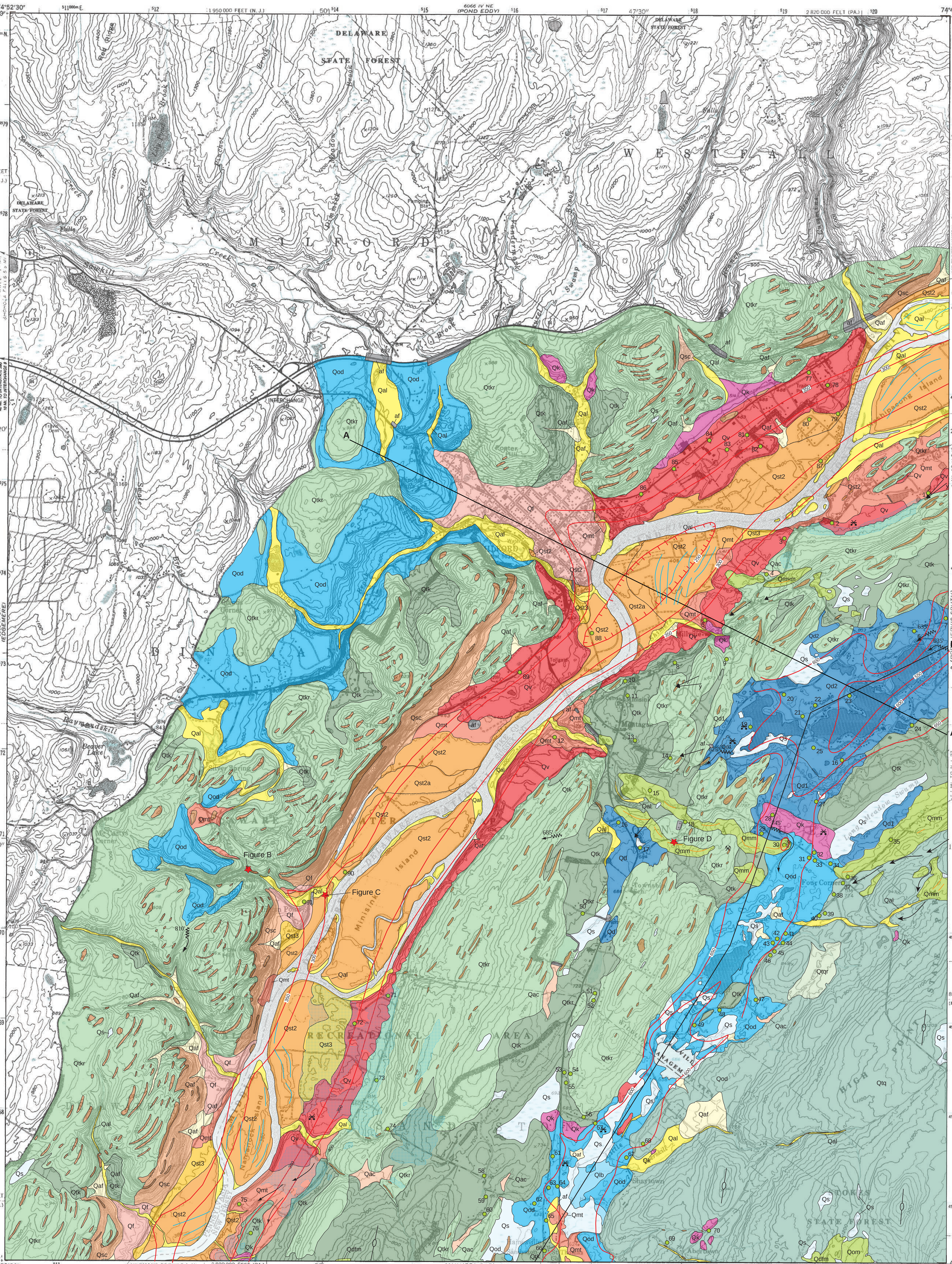
DEPARTMENT OF ENVIRONMENTAL PROTECTION
WATER RESOURCES MANAGEMENT
NEW JERSEY GEOLOGICAL AND WATER SURVEY

PREPARED IN COOPERATION WITH THE
U.S. GEOLOGICAL SURVEY
NATIONAL GEOLOGIC MAPPING PROGRAM



Base from U.S. Geological Survey Milford, 1957. Revised 1981

SCALE 1:24000

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

QUADRANGLE LOCATION

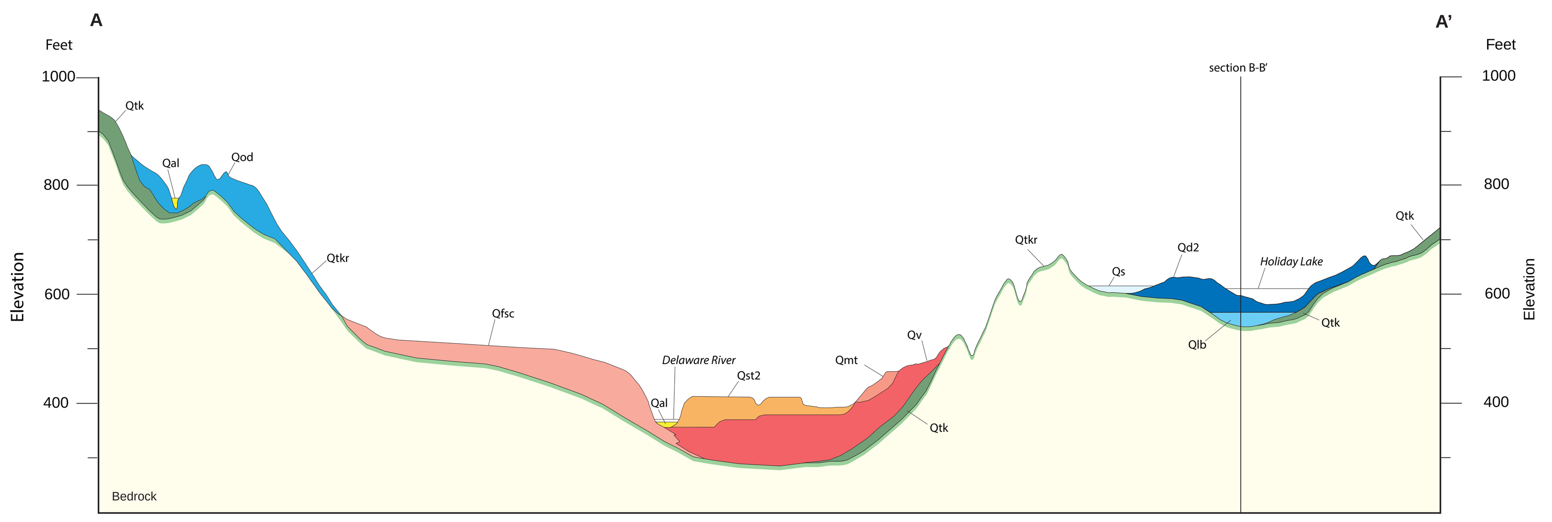
New Jersey surficial geology and Pennsylvania surficial geology in Delaware Water Gap National Recreation Area mapped by Ron W. Witte, 1991 - 1995. Elsewhere, Pennsylvania geology modified from Sevon and others (1989). Research supported by the U. S. Geological Survey, National Cooperative Geologic Mapping Program, under USGS award number 99HQAG0141. The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U. S. Government. GIS application by Mike Girard, New Jersey Geological and Water Survey. Digital cartography by Ron Witte, New Jersey Geological and Water Survey.

SURFICIAL GEOLOGIC MAP OF THE MILFORD QUADRANGLE SUSSEX COUNTY, NEW JERSEY AND PART OF PIKE COUNTY, PENNSYLVANIA

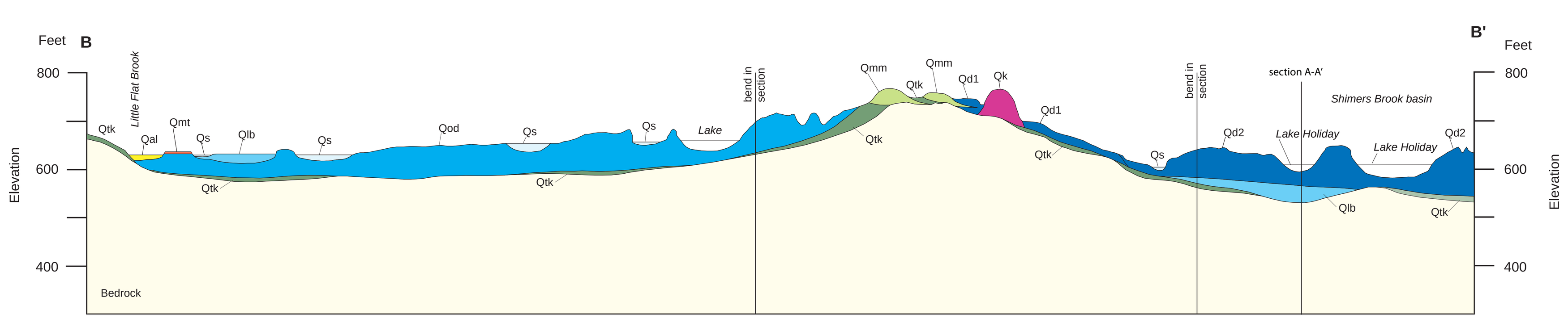
by

RON W. WITTE

2012



Vertical exaggeration = 10x. Rock outcrop is not shown on the section.



Vertical exaggeration = 10x. Rock outcrop is not shown on the section.

INTRODUCTION

Industrial, commercial, and residential expansion in New Jersey have promoted the increased use of surficial 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 Milford quadrangle are lithologically diverse, cover most of the bedrock surface, and occur 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. Collectively, these deposits may be as much as 340 feet (104 m) thick and they form the parent material on which soils form. They are defined by their lithic characteristics, stratigraphic position, location, and further delineated by genetic and morphologic criteria. Geologic history, detailed observations on surficial materials, and a list of references are 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

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 (3 m) thick. Primarily used to raise the land surface, construct earthen dams, and form a solid 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.

Qac

Alluvium and Colluvium, undifferentiated -- Stratified, poorly to moderately sorted, brown to yellowish-brown, gray sand, silt, and minor gravel; as much as 20 feet (6 m) thick. Interlayered with or overlying, massive to crudely layered, poorly sorted sand, silt, and minor gravel.

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 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 along present and former stream courses. In Minisink Valley (Delaware River valley) deposits form two distinct terraces. The youngest (Qst2) flanks early to late postglacial stream courses and overlies early to late postglacial valley gravel and sand. It lies 20 to 35 feet (6 to 11 m) above the mean annual elevation of the Delaware River and it typically 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 glacial and early postglacial stream courses and overlies glacial outwash and early postglacial 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 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.

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 along 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.

Qes

Wind-blown sand (late Wisconsinan) -- Well sorted, massively bedded, yellowish-brown (10YR 5/4) and brown (10YR 5/3) fine sand and very fine sand in thin sheets, low mounds, and ridges in Minisink Valley and on the western slopes of Wallpack Ridge. As much as 10 feet thick (3 m).

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 in Minisink Valley from ice-recessional positions (Figure 2 in booklet) and at and extending well beyond (greater than five miles (8 km)) the glacier 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. In places overlies glacial lake deposits previously laid down in sediment-dammed proglacial lakes. In places overlain by noncompact, well-sorted, very fine sand and fine sand presumed to be eolian; as much as 10 feet (3 m) thick. In Minisink Valley forms shingled sets of outwash terraces.

Qf

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 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 fine sand to sand and silt with minor clay drapes. Thickness may be as much as 100 feet (30 m). In the Shimers Brook basin, Qd deposits are labelled "1" and "2" to denote ages with "1" the oldest delta.

Qd deposits were laid down in Shimers Brook basin and Qod deposits were laid down in narrow sediment-dammed proglacial lakes in Flat Brook, Raymondskill Creek, and Sawkill Creek Valleys. Many of the deposits are extensively kettled, showing deposition on and around stagnant ice. In long lake basins, topset beds are extensively aggraded in their upstream sections.

