Department of Environmental Protection and Energy
Division of Science and Research
New Jersey Geological Survey

Introduction

The study area (fig. 1) is located in the southern part of Sussex County, in northern New Jersey. Most of the area lies in Kittatinny Valley except for the northwest corner, which includes part of Kittatinny Mountain and the eastern part, which includes part of the New Jersey Highlands. The upper part of the Wallkill River valley is referred to in this study as Sparta Valley. Boundaries and U.S. Geological Survey 7 1/2 - minute topographic quadrangles that cover this area are shown in figure 2.

Salisbury (1902) identified moraines, deltas, kames, kame terraces, and glacial lakes in Kittatinny Valley and assigned them a late Wisconsinan age. Salisbury determined that the retreat history of late Wisconsinan ice in the valley could be interpreted by the distribution of glacial-recessional deposits; although, they were never placed within a stratigraphic framework. He surmised that the deglaciation of Kittatinny Valley was by the gradual melting back of the ice margin with minor stagnation. During retreat, the ice halted at several places that are marked by moraines and outwash. Ridge (1983) defined the late Wisconsinan history of part of Kittatinny Valley extending from the terminal moraine northeastward to the Sussex-Warren County boundary. He did this by employing a morphostratigraphic approach developed by Koteff (1974), and Koteff and Pessl (1981) to map the distribution of glacial deposits. He concluded that glacial deposits in Kittatinny Valley north of and including the terminal Moraine are late Wisconsinan age and that deglaciation occurred by stagnation-zone retreat.

The purpose of this investigation is to interpret the glacial history of Kittatinny Valley in the southern part of Sussex County by morphostratigraphic methods, and describe in detail the surficial deposits.

Geologic and Physiographic Setting

Kittatinny Valley (fig. 1 and 2) is a broad northeast-to-southwest-trending lowland underlain by limestone, dolostone, claystone slate, and graywacke siltstone; all of Cambrian and Ordovician age. It is part of the Great Valley physiographic province.

The valley is bounded on the northwest by Kittatinny Mountain, a narrow upland of moderate relief, underlain by quartz-pebble conglomerate, quartzite, and red shale and sandstone, all of Silurian age. The mountain is part of the Valley and Ridge physiographic province. The New Jersey Highlands, an upland of moderate to rugged relief, borders the valley on the southeast. This region is underlain by crystalline rock of Precambrian age, with the exception of a few intermontane valleys underlain by sedimentary rock of Lower and Middle Paleozoic age. This area is part of the Highlands physiographic province.

A major drainage divide between the southwest flowing Pequest River and Paulins Kill, and northeast flowing Wallkill River lies within the study area. These river valleys generally overlie carbonate rock; separated by interfluves chiefly underlain by slate, siltstone, and sandstone.

The gross physiography of Kittatinny Valley is the result of the regional northeastward trend of fold and thrust-belt structures in the major lithologic units, and differences in relative resistance to fluvial erosion among rocks underlying the valleys, interfluves, and uplands. Multiple glacial episodes during the Pleistocene modified the fluvially-eroded landscape by widening and over-deepening valleys, and streamlining and smoothing bedrock ridges. During the late Wisconsinan, till was deposited on much of the pre-Wisconsinan surface. Till, as much as 100 feet thick, was deposited in drumlins, and on hill slopes that faced towards the regional direction of ice flow. Thick deposits of glaciodeltaic and glaciolacustrine sediment were laid down in proglacial lakes that formed in valleys now drained by the Wallkill and Pequest Rivers, and Paulins Kill, and their tributaries. Preglacial drainage of major river systems was probably similar to modern drainage, except for changes in headwater areas where drainage was modified by glacial erosion and deposition or meltwater deposits.

In postglacial to modern time, shallow lakes and ponds became filled with swamp deposits, and major streams downcut approximately 20 feet into the underlying glaciodeltaic and glaciolacustrine sediment. Isostatic rebound, estimated at 2.5 to 3.0 feet per mile in a north, northeast direction (Witte, 1988), retarded downcutting in north-draining valleys and accentuated downcutting in south-draining valleys. Colluviation of slope-deposit material occurred extensively after deglaciation when cold and wet climatic conditions, and lack of vegetative cover enhanced solifluction, freeze-thaw, and other mass-movement processes. Gradually as climatic conditions warmed, depositional rates decreased to the extent that erosion of colluvial-fill by streams and surface runoff, has become the dominant process.

Soils developed on late Wisconsinan and Holocene parent materials are young and usually thin (less than three feet thick). Pedogenic processes increase soil-color chroma by oxidation, remove or redistribute primary carbonate by leaching, form argillic B horizons through eluviation and in situ formation of clay minerals, and weather primary minerals by hydrolysis, hydration, oxidation, and to a lesser extent chelation and ion exchange. Physical weathering, largely by cryoturbation and bioturbation, and the addition of loess also changes the primary characteristics of the parent material.

Soils that form on till and stratified drift are chiefly inceptisols and alfisols; on modern alluvium generally entisols, and on swamp deposits, histosols. Entisols are the most poorly developed soils; they lack pedogenic horizons, and have only weakly developed surface horizons. Inceptisols have weakly developed pedogenic horizons related to chemical alteration of parent material in situ, and not accumulation. Alfisols are the best developed of the soils; these have argillic B horizons related to eluviation of clay, and in situ formation of clay in the B horizon. Histosols are organic soils, and chiefly form on muck or peat. Information on soils from Birkeland (1974), and Tedrow (1986).

Morphosequence Concept

The identification of meltwater deposits and delineation of ice-retreatal positions here is based on the morphosequence concept. The initial framework of the concept was introduced by Jahns (1941) in New England where he used it to identify meltwater deposits and reconstruct ice-retreatal positions. Jahns suggested that the morphology, depositional gradients and distribution of meltwater deposits in north-central Massachusetts indicated that the margin of the late Wisconsinan ice sheet retreated in a systematic manner, and that deglaciation did not occur by regional stagnation. Much earlier, Salisbury (1902, p. 128) had suggested that heads of outwash may represent ice-retreatal positions; however, Jahns was the first to use this to help define the distribution of stratified drift and interpret the glacial retreat history. Koteff (1974) and Koteff and Pessl (1981) developed Jahns methods into the morphosequence concept. A morphosequence as defined by Koteff and Pessl (1981), "...is a body of stratified drift laid down layer upon layer by meltwater at and beyond the margin of a glacier with deposition controlled by a specific base level." Koteff defined 8 types of morphosequences; 6 of which are shown in figure 3.

