and lowlands in the area. Locally, the top of the Rockaway is overlain by deposits of segments of the terminal moraine and recessional moraines. The base of the Rockaway Formation generally rests on Rahway Till, Netcong Till, or Kittatinny Mountain Till. In some valleys, the Rockaway Formation overlies deposits of the Lamington Formation, Bergen Till, or Flanders Till; locally it directly overlies hard, glacially eroded bedrock. The depositional facies of the Rockaway Formation generally have gradational boundaries within individual deposits (morphosequences); sharp boundaries separate facies of different age.

Extent and surface form—The Rockaway Formation forms a discontinuous network of stratified coarse- and fine-grained surface deposits that are confined to valleys, lowlands, and upland basins. Glacial-stream outwash and terrace deposits extend down valleys from the southern edges of the terminal moraine and also from ice-margin positions in northern parts of the map area (figs. 3 and 5). Glacial-lake deposits extend into glacially dammed valleys south of some segments of the terminal moraine. Other deposits of major glacial lakes are in northerly draining valleys that were dammed by the ice margin, or in basins dammed by slightly older stratified deposits or moraines. Deposits of small glacial lakes and ponds are in northerly draining valleys that were dammed by the ice margin, or in basins that were dammed by slightly older stratified deposits, moraines, or stagnant glacial ice.

Stratified meltwater deposits of the Rockaway Formation are subdivided into informal glacial-stream or glacial-lake map units on the basis of the distribution, stratigraphic relations, and altitudes of their sedimentary facies in different depositional basins. Map units show the extent of sediments in each glacial-stream deposit or sediments deposited in or graded to each glacial lake or related series of lakes. Deposits of each map unit are bounded by discontinuities, either at contacts between deposits of contiguous units, or by geographic separation within a valley or from valley to valley. The position and altitude of deltaic and lake-bottom deposits in each glacial lake are related to the paleogeography of the lake basin and to the altitude of lake spillways, which are preserved on the lowest points of the basin divides. Deposits of some major lakes are related to different lake stages, the levels of which were controlled by successively deglaciated lower-lake spillways. Deposits of some other major lakes are related to lake phases, the levels of which lowered due to erosion of sediment dams.

Most of the glacial-stream and glacial-lake map units contain multiple ice-marginal or near-ice-marginal meltwater deposits, known regionally as morphosequences (Koteff and Pessl, 1981). Each morphosequence typically contains a progression of landforms, grading from ice-contact forms (eskers, kettles, and collapsed topography) at the head of the deposit, to noncollapsed depositional landforms (outwash plains, lobate delta margins, and lake-bottom plains) in distal parts of the deposit. Glacial-stream deposits are preserved in promorainal or ice-marginal outwash plains across wide valley areas, and in discontinuous terrace deposits that extend down valleys. Ice-marginal delta deposits contain ice-contact landforms at their heads and flat delta plains. Fluviodelta deposits grade from terraces or outwash plains that extend down tributary valleys to the delta plain. Deltas commonly have lobate delta-plain and foreset-slope margins that grade into flat lake-bottom plains. Lacustrine fan deposits generally are low ridges or knolls, and some are connected to ice-channel ridges in some deposits. Hummocky ice-contact deposits form ridges that are topographically above adjacent glaciodeltaic deposits; locally these form transverse ridges on top of slightly older glaciodeltaic deposits.

Thickness—Glacial-stream deposits generally are 1.8 to 15.2 m (6–50 ft) thick, locally as much as 30.5 m (100 ft) thick. The total thickness of deltaic sediments is 6.1 to 45.7 m (20–150 ft). The total thickness of lake-bottom sediments is 3.0 to 61.0 m (10–200 ft).

Origin—The stratified deposits of the Rockaway Formation were deposited chiefly by glacial meltwater at and beyond the glacier margin, and are divided into two groups of map units on the basis of their sedimentary facies. Glacial-stream deposits originated as braided-stream outwash deposits that accumulated in promorainal or ice-marginal outwash plains across wide valley areas, and they originated as valley-train deposits, which are preserved as meltwater terrace deposits that extend down valleys. Deposits of glacial-lake units contain glaciodeltaic sediments, which include glaciofluvial facies in topset sediments, delta foreset and bottomset facies, glaciolacustrine fan facies, and lake-bottom facies. These deposits are products of braided streams, and of subglacial or englacial streams that flowed into glacial lakes as density underflows, depositing bedload sediments in delta and fan foreset and bottomset beds, and depositing lake-bottom sediments from bedload and suspension. Ice-marginal morphosequences record systematic ice-margin retreat positions in different depositional basins.

Age and regional correlations—Deposits of the Rockaway Formation were emplaced by meltwaters that drained from the margin of the Hudson-Champlain lobe of the Laurentide ice sheet. Subsurface meltwater deposits preserved beneath till deposits in the upper Passaic and Rockaway River basins, in the Delaware River valley, and in other areas near the glacial limit indicate that sediment deposition accompanied the advance of the ice sheet. Based on the distribution and stratigraphic position of tills, moraine segments, and meltwater deposits, the age of the oldest meltwater deposits generally becomes younger to the west across New Jersey. However, the outwash deposits beneath the Foul Rift moraine segment are probably older than meltwater sediments in upland basins near the terminal moraine in the Highlands. The relative ages of glacial-stream and glacial-lake deposits are based on local stratigraphic relations and on the positions and altitudes of glacial-lake deposits. The inferred ice-marginal recession positions (fig. 3) indicate relative ages of these deposits across the area. The lobate ice-margin positions indicate that valley ice lobes persisted in the large valleys of eastern and western New Jersey after the Highlands were deglaciated, and thus the age of the youngest near-ice-marginal deposit in the Hackensack/Hudson lowland is slightly younger than ice marginal deposits in adjacent basins in the Highlands in western New Jersey. On the basis of radiocarbon-dated materials from beneath or within the associated till deposits, and in sediments overlying the till, we infer that near-ice-marginal deposits of the late Wisconsinan Rockaway Formation were deposited from about 25 ka to about 18 ka radiocarbon years. Meltwater deposition of outwash deposits in the Delaware River valley persisted until about 16 ka radiocarbon years. Continued meltwater and meteoric deposition of sediments in some lake basins may have persisted until about 13 ka radiocarbon years.