Qlb

Glacial lake-bottom deposits (late Wisconsinan) -- Parallel-laminated, irregularly to rhythmically-bedded silt, clay, and very fine sand; minor cross-laminated silt, fine sand, and fine sand; 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.

Qmt

Meltwater-terrace deposits (late Wisconsinan) -- Stratified, well- to moderately-sorted, cobble-pebble to pebble gravel, sand, 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, 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 limestone, argillaceous limestone, shale, and sandstone from areas west of Kittatinny Mountain. "r" denotes area 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 (15m) 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 on Kittatinny Mountain. "r" denotes area of till generally less than 10 feet thick (3 m) with few to some bedrock outcrops.

Qmm Qdfm Qmvm

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 stratified 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 Montague (Qmm), Dingmans Ferry (Qdfm), and Millville (Qmvm) moraines.

Bedrock

Bedrock -- Extensive outcrops, minor frost-shattered rock, talus, and sparse erratics.

Table 1. Records of selected wells in the Milford quadrangle, Sussex County, New Jersey, and Pike County, Pennsylvania. The wells listed 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. Wells without a NJDEP permit number are from Davis (1989) and noted in the table as "Pike" followed by an identification number that was used in the report. Location accuracy and discharge were unavailable for "Pike" wells. Additional wells listed as "soil borings" are from Cerenzio and Panaro, P. C. (written comun. 1991). Accuracy in plotting well locations is listed as S, F, or T (100, 500, or 1000 feet of actual location). Locations are based on property maps, NJDEP atlas sheet coordinates, and driller's site maps. Key to driller's log for wells listed in Davis (1989); Qaoo - alluvium and Olean outwash, and Qoic - Olean ice-contact stratified and and gravel.

well number	NJDEP permit number	Location code	Discharge in gallons per minute	Depth in feet	Driller's log
1	22-21893	S	10	0-25	overburden
				25-188	shale
2	21-6360	S	7	0-46	sand and gravel
				46-225	shale
3	21-367	F	20	0-20	hardpan
				20-30	hardpan and boulders
				30-33	sand and water
				33-125	limestone
				125-140	rotten limestone
4	21-454	S	4	0-41	casing depth (well depth = 190 feet)
5	21-319	S	20	0-74	casing depth (well depth = 95 feet)
6	22-23428	F	4	0-30	clay and gravel overburden
				30-400	slate
7	21-5503	S	100	0-122	sand and gravel
				122-125	slate
8	22-2709	F	27	0-25	hardpan and boulders
				25-40	sandy loam, gravel, and water
				40-52	gravel and broken rock
				52-100	blue lime rock
				100-132	yellow lime rock
				132-154	brown sandstone
				154-187	yellow lime rock
				187-223	lime rock
				223-235	brown sandstone
9	21-6712	F	none	0-40	sandy loam
				40-310	shale
10	21-2700	F	15	0-15	hardpan and cobbles
				15-25	lime rock, broken up
				25-72	lime rock
				72-89	yellow lime rock
				89-128	lime rock
				128-136	brown sandstone
				136-349	lime rock
				349-375	brown sandstone
11	21-1040	F	6	0-25	hardpan
				25-50	hardpan, boulders, and gravel
				50-65	gravel, sand, and water
				65-165	shale
12	21-3732	T	22	0-50	hardpan and boulders
				50-70	sand, gravel, and water
				70-86	sand, gravel, and blue clay
				86-97	blue clay and broken up rock
				97-172	black lime rock
				172-210	shale rock
				210-262	hard gray rock
				262-286	brown sandstone
13	21-307	S	20	0-20	hardpan and boulders
				20-25	gravel and sand
				25-50	black shale
				50-70	gray rock
				70-98	shale and water
14	21-2392	F	56	0-20	hardpan
				20-50	lime rock, broken up
				50-70	lime rock, sand, and water
				70-112	blue lime rock
				112-118	yellow lime rock
				118-128	brown rock with quartz
15	21-1605	F	3	0-25	hardpan and boulders
				25-50	clay, gravel, and water
				50-62	blue clay
				62-131	blue shale rock
				131-200	hard gray rock
				200-289	blue shale rock
16	21-1372	F	35	0-50	hardpan and boulders
				50-75	gravel and blue clay
				75-100	sand, gravel, and water
				100-118	blue clay
				118-175	black lime rock
				175-258	limestone
				258-278	yellow limestone
17	21-1497	F	40	0-42	casing depth (well depth = 104 feet)
18	21-1435	F	22	0-25	hardpan
				25-42	hardpan and broken rock
				42-114	limestone
				114-135	soft yellow limestone
19	soil boring	S	none	0-2	brown silt and little fine sand
				2-4	brown sand
				4-12	brown silt and very fine sand
				12-30	brown fine sand and some silt
				30-35	gray clay and silt
				35-40	brown silt, sand, and some fine gravel
				40-41	brown to tan clay over dark gray
20	soil boring	S	none	0-6	brown clay and silt
				6-32	brown sand, some silt, and trace of clay
				32-40	gray clay and silt, trace of fine sand
				40-50	gray fine sand, trace of silt and clay
				50-52	sand and fine gravel
				52-57	gray clay and silt, some fine sand
21	soil boring	S	none	0-18	brown fine sand, silt, and fine gravel
				18-22	coarse gravel
				22-31	brown clay to fine sand
				31-33	brown silt to fine sand
				33-34	coarse gravel
				34-40	brown clay to fine sand, some fine gravel
				40-50	brown fine sand and silt
				50-55	gray to brown fine sand and silt
				55-70	gray to brown silt, some very fine sand
				70-75	gray to brown silt, trace of sand, and clayey seams
				75-82	gray to brown very fine sand and silt
22	soil boring	S	none	0-8	brown silt, some sand, and trace of gravel
				8-13	brown silt and clay, trace of sand
				13-16	brown sand and some silt
				16-17	gravel, littte silt and fine sand
				17-31	brown sand, trace of fine gravel and silt
				31-75	brown sand and trace of silt
				75-84	brown to gray clay and gray silt
				84-85	weathered bedrock
23	soil boring	S	none	0-50	clay, boulders and gravel
				50-100	gravel and red clay
				100-112	gravel
				112-150	red rock
				150-250	gray rock
				250-350	red rock
				350-450	brown sandstone
24	21-1849	F	100	0-60	casing depth (well depth = 250 feet)
25	soil boring	S	none	0-1	black silt
				1-22	brown sand, trace of silt
				22-27	brown silty clay
				27-50	brown sand, trace of silt
				50-51	hard gray clay and silt
				51-52	weathered limestone
26	soil boring	S	none	0-1	black silt
				1-3	brown silt, some sand, trace of fine gravel and silt
				3-7	brown sand, trace of clay, silt and fine gravel
				7-14	brown silt, trace of sand, and fine gravel
				14-18	brown sand and some silt
				18-20	brown clayey silt, some fine gravel
				20-21	gravel, some fine sand
				21-25	compact brown clayey silt, trace of gravel and sand
				25-26	weathered limestone
27	soil boring	S	none listed	0-3	brown silt, little sand, and trace of fine gravel
				3-8	brown clay, little sand and silt, and trace of fine gravel
				8-21	brown sand, little fine gravel, and trace of silt
				21-75	brown clay and silt, little sand, and trace of fine gravel
				75-86	brown clay, little sand and silt
				86-91	red brown clay, some brown fine sand, and trace of black gravel
				91-92	black shale
28	21-5652	S	75	0-130	sand, gravel, and boulders
				130-165	red rock
29	21-6248	F	30	0-120	sand and gravel
				120-188	red rock
30	21-6249	F	30	0-95	sand and gravel
				95-188	red rock
31	21-5456	S	20	0-112	boulders, sand, and gravel
				112-180	red rock
32	21-6410	F	20	0-90	sand and gravel
				90-208	red rock
33	21-6322	S	30	0-94	sand, gravel, and boulders
				94-280	red rock
34	21- 6878	S	none listed	0-50	boulders and gravel
				50-71	large gravel and sand
				71-208	red rock
35	21-5841	S	12	0-29	sand, clay, and gravel
				29-100	red slate
36	21-6075	S	50	0-65	gravel and boulders
				65-125	red rock
37	21-5525	S	6	0-70	gravel and boulders
				70-208	red rock
38	21-5847	S	5	0-30	sand, gravel, and boulders
				30-290	red rock
39	21-5500	S	10	0-55	boulders and gravel
				55-350	red rock
40	21-5914	S	6	0-15	gravel and boulders
				15-188	red rock
41	21-5375	S	4	0-68	boulders
				68-290	red rock
42	21-5989	S	25	0-83	cobbles, stones, and sand
				83-250	red rock
43	21-4984	S	30	0-100	gravel, sand, and boulders
				100-136	rock
44	21-6499	S	12	0-12	loam and boulders
				12-35	gravel and sand
				35-208	red rock
45	21-6422	S	15	0-86	overburden
				86-175	red rock
46	21-6155	S	75	0-48	gravel and boulders
				48-180	red rock
47	21-5110	S	12	0-40	overburden
				40-208	red rock
48	21-6331	S	30	0-80	sand and gravel
				80-145	red rock
49	22-20658	S	16	0-73	overburden (casing depth)
				73-125	red rock
50	21-1295	F/T	6	0-25	hardpan and boulders
				25-50	hardpan and gravel
				50-90	gravel, sand, and water
				90-95	blue clay and rock
				95-175	lime rock
				175-184	brown sandstone
				184-225	hard blue limestone
				225-233	yellow limestone
51	21-6944	S	15	0-43	sand, clay, and gravel overburden
				43-175	slate
52	21-6642	S	7 (artesian)	0-15	overburden
				15-200	shale
53	21-5744	S	5	0-70	boulders and gravel
				70-135	limestone
54	21-6936	S	12	0-50	sand, clay, and gravel overburden
				50-200	slate rock
55	21-1727	F	10	0-50	hardpan and boulders
				50-100	yellow clay and gravel
				100-110	gravel and water
56	21-5114	F	20	0-60	sand and coarse gravel
				60-105	rock
57	21-6676	S	75	0-50	gravel, sand, and some boulders
				50-166	red rock
58	21-7123	S	50	0-98	clay with some gravel
				98-310	shale
59	21-6912	F	20	0-48	clay, gravel, and water
				48-175	blue shale
60	21-5617	S	50	0-12	sandy loam
				12-290	shale
61	21-4785	S	10	0-55	casing depth
62	21-6153	S	10	0-35	sandy loam / limestone
63	21-5733	S	15	0-55	sand
				55-57	boulder
				57-63	sand and gravel
				63-123	shale
64	21-6978	S		0-73	sand, gravel, and boulders
				73-125	limestone
65	21-6724	S	none	0-15	silty gravel
				15-125	limestone
66	21-5872	S	20	0-15	overburden
				15-150	shale
67	22-25423	S	20	0-55	sand, clay, and gravel overburden
				55-125	red slate
68	21-7095	F	50	0-106	sand and gravel with some boulders
				106-145	red rock
69	21-2069	F	20	0-84	casing depth (well depth = 130 feet)
70	21-4100	S/F	5	0-42	sand and gravel overburden
				42-149	red shale rock
71	21-828	F	20	0-32	casing depth (well depth = 161 feet)
72	21-516	S	30	0-126	casing depth (well depth = 139 feet)
73	21-164	F/T	40	0-35	casing depth (well depth = 87 feet)
74	21-895	F	30	0-34	casing depth (well depth = 166 feet)
75	21-642	F/T	20	0-145	casing depth (well depth = 185 feet)
76	21-106	T	20	0-130	casing depth (well depth = 130 feet)
77	Pike - 231			0-136	Qoic
78	Pike - 106			0-131	Qoic
79	Pike - 233			0-145	Qoic
80	Pike - 232			0-130	Qaoo
81	Pike - 299			0-125	Qoic
82	Pike - 227			0-214	Qoic
83	Pike - 229			0-200	Qoic
84	Pike - 103			0-90	Qoic
85	Pike - 102			0-125	Qoic
86	Pike - 101			0-108	Qoic
87	Pike - 104			0-104	Qaoo
88	Pike - 32			0-160	Qaoo
89	Pike - 117			0-145	Qoic
90	Pike - 142			0-40	Qaoo
91	Pike - 141			0-58	Qaoo

Figure D. Stony till exposed in a foundation cut-face dug in the Montague moraine. The Montague moraine is a recessional moraine deposited at the margin of the Mininsink Valley ice sublobe (see fig. 2 in booklet). Recessional moraines in the Milford quadrangle consist largely of till with minor pockets and lenses of statified sediment. Entrenching shovel for scale near top left of photo.

