The Blairstown quadrangle is in the glaciated part of the Valley and Ridge and Highlands physiographic provinces in northwestern New Jersey. The main geographic features in the quadrangle are Jenny Jump Mountain and the valleys of the Paulins Kill, Beaver Brook, and the Pequest River, which flow in a southwestward direction to the Delaware River (fig. 1). The area is largely rural and is marked by patches of woodlands and cultivated land in the valleys, and large tracts of forest on Jenny Jump Mountain. The highest point is 1,134 feet above sea level on the summit of Jenny Jump Mountain, and the lowest is on the Paulins Kill, approximately 315 feet above sea level, where it flows west into the Portland

Surficial materials consist of till and glacial meltwater sediment deposited during the late Wisconsinan glaciation and postglacial deposits of alluvium, colluvium, talus, and peat. These materials are as much as 200 feet thick and are the parent material on which soils form. Till typically lies directly on bedrock, and is generally less than 20 feet thick. It is interspersed with numerous bedrock outcrops and most of these exhibit evidence of glacial erosion. Thicker till forms drumlins, moraines, and aprons on north-facing hillslopes. Meltwater sediment laid down at and beyond the glacier margin, lies in stream valleys through which Paulins Kill and its tributary Blairs Creek, Beaver Brook and its tributaries Honey Run and Muddy Run, and the Pequest River and its tributary Bear Creek, now flow.

PHYSIOGRAPHY AND BEDROCK GEOLOGY

The Blairstown quadrangle lies entirely in the Delaware River drainage basin. The Paulins Kill, Beaver Brook, and Pequest River flow southwestward through valleys that are underlain by dolomite, slate, and siltstone. The course of these streams generally flows over thick deposits of glaciofluvial and glaciolacustrine sediments. he physiography of the quadrangle is largely the result of differential erosion on the chiefly southwest-trending fold and thrust belts of dolomite, slate, siltstone, gneiss, and granite (Drake and Lyttle, 1985) (fig. 2). The uplands rise as much as 700 feet above the floors of the valleys, and they are mostly underlain by gneiss and granite. The topography on the uplands is rugged and the landscape is deeply dissected. Ridge lines chiefly follow layering in the bedrock, although discordant trends are common, and in places deep gaps cut across the southwest-trending

Intermediate areas of elevation are typically underlain by slate and siltstone. Overall, the average elevation here is about 300 feet higher than the dolomite-floored valleys, and relief is as much as 400 feet. The topography consists of rolling hills of moderate to steep slopes and strike-parallel ridges that have been streamlined by glacial erosion. In a few places, this surface is buried beneath drumlins and

Dolomite underlies most of the Paulins Kill valley, and relief here is as much as 200 feet. Rock outcrops are abundant, and in many places the land is marked by irregular, knobby topography of moderate to steep slopes. In other places, more resistant beds that contain chert and minor quartzite form narrow strike-parallel ridges. The lower parts of the valley are covered by glaciolacustrine and glaciofluvial deposits. These deposits rise as much as 100 feet above the Paulins Kill.

The Pequest valley is underlain by thick glacial drift that mostly consists of lakebottom deposits laid down in Lake Pequest. In places, lacustrine-fan deposits and ice-contact deltas rise above the broad alluvial and lake-bottom plain of the valley. In the quadrangle, there are only a few dolomite outcrops in the valley, and all of these crop out along a strike belt that extends southward from Stevens Island.

PREVIOUS INVESTIGATIONS

The surficial geology of the area encompassing the Blairstown quadrangle was first discussed by Cook (1877, 1878, 1880) in a series of Annual Reports of the State Geologist. He included detailed observations on the terminal moraine, recessional moraines, distribution and kinds of drift, and evidence of glacial lakes. Salisbury (1902) detailed the glacial geology of New Jersey region by region. The terminal moraine and all surficial deposits north of it were interpreted to be products of a single glaciation of Wisconsinan age. Salisbury also noted that "in the northwestern part of the state, several halting places of ice can be distinguished by the study of successive aggradation plains in the valleys." Cotter and others (1986) indicated that the youngest glacial deposits in this area are of late Wisconsinan age and correlate with the Olean drift in Pennsylvania (Crowl and

Epstein (1969), Ridge (1983), and Witte (1988, 1997a) detailed the late Wisconsinan deglaciation for northwestern New Jersey and a small part of northeastern Pennsylvania. Deglaciation was characterized by the systematic northeastward retreat of the Kittatinny Valley and Minisink Valley ice lobes (black lines on fig. 3). This interpretation was based on the distribution of ice-marginal meltwater deposits (morphosequences) and moraines, and correlative relationships between elevations of delta topset-foreset contacts, former glacial-lake-water plains, and lake spillways. The identification of ice-retreatal positions by mapping morphosequences was first introduced in New England by Jahns (1941) and later refined by Koteff and Pessl (1981).