The deposits of the Rockaway Formation are similar lithically to late Wisconsinan surface meltwater deposits on Long Island, N.Y. (Sirkin, 1982; Cadwell, 1989), and in eastern Pennsylvania (Crowl and Sevon, 1980; Braun, 1994), which extend to the terminal moraine of the late Wisconsinan glacial episode and are thus correlated with the Rockaway Formation.

UNITS OF MIDDLE PLEISTOCENE AGE, LATE ILLINOIAN GLACIATION

Two till deposits, of contrasting color and mineralogic composition related to underlying and northerly adjacent bedrock types, discontinuously cover a narrow area of northern New Jersey that is south of the limit of the late Wisconsinan glaciation (figs. 3 and 4). The late Illinoian till and meltwater deposits characteristically have more subdued morphology, and are more eroded and weathered than the late Wisconsinan deposits. In the weathered zone gravel clasts composed of gneiss have weathering rinds of altered feldspar; sand grains contain altered feldspar and clay derived from weathering. Other gravel clast lithologies are disintegrated or have surface iron stain or weathering pits. Soil features such as clay films and iron-manganese stains on fracture surfaces extend several meters into the deposits. Late Illinoian meltwater glacial-stream deposits extend south from the inferred late Illinoian glacial limit down two valleys. At the late Illinoian glacial limit and north of it, meltwater glacial-stream and glacial-lake sediments constitute six additional deposits in various lowland and valley basins. The age of the late Illinoian glacial episode is based on correlation with inferred Illinoian deposits of adjacent areas, particularly Long Island and the coastal islands of southern New England which are constrained by a minimum radiometric age of 133 ka (Oldale and others, 1982). The age range of the deposits is estimated to be 160 to 180 ka, also based in part on the age of the correlative marine oxygen-isotope stage 6 (Fullerton and Richmond, 1986).

FLANDERS TILL

Name and rank—The Flanders Till is proposed as a unit of formation rank, named for the stratotype locality at the abandoned Flanders Valley airport, 1.5 km (0.9 mi) southeast of the village of Flanders in the north-central part of the glaciated Highlands province (fig. 4). The lithogenetic term "till" is used in the name to denote the very poorly sorted, nonstratified, compact material of glacial origin (Dreimanis, 1989).

Type section—The type section for the Flanders Till is designated as a temporary excavation on the crest of the Flanders moraine, 244 m (800 ft) north of Reger Road, 2440 m (8000 ft) east of U.S. Route 206, at about 216 m (710 ft) altitude (40°50'21" N. lat, 74°40'46" W. long), in the township of Roxbury, Morris County, in the Chester 7.5-minute quadrangle. The following section at the stratotype locality of the Flanders Till was measured in 1991 by B.D. Stone:

Depth (m)	Description
0	Land surface
0–1	Eolian sand and soil developed in till
1–2.2	Strong brown (7.5*YR* 5/6) to yellowish-brown (10*YR* 5/4–6) till, with a silty to clayey very poorly sorted matrix, containing 5 to 20 percent pebbles and cobbles, and a few boulders. Matrix is compact, has moderate plasticity, and is noncalcareous; contains quartz, scattered weathered feldspar, shale fragments, and heavy minerals and biotite that have iron-oxide stains. Gravel clasts have thin silt caps and consist chiefly of quartzite and gneiss, and scattered black chert; gneiss gravel clasts have weathering rinds 0.2 to 1 cm (0.1–0.4 in.) thick.

Lithologic characteristics—Strong brown (7.5*YR* 5/6), pale-brown (10*YR* 6/3), yellow (10*YR* 7/6) to yellowish-brown (10*YR* 5/4–6) silty to sandy very poorly sorted (diamict) sediment (fig. 7), containing 5 to 20 percent pebbles and cobbles, and a few boulders. The sediment matrix generally is compact, homogeneous, and has low to moderate plasticity. Nonweathered till is calcareous in areas underlain by carbonate rock. Sand grains in the matrix and most gravel clasts are subangular to subrounded, and generally nonweathered. The matrix contains quartz, feldspar, shale fragments, and heavy minerals and biotite that have iron-oxide stains. The matrix silt-clay fraction is yellowish-brown to gray. Gravel clasts have thin silt caps that adhere to the tops of the clasts. Gravel clasts of gneiss, quartzite, sandstone or carbonate rock from local bedrock units are the dominant rock types in pebble and small cobble sizes, which also include chert and shale. Erratic clasts of gneiss and quartzite from the highland areas to the north constitute the majority of large cobbles and boulders.

The Flanders Till is chiefly a compact, dense, massive till facies that contains few lenses of sorted silt and fine sand. In naturally dried outcrops, the till exhibits a subhorizontal fissility defined by clayey parting surfaces that vary in spacing from less than 0.5 cm (0.2 in.) to 2.0 cm (0.8 in.). A subvertical system of joints, spaced at more than 5 cm (2 in.), imparts an angular blocky structure to the till. In shallow surface exposures the till is chiefly compact, firm to very firm, and has moderate dry strength.

Related deposits also include scattered subangular erratic gravel clasts that lie on the land surface on top of weathered bedrock or colluvium. Also, as shown on the map, the Flanders Till locally includes thin surface colluvium and small areas of weathered bedrock.

Soils and weathering characteristics—In the area south of late Wisconsinan glaciation, soils developed in the upper part of the Flanders Till typically are alfisols and ultisols. The upper 3 to 5.2 m (10–17 ft) of the Flanders Till, including the surface soils, contains a weathering profile, characterized by a pervasive stain of the matrix by iron oxide, with brown to black iron-manganese stain on clasts and sand grains. Clay and iron-manganese coatings are on ped faces and on vertical joint faces in the till. Gravel clasts of gneiss in the weathered zone have weathering rinds 0.2 to 1 cm (0.1–0.4 in.) thick. Gravel clasts of carbonate rock are entirely decomposed to depths of 3.0 m (10 ft). Quartzite, shale, and sandstone clasts generally are lightly weathered or have thin weathering rinds.