EXPLANATION OF MAP SYMBOLS

Contact, dashed where approximately located or gradational.

Striation, measurement at tip of arrow. The letter "y" denotes a younger striation based on crosscutting relationships.

Drumlin, line on crest, ellipse on summit.

Small meltwater channel.

Large kettle in glacial outwash or moraine. Smaller kettles on moraines are not shown. Tics point downslope.

Morainal ridge, line at crest.

925' Glacial-lake spillway with estimated elevation of its floor.

Fluvial scarp, line lies at base of scarp and tics point upslope.

Alluvial channel scroll, line along channel axis.

Active sand and gravel pit.

Inactive sand and gravel pit.

Quarry.

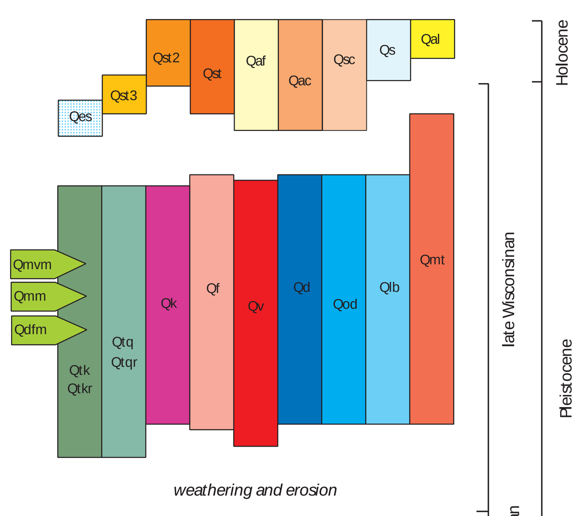
Inactive quarry.

550 Bedrock surface contour - Shown where rock surface is buried beneath thick glacial sediment. Approximately located, indicates altitude of rock surface in feet above sea level. Contour interval is 50 feet. Hachures indicate closed depression.

12 Location of well or boring listed in Table 1 on this plate and well id. listed in Table 1.

Location of photograph (figures B, C, and D).

CORRELATION OF MAP UNITS



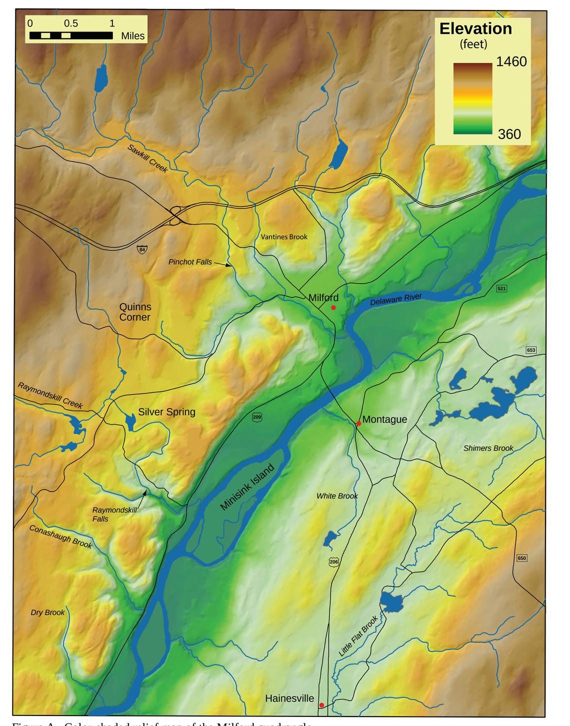


Figure A. Color-shaded relief map of the Milford quadrangle.

Figure B. Lower falls (right) and Bridal Veil Falls (left), Raymondskill Falls, Pike County, Pennsylvania. The upper falls (upper right of photo) has retreated about 250 feet from the lower falls. At one time, Raymondskill Falls may have existed as one large cataract more than 150 feet in height. Erosion, largely by meltwater streams of greatly varying discharge during the Illinoian and late Wisconsinan glaciations has cut back the falls to their present form.

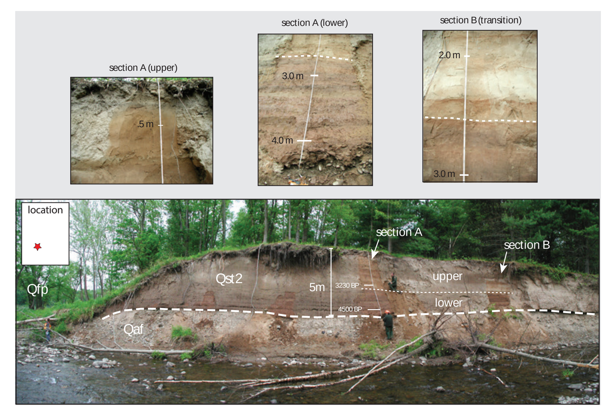


Figure C. Panorama of Raymondskill bluff with inset photographs showing close-ups of alluvial strata and buried paleosols. The bluff exposes coarse gravel of an older alluvial fan (Qaf) overlain by about 5 m of overbank sediment. Radiocarbon dates 4500+/- 40 yr B.P. (GX-28162-AMS) and 3230 +/- 40 yr B.P. (GX-28163-AMS) were determined from charcoal that was collected from charcoal-enriched alluvial stratum. The oldest date suggests that the Qst2 stream-terrace may be as old as 5000 years, an age that represents the last half of the Holocene. Cultural periods represented by the bluff include the Late Archaic (6000 to 4000 yr B.P.), Terminal Archaic (4000 to 3000 yr B.P.), Woodland (3000 to 400 yr B.P.) and Historic cultural periods. Qfp is the modern flood plain and it is equivalent to Qal on the surficial geologic map. Figure from Witte and Wright (2001).

NEW JERSEY GEOLOGICAL AND WATER SURVEY

OPEN-FILE MAP OFM 96

SURFICIAL GEOLOGY OF THE MILFORD QUADRANGLE
SUSSEX COUNTY, NEW JERSEY AND
PART OF PIKE COUNTY, PENNSYLVANIA

by

Ron W. Witte
New Jersey Geological and Water Survey
OPEN FILE MAP
OFM 96
2012

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

NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION

The mission of the New Jersey Department of Environmental Protection is to assist the residents of New Jersey in preserving, sustaining, protecting and enhancing the environment to ensure the integration of high environmental quality, public health and economic vitality.

NEW JERSEY GEOLOGICAL AND WATER SURVEY

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Cover photo: Looking east toward the wooded slope of Wallpack Ridge, low-relief sand dunes cover late Wisconsinan outwash in Minisink Valley east of Namanock Island, Delaware Water Gap National Recreation Area.   Photograph by Ron W. Witte.

SURFICIAL GEOLOGY OF THE MILFORD QUADRANGLE, SUSSEX COUNTY, NEW JERSEY AND PART OF PIKE COUNTY, PENNSYLVANIA

Ron W. Witte

New Jersey Geological and Water Survey

INTRODUCTION

The Milford quadrangle is located in the glaciated part of the Appalachian Valley and Ridge physiographic province in Sussex County, New Jersey, and Pike County, Pennsylvania. Its main geographic features are Wallpack and Minisink Valleys, Wallpack Ridge, and Kittatinny Mountain (fig. 1). This area is largely rural; its land covered by large tracts of forest that lie in the Delaware Water Gap National Recreation Area, Stokes State Forest, and High Point State Park, along side patchwork woodlands and cultivated fields in the valleys. The Delaware River, the master stream in this area, flows southwest through Minisink Valley and separates New Jersey and Pennsylvania. The highest point is on the western flank of Kittatinny Mountain, 1360 feet (415 m) above sea level and the lowest point is the Delaware River, approximately 365 feet (111 m) above sea level where it leaves the quadrangle. Mapped area in Pennsylvania in part extended to the western boundary of the Delaware Water Gap National Recreation Area. Elsewhere, the boundary was arbitrarily placed near the Interstate Route 84 corridor.

Surficial materials consist of till and meltwater sediment deposited during the late Wisconsinan glaciation, and postglacial deposits of alluvium, colluvium, talus, organic soil, and wind-blown sediment. These materials may be as much as 250 feet (76 m) thick, overlie bedrock, and form the parent material on which soils form. The glacial deposits are late Wisconsinan age and are correlative with the Olean Drift of northeastern Pennsylvania (Crowl and Sevon, 1980). Till typically overlies bedrock. In many places it is interspersed with numerous glacially-eroded bedrock outcrops. Thicker till forms drumlins, ground moraine, recessional moraine and aprons on north-facing hillslopes. Meltwater deposits, laid down at and beyond the glacier margin, lie in valleys in which the Delaware River and its tributaries Little Flat Brook, White Brook, Shimers Brook, Raymondskill Creek, and Sawkill Creek flow. The heads of outwash of these deposits and recessional moraines delineate retreat positions of the Minisink Valley and the Kittatinny Valley ice lobes. The postglacial deposits are late Pleistocene and Holocene age and occur in a variety of settings. Thickest deposits lie in Minisink Valley and consist of alluvium deposited by the Delaware River. For detailed discussions about the glacial and postglacial history of northwestern New Jersey see Witte (1997, 2001a, 2001b, 2008) and Witte and Epstein (2004).

PREVIOUS INVESTIGATIONS

Surficial deposits of Sussex County, New Jersey were discussed by Cook (1877, 1878, and 1880) in a series of Annual Reports of the State Geologist. He included detailed observations on recessional moraines, age of drift, distribution and types of drift, and evidence of glacial lakes. Shortly thereafter, White (1882) described the glacial geology of Pike County, 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 glacial 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." Crowl (1971) produced surficial geologic maps of parts of the quadrangles, and included detailed observations on glacial drift and its history in Minisink Valley. Crowl and Sevon (1980), and Cotter and others (1986) indicated that the youngest glacial deposits in New Jersey and eastern Pennsylvania are of late Wisconsinan age, and Sevon and others (1989) reported on the surficial geology of Pike County, Pennsylvania.

Recessional moraines in Kittatinny Valley were originally identified by Salisbury (1902), and latter remapped by Herpers (1961), Ridge (1983), and Witte (1997). The Ogdensburg-Culvers Gap and Augusta moraines (fig. 2) were traced on Kittatinny Mountain by Herpers (1961), and Minard (1961), and later remapped by Witte (1997), and Stone and others (2002). In Minisink and Wallpack Valleys, the Dingmans Ferry and Montague moraines (fig. 2) were identified by Salisbury (1902), Minard (1961), and Crowl (1971), and later remapped and correlated to the Ogdensburg-Culvers Gap and Augusta moraines by Witte (1997). The Millville and Steeny Kill Lake moraines were identified by Witte (1997).

PHYSIOGRAPHY AND BEDROCK GEOLOGY

The Milford quadrangle is in the Delaware River drainage basin. The Delaware flows southwestward through Minisink Valley following the Onondaga Limestone and Marcellus Shale. The western side of the valley is bordered by the Mahantango Formation and its eastern side is bordered by Wallpack Ridge. Tributaries in Pennsylvania typically flow at right angles to the Delaware River and are deeply incised, flowing over rock before entering the trunk valley. In New Jersey, Little Flat Brook flows southwestward in Wallpack Valley, following the strike of less resistant bedrock. Waterfalls are common, mostly they are products of knickpoint retreat due to glacial widening and deepening of Minisink Valley. Multiple knickpoints, abandoned and notched falls, and varying distances of falls from Mininsink Valley hint of multiple glaciations, and stream diversion by glacial ice and glacial deltas (Witte, 2001c).

