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Surficial Geologic Map of the Northern Sheet, New Jersey

by

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CONTENTS

EXPLANATION OF THE SURFICIAL GEOLOGIC MAP, MAP UNITS, AND ACCOMPANYING FIGURES

The surficial geologic map (plate 1), and sections (plate 2) show the distribution of surficial materials that overlie nonweathered bedrock and coastal plain deposits in northern New Jersey. On a companion map (Stone, Stanford, and Witte, 1995a), areas of bedrock outcrops and shallow bedrock are shown by map units and patterns, and the altitude of the bedrock surface in glaciated valleys and lowland areas 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 relationships, and age, as shown in the correlation diagram (plate 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. 2), bedrock geology (fig. 3), limits of glaciations, end moraines, glacial lakes, and late Wisconsinan retreatal ice-margin positions (fig. 1), till deposits and ice-flow directions (fig. 4), and glacial-stream and glacial-lake sediments (fig. 5).

Surficial materials in northern New Jersey are nonlithified deposits of glacial, meltwater, alluvial, colluvial, eolian, marsh and swamp, 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 modem pedogenic soils which have developed in them at the land surface. Materials in different map units are distinguished lithologically by grain size, mineralogy, and structure. Organic sediments in marsh and swamp, and estuarine deposits underlie modern wetland areas. Eolian deposits are shown as a unit where they are >lm thick, and as a pattern where they are continuous, but <lm thick. Eolian silt-to-fine sand is mixed within the surface soil horizons throughout the area. Alluvial deposits underlie modern floodplains and stream terraces, and are differentiated on the basis of weathering characteristics, stratigraphic relationships, and topographic position. Deposits of glacial origin 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 ages: 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. Meltwater deposits, 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 relationships of sedimentary facies within the depositional basins. The correlation diagram 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, map overprint patterns show the distribution of fine grained lake-bottom sediments and sand and gravel deposits of delta topset beds and tributary glacial-stream deposits. Map unit descriptions provide details about glacial lake dams and spillways, and drainage of the lakes. Colluvial deposits, which accumulated on hillslopes, are divided on the basis of lithologic characteristics related to upslope bedrock units from which they derived. 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.

DESCRIPTION OF MAP AND SUBSURFACE UNITS

Map units include surficial materials, more than 1 m (3.2 ft) thick, that overlie bedrock; color designations, in parentheses are based on naturally moist samples. A veneer of colluvium, less than 1 m (3.2 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; Tedrow (1986); and county soil surveys of the U.S. Department of Agriculture, Soil Conservation Service.

For the purpose of map legibility, artifical fill deposits are not shown on the map. These deposits, which are Earth and manmade materials that have been artificially emplaced, including gravel, sand, silt, clay, trash, cinders, ash, garbage, and mine and quarry tailings, are 1.8 m-35.0 m (6-115 ft) thick.

Holocene and late Wisconsinan artificial fill, alluvial, swamp, marsh, estuarine slope, and eolian deposits

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 1.8-9.1 m (6-30 ft). Along smaller streams alluvium is composed of sand and gravel derived from adjacent glacial, meltwater, colluvial, or weathered-rock materials; sand and gravel is 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 is 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 is poorly sorted. Unit includes lag accumulations of blocks and cobbles on eroded colluvial surfaces or locally on weathered-rock materials. Thickness 0.3-6.1 m (1-20 ft)

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

Qmt **Moonachie terrace deposits**--Coarse to fine sand, with minor pebbly sand and silt-clay; sand beds are moderately sorted; contains fragments of leaves and woody stems (Salisbury, 1902). Surface altitudes slope from 4 m (12 ft) to sea level; thickness 0.3-5.2 m (1-17 ft)

Qlpt **Passaic terrace deposits**--Sand and pebble gravel, moderately sorted. Surface altitudes slope from 18 m (60 ft) to sea level; thickness 0.3-6.1 m (1-20 ft)

Qpb **Pine Brook terrace deposit**--Sand and pebbly sand, and sand and gravel; sand and gravel is moderately to poorly sorted. Surface altitudes slope from 68 m to 52 m (220 ft to 170 ft); thickness 1.8-9.1 m (6-30 ft)

Qor **Oradell terrace deposits**--Coarse sand and pebbly sand, moderately sorted; surface altitudes slope from 13 m to 10 m (40 ft to 30 ft); as much as 6.1 m (20 ft) thick

Qrt **Raritan terrace deposit**--Sand and gravel, sand, and silt in lower terrace along the lower reach of the Raritan River; sand beds are poorly sorted; clasts are composed of gneiss, sandstone, mudstone, quartzite, chert, and are generally nonweathered. Surface altitudes slope from 14 m to 7 m (45 ft to 20 ft). Thickness 1.8-9.1 m (6-30 ft)

Qml **Millstone terrace deposit**--Sand and gravel, sand, and silt; clasts are quartz, siltstone, sandstone, quartzite, gneiss, ironstone, diabase; gneiss clasts are generally nonweathered. Surface altitudes range from 14 m to 13 m (45 ft to 40 ft); as much as 12.2 m (40 ft) thick. Unit includes some meltwater sediments

Qs **Swamp and 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 4.0 m (12 ft) thick; marl generally is less than 4.6 m (15 ft) thick (Waksman and others, 1943)

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 54.9 m (180 ft) thick in the Hudson River estuary, and as much as 10.1 m (33 ft) thick in other valleys. Peat is decomposed, fibrous or matted, herbaceous and silty herbaceous material. Muck is organic, clayey silt

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

Qse **Eolian sand**--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, locally in dunes. Thickness 0.9-4.0 m (3-13 ft)

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. 5b), 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(or) bedrock units. Gravel composition is polymict; gravel clasts are subrounded to well rounded, 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 deposits 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 glaciodeltaic sediments, which include glaciofluvial facies in topset sediments and 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 relationships, 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. 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 with B horizons 0.3-0.8 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 0.4-0.8 m (18-30 in) thick overlying 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 (3.2 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 0.2-1.2 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 cross-beds, 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 older alluvial deposits south of the terminal moraine; distal terrace deposits contain sediments locally derived from nonglacial sources. Glacial-stream deposits generally are 1.8-15.2 m (6-50 ft) thick, locally as much as 30.5 m (100 ft) thick

Qrsr **Saddle River outwash deposit**--Sand and gravel, minor coarse gravel, sand and pebbly sand of valley outwash deposit and outwash terrace; surface altitudes slope from 86 m to 46 m (280 ft to 150 ft); as much as 15.2 m (50 ft) thick in outwash; 1.8-6.1 m (6-20 ft) thick in terraces

Qrps **Pascack outwash deposit**--Coarse gravel of valley outwash deposit; surface altitudes slope from 68 m to 46 m (220 ft to 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 ft to 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 basin, and downstream from the Foul Rift moraine deposit (unit Qkfrm) during maximum glacial extent. Meltwater deposition in terraces continued during ice-margin retreat in the Wallkill and Delaware drainage basins in New York State area

Qrwq **Wanaque outwash deposit**--Coarse gravel and sand and gravel of at least four ice-marginal deposits in Wanaque valley, and outwash deposits in four tributary valleys; surface altitudes slope from 183 m to 61 m (600 ft to 200 ft); as much as 15.2 m (50 ft) thick. Unit includes deltaic and lacustrine sand to fine sand/silt in subsurface at and south of Wanaque-Midvale, as much as 30.5 m (100 ft) thick

Qrbf **Big Flat Brook outwash deposit**--Gravel, and sand and gravel of valley outwash deposits; surface altitudes slope from 240 m to 150 m (785 ft to 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 342 m to 61 m (1120 ft to 200 ft); as much as 15.2 m (50 ft) thick. Deposited in the Pequannock valley and in several northerly tributary valleys 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 54 m (230 ft to 175 ft); thickness about 7.0 m (23 ft) at head, 1.8-4.3 m (6-14 ft) in central part of deposit

Qrbd **Brookdale terrace deposits**--Sand and gravel; surface altitudes slope from 49 m to 40 m (160 ft to 130 ft); generally less than 6.1 m (20 ft) thick. Deposited by meltwater draining from 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 15.2 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 ft to 885 ft)

Qrvc **Van Campens outwash deposit**--Sand and gravel of valley outwash deposits; surface altitudes slope from 229 m to 122 m (750 ft to 400 ft); as much as 18.3 m (60 ft) thick. Unit includes minor deltaic sand and gravel as much as 18 m (60 ft) thick in subsurface at the confluence of Van Campens Creek and the Delaware River

Qrrh **Rahway River outwash deposit**--Sand and gravel of multiple valley outwash deposits; surface altitudes slope from 116 m to 7 m (380 ft to 20 ft); as much as 9.1 m (30 ft) thick in West Branch valley, 15.2 m (50 ft) thick in East Branch valley. Unit includes terrace deposits south of Maplewood, 0.9-3.1 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 ft to 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 214 m to 153 m (700 ft to 500 ft); as much as 15.2 m (50 ft) thick. Deposited in Rockaway valley and in three northerly tributary valleys 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 257 m to 190 m (845 ft to 620 ft); as much as 12.2 m (40 ft) thick. Unit includes deltaic and lacustrine sand in 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 ft to 50 ft); as much as 12.2 m (40 ft) thick. Unit includes minor deltaic sand and gravel and lacustrine sand and silt in 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 147 m (610 ft to 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 13 m (205 ft to 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

Qrbl **Belvidere outwash deposits**--Cobble gravel beneath and interbedded with till of the Foul Rift moraine deposit (unit Qkfrm), and coarse gravel and sand and gravel of valley outwash deposit; surface altitudes slope from 111 m to 91 m (365 ft to 300 ft); as much as 30.5 m (100 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 19 m (120 ft to 60 ft); as much as 24 m (80 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 ft to 0 ft); as much as 12.2 m (40 ft) thick. Deposit extends beneath estuarine sediments (unit Qm) in Raritan River estuary

Qrfl **Florham outwash deposits**--Subsurface unit (sections CC', GG'). 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 ft to 100 ft); as much as 18.3 m (60 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**--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. 0.6-6.1 m (2-20 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 2-10 m (6.5-33 ft) thick sets of thin foreset beds which dip 25-35°; 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 2-5.2 m (6.5-16 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°; 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°. Total thickness of deltaic sediments is 6-45.2 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 (stipple pattern) 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** 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) contain two facies: 1) the sandy facies, consisting of fine sand to silt in parallel laminated and minor ripple cross-laminated sets of beds; 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 <2 mm thick; **varve deposits** of this facies consist of couplets of microlaminated silt-to-very fine sand, and massive clay; couplets are 0.4-10 cm (0.1-4.0 in) thick; vertical sequences of varves show little variation in couplet thickness. Total thickness of lake-bottom sediments is 3.0-61.0 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 northerly 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, indicating postglacial isostatic tilting of 0.4-0.7 m/km (2-3.5 ft/mi) up to the north-northeast. 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 lake basins are in the upper parts of northerly 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 successively higher lake levels were 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 are shown in figure 1

Deposits of major glacial lakes

Highlands area

Qrbf **Glacial Lake Bearfort deposits**--Unit includes deposits of two lake stages undifferentiated. 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 ft to 1100 ft); spillway altitudes are 349 m and 332 m (1145 ft and 1090 ft). The lake basin occupied the north-draining valley of Longhouse Creek; initial spillway is on the Wallkill-Pequannock divide, the lower spillway is on the Wallkill-Wanaque divide. The lake lowered and drained when the ice margin retreated and uncovered lower spillways into the Wallkill valley in New York State area

Qrgr **Glacial Lake Greenwood deposits**--Unit includes deposits of three lake stages undifferentiated. Seven ice-marginal deltas, as much as 36.6 m (120 ft) thick, and glaciolacustrine fans, as much as 9.1 m (30 ft) thick; lake-bottom silt, fine sand, and clay is as much as 39.6 m (130 ft) thick. Delta-plain altitudes lower from 259 to 198 m (850 ft to 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 Belchers Creek; the initial lake spillway is on the Wanaque-Pequannock 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 valley in the Cooper area

Qrwy **Glacial Lake Wawayanda deposits**--Unit includes deposits of six lake stages in four basins which are undifferentiated. 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 ft to 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 Mossman's Brook drainage and glacial Lake Bearfort (unit Qrbf); 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 the Wawayanda Mountain in New York State area

Qrgp **Glacial Lake Green Pond deposits**--Unit includes deposits of two lake stages undifferentiated. 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 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 valley; the spillways are on the preglacial Pequannock-Rockaway divide. The lake drained when the ice margin retreated north of the Pequannock valley in the Newfoundland area