PREGLACIAL DRAINAGE

The primary drainage routes in the quadrangle and surrounding area were probably established well before the Pleistocene. The transverse gaps on Jenny Jump Mountain are possibly relicts of an earlier drainage system that flowed in a southeasterly direction in the middle and late Miocene. The Delaware River, through headward erosion and capture of the former southeasterly drainage in the late Miocene, has enlarged its drainage area chiefly by extending its tributaries up-valley along the strike of less resistant rock. In response to the overall lowering of sea level during the Pleistocene, the drainage has further evolved by incision, which along the larger tributaries of the Delaware River has resulted in the formation of a lower, narrower river valley. Extensive headward erosion by first and second-order streams has also resulted in the dissection of the older valley floor and surrounding uplands. The location of Illinoian glaciofluvial deposits in the Delaware valley south of the map area suggests that the river valleys in the study area had been lowered to their present levels by the time of the Illinoian glaciation. **GLACIAL EROSION**

The distribution and differences in the weathering characteristics of glacial drift in New Jersey indicate continental ice sheets covered the quadrangle at least three times during the Pleistocene (Salisbury, 1902; Stone and others, 2002; Stanford and others, 2021). Erosional features of only the late Wisconsinan glaciation are preserved, and they include polished, striated, and plucked bedrock outcrops (figs. 4-7), streamlined bedrock forms, and u-shaped valleys. The floors of the Pequest and Paulins Kill valleys have been deeply scoured by glacial erosion. The many unweathered and lightly weathered bedrock outcrops in the quadrangle show that most of the pre-existing weathered bedrock and surficial material has been removed by glacial erosion, although outcrops of saprolite beneath late Wisconsinan till observed in the adjoining Tranquility and Washington quadrangles (Stanford and Witte, 2002; Witte and Ridge, 2021) show that some preglacial materials were not eroded. SURFICIAL DEPOSITS

Surficial materials in the quadrangle include glacial deposits consisting of till and meltwater sediments and postglacial deposits consisting of hillslope sediment, organic deposits, and stream deposits. They are defined by their lithic characteris-

tics (composition, texture, color, and structure), and bounding discontinuities. Glacial Deposits

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

Till is typically a compact silt to silty sand containing as much as 20 percent pebbles, cobbles, and boulders. Clasts are sub-angular to sub-rounded, faceted, and striated, and measured clast fabrics indicate a preferred long axes orientation parallel to the regional direction of glacier flow. Presumably this material is lodgment 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 transverse to glacial flow. This material appears to be ablation till and flowtill, and 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 the till, making it less compact, reorienting stone fabrics, and

Till is divided lithologically into two types. They are 1) Kittatinny Valley till (Qwtk), which is an informal variety of the Kittatinny Mountain Till of Stone and others (2002), and 2) Netcong Till (Qwtn) (Stone and others, 2002), and their respective characteristics were largely dependent on the direction of ice flow over different suites of local source rocks. In some places, the composition of till is unlike that of the underlying rock because glacial flow was southward across different types of bedrock. Kittatinny Valley till is chiefly derived from slate, greywacke, dolomite, and limestone that underlie Kittatinny Valley with secondary amounts of quartzite, quartz-pebble conglomerate, and red sandstone derived from Kittatinny Mountain Netcong Till is chiefly made up of materials derived from gneiss and granite derived from Jenny Jump Mountain. The contacts between the two tills are gradational and were interpreted from field observations, and boulder and pebble counts. Kittatinny Valley till lies in Kittatinny Valley and on the northwest flanks of Jenny Jump Mountain and the New Jersey Highlands. Netcong Till lies on Jenny Jump Mountain and the Highlands.

located within areas of thin till, and rock outcrops near them suggest that some may have a bedrock core. Most of these drumlins parallel the local topographic grain. Stanford and others (1998) show that some drumlins in Kittatinny Valley in the Hamburg area north of the quadrangle have cores that consist of weathered, older till, but pre-Wisconsinan glacial deposits have not been recognized in the Blairstown quadrangle.

Drumlins in the Blairstown quadrangle are in Kittatinny Valley. Most of them are

Meltwater Deposits Sediment carried by glacial meltwater was chiefly laid down at and beyond the glacier margin in valley-train deposits (Qwfv) and ice-contact deltas (Qwde). Smaller quantities of sediment were deposited in meltwater-terrace deposits (Qwft), lacustrine fans (Qwlf), lake-bottom deposits (Qwlb), and as ice-contact deposits forming a few kames (Qwic). Most of this material was transported by meltwater through glacial tunnels to the glacier margin, and by meltwater streams draining ice-free upland areas adjacent to the valley (Witte, 1988; Witte and Evenson, 1989). Sources of sediment presumably included till and debris from beneath the glacier and in the basal dirty-ice zone and till and outwash in upland areas.