Kittatinny Mountain is underlain by quartz-pebble conglomerate, quartzite, red sandstone, and red shale; all of Silurian age. The mountain forms a ridge extending from the Shawangunk Mountains in New York southwestward through New Jersey into Pennsylvania, and its steep southeast face forms a nearly continu-

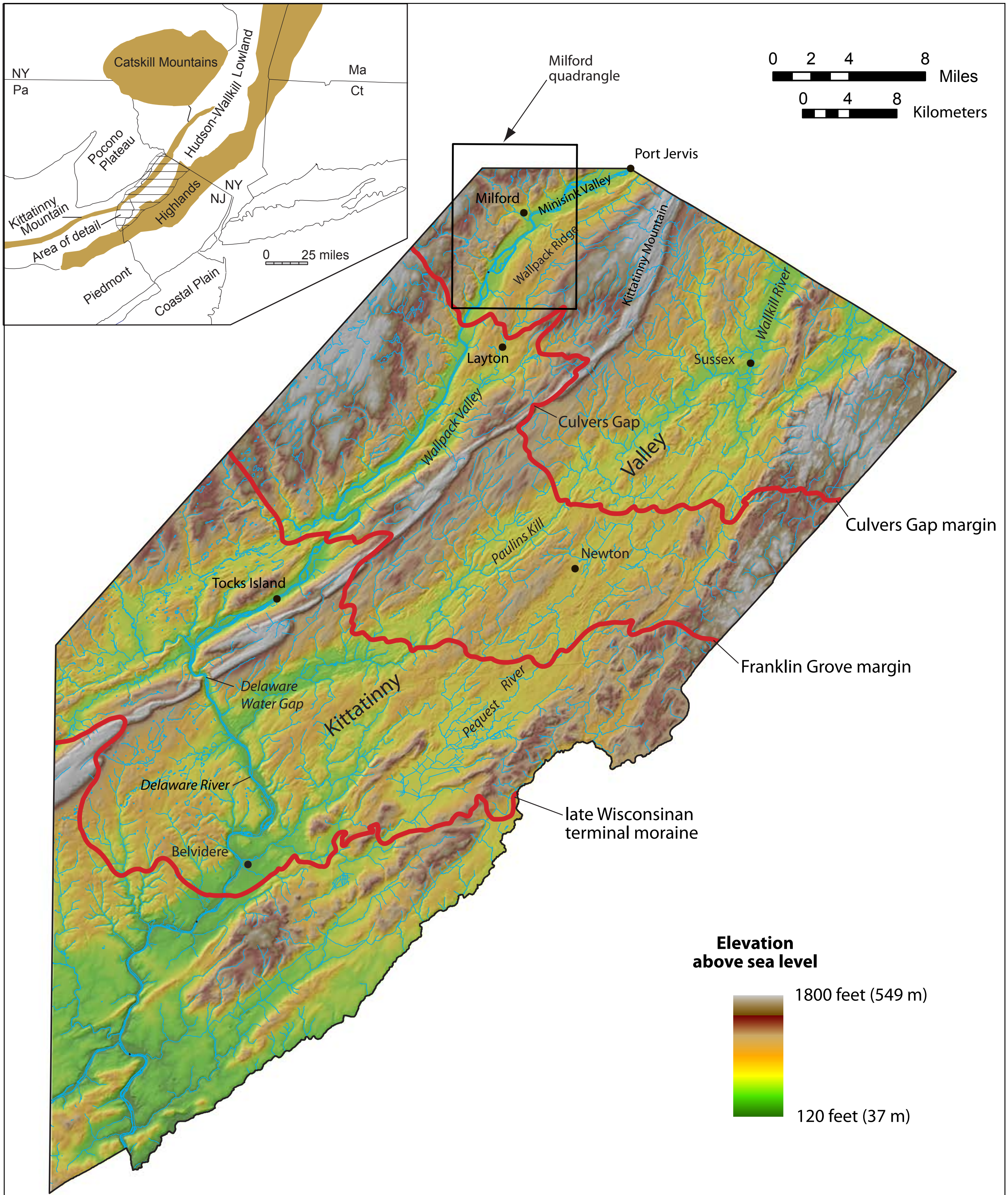


Figure 1. Physiography of northwestern New Jersey and part of northeastern Pennsylvania and location of the Milford quadrangle. Minisink Valley is a local geographic name for the Delaware River valley from Delaware Water Gap to Port Jervis, New York.

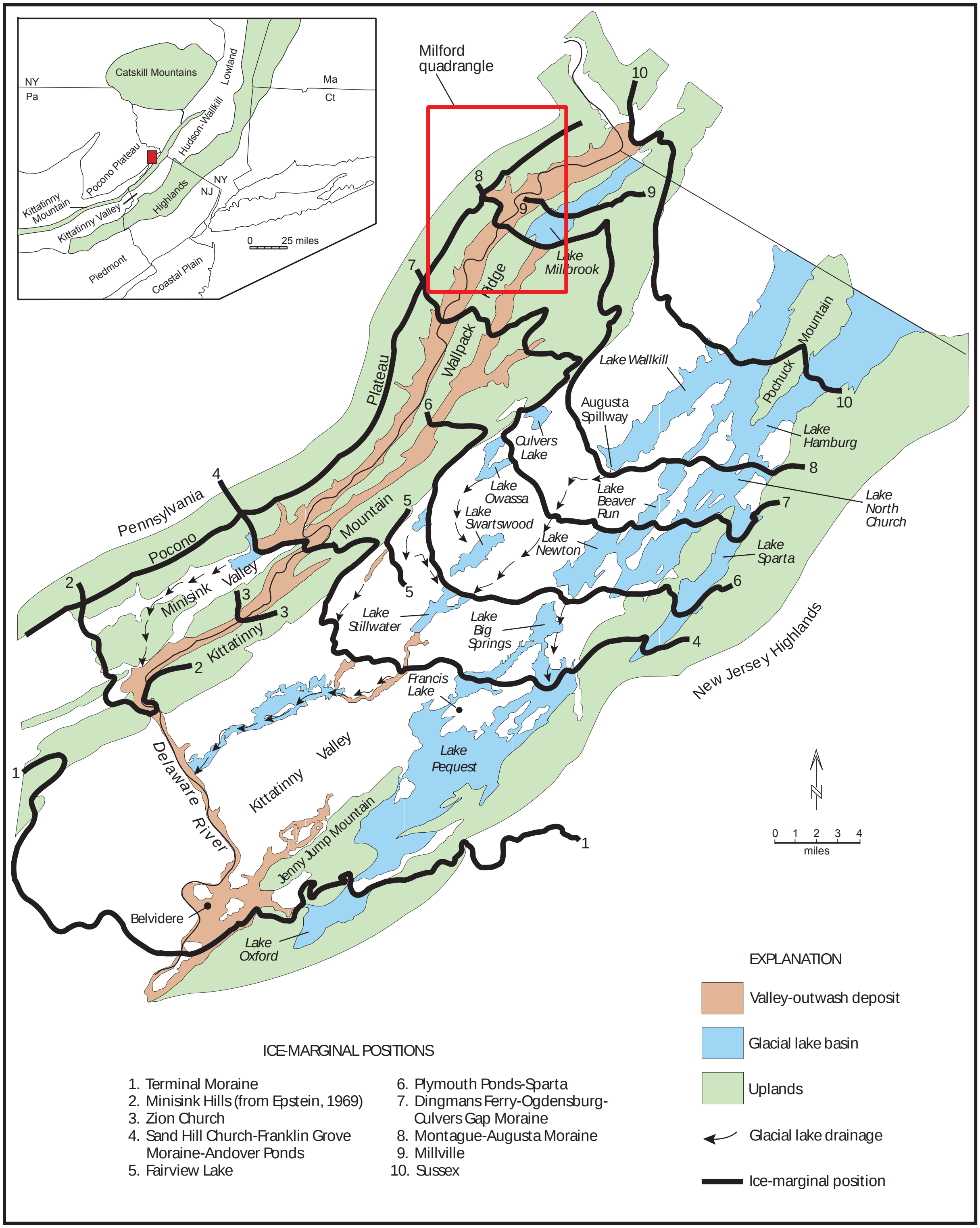


Figure 2. Late Wisconsinan ice margins of the Kittatinny and Minisink Valley ice lobes, and location of large glacial lakes, extensive valley-outwash deposits, and Milford 7.5-minute topographic quadrangle. Modified from data by Crowl (1971), Epstein (1969), Minard (1961), Ridge (1983), and Witte (1997).

ous escarpment (fig. 1). In places the continuity of the mountain is broken by wind gaps. The largest of these is Culvers Gap (fig. 1) and it marks the former site of a large river that abandoned its course at some time during the Late Tertiary (Witte and Epstein, 2004). Topography of the mountain is rugged, chiefly consisting of narrow- to broad-crested, strike-parallel ridges. Rock outcrops are very abundant and they exhibit extensive glacial scour and plucking. The high ridge area of the mountain is east of the quadrangle, but the mountain's long northwestern slope extends to Wallpack Valley. This area is underlain by red sandstone and shale, and in most places it is covered by thick glacial drift. Relief here may be as much as 300 feet (91 m), and the surface is marked by rolling topography of gentle to moderate slopes chiefly formed by drumlins and ground moraine.

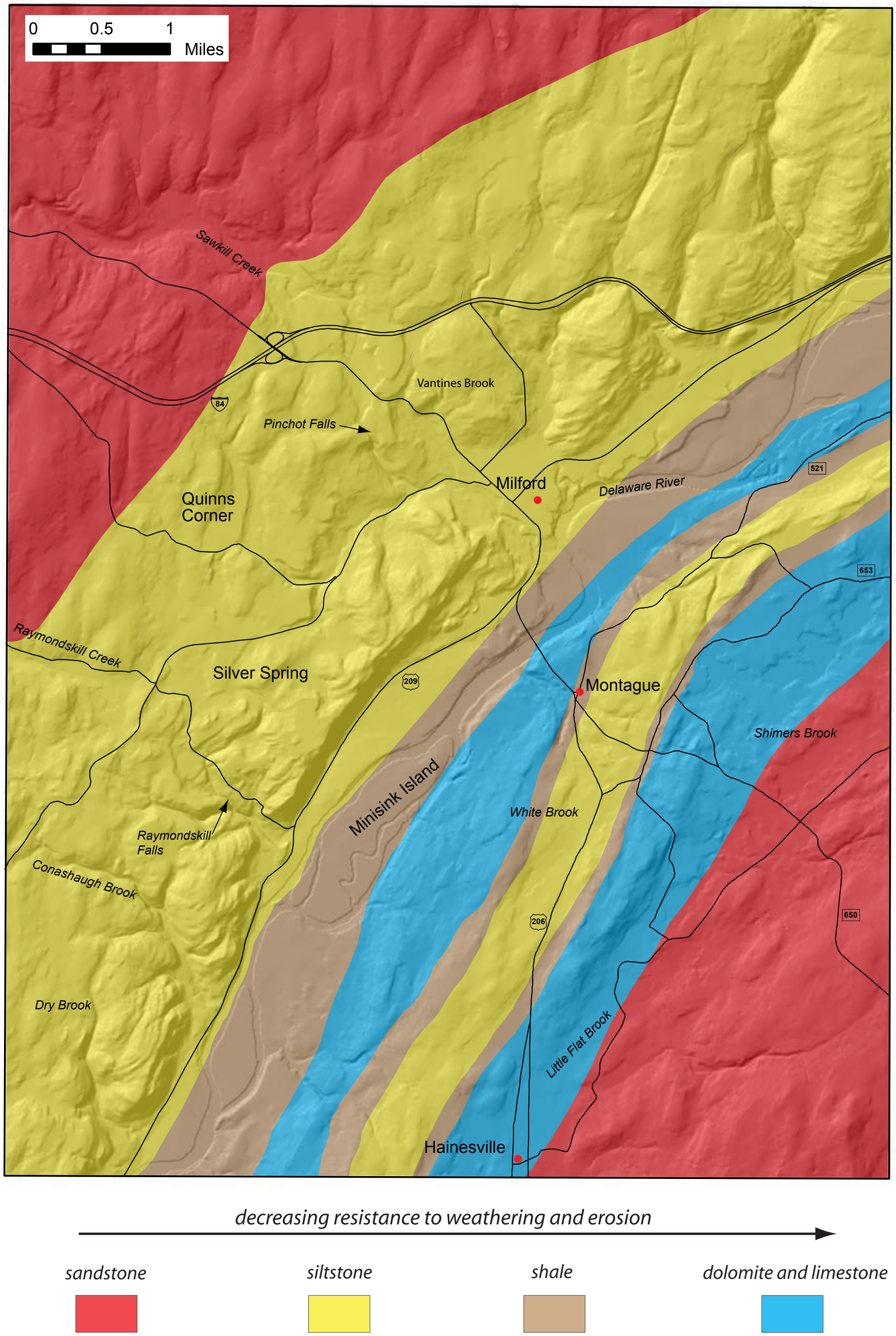


Figure 3. Simplified bedrock geologic map of the Milford quadrangle. Correlation to bedrock formations discussed in text. Kittatinny Mountain: Bloomsburg Red Beds (red sandstone and shale). Wallpack Valley, Wallpack Ridge, Minisink Valley and area west in Pennsylvania: Undifferentiated Silurian and Devonian formations divided into limestone and dolomite, sandstone, siltstone, and shale. Bedrock map for New Jersey modified from Drake and others (1996), and for Pennsylvania modified from Sevon and others (1989).