Qrsp **Glacial Lake Sparta deposits**--Unit includes five lake stages undifferentiated. Seven ice-marginal deltas, as much as 19.8 m (65 ft) thick, and minor glaciolacustrine fans; 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 ft to 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 rivers 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, and glaciolacustrine fans as much as 9 m (30 ft) thick lake-bottom silt, sand, and clay as much as 30.5 m (100 ft) thick. Delta-plain altitudes rise from 280 m to 286 m (920 ft to 940 ft); spillway altitude is 279 m (915 ft). The lake basin occupied the upper Musconetcong valley, which was dammed by the Budd Lake moraine (unit Qnbm); the spillway was over the moraine. The glacial lake lowered to a Lake Hopatcong level 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, and glaciolacustrine fans as much as 9.1 m (30 ft) thick; lake-bottom silt, fine sand, and minor clay as much as 46.1 m (150 ft) thick. Deposits locally overlain by Netcong Till of the Budd Lake moraine deposit (unit Qnbm, section CC'). Delta-plain altitudes rise from 162 m to 165 m (530 ft to 540 ft); spillway altitude is 160 m (525 ft). The glacial lake basin occupied part of the Rockaway 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 was on the Rockaway-Whippany drainage divide in the Tabor area. The lake drained when the ice margin retreated north of the Powerville-Boonton gap area

Qrpc **Glacial Lake Picatinny deposits**--Unit includes deposits of two lake stages undifferentiated. Three ice-marginal deltas, as much as 46.1 m (150 ft) thick, and glaciolacustrine fans as much as 18.3 m (60 ft) thick; lake-bottom silt, sand, and clay as much as 46.1 m (150 ft) thick. Delta-plain altitudes lower from 219 m to 210 m (720 ft to 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. 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 ft to 580 ft); spillway altitudes are 195 m and 177 m (640 ft and 580 ft). The lake basins occupied segments of the Rockaway 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**--Two ice-marginal deltas, one fluviodelta, as much as 30 m (100 ft) thick, and glaciolacustrine fans in subsurface; lake-bottom fine sand and 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 Qrbm, sections DD' and II'). Delta-plain altitudes rise from 210 m to 222 m (690 ft to 730 ft); spillway altitude is 206 m (675 ft). Unit includes deltaic deposits with aggraded topset-plain altitudes that rise from 216 m to 222 m (710 ft to 730 ft) and that are graded to a small lake with a local spillway at 216 m (710 ft) in Drakes Brook drainage west of the Succasunna area. The lake basins occupied preglacial, north-draining tributary valleys of the Rockaway 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 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, which is reversed from the preglacial drainage direction

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 286 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, Pequest, Musconetcong, and Pohatcong River basins

Qrw **Glacial Lake Wallkill deposits** (Augusta stage)--Nine ice-marginal deltas, four fluviodeltas, as much as 46.1 m (150 ft) thick, and multiple glaciolacustrine fans in five local basins, as much as 30.5 m (100 ft); lake-bottom silt and day, extensive beneath swamp deposits, as much as 30.5 m (100 ft) thick. Delta-plain altitudes rise from 160 m to 165 m (525 ft to 540 ft); spillway altitude is 151 m (495 ft). The glacial lake basin occupied the north-draining Wallkill valley and tributary valleys; the lake spillway channel is on the Paulins Kill-Wallkill drainage divide at Augusta. Lower stages of glacial Lake Wallkill were controlled initially by spillways over the Hudson River drainage divide between Goshen and Neeleyton, New York State

Qrma **Glacial Lake McAfee deposits**--Three ice-marginal deltas, as much as 39.6 m (130 ft) thick, and glaciolacustrine fans as much as 9.1 m (30 ft) thick; lake-bottom silt and fine sand as much as 55.2 m (180 ft) thick. Delta-plain altitudes rise from 166 m to 171 m (545 ft to 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, and glaciolacustrine fans, as much as 30.5 m (100 ft) thick; 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 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 valley in the Martins area

Qrwf **Glacial Lake Wallkill deposits, Frankford Plains phase**--Unit includes deposits of two lake stages undifferentiated. Three ice-marginal deltas and one fluviodelta, as much as 18.3 m (60 ft) thick, and multiple glaciolacustrine fans; 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 ft to 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. 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 ft to 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 valley

Qrnc **Glacial Lake North Church deposits**--Unit includes deposits of three lake stages undifferentiated. Two ice-marginal deltas, as much as 46.1 m (150 ft) thick, and glaciolacustrine fans as much as 61.0 m (200 ft) thick; 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 ft to 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 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 ft to 610 ft) during deposition in the lake. The lower spillway drained west over bedrock on the Wallkill-Beaver Run divide. The lake lowered to the level of glacial Lake Hamburg (unit Qhm) when the ice margin retreated north of the Hamburg area

Qro **Glacial Lake Owassa deposits**--Unit includes deposits of two lake stages undifferentiated. Two ice-marginal deltas, as much as 15.2 m (50 ft) thick, and minor glaciolacustrine fans; 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); spillways 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-Owassa Lake 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, and minor glaciolacustrine fans; lake-bottom silt and day, 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 ft to 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-Paulins Kill drainage divide. Meltwater deposition in the lake ceased after the ice margin retreated into the glacial Lake North Church basin (unit Qmc) 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. Four fluviodeltas, as much as 18.3 m (60 ft) thick; 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 ft to 500 ft); higher spillway altitude is 162 m (530 ft). The lake basin occupied a glacially overdeepened rock basin in a tributary valley of the Paulins Kill north 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. Five ice-marginal deltas, as much as 16.8 m (55 ft); 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 ft to 610 ft). The lake basins occupied scoured rock basins northeast of the Huntsburg area in the upper Pequest 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 altitude of about 186 m (610 ft). Meltwater deposition ceased after the ice margin retreated north into the Pequest valley

Qrpk **Glacial Lake Paulins Kill deposits**--Unit includes deposits of two lake stages undifferentiated. Five ice-marginal deltas, as much as 18.3 m (60 ft) thick; 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 ft to 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 valley

Qrpq **Glacial Lake Pequest deposits**--Unit includes deposits of two lake stages undifferentiated. Sixteen ice-marginal deltas, as much as 36.1 m (120 ft) thick; glaciolacustrine fans as much as 9.1 m (30 ft) thick; lake-bottom silt, sand, and clay as much as 30.5 m (100 ft) thick. Delta-plain altitude for higher stage is 174 m (570 ft), delta-plain altitudes for lower stage rise from 171 m to 186 m (560 ft to 610 ft); spillway altitudes are 172 m and 166 m (565 and 545 ft). The lake basin occupied the Pequest valley which was dammed by the Townsbury moraine (unit Qktm) and deltaic deposits (unit Qrpq); the spillway is 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

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

Qroxb **Glacial Lake Oxford deposits, Buckhorn stage**--Five ice-marginal deltas; as much as 27.4 m (90 ft) thick; 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 ft to 500 ft); spillway altitude is 139 m (455 ft). The glacial lake occupied two basins in the lower Pequest valley; the lake spillway is on the Pophandusing-Buckhorn creeks drainage divide. The Buckhorn stage of Lake Oxford drained when the ice margin retreated westward into the Delaware valley

Delaware River basin

Qrmb **Glacial Lake Millbrook deposits**--Three ice-marginal deltas, extensively collapsed and as much as 18.3 m (60 ft) thick, and minor glaciolacustrine fans; 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 ft to 680 ft); spillway altitude is 192 m (630 ft). The lake basin occupied the Mill and Clove Brook valleys south of the Duttonville area; the spillway is over Shimers Brook deposits (unit Qrsb). The lake drained into the Minisink valley after the ice margin retreated north of Wallpack Ridge near the Duttonville area

Upper Passaic, Ramapo, and Hohokus River basins

Qrpg **Glacial Lake Passaic deposits, Great Notch stage**--One ice-marginal delta and four fluviodeltas, as much as 24.4 m (80 ft) thick; 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 ft to 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 45.2 m (150 ft) thick; lake-bottom silt, sand, and clay, extensive beneath alluvium, as much as 12.2 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 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 45.2 m (150 ft) thick; twelve glaciolacustrine fans and two ice-channel deposits, as much as 18.3 m (60 ft) thick; eight near-shore spit deposits, chiefly pebble sand and gravel, 2-4 m (6-13 ft) thick; lake-bottom silt, sand, and clay as much as 45.2 m (150 ft) thick. Lake-bottom varve deposits (couplets 0.6-10 cm [0.25-4 in] thick) as much as 30.5 m (100 ft) thick. Delta-plain altitudes rise from 110 m to 125 m (360 ft to 410 ft); spillway altitude 103 m (339 ft). The glacial lake basin occupied the central Passaic and lower Pompton river valleys, which were dammed by the Perth Amboy moraine (unit Qram). The lake spillway is over the Passaic-Raritan divide. The level of the Moggy Hollow stage lowered to 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 BB', CC'). Glaciolacustrine fan deposits, as much as 15.2 m (50 ft); lake-bottom sand, silt, and clay as much as 21 m (70 ft) thick. Altitudes of tops of deposits range from 79 m to 30 m (260 ft to 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 ft to 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, and lower Passaic 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. 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 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-Sparkill Creek drainage divide at present altitude of about 9 m (30 ft); subsequently, the lake drained through the Oradell terrace deposit (unit Qror). 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, four fluviodeltas, as much as 21.3 m (70 ft) thick; local glaciolacustrine fan sand and gravel in subsurface, as thick as 15.2 m (50 ft); lake-bottom varve deposits (couplets 0.6-4 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 ft to 70 ft); altitudes of spillways over bedrock are -9 m (-30 ft) at Arthur Kill, -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. 1), and lowered to the level of the Oradell stage when the ice margin retreated north of Sparkill Gap in New York State area

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; 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 ft to 65 ft); spillway altitude is 17 m (55 ft). The lake basin occupied the Tenakill 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; 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 ft to 75 ft); spillway altitude is 15 m (50 ft). The lake basin occupied the lower Saddle River valley and part of the Passaic valley, which was dammed by Delawanna deposits (unit Qrdw); 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-, 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 (unit Qrhk) stage when the ice margin retreated north of the Bergenfield area

Qrwt **Glacial Lake Watsessing deposits**--Unit includes deposits of four lake stages undifferentiated. Three ice-marginal deltas, as much as 18.3 m (60 ft) thick; 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 ft to 120 ft); spillway altitudes are 55 m, 52 m, 37 m, and 30 m (180 ft, 170 ft, 120 ft, 100 ft). The lake basin occupied the Second River valley; lake spillways are on the Second River-Elizabeth River divide. The lake drained when 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); glaciolacustrine fans as much as 21.3 m (70 ft) thick; 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 ft to 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-Woodbridge Creek 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. Two ice-marginal deltas and one fluviodelta, as much as 18.3 m (60 ft) thick; 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 Robinson Branch valley; the initial spillway is on the Rahway-Raritan 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 AA'). Glaciolacustrine fans as much as 15.2 m (50 ft) thick; lake bottom silt, clay, and minor fine sand as much as 15.2 m (50 ft) thick. The lake basin occupied the glacially overdeepened Hudson valley, which was dammed by the terminal moraine at the Narrows; the spillway was over bedrock at an altitude of -9 m (-30 ft) at Hell Gate in the area of East River Strait (fig. 1). 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. Four ice-marginal deltas, as much as 45.7 m (150 ft) thick; 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 ft to 30 ft). The lake basin occupied the lowlands in the area of Arthur Kill, Kill van Kull, Newark Bay, Upper New York Bay, and East River Strait, which were dammed by the Perth Amboy moraine (unit Qram) and the terminal moraine in New York State at the Narrows (fig. 1); the higher spillway was across the moraine at an altitude of about 9 m (30 ft) at Richmond valley on Staten Island, New York State; the lower lake spillway eroded across the moraine at Perth Amboy at present altitude of about -9 m (-30 ft). 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 area

Deposits of small glacial lakes and ponds

Highlands area

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 ft to 375 ft); spillway altitudes range from 210 m to 113 m (690 ft to 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 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 ft to 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 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, deposits 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 ft to 355 ft); spillway altitudes range from 305 m to 107 m (1000 ft to 350 ft). Lake basins are in southerly tributary valleys of West Brook valley; higher spillways are south on 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 are locally highly collapsed and contain poorly sorted sediments, total thickness as much as 61.0 m (200 ft). Delta-plain or collapsed delta surface altitudes range from 259 m to 126 m (850 ft to 415 ft): spillway altitudes range from 259 m to 125 m (850 ft to 410 ft). Lake basins are in southerly tributary valleys of the Pequannock River basin and in one basin in the Rockaway River basin; higher spillways are on the Rockaway-Pequannock divide, lower spillways are on local divides in the Pequannock 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; lake-bottom sand and silt in subsurface as much as 36.1 m (120 ft) thick. Delta-plain altitudes rise from 213 m to 264 m (700 ft to 865 ft). Lake basins occupied the upper Rockaway valley, which was dammed by the Budd Lake moraine (unit Qnbl) 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: lake-bottom silt and fine sand beneath swamp deposits. Collapsed delta surface altitudes range from 349 m to 312 m (1145 ft to 1025 ft); spillway altitudes range from 351 m to 311 m (1150 ft to 1020 ft). Lake basins occupied four separate tributary valleys on the south side of the Pequannock valley; higher spillways drained south over the Rockaway- Pequannock and local divides, lower spillways drained eastward over local divides in the Pequannock basin. The lowest lakes drained when the ice margin retreated north of the Pequannock valley