Glacial recessional meltwater deposits; largely ice-marginal deltas, lacustrine fans, and fluviodeltas are used to interpret the glacial retreat history and define former ice-margin positions. These positions are delineated by morphology of the deposits, depositional gradient, texture, and relationship to erosional meltwater features. The extent of glacial lakes and their history helps interpret surface and subsurface deposits and define their place within a stratigraphic framework. The expanded ability to identify ice-retreatal positions in an area of few moraines, such as Kittatinny Valley, has several important results. First, the identification of ice-retreatal positions in Kittatinny Valley provides a more detailed analysis of ice recession. Second, these ice-retreatal positions, and deposits have been correlated across local interfluves, from valley to valley. Therefore, a much clearer understanding of regional and local ice-flow patterns has been established. Third, because the morphosequence concept has been successfully applied in this region (Ridge, 1983 and Witte, 1988), a pattern of systematic ice retreat from the late Wisconsinan terminal moraine has been established.

Glacial History

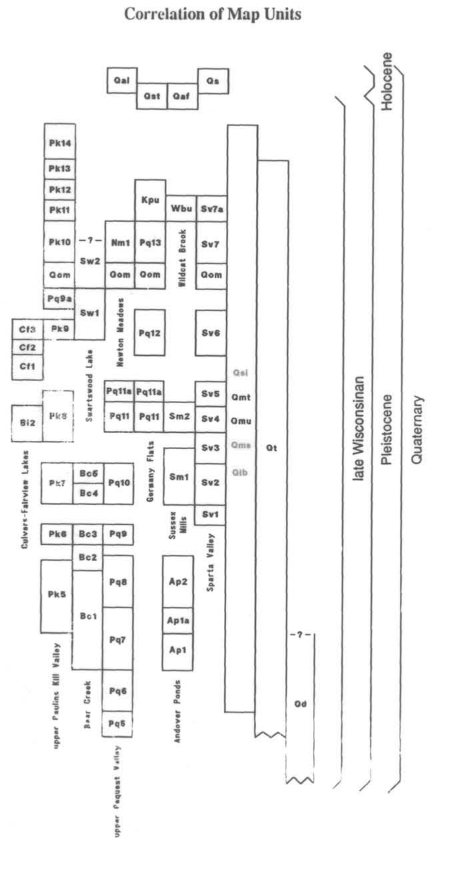
Glacial deposits in the study area record the late Wisconsinan glaciation. In northwestern New Jersey and northeastern Pennsylvania, palynologic and geochronologic studies by Cotter and others, (1986), Cotter, (1983), Crowl, (1980), Connally and Sirkin, (1973), Sirkin and Minard, (1972), and Harmon, (1968), and morphostratigraphic studies by Witte, (1991 and 1988), and Ridge, (1983) are used to estimate that deglaciation occurred sometime prior to 19,000 yrs. B.P.

Regional ice flow during the late Wisconsinan maximum was southward across the southwest trend of Kittatinny Valley. This suggests that ice flow into the valley was influenced by ice flowing from the Wallkill lowland and ice flowing southward over Kittatinny Mountain. The outer area of the ice sheet thinned during deglaciation and its flow became controlled by the northwest to southwest orientation of major lowlands. The change from regional- to valley-controlled ice flow changed the geometry of the ice sheet's margin and two large ice lobes were formed; called here Kittatinny Valley and Minisink Valley lobes (fig. 4). The distribution of erratics, orientation of striae, and reconstructed ice margins defined by moraines and interpreted from the stratigraphy defined by the meltwater deposits, strongly suggests that ice flow at he margin of the Kittatinny Valley lobe was divergent; also, indicating valley-controlled flow. Reconstruction of flow patterns is based on observations of striae, orientation of drumlins, distribution of erratics, and till lithology by Witte (1988) and Ridge (1983).

The late Wisconsinan stratigraphy as defined by meltwater deposits and moraines indicates that deglaciation of Kittatinny Valley was characterized by the northeastward retreat of the margin of the Kittatinny Valley ice lobe into the Wallkill Valley. Proglacial lakes successively developed in river valleys and their tributaries; now drained by the Wallkill and Pequest Rivers and Paulins Kill. This also occurred in upland basins; although, on a much smaller scale. These lakes formed when lake basins became dammed by the glacier or when meltwater deposits, moraine and stagnant ice blocked meltwater drainage away from the glacier. The distribution of meltwater deposits and moraine, and relationships between altitudes of delta plains, former glacial lake water plains, and lake spillways indicates that the margin of the Kittatinny Valley ice lobe retreated systematically and that regional or large-areal stagnation did not occur in this area.

Four major ice-retreatal positions, besides the Ogdensburg-Culvers Gap Moraine, have been identified in Kittatinny Valley in southern Sussex County (fig. 4). These named ice margins are: the Franklin Grove-Huntsburg-Andover (renamed from the Franklin Grove-Turtle Pond ice margin of Ridge, (1983), Middleville-Newton-Sparta, Balesville-Lafayette-Ogdensburg, and the Augusta-Harmonyvale-North Church ice margin. Because morphosequences associated with these ice-retreatal positions represent prolonged periods of meltwater deposition, ice-margin equilibrium, and possibly increased meltwater discharge, they may have been climatically controlled.

Correlation of Map Units



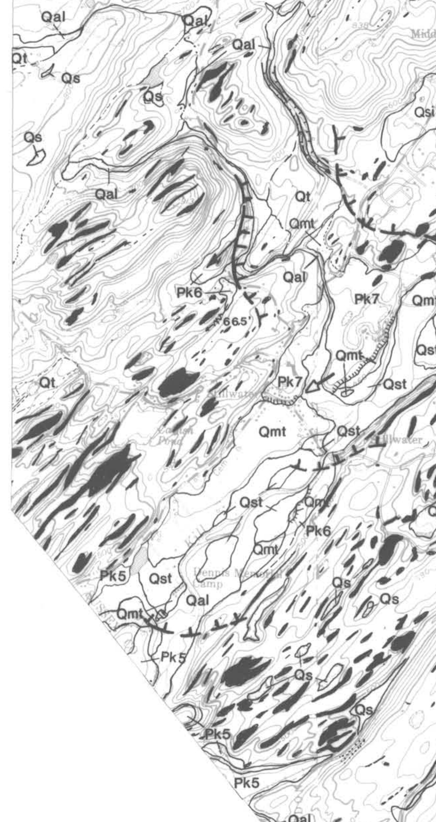


Figure 1. Location of the study area (ruled-lined pattern), and Kittatinny Valley in northern New Jersey.