Wallpack Valley, Minisink Valley, and Wallpack Ridge lie northwest of Kittatinny Mountain (fig. 1). The valleys are narrow, deep, and trend southwest, following belts of weaker rock; chiefly limestone, and limey shale of Silurian and Devonian age (fig. 3). The west side of Minisink Valley is marked by a 200- to 400-foot (61 -122 m) high escarpment formed by the Mahantango Formation. Wallpack Ridge is a narrow interfluve upheld chiefly by shale and sandstone. It separates Minisink Valley from Wallpack and Mill Brook valleys, and it rises as much as 300 feet (91 m) above their floors.

GLACIAL EROSION

Erosional features of the late Wisconsinan glaciation include polished, striated, and plucked bedrock outcrops, and streamlined bedrock forms called roches moutonnées. Both Minisink and Wallpack Valleys have been overdeepened by as much as 150 to 200 feet (52 - 61 m) by glacial erosion. Well records in the Delaware Valley (Witte and Epstein, 2012 and 2004; Witte and Stanford (1995) show that as much as 150 feet (46 m) of valley-bottom scour has occurred during the last two (late Wisconsinan and Illinoian) glaciations, and Braun (1989) suggested that as much as 450 feet (150 m) of land may have been removed in eastern Pennsylvania during the Pleistocene. The many unweathered and lightly weathered bedrock outcrops also show that most of the preglacial soil and weathered rock have been removed by glacial erosion.

Waterfalls are common along many of the Delaware River's tributaries in the Delaware Water Gap National Recreation Area (DEWA). Many of these are on the western side of Minisink Valley along a northeast-trending strike belt of the Mahantango Formation. Prior to the onset of continental glaciation in the Northern Hemisphere more than 2.6 million years ago (2.6 Ma), the Delaware's tributaries had normal graded profiles, the result of millions of years of erosion in a passive tectonic setting. Waterfalls may have existed, but only in places where streams crossed or cut back across rock layers that varied greatly in their ability to withstand erosion. Most of the falls in this area have formed on vertically-fractured, thin- to medium-bedded shale, siltstone, and sandstone of the Mahantango and overlying Trimmers Rock Formations. Because these rocks resist erosion similarly, waterfalls did not exist prior to glaciation, except possibly for a few low cascades.

Waterfalls formed in two distinct ways: 1) Preglacial tributaries were truncated by glacial scour where they entered the Minisink, forming hanging valleys and waterfalls at the tributary-trunk valley juncture and 2) falls developed along new reaches after streams were displaced from their preglacial courses by glacial ice and glacial-lake deposits. Glacial erosion over the course of at least 3 glaciations (Braun, 2004 and Stone and others, 2002): late Wisconsinan (21 ka), Illinoian (130 ka), and pre-Illinoian (2100 ka or 850 ka) has deeply scoured the floor of Minisink Valley and cut back its walls, especially on its western side where the Mahantango Formation was readily eroded. Following deglaciation, the Delaware's tributaries flowed over newly formed waterfalls in hanging valleys. Subsequent erosion of the falls by hydraulic plucking resulted in the falls migrating upstream; a process known as knickpoint retreat. During the many hundreds of thousands of years before the next glaciation, the waterfall retreated slowly upstream. Downstream from the falls, a narrow rock-walled gorge marks this retreat. Presumably, this process repeated itself during successive glacial and inter-glacial periods and with each glaciation, a new and lower fall closer to the main valley would form. Over the course of multiple glaciations multiple sets of falls will form, with the oldest one cut back farthest upstream. Both Dingmans Creek (fig. 4) and Bushkill Creek have two sets of falls that may correlate to two glaciations. Raymondskill Creek only has one. However, an "upper knick point" above Raymondskill falls (fig. 4), formed by many closely-spaced cascades, may represent an older, eroded falls. The absence of multiple, and widely-spaced falls on Raymondskill Creek suggests that it is much younger than creeks with multiple waterfalls. In this case the lower reach of Raymondskill Creek was largely cut

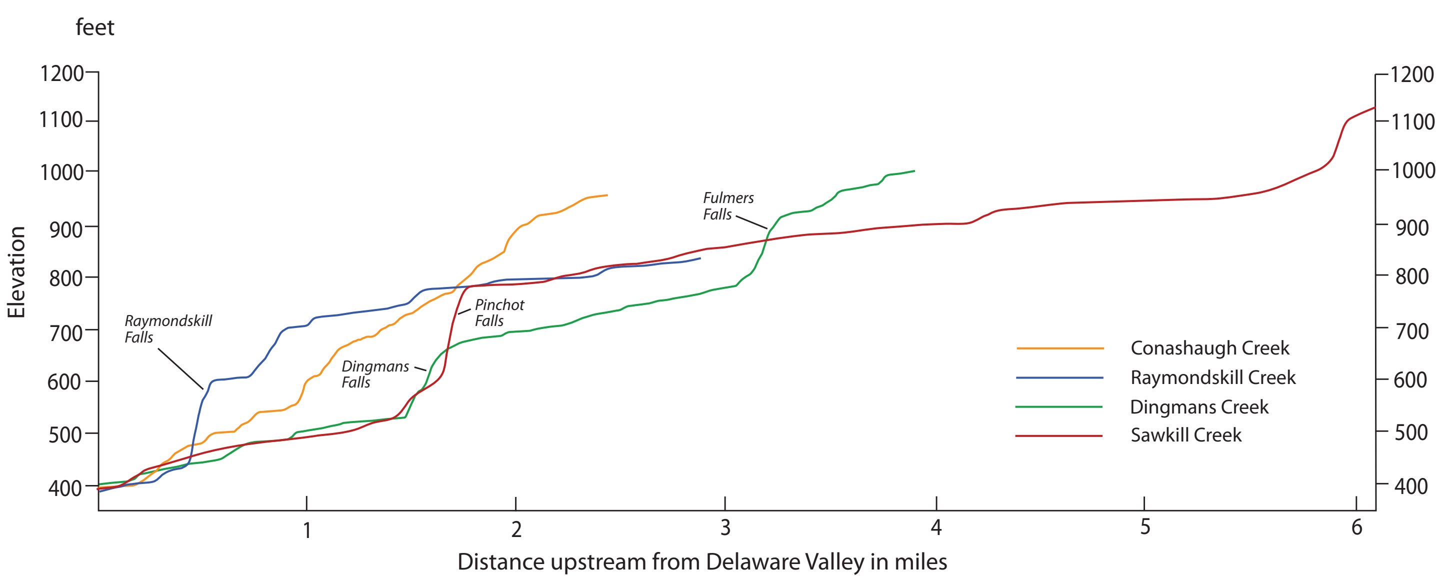


Figure 4. Profiles of selected tributaries and location of waterfalls in the Delaware River in Delaware Water Gap National Recreation Area (DEWA), Pennsylvania. Profiles measured upstream from trunk-valley juncture.

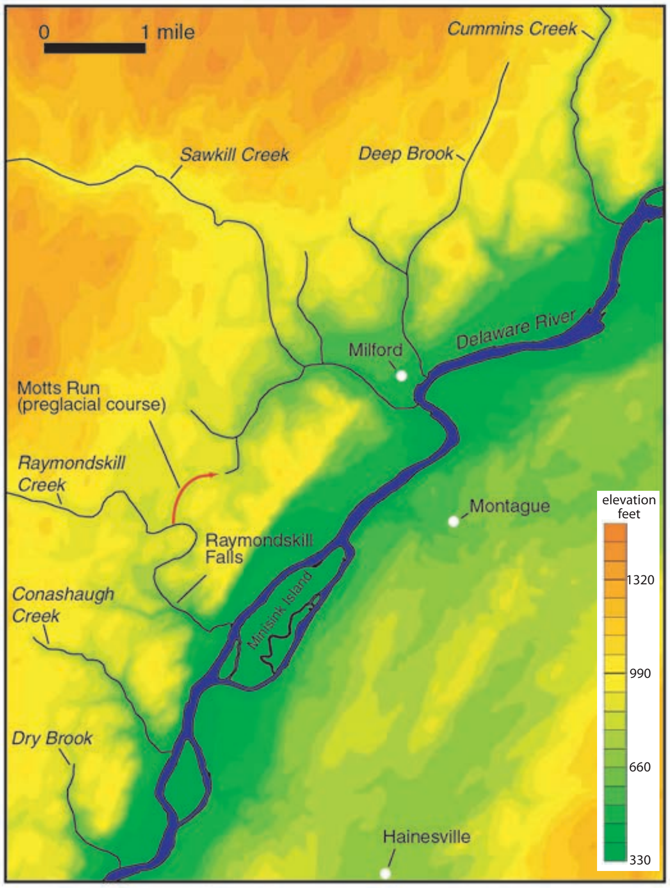


Figure 5. Location of Raymondskill Falls, Raymondskill Creek, Sawkill Creek, and nearby streams. Preglacial or early glacial course of Raymondskill Creek in Motts Run Valley is shown in red. Prior to diversion into the lower part of Raymondskill Creek Valley, Raymondskill Creek was a tributary of Sawkill Creek. White (1882) suggested that this alignment was of preglacial age. The proximity of Raymondskill Falls to the Delaware Valley suggests a younger age, possibly Illinoian.

by meltwater after its preglacial course was diverted by glacial ice and glacial lake deposits (fig. 5). Because Raymondskill Falls has only retreated 2200 feet from its mouth; the least of all the waterfalls in this area (fig. 4), an Illinoian or late Wisconsinan age is assumed for this diversion. Alternatively, hanging valleys cut by the late Wisconsinan glaciation may lie buried beneath thick deposits of alluvium and meltwater sediment, below the modern stream. The rock promontory at the mouth of the gorge 600 feet downstream from the lower falls is probably an abandoned falls that was later notched and eroded. This former falls may be a younger knickpoint related to the lW glaciation. Its position near the head of the valley-side reentrant suggests that a large part of this knickpoint may lie beneath alluvium and late Wisconsinan outwash. Both Conashaugh Creek (fig. 4) and Dry Brook, which lie downstream from Raymondskill Creek, lack waterfalls (other than a few very low cascades). These streams appear to be much younger than Raymondskill based on their much smaller drainage basins, and narrower valleys. Tributaries without waterfalls (i.e., Conashaugh Creek) were probably cut and greatly incised by meltwater during the late Wisconsinan glaciation. Waterfalls may also form where new channels have been cut by streams that were displaced by glacial ice and deposits. Pinchot Falls on Sawkill Creek is an example of this. Just upstream from Milford, high-standing glacial-lake deposits of late Wisconsinan age filled in the pre-late-glacial Sawkill Creek Valley, shifting the Creek's pre-late-glacial course about 1500 feet southwestward.

Raymondskill Falls: a product of multiple glaciations?

