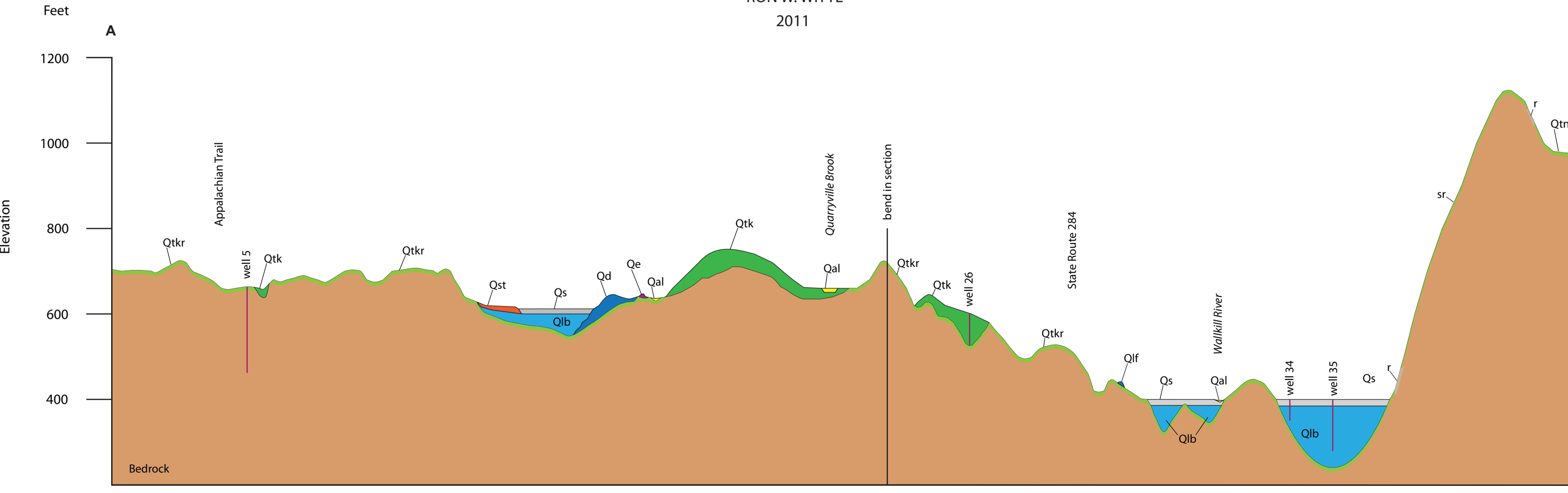


**SURFICIAL GEOLOGIC MAP OF THE NEW JERSEY PART OF THE UNIONVILLE QUADRANGLE
SUSSEX COUNTY, NEW JERSEY**

BY
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2011



vertical exogation = 10

INTRODUCTION

Industrial, commercial, and residential expansion in New Jersey has promoted the increased use of surficial geologic data for 1) land-use planning, 2) identification, management and protection of ground water resources, 3) locating and developing sources of geologic aggregate, and 4) delineation of geologic hazards. Surficial deposits in the Unionville quadrangle are lithologically diverse, cover much 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, hillside deposits, and wind-blown sediment laid down in postglacial time. Collectively, these deposits may be as much as 125 feet (38 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, and 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.

Postglacial Deposits

Artificial fill (Holocene) – Rock waste, soil, gravel, sand, silt, and manufactured materials put in place by man. As much as 25 feet (8m) 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 solid base for roads and railways.

Alluvium (Holocene) – Stratified, moderately to poorly-sorted sand, gravel, silt, and minor clay and organic material deposited by the Walkill River and its tributaries. As much as 25 feet (8m) 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.

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° from the trunk valley. Stratified sediment is locally interlayered with poorly sorted, sandy-silty to sandy gravel. Most fans dissected by modern streams.

Stream-terrace deposits (Holocene and late Wisconsinan) – Stratified, well to moderately-sorted, massive to laminated, and minor cross-bedded fine sand, and silt in terraces flanking present and late postglacial stream courses. As much as 20 feet (6 m) thick. In Walkill Valley overlies glacial lake-bottom deposits.

Swamp and Bog deposits (Holocene and late Wisconsinan) – Dark brown to black, 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, hollows in ground moraine, and in abandoned channels on the flood plain of the Walkill River. As much as 25 feet (8m) thick. Locally interbedded with alluvium and thin colluvium.

Colluvium and alluvium undifferentiated (Holocene and late Wisconsinan) – Stratified, thinly bedded, moderately to poorly sorted sand, silt, and minor gravel in thin sheets laid down on the floors of small upland tributaries and the lower parts of adjacent slopes. Interlayered with and overlying silt to silty-sandy diamicton (interpreted as a mass-flow deposit). Locally sandy. As much as 15 feet (5 m) thick.

Glacial Deposits

Valley-train deposits (late Wisconsinan) – Stratified, well to moderately-sorted sand, boulder-cobble to pebble gravel, and minor silt deposited by meltwater streams in the upper part of Clove Brook valley. As much as 30 feet (9 m) thick. Consists of massive to horizontally-bedded and imbricated 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.

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 (8m) 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 (30m).

Qd deposits were laid down in glacial Lake Walkill (Augusta stage) and Lake Wantage (fig. 1, on this plate). In places deposits are extensively collapsed indicating their deposition over and against stagnant ice. Numbered units in the Lake Wantage basin define successively younger ice-contact deltas that delineate local ice-retreat positions (see booklet for a detailed description of the lake's history).

Lacustrine-fan deposits (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 (30m). 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, rhythmically-bedded, alternating layers of thin clay and very fine silt, and silt and very fine sand deposited from suspension; and minor cross-laminated silt, and fine sand deposited on the floor of glacial lakes chiefly by subaqueous flows. As much as 100 feet (30m) thick. Thick deposits lie beneath Qs deposits in Walkill River valley.
- Qtk** Melwater-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 (6m) thick. Sediment and bedforms similar to the downstream, distal part of valley-train deposits. Includes boulder 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.
- Qe** Esker (late Wisconsinan) – Stratified, well- to poorly-sorted sand, and boulder-cobble to pebble gravel in narrow, sinuous collapsed ridges southwest of Unionville, New York. As much as 30 feet (9 m) thick. Attitude of bedding is unknown due to lack of exposure. Interpreted to be ice-tunnel deposits.
- Qak** Kame (late Wisconsinan) – Stratified, well- to poorly-sorted sand, boulder- to pebble-gravel, silt, and interbedded flowfill in small collapsed hills and ridges overlying till. Presumed to be ice-hole and crevasse fillings. As much as 50 feet (15m) 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 may overlie older pre-late Wisconsinan surficial deposits. Includes two varieties:
 - 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 100 feet (30 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.
 - Qtr** 2) Slightly compact to compact, unstratified, poorly sorted yellowish-brown (10YR 5/4), pale brown (10YR 6/3) to brown (10YR 5/3) noncalcareous silt and sandy silt that typically contains 5 to 15 percent gravel. As much as 65 feet (20 m) thick. Locally overlain by thin, discontinuous, non-compact, poorly sorted and layered, sand and minor silt 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 to lightly weathered gneiss, granite and minor amphibole, sandstone, and dolomite. Till derived chiefly from metasedimentary and intrusive rocks that underlie Pochuck Mountain.

