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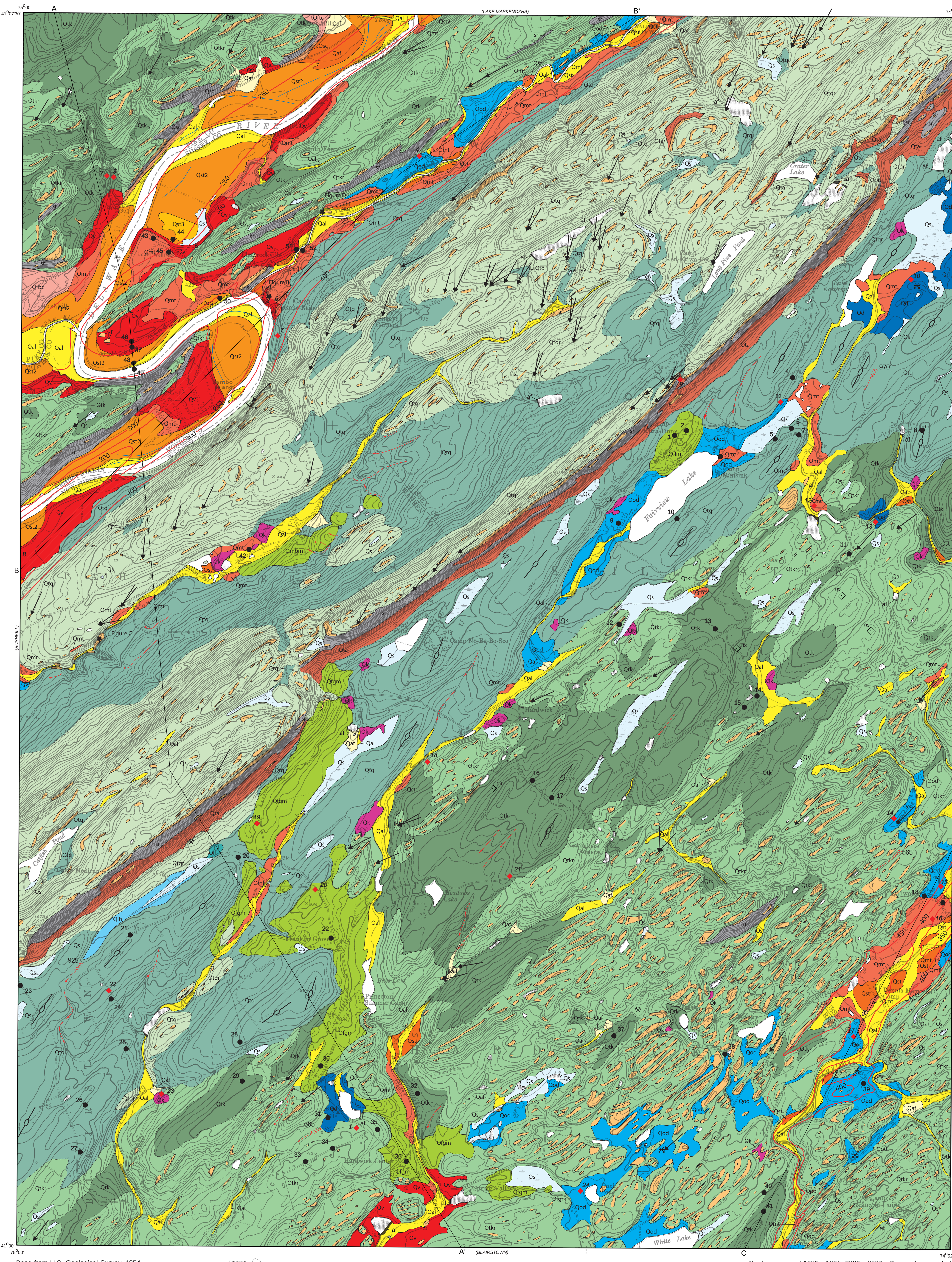

Base from U.S. Geological Survey, 1954
Photorevised, 1971

SCALE 1:24000

1 1/2 0 1 mile

1000 0 1000 2000 3000 4000 5000 6000 7000 feet

1 1/2 0 1 kilometer

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

Geology mapped 1985 - 1991, 2005 - 2007. Research supported by the U.S. Geological Survey, National Cooperative Mapping Program, under USGS award number 99HQAG0141. GIS appplication by Ron Pristas and Mike Girard, New Jersey Geological and Water Survey. Digital cartography by Ron W. Witte.

SURFICIAL GEOLOGIC MAP OF THE FLATBROOKVILLE QUADRANGLE, SUSSEX AND WARREN COUNTIES, NEW JERSEY, AND PIKE AND MONROE COUNTIES, PENNSYLVANIA

by

RON W. WITTE - NEW JERSEY GEOLOGICAL AND WATER SURVEY
and
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2012

INTRODUCTION

Industrial, commercial, and residential expansion in New Jersey and Pennsylvania has promoted the increased use of surficial geologic data for land-use planning, for identification, management and protection of ground water resources, siting of solid waste disposal sites, locating and developing sources of geologic aggregate, and delineation of geologic hazards. Surficial deposits in the Flatbrookville quadrangle are lithologically diverse, cover most of the bedrock surface, and are found in many types of landscape settings. They include glacial drift of late Wisconsinan age and alluvium, swamp and bog deposits, hillslope deposits, and wind-blown sediment laid down in postglacial time. These deposits may be as much as 200 feet (61 m) thick and they form the parent material on which soils form. They are defined by their lithic characteristics, stratigraphic position, location on the landscape, and further delineated by genetic and morphologic criteria. Geologic history, detailed observations on surficial materials, figures, tables, and a list of references are found in the accompanying booklet.

DESCRIPTION OF MAP UNITS

Map units denote unconsolidated deposits more than 5 feet (1.5 m) thick. Color designations are based on Munsell Soil Color Charts (1975), and were determined from naturally moist samples. Numbered stream-terrace deposits indicate relative ages of units based on heights of terraces in valley.

Postglacial Deposits

af Artificial fill (Holocene) -- Rock waste, soil, gravel, sand, silt, and manufactured materials put in place by man. As much as 25 feet (8 m) thick. Not shown beneath roads, and railroads where it is less than 10 feet (3m) thick. Primarily used to raise the land surface, construct earthen dams, and form a soild base for roads and railways.

Qal Alluvium (Holocene) -- Stratified, moderately- to poorly-sorted sand, gravel, silt, and minor clay and organic material deposited by the Delaware River and its tributaries. Locally bouldery. As much as 25 feet (8 m) thick. Includes planar- to cross-bedded gravel and sand, and cross-bedded and rippled sand in channel deposits, and massive and parallel-laminated fine sand, and silt in flood-plain deposits. May be interlayered with silty to silty-sandy diamicton (interpreted as a colluvium) in the upper parts of drainages.

Qaf Alluvial-fan deposits (Holocene and late Wisconsinan) -- Stratified, moderately to poorly sorted sand, gravel, and silt in fan-shaped deposits. As much as 35 feet (11 m) thick. Includes massive to planar-bedded sand and gravel and minor cross-bedded channel-fill sand. Beds dip as much as 30° toward the trunk valley. Stratified sediment is locally interlayered with poorly sorted, sandy-silty to sandy gravel. Typically graded to postglacial terraces or the modern floodplain. More rarely graded to glacial outwash terraces. Most fans are dissected by modern streams.

Qst **Qst2** **Qst3** Stream-terrace deposits (Holocene and late Wisconsinan) -- Stratified, well- to moderately-sorted, massive to laminated, and minor cross-bedded fine sand, and silt as much as 20 feet (6 m) thick, overlying planar to cross-bedded pebbly sand and gravel as much as 10 feet (3 m) thick in terraces flanking present and late postglacial stream courses. In Minisink Valley (Delaware River valley) deposits form two distinct terraces. The youngest (Qst2) flanks recent and late postglacial stream courses and overlies early to late postglacial fluvial gravel and sand. It lies 20 to 35 feet (6 to 11 m) above the mean annual elevation of the Delaware River and chiefly consists of as much as 20 feet (6 m) of fine sand and silt overlying as much as 10 feet (6 m) of pebble gravel and sand. The oldest (Qst3) flanks late glacial and early postglacial stream courses and overlies glacial outwash and early postglacial fluvial sand and gravel. It lies 40 to 50 feet above the river and consists of as much as 10 feet of fine sand and medium sand. Subscript "a" indicates elevation of terrace is slightly lower than similar nearby terraces. This lower substage has not been shown to be correlative throughout Minisink Valley at map scale. The lower elevation may be due to erosion or differences in local depositional conditions.

Qs Swamp and Bog deposits (Holocene and late Wisconsinan) -- Dark brown to black peat, partially decomposed remains of mosses, sedges, trees and other plants, and muck underlain by laminated organic-rich silt and clay. Accumulated in kettles, shallow postglacial lakes, poorly-drained areas in uplands, and hollows in ground moraine. As much as 25 feet (8 m) thick. Locally interbedded with alluvium and thin colluvium.

Qta Talus deposits (Holocene and late Wisconsinan) -- Unsorted, nonstratified, angular boulders as much as 15 feet (4 m) long, cobbles, and smaller fragments of quartzite and quartz-pebble conglomerate forming aprons over rock and till at the base of bedrock cliffs and steep hillslopes on Kittatinny Mountain. As much as 20 feet (6 m) thick.

Qsc Shale-chip colluvium (Holocene and late Wisconsinan) -- Thin to thickly bedded, noncompact, poorly sorted light yellowish-brown (10YR 6/4) to brownish-yellow (10YR 7/6) or light olive-brown (2.5Y 5/2) framework supported, shale-chip gravel, containing as much as 80 percent unweathered to lightly weathered angular to subangular shale chips, and minor tabular pebbles and cobbles of siltstone, and sandstone. Interstitial material consists of silty sand. Forms aprons below cliffs and some steep slopes on the west side of Minisink Valley; as much as 20 feet (3 m) thick. Beds dip as much as 25° toward valley. In places the distal (downslope) beds are interlayered with wind-blown sand and alluvium. Graded to glacial and postglacial stream terraces in valley.

Glacial Deposits

Stratified Materials

Qv Valley-train deposits (late Wisconsinan) -- Stratified, well- to moderately-sorted sand, boulder-cobble to pebble gravel, and minor silt deposited by meltwater streams at and extending well beyond (greater than five miles (8 km)) the glacier's margin. As much as 100 feet (30 m) thick. The proximal part of the deposit consists of massive to horizontally-bedded and imbricated coarse gravel and sand, and planar to tabular and trough cross-bedded, fine gravel and sand in bars, and channel-lag deposits with minor cross-bedded sand in channel-fill deposits. Clasts generally are smaller downstream, sand is more abundant, and trough and planar cross-bedding, and graded beds are more common. Based on well records (table 2, in booklet) overlies glacial lake deposits previously laid down in sediment-dammed proglacial lakes. In places overlain by nonlayered, well-sorted, very fine sand and fine sand presumed to be eolian; as much as 5 feet (2 m) thick. In Minisink Valley forms shingled sets of outwash terraces.

Qfbc **Qftc** Outwash-fan deposits (late Wisconsinan) -- Stratified, well- to moderately-sorted sand, cobble-pebble gravel, and minor silt deposited by meltwater streams in fan-shaped deposits at the mouth of large tributaries in Minisink Valley. As much as 60 feet (18 m) thick. Includes massive to planar-bedded sand and gravel, and minor cross-bedded and channel-fill sand. Bedding generally dips towards the trunk valley by as much as 10°. Fan deposits are graded to valley-train deposits.

Qd **Qod** Glacial-lake delta deposits (late Wisconsinan) -- Stratified, sand, gravel, and silt deposited by meltwater streams in proglacial lakes at and beyond the stagnant glacier margin. Includes well sorted sand and boulder-cobble to pebble gravel in planar to cross-bedded glaciofluvial topset beds that are as much as 25 feet (8 m) thick. Overlies and grades into foreset beds that dip 20° to 35° basinward and consist of well- to moderately-sorted, rhythmically-bedded cobble-pebble and pebble gravel and sand. These beds grade downward and outward into ripple cross-laminated and parallel-laminated, sand, silt and pebble gravel that dip less than 20°. Lower foreset beds grade into gently inclined prodelta bottomset beds of rhythmically-bedded, ripple cross-laminated to graded fine sand and silt with minor clay drapes. Thickness may be as much as 100 feet (30 m). Qd deposits were laid down in small ice-dammed lakes in tributaries of the Paulins Kill. Qod deposits were laid down in narrow sediment-dammed proglacial lakes in Paulins Kill and Wallpack Valleys. Deposits are extensively kettled. In long, narrow lake basins, topset beds are extensively aggraded in their upstream sections.

Qlf Lacustrine-fan depposits (late Wisconsinan) -- Stratified, sand, gravel, and silt deposited by meltwater streams in proglacial lakes at and beyond the stagnant glacier margin. Consists of foreset beds that dip 20° to 35° basinward and consist of well- to moderately-sorted, rhythmically-bedded cobble-pebble and pebble gravel and sand. These beds grade downward and outward into ripple cross-laminated and parallel-laminated sand, silt and pebble gravel that dip less than 20°. Lower foreset beds grade into gently inclined prodelta bottomset beds of rhythmically-bedded, ripple cross-laminated to graded fine sand and silt with minor clay drapes. Thickness may be as much as 100 feet (30 m). Interpreted to have been deposited at the mouth of a glacial meltwater tunnel. In places deposits are extensively collapsed indicating their deposition over and against stagnant ice. Differentiated from deltas by their lack of topset beds.

Qlb Glacial lake-bottom deposits (late Wisconsinan) -- Parallel-laminated, irregularly to rhythmically-bedded silt, clay, and very fine sand; and minor cross-laminated silt, fine sand, and minor clay deposited on the floor of glacial lakes chiefly by density currents and settling of fines. As much as 100 feet (30 m) thick. In subsurface only, thick deposits beneath Qs deposits and modern lakes in glacial Lake Owassa basin, Kittatinny Valley. Thin deposits presumed to be in subsurface in Paulins Kill, Wallpack, and Minisink Valleys.

Qmt Meltwater-terrace deposits (late Wisconsinan) -- Stratified, well- to moderately-sorted sand, cobble-pebble to pebble gravel, and minor silt deposited by meltwater streams as terraces incised in valley-train, glacial lake delta deposits, and other meltwater-terrace deposits. As much as 20 feet (6 m) thick. Sediment and bedforms similar to the downstream, distal part of valley-train deposits. Includes bouldery strath terraces cut in till along meltwater stream courses in uplands. May also include the distal part of valley-train deposits where they have cut into older valley-train deposits downvalley.

Qk Kame (late Wisconsinan) -- Stratified, well- to poorly-sorted sand, boulder- to pebble-gravel, silt, and interbedded flowtill in small collapsed hills and ridges overlying till. Presumed to be ice-hole and crevasse fillings. As much as 50 feet (15 m) thick. Attitude of bedding is highly variable.

Non-stratified Materials

Till (late Wisconsinan) -- Scattered patches of noncompact to slightly compact, bouldery "upper till" overlying a blanket-like compact "lower till" deposited chiefly on bedrock and locally some older pre-Wisconsinan surficial deposits. Includes two varieties:

Qtk **Qtkr** 1) Compact, unstratified, poorly sorted yellowish-brown (10YR 5/4), light yellowish-brown (2.5Y 6/4), light olive-brown (2.5Y 5/4) to grayish-brown (2.5Y 5/2), gray (5Y 5/1) to olive-gray (5Y 5/2) noncalcareous to calcareous silt and sandy silt that typically contains 5 to 15 percent gravel. As much as 200 feet (61 m) thick. Locally overlain by thin, discontinuous, non-compact to slightly compact, poorly sorted, indistinctly layered yellow-brown (10YR 5/6-8), light yellowish-brown (10YR 6/4) sandy silt that contains as much as 30 percent gravel, and minor thin beds of well- to moderately sorted sand, gravel, and silt. Clasts chiefly consist of unweathered slate, siltstone and sandstone, dolomite, limestone, chert, minor quartzite, and quartz-pebble conglomerate. Matrix is a varied mixture of unweathered quartz, rock fragments, and silt; minor constituents include feldspar and clay. Till derived chiefly from slate, graywacke, dolomite, and minor limestone bedrock in Kittatinny Valley, and limestone, argillaceous limestone, shale, and sandstone bedrock in Minisink Valley. "r" denotes areas of till generally less than 10 feet thick (3 m) with few to some bedrock outcrops.