Morphology of Raymondskill Falls suggests that it may once have consisted of one large falls or cataract, rather than the three smaller falls we see today. Abandoned falls, notched falls, and oversized plunge basins in Raymondskill Glen all show that the current falls are a product of multiple cycles of erosion and knickpoint retreat. Because waterfalls retreat largely by hydraulic plucking (the removal of rock by the impact of running water), increased rates of stream discharge due to the addition of meltwater, probably enhanced erosion and shaping of the falls. During the late Wisconsinan, meltwater flowed from several sources, including nearby, small upland proglacial lakes, and stages five and six of glacial Lake Wallenpaupack (Duane Braun, written commun. 2001). Based on morphologic criteria there appears to have been at least seven major periods of erosion (fig. 6) during the development of Raymondskill Falls.

1) Erosion of Minisink Valley during Illinoian glaciation and formation of hanging valley and falls at the mouth of an unnamed tributary (lower reach of Raymondskill Valley). Illinoian (150 to 130 ka).

2) Glacial diversion of Raymondskill Creek (originally a tributary of Sawkill Creek) into its present course. Retreat of falls unknown distance during time of meltwater drainage. Illinoian deglaciation (130 ka).

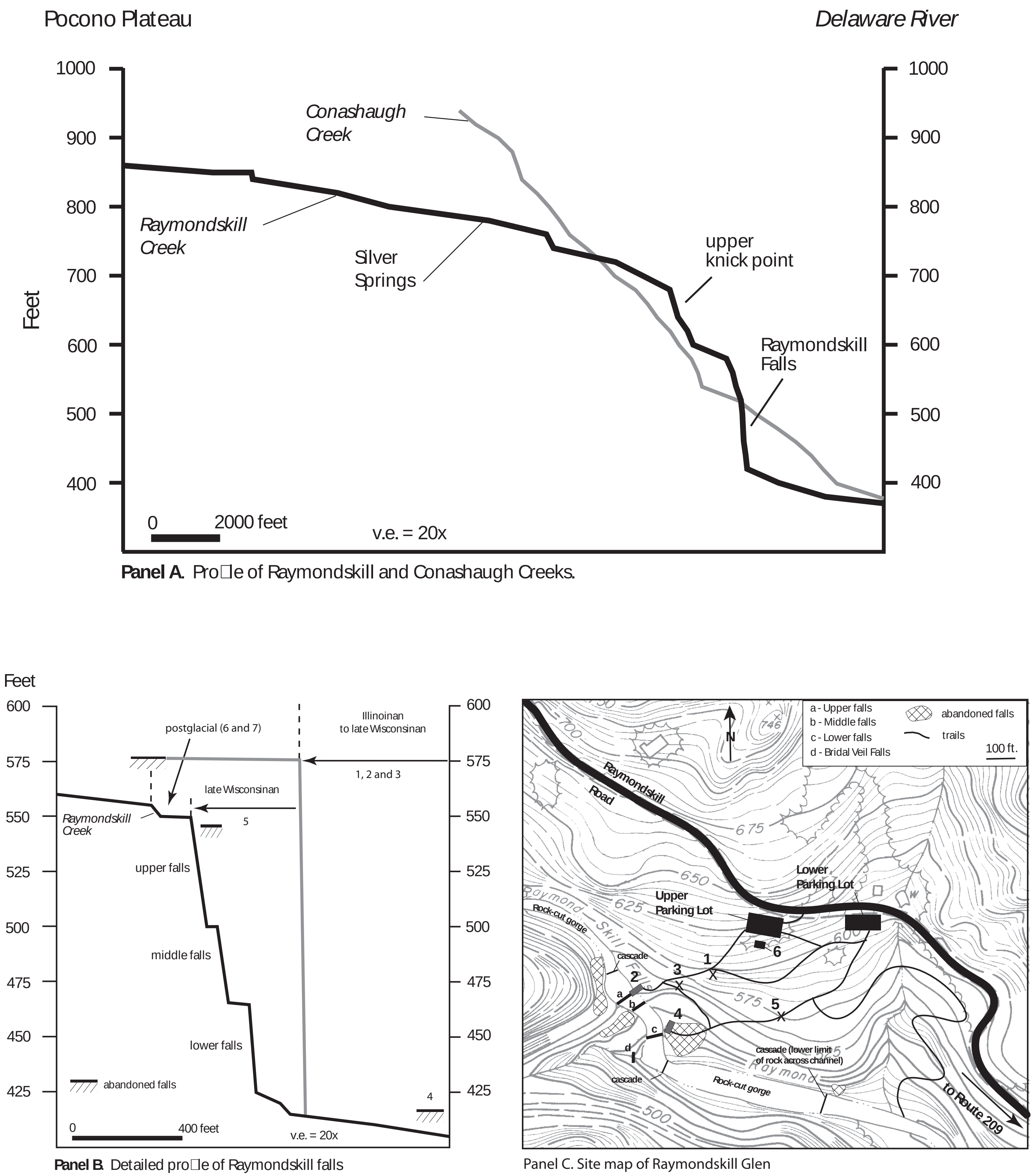
3) Retreat of falls to position slightly downstream from modern falls. Minor notching of falls and downcutting of channel by postglacial stream. Late Illinoian to late Wisconsinan (130 to 25 ka).

4) Erosion of Minisink Valley during late Wisconsinan glaciation and formation of lower knickpoint. Late Wisconsinan (25 to 19 ka).

5) Retreat of falls to present position. Formation of an upper and lower falls. Formation of large plunge basin below the greater upper falls during time of meltwater discharge. Retreat of upper falls to form the middle and upper falls and formation of the middle plunge basin. Retreat of upper falls (6 on fig. 6b and formation of upper plunge basin. Late Wisconsinan deglaciation (~19 to 17.5 ka).

6) Cutting of narrow gorge above upper plunge pool and erosion of the falls that formed the upper plunge basin (Late Wisconsinan).

7) Minor notching (less than three feet) and retreat of the falls' threshold (less than 10 feet) (postglacial late Wisconsinan and Holocene).



Panel A. Profile of Raymondskill and Conashaugh Creeks.

Panel B. Detailed profile of Raymondskill falls

Panel C. Site map of Raymondskill Glen

Figure 6. Waterfalls are common along many of the the Delaware River's tributaries in Delaware Water Gap National Recreation Area (DEWA). Most of them are found on the western side of Minisink Valley, where they formed on thin, interlayered sequences of shale and siltstone of the Mahantango Formation. Raymondskill Falls and other waterfalls in DEWA formed over the course of multiple glaciations. Glacial ersoion widened and deepened Minisink Valley, forming new knick points where tributaries entered the main valley. Over time these knickpoints migrated upstream forming notched stream profiles. Smaller notches cut into threshold of some falls are due to large fluctuations of meltwater discharge due to ice-dammed glacial lakes draining uplands west of the falls.

GLACIAL DEPOSITS

Till

Till typically covers 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 mostly controlled by the topography of the underlying bedrock. Extending through this cover are numerous bedrock outcrops that show evidence of glacial erosion. Thicker, more continuous till subdues bedrock irregularities, and in places may completely mask them. Very thick till forms drumlins, aprons on north-facing hillslopes, recessional moraine, and ground moraine. It also fills narrow preglacial valleys, especially those oriented transverse to glacier flow.

Till is a compact sandy silt to silty sand containing as much as 20 percent pebbles, cobbles, and boulders. Till clasts are subangular to subrounded, faceted, and striated, and measurements of their long axis indicate a preferred orientation that is generally 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 appears to be ablation till and flowtill, but it has not been mapped separately due to its scant distribution and poor exposure. Also, cryoturbation and bioturbation have 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. They are informally called here lowland till (Qtk) and upland till (Qtq), and their lithology was largely dependent on the direction of ice flow over different suites of local source rocks. Lowland till (Qtk) is chiefly derived from limestone, shale, limey shale, and sandstone that underlie the Minisink and Wallpack Valleys, and Wallpack Ridge. It lies in the valleys and on Wallpack Ridge. Upland till (Qtq) is chiefly made up of materials derived from quartzite, quartz-pebble conglomerate, and red sandstone and shale that underlie Kittatinny Mountain. It lies only on the mountain. In a few places on Kittatinny Mountain, a reddish till derived from red sandstone and shale of the Bloomsburg Red Beds was observed underlying a yellowish-brown till that was chiefly derived from the quartzite and quartz-pebble conglomerate of the Shawangunk Formation. This stratigraphy is consistent with changes in the direction of ice flow on Kittatinny Mountain during deglaciation (Witte, 1997) when ice flow shifted from southward to southwestward.

Drumlins

A few drumlins are found in the Milford quadrangle. Most of them are on Kittatinny Mountain in an area of very thick and widespread till. Well records and seismic refraction data (unpublished data on file at the N.J. Geological and Water Survey, Trenton, New Jersey) show that the overburden here is typically thicker than 100 feet (30 m), and most of the drumlins do not have a bedrock core. A few drumlins occur amongst areas of thinner till. Well records and rock outcrops near them suggest that many of these have a bedrock core.

Moraines

Moraines include the Ogdensburg-Culvers Gap, Dingmans Ferry, Montague, and Millville moraines (fig. 2). They were deposited at the margin of the Kittatinny Valley and Minisink Valley lobes (Witte, 1997) during deglaciation. Only smalls part of the Ogdensburg-Culvers Gap and Dingman Ferry moraines are in the quadrangle where they form an interlobate ridge in Stokes State Forest. The Montague moraine follows a similarly looping course as the Dingmans Ferry moraine across Kittatinny Mountain (fig. 2). From here it traces a nearly continuous course into Wallpack Valley where it splits into two distinct ridges and continues across Wallpack Ridge into Minisink Valley. It abruptly ends near the village of Montague. The moraine does not continue across Minisink Valley, and it has not been observed in Pennsylvania. The smaller Millville moraine, which lies in Minisink Valley and crosses Wallpack Ridge, marks a minor recessional position that correlates with a large ice-contact delta located in the Shimers Brook drainage basin (fig. 2).

These recessional moraines are as much as 65 feet thick, and 2500 feet wide, although most are less than 1000 feet wide. Their surfaces are bouldery, and they consist of poorly compacted stony till with minor beds of stratified sand, gravel, and silt (fig. C on map). The moraines generally have asymmetrical cross sections and their distal slopes are the steepest. Their distal margins are sharp, whereas the innermost margins are indistinct. The outermost parts of the moraines are generally marked by single or parallel sets of ridges that are as much as 25 feet (8 m) high, 150 feet (46 m) wide, and 2000 feet (610 m) long. However, most are less than 500 feet (152 m) long. Many appear to have been formerly continuous, but may have been disconnected by collapse during melting of buried ice. Sets of ridges are separated by elongated depressions that are as much as 20 feet (6 m) deep below their rim, 100 feet (30 m) wide, and 300 feet (91 m) long. The depressions parallel the ridges, and many contain organic deposits. Irregularly-shaped depressions also occur; these are as much as 40 feet (12 m) deep, as much as 500 feet (152 m) wide and probably were caused by melting of ice blocks. The innermost parts of the morainal segments have fewer ridges, fewer elongated depressions, and are marked by knob-and-kettle rather than ridge-and-kettle topography. Where moraines abut thick and widespread till, they are generally larger, more continuous, and have more fully developed moraine-parallel ridges than those abutting thin patchy drift.

The lobate course of the end moraines, their morphology, and evidence of glacial readvance suggests 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 saturation and collapse of sediment (Witte, 2001a). The source and mechanism of sediment transport is 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 carrying the sediment to the margin by some kind of "conveyor-belt" process. Inwash is not a viable mechanism because the larger deposits lie on Kittainny Mountain.

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). Smaller quantities of sediment were deposited in meltwater-terrace deposits (Qmt), and a few kames (Qk). Most of this material was transported by meltwater through glacial tunnels to the glacier margin, and by meltwater streams draining deglaciated upland areas adjacent to the valley (Witte, 1988; Witte and Evenson, 1989). Sources of outwash sediment include till beneath the glacier and debris in its 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 was minor.

Glaciofluvial sediments were laid down by meltwater streams in valley-train (Qv), outwash-fan (Qf), meltwater-terrace deposits (Qft), and delta topset beds (Qd, Qod). 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's 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, the overall grain size typically decreases, sand is more abundant and cross-bedded and graded beds are more common. Outwash-fan deposits consist of gently inclined beds of planar to cross-bedded sand and gravel (fig. 7) 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.