Contact relations—The Flanders Till is a surface deposit in the central and western part of the map area, and it is a subsurface deposit in northern New Jersey where it is inferred to be present in some thick till deposits in large drumlins. The Flanders unconformably overlies bedrock units of Middle Proterozoic to Devonian age (figs. 2 and 4). Water-well descriptions refer to distinct subsurface contact relations of the Flanders with underlying fresh or weathered bedrock. In some areas, a zone of weathered bedrock several meters thick has been reported beneath the Flanders. The Flanders Till is overlain by the younger Netcong Till and Kittatinny Mountain Till, as reported in water-well records. The contact between the tills was not well exposed during field mapping; a few exposures indicate that the contact is diffuse or gradational.

Boundaries—The top of the Flanders Till is at the land surface in upland areas in the central western part of the map area. To the north, the weathered zone in the top of the Flanders Till is truncated by the Netcong Till and Kittatinny Mountain Till, which are the surface tills in drumlins in the northwestern part of the map area. The base of the Flanders Till generally rests on weathered rock, and locally on hard, glacially eroded bedrock. To the west, the Flanders extends to the Delaware River valley. To the east, the Flanders extends to the eastern edge of the Highlands province.

Extent and surface form—The distribution of the Flanders Till in northern New Jersey is coincident with sedimentary rocks in the Kittatinny Valley and granitic gneiss in the Highlands province, from which it is principally derived. The Flanders Till extends to the limit of late Illinoian glaciation, marked by discontinuous patches of till and moraine. To the north, the distribution of the Flanders Till is coincident with some thick till deposits in large drumlins that overlie sedimentary rocks in the Kittatinny Valley.

Thickness—The thickness of the Flanders Till generally is less than 6.1 m (20 ft), but as much as 65.5 m (215 ft) in areas of thick till in drumlins.

Origin—The Flanders Till is a glacial sediment, deposited directly from glacial ice. The till is inferred to be a basal till of lodgement and basal-meltout origin (in the genetic classification of Dreimanis, 1989).

Age and regional correlations—The Flanders Till discontinuously extends across the Highlands and Kittatinny Valley provinces. Based on its upland position, the base of the Flanders Till is inferred to be slightly younger than the base of the Bergen Till in the lowland areas to the east. On the basis of correlation with inferred Illinoian deposits of the region, the age range of the Flanders Till is estimated to be 160 to 180 ka.

The Flanders Till is similar lithically and in weathering characteristics to inferred late Illinoian subsurface tills derived from metasedimentary and igneous rocks of southern New England (Stone and others, 1992; Melvin and others, 1992). Subsurface tills on Long Island (Sirkin, 1982; Cadwell, 1989), and in northeastern New Jersey (Bergen Till of this report), extend beyond the terminal moraine of the late Wisconsinan glacial episode and have similar weathering characteristics, and are thus correlated with the Flanders Till.

BERGEN TILL

Name and rank—The Bergen Till is proposed as a unit of formation rank, named for the stratotype locality in Bergen County, in the northern part of the glaciated Newark basin of the Piedmont lowland province (figs. 4 and 6). The lithogenetic term "till" is used in the name to denote the very poorly sorted, nonstratified, compact material deposited directly by or from glacial ice (Dreimanis, 1989).

Type section—The type section for the Bergen Till is designated as a temporary excavation 488 m (1600 ft) north of Masonicus Brook, 183 m (600 ft) east of Franklin Turnpike, at about 137 m (450 ft) altitude (41°04'49" N. lat, 74°08'18" W. long), in Bergen County, in the Ramsey 7.5-minute quadrangle. The following section at the stratotype locality of the Bergen Till was measured in 1990 by B.D. Stone:

Depth (m)	**Description**
0	Land surface
0–1	Soil developed in gray till
1–4	Gray till, sandy, containing 5 to 7 percent gravel clasts, notably including strongly weathered ghosts of shale and gneiss; red silt and clay fills shear-zone partings that divide till slabs of slightly different color
4–8	Red (2.5*YR* 4/6) silty, very poorly sorted till containing more than 10 percent cobbles and pebbles; gravel clasts do not have silt caps or iron-manganese stain. Unit grades upward into mixed red and brown (7.5*YR* 5/4) matrix with red silt and clay partings that divide till slabs of slightly different color; this unit appears to be transitional at the base of the Netcong Till with underlying Bergen Till
8–9	Reddish-brown (5*YR* 4/4) to red (2.5*YR* 4/6) till, silty to clayey, very poorly sorted, containing 5 to 10 percent pebbles and cobbles. Matrix is very compact, hard, moderately plastic, and noncalcareous; sand grains in the matrix and most gravel clasts are subangular to subrounded, and variably weathered; gravel clasts of gneiss, red sandstone, and quartzite are dominant rock types; shale and gray sandstone gravel clasts are minor constituents. Gravel clasts have thin silt caps that adhere to the tops of the clasts; a pervasive iron-manganese stain is on all fracture surfaces and on most gravel clasts; thin subhorizontal silty shear zones divide angular slabs of brown and red till.

Lithologic characteristics—Brown (7.5*YR* 5/4) to reddish-brown (5*YR* 4/4) to red (2.5*YR* 4/6) silty and silty-to-clayey (fig. 7) very poorly sorted (diamict) sediment containing 5 to 20 percent pebbles, cobbles, and boulders. Matrix generally is very compact and homogeneous, has low to moderate plasticity, and is noncalcareous. Sand grains in the matrix and most gravel clasts are subangular to subrounded, and variably weathered. Matrix contains abundant shale and siltstone fragments, and reddish-brown silt and clay. Many gravel clasts have thin silt caps that adhere to the tops of the clasts. Gravel clasts of gneiss, red sandstone, and quartzite are the dominant rock types in pebble and small cobble sizes, which also include gray sandstone, and basalt. Erratic clasts of gneiss and quartzite from the highland areas to the north constitute the majority of large cobbles.

The Bergen Till is chiefly a dense, massive till that contains few lenses of sorted silt and fine sand. In naturally dried outcrops, the till exhibits a subhorizontal fissility defined by clayey parting surfaces that vary in spacing from less than 0.5 cm to 2.0 cm (0.2–0.8 in.). A subvertical system of joints, spaced at more than 5 cm (2 in.), imparts an angular blocky structure to the till. Dark-brown to black iron-manganese coating stains joint faces and fissility surfaces. In shallow surface exposures the till is chiefly compact, firm to very firm, and has moderate dry strength. In water-well records, the subsurface Bergen Till is reported as characteristically hard, dense, or clayey.