Qtq **Qtqr** 2) Slightly compact to compact, unstratified, poorly sorted yellowish-brown (10YR 5/4), brown (10YR 5/3, 7.5 YR 5/4) to light olive-brown (2.5Y 5/4) and reddish-brown (5YR 4/3) silty sand and sand containing 10 to 20 percent gravel. As much as 50 feet (15 m) thick. Locally overlain by thin, discontinuous, non-compact, poorly sorted and layered, sand and minor silty sand, similar in color to lower till, that contains as much as 35 percent gravel, and minor thin beds of well- to moderately-sorted sand and pebbly sand. Clasts chiefly consist of unweathered quartz-pebble conglomerate, quartzite, red sandstone, and red shale. Matrix is a varied mixture of quartz, rock fragments, silt, minor feldspar, and clay. Till derived chiefly from quartzite, quartz-pebble conglomerate, and red sandstone bedrock on Kittatinny Mountain. "r" denotes areas of till generally less than 10 feet thick (3 m) with few to some bedrock outcrops.

Qmbm **Qfgm** **Qflm** Recessional moraine (late Wisconsinan) -- Unstratified to poorly stratified sand, gravel, and silt deposited at the active margin of the Kittatinny and Minisink Valley ice lobes. As much as 80 feet (24 m) thick. Consists of poorly compact, stony till, silty-sandy compact till, and minor lenses and layers of water-laid sand, gravel, and silt, in discontinuous, bouldery, chiefly cross-valley segmented ridges marking the former lobate glacier margin. Overlies "lower till" in uplands and locally outwash in river valleys. Locally named Millbrook Village (Qmbm), Franklin Grove (Qfgm), and Fairview Lake moraines (Qflm).

Pre-Wisconsinan glacial deposits

Qi?t Pre-Wisconsinan drift (Illinoian ?) -- Unstratified to poorly stratified sand, gravel, and silt; presumably Illinoian till. Shown only in subsurface on cross-section beneath late Wisconsinan drift.

Bedrock

r Bedrock -- Extensive outcroppings, minor regolith, and scattered erratics.

sr Bedrock -- Regolith; chiefly rock waste on steep hillslopes and ridge crests, minor talus, scattered erratics, and a few small outcrops.

Explanation of Map Symbols

Contact, dashed where approximately located or gradational.

Striation, measurement at tip of arrow. Multiple striations show two well de ned directions of ice ow with the more westerly direction the youngest.

Drumlin, line on crest, ellipse on summit.

Meltwater channel.

875' Glacial-lake spillway with estimated elevation of its oor.

Alluvial channel scroll.

Inactive sand and gravel pit.

Inactive quarry.

17 Pebble-count sample location, composition listed in Table 1 (accompanying booklet).

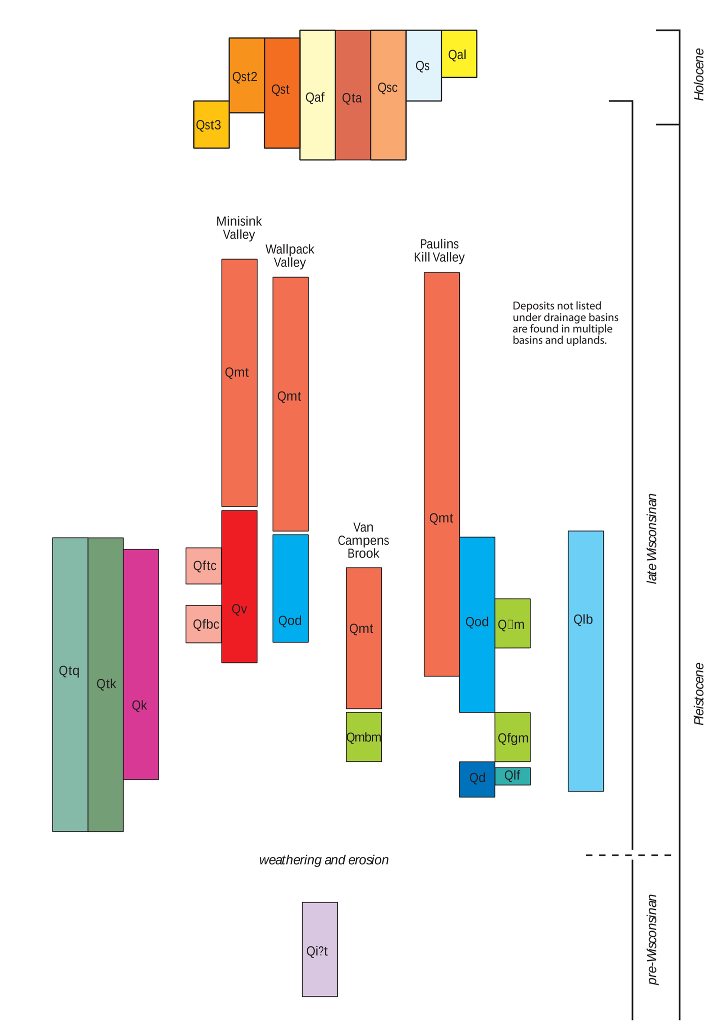
39 Well location, geologic record listed in Table 2 (accompanying booklet).

400 Bedrock-surface contour beneath valley ll. Contour interval 50 feet.

well 47 Well location on cross-section. Geologic record listed in Table 2 (accompanying booklet).

ns Nephelene syenite erratic.

Correlation of Map Units



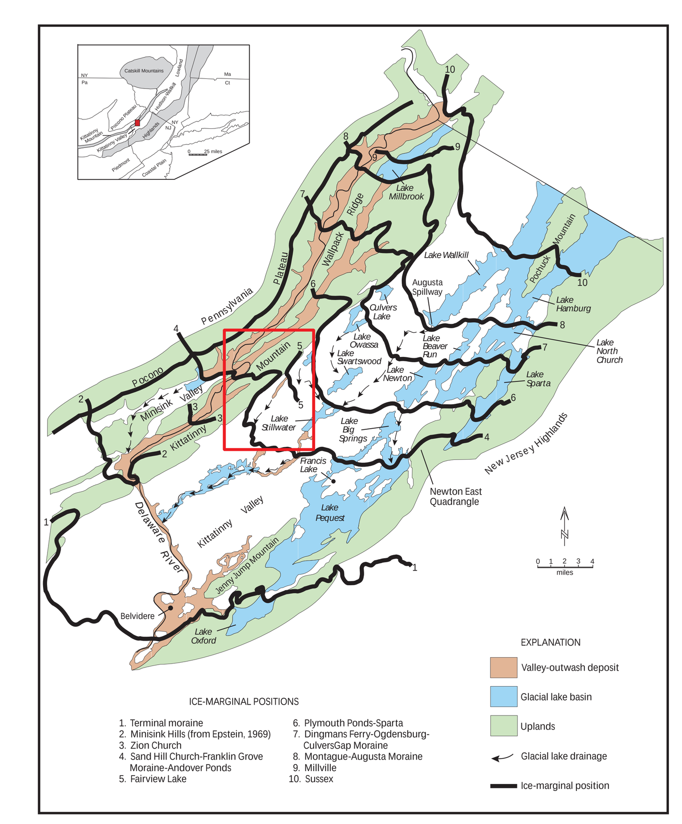


Figure A. Physiography of Kittatinny Valley and surrounding area. Late Wisconsinan ice-margin positions of the Kittatinny and Minisink Valley ice lobes, and location of large glacial lakes, extensive valley-outwash deposits, and Flatbrookville 7.5-minute topographic quadrangle. Modified from data by Crowl (1971), Epstein (1969), Minard (1961), Ridge (1983), and Witte (1997).

Figure B. Downstream section of Wallpack Bend looking southwest from the confluence with Flat Brook. The Delaware River flows from right to left in photo. This large s-shaped meander may have formed during an early glaciation when the Echo Lake Lowland became blocked by outwash during deglaciation. Meltwater, which could no longer flow down the old course of the Delaware River, diverted through a low col across Wallpack Ridge into a preglacial valley cut by Flat Brook, establishing its present course.

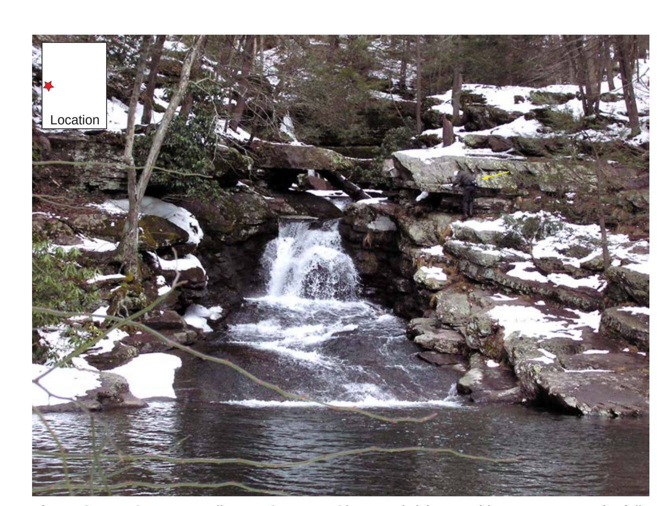
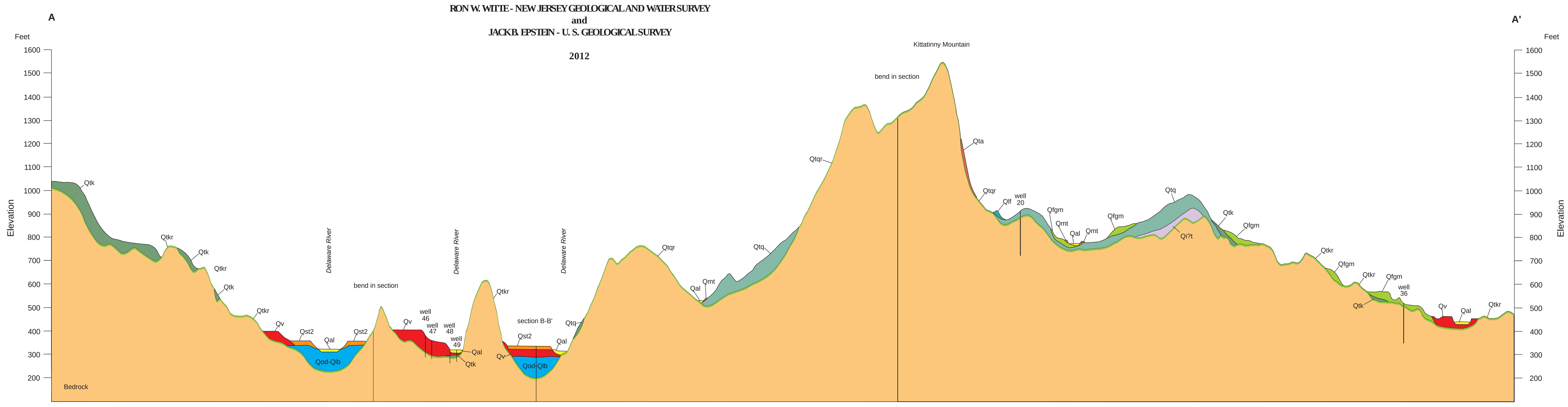
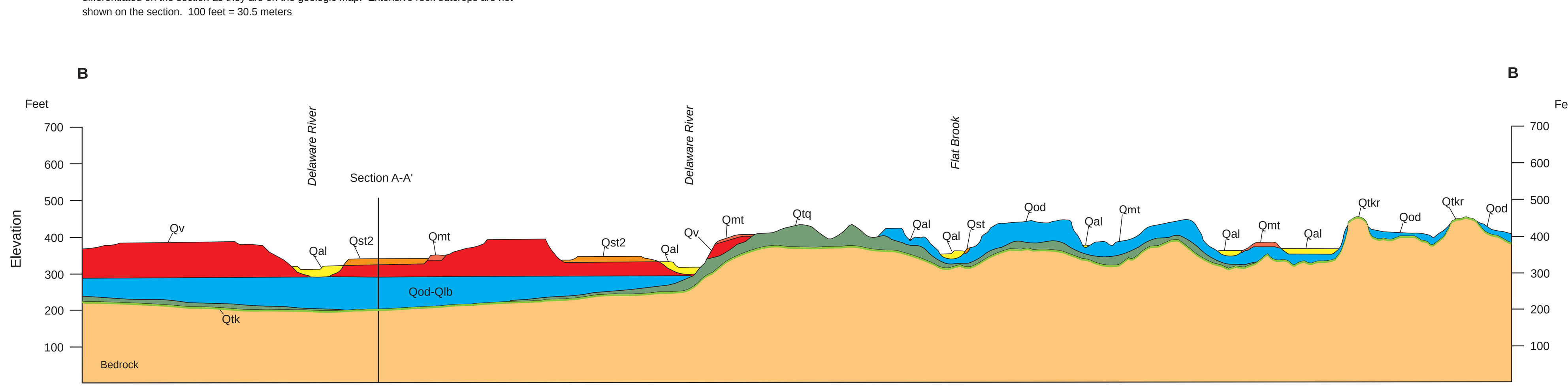


Figure C. Van Campens Falls, Van Campens Glen, Hardwick Township, New Jersey. The falls consists of low cascades and glides over southeast dipping beds of shale, siltstone, and sandstone of the High Falls Formation. The falls are located about 4000 feet (1.2 km) upstream from the Delaware River valley. The upstream migration of the falls, a process called knick-point retreat, is related to the lowering of base level in the Delaware Valley by glacial erosion. The thick notched bed above the geologist (yellow arrow) is the former lip of a higher cascade that has since been breached by postglacial erosion.

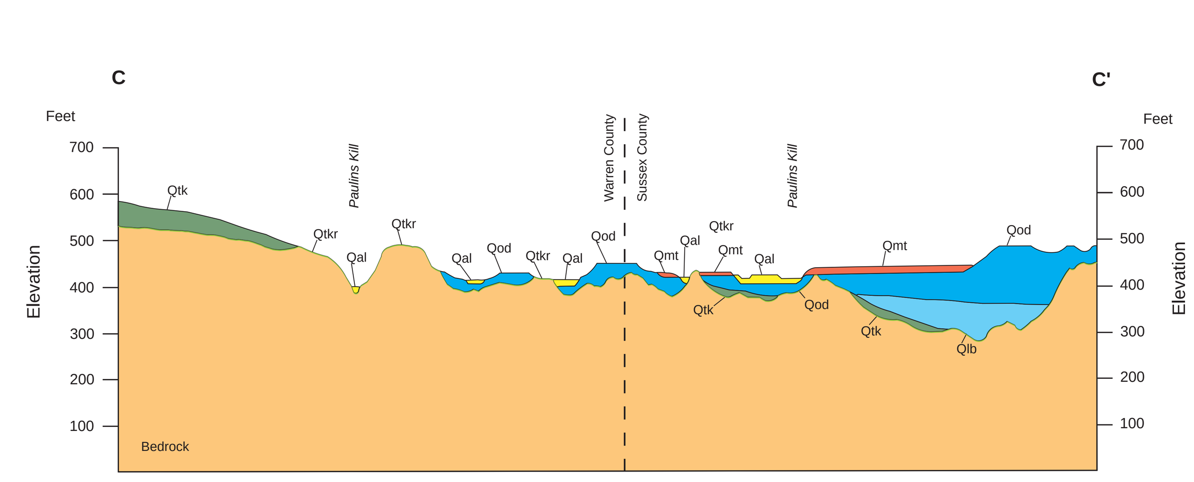
Figure D. Cemented cobble-pebble gravel outwash (Qod) just north of Flatbrookville along the west side of County Route 615 overlying limestone of the Rondout Formation.