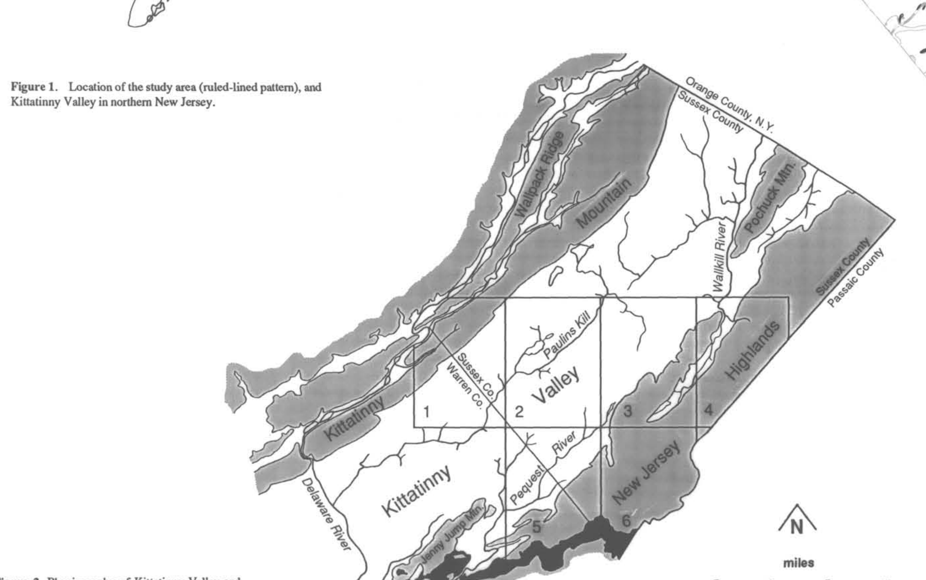
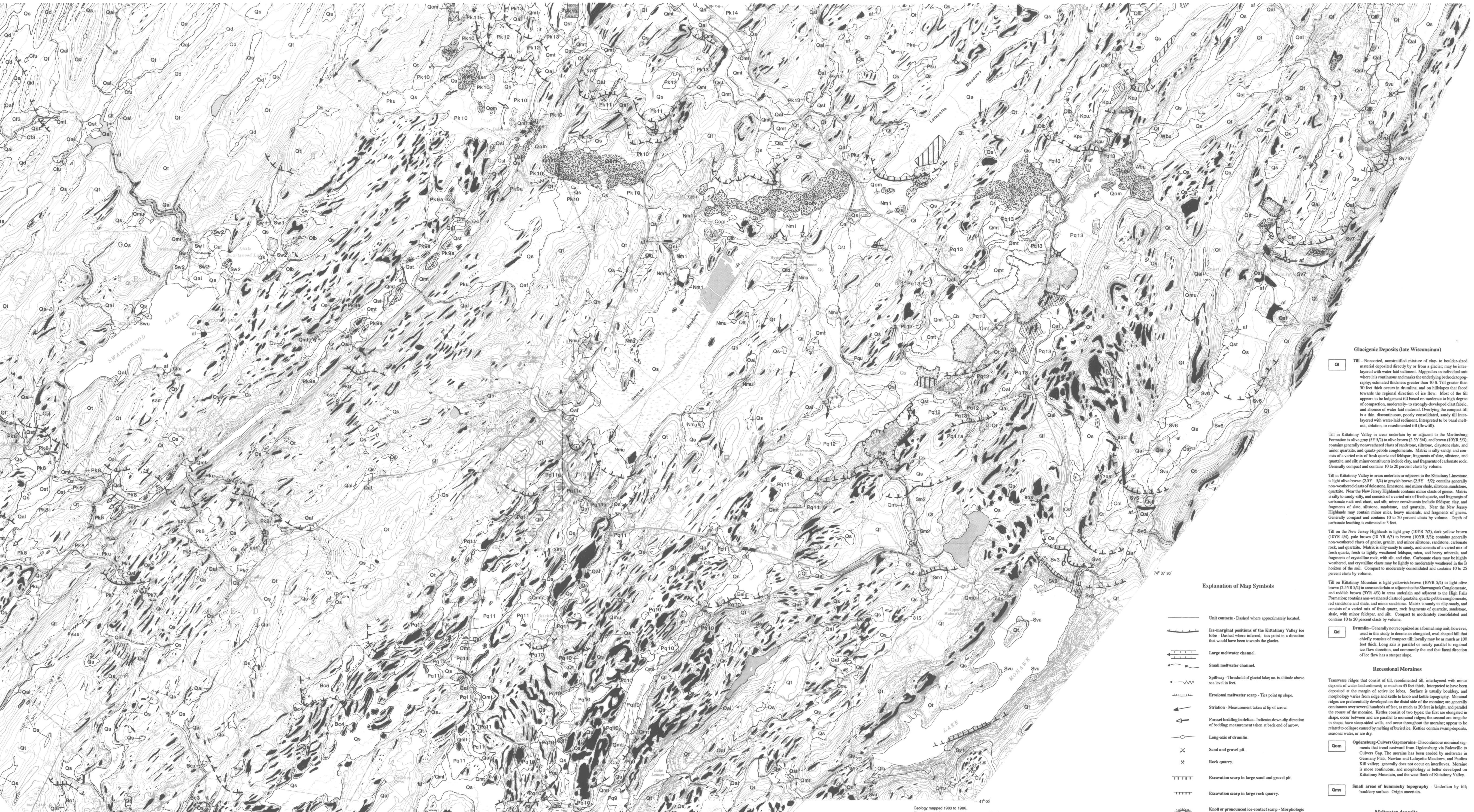


Figure 2. Physiography of Kittatinny Valley and vicinity, and location of 7 1/2 minute topographic quadrangles that the study area covers. Key to quadrangles: 1) Flatbrookville, 2) Newton West, 3) Newton East, 4) Franklin, 5) Tranquility, and 6) Stanhope.