Figure 7. Planar-bedded to slightly imbricated fine cobble-pebble gravel exposed in small slump above Raymondskill Creek near Indian Point. The gravel makes up part of a large glacial outwash fan (Qfrc) that was laid down at the creek's mouth where it enters Minisink Valley.

Glaciolacustrine sediments were laid down by meltwater streams in ice-contact and non-ice-contact deltas (Qd, Qod), and lake-bottom deposits (Qlb); all deposited in proglacial lakes. 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 are generally steeply inclined (25º to 35º) 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, 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.

Typically, deltas consist of many individual lobes that prograde outward from the delta front across the lake floor, thinning and widening with distance. Because lake basins in the Milford quadrangle were narrow and small, they became filled with deltaic deposits of gravel and sand.

Lake-bottom deposits include 1) glacial varves and rhythmites and 2) subaqueous-flow deposits. Glacial varves are stacked annual layers consisting of a silty lower "summer" layer 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, kames were laid down in a meltwater ponds that formerly occupied an ice-crevasse, ice-walled sink, or moulin at the glacier's margin.

POSTGLACIAL DEPOSITS

Wind-blown sediment

In Minisink Valley, thin deposits of very fine sand (Qes, shown by a stippled pattern) lie at the base of the northwest-facing slope of Wallpack Ridge. They extend up the hillslope as much as 200 feet in elevation as a thin sheet, collecting in thicker deposits on the lee side (southeast) of rock ridges. A small area of sand dunes is located in Minisink Valley just south of Minisink Island (fig. 8). Topography consists of low knolls and hollows with relief as much as 5 feet. Dune crests in many places are aligned northward suggesting, as do the lee-side deposits, that the dunes

Figure 8. Thin deposits of wind-blown sand forming a low area of dunes in Minisink Valley about one mile downstream from Minisink Island, Sandyston Township, New Jersey. These eolian deposits are found only on the highest of postglacial stream terraces (Qst3) and higher glacial deposits. They are absent on lower terraces, which suggests they are of late Pleistocene age and formed when the Delaware River was transitioning from a meltwater stream to meteoric-sourced stream.

were formed by strong westerly winds. Maximum thickness of eolian material, determined by hand augering, is 12 feet.

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, described in Sevon and others (1989) and Witte (2001d), consists of angular, elongated, platy, prismatic and bladed clasts. Average clast length ranges from one to six inches. Larger clasts, some 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 do have a substantial matrix component display a coarsening upwards of shale clasts, suggesting deposition as a slurry flow. Bedding is slope-parallel, and averages 1 to 4 inches thick. However, in many places the homogeneity of the rubble makes it difficult to discern bedding. Most of the elongated fragments are oriented downslope. Bedding, sorting, and clast orientation of the rubble suggests that most of this material moves downslope as a massive sheetflow, after it has 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 instances may have involved water.

Glacial erosion and the lithology and structural elements of the parent rock may produce very large volumes of shale-chip rubble in a short time. At least three glaciations have cut back the western side of Minisink Valley and formed a very steep rock face that is as much as 500 feet 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. 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 promoting rapid fragmentation. The size of the rubble clasts is directly related to cleavage spacing, bedding thickness, and joint penetration.

Organic deposits

Swamp and bog deposits (Qs) are numerous in the Milford quadrangle. They formed in glacially-scoured bedrock basins and kettles in outwash and moraine that previously contained shallow lakes, in glacial lakes that persisted into the Holocene, in abandoned stream channels on alluvial plains, and in poorly-drained areas in ground moraine. These deposits typically consist of peat, underlain by silty peat and minor mineral detritus, which in turn is underlain by organic-rich clay and silt. In some places the basal section consists of postglacial deposits of lacustrine silt and clay. Peat is typically of woody origin, or consists 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 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 marked by a terrace that lies as much as 12 feet (4 m) above the mean annual elevation of the Delaware River (fig. 9). This terrace forms all or parts of the lower islands in the river and it also forms narrow terraces that flank its present course. 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 the level of meltwater-terrace deposits (fig. 9). In Minisink Valley they may be grouped into two distinct sets. The youngest (Qst2) lies 20 to 35 feet (6 to 11 m) above the mean-annual elevation of the river and consists of as much as 15 feet (4m) 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 a terrace lie next to the Delaware River and typically form a levee. In places the levee is well developed and forms a prominent ridge that is as much as 8 feet (2 m) high. More commonly, the levee is 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 marked by a back-channel, which may contain swamp deposits. In many places, multiple levees, and channel scrolls are preserved, espe-

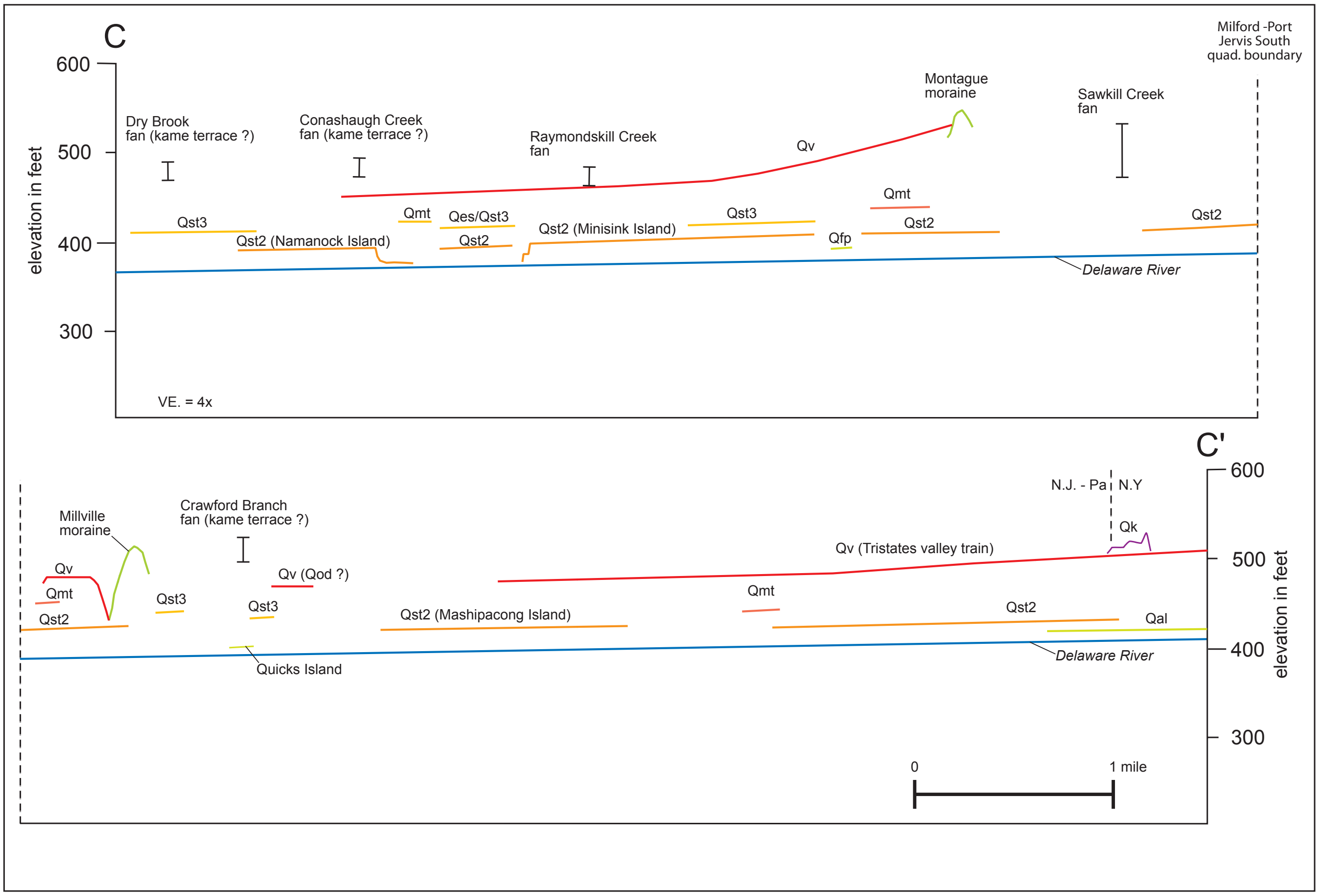


Figure 9. Longitudinal profiles of glacial outwash and postglacial alluvial terraces in Minisink Valley, Milford and Port Jervis South quadrangles. Profiles constructed by projecting elevation andcontacts to a center line drawn up Minisink Valley. Additional elevation data determined from 1:4800 (5 foot contour interval) topographic maps constructed for the Delaware Water Gap National Recreation Area, and measurements using a hand level. List of units: Qv - valley train deposit, Qmt - meltwater-terrace deposit, Qk - kame, Qst3 - abandoned Pleistocene flood plain, Qst2 - abandoned Holocene floodplains, Qal - modern flood plain. The range in elevation shown for the outwash fans represent the distal and proximal parts of their plains projected perpendicular to the section.

cially where the terrace lies on a large inside bend of the river. The 15-foot (5 m) range in elevation of the terrace throughout the valley is due in part to as much as 8 feet (2 m) of relief on the terrace, and parts of the terrace have been lowered by erosion as the river cut down to its modern level. Possibly, the Qst2 terrace may consist of several levels as shown by Wagner (1994). However, without better elevation control, it is difficult to correlate these terrace subsets on a regional scale. The differing levels may also be related to local riparian conditions and channel geometry of the postglacial Delaware River. Archaeological investigations in the Delaware River valley above the Delaware Water Gap (Stewart, 1989) indicate that the base of the Qst2 terrace may be as old as 11,000 yrs B.P., and the upper 1 foot (less than 1 m) has been dated to historic times. This indicates that the Qst2 terrace is Holocene age and it has been largely built up over time by vertical accretion. However, in a few places, channel scrolls on some of the deposits, and the course of the Delaware River, indicate the terrace has 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 mean annual elevation of the river and typically consists of as much as 10 feet (3 m) of overbank fine and medium sand overlying glacial outwash. In places this material has been eroded revealing the underlying outwash. The Qst3 terraces are typically smaller than, and flank, the younger Qst2 deposits. In places they lie completely surrounded by Qst2 deposits. No dates 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 scattered throughout the quadrangle. They form fan-shaped deposits that lie at the base of hillslopes at the mouths of gullies, ravines, and tributary valleys. Sediment is highly varied and is derived chiefly from local surficial sediment, eroded by and laid down by streams draining adjacent uplands. Most alluvial fans are entrenched by modern streams. This suggests that most 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

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 margins of the Kittatinny and Minisink Valley lobes retreated systematically with minimal stagnation.

Based on the morphosequence concept of Koteff and Pessl (1981), many ice-recessional positions have been delineated in Kittatinny Valley by mapping glacial heads-of-outwash (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 Mountain

Outwash deposits are absent in this area, largely because the floors of most valleys have steep gradients that impede the deposition of sediment by meltwater streams. Valley floors are typically covered by a lag of boulders and cobbles that were left after meltwater eroded matrix material from till. In places, meltwater channels are deeply cut in thick till, and a few may mark the former lobate edge of the glacier margin. Others are located in front of the recessional moraines. Most of the material eroded from these upland channels was transported to Wallpack Valley where it was deposited in deltas and outwash fans.

Little Flat Brook, White Brook, Shimers Brook, and Mill Brook Valleys

Meltwater deposits in the Little Flat Brook Valley consist of a large valley-train deposit (Qv), and meltwater-terrace deposits (Qmt). The valley train extends southward from its head-of-outwash located near the village of Four Corners downstream to Hainesville. Its upstream part reaches an elevation of 750 feet (229 m) above sea level, and it consists of coarse gravel and sand; kettles are also common. Downstream, its surface drops to 670 feet (204 m) above sea level, and it consists of fine gravel and sand. Channels and meltwater-terrace deposits mark parts of the valley-train deposit that were eroded by later meltwater draining from the Shimers Brook basin. In some places, such as the Hainesville Wildlife Management Area, large blocks of stagnant ice occupied parts of the valley during deposition of the valley-train deposit.