Vertical exaggeration = 8. Thin till (Qtqr and Qtkr) are shown by a thick green line and are not differentiated on the section as they are on the geologic map. Extensive rock outcrops are not shown on the section. 100 feet = 30.5 meters



Vertical exaggeration = 8
Extensive rock outcrops in areas mapped as Qtqr and Qtkr are not shown on section
100 feet = 30.5 meters



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NEW JERSEY GEOLOGICAL AND WATER SURVEY
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Booklet accompanies Surficial Geologic Map of the Flatbrookville Quadrangle (one Plate, part of GMS 12-1)

Prepared in cooperation with the U.S. Geological Survey National Geologic Mapping Program

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Cover photo: View from Wallpack Ridge near Flatbrookville, Sussex County, New Jersey looking northwest across Minisink Valley. Photograph by Ron W. Witte, 2005.

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INTRODUCTION

The Flatbrookville quadrangle lies in the glaciated part of the Valley and Ridge physiographic province in Sussex and Warren Counties, northwestern New Jersey, and Pike and Monroe Counties, northeastern Pennsylvania. Main geographic features in the quadrangle are Kittatinny, Minisink, and Wallpack Valleys, Wallpack Ridge and Kittatinny Mountain (fig. 1). The Delaware River, which separates New Jersey from Pennsylvania, flows southwest in Minisink Valley largely through the Delaware Water Gap National Recreational Area. The highest point is 1606 feet (490 m) above sea level on the crest of Kittatinny Mountain, and the lowest point lies on the Delaware River, approximately 310 feet (95 m) above sea level.

Surficial materials include glacial deposits of till and outwash deposited during the late Wisconsinan glaciation, and postglacial deposits of alluvium, colluvium, talus, organic soil, and wind-blown sediment. These materials are as much as 200 feet (61 m) thick, lie on bedrock, and are the parent material on which soils form. The glacial deposits are correlative with the Olean Drift in northeastern Pennsylvania (Crowl and Sevon, 1980). Till is generally less than 20 feet (6 m) thick and covers bedrock in most places. In some areas, bedrock outcrops are abundant and most of these exhibit signs of glacial erosion. Thicker till forms aprons on the north-facing hillslopes, drumlins, and ground moraine. Outwash laid down at and beyond the glacier margin lies in stream valleys through which Paulins Kill, Blair Creek, Flat Brook, Trout Brook, Van Campens Brook, and the Delaware River now flow. The ice-contact heads of these deposits and the Franklin Grove moraine mark ice-recessional positions of Kittatinny Valley and Minisink Valley ice lobes.

PREVIOUS INVESTIGATIONS

Cook (1877, 1878, 1880) discussed the geology of surficial deposits in Sussex and Warren Counties, New Jersey, in a series of Annual Reports to the State Geologist. He included detailed observations on the terminal moraine, recessional moraines, ages of drift, distribution and kinds of drift in Kittatinny Valley, and evidence of glacial lakes. Shortly thereafter, White (1882) described the glacial geology of Pike and Monroe Counties, Pennsylvania, and a voluminous report by Salisbury (1902) detailed the glacial geology of New Jersey, region by region. The terminal moraine (fig. 2) and all surficial deposits north of it were interpreted to be products of a single glaciation of Wisconsinan age. Salisbury also noted that "in the northwestern part of the state, several halting places of ice can be distinguished by the study of successive aggradation plains in the valleys." In Pennsylvania, Leverett (1934) also assigned a Wisconsinan age to the terminal moraine and the glacial drift north of it. Crowl and Sevon (1980) and Cotter and others (1986) also indicated the youngest glacial deposits in eastern Pennsylvania and northwestern New Jersey are late Wisconsinan age. Crowl (1971), Ridge (1983), Witte (1988), and Sevon and others (1989) produced surficial geologic maps of parts of the Flatbrookville quadrangle, and Witte (1997, 2001b) described the glacial history for the upper part of Kittatinny Valley and Minisink Valley.

PHYSIOGRAPHY AND BEDROCK GEOLOGY

The Flatbrookville quadrangle (base map, pl. 1) lies entirely within the Delaware River drainage basin (fig. 1). The Delaware River, the master stream in this area, flows southwestward from Port Jervis, New York, to Wallpack Bend following the trend of shale and limestone through Minisink Valley. At Wallpack Bend, the river follows a large meander that cuts through Wallpack Ridge. It is also joined here by the Bush Kill in Pennsylvania and Flat Brook in New Jersey. Van Campens Creek, which drains part of Kittatinny Mountain, joins the Delaware River west of the quadrangle. In Kittatinny Valley, the Paulins Kill flows southwestward to the Delaware River, generally following a course that overlies dolomite. Its tributaries include Jacksonburg Creek, Blair Creek, and Trout Brook. Most of the Delaware River's tributaries form a modified trellis drainage pattern following the southwest structure and cross joints of the local rock formations. In places this pattern is overprinted or replaced by a dendritic one that has formed over thick unconsolidated deposits of late Wisconsinan age.

Kittatinny Valley is a broad northeast-to-southwest-trending lowland underlain by the Allentown Formation (dolomite), the Beekmantown Formation (dolomite), the Jacksonburg Formation (limestone), and the Martinsburg Formation (slate, siltstone, and sandstone) (fig. 3). Dolomite underlies Paulins Kill valley and relief there is as much as 200 feet (61 m). Rock outcrops are very abundant and karst topography is commonplace. Slate, siltstone, and sandstone underlie the area between Paulins Kill valley and Kittatinny Mountain. Overall, the average elevation here is about 300 feet (91 m) higher than the carbonate-floored valleys, and relief may be as much as 400 feet (122 m). Topography consists of undulant hills of moderate to steep slopes and many strike-parallel ridges streamlined by glacial erosion. In many places, bedrock is deeply buried beneath drumlins and thick ground moraine.

Kittatinny Mountain forms a prominent continuous ridge (inset map, fig. 1) from the Shawangunk Mountains in New York southwestward through New Jersey into Pennsylvania. In places, its continuity is broken by gaps, such as Culvers Gap and Delaware Water Gap. The mountain is divided into two distinctive physiographic areas. The first is the "high ridge" area that forms

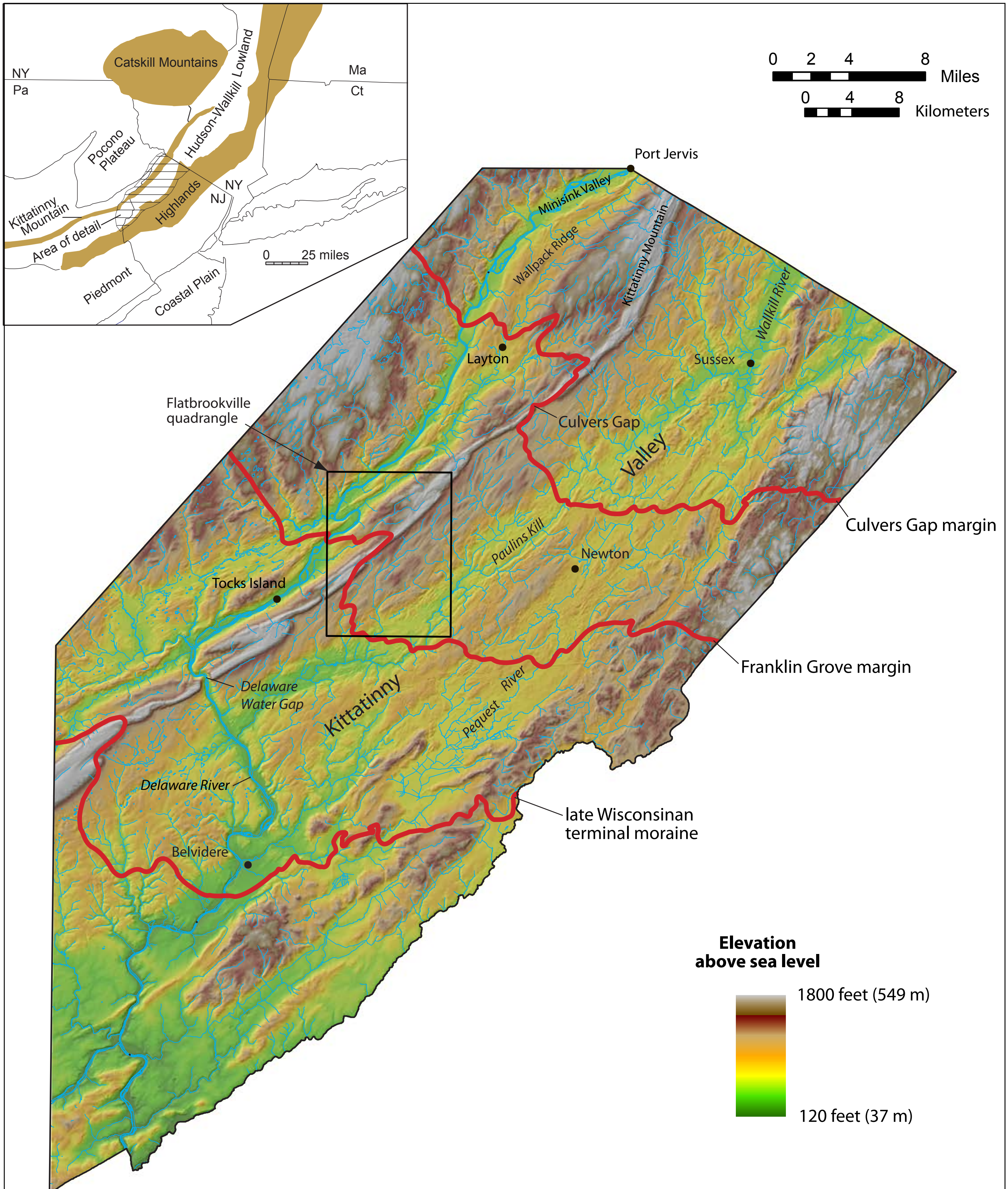

Figure 1. Physiography of northwestern New Jersey and part of northeastern Pennsylvania and location of the Flatbrookville quadrangle. Kittatinny Valley is a local geographic name for the southwest continuation of the Hudson-Wallkill lowland.

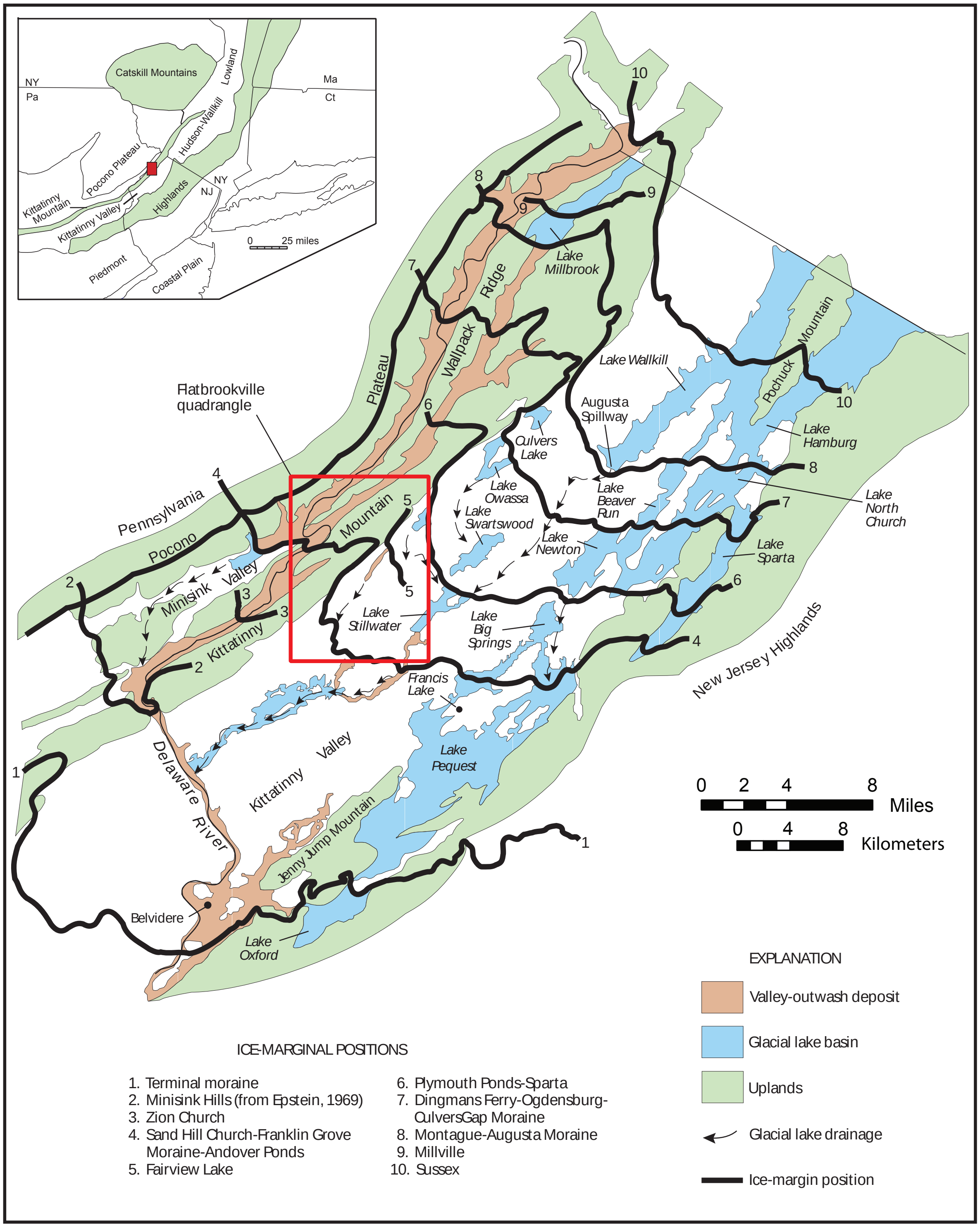

Figure 2. Late Wisconsinan ice margins of the Kittatinny and Minisink Valley ice lobes, and location of large glacial lakes, extensive valley-outwash deposits, and Flatbrookville 7.5-minute topographic quadrangle. Modified from data by Crowl (1971), Epstein (1969), Minard (1961), Ridge (1983), and Witte (1997).

the eastern part of the mountain. It is held up by the Shawangunk Formation, a quartz-pebble conglomerate and quartzite unit of Silurian age that is very resistant to erosion (fig. 3). Outcrops, most smoothed by glacial erosion, are abundant. Topography is rugged, consisting of steep-sided, parallel, narrow- to broad-crested ridges that trend southwest following the main trend of the mountain. The mountain's steep southeast face forms a nearly continuous escarpment in New Jersey. The second area, which lies on the western part of the mountain, is underlain by the Bloomsburg Red Beds (fig. 3), an interlayered red shale and red sandstone. Topography is moderate, chiefly formed by low relief, strike-parallel ridges. Bedrock exposures are fewer because of thick till cover.