- Letter "r" denotes areas of till generally less than 10 feet thick (3 m) with few to some bedrock outcrops.**
- Bedrock**
- sf** Bedrock – Extensive outcroppings, minor regolith, and scattered erratics.
- sf** Bedrock – Regolith; chiefly rock waste on very steep hillslopes and ridge crests, minor talus, scattered erratics, and a few small outcrops.

Table 1. Records of selected wells in the Unionville quadrangle, Sussex County, New Jersey. 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 Bureau of Water Allocation, Division of Water Resources, New Jersey Department of Environmental Protection. Exploratory borings are designated as explor., and their geologic record is on file at the New Jersey Geological Survey, P.O. Box 420, Mail Code 29-91, Trenton, New Jersey. The location of wells listed with NJDEP numbers is based on property maps and the location of exploratory borings is based on detailed site maps. Discharge listed in gallons per minute (gpm). Location accuracy designated by the letters "s" and "r" indicate map location generally within 200 feet and 500 feet respectively of actual location. Depth of overburden is based on depth of casing where shown by "cd" in driller's log.

Well id.	NJDEP Permit no.	Map location accuracy	Discharge in gpm	Depth in feet	Driller's log
1	22-20515	s	1	0-23	clay and gravel shale
2	22-25504	s	1	0-15	sand, clay, and gravel shale
3	22-15192	s	30	0-60	sand and gravel (cd) shale
4	22-20843	f	8	0-28	shale
5	22-23952	f	35	0-24	sand, clay, and gravel shale
6	22-15608	s	8	0-30	sand and gravel (cd) shale
7	22-17625	f	4	0-16	hardpan and gravel shale
8	22-13007	f	30	16-125	sand and gravel (cd) shale
9	22-19530	f	30	0-27	clay and gravel shale
10	22-24534	f	15	0-41	sand, clay, and gravel shale
11	22-13014	f	2	0-20	sand and gravel (cd) shale
12	22-24611	s	2	0-12	sandy loam shale
13	22-17052	f	30	0-22	sand and gravel (cd) shale
14	22-12449	f	2	0-20	sand and gravel (cd) shale
15	22-12334	s	3	0-20	sand and gravel (cd) shale
16	22-24597	f	2	0-4	sand, clay, and gravel shale
17	22-25655	f	3	0-15	clay and loam shale
18	22-24663	f	10	0-26	sand, clay, and gravel granite (?)
19	22-24621	f	25	0-14	sand, clay, and gravel shale
20	22-26928	f	2	0-10	sand, clay, and gravel shale
21	22-24791	f	20	0-35	sandy clay shale
22	22-18227	s	35	0-12	clay, sand, and gravel shale
23	22-25347	s	10	0-45	sand, clay, and gravel shale
24	22-25980	f	12	0-33	sand, clay, and gravel shale
25	22-24793	f	30	0-50	sandy clay, gravel shale
26	22-19808	s	75	0-75	clay with boulders shale
27	22-21747	f	4	0-21	clay and stones shale
28	22-17948	s	9	0-56	clay and gravel granite
29	22-19834	s	10	0-90	clay and gravel limestone
30	22-19747	s	50	0-94	clay and gravel limestone
31	22-18897	s	4	0-50	clay and gravel granite
32	22-20972	f	4	0-10	clay overburden granite
33	22-24722	s	12	0-44	sand, clay, and gravel granite
34	explor.	s	nr	0-3	humus gray clay and silt
35	explor.	s	nr	0-5	silt and fine sand
36	explor.	s	nr	0-5	humus gray clay and silt
37	22-13792	s	15	0-20	sand and gravel (cd) granite