Soils and weathering characteristics—The upper part of the Bergen Till preserves part of a thick weathering zone. Clay and iron-manganese coatings are on ped faces and on vertical joint faces in the till.

Contact relations—The Bergen Till is a subsurface till of northeastern New Jersey, where it is present in the thick till deposits in large drumlins in the northern part of the area and where it unconformably overlies bedrock units of early Mesozoic age (figs. 2 and 4). Water-well descriptions commonly refer to distinct subsurface contact relations of the Bergen with underlying fresh bedrock. However, in some areas, a zone of weathered bedrock, several meters thick, has been reported beneath the till. The Bergen Till is overlain by the younger Rahway Till and the Netcong Till, as reported in water-well records. The contact between the tills was not well exposed during field mapping; a few exposures indicate that the contact is diffuse or gradational. The surface Rahway Till is generally less than 6.1 m (20 ft) thick and comprises a mixed zone that includes clasts and disseminated matrix materials of the underlying Bergen Till. The Bergen Till may be present beneath the Rahway in the area of the Perth Amboy segment of the terminal moraine.

Boundaries—The weathered zone in the top of the Bergen Till is truncated by Rahway Till or Netcong Till, which are the surface tills in drumlins. The base of the Bergen Till generally rests on hard, glacially eroded bedrock, and locally on weathered rock. To the west, the Bergen extends to the edge of the Piedmont province.

Extent and surface form—The distribution of the Bergen Till in northern New Jersey is coincident with thick till deposits in large drumlins that overlie sedimentary, volcanic, and intrusive rocks of the Newark basin, from which it is principally derived. The Bergen Till extends nearly to the limit of late Illinoian glaciation, marked by discontinuous patches of till beneath meltwater sediments of the Lamington and Rockaway Formations in the Great Swamp basin in southern Morris County. Eroded Bergen Till crops out locally near the Bernardsville deposits of the Lamington Formation west of the Great Swamp. The Bergen may also be present beneath the Rahway Till at the southern edge of the Perth Amboy segment of the terminal moraine.

Thickness—The thickness of the Bergen Till generally is greater than 9.1 m (30 ft), and as much as 21.3 m (70 ft), as reported in water-well records.

Origin—The Bergen Till is a glacial sediment, deposited directly from glacial ice. The till is inferred to be a basal till of lodgement and basal-meltout origin (in the genetic classification of Dreimanis, 1989).

Age and regional correlations—The Bergen Till coincides with the axial part of the Hudson-Champlain lobe of the Laurentide ice sheet. Based on its axial position, the base of the Bergen Till is inferred to be slightly older than the base of the Flanders Till in areas to the west. On the basis of correlation with inferred Illinoian deposits of the region, the age range of the Bergen Till is estimated to be 160 to 180 ka.

The Bergen Till is similar lithically and in weathering characteristics to inferred late Illinoian subsurface tills derived from sedimentary and igneous rocks of the Hartford basin in Connecticut and Massachusetts (Stone and others, 1992; Melvin and others, 1992). Subsurface tills on Long Island (Sirkin, 1982; Cadwell, 1989) and in northwestern New Jersey (Flanders Till of this report) extend beyond the terminal moraine of the late Wisconsinan glacial episode and have similar weathering characteristics, and are thus correlated with the Bergen Till.

LAMINGTON FORMATION

Name and rank—The Lamington Formation is proposed as a unit of formation rank, named for the stratotype locality in the Lamington River valley in the south-central part of the glaciated Highlands province (figs. 5 and 6).

Type section, glaciofluvial facies—The type section for the Lamington Formation is designated as the exposure in the Lamington River valley in an active gravel pit on the north side of a ridge that is about 2073 m (6800 ft) north-northwest of the village of Ironia, 640 m (2100 ft) east of the Lamington River, 671 m (2200 ft) north of Ironia Road, at about 218 m (715 ft) altitude (40°50'29" N. lat, 74°38'05" W. long) in the township of Randolph, Morris County, in the Chester 7.5-minute quadrangle. The following section at the stratotype locality of the Lamington Formation was measured in 1991 and 1996 by B.D. Stone:

Depth (m) **Description**

0 Land surface; soil excavated

0–0.38 Brown silty sand and pebble-cobble gravel; base is stony and top has scattered small cobbles and pebbles; contact at base is indistinct

0.38–1.70 Orange-brown silty sand and pebble-cobble gravel; matrix mode is estimated to be silt to very fine sand; matrix crushes easily between two fingers. Unit appears homogeneous, without stratification or fissility. Unit contains 5 to 7 percent gravel clasts, notably angular cobbles and small boulders of striated quartzite, and rounded clasts of gneiss; unit also contains scattered small pebbles of deeply weathered gneiss. Largest boulders are composed of quartzite, 91 to 94 cm (36–37 in.) in length, having intermediate axes 36 to 53 cm (14–21 in.) long. Unit has sharp basal contact

1.70–2.36 Pebble-cobble gravel and sand; framework gravel clasts are rounded to well rounded, consisting of quartzite, weathered gneiss, and scattered sandstone, shale, and weathered carbonate; gravel clasts have silt caps. Matrix sand is loose and poorly sorted, with medium sand mode, ranging from silt and clay to very fine sand; sand grains are angular to rounded, and iron stained. Matrix sand contains illuviated brown silt and clay

2.36–2.61 Brown coarse sand and fine gravel, containing eastward-dipping planar and tabular crossbed sets; sand beds have coarse matrix, ranging from medium to very coarse, and containing scattered granules and small pebbles; granular beds are less than 2 cm (0.8 in.) thick and contain scattered small pebbles

2.61–2.76 Pebble-cobble gravel and sand; framework gravel clasts are subangular to chiefly rounded, consisting of quartzite, weathered gneiss, and scattered sandstone and shale; matrix sand is loose and poorly sorted, with coarse sand mode, ranging from fine to very coarse sand; sand grains are angular to rounded, and iron stained

2.76–3.22 Cobble-pebble gravel and sand; framework gravel clasts are subangular to rounded, consisting of weathered gneiss, quartzite, and scattered sandstone, shale and weathered carbonate; matrix sand is poorly sorted, with coarse sand mode, ranging from silt and very fine sand to very coarse sand; sand grains are angular to rounded, and iron stained

3.22–3.35 White and brown sand with medium sand mode, ranging from fine to very coarse sand; laminated in trough crossbed sets that are 1 to 4 cm (0.4–1.6 in.) thick; dark sand layers consist of magnetite grains finer than medium sand; crossbed sets dip toward an azimuth of 24°.