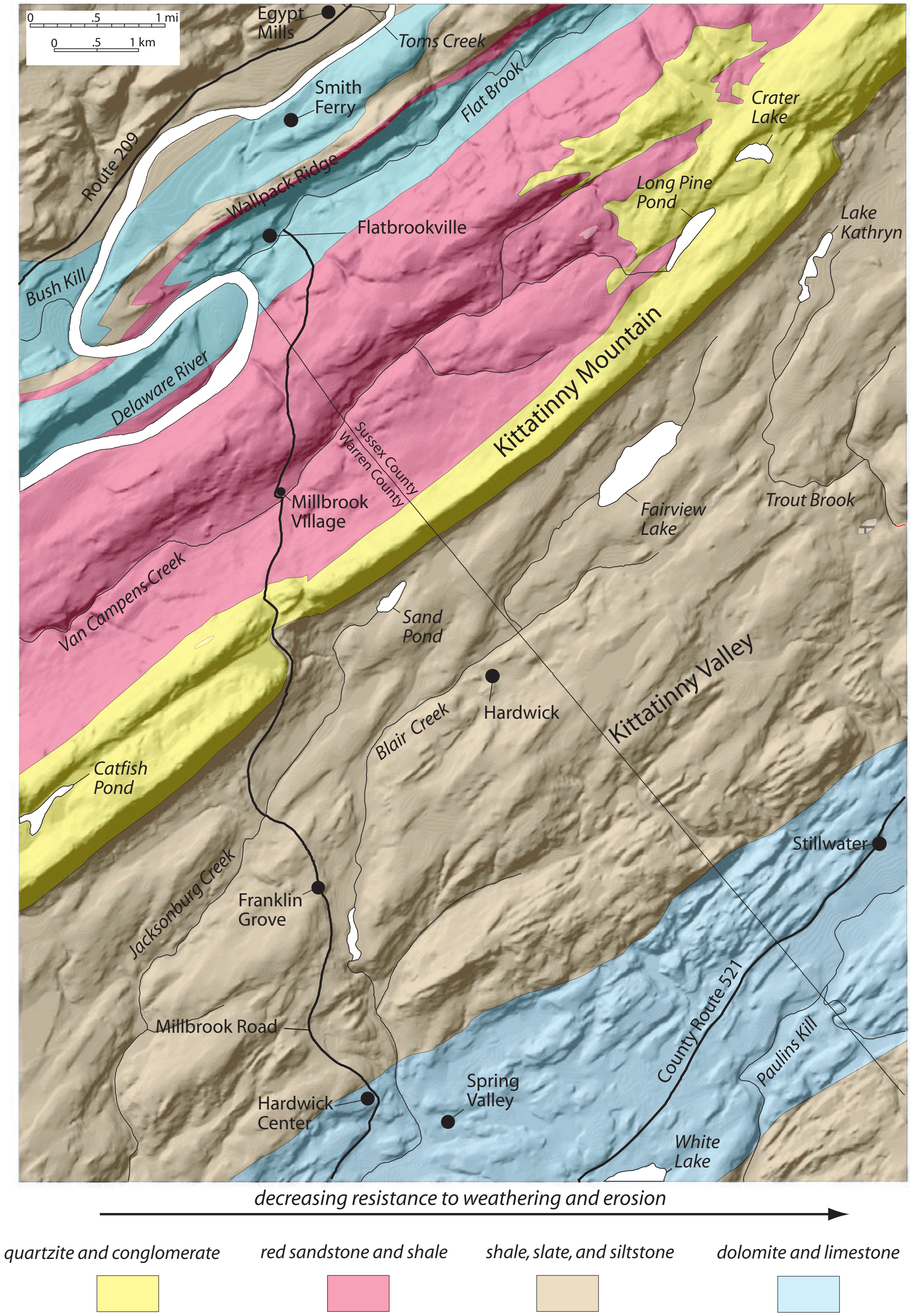

Figure 3. Simplied bedrock geologic map of the Flatbrookville quadrangle. Correlation to bedrock formations discussed in text. Kittatinny Valley: Allentown, Beekmantown, and Jacksonburg Formations (dolomite and limestone); Martinsburg Formation (slate and siltstone). Kittatinny Mountain: Shawangunk Formation (quartzite and conglomerate); Bloomsburg Red Beds (red sandstone and shale). Minisink Valley, Wallpack Valley, and Wallpack Ridge: Undifferentiated Silurian and Devonian formations divided into limestone, dolomite, shale, siltstone and sandstone. Bedrock map modified from Drake and others (1996).

Wallpack Valley (informal name for Flat Brook valley), Minisink Valley, and Wallpack Ridge lie northwest of Kittatinny Mountain (fig. 1). Bedrock (fig. 3) consists of thin Silurian and Devonian strata that dip gently to moderately northwest (Drake and others, 1996; Sevon and others, 1989). Minisink and Wallpack Valleys are narrow, deep, and trend southwest following belts of weaker rock. High cliffs of shale and siltstone border the western side of Minisink Valley. The valleys were also the former sites of a planned hydroelectric and water storage project by the Army Corps of Engineers. A presently deauthorized dam, constructed at Tocks Island (fig. 1), would have flooded Minisink Valley upstream to Port Jervis, New York, and Wallpack Valley upstream to Layton. The reservoir would have provided a storage capacity of 133.6 billion gallons (Corps of Engineers, 1967).

Wallpack Ridge (fig. 1) separates Minisink and Wallpack Valleys. It is held up by thinly-bedded sandstone, siltstone, and some limestone, rising as much as 300 feet (91 m) above the adjacent valley floors.

PREGLACIAL DRAINAGE

The overall drainage pattern of the study area has probably not significantly changed since the middle Pleistocene. The low position of Illinoian outwash in the Delaware River valley (Witte and Stanford, 1995) shows that the Delaware River and its larger tributaries have occupied nearly the same course for at least the last 130,000 years. In contrast, pre-Illinoian glacial outwash, which is estimated to be older than 800,000 years (Stone and others, 2002), lies 100 to 150 feet above the floor of the Delaware River valley and only in areas that have been protected from fluvial and hillslope erosion. Braun (1989) in eastern Pennsylvania has shown that there has been as much as 300 feet (91 m) of incision in major stream valleys throughout the Pleistocene. Given the constraints on paleogeography of the Delaware River since the Illinoian glaciation and amount of Pleistocene incision, major changes in drainage in the vicinity of the study area would have occurred during the early part of the Pleistocene or earlier during the Pliocene or Late Miocene.

Based on the above observations, the large meander at Wallpack Bend is probably early Pleistocene age, the result of derangement of the Delaware River during a pre-Illinoian glaciation. Analysis of topography around Wallpack Bend suggests that time the Delaware River may have flowed southwestward through the Echo Lake lowland toward Brodhead Creek valley, where it turned back to the southeast towards the Delaware Water Gap (fig. 4). The Delaware River may have also cut through Wallpack Ridge at North Water Gap, or along the valley now drained by Shawnee Creek; both courses are slightly more northward than the Brodhead Creek course. At the same time the Wallpack River, which followed a parallel course to the Delaware River, flowed through the valley that lies on the southeast side of Wallpack Bend, joining the Delaware River just north of the Delaware Water Gap (fig. 4).

Given the above hydrographic setting, it is rather unlikely that the Wallpack River could capture the Delaware River at Wallpack Bend by stream piracy. A more likely scenario is that the change in its course at Wallpack Bend was caused by derangement related to the damming of the Echo Lake lowland by glacial drift in pre-Illinoian time. There is ample evidence that the Delaware River has shifted its course in other places during the Pleistocene. Buried-bedrock contours in the vicinity of Belvidere in Warren County (Witte and Stanford, 1995) showed that some reaches of the river changed course when glacial sediment, deposited earlier downvalley, diverted drainage.

As previously shown, the effects of glaciation can change the course of streams. However, in the case of Wallpack Bend, there must have been a pre-existing col in Wallpack Ridge that was lower than the drift-filled Echo Lake lowland at the time of the diversion. Although the Delaware River flows over alluvium and glacial outwash throughout Wallpack Bend, its course generally parallels the folded structure of the local bedrock (fig. 3). This course may have been inherited from its past when, during the initial phase of the bends formation, the river flowed over rock.

Based on the estimated elevation of the bedrock surface divide in Marshalls Creek valley (400 feet (122 m) above sea level), it is postulated that the initial diversion of the Delaware River across Wallpack Ridge occurred in pre-Illinoian time. The large volume of meltwater that flowed across the ridge accelerated the erosion of the newly cut rock channel to a point where the Delaware River permanently shifted its course into the valley formerly occupied by the Wallpack River.

GLACIAL DEPOSITS

Till

Till typically covers most of the bedrock surface and it is widely distributed throughout the quadrangle. It is generally less than 20 feet (6 m) thick, and its surface expression is generally controlled by the shape of the underlying bedrock surface. Extending through this cover are numerous unweathered to lightly weathered bedrock outcrops. Thicker, more continuous till subdues bedrock irregularities and in places completely masks them. Very thick till forms drumlins, aprons on north-facing hillslopes, and ground moraine. It also fills narrow preglacial valleys, especially those oriented tranverse to glacier flow.

Till consist of two parts, a lower and an upper. Lower till is typically compact silt to silty sand containing as much as 15 percent pebbles, cobbles, and boulders. Clasts are subangular to subrounded, faceted, and striated. Presumably this material is lodgement till. Overlying this is a thin, discontinuous, noncompact, poorly sorted silty sand to sand containing as much as 35 percent pebbles, cobbles, boulders, and interlayered with lenses of sorted sand, gravel, and silt. Overall, clasts are more angular, and their fabrics lack a preferred orientation or have a weak orientation oblique to regional glacial flow (Witte, 1988). This material appears to be ablation till and flowtill, and it has not been mapped separately from the lower till due to its scant distribution and poor exposure. Also, cryoturbation and bioturbation have altered the upper few feet of all till, masking its original character by making it less compact, reorienting stone fabrics, and sorting clasts.

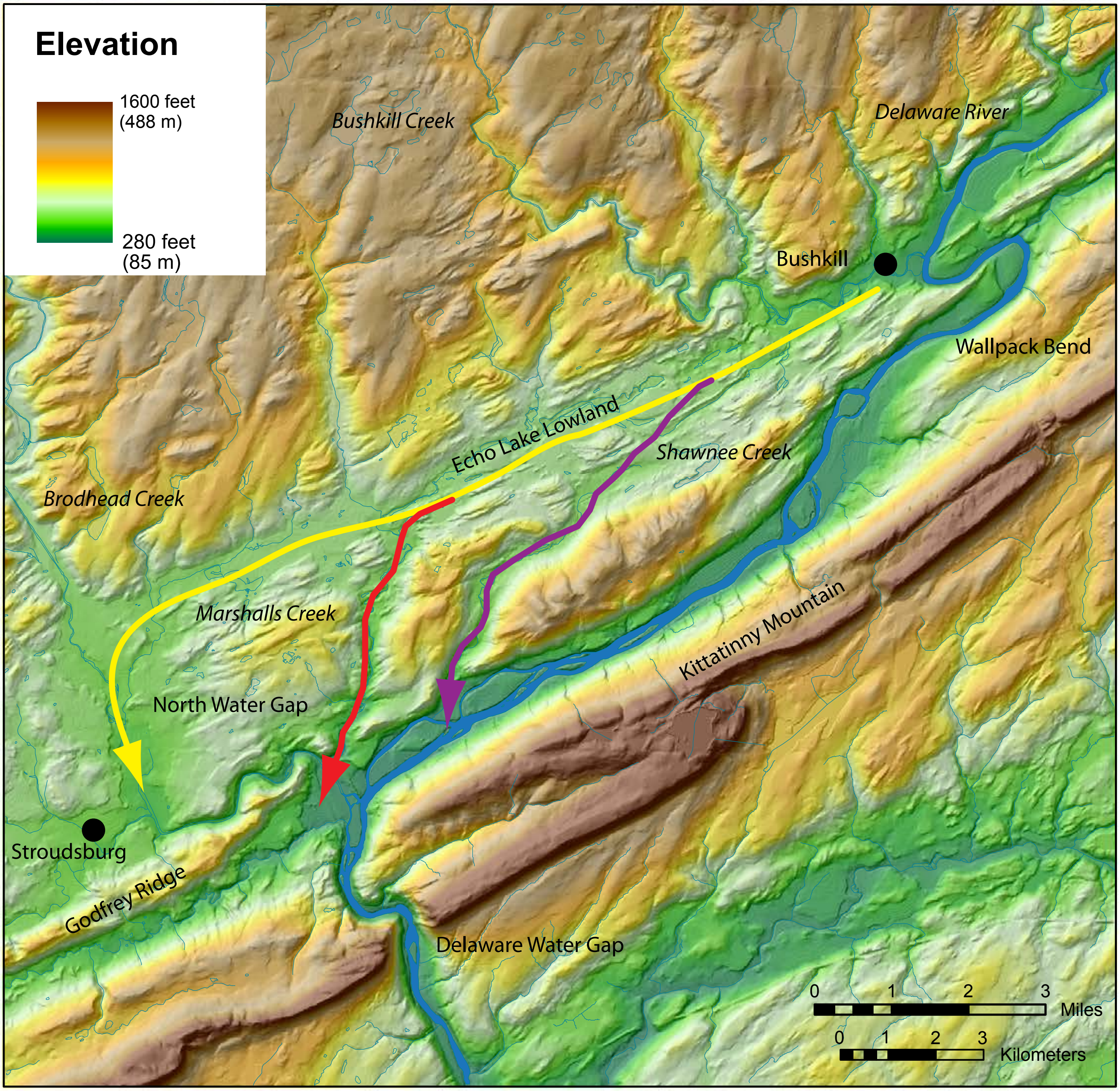

Figure 4. Possible courses of the ancestral Delaware River prior to the formation of Wallpack Bend. Diversion of the Delaware River into its modern course (shown by blue) occurred during the late Pliocene or early Pleistocene and was facilitated by glacial drift blocking drainage through the Echo Lake Lowland. The narrow width of Wallpack Ridge and folded Silurian and Devonian strata at Wallpack Bend formed a weak zone that was breached by meltwater flowing out of the Echo Lake Lowland. The Echo Lake Lowland - Broadhead Creek course (yellow) is the southwest continuation of the Delaware Valley upstream from Wallpack Bend. The North Water Gap (red) and Shawnee Creek courses (purple) are alternative paths that cut through the wider parts of Wallpack Ridge. Both valleys contain underfit streams suggesting they were cut by a much larger river; either the Delaware or one of its larger tributaries such as Bushkill Creek.

Till in the quadrangle has been divided lithologically into two types and they are informally called here lowland (Qtk) and upland (Qtq) till. Their mineralogy was dependent on the south to southwest direction of ice flow over narrow, southwest-trending belts of local sedimentary source rocks. Till in Kittatinny Valley (Qtk) was chiefly derived from slate, graywacke, dolostone, and limestone of Cambrian and Ordovician formations. In Minisink Valley and atop Wallpack Ridge, till (Qtk) was chiefly derived from limestone, shale, limey shale, siltstone, and sandstone of Devonian and Silurian age. On Kittatinny Mountain, till (Qtq) was chiefly derived from quartzite, quartz-pebble conglomerate, and red sandstone and shale of Silurian age that underlies Kittatinny Mountain. Due to the southward movement of the ice sheet across the mountain, this till (Qtq) also lies in a narrow belt along mountain's base in Kittatinny Valley, a position that overlies Ordovician shale and siltstone.

Drumlins

Drumlins are elongate hills of till that are found in two different settings. The first consists of multiple drumlins in areas underlain by very thick and widespread till. This includes a one-to-two mile (1.6 to 3.2 km) wide belt along the western side of Kittatinny Valley that is part of a much larger belt extending from the Delaware River northeastward to Culvers Lake (Witte and Epstein, 2004; Witte, 1988; Ridge, 1983). Well records (table 2) show that the glacial overburden in this setting is typically greater than 100 feet (30 m) thick, showing that most of these drumlins do not have a rock core. The trend of their long axes varies between S 25^o W to S 38^o W and crosscuts the more southwesterly trend of Kittatinny Valley. A few drumlins have a compound shape, suggesting that multiple directions of ice flow during the late Wisconsinan may have molded them. The second setting consists of solitary to few drumlins found among areas of thin till. These drumlins lie scattered throughout the quadrangle. Well records and rock outcrops near them suggest that most have a bedrock core.

Moraines

Morainal deposits (Qfgm, Qmbm, and Qflm) in the quadrangle make up the Franklin Grove, Millbrook, and Fairview Lake moraines. The Franklin Grove moraine marks a major recessional position of the Kittatinny Valley ice lobe (fig 2). It was first described by Salisbury (1902) and later named by Ridge (1983). The moraine trends northwestward from Spring Valley, through Franklin Grove, towards Sand Pond where it ends abruptly at the base of Kittatinny Mountain. The moraine does not continue across the mountain and is absent east of Spring Valley. However, it is correlative with Lake Pequest and Andover Ponds morphosequences situated farther east (Ridge, 1983; Witte, 1988, 1997), and with the Sand Hill Church deposits in Pennsylvania (Witte, 1997). Its course reflects the lobate margin of the Kittatinny Valley lobe, and this lobation is especially evident where it crosses stream valleys. The moraine consists of noncompact, stony till with minor stratified sand, gravel, and silt. Its morphology is highly variable; in places ridge-and-kettle or knob-and-kettle topography are well developed. Elsewhere, morainal topography is very subdued. Meltwater and postglacial streams have eroded the moraine where it crosses Blair Creek and Jacksonburg Creek Valleys. A small belt of faint hummocky ground near Millbrook Village, the Millbrook moraine, appears to be correlative to the Franklin Grove moraine based on tracing the lobate margins of the Kittatinny and Minisink Valley lobes. The Fairview Lake moraine lies on the western side of Fairview Lake and marks a minor recessional position of the Kittatinny Valley lobe (fig. 2). It is correlative with ice-contact deltas that lie to the east in the Paulins Kill, Pequest River, and Wallkill River valleys (Witte, 1997).