Topography mapped by the Army Map Service.
Base from U.S. Geological Survey, 1954. Photorevised, 1971.

Geology mapped 1983 to 1988.
The interpretations presented here are provisional.
There may be revisions prior to publication.

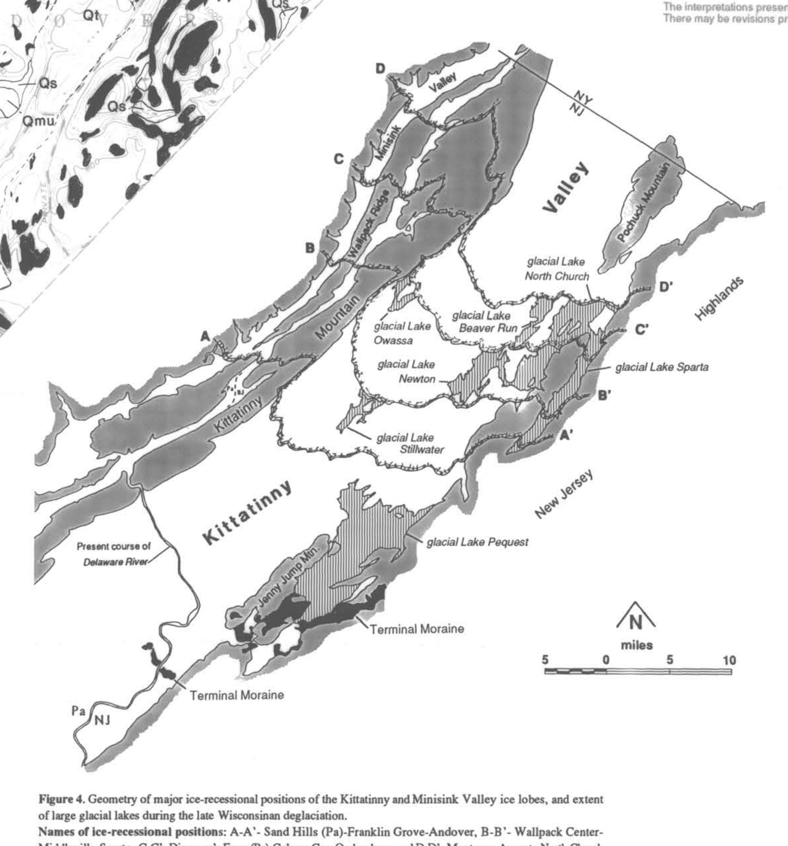


Figure 4. Geometry of major ice-recessional positions of the Kittatinny and Minisink Valley ice lobes, and extent of large glacial lakes during the late Wisconsinan deglaciation.
Names of ice-recessional positions: A-A'- Sand Hills (Pa)-Franklin Grove-Andover, B-B'- Wallpack Center-Middleville-Sparta, C-C'- Dingman's Ferry (Pa)-Culvers Gap-Ogdensburg, and D-D'- Montague-Augusta-North Church.

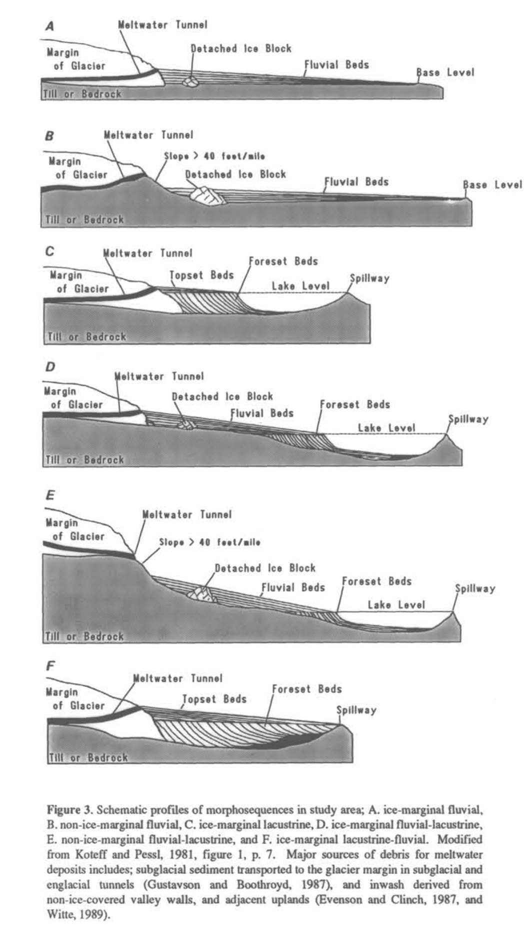


Figure 3. Schematic profiles of morphosequences in study area; A. ice-marginal fluvial, B. non-ice-marginal fluvial, C. ice-marginal lacustrine, D. ice-marginal fluvial-lacustrine, E. non-ice-marginal fluvial-lacustrine, and F. ice-marginal lacustrine-fluvial. Modified from Koteff and Pessl, 1981, figure 1, p. 7. Major sources of debris for meltwater deposits includes; subglacial sediment transported to the glacier margin in subglacial and englacial tunnels (Gustavson and Boothroyd, 1987), and inwash derived from non-ice-covered valley walls, and adjacent uplands (Evenson and Clinch, 1987, and Witte, 1989).