Lithologic characteristics—The Lamington Formation is highly variable texturally and compositionally. It includes light-gray (10*YR* 7/1) to very pale brown (10*YR* 7/3–4) to pale-yellow (2.5*Y* 7/4), or light-brown (7.5*YR* 6/4) to reddish-brown (2.5*YR* 5/4) gravel, sand, and silt that is stratified and poorly to well sorted; and reddish-brown (2.5*YR* 5/4) or dark-gray (10*YR* 4/1) silt and clay that is stratified and poorly to moderately sorted. The color and the mineralogic composition of the deposits are similar to the color and composition of underlying and northerly adjacent till and bedrock units. Gravel composition is polymict; gravel clasts are subrounded to well rounded. Gravel clasts are variably weathered in the shallow subsurface, and include abundant clasts having weathering rinds 0.2 to 1 cm (0.1–0.4 in.) thick, and many friable disintegrated clasts. Some coarse gravel clasts are striated. Sand composition is highly variable, from lithic coarse sand to sublithic or subarkosic fine sand; grains are weathered in the shallow subsurface.

Two principal types of deposits, glacial-stream and glacial-lake deposits (fig. 5), are recognized within the Lamington, based on lithic characteristics, local stratigraphic successions, and comparison with modern depositional systems. Deposits of glacial streams consist of horizontally stratified, interbedded sand and gravel that is moderately to poorly sorted. Deposits grade from (1) coarse gravel facies in ice-proximal heads of units, to (2) sand and gravel facies, to (3) pebbly coarse sand facies in distal parts of some units. The coarse gravel facies consists of massive cobble-gravel beds that have a poorly sorted sand matrix; beds of small boulders are common. Beds composed of finer grained sediment are rare. The sand and gravel facies consists of pebble- and cobble-gravel beds interbedded with beds of medium to coarse sand. Gravel beds are 0.2 to 1.5 m (0.7–5 ft) thick. Sand beds are chiefly coarse sand with pebbles and granules, poorly sorted. Medium and fine sand beds are minor constituents. The pebbly coarse sand facies consists chiefly of coarse sand with pebbles; thin beds of pebble gravel are minor constituents.

Deposits of glacial lakes consist of sand, sand and gravel, and silty sand in deltaic, glaciolacustrine fan and ice-channel deposits; and fine sand, silt, and clay in lake-bottom deposits. Deltaic deposits have sand and gravel glaciofluvial topset beds, which overlie deltaic foreset and bottomset facies. Foreset facies include sand and gravel and sandy beds. Delta bottomset facies include sand, silt, and clay beds. Lake-bottom deposits contain sandy silt and clay beds.

Soils and weathering characteristics—Soils in some sand and gravel deposits are inceptisols with B horizons 0.9 m (34 in.) thick overlying C horizons in sediments oxidized to more than 1.5 m (60 in.). Gravel clasts have silt caps in the C horizon and in the upper part of the deposits. In some areas, soils are developed in eolian sand, congeliturbate, colluvium, or solifluction deposits containing ventifacts, and are alfisols with argillic B horizons 0.6 to 0.9 m (22–34 in.) thick overlying the C horizon in oxidized sediments.

Contact relations—The Lamington Formation unconformably overlies the Flanders Till and Bergen Till, or it locally overlies bedrock. At its type locality, the Lamington Formation overlies the Flanders Till and weathered bedrock.

Boundaries—The top of the Lamington Formation is at the land surface in valleys and lowlands in the map area. Locally, the top of the Lamington is overlain by deposits of segments of the terminal moraine, deposits of the Rockaway Formation, Netcong Till, Rahway Till, or Wharton fluvial deposits and colluvium. The base of the Lamington Formation generally rests unconformably on Flanders Till or Bergen Till, or on weathered bedrock or colluvium. Locally it directly overlies hard, glacially eroded bedrock. The depositional facies of the Lamington Formation generally have gradational boundaries within individual deposits (morphosequences); sharp boundaries separate facies of different age.

Extent and surface form—The Lamington Formation forms a discontinuous network of coarse- and fine-grained, stratified surface and subsurface deposits confined to valleys and lowlands beneath and south of the late Wisconsinan terminal moraine. Lamington deposits and glacially transported clasts of the Lamington may be preserved locally in drumlins and other thick-till deposits beneath the Rahway, Netcong, or Kittatinny Mountain Tills. Glacial-stream outwash and terrace deposits of the Lamington extend down two valleys from the southern edges of the terminal moraine and are also present as subsurface units in the upper Passaic River basin. Glacial-lake deposits of the Lamington also fill parts of four valleys south of the terminal moraine. Other deposits of the Lamington emplaced in major glacial lakes are in the Rockaway, Passaic, and Musconetcong River valleys that were dammed by the ice margin.

Stratified meltwater deposits of the Lamington Formation are subdivided into informal glacial-stream or glacial-lake map units on the basis of the distribution, stratigraphic relations, and altitudes of facies in different depositional basins. Map units show the extent of sediments in each glacial-stream deposit or sediments deposited in or graded to each glacial lake or related series of lakes. Deposits of each map unit are bounded by discontinuities, either at contacts between deposits of contiguous units, or by geographic separation within a valley or from valley to valley. The position and altitude of deltaic and lake-bottom deposits in each glacial lake are related to the paleogeography of the lake basin and to the altitude of lake spillways, which are preserved on the lowest points of the basin divides.