The lobate course of the Franklin Grove moraine and other recessional moraines in Kittatinny Valley, their morphology, and evidence of glacial readvance (Witte, 2001a, 1997) suggest they were formed by 1) the pushing or transport of debris and debris-rich ice by the glacier at its margin, and 2) penecontemporaneous and postdepositional sorting and mixing of material by mass movement, chiefly resulting from slope failure caused by melting ice, and collapse of saturated sediment. The source and mechanism of sediment transport are unclear. Most of the morainal material appears to be of local origin, but it is not known whether the glacier was simply reworking drift at its margin or was transporting sediment to the margin along shear planes (Koteff and Pessl, 1981). Inwash is not a viable mechanism because the larger deposits lie on mountains and ridges.

Deposits of Glacial Meltwater Streams

Sediment carried by glacial meltwater streams was chiefly laid down at and beyond the glacier margin in valley-train deposits (Qv), outwash-fan deposits (Qf), and ice-contact deltas (Qd, Qod) (fig. 5). Smaller quantities of sediment were deposited in meltwater-terrace deposits (Qmt), and in a few kames (Qk). Most of this material was transported by meltwater through englacial and subglacial tunnels to the glacier margin, and by meltwater streams draining deglaciated uplands adjacent to the valley (Witte, 1988; Witte and Evenson, 1989). Sources of sediment include till and debris from beneath the glacier and the glacier's basal dirty-ice zone, and till and reworked outwash in upland areas. Debris carried to the margin of the ice sheet by direct glacial action is a minor component.

Glaciofluvial sediments were laid down by meltwater streams in valley-train (Qv), outwash-fan (Qf), and meltwater-terrace deposits (Qmt). Delta topset beds of units Qd, and Qod are also glaciofluvial, but they are discussed in the following section on glaciodeltaic sediments. These sediments include cobbles, pebbles, sand, and minor boulders laid down in stream channels and sand, silt, and pebbly sand in minor overbank deposits. Sediment laid down near the glacier margin in valley-train deposits and delta-topset beds typically includes thickly-bedded, imbricated, planar coarse gravel and sand, and minor channel-fill deposits that consist largely of cross-stratified pebbly sand and sand. Downstream the overall grain size of the outwash decreases, sand is more abundant, and crossbedded and graded beds are more common. Outwash-fan deposits consist of gently inclined beds of planar to cross-bedded sand and gravel that form large fan-shaped deposits (similar to alluvial fans), at the mouth of tributary valleys. These deposits were laid down beyond the glacier margin, and are graded to the surface of the valley-outwash deposits that lie in the trunk valley.

Glaciodeltaic sediments were laid down by meltwater streams in ice-contact and valley-outwash deltas (Qd, Qod), lacustrine-fan deposits (Qlf), and lake-bottom deposits (Qlb); all deposited in glacial lakes. Deltas consist of coarse, planar-bedded to cross-bedded topset beds of coarse gravel and sand that overlie inclined foreset beds of sand and fine gravel. Near the meltwater feeder stream, foreset beds are generally steeply inclined (25^o to 35^o) and consist of thick to thin rhythmically bedded fine gravel and sand. Farther out in the lake basin, these sediments grade into less steeply dipping foreset beds of graded, ripple-drift cross-laminated, parallel-laminated sand and fine gravel with minor silt drapes. These in turn grade into gently dipping bottomset beds of ripple cross-laminated, parallel-laminated sand and silt with clay drapes.

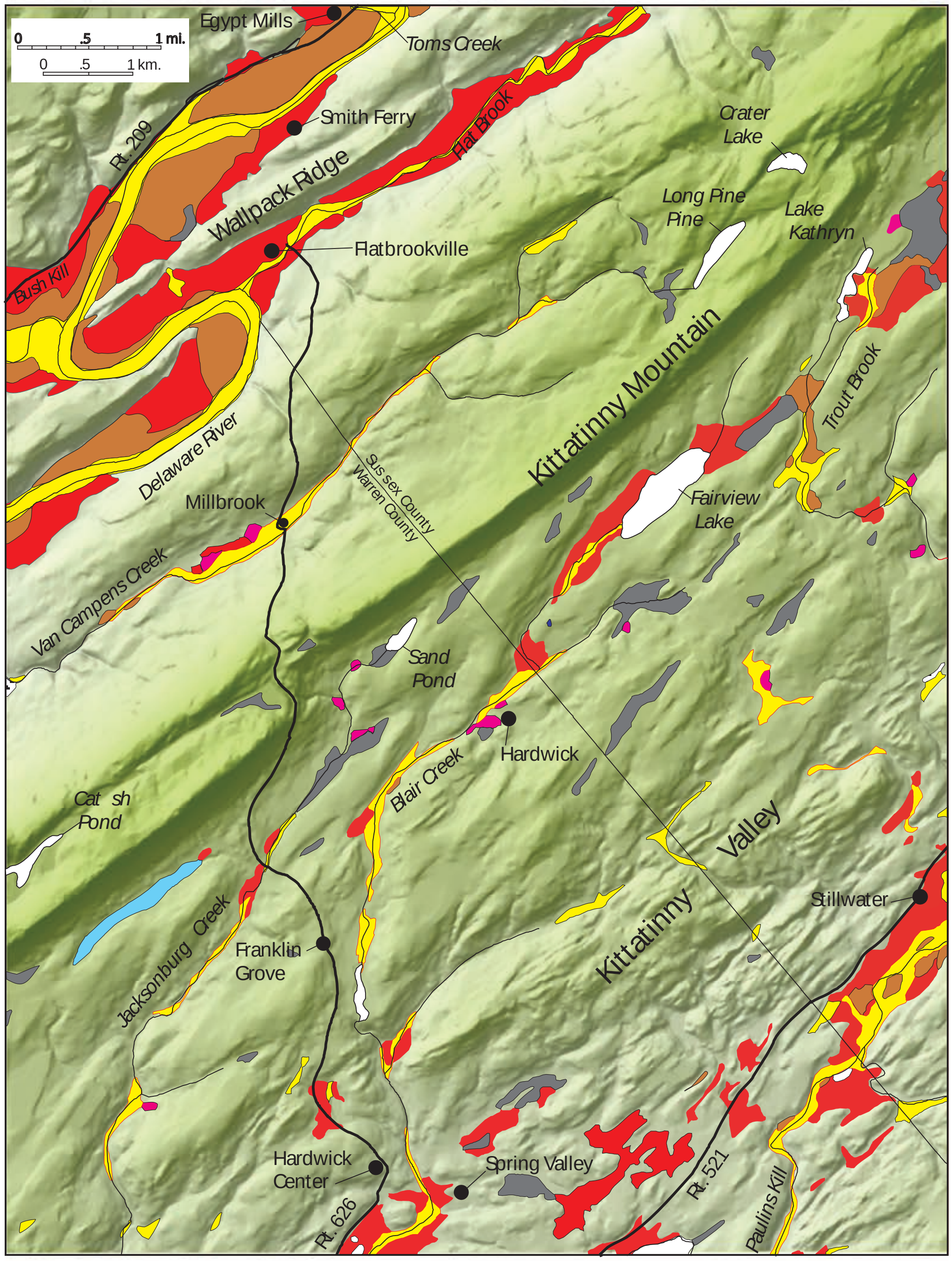

Figure 5. Simplified surficial geologic map of the Flatbrookville quadrangle showing the distribution of stratified materials and organic deposits. Coarse to fine gravel and pebbly sand were laid down by glacial meltwater streams in valley-train, and outwash-fan deposits, topset beds of deltaic deposits, meltwater-terrace deposits, and kames. Sand and silt were laid down by postglacial streams in stream-terrace deposits, and silt and clay were laid down in glacial lakes in lake-bottom deposits. Pebbly sand, sand, and silt laid down in glacial delta foreset beds is in subsurface only.

coarse to ne gravel and pebbly sand | *sand and silt* | *silt and clay* | *alluvium* | *swamp deposits*

Typically, deltas consist of many individual lobes that extend outward from the delta front across the lake floor, thinning, widening, and fining with distance (Gustavson and others, 1975). Because proglacial lake basins in the Minisink, Wallpack, and Paulins Kill Valleys were very narrow, they were filled with glaciolacustrine sediment and covered by a thick wedge of glaciofluvial sand and gravel from valley wall to valley wall. In a few places, outwash was laid down over and around stagnant ice.

Unlike deltas, lacustrine-fan deposits lack topset beds; they were deposited at the mouth of subglacial tunnels that exited the glacier near the floor of the lake basin below lake level. Lacustrine fans also become progressively finer grained basinward. However, near the former tunnel mouth, sediments may be poorly sorted because of high rates of sedimentation. If the tunnel remained open and the ice front remained stationary, the fan eventually might have built up to lake level and formed a delta. Only one lacustrine fan has been recognized in the quadrangle (section A-A' pl. 1). However, some deltas probably started out as tunnel-mouth deposits.

Lake-bottom deposits include 1) glacial varves and rhythmites and 2) subaqueous-flow deposits. Glacial varves consist of stacked annual layers that consist of a lower "summer" layer of chiefly silt that grades upward into a thinner "winter" layer of very fine silt and clay. Most of these materials were deposited from suspension, although the summer layer may contain sand and silt carried by density currents. Each summer and winter couplet represents one year. Rhythmites have similar layering as varves, but the layer couplets are subannual, their distribution and layering related to changes in sediment source along the delta front rather than seasonal changes that affect meltwater supply.

Subaqueous-flow deposits consist of graded beds of sand and silt that originated from higher areas in the lake basin, such as the prodelta front, and were carried down slope into deeper parts of the lake basin by turbulent gravity flows. Lake-bottom deposits grade laterally into bottomset beds of deltas.

Kames (Qk) consist of a varied mixture of stratified sand, gravel, and silt interlayered with flowtill. In many places they lie above local glacial lake, base-level controls. However, exposures reveal collapsed deltaic foreset bedding. Presumably, the kame was laid down in a meltwater pond that formerly occupied an ice-crevasse, ice-walled sink, or moulin at the glacier's margin.

POSTGLACIAL DEPOSITS

Wind-Blown Sediment

In the Flatbrookville quadrangle no areas of wind-blown materials have been recognized. However, just upvalley thick deposits of sand dunes and sheet sands have been identified (Witte and Epstein, 2004; Witte, 2001b) in Minisink Valley and along the base of Wallpack Ridge. Wind-blown silt (loess), if present, has been incorporated into the upper part of the soil.

Hillslope Sediment

Thin deposits of shale-chip colluvium (Qsc) lie at the base of cliffs formed by the Mahantango and Marcellus Formations in Minisink Valley. The rubble, well described in Sevon and others (1989) and Witte (2001c), consists of angular, elongated, platy, prismatic and bladed clasts. Average clast length varies between one and six inches. Larger clasts, up to boulder size, may be interspersed throughout the deposit. Typically, the rubble has very little matrix, although many of the clasts exhibit a thin coating of clay. The few beds that did have a substantial matrix component displayed a coarsening upwards of shale clasts, suggesting it was deposited as a slurry flow. Bedding is slope parallel, and averages between one to four inches (10 cm) thick. However, in many places the homogeneity of the rubble makes it difficult to discern bedding. Most of the elongated fragments are oriented down slope. Bedding, sorting, and clast orientation of the rubble suggest that most of this material moves downslope as a massive sheetflow, after it had fallen off the outcrop and accumulated at the top of the apron. Bedding and grading show that this downslope transport is episodic and in some cases may have involved water.

Glacial erosion and the lithology and structural elements of the parent rock have created a geologic setting that is conducive to the formation of very large volumes of shale-chip rubble over a short time. Glacial erosion over the course of at least three glaciations has cut back the western side of Minisink Valley, forming a very steep rock face that is as much as 500 feet (152 m) high. Mechanical weathering of the rock by frost shattering has formed an extensive apron of shale-chip rubble that has accumulated since Minisink Valley was deglaciated about 18,000 years ago (Witte, 2001b). The steep southeast-dipping cleavage of the Mahantango Formation, its thin, northwest-dipping beds of shale and siltstone, and the vertical joints form weak zones and provide an extensive surface area required for rapid fragmentation. The size of the rubble clasts is directly related to cleavage spacing, bedding thickness, and joint penetration.

Other hillslope deposits include thick talus (Qta), which is chiefly made up of blocks of conglomerate and quartzite of the Shawangunk Formation. This material forms an extensive apron of rock debris on the southeast face of Kittatinny Mountain and at the base of a few cliffs higher on the mountain.

Organic Deposits

There are many swamp and bog deposits (Qs) in the quadrangle. They formed in kettles and glacially scoured bedrock basins, in glacial lakes that persisted into the Holocene, in abandoned stream channels on alluvial plains, and in poorly drained areas of thick till. These deposits principally consist of peat, muck, marl, and minor detritus. Peat in Kittatinny Valley is largely of the reed and sedge type. In parts of the valley where limestone and dolomite crop out, peat is commonly underlain by calcareous marl (Waksman and others, 1943). Peat deposits on Kittatinny Mountain, in Minisink Valley, and those northwest of the Paulins Kill Valley are typically of woody origin, or consist of mixed wood and sedge peat (Waksman and others, 1943).

Stream Deposits (modern alluvium, stream-terrace deposits, and alluvial-fan deposits)

Alluvium (Qal) is chiefly late Holocene in age and includes both channel (sand and gravel), and overbank (sand and silt) deposits laid down by streams. It typically forms narrow, sheet-like deposits on the floors of modern valleys. Channels, channel scarps, and levees are commonly preserved on flood plains along the larger rivers. In Minisink Valley, the modern floodplain is typically a narrow terrace that lies as much as 12 feet (4 m) above the mean-annual elevation of the Delaware River. This terrace also forms all or parts of the lowest islands in the river's channel.

Stream-terrace deposits (Qst) include both channel and flood-plain sediment, and they lie 5 to 35 feet (2 to 11 m) above the modern flood plain and below meltwater-terrace deposits. In Minisink Valley they may be grouped into two distinct sets (Witte, 2001b). The youngest (Qst2) lies between 20 and 35 feet (6 to 11 m) above the river and consists of as much as 15 feet (4 m) of overbank fine sand and silt overlying cobble-pebble gravel and sand. The underlying gravel and sand are channel-bar and point-bar deposits, and in places strath terraces of a postglacial river. The Qst2 deposits typically form broad terraces that flank the present course of the river. The highest parts of the terrace lie next to the Delaware River on a levee. In a few places the levee is well developed and forms a prominent ridge that is as much as 8 feet (2 m) high. However, the levee is commonly the highest point on a gently inclined surface that slopes away from the river to the valley wall. At the base of the valley wall the terrace is cut by a shallow channel (flood chute) that typically contains organic deposits. In many places, multiple levees and channel scrolls are preserved, especially where the terrace lies on the inside of a large river bend. The 15 foot (5 m) range in elevation of the terrace throughout Minisink Valley is due to: 1) as much as 8 feet (2 m) of constructional relief on the terrace, and 2) parts of the terrace have been lowered by erosion as the river cut down to its modern level. It is also possible that the Qst2 terrace consists of several levels as shown by Wagner (1994). However, without better elevation control, these terrace subsets are difficult to correlate on a valley-wide scale. The differing levels may also be related to local riparian conditions and channel morphology of the postglacial Delaware River. Archaeological investigations in the Delaware River valley above Delaware Water Gap (Stewart, 1991) showed that the base of the Qst2 terrace may be as old as 11,000 yr BP, with its surface dated to historic times. These ages suggest that the Qst2 terrace is mostly Holocene age and that it has been largely built up by vertical accretion, although, in a few places, channel scrolls preserved on some terraces and the course of the Delaware River show that stream-terrace deposits have also been built by lateral accretion.