Qrsm **Sussex Mills deposits**--Deltaic deposits of two lake stages undifferentiated, as much as 16.8 m (55 ft) thick; lake-bottom sand and silt in subsurface as much as 12.2 m (40 ft) thick. Delta-plain altitudes lower from 251 m to 222 m (825 ft to 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 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 ft to 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-Musconetcong 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 ft to 950 ft); spillway altitudes range from 332 m to 290 m (1090 ft to 950 ft). The lake basins occupied separate tributary valleys on the east side of the Beaver Brook valley; higher spillways drained easterly over the Rockaway-Musconetcong divide, lower spillways drained southerly 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 Lake Shawnee area

Qrwb **Wills Brook deposits**--Unit includes deposits of three lake stages undifferentiated. Deltaic deposits, as much as 16.8 m (55 ft) thick, and ice-channel deposits. Delta-plain altitudes lower from 259 m to 238 m (850 ft to 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

Kittatinny Valley, Pequest, Musconetcong, and Pohatcong River basins

Qrwn **Wantage deposits**--Deltaic deposits of two lake stages undifferentiated, as much as 30.5 m (100 ft) thick. Delta-plain altitudes lower from 202 m to 189 m (660 ft to 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 basin; lake spillways are across local drainage divides. The lakes drained when the ice margin retreated north into New York State area

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; lake-bottom sand and silt in subsurface as much as 12.2 m (40 ft) thick. Delta-plain altitudes lower from 250 m to 203 m (820 ft to 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

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 190 m (700 ft to 625 ft); spillway altitudes range from 207 m to 192 m (680 ft to 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

Qrup **Paulinskill deposits**--Ten ice-marginal deltas, as much as 18.3 m (60 ft) thick, and minor glaciolacustrine fans; lake-bottom sand, silt, and clay in subsurface as much as 12.2 m (40 ft) thick. Delta-plain altitudes rise from 146 m to 177 m (480 ft to 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)

Qrpy **Plymouth Pond deposits**--Deltaic and minor glaciolacustrine fan deposits of multiple lake stages undifferentiated, as much as 15.2 m (50 ft) thick; lake-bottom sand and silt in subsurface as much as 12.2 m (40 ft) thick. Delta-plain altitudes range from 299 m to 286 m (980 ft to 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 19.8 m (65 ft) thick, and minor glaciolacustrine fans; lake-bottom sand and silt in subsurface as much as 9.1 m (30 ft) thick. Delta-plain altitudes rise from 171 m to 190 m (560 ft to 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); the lowest lake spillway was 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; lake-bottom sand and silt in subsurface as much as 12.2 m (40 ft) thick. Delta-plain and collapsed delta surface altitudes lower from 215 m to 199 m (705 ft to 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 Valley when the ice margin retreated north of the Andover area

Qrml **Mountain Lake deposits**--One ice-marginal delta, as much as 35.2 m (115 ft) thick; 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 Qkmm). 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**--Five ice-marginal deltas with aggraded glacioalluvial deposits, and multiple fluviodeltas, as much as 30.5 m (100 ft) thick; lake-bottom sand, silt, and clay in 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 ft to 525 ft). The lake basins occupied the Delaware valley north of Delaware Water Gap, which was dammed initially by Columbia deposits (unit Qrcl); the lowest lake spillway was over the sediment dam. Meltwater deposition of deltaic deposits ceased after the ice margin retreated north of the area of the confluence of the Delaware and Neversink Rivers

Qrsb **Shimers Brook deposits**--Deltaic deposits of two lake stages undifferentiated, as much as 30.5 m (100 ft) thick; lake-bottom sand and fine sand in subsurface as much as 15.2 m (50 ft) thick. Delta-plain altitudes lower from 207 m to 195 m (680 ft to 640 ft); spillway altitudes are 204 m and 190 m (670 ft and 625 ft). The lake basin occupied the north-draining Shimers Brook valley, which was dammed by Flatbrook and high ice-channel deposits (units Qrf, Qrhu); 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; lake-bottom sand and silt as much as 15 m (50 ft) thick. Delta-plain altitudes lower from 221 m to 209 m (725 ft to 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 Flat Brook, White Brook, and Delaware River drainage basins. The lake drained after the ice margin retreated north of the area of confluence of White Brook and Delaware River

Qrf **Flatbrook deposits**--Multiple ice-marginal deltas with aggraded glacioalluvial deposits, as much as 24.4 m (80 ft) thick; lake-bottom sand, silt, and clay in 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 ft to 760 ft). Lake basins occupied a series of basins that were dammed by ice blocks and drift in the Wallpack 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**--Multiple ice-marginal deltas with aggraded glacioalluvial deposits, fluviodeltas, and minor alluvial terrace deposits as much as 21.3 m (70 ft) thick; lake-bottom sand, silt, and clay in 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 ft to 490 ft). The lake basins occupied a valley reach that was dammed by ice blocks and drift between the area of Manuaka Chunk and the Delaware Water Gap; the lowest spillway was over Belvidere deposits (unit Qrbl). Meltwater deposition ceased when the ice margin retreated north of the Delaware Water Gap area

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

Upper Passaic, Ramapo, and Hohokus River basins

Qrrv **Ramapo Valley deposits**--Five ice-marginal deltas and two fluviodeltas, as much as 18.3 m (60 ft) thick; lake-bottom sand and silt in subsurface as much as 6.1 m (20 ft) thick. Delta-plain altitudes rise from 76 m to 91 m (250 ft to 300 ft). The lake basin occupied the upper Ramapo 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 State area

Qrrm **Ramapo deposits**--Multiple ice-marginal deltas, as much as 18.3 m (60 ft) thick; lake-bottom sand in subsurface as much as 9.1 m (30 ft) thick. Delta-plain altitudes rise from 61 m to 69 m (200 ft to 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 ft to 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 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 55.2 m (180 ft) thick. Surface altitudes range from 134 m to 143 m (440 ft to 470 ft). Meltwater deposition in these deposits 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, and lower Passaic River basin

Qrtp **Tappan deposits**--Sand and gravel, coarse gravel, and sandy flowtill or ablation fill at the surface, and sand, and sand and gravel in subsurface, total as much as 30.5 m (100 ft) thick. Surface altitudes range from 24 m to 40 m (80 ft to 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 ft to 130 ft). Meltwater deposition in these deposits 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 ft to 330 ft); spillway altitudes are 105 m and 99 m (345 ft and 325 ft). The lake basins occupied the north-draining Masonicus Brook drainage basin; the higher spillway is across the Masonicus Brook-Valentine Brook drainage divide. 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; lake-bottom sand and silt in 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 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 ft to 240 ft); spillway altitudes lower from 136 m to 70 m (445 ft to 230 ft). The lake basins occupied tributary valleys of Hohokus and Goffle Brook valleys; lake spillways are across local drainage divides. The lowest lake drained when till in the lowest dam in the Ringwood area was eroded

Qrhh **Highwood deposits**--Sand and gravel, and coarse gravel at the surface, and sand, and sand and gravel in subsurface, total as much as 18.3 m (60 ft) thick. Surface altitudes range from 27 m to 37 m (90 ft to 120 ft). Meltwater deposition in these deposits 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 ft to 50 ft); spillway altitudes range from 37 m to 12 m (120 ft to 40 ft). The lake basins are in westerly tributary valleys 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 17 m (60 ft) thick. Delta-plain altitudes lower from 44 m to 34 m (145 ft to 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 ft to 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

Qrbf **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 ft to 180 ft). Meltwater deposition in these deposits 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; minor lake-bottom silt and fine sand in subsurface. Delta-plain altitude is 128 (420 ft); spillway altitude is 125 m (410 ft). The lake occupied the north-draining valley of Peckman River, the spillway is on the Peckman-Rahway 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; lake-bottom sand and silt in subsurface as much as 15.2 m (50 ft) thick. Delta-plain altitudes rise from 9 m to 21 m (30 ft to 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 area; the lake spillway was over till, subsequently eroded. The lake drained to the level of glacial Lake Bayone (unit Qrbn) when the ice margin retreated north of Weequahic Lake area

Qrgh **Galloping Hills deposits**--Sand and gravel at the surface, and sand, and sand and gravel in subsurface, total as much as 61.0 m (200 ft) thick; unit includes esker deposits. Surface altitudes range from 43 m to 49 m (140 ft to 160 ft). Meltwater deposition in these deposits 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 which was dammed by the Perth Amboy moraine (unit Oram); 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 Qrwb) 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 Qrwb) when the ice margin retreated east of the Millburn area

Qrlu **Small glacial lake deposits, undifferentiated**--Minor deltaic deposits of sand and gravel generally less than 15.2 m (50 ft) thick

Qriu **Ice-contact deposits, undifferentiated**--Sand and gravel, coarse gravel, and minor sandy flowtill or ablation till at the surface; deposits are in hummocky ridges, locally transverse to ice-flow direction; generally less than 45.2 m (150 ft) thick

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. 4b) containing commonly 5-50 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 50-90 percent of clasts. The distinguishing color, grain size, and composition of three till formations (units Qr, Qn, Qk) are related to the underlying bedrock source and local ice-flow directions (compare figures 3, 4). 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, and 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 moraines: thickness is 0.9-24.4 m (3 to 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, although in some large valleys near the terminal moraine it overlies older stratified deposits (sections DD', II', JJ', and KK'). Till units include thin surface colluvium and small deposits of stratified meltwater sediments locally. Soils chiefly are alfisols with argillic B horizons, 0.2-0.6 m (8-24 in) thick, overlying Bx fragipan horizons, 0.4-1 m (15-40 in) thick, which overlie the C horizon in slightly weathered till, oxidized as deep as 2 m (6 ft). In shallow-rock areas or in tills with abundant gravel, soils are inceptisols with cambic B horizons, 0.2-0.5 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. 4b), containing commonly 5-20 percent pebbles, cobbles, and boulders of gneiss, sandstone, basalt, and quartzite; in areas underlain by shale and sandstone (figs. 3,4): matrix contains abundant shale and siltstone fragments and reddish brown silt and clay; noncalcareous; chiefly compact, firm to hard consistency; gravel clasts are generally nonweathered, subangular to subrounded; gravel clasts of fine-grained sandstone commonly are striated; rounded gravel clasts are abundant locally (fig. 4). Deposit contains few thin lenses of stratified gravel, sand, and silt; minor iron-manganese stain is on joint faces locally. Thickness generally 3.0-9.1 m (10-30 ft); as much as 15.2 m (50 ft) thick in small drumlins (fig. 4). Unit includes brown (7.5 YR 4/4) to strong brown (7.5 YR 5/6) silty till, containing 5-35 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; very soft to firm consistency, locally exhibiting subhorizontal fissility. Thickness generally less than 1.8 m (6 ft)

Qn **Netcong Till**--Light gray (10 YR 7/2), 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. 4b), containing commonly 5-30 percent pebbles, cobbles, and boulders of gneiss, quartzite, carbonate rock, and sandstone; in areas underlain by gneiss (figs. 3,4); matrix contains quartz, feldspar, nonweathered heavy minerals and micas; matrix silt-clay fraction is gray; noncalcareous; chiefly compact, 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. Till is strong brown (7.5 YR 5/6) in local areas where it contains weathered and iron-manganese-stained gravel clasts and sand grains. Thickness of compact till generally 3.0-6.1 m (10-20 ft). Unit includes loose, sandy till (fig. 4b), containing 10-40 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 3.0-12.2 m (10-40 ft). The loose sandy till underlies areas of hummocky topography in small recessional moraines in the Highlands (units Qnsm, Qnpm, Qncm, Qnu) 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, and carbonate rocks (figures 3, 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, firm to hard consistency; gravel clasts are generally nonweathered. Three varieties of till are recognized:

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; noncalcareous; compact. Unit includes reddish brown (5 YR 4/3) to reddish yellow silty till and minor clayey till, containing quartzite and gneiss clasts, in areas underlain by shale near Green Pond Mountain (figure 4); noncalcareous, compact. Thickness as much as 7.6 m (25 ft)

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; noncalcareous; compact. Thickness reportedly as much as 30.5 m (100 ft)

Light olive brown (2.5 YR 5/4) silty till containing carbonate-rock, gneiss, sandstone, and shale pebbles, cobbles, and boulders; in eastern part of Kittatinny Valley; matrix contains sand-sized grains of shale; calcareous, but reacts weakly to dilute hydrochloric acid; compact. Calcareous till is leached to depth of about 0.7 m (24 in). Thickness generally less than 3.0 m (10 ft)