A large kame located just north of the Montague moraine at the head of Little Flat Brook Valley lies at an elevation of 765 feet (233 m) above sea level, and consists of foreset beds of gravel and sand. Its height above the adjacent valley-train deposit, its cross-valley orientation, and sedimentary bedding suggest that it may have been laid down in a small cross-valley crevasse that formerly held a glacial pond.

Meltwater deposits in the north-draining White Brook Valley consist of two ice-contact deltas laid down in a small proglacial lake. The oldest deposit lies just south of the Montague Township School. It lies at an elevation of 725 feet (221 m) above sea level, and it is graded to a spillway on a drainage divide at the south end of the valley, which discharged into the Little Flat Brook valley. The youngest deposit is correlative with the Montague moraine. It lies at an elevation of 685 feet (209 m) above sea level, and it was laid down in a small proglacial lake that discharged into Minisink Valley over a low threshold located across Wallpack Ridge.

Meltwater deposits in the Shimers Brook drainage basin consist of ice-contact deltas, and an outwash-fan deposit laid down in small proglacial lakes that formed when the margin of the Minisink Valley lobe retreated into the head of the north-draining Mill Brook valley. Initially, ponded meltwater discharged into the Little Flat Brook Valley across a spillway cut down in the kame and valley-train deposit near the village of Four Corners. The deltaic deposits that lie directly north of the large kame, and west of Long Meadow Swamp were laid down in this initially high lake stage. These deposits reach an elevation of 725 feet (221 m) above sea level and are on grade to the Four Corners spillway. Further retreat of the ice margin uncovered a lower outlet in the southwest part of the lake basin on a drainage divide between White and Shimers Brooks. The elevation of this spillway is approximately 630 feet (192 m) above sea level, and deltas laid down in this lower stage range in elevation from 645 to 665 feet (197 m to 203 m) above sea level. These deposits are above the spillway suggesting that the spillway may have been initially higher, possibly held up by till, before it was eroded at a later time after the glacier had retreated into the main part of Mill Brook valley. The elevation of the deltas also indicates that the modern outlet into Minisink Valley did not exist or that it also was at a higher elevation. The ice-retreatal position that is associated with these deposits is correlative with the Millville moraine, and collectively they define a minor recessional position of the Minisink Valley lobe (fig. 2). The kame in the northern part of the basin and that lies at an elevation of 685 feet (209 m) may have been laid down in an ice-walled pond prior to retreat to the Millville position.

Minisink Valley

Meltwater deposits in Minisink Valley consist of valley-train deposits (Qv), outwash-fan deposits (Qf), and meltwater-terrace deposits (Qmt). Valley-train deposits are remnants of 2 extensive valley trains. The oldest one rises from approximately 460 feet (140 m) at the southern boundary of the study area to 520 feet (158 m) upstream at its head near the village of Montague, and the younger one rises from approximately 460 feet (140 m) near the village of Millville to 510 feet (155 m) at its head near the village of Tristates, New York. These outwash remnants form discontinuous, narrow terraces that are typically attached to the valley wall. They have flat surfaces that slope 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. Based on projected longitudinal profiles of terraces in the valley and an increase in grain size upstream, the outwash appears to have been laid down from an ice-recessional position located at the Augusta and Sussex ice margins (fig. 2).

In Pennsylvania, large fan-shaped deposits of sand and gravel lie at the mouths of Dry Brook (Qfdb), Conashaugh Creek (Qfcc), Raymondskill Creek (Qfrc), and Sawkill Creek (Qfsc). Meltwater streams draining the upper reaches of the tributaries laid down these fans and all are graded to the surface of the valley-outwash deposits (Qv) in Minisink Valley.

Meltwater-terraces (Qmt) in Minisink Valley are chiefly strath terraces that were cut down in valley-train deposits by meltwater streams emanating from the glacier margin upvalley from the Montague moraine. These deposits are as much as 15 feet (5 m) thick and they largely consist of material eroded and reworked from adjacent and upstream parts of valley-outwash deposits, and till that covers the lower part of valley slopes. These terraces generally have flat surfaces, locally cut by later meltwater channels, and they range in elevation from 440 feet (134 m) near the moraine to 410 feet (125 m) downvalley (fig. 9).

Records of wells in Minisink Valley (table 1 on map) show that in places silt, very fine sand, and clay underlie the coarse gravel and sand of the valley-train deposits. This stratigraphy has also been indicated for other parts of Minisink Valley (Witte and Epstein, 2012). This fine sediment may consist of distal-deltaic and lake-bottom deposits laid down in short-lived proglacial lakes that formed between heads-of-outwash downvalley and the retreating glacier margin. Because the distribution of these materials is poorly known, they are not on the cross-sections shown on the map.

Raymondskill Creek and Sloat Brook

Outwash along the upper reaches of Raymondskill Creek near Silver Spring and Quinns Corner forms flat-topped deposits that reach elevations of 820 to 840 feet (250 m – 256 m). Their position initially requires ice blocking the lower part of Raymondskill Creek and diverting drainage into Conashaugh Creek by way of a high sluiceway (810 feet (247 m)) just south of the falls. Later, during glacial retreat a lake expanded northeastward of these deposits to Quinns Corner. A spillway, now marked by meltwater terrace deposits (Qmt) in the glacial delta south of Silver Spring, drained this lake into the lower Raymondskill Valley. Deltaic deposits as high as 600 feet (183 m) along the lower reaches of Sloat Brook northeast of Quinns Corner show that as ice retreated off the *Knob* just southwest of Milford, lake drainage abandoned the Raymondskill Valley and flowed into Sawkill Creek Valley.

Summary of Deglaciation

The delineation of ice-retreatal positions marked by end moraines and the heads-of-outwash of ice-contact deltas and valley-train deposits indicate that the margins of the Kittatinny Valley and Minisink Valley lobes retreated in a systematic manner, chiefly by stagnation-zone retreat, to the northeast. Three ice-marginal positions, named the Culvers Gap, Augusta and Sussex margins (Witte, 1997), mark major recessional positions of the ice lobes, and a third, named the Millville margin, marks a minor recessional position. Meltwater deposits consist chiefly of ice-contact deltas laid down in Lake Wallkill, Lake Mill Brook, and several other smaller, unnamed glacial lakes. In Minisink Valley and part of Wallpack Valley valley-train deposits extended many miles downstream from heads-of-outwash associated with the Augusta and Sussex margins. Subsurface data indicates that these coarse-grained glaciofluvial deposits overlie sand and silt of presumably glaciolacustrine origin. This stratigraphy suggests that proglacial lakes may have formed in the narrow south-draining valleys when meltwater became ponded behind heads-of-outwash and recessional moraine. Additionally, meltwater-terrace deposits show that many parts of older valley-train deposits were eroded as the meltwater stream adjusted itself to a longer course.

POSTGLACIAL HISTORY

The Milford quadrangle is estimated to have been deglaciated by 17,500 yr B.P. based on the oldest Francis Lake radiocarbon date (Cotter, 1983). Meltwater continued to flow down Minisink Valley until the glacier margin retreated out of the Delaware River drainage basin and into the Susquehanna drainage basin about 14,000 yr B.P. (estimated from Ozvath and Coates, 1986).

The postglacial landscape immediately following deglaciation 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. In Minisink Valley, deposits of shale-chip colluvium mantle the lower part of the cliffs and steep hillslopes along the Delaware River. In areas of less relief, boulder fields formed at the base of slopes where rocks were transported by soil creep or where fine sediment was winnowed from till by groundwater seepage. Other fields were formed where meltwater left a lag deposit consisting of the heavier stones, and few others may have been concentrated and directly 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 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. Several studies on bogs and swamps in northwestern New Jersey and northeastern Pennsylvania have established a dated pollen stratigraphy that goes back nearly to the onset of deglaciation (Cotter, 1983). Pollen analysis, shows 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 B.P., 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 B.P.) 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 ice age to a temperate climate. About 9,400 yr 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, forming bogs and swamps. These organic-rich deposits principally consist of peat, muck, and minor rock and mineral fragments. Mastodon remains, excavated from Shotwell Pond in Stokes State Forest (Jepsen, 1959) located 3.6 mi. (5.8 km) south of the quadrangle, show the presence of these large mammals in northwestern New Jersey during the close of ice age.

Late Wisconsinan postglacial fluvial history in Minisink Valley began during the later stages of deglaciation when ice had retreated into the upper part of the Delaware Valley. This was a period of erosion in the valley and is marked by further development of meltwater-terrace deposits as the meltwater stream lowered into the valley fill. The onset of stream-terrace deposition 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. Later, there was renewed downcutting and extensive vertical and lateral accretion of overbank deposits. Over the course of the Holocene, these flood-plain materials sequentially built up to heights as much as 35 feet (11 m) above the modern river. This interval was initiated by: 1) rebound of the Earth's crust, which commenced about 14,000 yr B.P. in this region (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

The most important natural resource in the quadrangle, other than ground water, is stratified sand and gravel, most of which lies in valley-train deposits (Qv), and ice-contact deltas (Qd, Qod). Sediment may be used as aggregate, subgrade fill, select fill, surface coverings, and decorative stone. Shale-chip colluvium (Qsc) and weathered slate make excellent subgrade material. The location of all sand and gravel pits and quarries is shown on the map. All pits are currently inactive except for occasional local use. Till can be used for fill and subgrade material, and till stones can supply building stone. Humus and marl from swamp deposits (Qs) may be used for soil conditioning.

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Geologic Time Scale

Years Ago	Eon	Era	Period	Life and Environment
0 to 2.6 million	PHANEREOZOIC (Evident Life)	CENOZOIC (Recent Life)	QUATERNARY	*First humans evolve and coexist with mammouths, mastodons, saber-toothed cats, and giant sloths.*
2.6 to 67 million			TERTIARY	*First large mammals appear and dominate the period. Primitive whales, rodents, primates followed by pigs, cats, horses, dogs, bears and the first hominids. Grasses and modern birds also appear.*
67 to 140 million		MESOZOIC (Medieval Life)	CRETACEOUS	*Heyday of dinosaurs at the start of the Cretaceous followed by their extinction (with many plants and animals) at the end of the period from volcanism and/or asteriod impact. First flowering plants.*
140 to 208 million			JURASSIC	*Earliest birds appear. Giant dinosaurs (Sauropods) flourish. Plants include ferns, cycads and gingkos.*
208 to 250 million			TRIASSIC	*Age of dinosaurs begins. First mammals appear. Mollusks are the dominant invertebrate. Many reptiles (turtles and ichthyosaurs).*
250 to 290 million		PALEOZOIC (Ancient Life)	PERMIAN	*Age of amphibians. Supercontinent known as Pangaea forms. Greatest mass extinction ever at end of period. Trilobites go extinct.*
290 to 365 million			PENNSYLVANIAN AND MISSISSIPPIAN (Carboniferous)	*Widespread coal swamps. Large primitive trees. First winged insects and reptiles. Many ferns. Amphibians common.*
365 to 405 million			DEVONIAN	*Age of Fishes. Fish and land plants become abundant and diverse. First shark. Earliest amphibians, ferns and mosses.*
405 to 430 million			SILURIAN	*First insects, jawed fish and vascular plants on land (plants with water-conducting tissue).*
430 to 500 million			ORDOVICIAN	*First corals. Primitive fishes, seaweed and fungi. First non-vascular land plants (like mosses).*
500 to 570 million			CAMBRIAN	*Age of Trilobites. The Cambrian Explosion of life occurs. All Phyla that exist today develop. First vertebrates and earliest primitive fish. First shells appear on shellfish, mollusks, echinoderms, brachiopods, trilobites.*
570 to 2500 million	PROTEROZOIC (Early Life)	PRECAMBRIAN		*First soft-bodied invertebrates and colonial algae. Oxygen build-up: Mid Proterozoic.*
2500 to 3800 million	ARCHEAN (Ancient)			*Life appears. First bacteria and blue-green algae begins to free oxygen to atmosphere.*
3800 to 4600 million	PRE-ARCHEAN			*Earth molten.*

Dark shading (bedrock) and light shading (surficial materials) indicate that geologic deposits from these time periods are present in the Milford quadrangle.