Surficial Geology of Kittatinny Valley and Vicinity in the Southern Part of Sussex County, Northern New Jersey

by

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Explanation of Map Symbols

- **Unit contacts** - Dashed where approximately located.
- **Ice-marginal positions of the Kittatinny Valley ice lobe** - Dashed where inferred; tics point in a direction that would have been towards the glacier.
- **Large meltwater channel.**
- **Small meltwater channel.**
- **Spillway** - Threshold of glacial lake; no. is altitude above sea level in feet.
- **Erosional meltwater scarp** - Tics point up slope.
- **Striation** - Measurement taken at tip of arrow.
- **Foreset bedding in deltas** - Indicates down-dip direction of bedding; measurement taken at back end of arrow.
- **Long-axis of drumlin.**
- **Sand and gravel pit.**
- **Rock quarry.**
- **Excavation scarp in large sand and gravel pit.**
- **Excavation scarp in large rock quarry.**
- **Knoll or pronounced ice-contact scarp - Morphologic features of morainal and stagnant-ice deposits; hachures point to center of knoll or up slope.**
- **Bedrock outcrop, regolith, and thin surficial cover - Solid pattern indicates extensive outcrop and regolith. Unlabeled ares indicate thin surficial cover, generally less than 10 feet thick; includes drift, colluvium, and regolith.**
- **Long axis of ridge crest** - Linear trends generally follow the crest of strike ridges underlain by shale, slate, and graywacke siltstone.
- **Umlaufberg** - Small hill or knoll, underlain by bedrock and surrounded by glacial outwash, lake bottom deposits, alluvium, or swamp deposits.
- **Morainal deposits.**
- **Lake-bottom deposits.**
- **Talus and large boulder fields.**
- **Landfill.**

Description of Map Units

Postglacial Deposits

af — **Artificial fill** - Manmade accumulations of unconsolidated sediment; chiefly sand and gravel, till, rock, and mine tailings.

Qal — **Alluvium** - Gravel, sand, silt, some clay and organic material in floodplains of modern streams; includes planar to cross-stratified sand and gravel of channel deposits, and massive to planar-bedded sand, minor gravel, and silt of overlying, and laterally contiguous overbank deposits. Highly variable texture; as much as 25 feet thick. Locally, interlayered and overlain with minor colluvium and swamp deposits. Alluvium of tributary streams with moderate to steep gradients is usually bouldery.

Qaf — **Alluvial fans** - Sand, gravel, and some silt in fan-shaped deposits on the lower part of hillslopes at the mouths of gullies and ravines. Bedding varies from massive to planar-bedded; bedding usually dips towards the valley bottom. Highly variable texture, as much as 25 feet thick; coarser material in small channels. Includes alluvium, and slope deposits.

Qst — **Stream terrace deposits** - Gravel, sand and some silt in terraces adjacent to, and slightly higher than modern alluvium; includes planar to cross-stratified sand and gravel of channel deposits, and massive to planar-bedded sand, minor gravel, and silt of overlying and laterally contiguous overbank deposits. Moderately to well sorted; as much as 20 feet thick.

Qs — **Swamp deposits** - Peat and muck underlain by laminated organic-rich silt and clay that accumulate in poorly drained areas, shallow lakes, and ponds; as much as 25 feet thick. Locally interlayered with thin beds of marl, minor lacustrine silt and sand, and alluvium.

Glacigenic Deposits (late Wisconsinan)

Qt — **Till** - Nonsorted, nonstratified mixture of clay- to boulder-sized material deposited directly by or from a glacier; may be interlayered with water-laid sediment. Mapped as an individual unit where it is continuous and masks the underlying bedrock topography; estimated thickness greater than 10 ft. Till greater than 50 feet thick occurs in drumlins, and on hillslopes that faced towards the regional direction of ice flow. Most of the till appears to be lodgement till based on moderate to high degree of compaction, moderately- to strongly-developed clast fabric, and absence of water-laid material. Overlying the compact till is a thin, discontinuous, poorly consolidated, sandy till interlayered with water-laid sediment. Interpreted to be basal meltout, ablation, or resedimented till (flowtill).

Till in Kittatinny Valley in areas underlain by or adjacent to the Martinsburg Formation is olive gray (5Y 5/2) to olive brown (2.5Y 5/4), and brown (10YR 5/3); contains generally nonweathered clasts of sandstone, siltstone, claystone slate, and minor quartzite, and quartz-pebble conglomerate. Matrix is silty-sandy, and consists of a varied mix of fresh quartz and feldspar; fragments of slate, siltstone, and quartzite, and silt; minor constituents include clay, and fragments of carbonate rock. Generally compact and contains 10 to 20 percent clasts by volume.

Till in Kittatinny Valley in areas underlain or adjacent to the Kittatinny Limestone is light olive brown (2.5Y 5/4) to grayish brown (2.5Y 5/2); contains generally non-weathered clasts of dolostone, limestone, and minor shale, siltstone, sandstone, quartzite. Near the New Jersey Highlands contains minor clasts of gneiss. Matrix is silty to sandy-silty, and consists of a varied mix of fresh quartz, and fragments of carbonate rock and chert, and silt; minor constituents include feldspar, clay, and fragments of slate, siltstone, sandstone, and quartzite. Near the New Jersey Highlands may contain minor mica, heavy minerals, and fragments of gneiss. Generally compact and contains 10 to 20 percent clasts by volume. Depth of carbonate leaching is estimated at 3 feet.

Till on the New Jersey Highlands is light gray (10YR 7/2), dark yellow brown (10YR 4/4), pale brown (10 YR 6/3) to brown (10YR 5/3); contains generally non-weathered clasts of gneiss, granite, and minor siltstone, sandstone, carbonate rock, and quartzite. Matrix is silty-sandy to sandy, and consists of a varied mix of fresh quartz, fresh to lightly weathered feldspar, mica, and heavy minerals, and fragments of crystalline rock, with silt, and clay. Carbonate clasts may be highly weathered, and crystalline clasts may be lightly to moderately weathered in the B horizon of the soil. Compact to moderately consolidated and contains 10 to 25 percent clasts by volume.

Till on Kittatinny Mountain is light yellowish-brown (10YR 5/4) to light olive brown (2.5YR 5/4) in areas underlain or adjacent to the Shawangunk Conglomerate, and reddish brown (5YR 4/3) in areas underlain and adjacent to the High Falls Formation; contains non-weathered clasts of quartzite, quartz-pebble conglomerate, red sandstone and shale, and minor sandstone. Matrix is sandy to silty-sandy, and consists of a varied mix of fresh quartz, rock fragments of quartzite, sandstone, shale, with minor feldspar, and silt. Compact to moderately consolidated and contains 10 to 20 percent clasts by volume.