Moraine deposits--Composed chiefly of till, commonly more than 15 m (50 ft) thick; moraines have characteristic 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; slopes along the southerly boundaries of moraines are relatively steep and northerly slopes of moraines are moderate, locally hummocky; moraine deposits commonly overlie promorainal meltwater deposits of the Rockaway Formation (sections AA', BB', HH'); moraine deposits are as much as 20 m (65 ft) thick. 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; also contains loose, lose stony till, flowtill and colluvial deposits, local boulder accumulations, and minor meltwater sediments; ridge-and-kettle and hummocky surface morphology is common: moraine deposits overlie promorainal meltwater deposits of the Rockaway Formation in some valleys (sections DD', GG', II', JJ', KK); moraine deposits overlie bedrock and underlie meltwater deposits in some valleys and upland areas (sections DD', HH'); moraine deposits are as much as 61.0 m (200 ft) thick

Recessional Moraines

Qncm **Cherry Ridge moraine deposit**--Netcong Till: as much as 18 m (60 ft) thick

Qnpm **Mud Pond moraine deposit**--Netcong Till; as much as 24 m (80 ft) thick

Qnsm **Silver Lake moraine deposit**--Netcong Till; as much as 18 m (60 ft) thick

Qnu **Moraine deposits, undifferentiated**--Netcong Till, as much as 15 m (50 ft) thick

Qklm **Libertyville moraine deposit**--Netcong Till: as much as 14 m (45 ft) thick

Qkmu **Moraine deposits, undifferentiated**--Kittatinny Mountain Till; in small areas; as much as 9 m (30 ft) thick

Qkvm **Millville moraine deposit**--Kittatinny Mountain Till: as much as 9 m (30 ft) thick

Qksm **Steeny Kill Lake moraine deposit**--Kittatinny Mountain Till; as much as 14 m (45 ft) thick

Qkmm **Montague moraine deposit**--Kittatinny Mountain Till; as much as 20 m (65 ft) thick

Qkam **Augusta moraine deposit**--Kittatinny Mountain Till; as much as 20 m (65 ft) thick

Qkdm **Dingmans Ferry moraine deposit**--Kittatinny Mountain Till; as much as 20 m (65 ft) thick

Qkom
Qnom **Ogdensburg-Culvers Gap moraine deposit**--Kittatinny Mountain Till and Netcong Till; as much as 20 m (65 ft) thick

Qkgm **Franklin Grove moraine deposit**--Kittatinny Mountain Till; as much as 14 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)

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

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

Qnpm **Pequest moraine deposit**--Netcong Till; average thickness is about 16.8 m (55 ft)

Qkbm
Qnbm **Budd Lake moraine deposit**--Netcong Till and Kittatinny Mountain 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 45.7 m (150 ft)

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 m (50 ft)

Middle Wisconsinan to Illinoian Alluvial Deposits

Qw **Wharton deposits**--Subsurface unit (sections DD', II'). Sand and gravel alluvial deposits, probably including proglacial outwash deposits of the Lamington Formation (Illinoian) at the base; as much as 9 m (30 ft) thick

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

Qrtu **Raritan terrace deposit**--Silt, sand, sand and gravel, and clay in upper terrace along the Raritan River; sand and gravel is poorly sorted; clasts are gneiss, sandstone, quartzite, chert; gneiss clasts have weathering rinds 0.2-1 cm (0.01-2.5 in) thick; surface altitudes slope from 61 m to 6 m (200 ft to 20 ft); 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) sand, silt and gravel (fig. 5b), 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 composition of underlying and northerly adjacent till and bedrock units. Gravel is polymict; gravel clasts are subrounded to well rounded, variably weathered; gravel clasts include abundant clasts with weathering rinds 0.2-1 cm (0.01-0.4 in) thick, and many friable disintegrated clasts; 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 deposits 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 and 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 the position and facies relationships 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) 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; soils in eolian sand, congelliturbate, colluvium, or solifluction deposits, as much as 6 m (20 ft) thick, that overlie sand and gravel deposits contain ventifacts, and are alfisols with argillic B horizons, 0.5-0.9 m (22-34 in) thick overlying 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 degree of clast weathering 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 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 1.8-15.2 m (6-50 ft) thick, locally reported to be as much as 30.5 m (100 ft) thick

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 ft to 650 ft)

Qlbr **Brainards outwash deposit**--Sand and gravel of terrace deposit; as much as 6.1 m (20 ft) thick. Surface altitudes in discontinuous terrace slope from 99 m to 67 m (325 ft to 220 ft). Unit includes local sand and gravel deposits with surface altitudes ranging from 122 m to 146 m (400 ft to 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 0.6-6.1 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 6-45.2 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 stipple 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 northerly draining valleys that were dammed by the ice margin. The spillway over bedrock for one lake is preserved (unit Qli). Ice-margin-position lines 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 selected glacial lakes are shown in figure 1

Qlh **Harmony Station deposits**--Deltaic deposits of two lake stages undifferentiated, as much as 21 m (70 ft) thick. Delta-plain altitudes are 148 m (485 ft) and 130 m (485 ft and 425 ft). Lake spillways were across glacial ice in the Delaware 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 valley

Qli **Glacial Lake Ironia deposits**--Two ice-marginal deltas, as much as 22.9 m (75 ft) thick; lake-bottom sand, silt, and clay in subsurface as much as 9.1 m (30 ft) thick. Delta-plain altitudes rise from 211 m to 214 m (690 ft to 700 ft), spillway altitude is 207 m (680 ft). The lake basin occupied a preglacial, north-draining tributary valley of the Rockaway 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 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 45.2 m (150 ft) thick; 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 ft to 640 ft); highest spillway altitude is 259 m (850 ft), altitudes of lower spillways 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-Whippany divide, lower spillways were eastward over local divides in the Rockaway 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; 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 altitudes of 107 m (350 ft). The lake basin occupied a small tributary valley on the Passaic-Raritan 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 **Alamatong deposit**--Deltaic deposits with sand and gravel topset beds in two ice-contact ridges, as much as 30.5 m (100 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. 4b) containing commonly 5-20 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 50-90 percent of clasts. The distinguishing color, grain size, and composition of two till formations (units Qb, Qf) are related to the underlying bedrock source and local ice-flow directions (figures 3, 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 3-5.2 m (10-17 ft) of till is weathered, characterized by a pervasive stain of matrix by oxidized iron (Flanders Till), 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 0.2-1 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 Wisconsin glaciation, compact tills are present beneath hillslopes that faced the direction of glacial flow, as local patches of thin till, and in one moraine; thickness is generally less than 6 m (20 ft). Soils are alfisols with argillic B horizons, 0.8-1.3 m (30-51 in) thick, including or overlying Bx fragipan horizons that overlie the C horizon in weathered till.

oxidized as deep as 8 m (26.2 ft). Compact and weathered Bergen and Flanders tills are inferred to underlie tills of late Wisconsinan age in large drumlins in the northern part of the area; thickness of the Illinoian tills is 3-50 m (10-150 ft), commonly greater than 24.4 m (80 ft) in drumlins (sections AA', BB', CC').

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. 4b), containing 5-20 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. 3, 4a); 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 30-5 m (100 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 is supported by degree of clast weathering 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. 4b), containing 5-20 percent pebbles, cobbles and few boulders of gneiss, sandstone, and quartzite; in areas underlain by sandstone and shale (figs. 3, 4); matrix contains abundant shale and siltstone fragments; matrix silt-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 45.2 m (150 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 Wisconsin glaciation

Moraine deposits--Composed chiefly of compact till, more than 15 m (50 ft) thick.

Qfm **Flanders moraine deposit**--Flanders Till; scattered surface boulders; elongate, smooth ridge; the moraine is inferred to be a segment of the terminal moraine of the Flanders Till; reportedly as much as 36.1 m (120 ft) thick

Pre-Illinoian Stratified and Till Deposits

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 (16 ft). Soils are alfisols with argillic B horizons, 0.4-1.3 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. 4b), containing 5-10 percent pebbles and cobbles of quartzite, gneiss, sandstone, shale, and carbonate rock, and few boulders of quartzite and gneiss; in areas underlain by shale, carbonate rock, or gneiss (figs. 3, 4). Matrix contains quartz, scattered weathered feldspar, few heavy minerals, weathered shale fragments; matrix silt-clay fraction is brown to strong brown; noncalcareous; compact, 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 50-90 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 (figs. 3, 4), 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 3.1 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; these soils have argillic B horizons, 0.8-1.5 m (30-72 in) thick overlying the C horizon in weathered till, which is oxidized to the base. Soils are alfisols in areas underlain by shale and sandstone. The sediments of this unit were correlated in the southern belt of till deposits of the Jerseyan drift of Salisbury (1902, and 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

Late Wisconsinan to Middle Pleistocene Colluvium 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. 4b), commonly containing 5-60 percent (by volume) angular rock chips, tabular-shaped pebbles and cobbles, and small boulders; commonly massive to indistinctly layered; locally stratified; compact to loose, firm to hard consistence; 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 from silty sand matrix with angular gravel, less than 2 m (6.6 ft) thick, on steep upper slopes, to silty sand matrix with less than 40 percent pebbles and small cobbles, 2-3 m (6.6-10.0 ft) thick, to 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 deposited on slopes by creep; 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 include massive to indistinctly layered, very poorly sorted, silty, sparsely stony solifluction deposits, and local boulder talus below steep bedrock outcrops.

Unit includes multiple colluvium deposits: surface colluvium generally is composed of lightly weathered clasts; it overlies local older colluvium deposits containing weathered clasts and buried red soil profiles. Total thickness 3.0-21.3 m (10-70 ft). Soils are alfisols with argillic B horizons, 0.8-1 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; poorly to very poorly sorted; chiefly compact, firm to hard consistence, locally cemented with iron-manganese; 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, and as much as 2 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 3.0-21.3 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, firm consistence; blocky gravel clasts have weathering rinds 0.2-1 cm (0.01-0.4 in) thick. Unit includes local surface bouldery rubble of subrounded joint-block core stones of partly weathered rock. Thickness of deposits 1.8-15.2 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, firm consistence; blocky gravel clasts have weathering rinds 0.2-1 cm (0.01-0.4 in) thick. Unit includes local surface bouldery rubble of subrounded joint-block cores stones of partly weathered rock. Thickness of deposits 1.8-15.2 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, firm consistence; 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, and as much as 1 m (3.2 ft) thick, of creep or possible solifluction origin. Unit also includes local surface rock rubble composed of partly weathered rock. Thickness of deposits 3.0-9.1 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, soft to firm consistence. Unit includes minor silt, laminated, moderately sorted, with lamination parallel to surface slope, and as much as 1 m (3.2 ft) thick, of creep or possible solifluction origin. Thickness of deposit as much as 5.2 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 5-50 percent (by volume) angular pebbles and cobbles; loose to compact, firm to hard consistence; the 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 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 sand 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 rock on some ridge crests. Residuum and saprolite grade downward into partly weathered bedrock through a zone of weathered rock, which is composed of rock altered and iron-manganese-stained along joint planes or bedding, or 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 3-5°, thin alluvium and sheetwash deposits, and debris-flow sediments. Soils are ultisols and alfisols, with argillic B-horizons, 0.56 to 1.17 m (22 to 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 10-50 percent angular pebbles and cobbles of partly weathered basalt; nonsorted; gravel clasts have weathering rinds 0.2-1 cm (0.01-0.4 in) thick; as much as 6.1 m (20 ft) thick, overlying silty clay structured saprolite, generally less than 2 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 silt structureless saprolite containing 10-50 percent angular pebbles and cobbles of partly weathered diabase; nonsorted; gravel clasts have weathering rinds 0.2-1 cm (0.01-0.4 in) thick; as much as 6.1 m (20 ft) thick, overlying sandy silt structured saprolite, generally less than 2 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 10-50 percent chips and tabular pebbles and cobbles of shale, siltstone, or sandstone, nonsorted; compact. Thickness less than 1 m (3 ft) on ridges, as much as 3 m (10 ft), including colluvium, at bases of slopes. Unit includes light olive brown (2.5 YR 5/2) silty shale/slate residuum containing 10-50 percent shale or slate chips and flat pebbles of shale or slate; nonsorted, compact, less than 2 m (6 ft) thick. Unit 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 10-50 percent pebbles and cobbles of quartzite and weathered conglomerate; nonsorted; as much as 21.3 m (70 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 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 Bridgeton Formation. The colluvium is generally less than 1 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 sand to clayey silt structureless saprolite containing 20-60 percent pebbles and cobbles of partly weathered gneiss; nonsorted to very poorly sorted; nonstratified, friable; clasts are angular, with weathering rinds 0.1-0.5 cm (0.01-0.2 in) thick; thickness 1-3 m (3.2-10.0 ft); overlies partly weathered bedrock on some slopes, and in upland areas overlies yellowish brown silty sand structured saprolite, locally micaceous, containing 10-30 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 stony colluvium, 1-3 m (3.2-10.0 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

Tb **Bridgeton 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 cross-bedded 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 have 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 2-8 m (6.6-26.2 ft). Surface altitudes slope from 43 m to 34 m (140 ft to 110 ft); includes small, thin deposits north of Somerville, with surface altitudes ranging from 49 m to 55 m (160 ft to 180 ft). A weathered zone extends from the surface to depths of more than 6 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, 0.5-0.7 m (20-26 in) thick overlying the C horizon in deeply weathered sediment

Materials of this unit formerly were included in the Pensauken Formation (late Tertiary or early Pleistocene-Jerseyan [glacial] Stage) of Salisbury and Knapp (1917). Salisbury and Knapp (1917), Owens and Minard (1975, 1979), and Martino (1981) interpreted the sediments to be of nonglacial alluvial origin. The deposits in the map area are continuous to the southwest with the extensive Bridgeton Formation which overlies the Cohansey Formation of Middle Miocene age in southern New Jersey (Owens and Minard, 1979). To the south, the Pennsauken Formation of Owens and Minard (1979; W.L. Newell, pers. comm., 1994), which is entrenched below and is therefore younger than the Bridgeton, extends to Delaware and Maryland where it is equivalent in part to the Columbia Group of Jordan (1964) of Pliocene--Pleistocene age. Thus the Bridgeton may range in age from Late Miocene to Pliocene.