The oldest stream-terrace deposits in Minisink Valley (Qst3) lie 40 to 48 feet (12 to 15 m) above the modern river and typically consist of as much as 10 feet (3 m) of overbank fine sand and medium sand overlying gravel and sand. In places, this material has been eroded revealing the underlying gravel. The gravelly substrate is interpreted as reworked glacial outwash deposited by the Delaware River during the earlier part of postglacial time (14-16 ka). The Qst3 terraces are typically small and flank the younger Qst2 deposits. In some places they lie surrounded by Qst2 deposits. No ages are available for the Qst3 terrace, but based on the age of the Qst2 terrace, it is late Wisconsinan age and it may represent a transition between glaciofluvial and postglacial fluvial environments.

Alluvial-fan deposits (Qaf) are fan-shaped deposits that lie at the base of hillslopes at the mouths of gullies, ravines, and tributary valleys. Their sediment is highly variable and is derived chiefly from local surficial materials eroded and laid down by streams draining adjacent uplands. Most of the alluvial fans in the quadrangle are deeply entrenched by modern streams, suggesting that they are probably of late Wisconsinan and early Holocene age when climate, sediment supply, and amount and type of hillslope vegetation were more favorable for their deposition.

GLACIAL HISTORY

Glacial Erosion

The distribution and differences in weathering characteristics of glacial drift in northwestern New Jersey (Salisbury, 1902; Stone and others, 2002) show that continental ice sheets covered northern New Jersey at least three times during the Pleistocene epoch. The action of each ice sheet modified the landscape by deeply scouring valleys, and wearing down and streamlining bedrock ridges, hills, and slopes. Both the floor of the Minisink and Wallpack Valleys and part of Kittatinny Valley were deeply scoured by glacial erosion. Depressions in the buried-bedrock floor of Mininsink Valley indicate that glacial scour exceeds 50 feet (15 m) and may be as much as 150 feet (46 m) (Witte and Stanford, 1995). Due to weathering, only erosional features of the late Wisconsinan glaciation are preserved. These include polished and plucked bedrock, striations, and streamlined bedrock forms called *roche moutonnées*. Glacial erosion has also removed any pre-Wisconsinan saprolite and soil. However, an outcrop of saprolite observed by the authors on the Poxono Island Formation downvalley in the Bushkill quadrangle shows that at least some preglacial materials were not completely eroded in the Delaware River valley.

Glacial Advance and Changes in Direction of Regional Ice Flow

The initial late Wisconsinan advance of ice into the upper part of Kittatinny Valley is obscure because striae and glacial drift that record this history have been eroded or were buried by younger late Wisconsinan deposits. If the ice sheet advanced in lobes as suggested by the lobate course of its terminal moraine, then its initial advance was marked by lobes of ice moving down the Kittatinny and Minisink Valleys. Sevon and others (1975) speculated that ice from the Ontario basin first advanced southward into northeastern Pennsylvania and northwestern New Jersey. Later, ice from the Hudson-Wallkill lowland, which initially had lagged behind, overrode Ontario ice, and ice flow turned to the southwest. In this scenario, the course of the terminal moraine in Kittatinny Valley (fig. 2) was controlled by ice flowing

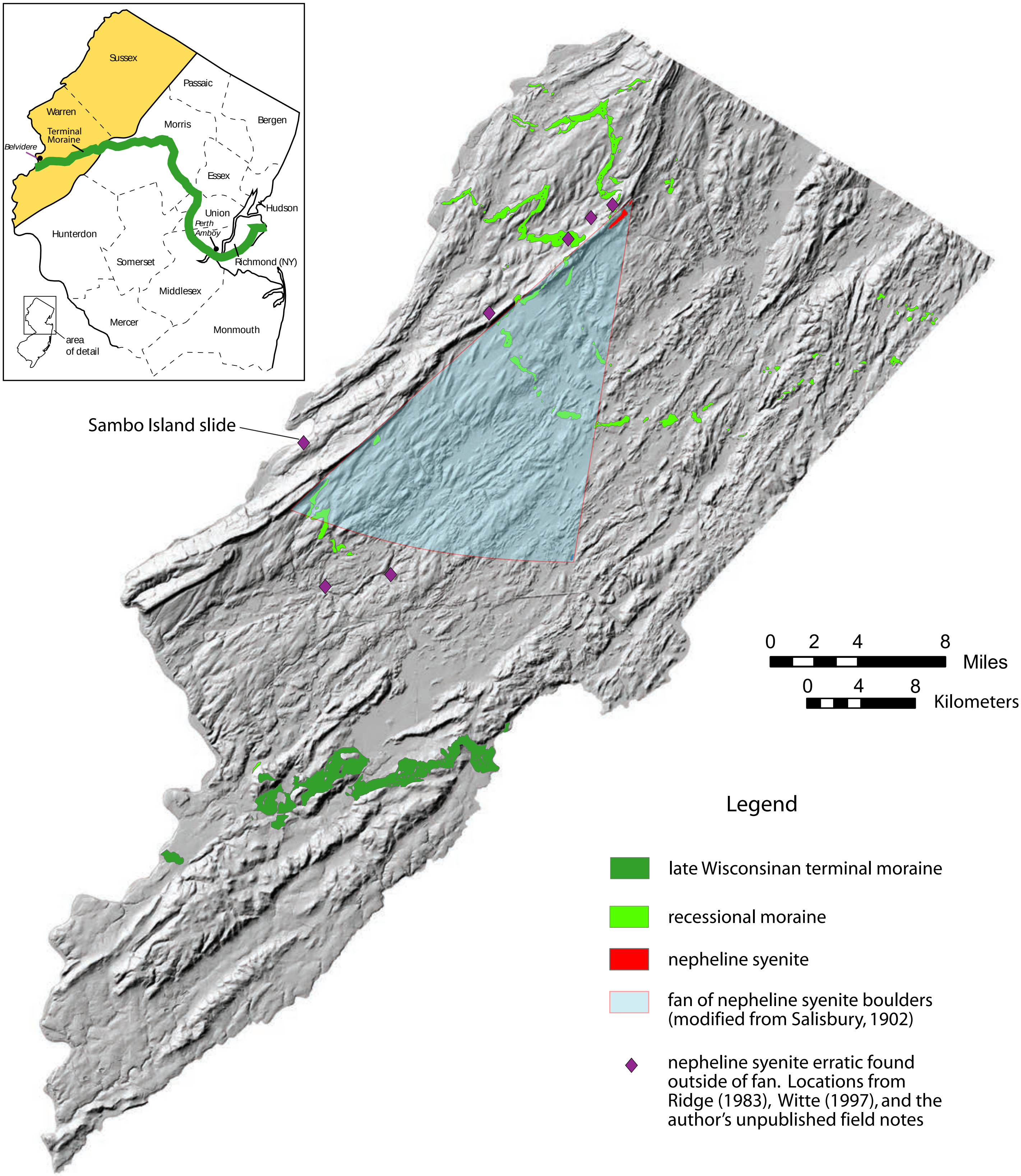

Figure 6. Location of nepheline syenite (Obs) erratics and source in northwestern, New Jersey. The original limits of the boulder fan were delineated by Salisbury (1902). Later glacial investigations by Ridge (1983) extended the erratic dispersal farther south in Kittatinny Valley and Witte (1997) found several syenite erratics on the west side of Kittainny Mountain. The northern-most occurrence of Obs erratics defines an ice flow of S74˚W measured from the northern tip of the Obs outcrop.

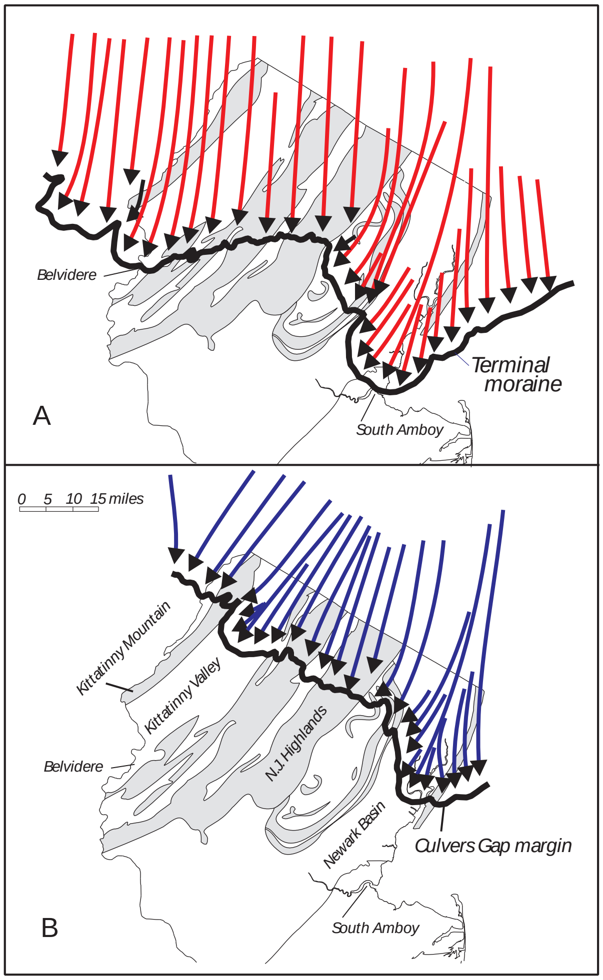

Figure 7. Generalized direction of ice movement in northern New Jersey during the late Wisconsinan. Lines represent regional ice-flow movement at the base of the ice sheet. Flow directions are based on striae, drumlins, dispersal of erratics, and till provenance. Shaded areas represent major uplands. Figure 7a shows direction of ice flow when the glacier margin was at the terminal moraine.
Figure 7b shows direction of ice flow during deglaciation. Flow lines in Kittatinny and Minisink Valleys and surrounding uplands are oriented in a southwest direction with well developed lobate ice flow at the glaciers margin. The change in regional ice flow to a southwest direction appears to be related to thinning of the ice sheet at its margin, and reorganization of ice flow around the Catskill Mountains, and in the Hudson-Wallkill Valley. Data from Ridge (1983), Sevon and others (1989), Witte (1997), Stone and others (2002), and unpublished field maps on file at the New Jersey Geological Survey, Trenton, New Jersey.

from the Hudson-Wallkill lowland. Connally and Sirkin (1986) suggested that the Ogdensburg-Culvers Gap moraine represents or nearly represents the terminal late Wisconsinan position of the Hudson-Champlain lobe based on changes in ice flow noted by Salisbury (1902) in the vicinity of the moraine. Ridge (1983) proposed that a sublobe of ice from the Ontario basin overrode Kittatinny Mountain and flowed southward into Kittatinny Valley. Southwestward flow occurred only near the glacier margin where ice was thinner, and its flow was constrained by the southwesterly trend of the valley. Analyses of striae, drumlins, and the distribution of erratics in the upper part of Kittatinny Valley (Witte, 1988) and adjacent Kittatinny Mountain (Witte, 2008; Witte and Epstein, 2004) partly support Ridge's view. These data further show that by the time the Ogdensburg-Culvers Gap moraine was formed, ice flow in Kittatinny Valley had turned completely to the southwest with extensive lobation at the glacier's margin.

Several small boulders and cobbles of nepheline syenite found in the Delaware Valley downstream from Wallpack Bend may provide additional information on the advance history of the Kittatinny and Minisink Valley ice lobes (fig. 6). The erratics were first observed in the toe deposit of a small landslide that was described by Epstein (2001). The syenite clasts (SI Obs), located 18 miles (29 km) from their source, look to be from till that mantles the lower part of the valley slope. Samples have been positively identified as the same rock as the large intrusion west of Beemerville. Previous investigations by Salisbury (1902), Ridge (1983), and Witte (1988, 1991) showed that the nepheline syenite erratics occur in a well-defined fan in Kittatinny Valley (fig. 6). Based on their distribution in Kittatinny Valley and on Kittatinny Mountain, two phases of ice flow have been recognized (fig. 7). The first and earlier phase consisted of southward flow across the northeast-to-southwest topographic grain of northwestern New Jersey. Later during deglaciation, ice flow turned to the southwest as the edge of the glacier thinned and its flow became more topographically controlled. Erratics west of the nepheline syenite outcrop (fig. 6) indicate divergent flow at the margin of the Kittatinny Valley ice lobe, the result of well-developed lobation of the glacier's margin. This ice flow reconstruction agrees with that determined by analyses of striae, drumlins, and till provenance by Witte (1997).

Excluding the slide area near Wallpack Bend, syenite erratics on Kittatinny Mountain have been found only as far south as Culvers Gap, several miles northeast of the Flatbrookville quadrangle (fig. 6), and have not been observed in Delaware or Wallpack Valleys. Over a dozen syenite clasts have been recognized at the Sambo Island slide ranging from subangular to subrounded large cobble to pebbles. They lie on the lower part of the steep slope above the Delaware, either in slide debris that lies as much as 40 feet above the river or along an old trail that runs along the base of the slope about 20 feet above the river.

There are three explanations for the SI Obs. Firstly, the syenite clasts are from till that mantles the lower part of the slope above the Delaware. Some of these clasts were uncovered by the slide and others were weathered out of the thin soil largely by frost heave. Their location suggests they were carried here by the initial advance of late Wisconsinan ice into this area and that ice from the Hudson-Wallkill lowland may have been the first to reach the area. Based on the erratic's location at the slide, ice would have had to flow S 55º W across Kittatinny Mountain, from the small area of nepheline outcrop near Beemersville in Kittatinny Valley. Later as the ice thickened and the Kittatinny and Minisink Valleys lobes coalesced, ice flowed turned southward. Secondly, SI Obs may have been derived from glacial outwash that forms a thin mantle on the lower part of the slope. In many places the outwash is covered by thin colluvium consisting of reworked till and Bloomsburg Red Bed regolith. Many of the syenite clasts are subrounded suggesting wear by fluvial action. Because they are only found at heights up to 40 feet above the Delaware River, the level of outwash in this area, it is plausible that they were transported by meltwater. However, their occurrence in outwash is still significant because it also suggests an earlier ice flow across Kittatinny Mountain. Thirdly, nepheline syenite was used by Munsee Lenape as a tempering agent in pottery of Late Woodland age (Kraft, 1975). Three lumps of syenite and a ball of unfired clay were uncovered at the Harry's Farm site (Lattanzi, 2009) located about 6 miles (10 km) downstream from the Sambo Island slide. It is likely that the SI Obs were carried from their source near Beemersville into the Delaware Valley. Whether the syenite was actively quarried or picked up loose near the outcrop has not been established.

Style and Timing of Deglaciation

The recessional history of the Laurentide ice sheet is well documented for northwestern New Jersey and parts of eastern Pennsylvania. Epstein (1969), Ridge (1983), Cotter and others (1986), and Witte (1988, 1991, 1997) showed that the margin of the Kittatinny and Minisink Valley lobes retreated systematically with minimal stagnation. However, the age of the terminal moraine, timing of the late Wisconsinan maximum, and precise chronology of deglaciation are uncertain. This is due to a lack of appropriate organic material for radiocarbon dating, inadequacies of dating bog-bottom organic material and concretions, and use of sedimentation rates to extrapolate bog-bottom radiocarbon dates. Also, varved lake-bottom exposures that can be used for chronology are scarce.

A few radiocarbon dates bracket the age of the terminal moraine and retreat of ice from New Jersey. Radiocarbon dating of basal organic material cored from Budd Lake by Harmon (1968) yielded an age of 22,890 +/- 720 yr BP (I-2845), and a concretion sampled from sediments of Lake Passaic by Reimer (1984) that yielded an age of 20,180 +/- 500 yr BP (QC-1304) suggests that the age of the terminal moraine dates to 22,000 to 20,000 yr BP. Basal organic material cored from a bog on the side of Jenny Jump Mountain approximately 3 miles (4.8 km) north of the terminal moraine by D. H. Cadwell (written commun., 1997) indicates a minimum age of deglaciation at 19,340 +/- 695 yr BP (GX-4279). Similarly, basal organic material from Francis Lake in Kittatinny Valley, which lies approximately 8 miles (12.9 km) north of the terminal moraine indicates a minimum age of deglaciation at 18,570 +/- 250 yr BP (SI-5273) (Cotter, 1983). Because the lake lies approximately 3 miles (4.8 km) southeast of the Franklin Grove moraine, this age is also probably a minimum date for that feature. Exactly when ice retreated out of the New Jersey part of Kittatinny Valley is also uncertain. A concretion date of 17,950 +/- 620 yr BP (I-4935) from sediments of Lake Hudson (cited in Stone and Borns, 1986) and an estimated age of 17,210 yr B.P. for the Wallkill moraine by Connally and Sirkin (1973) suggest ice had retreated from New Jersey by 18,000 yr BP.