Most of the glacial-stream and glacial-lake map units contain multiple ice-marginal or near-ice-marginal meltwater deposits, known regionally as morphosequences (Koteff and Pessl, 1981). Each morphosequence typically contains a progression of landforms, grading from ice-contact forms (eskers, kettles, and collapsed topography) at the head of the deposit, to noncollapsed depositional landforms (outwash plains, lobate delta margins, and lake-bottom plains) in distal parts of the deposit. Glacial-stream deposits are preserved in promorainal, discontinuous terrace deposits that extend down valleys. Ice-marginal delta deposits contain ice-contact landforms at their heads and flat delta plains with lobate distal slopes. Deltas commonly have lobate delta-plain and foreset-slope margins that grade into flat lake-bottom plains. Lacustrine fan deposits are low ridges or knolls. Hummocky ice-contact deposits form ridges that are topographically above adjacent glaciodeltaic deposits.

Thickness—Glacial-stream deposits generally are 1.8 to 15.2 m (6–50 ft) thick. The total thickness of deltaic sediments is 6.1 to 45.7 m (20–150 ft). The total thickness of lake-bottom sediments is 3.0 to 24.4 m (10–80 ft).

Origin—The stratified sediments of the Lamington Formation were deposited chiefly by glacial meltwater, and are divided into two groups of map units based on their sedimentary facies. Glacial-stream deposits, which are preserved as terrace or subsurface deposits extending down valleys, originated as braided-stream outwash sediments that accumulated in promorainal or ice-marginal valley-train deposits. Deposits of glacial-lake units contain glaciodeltaic sediments, which include glaciofluvial facies in topset sediments and delta foreset and bottomset facies, and also glaciolacustrine fan facies, and lake-bottom facies. These deposits are products of braided streams that flowed into glacial lakes as density underflows, depositing bedload sediments in delta- and fan-foreset and bottomset beds, and depositing lake-bottom sediments from bedload and suspension. Morphosequences record systematic ice-margin retreat positions in different depositional basins.

Age and regional correlations—Deposits of the Lamington Formation were emplaced by meltwaters that drained from the margin of the late Illinoian Laurentide ice sheet. The relative ages of glacial-stream and glacial-lake deposits are based on local stratigraphic relations and on positions and altitudes of glacial-lake deposits. On the basis of correlation with inferred Illinoian deposits of the region, the age range of the Lamington Formation is estimated to be 160 to 180 ka. Continued meltwater and meteoric deposition of sediments in some lake basins may have persisted after this time.

The deposits of the Lamington Formation are similar lithically to late Illinoian surface meltwater deposits in eastern Pennsylvania (Crowl and Sevon, 1980; Braun, 1994), which extend to the terminal moraine of the late Illinoian glacial episode and are thus correlated with the Lamington Formation.

UNITS OF EARLY PLEISTOCENE TO LATE PLIOCENE(?) AGE, PRE-ILLINOIAN GLACIATION

PORT MURRAY FORMATION

Name and rank—The Port Murray Formation is proposed as a unit of formation rank, named for the stratotype locality near the village of Port Murray in the southern part of the glaciated Highlands province (location map and fig. 1). The lithogenetic term "till" is used to denote a sediment facies of very poorly sorted, nonstratified, compact material deposited directly by or from glacial ice (Dreimanis, 1989).

Type section for till facies—The type section for the till facies of the Port Murray Formation is designated as the northeast corner of an inactive quarry, 152 m (500 ft) west of the Erie Lackawanna Railroad tracks, 610 m (2000 ft) southwest of the village of Port Murray, at about 183 m (600 ft) altitude (40°46'55" N. lat, 74°55'18" W. long), Warren County, in the Washington 7.5-minute quadrangle. The following section at the stratotype locality of the till facies of the Port Murray Formation was measured in 1994 by R.W. Witte:

Depth (m) **Description**

0 Land surface, excavated

0–3 Yellowish- to reddish-brown (5*YR* 5/6–8) till, with matrix consisting of sandy silt with some clay and containing 2 to 3 percent by volume pebbles, small cobbles, and scattered boulders. Matrix is compact, homogeneous, has moderate plasticity, and is noncalcareous. Gravel clasts in matrix are subangular to subrounded chert, gneiss, shale, sandstone, quartzite, and conglomerate; clasts are highly weathered and all exhibit extensive rubification. Gneiss and shale clasts are thoroughly decomposed or have very thick weathering rinds, and the more resistant lithologies exhibit thin weathering rinds. Ferromanganese staining is pervasive on clasts and the surface of subvertical joints in the matrix. In places, color is variegated and alternates between yellowish red to yellowish brown (10*YR* 5/8)

3–5.9 Yellowish-brown (10*YR* 5/6–8) till; matrix consists of sandy silt with some clay and contains 5 percent gravel clasts by volume; matrix has high dry strength

5.9–6.8 Yellowish-brown (10*YR* 5/6–8) till; matrix consists of sandy silt with some clay and contains 10 percent gravel clasts by volume; more than 60 percent of the gravel clasts are shale. Matrix has high dry strength and high compaction; rubification of clasts is minor

6.8–7.92 Weathered shale (2.5*YR* 5/6); matrix is clayey silt and contains many highly weathered and iron-manganese-stained clasts of shale

7.92–8.5 Shale of the Middle to Late Ordovician Martinsburg Formation, highly cleaved, with fractured regolith; pervasive red (2.5*YR* 5/8) clay films cover joint and cleavage surfaces.

Lithologic characteristics of till facies—The till facies of the Port Murray Formation in areas underlain by gray shale, gray sandstone, carbonate rock, or gneiss, typically consists of reddish-yellow (7.5*YR* 6/6–8) to strong brown (7.5*YR* 5/6–8) to yellowish-brown (10*YR* 5/6–8), sandy silty to clayey silty, very poorly sorted (diamict) sediment, containing 2 to 10 percent pebbles and cobbles, and few boulders. The sediment matrix generally is compact, homogeneous, has moderate plasticity and high dry strength, and is noncalcareous. Subhorizontal fissility and subvertical joints are well developed in the matrix. Sand grains in the matrix are subangular to subrounded, and include quartz, scattered weathered feldspar, few heavy minerals, weathered shale fragments, and brown to strong brown silt and clay. Gravel clasts have thin silt caps that adhere to the tops of the clasts. Gravel clasts of quartzite, gneiss, sandstone, shale, and chert from local bedrock units are the dominant rock types in pebble and small cobble sizes. Boulders are quartzite, quartz-pebble conglomerate, and gneiss. Gravel clasts are subangular to subrounded; some are striated. Carbonate rock clasts are entirely decomposed to depths of more than 3.1 m (10 ft). Gneiss clasts are deeply weathered to entirely decomposed. Chert, quartzite, and sandstone clasts have thin weathering rinds. Quartzite and quartzite conglomerate clasts have a reddish-yellow iron-oxide surface stain; many have small surface weathering pits.