Bedrock (early Mesozoic to Precambrian)--Exposed bedrock in quarries, other large excavations, and large natural outcrops; partly weathered along fractures in upper part

Table 1. Selected localities of radiocarbon dates

Map Symbol	Radiocarbon age (multiple ages in vertical sequence)	Locality	Material dated	Reference
2.0	2,025+300	Hackensack Meadows	salt marsh peat	Heusser (1963)
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	
9.1	9,130+150	Lake Rogerine	top of pine zone	Nicholas (1968)
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	
10.2	10,280+270 (I-5200)	Hudson River	mollusc shells	Weiss (1974)
11.5	11.520+90 (SI-4922)	Lawyers Bog	unknown	Cotter. et al. (1984)
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	
12.3	12,300+300	Saddle Bog	unknown	Sirkin and Minard (1972)
12.29	12,29+440(RIDDL 1136)	Alpine swamp	spruce needle	Peteet et al. (1990)
12.8	12,840±110 (WIS-1482)	do	basal gyttja	
14.0	14,060+240 (OC-1305)	Great Swamp	concretion	Stone et al. (1989)
20.1	20,180+500 (OC-1304)	do	concretion	
11.2	11,220+110 (SI-5301)	Francis Lake	peaty gyttja	Cotter et al (1985)
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	
12.8	12,870+200 (QC-296)	Dwars Kill. Norwood	peat	Averill and others (1980)
12.1	12,150+210 (QC-297)	do	peat	
19.3	19,340+695 (GX-4279)	Jenny Jump Mountain	wood/organic materials	D.H. Caldwell, N.Y. State Geological Survey, personal communication

Figure 1. Map showing maximum extents of glaciations, moraines, selected glacial lakes, and correlated ice-margin positions of northern New Jersey

The maximum extents of glacial advances of three glacial episodes are based on the southerly most extent of till in end moraines or compact till that locally extends south of the moraines. In late Wisconsinan deposits, maximum glacial advance also is known locally from kettles that are south of the terminal moraine. Maximum extent of Illinoian glaciation and early Pleistocene glaciation of the Port Murray Formation are based on the maximum extent of discontinuous till deposits and erratics.

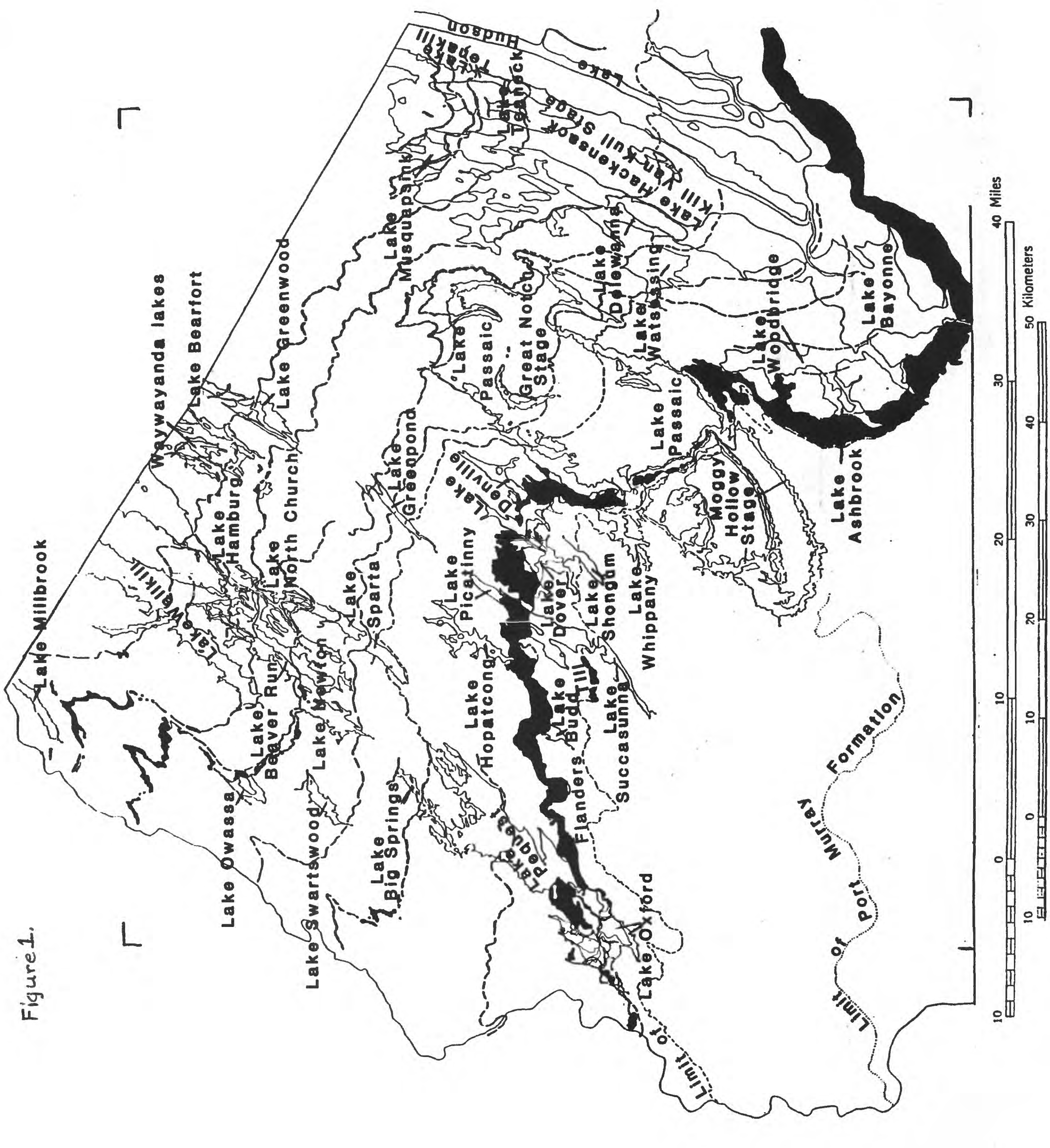
Two classes of moraines are shown in the figure: 1) segments of terminal moraines (Salisbury, 1902), and 2) recessional moraines. Moraines are composed chiefly of till but also contain stratified deposits, flowtill, and colluvial deposits. Moraine deposits accumulated by various processes at the edge of the ice sheet during stillstands of the advancing or retreating ice-margin. Transverse ridges at the surface of parts of the late Wisconsinan terminal moraine and in recessional moraines that are known to overlie promorainal stratified sediments are related to minor readvances of the glacier margin and glacial transport of sediments. The ridge deposits may be the surface expression of glacially thrusted blocks of sediment, or ice-marginal deposition of colluvial debris or meltwater sediments. Circular ridge-and-kettle topography in other parts of the moraines is attributed to collapse of morainal sediments that overlay blocks of stagnant ice.

Segments of the late Wisconsinan terminal moraine are closely related in age (see correlation diagram). Stratigraphic evidence indicates that the ice sheet advanced first into the lower Hudson valley, closely followed by arrival of the ice margin in the central and then the western parts of the area. The age of the youngest parts of the terminal moraine segments is shown to be in part synchronous, from about 20,000 to 21,000 radiocarbon years ago (Stone, 1995). The westerly younging relative ages of different segments of the terminal moraine are deduced from stratigraphic relationships of submoraine deposits of ice-dammed lakes (glacial lakes Passaic, Denville, Succasunna) near the terminal position. These lakes were dammed sequentially from east to west by valley ice lobes that subsequently deposited morainal sediments on top of the lake deposits.

The extents of major and selected small glacial lakes, and locations of lake spillways are shown in figure 1. The extents of the lakes are based on the distribution of lake deltas, lake-bottom deposits, and positions of ice margins in the lake basins. Major glacial lakes were dammed by the ice margin in large, northerly draining basins and by moraines or slightly older meltwater deposits in southerly draining basins. Some major glacial lakes had different lake-level stages, the levels of which were controlled by separate lake spillways. Some other major lakes include lake phases related to lake levels that lowered due to erosion of sediment dams. Small glacial lakes and ponds were dammed by the ice margin in small, northerly draining basins. In some basins, lake stages lowered as ice-margin retreat uncovered successively lower spillways. In some valleys, small lakes were impounded at higher levels behind slightly older sediment dams composed of thick deltaic deposits.

The correlated ice-margin positions shown in figure 1 are based on correlation of the youngest parts of the terminal moraine, and on relative ages of ice-dammed glacial lakes and recessional moraines. The maximum northerly extent of large, ice-marginal delta deposits of ice-dammed lakes are used to infer the youngest position of the ice margin that was required to dam the glacial lake. In basins of major glacial lakes, ice-margin positions are shown in higher, older lake stages that lowered when the ice-margin retreated and dammed a new lake at a lower altitude. In basins of small glacial lakes and ponds in upland areas, ice-margin positions show the general trend of the ice margin from basin to basin. The fanning pattern of recessional moraines and correlated ice-margin positions reveals that the edge of the ice sheet retreated more rapidly across the western part of the area.

Figure 1.



Lake Millbrook
Lake Wallkill
Wawayanda lakes
Lake Bearfort
Lake Greenwood
Lake Hamburg
Lake North Church
Lake Beaver Run
Lake Newton
Lake Owassa
Lake Swartswood
Lake Big Springs
Lake Sparta
Lake Greenpond
Lake Musquapsink
Lake Tappan
Lake Teaneck
Lake Hudson
Lake Hackensack
Kill Van Kull Stage
Lake Passaic
Great Notch Stage
Lake Delawanna
Lake Watsessing
Lake Denville
Lake Picatinny
Lake Hopatcong
Lake Dover
Lake Shongum
Lake Whippany
Lake Budd
Flanders
Lake Succasunna
Lake Pequest
Lake Oxford
Moggy Hollow Stage
Lake Woodbridge
Lake Bayonne
Lake Ashbrook
Limit of Port Murray Formation
Limit of
Miles
Kilometers

Figure 1A and 1B. Ice-sheet lobes and ice flow directions of the late Wisconsin glaciation

Figure 1A shows the direction of ice flow during the maximum southerly extent of the late Wisconsinan Laurentide ice sheet in northern New Jersey. The limit of glaciation coincides generally with the southern edge of the terminal moraine. Ice-flow directions are based chiefly on mountain-top striations and dispersal patterns of nepheline syenite erratics in the Kittatinny Valley and basalt erratics in the Newark basin. The field data indicate that regional ice flow was predominantly in a southerly direction during the glacial maximum. Because the ice sheet was thicker in the major valleys near the edge of the ice sheet, ice flow resulted in the formation of valley ice lobes with lobate ice margins. The reconstructed flow lines based on the striation data show the diverging ice-flow direction in ice lobes in the Hackensack and upper Passaic valleys in the Newark basin and in the Kittatinny Valley. In other smaller valleys in the ice terminal zone the thin ice edge flowed in response to local topographic features. Based on a simplified formula for calculating ice-surface gradients (Nye, 1952), the thickness of the ice sheet at the north end of the Newark basin in New Jersey was about 1200 m (4000 ft) during maximum ice extent.

Figure 1B shows the generalized directions of ice flow following ice-margin retreat to the correlated recessional ice-margin position from Dingmans Ferry to Bloomfield. Ice-flow directions are based on valley-side and valley-bottom striations, provenance of upper parts of till deposits, trends of ice-margin positions along meltwater deposits and ice dams of glacial lakes, and dispersal patterns of erratics. The data show a general south-southwesterly flow during deglaciation. Large valley ice lobes persisted in the Newark basin lowland and the Kittatinny Valley and minor lobes filled smaller valleys.