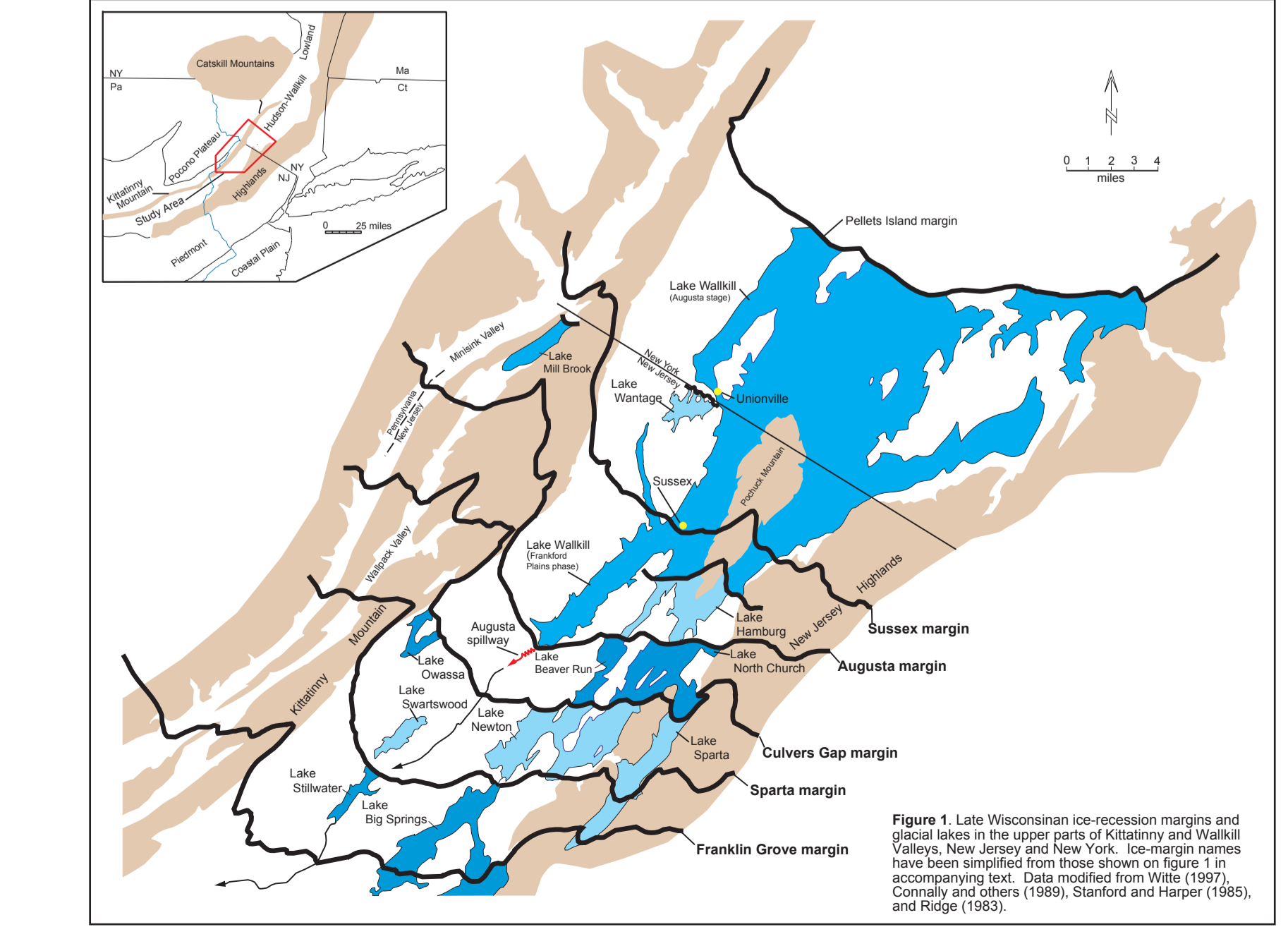
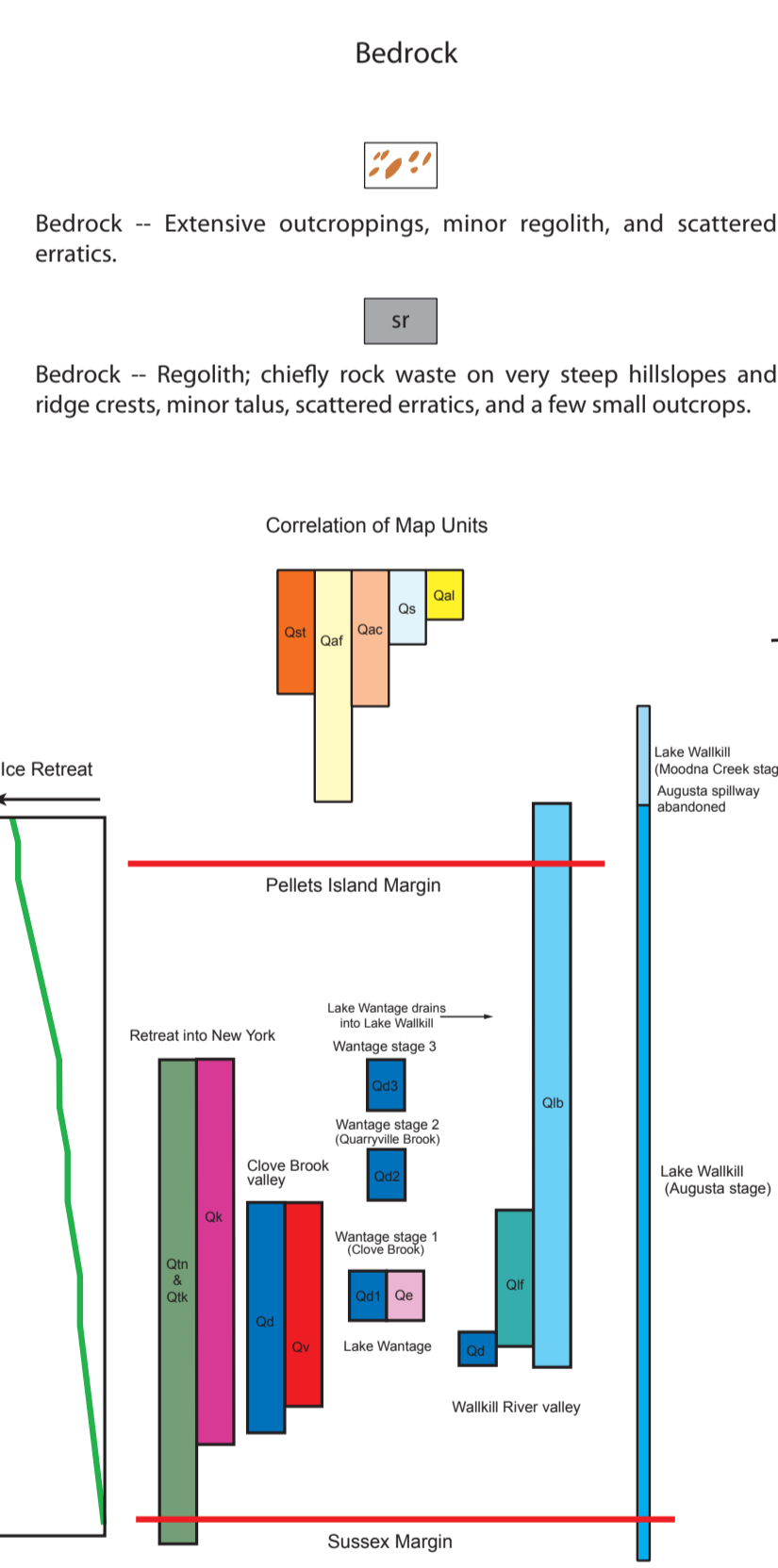


Figure 1. Late Wisconsinan ice-recession margins and glacial lakes in the upper part of Kittatinny and Walkill Valleys, New Jersey and New York. Ice margin names have been simplified from those shown on figure 1 in accompanying text. Data modified from Witte (1997), Cornally and others (1999), Stanford and Harper (1999), and Hedge (1992).

**Surficial Geologic Map of the New Jersey Part of the
Unionville Quadrangle, Sussex County, New Jersey**

by

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Open File Map

OFM 82

2011

Prepared in Cooperation with the
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National Geologic Mapping Program

Introduction

The Unionville quadrangle is located in the upper Wallkill Valley, a southern extension of the Champlain-Hudson Lowland in Sussex County, New Jersey, and Orange County, New York (fig. 1). Pochuck Mountain forms a rugged upland in the quadrangle's southeastern corner, and Kittatinny Mountain forms a high and narrow ridge in its far northwestern corner. The quadrangle's rural landscape is a mosaic of patchwork woodlands and cultivated land in valleys, larger tracts of forested land on the mountains, and a few treeless ridges. The highest point is on Shawangunk Mountain, about 1445 feet (440 m) above sea level; the lowest point lies on the Wallkill River, approximately 385 feet (117 m) above sea level.