Qd — **Drumlin** - Generally not recognized as a formal map unit; however, used in this study to denote an elongated, oval-shaped hill that chiefly consists of compact till; locally may be as much as 100 feet thick. Long axis is parallel or nearly parallel to regional ice-flow direction, and commonly the end that faced direction of ice flow has a steeper slope.

Recessional Moraines

Transverse ridges that consist of till, resedimented till, interlayered with minor deposits of water-laid sediment; as much as 45 feet thick. Interpreted to have been deposited at the margin of active ice lobes. Surface is usually bouldery, and morphology varies from ridge and kettle to knob and kettle topography. Morainal ridges are preferentially developed on the distal side of the moraine; are generally continuous over several hundreds of feet, as much as 20 feet in height, and parallel the course of the moraine. Kettles consist of two types: the first are elongated in shape, occur between and are parallel to morainal ridges; the second are irregular in shape, have steep-sided walls, and occur throughout the moraine; appear to be related to collapse caused by melting of buried ice. Kettles contain swamp deposits, seasonal water, or are dry.

Qom — **Ogdensburg-Culvers Gap moraine** - Discontinuous morainal segments that trend eastward from Ogdensburg via Balesville to Culvers Gap. The moraine has been eroded by meltwater in Germany Flats, Newton and Lafayette Meadows, and Paulins Kill valley; generally does not occur on interfluves. Moraine is more continuous, and morphology is better developed on Kittatinny Mountain, and the west flank of Kittatinny Valley.

Qms — **Small areas of hummocky topography** - Underlain by till; bouldery surface. Origin uncertain.

Meltwater deposits

Meltwater deposits in the study area consist primarily of ice-marginal and non-ice-marginal lacustrine and lacustrine-fluvial morphosequences (fig. 3). Morphosequences include; ice-marginal deltas, lacustrine fans, fluviodeltas, and lake-bottom deposits. Fluvial morphosequences that consist of valley-outwash deposits and meltwater terraces are of minor extent. Four depositional settings are indicated by morphosequences in the study area; based on meltwater depositional systems defined by Stone, Stanford and Witte (1989).

1. ***Glaciofluvial deposits laid down as valley outwash or terrace deposits*** - Well-sorted gravel and sand, sand, and coarse gravel; includes massive to horizontally-bedded and imbricated coarse gravel in the proximal facies with minor channel-fill and cross-stratified sand. As average grain size decrease downstream to sand and gravel, and sand, trough and tabular planar cross-stratification becomes more common; overbank deposits are rare, and grading and reverse grading of bedding is common. As much as 50 feet thick. Deposits usually overlie till or bedrock except where lacustrine deposits predate glaciofluvial sediment. Although, not recognized as a separate unit, deltaic topset beds of deltas, and the fluvial part of fluviodeltas consist of glaciofluvial deposits.

Qmt — **Meltwater terrace deposits** - Well-sorted sand and gravel, and sand in terraces adjacent to and higher than stream-terrace deposits; chiefly consists of planar to cross-stratified sand and gravel of channel deposits, over bank deposits are rare. As much as 10 feet thick. May be distal parts of morphosequences or erosional terraces downcut in older meltwater deposits. Sediment largely derived from reworked local sources.

2. ***Glaciodeltaic and glaciolacustrine deposits laid down in large glacial lakes which formed in north-draining valleys*** - Includes well-sorted sand and gravel, sand, fines, and minor coarse gravel in ice-marginal and fluviodeltas, lacustrine fans and lake-bottom deposits. The upper delta facies includes; rhythmically-bedded sand and gravel and coarse sand in beds that dip 25 to 35 degrees, and the middle to lower delta facies includes; fining upwards foreset beds to ripple cross-laminated, parallel laminated, coarse sand and sand in foreset beds that dip less than 25 degrees. Draped laminations of silt and clay common in the lower or more distal part of the delta. Overlies lake-bottom deposits, till or bedrock. The collapsed, ice-contact and proximal (near-ice) part of the delta or lacustrine fan is commonly interlayered with resedimented till and water-laid material derived from adjacent glacial ice and ice-free hillslopes. These lakes usually have extensive lake-bottom deposits and had stable spillways.

Nm — **Glacial Lake Newton deposits** - Ice-marginal deltas and minor lacustrine fans as much as 80 ft. thick. Lake-bottom silt, sand and clay, extensive beneath swamp deposits, as much as 100 ft. thick. Delta plain altitudes range from 620 ft. in Newton Meadows, and 610 to 670 ft. on the aggraded delta plain in Germany Flats. This lake occupied the lowland north of Newton, and Germany Flats; both in the Paulins Kill drainage basin. The spillway is located at the south end of the Newton Meadows over rock on a drainage divide between the Pequest and Paulins Kill drainage basins. Deposition in Germany Flats ceased after the ice margin retreated north into a small valley north of Lake Grinnel, and into the Wildcat Brook Valley. Contemporaneously, deposition ceased in the western part of the lake basin after the ice margin retreated into Glacial Lake Beaver Run in Lafayette Meadows, and a small unnamed lake in the upper Paulins Kill drainage basin north of Newton Meadows. Lake Newton, which was held in by the Ogdensburg-Culvers Gap Moraine and Nm deposits, persisted until the moraine and outwash south of Lafayette became breached by erosion and the lake slowly or catastrophically drained. Based on the occurrence of swamp deposits in Newton Meadows, a shallow lake persisted into the Holocene. Includes Pq13 deposits.

Sv — **Glacial Lake Sparta deposits** - Unit includes deposits of five lake stages. Ice-marginal deltas, fluviodeltas, and minor lacustrine fans as much as 65 ft. thick and lake-bottom sand, silt, and clay, extensive beneath swamp deposits, as much as 100 ft. thick. Altitudes of delta plains range from 845 ft. to 645 ft. This lake occupied the Wallkill River valley south of Franklin. Five lake stages correspond to the uncovering of successively lowering spillways; altitudes 845 ft., 825 ft., 805 ft., 700 ft., and 650 ft., located on the drainage divide between the Pequest River and Paulins Kill, and Wallkill River. The lake lowered to the level of glacial Lake North Church (see Stanford and Harper, (1985) for description of glacial Lake North Church) after the ice margin retreated north of the Pimple Hills near Franklin. The delta east of Franklin was laid down in glacial Lake North Church.