Figure 1a, b.

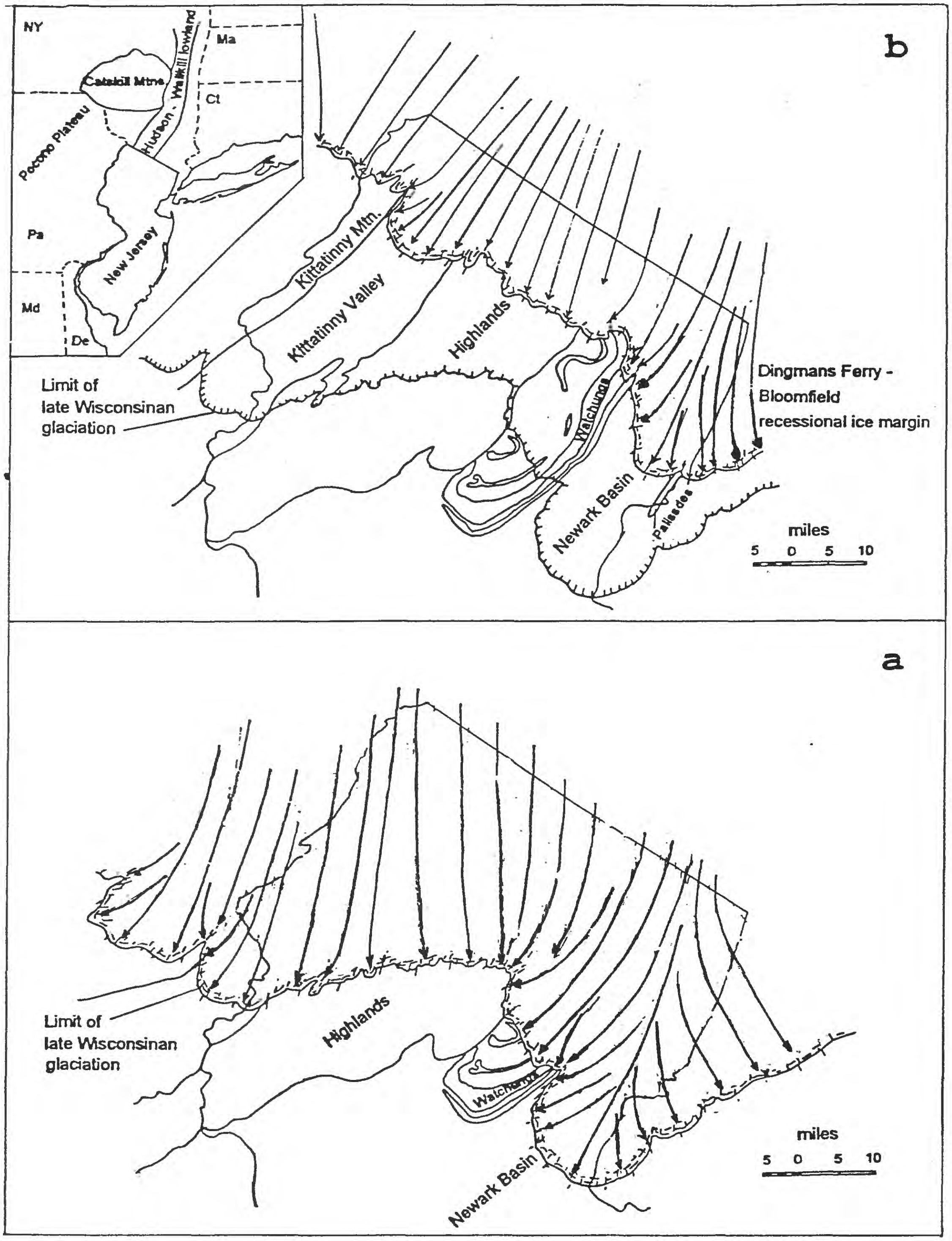

b
NY
Ma
Catskill Mtns
Ct
Hudson - Walkill lowland
Pocono Plateau
Pa
New Jersey
Md
De
Kittatinny Mtn.
Kittatinny Valley
Highlands
Watchung
Newark Basin
Palisades
Limit of late Wisconsinan glaciation
Dingmans Ferry - Bloomfield recessional ice margin
miles
5 0 5 10
a
Highlands
Watchung
Newark Basin
Limit of late Wisconsinan glaciation
miles
5 0 5 10

Figure 2. Map of physiographic units of northern New Jersey. Modified from Fenneman (1938).

Figure 3. Map of bedrock lithologic units of northern New Jersey

Bedrock units are classified on the basis of lithologic characteristics and relative resistance to weathering and erosion. Rocks that are resistant to erosion underlie mountainous and upland areas. Rocks of intermediate resistance form hilly areas of moderate relief. Rocks of low resistance underlie lowlands and valleys. Distribution of rock units modified from Drake and others (1994).

DESCRIPTION OF MAP UNITS

Rocks Resistant to Erosion

Rock units of variable composition and fracture density underlie mountains and extensive upland areas such as Kittatinny Mountain, the New Jersey Highlands, the Watchung Mountains, and the Palisades (fig. 2). Linear rock features, including trace of bedding or compositional layering, joint sets, and fault-line scarps control the distribution and shape of linear topographic elements underlain by shallow bedrock, and continuous, steep cliffs

b **Basalts of the Newark basin (Early Jurassic)**--Basalt, in multiple concordant sheets within each mapped unit

d **Diabase of the Newark basin (Early Jurassic)**--Diabase in discordant sheets and stocks

q **Quartzite and quartzite conglomerate (Devonian and Silurian)**--Quartzite, arkosic quartz-pebble conglomerate, quartz and feldspathic sandstone, thin to very thick bedded

gn **Gneisses of the New Jersey Highlands (Precambrian)**-- Gneisses of granitic composition, alaskite gneisses, and local amphibolite gneisses, granite, syenite, marble, quartzite, diorite, and diabase; includes schist of the Manhattan prong

Rocks of Intermediate Resistance to Erosion

Rock units consisting of resistant sandstone beds interbedded with shale or slate that underlie hilly areas with moderate relief at the base of mountains and upland areas. Trace of bedding, joint sets, cleavage, and fault-line scarps control the distribution and shape of linear topographic elements underlain by shallow bedrock, and continuous rock outcrops

cs **Conglomerates and sandstones of the Newark basin (Early Jurassic to Middle Triassic)**--Pebble-to-cobble conglomerate, pebbly medium-to-coarse grained and medium grained feldspathic sandstone

sf **Siltstone and sandstone of Kittatinny Mountain upland and Green Pond Mountain area (Devonian and Silurian)**--Siltstone and fine-to-medium grained quartz sandstone and minor interbedded shale

I **Intrusive rocks of Kittatinny Valley (Late Ordovician)**--Nepheline syenite

sm **Sandstone, siltstone, and slate of Kittatinny Valley sequence (Middle Ordovician)**--Medium-to-coarse grained greywacke sandstone and siltstone, with interbedded shale or slate

Rocks of Low Resistance to Erosion

Rock units consisting of shale, slate, carbonate rocks, and Coastal Plain deposits that underlie eroded and locally glacially overdeepened lowland basins, or valleys underlain by deeply weathered carbonate rocks. Trace of bedding of nonresistant rock types and fault zones are coincident with areas of deep glacial scour scp **Sand and clay of the Coastal Plain (Cretaceous)**--Fine-to-medium grained sand and compact clay

sh **Shale and sandstone of the Newark basin (Early Jurassic to Middle Triassic)**--Shale, mudstone, and interbedded fine-to-medium grained feldspathic and arkosic sandstones

shs **Shale, limestone, and sandstone of the Valley and Ridge Province (Middle and Early Silurian)**--Shale, limestone, sandstone, mudstone, siltstone, quartz pebble conglomerate, and dolostone

sl **Slate of Kittatinny Valley (Middle Ordovician)**--Slate, shale, and interbedded thin greywacke sandstone; includes shale of the Jutland and the Peapack Klippe

Figure 3.

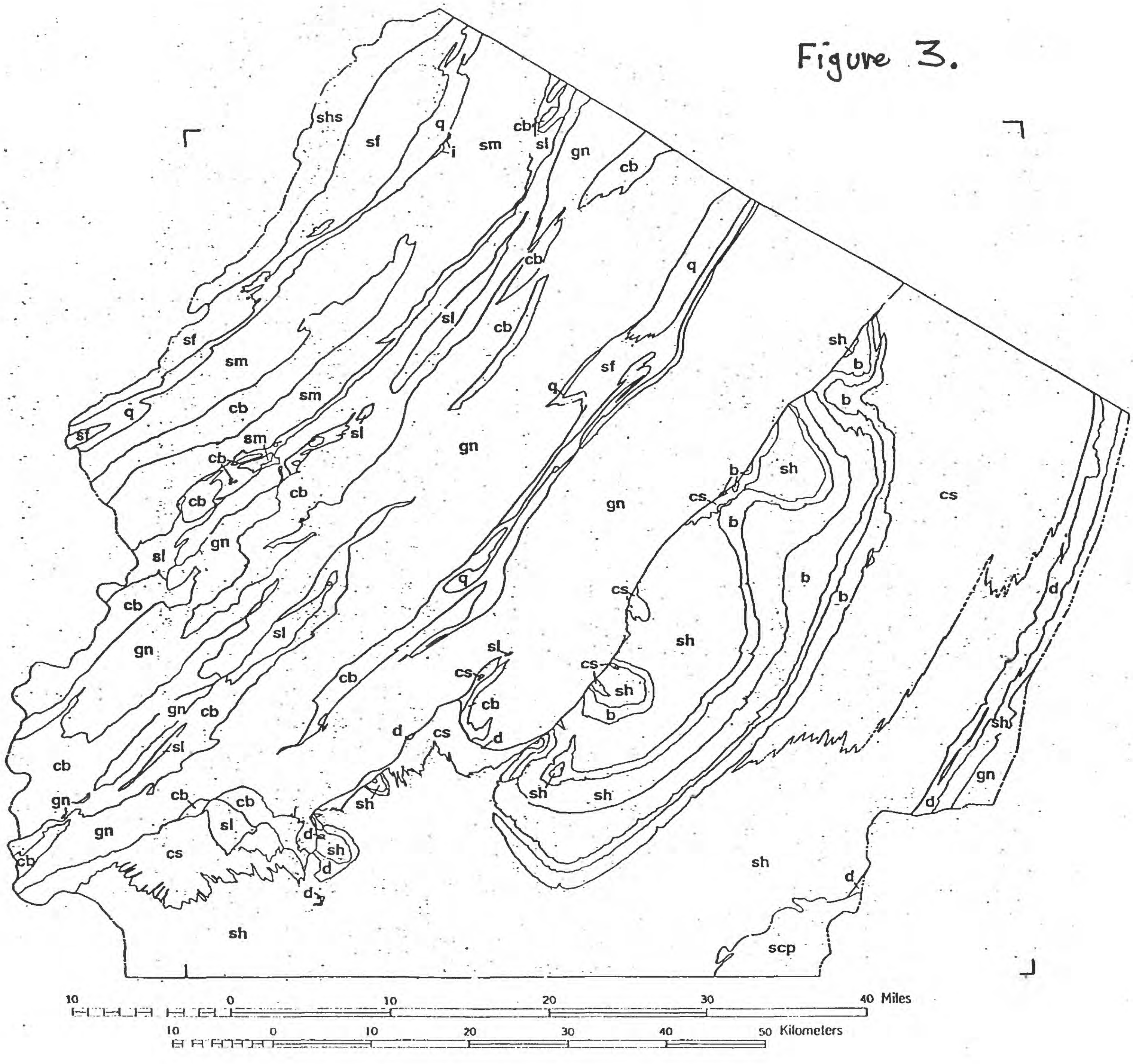


Figure 4a. Map of till deposits of northern New Jersey

Till deposits of formation rank are differentiated on the basis of lithologic characteristics that are related to bedrock source areas (figs. 3, 4b, 5b), and to degree of weathering of the surface soil and the underlying till parent material. Till units are further subdivided into local till types on the basis of local variations in lithologic characteristics, which are related to local differences in bedrock sources or inferred depositional processes; the generalized distribution of these local till-type deposits is shown in figure 4a.