The topography of the quadrangle is varied. In its southeastern part, the Wallkill River meanders northeastward across a broad, flat-floored valley. The valley bottom, formerly the floor of Lake Wallkill, consists of thin deposits of humus and alluvium overlying thick deposits of glacial lake-bottom sediment. Islands and pinnacles of Cambrian and Ordovician carbonate rock poke through the surficial cover. Pochuck Mountain rises about 700 feet (213 m) above the floor of the Wallkill Valley. Its topography is rugged, its rough land chiefly underlain by metasedimentary and intrusive rocks of Proterozoic age. Glacially scoured outcrops are common. Northwest of the Wallkill River is an upland underlain by slate, siltstone, and sandstone of Ordovician age (Martinsburg Formation). This area is as much as 500 feet (152 m) above the Wallkill River and it has a distinctive northeast topographic grain. The Wallkill's tributaries are deeply incised here and the surrounding hills and ridges have been streamlined by glacial erosion.

Surficial materials include glacial drift (till and meltwater deposits), and alluvium, colluvium, talus, lacustrine sediment, and swamp deposits of postglacial age. Collectively, they may be as much as 125 feet (38 m) thick, overlie bedrock, and form the parent material for soil. The glacial deposits are late Wisconsinan age and they correlate with the Olean drift in northeastern Pennsylvania (Crowl and Sevon, 1980). Meltwater deposits, consisting of ice-contact deltas, fluviodeltas, and lacustrine fans, were laid down at and beyond the glacier margin in Lake Wallkill and Lake Wantage.

Previous Investigations

Glacial deposits in Sussex County, New Jersey were discussed by Cook (1877, 1878, 1880) in a series of annual reports to the State Geologist. He included observations on recessional moraines, ages of glacial drift, distribution and kinds of drift, and evidence of glacial lakes. A voluminous report by Salisbury (1902) detailed the entire glacial geology of New Jersey, region by region. The Terminal Moraine and all drift north of it were interpreted to be products of a single glaciation of Wisconsinan age. Salisbury recognized kames, kame terraces, deltas and moraines in the Wallkill Valley, and although he realized that some of these deposits defined ice-retreat positions, he did not document them within a larger chronostratigraphic framework. Most stratified deposits were thought to have been laid down in crevasses, or in small, short-lived proglacial lakes. Based on the collapsed morphology of the meltwater deposits, their position on the sides of the valley, and exposed bedrock and till on the valley floor, it was thought that stagnant ice had covered large parts of the upper Wallkill River valley and its tributary Papakating Valley during deglaciation. The former existence of Lake Wallkill in the upper Wallkill Valley was also overlooked, largely in part because isostatic rebound was not yet recognized.

Fairchild (1912) alluded to probable glacial lakes in Wallkill Valley, and Adams (1934), Connally and Sirkin (1973), Connally and others, (1989), and Stanford and Harper (1985) suggested a large

glacial lake consisting of several stages. The highest and oldest stage, which Adams termed the 500-foot lake, was controlled by a spillway at the head of Papakating Valley near Augusta. The lake's outlet lies 495 feet (151 m) above sea level, and it straddles a drainage divide between Paulins Kill and Papakating Creek. Adams envisioned glacial meltwater in the upper Wallkill Valley, especially in Papakating Valley, flowing through a system of ice-contact lakes, crevasse passageways and superglacial valleys to the Augusta divide. The open waters of the 500-foot lake occupied only the wide parts of the Wallkill Valley near the New Jersey-New York border. A later stage, which Adams (1934) called the 400-foot lake, formed when a drainage divide between Wallkill River and Moodna Creek, located east of Middletown, New York, was uncovered by melting stagnant ice. Connally and Sirkin (1973) further added that a series of local ice-contact lakes occupied the upper Wallkill Valley before the formation of the 500-foot lake, and that a lower and final stage, called the 230-foot lake, formed when a low divide near Wallkill, New York was uncovered.

Witte (1991, 1992, 1997, 2010) detailed the deglaciation history for Kittatinny Valley, which includes the upper Wallkill Valley. During retreat of the Kittatinny Valley lobe in the late Wisconsinan, proglacial lakes formed in the Paulins Kill, Pequest, and Wallkill River valleys where drainage became blocked by meltwater sediment, moraine, and ice. The history of these glacial lakes, and ice-recessional positions marked by end moraines, and heads-of-outwash of ice-contact deltas, show that the margin of the Kittatinny Valley lobe retreated in a systematic manner to the northeast, chiefly by a process of stagnation-zone retreat. In addition, minor readvances are indicated by the Ogdensburg-Culvers Gap and Augusta moraines where they overlie glacial lake deposits (Witte, 1997). Five ice margins, the Franklin Grove, Sparta, Culvers Gap, Augusta, and Sussex, have been identified, and they delineate major recessional positions of the Kittatinny Valley lobe. The strong evidence of systematic deglaciation, and at least two readvances, show that regional or valley-ice lobe stagnation was not a valid style of deglaciation for the upper part of Kittatinny Valley. Witte (1997, 2010) refined the history of Lake Wallkill by naming the "500 foot level" the Augusta stage and adding a higher pre-Augusta, Frankford Plains phase, based on the elevation of ice-contact deltas in the upper part of Papakating Creek valley.

Glacial deposits

Till

Till overlies much of the bedrock surface and is widely distributed throughout the quadrangle. It is generally less than 20 feet (6 m) thick, and its surface expression is mostly controlled by the shape of the underlying bedrock surface. Extending through this cover are many bedrock outcrops that exhibit evidence of glacial erosion. 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.

Till is typically a compact, massive, silt to silty sand containing as much as 20 percent pebbles, cobbles, and boulders. Clasts are subangular to subrounded, faceted, and typically striated. Measured clast fabrics (R. W. Witte, unpublished data, New Jersey Geological Survey) show a preferred long-axes orientation parallel to the regional direction of glacier flow. Presumably this material is lodgement till. Overlying this lower compact till 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 clast fabrics lack a preferred orientation, or have a weak orientation that is oblique to the regional

direction of glacier flow. This material is ablation till and flowtill; they have not been mapped separately due to their scant distribution and poor exposure. Cryoturbation and colluviation have also altered the upper few feet of till making it less compact, reorienting stone fabrics, and sorting clasts.