Based on the morphosequence concept of Koteff and Pessl (1981), many ice-recessional positions have been delineated in Kittatinny Valley (Ridge, 1983; Witte, 1997, 1988). In addition, moraines and interpretation of glacial lake histories, based on correlative relationships between elevations of delta topset-foreset contacts, former glacial-lake-water plains, and lake spillways, provide a firm basis for reconstruction of the ice-recessional history of the Kittatinny and Minisink Valley ice lobes. Recessional deposits are discussed in reference to deposition at the margin of the Kittatinny Valley lobe or the Minisink Valley lobe. Locally, the two lobes wasted back synchronously, although regionally the Minisink lobe retreated more rapidly (Witte, 1997).

Kittatinny Valley lobe

Paulins Kill Valley

Meltwater deposits in the Paulins Kill Valley consist of valley-train deposits, ice-contact deltas, kames, and meltwater-terraces. Ice-contact deltas and kames that are located north of White Lake are the oldest meltwater deposits in the valley. These deposits were chiefly laid down in small proglacial ponds that formed in a poorly drained area of karst and stagnant ice. They are generally collapsed, and range from boulder-cobble gravel to fine sand, interlayered with flowtill. They are as much as 505 feet (154 m) above sea level, and apparently do not define an ice-retreatal position because they lack a head-of -outwash. A small ice-contact delta located 0.5 miles (0.4 km) north of Stillwater (map, location 14) marks a minor retreatal position.

Ice-contact deltaic outwash (Qod) in the main part of Paulins Kill Valley was laid down from an ice-retreatal position located just northeast of the quadrangle (fig. 2, position 6). Near Stillwater its elevation is approximately 490 feet (149 m) above sea level, and it consists of cobble-pebble gravel and sand. Downvalley the surface drops to approximately 475 feet (145 m) where it consists chiefly of pebble gravel and pebbly sand. Foreset bedding at pebble-sample location 15 near Stillwater shows that the outwash is deltaic, and was laid down in a small proglacial lake here named Lake Stillwater. Apparently, glacial sediment of slightly older age had formed a temporary dam downstream, where the valley is narrow.

Meltwater-terrace deposits that cover parts of the valley floor were laid down after Lake Stillwater drained. Presumably glacial sediment that had dammed the valley downstream was eroded by the lake's discharge. The timing of this event is not clear because outwash from successive ice-retreatal positions upvalley (Witte, 1997) rise in elevation. Erosion may have been delayed until the margin of the Kittatinny Valley lobe retreated north of the Wallkill River-Paulins Kill drainage divide. At this time Lake Wallkill was formed (fig. 2). Water from this lake continued to flow across the spillway at Augusta (fig. 2) and erode meltwater deposits in Paulins Kill Valley, up until a lower spillway was uncovered in the Wallkill Valley, and the lake drained into the Hudson Valley in New York State.

Blair Creek Valley

Meltwater deposits in Blair Creek Valley consist of proglacial fluvial and deltaic deposits, an outwash-fan deposit, minor kames, and meltwater-terrace deposits. In the main part of the valley southeast of Hardwick Center, fluvial outwash covers the valley floor in front of the Franklin Grove moraine. Near the moraine the outwash is as high as 470 feet (143 m) above sea level and consists of boulder-cobble gravel and sand. Northwest of Hardwick Center a small ice-contact delta marks a minor recessional position south of the Franklin Grove moraine. This deposit was laid down in a proglacial lake that formed in a small north-draining valley.

North of the moraine there are a few kames, and valley-outwash deltas. Kames here are small, collapsed, and typically consist of deltaic sediment. Their origin is uncertain, but they may have been laid down in small ice-walled ponds within the stagnant glacier margin. Pebbly gravel and pebbly sand outwash in the small valley north of Spring Valley apparently was laid down in a small lake dammed by the Franklin Grove moraine. These deposits were laid down from a retreatal position located in the head of the valley. The valley-outwash deposit that was laid down in front of the Fairview Lake moraine is in part deltaic as shown by exposures near Hardwick (map, location 25). Its elevation near Hardwick is 865 feet (264 m) above sea level, suggesting that it may have been laid down in a glacial lake dammed by the Franklin Grove moraine. A small outwash-fan deposit north of Fairview Lake marks the last stratified deposit laid down in the valley before the glacier margin retreated into Trout Brook Valley. A meltwater-terrace deposit cut into the outwash downvalley shows that base level had lowered in the valley prior to ice retreat from the Blair Creek drainage basin. This decrease in elevation was probably caused by erosion of the moraine downvalley.

Trout Brook Valley

Meltwater deposits in Trout Brook Valley consist of ice-contact deltas, minor meltwater-terrace deposits, and a few kames. The small ice-contact deltas east of Fairview Lake were laid down in small proglacial lakes that were ponded between the margin of the Kittatinny Valley lobe and the drainage divide between Blair Creek and Trout Brook. These deposits consist of cobble-pebble gravel and sand overlying sand and minor fine gravel. Lake level here was controlled by local spillways that lie just south of the deltas. Deposits east of Lake Kathryn are part of a much larger ice-contact delta laid down in a proglacial lake that was held in between the glacier margin and drumlins that lie to the south. A spillway located along the modern course of Trout Brook and the 970' (296 m) spillway that lies southeast carried the lake's outlet waters through low areas in the drumlin field and controlled the level of the lake. It is assumed that the 970' (296 m) spillway initially controlled lake level. Later it was abandoned when till along Trout Brook was eroded by the lake's discharge. Deltaic deposits here are highly collapsed and have varied composition. A small sand-and-gravel pit east of Lake Kathryn (pl. 1, location 10) revealed 8 feet (2.4 m) of cobble-gravel and cobble-pebble-gravel topset beds overlying 18 feet (5.5 m) of pebble gravel, pebbly sand, and sand foreset beds. Meltwater-terrace deposits cut into the delta indicate that prior to ice retreat, the level of the lake lowered progressively in response to lowering of its spillway floor by erosion.

Jacksonburg Creek Valley

Meltwater deposits in Jacksonburg Creek Valley are few. They are small, exhibit ice-contact forms, and consist of a variety of sediments. These deposits are probably crevasse fillings, deposited in the glacier's marginal stagnant zone. Due to this interpretation they have all been mapped as kames.

Summary of deglaciation in Kittatinny Valley

The Franklin Grove moraine and its associated outwash mark a major ice-retreatal position of the Kittatinny Valley lobe. The moraine has been correlated with ice-contact deltaic deposits that lie to the east in the upper Pequest Valley (Witte, 1988, 1997; Ridge, 1983), and it may be correlative with the Sand Hill Church deposits in Pennsylvania (fig. 2, position 4). Like the Ogdensburg-Culvers Gap and Augusta moraines that lie further north in Kittatinny Valley (Witte, 1991), it was probably laid down at an active glacier margin.

Following glacial retreat from the Franklin Grove position, several small, short-lived proglacial lakes flooded river valleys and small rock-cut basins behind the moraine. The Fairview Lake moraine and outwash in Paulins Kill valley mark a minor pause of the Kittatinny Valley lobe (fig. 2, position 5).

Retreat from the Fairview Lake position resulted in the formation of Lake Stillwater in Paulins Kill valley, and the formation of several small proglacial lakes in the Trout Brook drainage basin. The Sparta ice margin (fig. 2, position 6) represents a major recessional position from which outwash was laid down in Trout Brook Valley and Lake Stillwater. These deposits have been correlated with ice-contact deltas farther east in the upper parts of the Pequest and Wallkill Valleys (Witte, 1988).

Minisink Valley lobe

Kittatinny Mountain and Mill Brook Valley

With the exception of outwash south of Millbrook Village, meltwater deposits are absent because the floor of most drainages have steep, south-draining courses that prohibit deposition. Valley floors are typically covered by a lag of boulders and cobbles formed by meltwater winnowing matrix material from till. South of Millbrook Village, remnants of meltwater terrace deposits and kames rise above the alluvial plain of Van Campens Creek. The valley-train deposits consist of cobble-pebble gravel, pebble gravel, and sand presumably laid down from an ice-retreatal position located north of village. Meltwater channels cut into thick till may mark former ice-retreatal positions here. The coarse-grained kame located just south of Millbrook Village may also mark an ice-recessional position. Based on its location it may be coeval with the Franklin Grove moraine.

Wallpack Valley

Meltwater sediment in Wallpack Valley consists of valley-train, and meltwater-terrace deposits. Valley-train deposits form collapsed and discontinuous terraces that cover most of the floor of Wallpack Valley. Outwash in the lower part of the valley near the confluence with the Delaware River lies 440 feet (134 m) above sea level and is fluvial, as shown by exposures at pebble-sample location 6 (pl. 1). Sediment consists of planar-bedded cobble gravel, cobble-pebble gravel, and sand. Based on its elevation, it presumably was laid down from a short-lived ice-retreatal position located north of Flatbrookville. Valley outwash deposits north of the gauging station are deltaic, as shown by exposures at pebble-sample location 4 (map). They consist of cobble-pebble gravel, pebble gravel, and sand topset beds that overlie pebble gravel, pebbly sand, and sand foreset beds. In places foresets are interlayered with massive, coarse, sediment-grain-flow deposits and flow till. Deposits are as much as 450 feet (137 m) above sea level and are collapsed in many places. Apparently, they were laid down in a proglacial lake that was dammed by higher deposits downvalley and/or laid down in ice-contact ponds within areas of stagnant ice. Topographic profiles of the outwash surface upvalley from location 4 indicate these deposits were laid down from the Dingmans Ferry ice-retreatal position (fig. 2, position 7). Meltwater-terrace deposits in the valley are common. Downcutting and lateral erosion by meltwater streams are shown by slip-off slopes that cut down in the higher valley-outwash deposits. These are found on the inside bend of channels and they represent a period of rapid downcutting. More commonly, these terraces are also beveled outwash surfaces, cut by meltwater streams emanating from ice margins farther up valley.

Minisink Valley

Meltwater deposits in Minisink Valley consist of valley-train, outwash-fan, and meltwater-terrace deposits. Valley-train deposits are remnants of an extensive outwash deposit that rises from approximately 390 feet (119 m) above sea level near the boundary with the Bushkill quadrangle to 425 feet (130 m) above sea level upstream near Smith Ferry. The outwash remnants form discontinuous, narrow terraces that are typically attached to the valley wall. They have a flat surface that slopes gently downvalley and have steep-sided erosional escarpments that lie against the younger meltwater-terrace, stream-terrace and alluvial deposits that cover the lower parts of the valley floor. The surface of some terraces dips towards the center of the valley. These are interpreted to be slip-off slopes that were formed by the rapid downcutting and the lateral migration of meltwater streams across the valley bottom as local base level was lowered by erosion downstream. Sediment, which can be observed at pebble-sample locations 5, 6, and 25 (map), consists of cobble-pebble gravel and pebble gravel and sand. Coarser beds are generally planar-bedded and graded. Some sand beds show trough cross-stratification. Based on projected longitudinal profiles of terraces in the valley (Witte, 2001b) and increase in grain size upstream, the outwash appears to have been laid down from an ice-recessional position upstream at the Dingmans Ferry moraine (fig. 2, position 7). Lake-bottom deposits in Minisink Valley north of Wallpack Bend (section A-A', subsurface only) indicate that a proglacial lake occupied the valley before outwash from the Dingmans Ferry position buried the lacustrine sediments. The valley floor is deeply scoured on both sides of Wallpack bend and as the glacier margin retreated northward, a proglacial lake formed in the scoured depression. The lake's spillway was across older outwash downstream from Wallpack Bend, now buried by glaciofluvial deposits and alluvium. The extent of the glaciolacustrine sediment is uncertain. Records of wells in the valley (U.S. Army Corps of Engineers borings) show that it is discontinuous. It is shown here locally underlying the Dingmans Ferry valley-train deposit.

On the Pennsylvania side of Minisink Valley, large fan-shaped deposits of sand and gravel lie near Bushkill (Qfbc) and Egypt Mills (Qftc). They head in the small valleys now drained by Little Bushkill and Toms Creek, reach an elevation of as much as 450 feet (137 m), and are graded to the surface of the valley-outwash deposits. Meltwater streams draining the upper reaches of the tributaries laid down these fans.

Meltwater-terrace deposits in Minisink Valley are chiefly strath terraces cut in aggraded valley-train deposits by meltwater streams emanating from ice-recessional positions north of the Dingmans Ferry margin (fig. 2, position 7). These deposits are as much as 15 feet (5 m) thick and consist largely of reworked sediment eroded from the adjacent or the upstream parts of valley-train deposits and till that covers the lower part of valley slopes. They range in elevation between 405 and 350 feet (123 and 107 m) above sea level and were formed during a period of fluvial incision following the lowering of local base level downvalley as the glacial Delaware River adjusted to its longer course.

Summary of deglaciation in Minisink and Wallpack Valleys

The Zion Church ice margin marks a minor stillstand of the Minisink Valley lobe (fig. 2, position 3). It is southwest of the Flatbrookville quadrangle and tentatively correlated here with ice-contact deltaic deposits in the Marshalls Creek Valley in Pennsylvania. The Sand Hill Church ice margin (fig. 2, position 4) marks a major retreatal position in the Minisink Valley. In Pennsylvania, ice-contact deltaic deposits laid down at the head of Marshalls Creek Valley delineate it. The margin is correlated with the Franklin Grove moraine in New Jersey based on the reconstruction of ice margin geometry in Kittatinny and Minisink Valleys. Retreat of the glacier from the Sand Hill Church margin resulted in a proglacial lake occupying a glacially scoured bedrock basin in Minisink Valley on the western side of Wallpack Bend. Records of borings near Tocks Island by the U.S. Army Corps of Engineers (on file at the New Jersey Geological Survey, Trenton, New Jersey), also suggest that a short-lived proglacial lake may have existed in the Minisink Valley south of Wallpack Bend. Initially, the lake may have been dammed by outwash laid down from the Zion Church ice margin. The Dingmans Ferry moraine marks the next ice-recessional position, which is approximately 10 miles (16 km) northeast of the quadrangle. It has been correlated with the Ogdensburg-Culvers Gap moraine (fig. 2, position 7). In Minisink and Wallpack Valleys, valley-train deposits extend downstream from the moraine.

The lack of intermediate recessional positions between Sand Hill Church and Dingmans Ferry may reflect rapid backwasting of the ice margin. Alternatively, the glacier margin remained at the Dingmans Ferry margin long enough so that older heads-of-outwash downvalley were buried.

POSTGLACIAL HISTORY

The Flatbrookville quadrangle is estimated to have been deglaciated by 18,000 yr BP based on the oldest Francis Lake radiocarbon date (Cotter, 1983). Meltwater continued to flow down

Minisink Valley up until the glacier margin retreated out of the Delaware River drainage basin and into the Susquehanna drainage basin about 14,000 yr BP (estimated from Ozvath and Coates, 1986). Meltwater from Augusta stage of Lake Wallkill (fig. 2) continued to flow down the Paulins Kill Valley until a lower spillway, located on a divide between Moodna Creek and presently at about 400 feet (122 m) above sea level, was uncovered in the mid-Wallkill Valley and the lake's drainage flowed to the Hudson Valley. This occurred around 17,000 yr BP based on the estimated age of the Pellets Island moraine in Wallkill Valley by Connally and Sirkin (1986).