DESCRIPTION OF MAP UNITS

Qr **Rahway Till, reddish brown sandy-to-silty-to-clayey type (late Wisconsinan)**--Derived chiefly from shale and sandstone

Qrs **Rahway Till, brown silty type (late Wisconsinan)**--Derived chiefly from basalt and diabase

Qn **Netcong Till, gray sandy and silty types (late Wisconsinan)**--Derived chiefly from gneiss

Qns **Netcong Till, sandy facies (late Wisconsinan)**--Derived chiefly from gneiss; containing boulders; noncompact and loose

Qk **Kittatinny Mountain Till, olive to reddish brown silty-to-sandy type (late Wisconsinan)**--Derived from shale, sandstone, and quartzite

Qk **Kittatinny Mountain Till, olive gray silty shale-chip type (late Wisconsinan)**--Derived chiefly fom shale and sandstone

Qk **Kittatinny Mountain Till, light olive brown silty calcareous type (late Wisconsinan)**--Derived chiefly from carbonate rocks and shale

Qf **Flanders Till, brown silty-to-sandy type (Illinoian)**--Derived chiefly from gneiss

Qfc **Flanders Till, yellow brown silty calcareous type (Illinoian)**--Derived from carbonate rocks and shale

Qb **Bergen Till, reddish brown silty and silty-to-clayey types (Illinoian)**--Outcrop locality; derived from sandstone and shale

Qp **Port Murray Formation, till, reddish brown silty-to-sand and silty-to-clayey types (pre-Illinoian)**--Derived chiefly from shale and sandstone

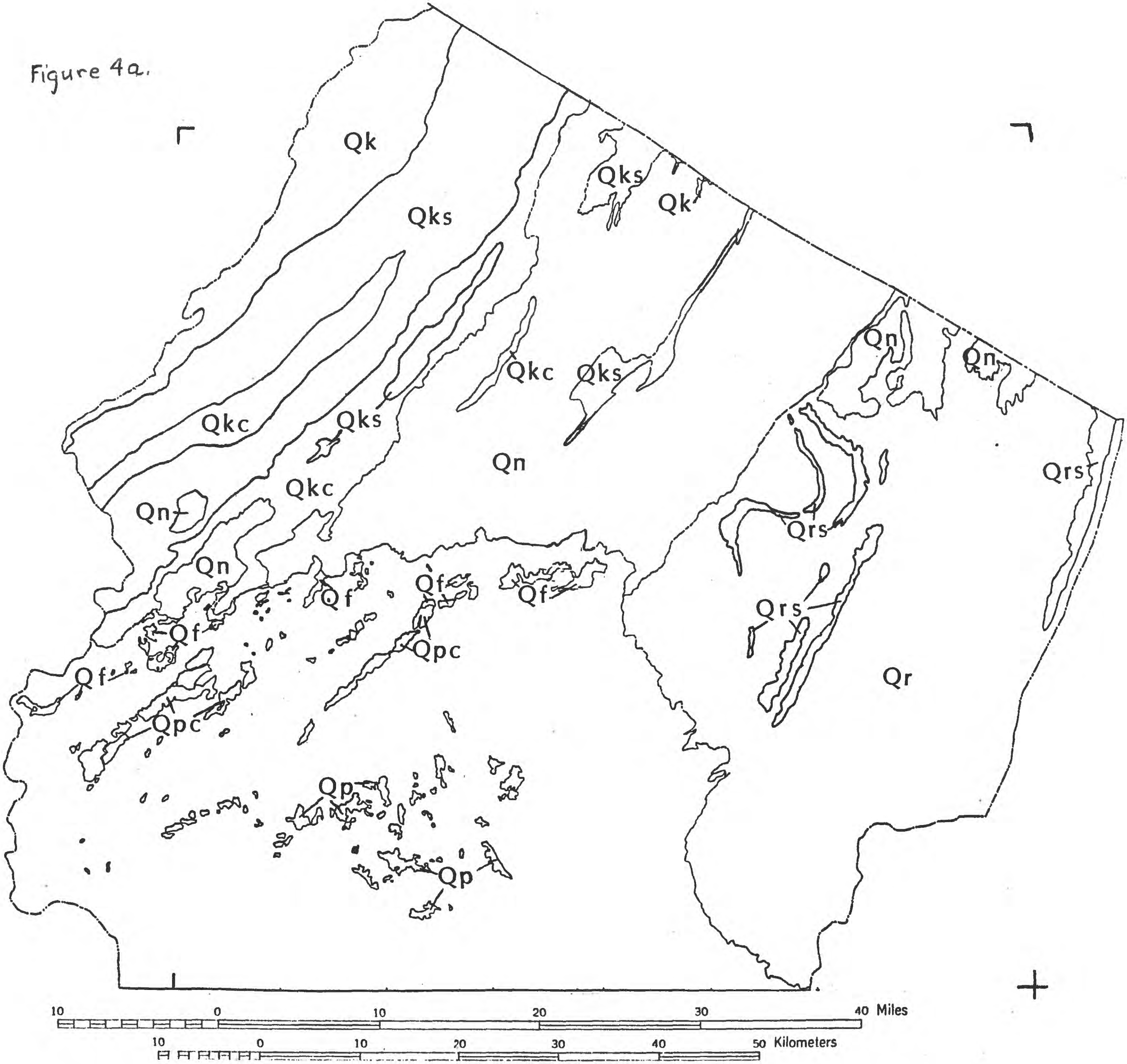
Qpc **Port Murray Formation, till, strong brown silty-to-clayey type (pre-Illinoian)**--Derived from carbonate rock

Explanation of map symbols

Areas of morainal topography--Terminal moraine and recessional moraines

Type-section locality of labelled map unit

Figure 4a.


Qk
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Qrs
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Qf
Qf
Qf
Qf
Qf
Qpc
Qpc
Qp
Qp
10
0
10
20
30
40 Miles
10
0
10
20
30
40
50 Kilometers

Figure 4b. Grain-size classification of till matrix, based on U.S. Department of Agriculture soil texture classification; limits of fields of compact, basal tills based on Sladen and Wrigley (1983), and data in the cited references for the Engineering Soil Survey of New Jersey, Engineering Bulletin series

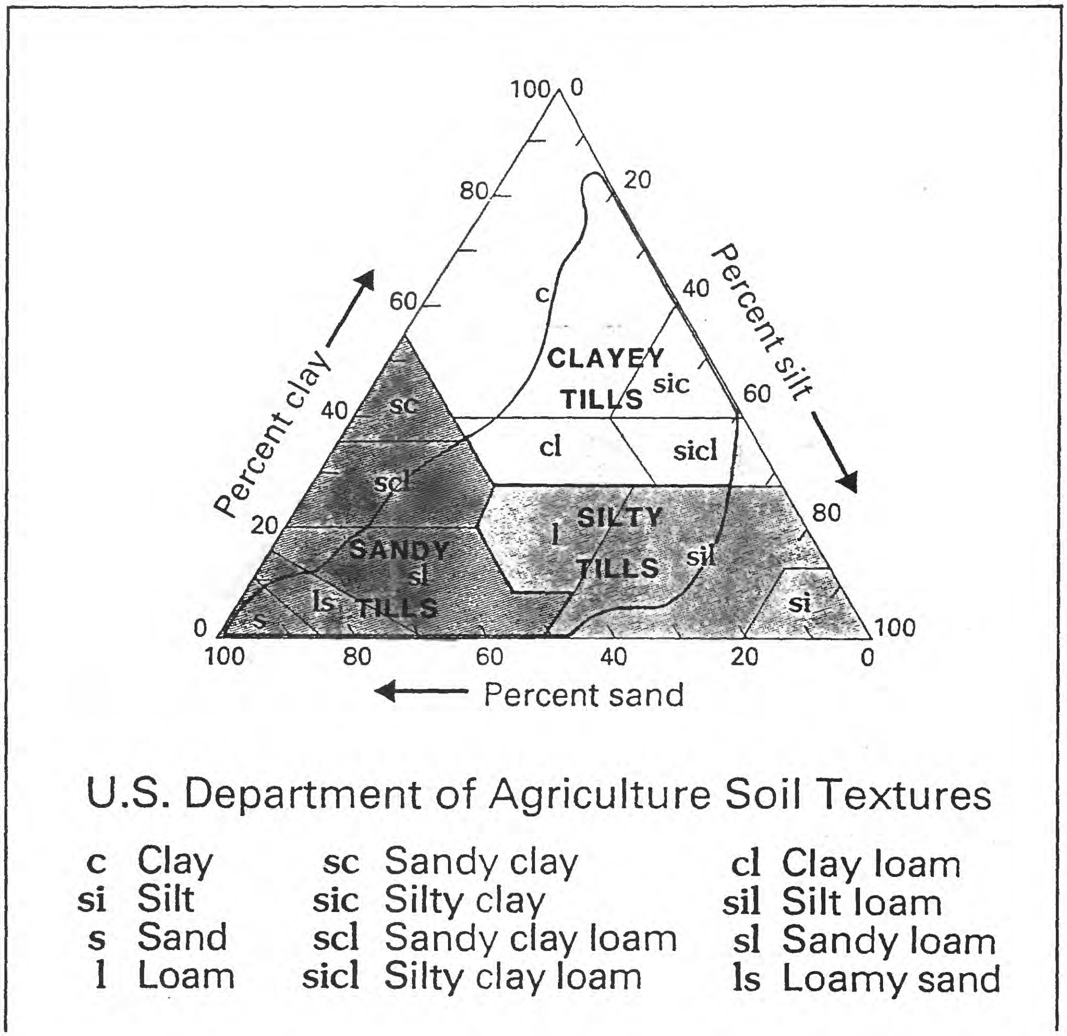


Figure 5a. Map of glacial meltwater deposits of northern New Jersey

Meltwater deposits are sorted and stratified deposits of gravel, sand, silt, and clay (fig. 5b), deposited by glacial meltwater; deposits are grouped in three units of formation rank, , which are differentiated on the basis of lithologic characteristics, the degree of weathering and soil development, and age. Meltwater sediments are subdivided into glaciofluvial deposits, which were deposited by meltwater streams, and glaciolacustrine deposits, which were deposited as lake-bottom and deltaic deposits in glacial lakes including tributary stream deposits graded to the lake deltas

Description of map units

Qf **Rockaway Formation**--Glaciofluvial deposits

Qrd **Rockaway Formation**--Glaciodeltaic and tributary-stream deposits, and glaciolacustrine fan deposits

Qrl **Rockaway Formation**--Glaciolacustrine lake-bottom deposits

Qlf **Lamington Formation**--Glaciofluvial deposits

Qld **Lamington Formation**--Glaciodeltaic deposits, and glaciolacustrine fan deposits

Qll **Lamington Formation**--Glaciolacustrine lake-bottom deposits

Qps **Port Murray Formation**--Stratified Deposits

Explanation of map symbols

Qp• **Type-section locality of labelled map unit**

Figure 5a.

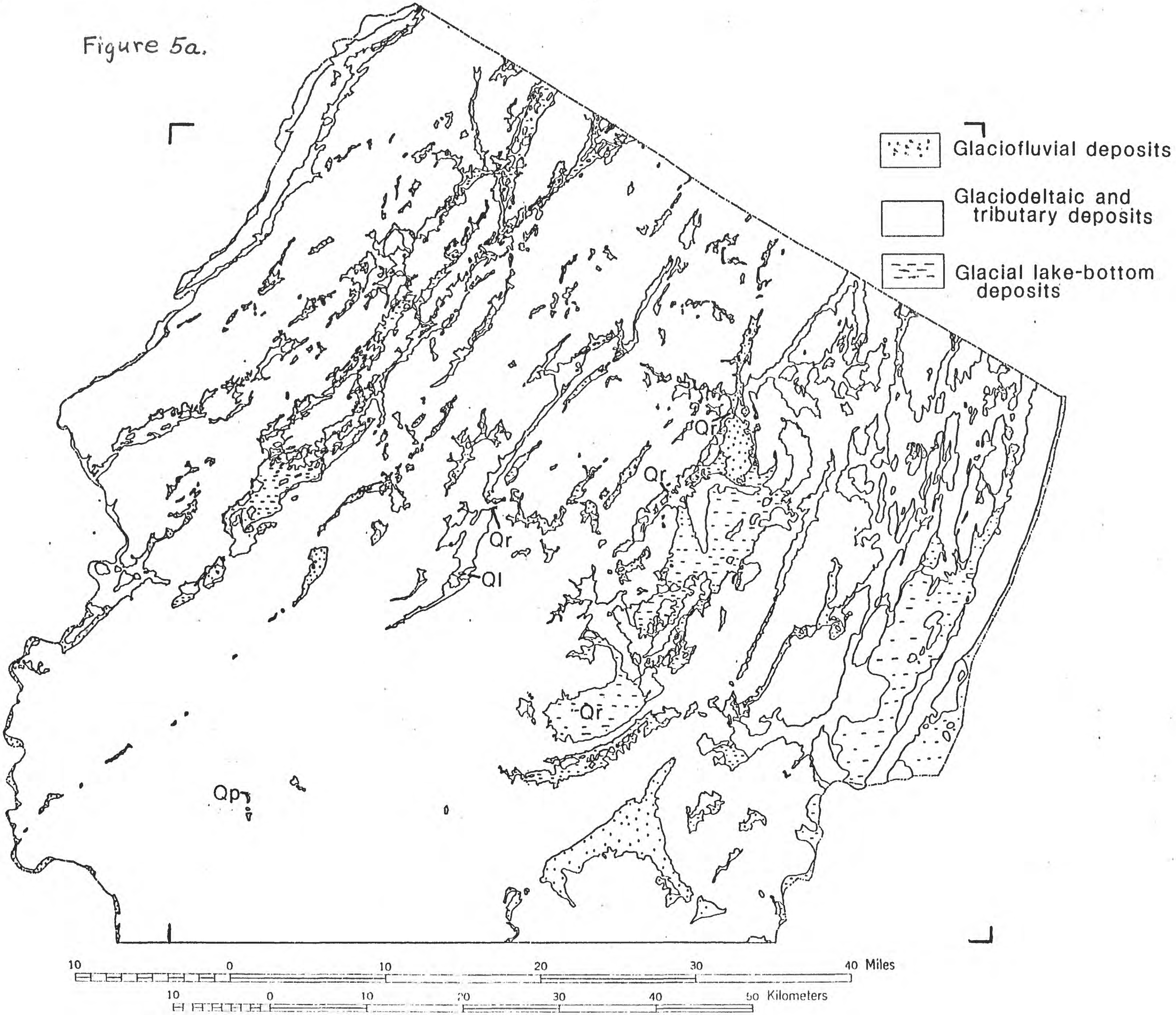

Glaciofluvial deposits
Glaciodeltaic and tributary deposits
Glacial lake-bottom deposits
Qr
Qr
Qr
Qr
Ql
Qp
10 0 10 20 30 40 Miles
10 0 10 20 30 40 50 Kilometers

Figure 5b. Grain-size classification of meltwater deposits and till.