Till has been divided lithologically into two types, and each reflects a different suite of local source rocks. These units are: (1) Qtn, chiefly from metasedimentary and intrusive rocks of Pochuck Mountain, and (2) Qtk, chiefly from slate and sandstone of the Martinsburg Formation, and dolomite of the Kittatinny Supergroup. Unit Qtn is restricted to Pochuck Mountain, whereas unit Qtk covers the bedrock floor of the Wallkill Valley and also occurs on the northwest flank of Pochuck Mountain.

Drumlins are few in the quadrangle; their long axes parallel the valley's southwesterly topographic grain. Based on nearby bedrock outcrops, and wells (table 1), most of these have bedrock cores. Other areas of thick till include aprons on north-facing hillslopes. Several records of wells drilled in the Wallkill River valley list sand and gravel, and silt and clay, directly overlying bedrock (Witte, 2010). The absence of reported till here may be due to overgeneralized driller's logs, or it may have been eroded by subglacial meltwater or active glacier ice. Based on its distribution elsewhere in the quadrangle, a thin layer of till is believed to mantle most of the buried bedrock in the valleys.

Deposits of glacial meltwater streams

Sediment carried by glacial meltwater streams was laid down at and beyond the glacier margin in valley-train deposits (Qv), ice-contact and non-ice-contact deltas (Qd), lacustrine-fan deposits (Qlf), and lake-bottom deposits (Qlb). Smaller quantities of sediment were deposited in meltwater-terrace deposits (Qft), and a few kames (Qk). Most of this material was transported by meltwater through tunnels to the glacier margin, and by meltwater streams draining deglaciated upland areas alongside the valley (Witte, 1988; Witte and Evenson, 1989). Sources of sediment are till beneath the glacier, debris in the glacier's basal dirty-ice zone, and till and reworked outwash in adjacent deglaciated uplands. Debris carried to the margin of the ice sheet by direct glacial action was minor.

Glaciofluvial sediments were laid down by meltwater streams in valley-train (Qv), meltwater-terrace deposits (Qft), and delta (Qd) topset beds. These sediments include cobbles, pebbles, sand, and minor boulders laid down in channel bars, and sand, silt, and pebbly sand in channel fill and minor overbank deposits. Sediments laid down near the glacier margin in valley-train deposits, and delta-topset beds typically includes thick, planar-bedded, and imbricated coarse gravel and sand, and minor channel-fill deposits that consist largely of cross-stratified pebbly sand and sand. Downstream (farther from the glacier's margin), the overall grain size typically decreases, sand is more abundant, and crossbedded and graded beds are more common.

Glaciolacustrine sediments were laid down by meltwater streams in glacial lake deltas (Qd), lacustrine-fan deposits (Qlf), lake-bottom deposits (Qlb), and in ice-hole fillings mapped as kames (Qk). Deltas consist of topset beds of coarse gravel and sand overlying foreset beds of fine gravel and sand. Near the meltwater feeder stream, foreset beds generally are steeply inclined (25° to 35°) 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 cross-laminated and 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.

Unlike deltas, lacustrine-fan deposits lack topset beds. They were laid down at the mouth of glacial tunnels that generally exited the glacier near the floor of the lake basin. In Lake Wallkill, a few fans may have also been laid down on the floors of unroofed glacial meltwater tunnels that were connected to the lake. Lacustrine fans also become progressively finer grained basinward. However, near the former tunnel mouth, sediments may be coarser grained and less sorted because of high sedimentation rates and little chance for sorting. If the tunnel remained open and the ice front remained stationary, the fan may have built up to lake level and formed a delta. Sedimentary layering is similar to that in deltas, except that foreset beds deposited near the tunnel mouth are more flat lying, or may dip toward the glacier margin forming backset beds.

Glacial lake-bottom deposits include 1) glacial varves and 2) subaqueous-flow deposits. Glacial varves consist of stacked annual layers that consist of a lower “summer” layer consisting chiefly of 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. Subaqueous-flow deposits consist of graded beds of sand and silt. These deposits originate from higher areas in the lake basin, such as the prodelta front, and are carried downslope into deeper parts of the lake basin by mass flows. Glacial varves grade laterally into bottomset beds of deltas and lacustrine-fan deposits.

Kames (Qk) consist of a varied mixture of stratified sand, gravel, and silt interlayered with flowtill. In many places they lie above local base-level controls and exposures show collapsed deltaic foreset bedding. Presumably they were laid down in meltwater ponds that formerly occupied an ice-crevasse, ice-walled sink, or moulin near the edge of the glacier.

Postglacial Deposits

Postglacial deposits include alluvial fan, stream-terrace, and swamp deposits, alluvium, and colluvium. Alluvium lies along Wallkill River and its tributaries, forming a narrow flood plain. Swamp deposits consisting of peat and muck, and some marl occur throughout the quadrangle. The most extensive swamp deposits cover the Wallkill River valley; formerly the floor of glacial lake Wallkill.

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

Alluvium (Qal) is chiefly middle to late Holocene in age and includes both channel (sand and gravel), and overbank (sand and silt) deposits laid down by streams. It forms narrow, sheet-like deposits on the floors of modern valleys. Upland streams are floored in places by coarse alluvium, chiefly derived from eroded till and weathered bedrock. In the Wallkill River valley, the modern flood plain lies as much as 6 feet (2 m) above the mean annual elevation of the river. At the heads of some tributaries, interlayered alluvium and colluvium (Qac) forms thin sheets of sand, silt, and gravel on the valley floor and the lowest parts of adjacent slopes.

Stream-terrace deposits (Qst) include both channel and flood-plain sediment, and they lie above the modern flood plain and below meltwater-terrace deposits. They form terraces that flank the course of modern streams.

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

Organic deposits

Many swamp and bog deposits (Qs) are 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 on ground moraine. These deposits consist principally of peat, muck, marl, and minor detritus. Peat is derived largely from decomposed reeds and sedges. Peat is typically underlain by marl in areas of carbonate bedrock where pond water is alkaline (Waksman and others, 1943).

Preglacial (late Wisconsinan) drainage

The Wallkill River, prior to the onset of the late Wisconsinan glaciation, flowed northeastward across a preglacial karst valley floor. This presumption is based on evidence that the bedrock surface beneath the thick deposits of Lake Wallkill; although highly irregular, decreases in elevation northward (Stanford and Harper, 1985; Witte (1992, 2010). Buried bedrock surface contours in Papakating Creek valley (Witte, 2010) and barbed tributaries show that Papakating Creek may have previously flowed southwest to the Paulins Kill. Glacial deposits laid down at the head of the valley near Augusta (Witte, 2010) during the late Wisconsinan deglaciation blocked the preglacial course of the creek. Following the draining of Lake Wallkill's Augusta stage, a northeastward-flowing course was established over the newly exposed lake floor.