3. ***Glaciodeltaic and glaciolacustrine deposits laid down in small glacial lakes which formed in north-draining valleys; chiefly in uplands*** - Includes well-sorted sand and gravel, sand, fines, and minor coarse gravel in ice-marginal deltas, lacustrine fans, and lake-bottom deposits. Sedimentary facies similar to large-lake depositional systems. However, because lake basins are usually small, the deposits are generally more collapsed, consist largely of deltaic sediment, and lake-bottom deposits are rarely exposed at the surface. Lake-bottom sediment chiefly consists of sand and silt with minor clay in ripple-cross-bedded rhythmites, and parallel irregularly-laminated graded beds of fine sand and silt, with minor layers of clay drapes. Deposition of this material was largely the result of underflows and slump-generated density flows. Seasonally-controlled rhythmic deposits (varves) are absent or poorly developed. In this depositional setting the elevation of topset-foreset contacts of the deltas usually decreases northward because lower outlets are uncovered by the retreating glacier. Deltas are commonly contiguous in distribution.

Ap — **Andover Pond Deposits** - Ice-marginal deltas, and lacustrine fans of three lake stages; thickness as much as 50 ft. Lake-bottom sand and silt in subsurface as much as 40 ft. Altitudes of delta plains range from 705 ft. to 650 ft. These lakes occupied a tributary valley of the Pequest River north of Andover. Spillways are located over local drainage divides between tributaries in the Pequest drainage basin; altitudes 715 ft. and 645 ft. Deposition ceased after the ice margin retreated north into the upper Pequest Valley and the youngest lake drained.

Cf — **Culvers-Fairview Lakes deposits** - Ice-marginal deltaic, and minor lacustrine fan deposits of multiple lake stages; thickness as much as 50 ft. Lake-bottom sand and silt in subsurface as much as 40 ft. thick and altitudes of delta plains range from 980 ft. to 940 ft. These lakes occupied the Trout Brook and Swartswood Creek valleys which are tributaries of the Paulins Kill. Spillways are underlain by till, and located over local drainage divides; altitudes 985 ft. and 945 ft. Deposition ceased after the ice margin retreated into the Culvers Creek drainage basin.

Sm — **Sussex Mills Deposits** - Ice-marginal deltaic deposits of two lake stages; thickness as much as 55 ft. Lake-bottom sand and silt in subsurface as much as 40 ft. Altitudes of delta plains are 825 ft. and 730 ft. These lakes occupied a small drainage basin in the New Jersey Highlands west of Sparta. Spillways are located over till and rock on local drainage divides; altitudes 815 ft. and 725 ft. Deposition ceased after the ice margin retreated northward in the Pequest Valley; uncovered a northwest-draining tributary valley and the youngest lake drained.

4. ***Glaciodeltaic and glaciolacustrine deposits laid down in small glacial lakes that formed in valleys dammed by recessional meltwater deposits, moraine, or stagnant ice*** - Includes well-sorted sand and gravel, sand, fines, and minor coarse gravel in ice-marginal deltas and fluviodeltas, lacustrine fans, and lake-bottom deposits. Sedimentary facies similar to depositional systems in small lakes of north-draining valleys. Aggradation of fluvial-topset deposits occurred extensively because lake basins were generally narrow, and rapidly filled with deltaic and lacustrine sediment. Younger deposits frequently aggraded over older deposits. Outlets for most lakes was usually over older-recessional deposits down valley. The elevation of topset-foreset contacts of deltas laid down in these lakes generally increases northward as meltwater became ponded behind successively higher aggraded outwash.

Bc — **Bear Creek Deposits** - Deposits in local lake basins which are not differentiated. Ice-marginal deltas as much as 55 ft. thick and lake-bottom silt, clay, and sand extensive beneath swamp deposits, as much as 50 ft. thick. Altitudes of delta plains range from 645 ft. to 610 ft. These lakes occupied scoured rock basins northeast of Huntsburg in the upper Pequest Valley. Spillways are located over older meltwater deposits and local drainage divides over rock. Deposition ceased after the ice margin retreated north into the Pequest River Valley. Bc1 is graded to the level of Glacial Lake Pequest, stage II (see Ridge, (1983), and Witte, (1988) for description of glacial Lake Pequest).

Bl — **Blairs Creek Deposits** - Valley outwash deposits and minor ice-marginal deltas as much as 50 ft. thick. Surface altitudes range from 930 ft. to 885 ft. Deltas were laid down in small glacial lakes dammed by the Franklin Grove moraine (Ridge, 1983), and older Blairs Creek deposits. Deposition ceased after the ice margin retreated north into the Trout Brook drainage basin.

Kp — **Kimbels Pond deposits** - Deposits of small local lake basins, undifferentiated. Ice-marginal deltas as much as 60 ft. thick and lake-bottom silt, sand, and clay in subsurface as much as 50 ft. thick. Altitudes of delta plains range between 620 and 640 ft. Deposits were laid down in a proglacial lake that occupied a small valley northeast of Lake Grinnel, Germany Flats. Spillways were located over glacial Lake Newton deposits and stagnant ice in Germany Flats. Deposition ceased after the ice margin retreated northward into the glacial Lake North Church basin.

Pk — **Upper Paulins Kill Deposits** - Ice-marginal deltas, and minor lacustrine fans as much as 60 ft. thick, and lake-bottom sand, silt, and clay in subsurface as much as 50 ft. Altitudes of delta plains range from 480 ft. to 590 ft. Deposits were laid down in small lakes that occupied the main part of the upper Paulins Kill Valley and were chiefly dammed by older meltwater deposits downvalley. Spillways were over the same deposits. Deposition ceased after the ice margin retreated north into the Papakating Creek drainage basin.

Pq — **Upper Pequest Valley Deposits** - Ice-marginal deltas and minor lacustrine fans as much as 65 ft. thick and lake-bottom sand, silt, and clay in subsurface as much as 30 ft. thick. Altitude of delta plains range from 560 ft. to 625 ft. Deposits were laid down in small lakes that occupied the upper part of the Pequest River valley; these were dammed initially by glacial Lake Pequest deposits, and later older upper Pequest Valley deposits. Spillways were over these deposits and ice down-valley. Morphosequences Pq5 and Pq6 were laid down in glacial Lake Pequest, stage II. Deposition ceased after the ice margin retreated north into glacial Lake Newton.