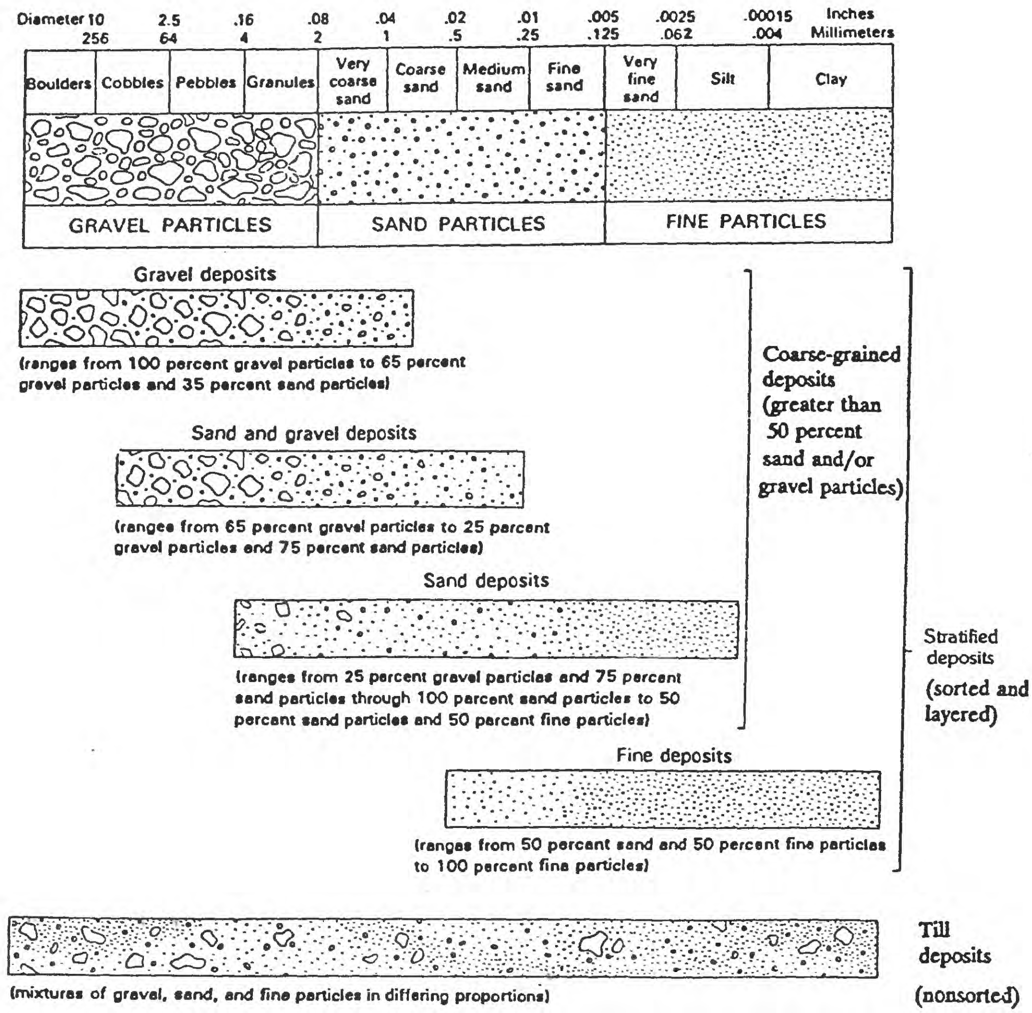


Figure 6. Previous mapping studies.

Numbered references are shown for areas mapped in previous geologic-map studies.

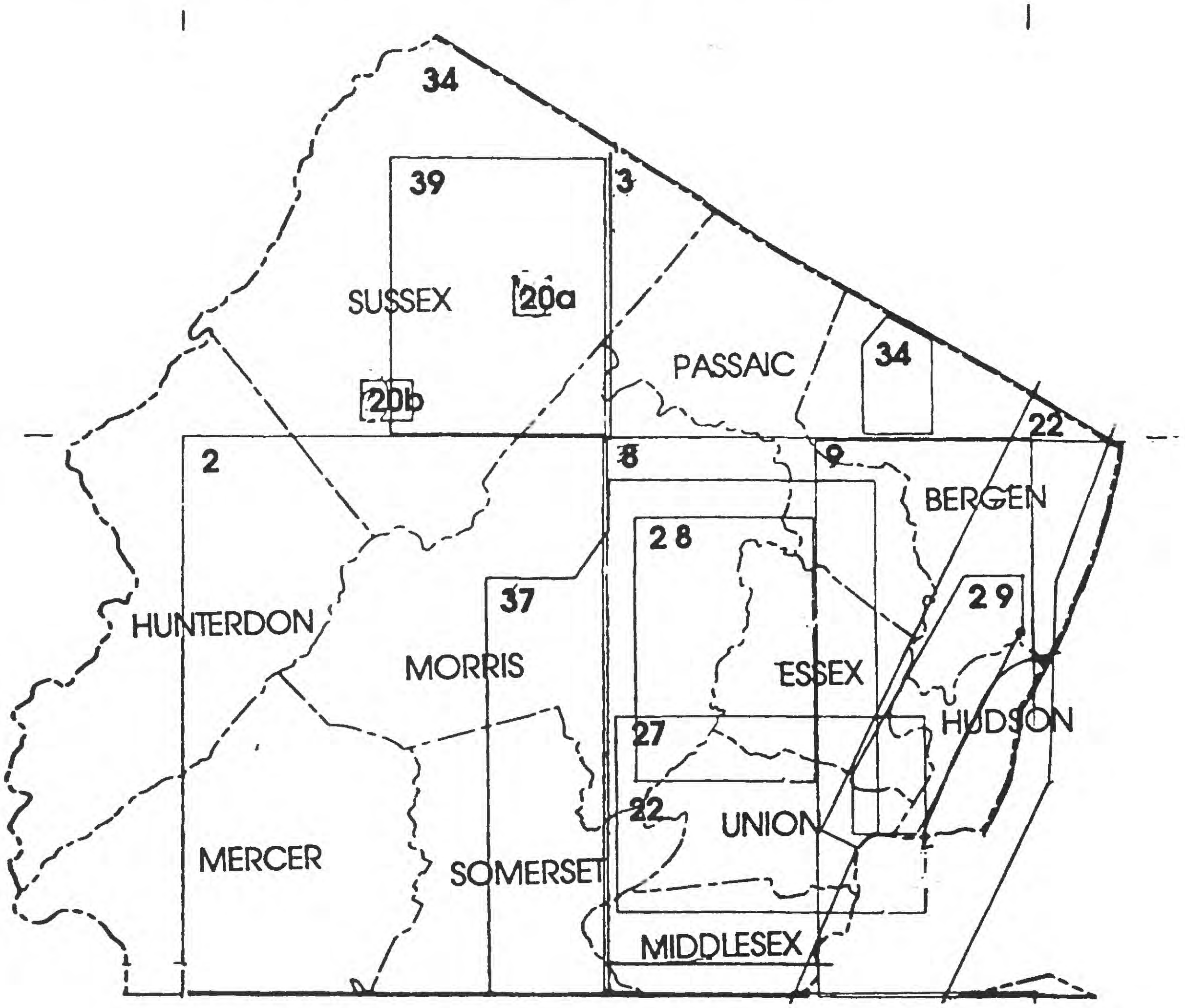
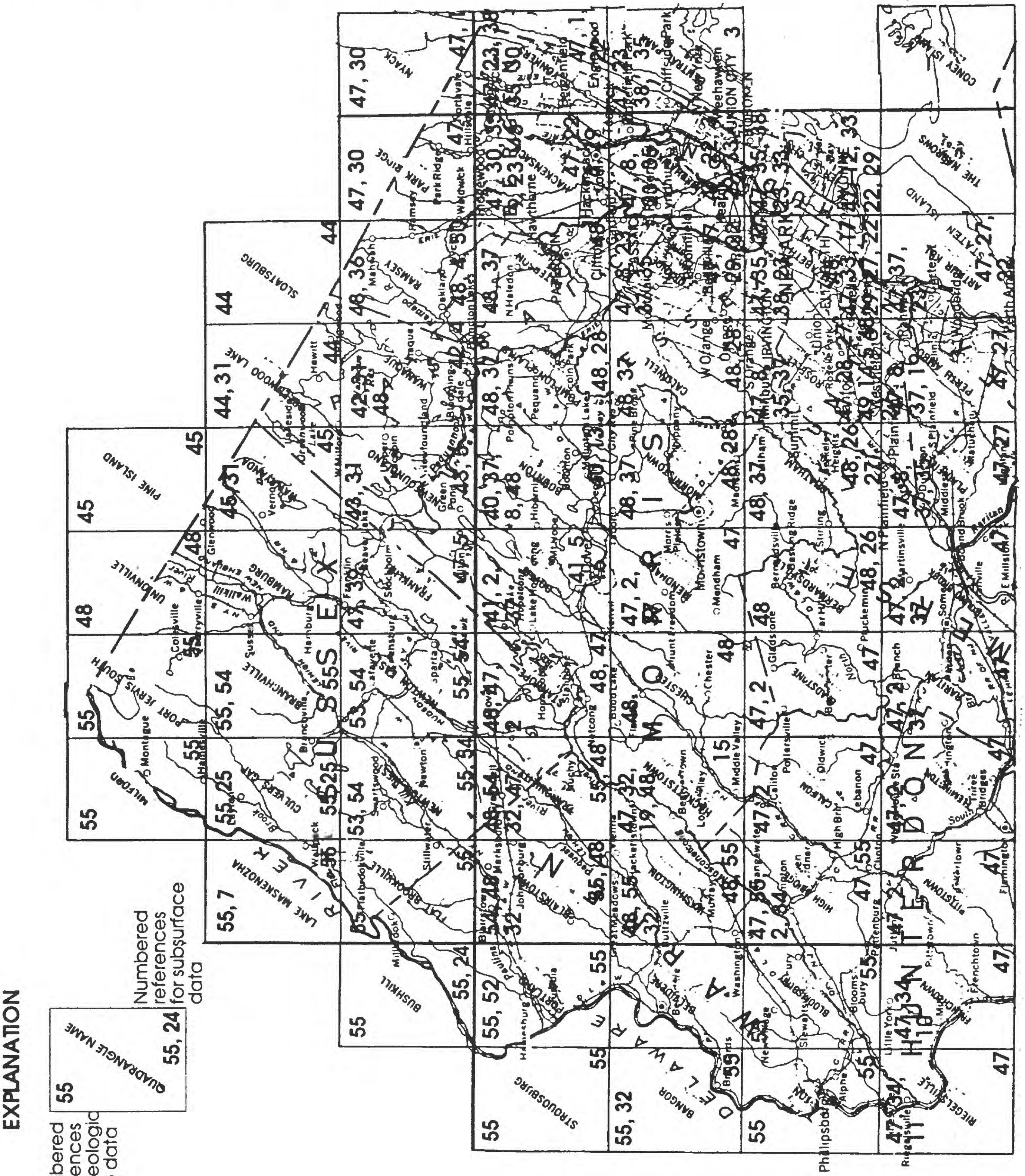


Figure 7. Geologic mapping and compilation credits, and sources of map data.

Numbered references for geologic-map data and subsurface data are shown for each 7.5' quadrangle in the map area.



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