Quaternary History

During the last ice age, the Laurentide ice sheet reached its maximum extent in New Jersey about 21,000 yrs BP (Harmon, 1968; Reimer, 1984; Cotter and others, 1986). Its most southerly limit is marked by a terminal moraine (fig. 1), except in a few places where the glacier advanced as much as a mile farther south (Witte and Stanford, 1995). The initial advance of ice into upper part of the Wallkill Valley is unclear because glacial drift and striae that record this history have been eroded or are deeply buried. If the ice sheet advanced in lobes, as suggested by the lobate course of its terminal moraine, its initial advance was marked by an ice lobe moving down the Wallkill Valley. During its maximum extent, ice flowed southward over Kittatinny Mountain into Kittatinny Valley except near the ice sheet's margin where ice was thin and its flow was constrained by the southwesterly trend of the valley. During deglaciation ice near the glacier margin further thinned, and local topography exerted greater control on the direction of ice flow and for a larger distance inward from the glacier margin (Witte, 1997). Striae in the Unionville quadrangle and elsewhere in the upper part of the Wallkill Valley (Witte, 1997) show that ice flow during deglaciation was southwestward along the axis of the valley, and that flow at the margin of the ice lobe was divergent, indicative of well-defined ice lobation. Westward-oriented striae, and the occurrence of nephelene-syenite and graywacke-sandstone erratics on Kittatinny Mountain, also indicate ice lobation (Witte, 1997, and unpublished data, on file at New Jersey Geological Survey).

Deglaciation

The recessional history of the Laurentide ice sheet has been well documented for northwestern New Jersey and parts of eastern Pennsylvania. Epstein (1969), Ridge (1983), Cotter and others (1986), and Witte (1988, 1997) showed that the margin of the Kittatinny and Minisink Valley lobes retreated systematically with minimal stagnation. Radiocarbon dating of organic material cored from Francis Lake by Cotter (1983) shows a minimum age of deglaciation at 18,750 yr BP

Reconstruction of the deglacial chronology is largely based on the morphosequence concept of Jahns (1941) and modified by Koteff and Pessl (1981), which permits delineation of ice-retreat positions by identifying heads-of-outwash laid down at the glacier's margin. Besides these positions, the distribution of moraines, and the interpretation of glacial lake histories based on correlative relationships between elevations of delta topset-foreset contacts, former glacial-lake-water plains, and lake spillways, provides a firm basis to reconstruct the ice-recessional history of the Kittatinny Valley lobe.

The distribution of morphosequences and moraines shows that late Wisconsinan deglaciation of Kittatinny Valley was characterized by the systematic northeastward retreat of the margin of the Kittatinny Valley ice lobe into the Wallkill Valley (Ridge, 1983; Witte, 1988, 1991, 1997). Minor readvances are marked by the Ogdensburg-Culvers Gap and Augusta moraines, and possibly the Libertyville moraine (Witte, 1997, 2010). During retreat, proglacial lakes developed successively in basins dammed by the glacier, and in valleys dammed by recessional meltwater deposits, moraines, and stagnant ice (fig. 1).

Formation of Lake Wallkill

Retreat of the Kittatinny Valley ice lobe from the Augusta moraine resulted in the formation of glacial Lake Wallkill in Papakating Creek valley (fig. 1). The lake initially drained south across the moraine into the Paulins Kill valley. As the size of the lake and its drainage basin increased during retreat of the ice lobe, discharge increased and the spillway was lowered by fluvial erosion into an underlying outwash deposit. Eventually, a narrow deep channel was cut through the outwash by the outflowing stream. Erosion of the channel continued until bedrock was reached, and the level of the lake stabilized. Present elevation of this threshold, called the Augusta spillway, is estimated to be 495 feet (151 m) above sea level and the period during which Lake Wallkill utilized this spillway is called the Augusta stage. Based on the estimated elevation of topset-foreset contacts in Papakating Creek valley (Witte, 2010), Lake Wallkill lowered to the Augusta stage prior to ice retreat to the Sussex margin (fig. 1). The period prior to the formation of the stable spillway is called the Frankford Plains phase of glacial Lake Wallkill.

Local Glacial History

Retreat from the Sussex margin (fig. 1) resulted in the expansion of Lake Wallkill in the upper part of the Wallkillkill Valley. Based on the elevation of the Sussex delta of 545 feet (166m), the Lake Wallkill shoreline is estimated at 550 feet (168 m) above sea level (fig. 2) in the Unionville quadrangle. At this elevation the lake also expanded up the narrow Clove Brook valley. Non-ice-contact deltaic deposits in this valley mark the former shoreline of lake. In the Wallkill River valley, Lake Wallkill deposits consist of a small non-ice-contact delta on the west shore of the lake near Quarryville and lacustrine-fan deposits along shoreline margins throughout the valley. Based

on depth to bedrock (table 1), Lake Wallkill was more than 122 feet (37 m) deep. The large lacustrine fan west of the gaging station may have been laid down in an unroofed tunnel, based on its elongated valley-parallel shape and outcroppings of sandy foreset beds. The Pellets Island margin (fig. 1 on plate 1) marks another significant halt in the retreat of the Wallkill Valley lobe. Lacustrine-fan deposits in the deeper part of the lake along the valleys axis and ice-contact deltas along the edge of the lake basin delineate the margin.

The small upland basin southwest of Unionville, New York contains ice-contact deltas that define successive ice-retreat positions. Retreat of the Wallkill lobe into this north-draining basin resulted in the formation of a small proglacial lake, called here Lake Wantage. Initially, the lake drained over a high spillway (670 feet, 204 m) into the Clove Brook valley. Qd1, an esker fed ice-contact delta was laid down in this higher stage. Further northeastward retreat uncovered a lower spillway (655 feet, 200 m) and the lake drained into Quarryville Brook valley. Qd2 was laid down in this lower stage. Deposits Qd3 were laid down in the waning phase of Lake Wantage. Based on their elevation (620 feet, 189 m) the 655 foot spillway had been abandoned; the lake presumably drained eastward following a course between the glacier's margin and shale hills south of Unionville. Glacial retreat north of Unionville, New York uncovered a small valley draining eastward toward Lake Wallkill and Lake Wantage ceased to exist.