In the eastern part of the outcrop area, underlain by red siltstone, shale, and sandstone, the till facies typically consists of reddish-brown (5*YR* 4/3) to weak red (2.4*YR* 4/3) sandy silty to clayey silty very poorly sorted (diamict) sediment, containing 5 to 10 percent pebbles and cobbles, and few boulders. The sediment matrix generally is compact and homogeneous, has moderate plasticity, and is noncalcareous. Sand grains in the matrix are subangular to subrounded, and include quartz, scattered weathered feldspar, a few heavy minerals, and weathered shale fragments; the silt-clay fraction in the matrix is strong brown to reddish brown. Gravel clasts are quartzite, gneiss, sandstone, shale, and a few boulders of quartzite and gneiss.

Related deposits include scattered, weathered, subangular erratic gravel clasts that lie on the land surface on top of weathered bedrock or colluvium. Also, as shown on the map, the Port Murray Formation locally includes thin surface colluvium and small areas of weathered bedrock.

Type section for stratified facies—The type section for the stratified facies of the Port Murray Formation is a shallow roadcut along the south side of an access road 91 m (300 ft) south of Interstate Route 78, at about 81 m (265 ft) altitude (40°38'03" N. lat, 74°54'18" W. long), Hunterdon County, in the High Bridge 7.5-minute quadrangle. The following section at the stratotype locality of the stratified facies of the Port Murray Formation was measured in 1991 by S.D. Stanford, B.D. Stone, and R.W. Witte:

Depth (m) **Description**

0 Land surface

0–0.4 Soil B horizon; brownish-yellow to yellowish-brown (10*YR* 6/6–5/8); noncompact, loose

0.4–1.0 Brownish-yellow to yellowish-brown (10*YR* 6/6–5/8) to strong brown (7.5*YR* 5/9) medium to coarse sand and some fine sand. Grains are quartz, rock fragments, and a few heavy minerals; quartz grains are iron stained, and some have a trace of clay coatings on grain surfaces. Matrix has low to medium dry strength, the possible result of iron cementation; contains scattered granules and small pebbles of quartz and quartzite. Deposit appears structureless, but a subhorizontal iron-manganese stain zone, 0.3 mm thick, marks the surface of the medium to coarse sand, which is overlain by fine sand; scattered white medium to coarse sand grains are milky quartz; one layer of medium to coarse sand is 1 cm (0.4 in.) thick and is bounded by fine sand in 0.5-cm- (0.2-in.-) thick laminae above and below; layers are subhorizontal, dipping 32° toward an azimuth of 173°

1.0–1.1 Pebble and small-cobble gravel and sand; gravel is clast supported with poorly sorted fine to coarse sand matrix

1.1–1.6 Covered

1.6–2.0 Sand and gravel; silt caps on clasts; long and intermediate axes of clasts are subhorizontal; clasts have pitted surfaces.

Lithologic characteristics of stratified facies—Stratified deposits of the Port Murray Formation are reddish-yellow (7.5*YR* 6/6–8) to strong brown (7.5*YR* 5/6–8) sand and pebble-to-cobble gravel; clasts are rounded to subangular. Carbonate rock and gneiss clasts are deeply weathered to fully decomposed, and chert and quartzite clasts have thin weathering rinds. Gravel clasts have thin silt caps; quartzite and quartzite conglomerate clasts have a reddish-yellow iron-oxide stain; a black iron-manganese coating covers some clasts.

Soils and weathering characteristics—Soils developed in the upper part of till deposits thicker than 1 m (3.3 ft) are alfisols and ultisols in areas underlain by shale, sandstone, or carbonate rock in the western part of the outcrop area. These soils have argillic B horizons, 0.8 to 1.8 m (30–72 in.) thick, overlying the C horizon in weathered till, which is oxidized to the base. A weathered zone extends from the surface through the entire deposit and into weathered bedrock; the zone is characterized by relatively high clay content and plasticity, pervasive weathering of matrix minerals and rock fragments, and iron-manganese coatings and clay coatings on joint faces. Carbonate rock and gneiss clasts are deeply weathered to entirely decomposed to depths of more than 3.1 m (10 ft). Chert and quartzite clasts have thin weathering rinds. Quartzite and quartzite conglomerate clasts have a reddish-yellow iron-oxide surface stain; many have small surface weathering pits. Subhorizontal fissility and subvertical joints are well developed. In the southern part of the area, soils developed in the upper part of till deposits thicker than 1 m (3.3 ft) are alfisols and ultisols in areas underlain by shale. These soils have argillic B horizons, 0.2 to 0.6 m (8–24 in.) thick, overlying Bx fragipan horizons that are 0.4 to 1 m (15–40 in.) thick, which overlie the C horizon in weathered till, oxidized as deep as 2 m (6.6 ft). Clay and iron-manganese coatings are on ped faces in the lower B horizon, and on vertical joint faces in the till below the solum.

Soils in stratified deposits are alfisols with argillic B horizons, 0.4 to 1.3 m (15–50 in.) thick, overlying the C horizon in weathered sediment. A weathered zone extends from the surface through the entire deposit and into weathered rock. Carbonate rock and gneiss clasts are deeply weathered to fully decomposed to depths of more than 3.0 m (10 ft). Gravel clasts have thin silt caps. Chert and quartzite clasts have thin weathering rinds; quartzite and quartzite conglomerate clasts have a reddish-yellow iron-oxide stain. A black iron-manganese coating covers some clasts.

Contact relations—The Port Murray Formation is the surface deposit of southwestern and southern parts of northern New Jersey, where it unconformably overlies bedrock units of Middle Proterozoic to early Mesozoic age in the area (figs. 2 and 4). At its type locality, the Port Murray overlies shale of the Middle to Late Ordovician Martinsburg Formation. In most exposures, the Port Murray was observed to overlie a distinct contact with weathered bedrock. In some large valleys, the Port Murray Formation extends beneath colluvium along the sides of valleys, and was observed to overlie colluvium in one excavation.