Sw — **Glacial Lake Swartswood Deposits** - Unit includes deposits of two lake stages. Fluviodeltas as much as 60 ft. and lake-bottom silt, clay, and sand in subsurface as much as 75 ft. thick. Altitudes of delta plains range from 500 ft. to 535 ft. The lake occupied a scoured-rock basin north of Middleville, that drains to the Paulins Kill. Spillways are located over rock and till at the south end of the lake basin; altitude of rock-floored spillway. 530 ft. Later the till-floored spillway was lowered by erosion and lake level dropped approximately 30 feet. Meltwater deposition in the lake ceased after the ice margin retreated north into a minor tributary drainage basin of the Paulins Kill. Sw2 deposits may consist of sediment transported by postglacial streams.

Wb — **Wildcat Brook deposits** - Lacustrine fans as much as 50 ft. thick and lake-bottom silt, sand, and clay as much as 80 feet thick; includes lake-bottom deposits laid in glacial Lake North Church. Deposits were laid down in a small lake basin, located at the south end of Wildcat Brook valley. The lake was held in by glacial lake Newton deposits and the Ogdensburg-Culvers Gap Moraine. Deposition ceased in the lake basin after the ice margin retreated north into the glacial Lake North Church basin.

Undifferentiated meltwater deposits

Qmu — **Meltwater deposits in upland areas** - Gravel and sand, coarse gravel, and sand in small, usually collapsed deposits as much as 40 feet thick. Depositional settings uncertain.

Qsi — **High ice-contact deposit** - Sand and gravel, and coarse gravel as much as 45 feet thick; chiefly of deltaic origin and usually interlayered with glacigenic sediment. Interpreted to have been deposited in ice-walled lakes or ponds within the stagnant margin of the glacier.

Qlb — **Lake-bottom deposits** - Laminated, irregular to rhythmically-bedded silt, sand, and clay, and minor ripple cross-laminated silt, sand, and minor clay; chiefly of glaciolacustrine origin; as much as 100 feet thick. May be locally contiguous with minor swamp deposits and alluvium. Extensive lake-bottom deposits occur beneath swamp deposits and alluvium in Sparta Valley, and Newton and Lafayette Meadows.

Numbers after morphosequence unit symbol on map refer to an unique morphosequence associated with an ice-retreatal position. The first two letters are related to the drainage basin, glacial lake name, or local geographic name. Proceeding numbers represent individual morphosequences with greater numbers indicating younger deposits, and similar numbers representing correlative deposits. Numbering scheme continued and modified from Ridge, (1983). The letter "u" indicates an uncorrelated deposit.

References Cited

Birkeland, P. W., 1974, *Pedology, Weathering, and Geomorphological Research*: Oxford University Press, Inc., New York, 285 p.

Connally, G. G., and Sirkin, L. A., 1973, Wisconsinan history of the Hudson Champlain lobe, in Black, R. F., Goldthwait, R. P. and William, H. B. (eds.), The Wisconsinan stage: Geol. Soc. Amer. Memoir 136, p. 47-69.

Cotter, J.F.P., Ridge, J. C., Evenson, E. B., Sevon, W. D., Sirkin, L. A. and Stuckenrath, Robert, 1986, The Wisconsinan history of the Great Valley, Pennsylvania and New Jersey, and the age of the "Terminal Moraine", in New York St. Mus. Bull. no 445

Crowl, G. H., 1980, Woodfordian age of the Wisconsinan glacial border in northeastern Pennsylvania: Geology, v. 8, p. 51-55.

Evenson, E. B., and Clinch, M. J., 1987, Debris Transport mechanisms at active alpine glacier margins: Alaskan case studies; Geological Survey of Finland, Special Paper 3, p. 111-136.

Gustavson, T. C., and Boothroyd, J. C., 1987, A depositional model for outwash, sediment sources, and hydrologic characteristics, Malaspina Glacier, Alaska: A modern analog of the southeastern margin of the Laurentide ice sheet: Geol. Soc. Amer. Bull., v. 99, p. 187-200.

Harmon, K. P., 1968, Late Pleistocene forest succession in northern New Jersey: unpublished M.S. thesis, Rutgers Univ., New Brunswick, New Jersey, 164 p.

Ridge, J. C., 1983, The surficial geology of the Great Valley section of the Valley and Ridge province in eastern Northampton Co., Pennsylvania and Warren Co., New Jersey: unpublished M.S. thesis, Lehigh Univ., Bethlehem, Pa., 234 p.

Sirkin, L. A., and Minard, J. P., 1972, Late Pleistocene glaciation and pollen stratigraphy in northwestern New Jersey: U.S. Geological Survey Prof. Paper 800-D, p. D51-D56.

Stanford, S. D., and Harper, D. P., 1985, Reconnaissance map of the glacial geology of the Hamburg quadrangle, New Jersey: N.J. Geological Survey Geologic Map Series 85-1.

Stone, B.D., Stanford, S. D., and Witte, R. W., 1989, Preliminary surficial geologic map of northern New Jersey in Northeastern Section Geol. Soc. Amer. Abstr. with Programs, v. 21, no. 2, p. 76.

Tedrow, J. C. F., 1986, *Soils of New Jersey*: Robert E. Krieger Publishing Company, Malabar, Florida, 479 p.

Witte, R.W., 1991, Deglaciation of the Kittatinny and Minisink Valley area of northwestern New Jersey: Stagnant and active ice at the margin of the Kittatinny and Minisink Valley lobes. in Northeastern and Southeastern Section Geol. Soc. Amer. Abstr. with Programs, v. 23, no. 1, p. 151

________, 1989, Debris sources of morphosequences deposited at the margin of the Kittatinny Valley lobe during the Woodfordian deglaciation of Sussex County, northern New Jersey: in Northeastern Section Geol. Soc. Amer. Abstr. with Programs, v. 21, no. 2 p. 76.

________, 1988, The surficial geology and Woodfordian glaciation of a portion of the Kittatinny Valley and the New Jersey Highlands in Sussex County, New Jersey: unpublished M.S. thesis, Lehigh Univ., Bethlehem, PA., 276p.