Postglacial History

It is estimated that the Unionville quadrangle was uncovered by ice approximately 18,000 to 17,500 yrs. BP based on the oldest Francis Lake date (Cotter, 1983). The Augusta stage of Lake Wallkill continued to expand along the retreating margin of the Wallkill Valley lobe 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 drained into the Hudson Valley. This occurred about 17,000 yrs. BP, based on the estimated age of the Pellets Island moraine (fig. 1 on plate 1) in Wallkill Valley (Connally and Sirkin, 1986). In the upper part of the valley thin stream-terrace deposits and alluvial fans were laid down on the exposed floor of Lake Wallkill. Following this period of deposition the former lake basin became tilted southward due to delayed isostatic rebound, which is estimated to have begun by 14,000 yrs. BP (Koteff and Larsen, 1989). The rate of uplift has been measured at 4.79 feet per mile by Koteff and Larsen (1989) in the Connecticut Valley. In the Wallkill Valley, the rate of uplift following the valley's axis northeastward, has been estimated at three feet per mile based on a reconstruction of the Lake Wallkill water plain using delta top elevations (determined from topographic maps) and the elevation of the Augusta spillway.

As a consequence of rebound, a shallow lake flooded the upper part of the valley in late glacial to early Holocene time. The lake eventually became filled with swamp deposits and later alluvium laid down by the Wallkill River during the latter part of the Holocene. Also, following the onset of rebound, streams in south-draining valleys began a renewed period of incision, further eroding glacial valley-fill materials.

Initially, cold and wet conditions, and sparse vegetative cover enhanced erosion of hillslope material by solifluction, soil creep, and slope wash. Mechanical disintegration of rock outcrops by freeze-thaw provided additional sediment. Some of this material forms extensive aprons of talus at the base of cliffs on Kittatinny Mountain. A few small boulder fields were formed where boulders, transported downslope by creep, accumulated at the base of hillslopes and in first-order drainage basins. These fields, and other boulder concentrations formed by glacial transport and meltwater

erosion, were further modified by freeze and thaw, their stones in some places reoriented to form crudely-shaped stone circles. Gradually as the climate warmed, vegetation spread and was succeeded by types that further limited erosion.

The many swamps and poorly-drained areas in Kittatinny Valley 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 poorly-drained areas formed during the last ice age. Between 14,000 and 11,000 years ago, relatively barren lake and pond sediments, which largely consisted of weathered rock and soil washed in from surrounding uplands, became enriched with organic material. This transition probably represents a regional increase in temperature brought about by the northward retreat of the Laurentide ice sheet, resulting in an environment where it became possible for aquatic vegetation to thrive. Also, the landscape changed from tundra to a mix of small expanses of spruce and hemlock, and open land populated by shrubs and grasses. Eventually a closed boreal forest of conifers covered the area. About 10,000 years ago, at the start of the Holocene, oak and other hardwoods began to populate the landscape, eventually displacing the conifers. 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 is calcium carbonate precipitated by aquatic plants, chiefly chara (Waksman and others, 1943). Marl lies below peat in most ponds. Interlayering does occur along the pond edges and where sedimentary peat has formed in the deeper parts of the pond.

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 and animal material retrieved from swamps by coring provides stratigraphic control on regional and local changes in vegetation, which can be used as a proxy for climatic change. Several studies on bogs and swamps in northwestern New Jersey and northeastern Pennsylvania (Cotter, 1983) have established a dated pollen stratigraphy that nearly goes back to the onset of deglaciation. 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 largely consisted of spruce. During the period from about 14,250 to 11,250 years ago the regional pollen record (Cotter, 1983) shows the transition to a dense closed boreal forest that consisted of spruce and fir blanketing uplands. This was followed by a period (11,250 and 9,700 years ago) 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 the transition from the ice age to a temperate climate. About 9,400 years ago, oak became dominant, displacing conifers and marking the transition from a boreal to a mixed-hardwoods temperate forest.

Surficial Economic Resources

The most important natural resource in the quadrangle is stratified sand and gravel. Most of it lies in ice-contact deltas (Qd) and lacustrine fans (Qlf). It may be used as aggregate, subgrade fill, select fill, surface coverings, and decorative stone. The location of all sand and gravel pits and quarries is shown on the geologic map (plate 1). All pits are currently inactive except for occasional use by the land owner. Till may be used for fill and subgrade material, and large cobbles and small boulders may supply building stone. Humus and marl from swamp deposits (Qs) may be used as a soil conditioner.

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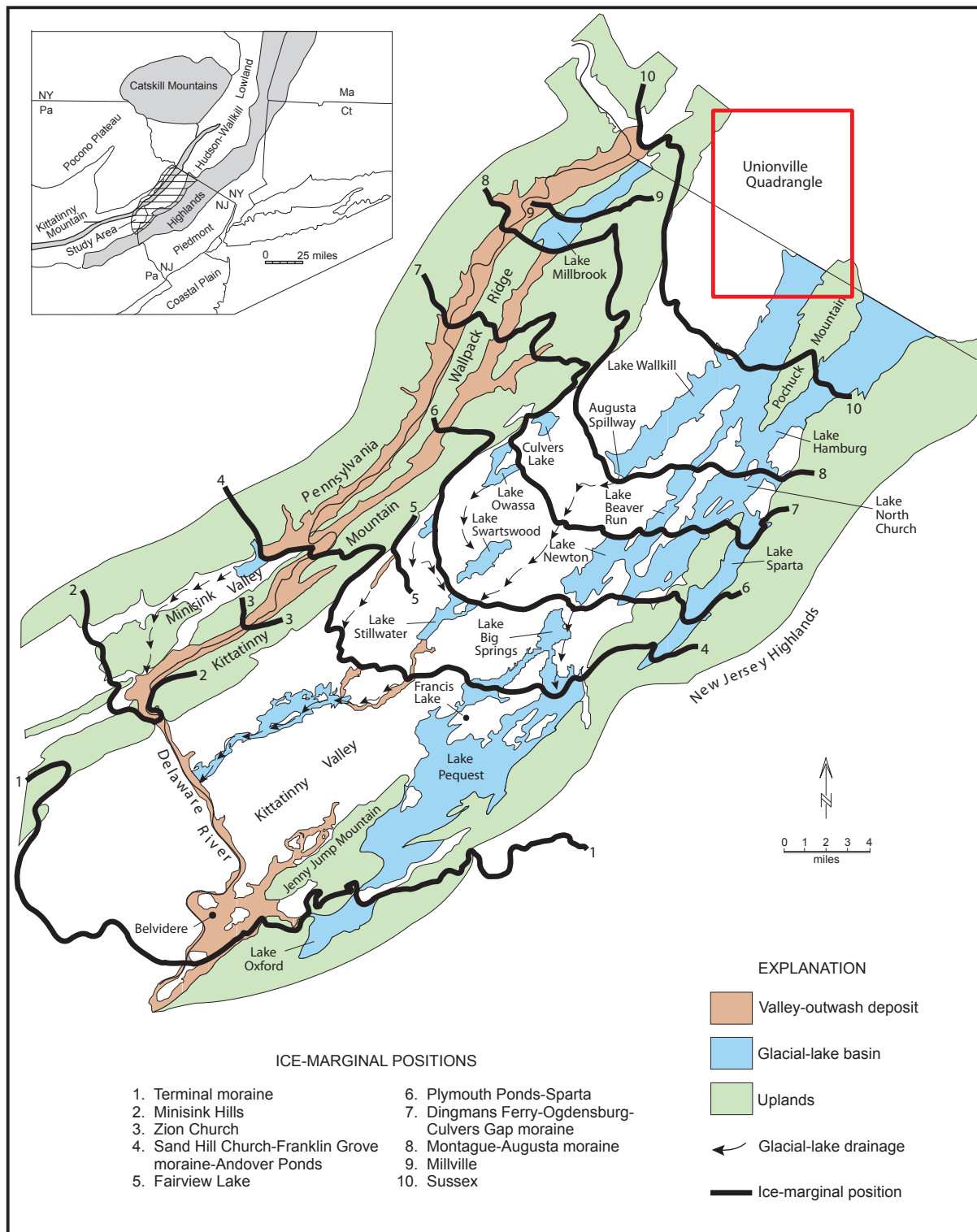