Boundaries—The till facies of the Port Murray Formation is at the land surface in discontinuous deposits on flat to gently sloping interfluves in valleys and lowland areas. The stratified facies of the Port Murray is at the land surface in small deposits associated with deposits of the till facies. The base of the Port Murray Formation generally rests on weathered bedrock.

Extent and surface form—Deposits of the Port Murray Formation are widespread but preserved in small areas in the southwestern and southern parts of the map area south of the late Wisconsinan terminal moraine. The till facies of the Port Murray Formation is preserved only as discontinuous deposits, chiefly in valleys and lowland areas of the southwestern and southern parts of the map area, but also locally in broad upland areas. The stratified facies of the Port Murray is preserved in small, discontinuous deposits in lowland areas near the till facies and also in upland areas south of the limit of the till facies (sheet 1; fig. 4). In many localities, erratic gravel clasts are at the land surface or are in the upper part of the soil, which overlies weathered-rock residuum.

Thickness—The thickness of the till facies of the Port Murray Formation is as much as 9.1 m (30 ft). The thickness of the stratified facies of the Port Murray Formation is generally less than 5.2 m (17 ft).

Origins—The erratic gravel clasts, with their preserved striations and polish, and the very poorly sorted matrix composed of minerals of local origin, indicate that the clayey silt facies of the Port Murray Formation is chiefly a till. At the type section, deformation of the underlying shale and inclusion of shale blocks in the matrix indicate that the till is a basal till, deposited directly from glacial ice, and also in part a deformation till (in the genetic classification of Dreimanis, 1989). Till is preserved in flat areas of landscape interfluves, and in carbonate valleys. In carbonate valleys, the deposits may have been disaggregated and mixed during weathering and collapse of underlying bedrock. At the base of slopes, the deposits may include materials derived from colluvium that in turn may have derived from till deposits upslope.

The distribution of the stratified facies of the Port Murray Formation, its erratic clast and sand content, and weathering characteristics indicate that the facies includes probable meltwater sediments. However, the thickness and patchy distribution of the stratified facies do not reveal a glacial stream or lake origin.

Age and regional correlations—Based on weathering characteristics and preservation in valley interfluves, the Port Murray Formation contains the oldest glaciogenic deposits in New Jersey. Correlation of the Port Murray Formation with the oldest glaciation (the Jerseyan stage of Salisbury, 1902) is retained, but the precise age of the sediments remains problematic. Because the modern soil in the surface overlies weathered materials of these deposits, and because the surface soil appears to have been truncated by erosion, the soils are minimum-age indicators of the age of the parent material. The Port Murray may contain sediments related to multiple late Pliocene(?) to early Pleistocene glacial advances into northern New Jersey. It may also include colluvium, solifluction debris, or glaciofluvial sediments, which in turn were derived from older glacial sediments on upper slopes. The age of the Port Murray is tentatively related to marine oxygen-isotope stage 22, about 850 ka (Fullerton and Richmond, 1986), based on correlation with magnetically reversed, early Pleistocene tills of central Pennsylvania (Braun, 1994; Gardner and others, 1994).

The weathering characteristics, distribution, and erosional incision of the Port Murray Formation are similar features of the early Pleistocene till deposits of central Pennsylvania (Marchand and Crowl, 1987; Braun, 1994). However, the clast lithic types in Pennsylvania are chiefly sandstone and shale, and matrix composition differs so that direct comparison is not precise. The surface tills in Pennsylvania that extend south of the late Illinoian glacial limit (Braun, 1994) are thus correlated with the Port Murray Formation.

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Table 1.—Selected localities of radiocarbon age-dated material.
[Localities are shown by map number on sheet 1.]

Map number	Abbreviated age shown on map (years x 10^3)	Radiocarbon age in years	Sample number	Locality	Material dated	Reference
1	2.0	2,025±300	—	Hackensack Meadows	Salt-marsh peat	Heusser (1963)
2	4.1	4,170±110	I–3993	Glovers Pond	Gyttja	Buckley and Willis (1970)
	8.6	8,690±140	I–3980	do	Reed and sedge peat	
	10.3	10,310±160	I–3979	do	Reed and sedge peat	
	10.4	10,420±160	I–3978	do	Gyttja	
	14.7	14,720±260	I–4162	do	Organic-rich silt	
3	9.1	9,130±15	—	Lake Rogerine	Top of pine zone	Nicholas (1968)
4	10.1	10,135±180	QC–507	Beechwood Park, Hillsdale	Peat, pine zone	Averill and others (1980)
	10.5	10,575±250	QC–700	do	Peat	
5	10.2	10,280±270	I–5200	Hudson River	Mollusk shells	Weiss (1974)
6	12.2	12,290±500	GXO–330	Budd Lake	Organic layer	Harmon (1968)
	22.8	22,890±720	I–2845	do	Lake clay with gyttja	
7	12.3	12,300±300	—	Saddle Bog	Unknown	Sirkin and Minard (1972)
8	12.29	12,290±440	RIDDL–1136	Alpine (swamp)	Spruce needle	Peteet and others (1990)
	12.8	12,840±110	WIS–1482	do	Basal gyttja	
9	14.0	14,060±240	OC–1305	Great Swamp	Concretion	Stone and others (1989a)
	20.1	20,180±500	OC–1304	do	Concretion	
10	11.2	11,220±110	SI–5301	Francis Lake	Peaty gyttja	Cotter and others (1986)
	13.5	13,510±135	SI–5300	do	Lake clay	
	16.4	16,480±430	SI–5274	do	Lake clay	
	18.3	18,390±200	SI–4921	do	Lake clay	
	18.5	18,570±250	SI–5273	do	Lake clay	
11	12.1	12,150±210	QC–297	Dwars Kill, Norwood	Peat	Averill and others (1980)
	12.8	12,870±200	QC–296	do	Peat	
12	19.3	19,340±695	GX–4279	Jenny Jump Mountain	Wood/organic materials	D.H. Cadwell, New York State Geological Survey, oral commun., 1982

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