The postglacial landscape immediately after the late Wisconsinan glacier retreated from Kittatinny and Minisink Valleys was cold, wet, and windswept. This harsh climate and sparse vegetation enhanced erosion of the land by streams and by mass wasting of material on slopes. Mechanical disintegration of exposed bedrock by frost shattering was extensive. On Kittatinny Mountain, frost-rived blocks of conglomerate and quartzite as large as 20 feet (6 m), form an apron of thick talus below cliffs. In Minisink Valley, deposits of shale-chip colluvium mantle the lower part of the cliffs and steep hillslopes between Bushkill and Toms Creeks. In areas of less relief, boulder fields formed at the base of slopes where rocks were transported by soil creep. Other fields were formed where meltwater left a lag deposit consisting of the heavier stones, and few others may have been concentrated and deposited by the glacier. These fields, and other concentrations of boulders that were formed by glacial transport and meltwater erosion, were further modified by freeze and thaw, their stones reoriented to form crudely-shaped stone circles.

The many swamps and poorly drained areas in the Flatbrookville quadrangle are typical of glaciated landscapes. Upon deglaciation, surface water, which had in preglacial time flowed in a well-defined network of streams, became trapped in the many depressions, glacial lakes and ponds, and other poorly drained areas created during the last glaciation. Swamps and bogs contain sedimentary and organic records that can be used to reconstruct past climatic conditions. Because these materials were laid down layer upon layer, they may preserve a climatic record from the time of deglaciation to the present. The identification of pollen and radiocarbon dating of plant material retrieved from swamps have provided information on regional and local changes in vegetation, which have been used to interpret past climates. Several studies on bogs and swamps in northwestern New Jersey and northeastern Pennsylvania have established a dated pollen stratigraphy that nearly goes back to the onset of deglaciation (Cotter, 1983). Paleoenvironments, interpreted from pollen analysis, show a transition from tundra with sparse vegetal cover, to open parkland of sedge and grass with scattered arboreal stands that consisted largely of spruce. From about 14,000 to 11,000 yr BP, the regional pollen sequence records the transition to a dense closed boreal forest that consisted largely of spruce and fir blanketing the uplands. This was followed by a period (11,000 to 9,700 yr BP) when pine became the dominant forest component. These changes in pollen spectra and percentages record the continued warming during the latter part of the Pleistocene and transition from the ice age to a temperate climate. About 9,400 yrs. B.P., oak and other hardwoods began to populate the landscape, eventually displacing the conifers and marking the transition from a boreal forest to a mixed-hardwoods temperate forest. Throughout the Holocene the many shallow lakes and ponds left over from the ice age slowly filled with decayed vegetation, eventually forming bogs and swamps. These organic-rich deposits principally consist of peat, muck, and minor rock and mineral fragments. Calcareous ponds also became filled with marl, which largely consists of calcium carbonate precipitated by aquatic plants (Waksman and others, 1943). Marl lies below the peat in most ponds. However, interlayering of marl and peat does occur along the pond edges and where sedimentary peat has formed in the deeper parts of the pond. Mastodon remains excavated from Shotwell Pond, located seven miles (11 km) northeast in Stokes State Forest, show the presence of these large mammals on Kittatinny Mountain during the close of ice age (Jepsen, 1959).

The late Wisconsinan glacial and postglacial fluvial history is well preserved in the Minisink Valley where events can be divided in four phases (Witte, 2001b). Phase 1 was a period of valley filling where glacial stream deposits were laid down at the margin of the Minisink Valley lobe. At times the glacier's margin remained stationary and outwash built up in front of it, extending many miles downstream. One such retreatal position is marked by the Dingmans Ferry moraine (fig. 2) where outwash deposits now lie as much as 130 feet (40 m) above the modern river. Downvalley, meltwater-terrace deposits were cut by meltwater in slightly older valley outwash deposits, as the proglacial river adjusted to its longer course. Phase 2 occurred during the later stages of deglaciation when ice had retreated into the upper part of the Delaware Valley. It marks a period of erosion in the valley and further development of meltwater-terrace deposits as the meltwater stream lowered into the valley fill. Initially meltwater from a distant ice margin may have cut a deep narrow channel in the glacial-valley fill. In a few places this channel is still preserved. However, in most parts of the valley, meltwater-terrace deposits indicate that meltwater streams shifted laterally across the valley floor. These terraces are erosional and meltwater sediment, at least its gravel fraction, was derived from eroded local valley fill, rather than outwash laid down from a distant ice margin upvalley.

The timing of phases 1 and 2 is uncertain due to the scarcity of organic material that can be radiocarbon dated. Based on a few bog-bottom dates by Cotter and others (1986) and Connally and Sirkin (1973) it is estimated here that the Minisink Valley lobe had retreated north of New Jersey by about 17,500 to 18,000 yr BP with deglaciation of the entire Delaware River drainage basin by about 14,000 years ago (Ozvath and Coates, 1986).

Phase 3 marks the onset of stream-terrace deposition and presumably starts when the ice sheet retreated from the Delaware River drainage basin, and stream discharge diminished substantially. This promoted an interval of extensive lateral erosion and deposition on the valley floor as the main channel of the river began to meander. The Qst3 terrace is a relict of this phase and it represents the oldest flood-plain deposits preserved in the valley. It lies as much as 48 feet (15 m) above the modern river and it sits on gravelly strath terraces and in some places sand and gravel that was deposited in point bars and channel bars. Phase 4 marks renewed downcutting and extensive vertical and lateral accretion of overbank deposits. Over the course of the Holocene these flood-plain materials built up to heights as much as 35 feet (11 m) above the modern river. This interval appears to have been initiated by 1) rebound of the Earth's crust, which commenced around 14,000 yr BP (Koteff and Larsen, 1989), and 2) the onset of warmer climate, such that deeper rooted and more extensive vegetation reduced sediment load in the drainage basin.

SURFICIAL ECONOMIC RESOURCES

Wells (table 2) drilled in thick deposits of glacial outwash provide substantial supplies of potable water throughout the quadrangle. Many of these are located in Minisink Valley. Stratified sand and gravel (fig. 5), most of which lies in valley-train deposits (Qv), and ice-contact deltas (Qd, Qod) may be used as aggregate, subgrade fill, select fill, surface coverings, and decorative stone. Shale-chip colluvium (Qcs) and weathered slate make excellent subgrade material. The location of all sand and gravel pits and quarries is shown on the geologic map, and the lithology of the pebble fraction of till and outwash is shown in table 1. All pits are currently inactive except for occasional local use. Till could be used for fill and subgrade material, and till stones could supply building stone. Humus and marl from swamp deposits (Qs) may be used as a soil conditioner.

Table 1. Pebble composition of glacial sediment in the Flatbrookville quadrangle, New Jersey and Pennsylvania. **Asterisk** after sample number indicates pebbles were collected by the authors. Data for samples 10 through 17 are from Witte (1988) and samples 18-24 are from Ridge (1983). Percentage is calculated from 100 to 150 pebbles that are 1 to 3 inches in diameter.

Sample	Surficial deposit	Percentage							
		gneiss and granite	dolostone, limestone, and chert	slate and graywacke	quartzite and conglomerate	red sandstone	shale and limey shale	feldspathic sandstone	nephelene syenite
1*	Qtkr	0	0	61	33	6	0	0	0
2*	Qtk	0	1	0	1	0	87	12	0
3*	Qtk	0	20	0	4	0	41	35	0
4*	Qod	0	14	0	43	16	17	10	0
5*	Qov	1	17	0	30	1	42	10	1
6*	Qov	1	37	0	29	10	14	8	1
7*	Qtk	2	46	0	16	2	33	2	0
8*	Qov	0	10	0	10	6	27	47	0
9*	Qtq	0	0	0	92	7	0	0	1
10	Qd	0	0	29	59	10	0	3	0
11	Qf	0	0	17	64	16	0	3	0
12	Qft	0	0	28	49	19	0	5	0
13	Qd	0	0	50	39	7	0	4	0
14	Qd	0	7	62	26	3	0	2	0
15	Qod	0	1	84	9	0	0	6	0
16	Qft	0	0	80	13	2	0	6	0
17	Qod	0	0	82	11	2	0	5	0
18	Qtkr	0	0	34	47	19	0	0	0
19	Qem	0	0	14	68	13	0	5	0
20	Qem	0	0	48	47	5	0	1	0
21	Qtk	0	0	42	42	15	0	0	0
22	Qtq	0	0	27	59	12	0	3	0
23	Qk	0	0	43	50	6	0	0	0
24	Qk	0	53	11	29	7	0	0	0

Table 2. Records of selected wells. The listed wells were drilled for private and public water supply, and exploration. Wells listed with a NJDEP permit number are from the files of the New Jersey Department of Environmental Protection. If the permit number is not listed the well log is listed on a record of an exploratory boring on file at the New Jersey Geological Survey, Trenton, New Jersey. Well locations are based on property maps and information supplied by the driller and generally within 500 feet of actual location.

Well number	NJDEP permit number	Discharge reported by drillers in gallons per minute	Depth in feet	Driller's log
1	21-275	12	0-10	clay
			10-70	hardpan
			70-80	yellow clay
			80-125	slate
2	21-7838	45	0-76	sand, clay, and gravel
			76-250	shale
3	21-37	15	0-10	gravel, hardpan
			10-90	gray fine sand
			90-155	sticky gray clay
			155-160	gravel
4	21-426	13	0-10	clay
			10-30	hardpan
			30-152	clay
			152-208	slate
5	21-7115	5	0-10	overburden
			10-102	clay, gravel
			102-275	shale
6	21-3045	11	0-115	clay, hardpan
			115-145	clay
			145-155	gravel
7	21-7535	20	0-122	sand, gravel
			122-130	soft gray shale
			130-208	shale
8	21-7793	15	0-60	sand, clay, and gravel
			60-150	shale

Well number	NJDEP permit number	Discharge reported by drillers in gallons per minute	Depth in feet	Driller's log
9	21-5331	20	0-20	boulders, clay
			20-40	sand, gravel, and clay
			40-55	clay, gravel
			55-115	shale
10	21-2854	6	0-30	clay, hardpan
			30-55	clay, gravel
			55-80	sandy clay
			80-115	slate
11	21-7278	5	0-5	shaly dirt
			5-145	shale
12	21-7016	14	0-7	overburden
			7-12	broken gray shale
			12-300	hard gray shale
13	21-7411	7	0-60	clay, hardpan
			60-120	slate
14	21-7305	7	0-40	clay, hardpan
			40-101	sandy clay
			101-125	slate
15	21-7471	1	0-30	overburden
			30-555	shale
16	21-8205	20	0-90	overburden
			90-200	shale
17	21-5631	12	0-148	sand, clay, and gravel
			148-150	gravel, sand
18	21-136	15	0-70	boulders, clay
			70-150	slate
19	21-7237	50	0-165	sand, clay, and gravel
			165-187	gravel
20	21-8389	30	0-51	sand, clay, and gravel
			51-200	shale

Well number	NJDEP permit number	Discharge reported by drillers in gallons per minute	Depth in feet	Driller's log
21	21-8098	20	0-65	gray clay, large gravel
			65-113	pink clay, gravel
			113-125	pink sandstone
			125-158	brown clay, shale
			158-323	slate
22	21-8021	10	0-20	boulders
			20-68	hardpan
			68-77	rotten shale
			77-202	shale
23	21-3273	12	0-180	clay, gravel, and boulders
			180-185	small gravel and water
24	21-3479	20	0-131	clay, gravel, and boulders
			131-198	shale
25	21-7296	3	0-51	clay, cobbles, sand, and gravel
			51-448	blue slate
26	21-7336	15	0-90	overburden, layers of clay and gravel with water
			90-500	shale
27	21-8020	15	0-129	sand, clay, and gravel
			129-200	shale
28	21-7397	10	0-2	topsoil
			2-15	clay
			15-25	boulders
			25-50	clay, gravel
			50-70	clay
			70-375	limestone
29	21-7767	4	0-4	clay
			4-67	sandy clay, gravel
			67-87	red sandstone
			87-487	gray shale
30	21-4464	10	0-40	clay, gravel
			40-74	clay, sand
			74-97	slate

Well number	NJDEP permit number	Discharge reported by drillers in gallons per minute	Depth in feet	Driller's log
31	21-7288	25	0-2	soil
			2-40	sand, gravel, and boulders
			40-210	shale
32	21-7940	8	0-50	sand, clay, and gravel
			50-475	slate
33	21-8189	none reported	0-11	overburden
			11-130	shale
34	21-8105	5	0-10	sandy clay, boulders
			10-18	gravel, boulders
			18-19	boulder
			19-25	clay, gravel
			25-295	slate
			295-490	limestone
35	21-6905	none reported	0-14	overburden
			14-200	shale
			200-298	limestone
36	21-7712	25	0-10	boulders, gravel
			10-20	sandy clay, gravel
			20-30	sandy clay
			30-58	fractured limestone
			58-125	limestone
37	21-2438	9	0-20	clay, hardpan
			20-40	clay
			40-85	slate
38	21-7813	11	0-28	clay, gravel
			28-198	limestone
39	21-6409	20	0-3	soil
			3-15	gravel, sand
			15-115	clay, gravel
			115-125	water-bearing gravel
40	21-5846	10	0-12	loam
			12-145	limestone

Well number	NJDEP permit number	Discharge reported by drillers in gallons per minute	Depth in feet	Driller's log
41	21-8353	none reported	0-3	topsoil
			3-20	coarse sand, gravel with clay
			20-43	coarse sand, gravel
			43-47	weathered rock
			47-122	limestone
42	21-4959	15	0-40	boulders, clay, and water
			40-63	hardpan
			63-80	gravel, clay (very hard)
			80-172	red rock
43	21-70	4	0-10	fine sand, silt
			10-125	fine sand, silt, and pebbles
			125-175	gray limey shale
44		none reported	0-20	silt, some gravel
			20-25	gray hard-packed silt
			25-48	gray plastic clay, some silt, and clayey pink
			48-81	gray silt, some clay, and a few pebbles
			81-110	gray silt, fine to coarse gravel, and some sand
			110-115	decomposed limestone
			115-140	bluish-black limestone
45		none reported	0-20	silt, some gravel
			20-30	gravel, silt, and some clay
			30-35	brown silt
			35-60	gray silt
			60-92	gray clayey silt with some pink lamina
			92-99	boulders
			99-109	gravel, clayey grit
			109-112	limestone boulder
			112-125	very compact blue-gray clay
			125-132	boulders in clayey silt
			132-145	weathered limestone
			145-170	argillaceous limestone

Well number	NJDEP permit number	Discharge reported by drillers in gallons per minute	Depth in feet	Driller's log
46		none reported	0-5	topsoil, sandy loam, and gravel
			5-20	coarse grit, gravel
			20-25	clayey grit
			25-30	fine gravel
			30-35	brown silt
			35-40	brown silt with pink clay lamina
			40-45	fine brown sand
			45-50	gravel, fine sand
			50-60	medium and fine sand
			60-65	gravel, clayey sand
			65-73	brown sand, some pebbles
			73-100	black shale
47		none reported	0-20	stream gravel, trace of clayey silt
			20-25	coarse sand
			25-45	coarse gravel and sand, some silt
			45-62	coarse to fine sand
			62-68	weathered rock
			68-93	calcareous shale
48		none reported	0-3	fine sand
			3-35	gravel, sand
			35-47	sand, grit, and gravel
			47-72	blue to black limestone
49		none reported	0-5	bouldery bed, gravel, and sand
			5-10	coarse gravel, sand
			10-25	gravel, sand, and some clay
			25-30	coarse gravel, sand
			30-38	gravel bound by clayey silt
			38-63	dark gray fossiliferous limestone
50		none reported	0-20	fine sand and silt
			20-25	coarse sand
			25-60	fine sand, trace of silt

Well number	NJDEP permit number	Discharge reported by drillers in gallons per minute	Depth in feet	Driller's log
			60-70	coarse gravel and sand
			70-75	bouldery bed
			75-100	limestone
51		none reported	0-6	brown coarse to medium sand, trace of silt and boulders
			6-17	shale cobbles and boulders
			17-24	shale cobbles
			24-42	limestone
52		none reported	0-8	brown coarse to medium sand, trace of silt and boulders
			8-18	shale cobbles and boulders
			18-23	shale cobbles and boulders interlayered with stiff clay
			23-48	shale cobbles and pebbles, clay coating on clasts
			48-63	limestone

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