Figure 1. Late Wisconsinan ice-marginal positions of the Kattatinny and Minisink Valley ice lobes, and location of large glacial lakes, extensive valley-outwash deposits, and the Unionville 7.5-minute topographic quadrangle. Modified from data by Crowl (1971), Epstein (1969), Minard (1961), Ridge (1983), and Witte (1991b, 1997, 2010).

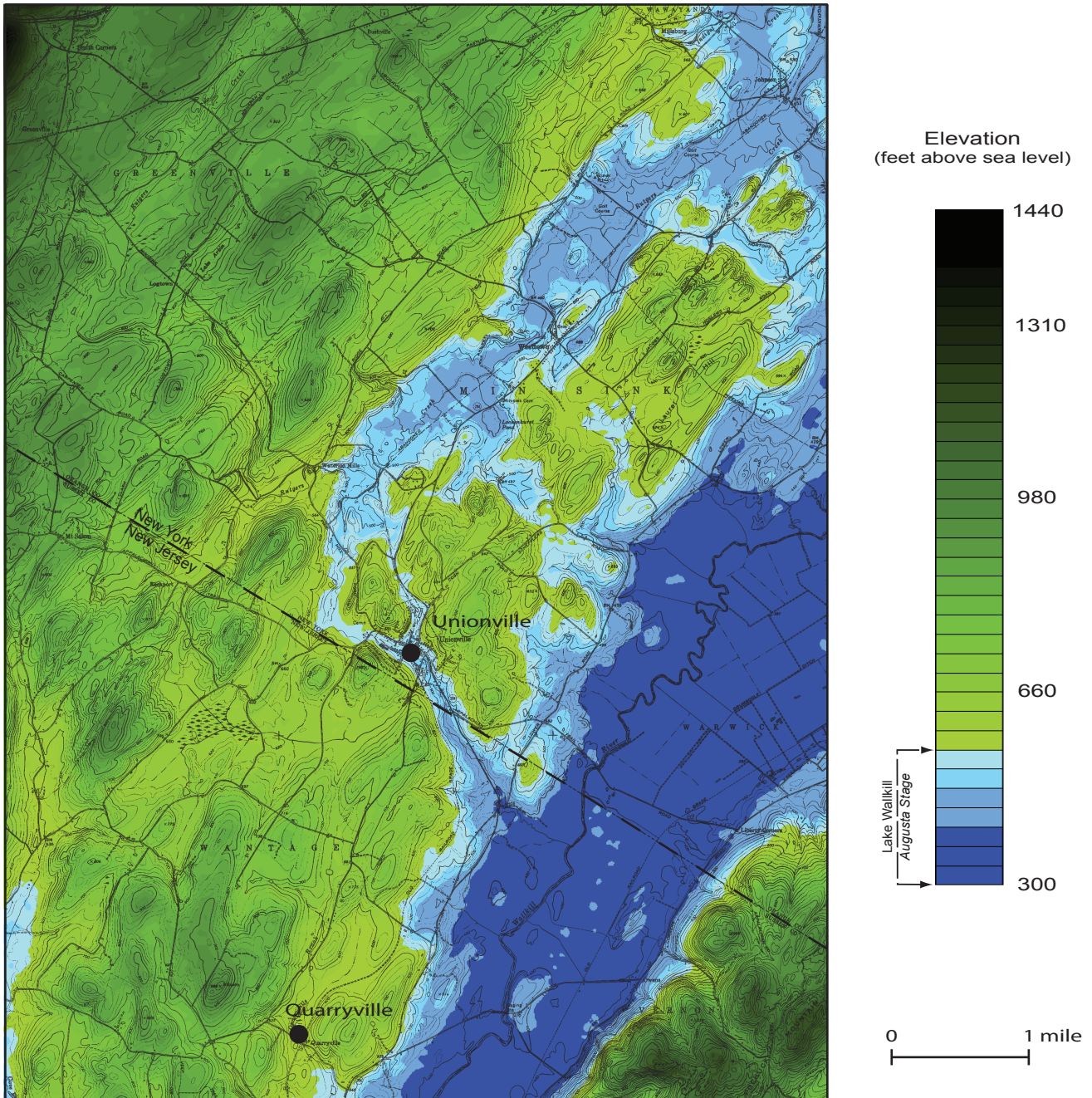


Figure 2. Shaded contour map of the Unionville quadrangle, Sussex County, New Jersey and Orange County, New York. Blue-shaded areas represent Lake Wallkill (Augusta Stage) projected to an average elevation of 550 feet. Reconstruction of Lake Wallkill's shoreline is based on the elevation of ice-contact deltas laid down in the lake. Rate of isostatic rebound along the valley's axis has been estimated at 3 feet per/ mile northeastward (Witte, 1988).