Glaciofluvial sediments were laid down by meltwater streams in valley-train and meltwater-terrace deposits, and delta topset beds. These sediments include cobbles, pebbles, sand, and minor boulders laid down in stream channels; and sand, silt, and pebbly sand in minor overbank deposits. Sediment laid down near the glacier margin in valley-train deposits, and in delta topset beds, typically includes thickly bedded, imbricated, planar coarse gravel and sand, and minor channel-fill deposits that consist largely of cross-stratified pebbly sand and sand. Downstream the overall grain size of the outwash decreases, sand is more abundant, and cross-bedded and graded beds are more common. 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.

Debris carried to the margin of the ice sheet by direct glacial action was minor.

Glaciolacustrine sediments were laid down by meltwater streams in ice-contact and valley-outwash deltas, lacustrine-fan deposits, and lake-bottom deposits; all deposited in glacial 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 (25° to 35°) and consist of thick to thin rhythmically bedded fine gravel and sand. Farther out in the lake basin these sediments grade into less steeply dipping foreset beds of graded, ripple cross-laminated, parallel-laminated sand and fine gravel with minor silt drapes. These in turn grade into gently dipping bottomset beds of ripple cross-laminated,

Typically, deltas consist of many individual lobes that prograde outward from the delta front across the lake floor, thinning and widening with distance (Gustavson, and others, 1975). Because lake basins in the Paulins Kill valley were very narrow and small, deltaic sediments filled in the lakes and in places, were covered by a

parallel-laminated sand and silt with clay drapes.

Unlike deltas, lacustrine-fan deposits lack topset beds; they were deposited at the mouth of glacial tunnels that generally exited the glacier near the floor of the lake basin. Lacustrine fans also become progressively finer-grained basinward. However, near the former tunnel mouth, sediments may be poorly sorted because of high sedimentation rates. If the tunnel remained open and the ice front remained stationary, the fan eventually may have built up to lake level and formed

Lake-bottom deposits consist of laminated, rhythmically bedded silt, clay, and very fine sand that has progressively settled out of suspension, and coarser sand and silt that has been carried by turbidity currents in the lake basin. These deposits grade laterally into bottomset beds of deltas and lacustrine-fan deposits. Ice-contact deposits consist of a varied mixture of stratified sand, gravel, and silt interlayered with flowtill. In most places, they lie above local base-level controls. Knob-and-kettle topography is typical, and a few deposits form isolated hills (kames). These deposits were either laid down in an ice-crevasse, ice-walled sink,

or moulin at a stagnant glacier margin. In other places, they may include small,

Thin deposits of undifferentiated colluvium (Qcu) lie in the upper parts of first-order drainage basins and the base of a few hillslopes. This material is made of a mixture of bedrock rubble (chiefly derived from frost riving) and colluviated till. Undifferentiated alluvium and colluvium (Qcal) is a mixture of alluvium and colluvium that has accumulated in narrow valleys in the upper parts of first-order drainage basins. These deposits in places also include the toe slopes of small colluvial aprons. Talus deposits (Qta) lie chiefly on Jenny Jump Mountain, where they form thin aprons of rock rubble that lie at the base of large cliffs. Elsewhere, thin talus is included with colluvium or is too small and discontinuous to map.

Swamp and bog deposits (Qs) are common in the quadrangle. They formed in glacially scoured bedrock basins, kettles in outwash and moraine, glacial lakes that persisted into the Holocene, abandoned stream channels on alluvial plains, and poorly drained areas on thick till. 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 largely the decayed remains of plants that grew in shallow bodies of water and, upon their expiration, accumulated on the floor of the watery basin. Muck is a mass of finely-divided organic matter, having no resemblance to the original plant remains, and in addition, it contains silt and clay washed in from adjacent upland soils (Waksman, 1942).

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

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. Stream-terrace deposits (Qst) include both channel and flood-plain sediment, and they lie five to 10 feet above the modern flood plain and below the level of meltwater-terrace and deltaic deposits. Alluvial-fan deposits (Qaf) are scattered throughout the quadrangle. They form fan-shaped deposits at the mouths of gullies and ravines, where small streams enter larger valleys. Sediment is highly variable and is derived chiefly from local surficial sediment, eroded by streams draining adjacent uplands. Many alluvial fans are deeply entrenched by modern streams. This suggests that most are probably of late Wisconsinan age when climate, sediment supply, and amount and type of hillslope vegetation were more favorable for their deposition.

The geologic framework of the late Wisconsinan stratified valley-fill deposits shows that meltwater deposits were laid down in two depositional settings. The first includes deposits laid down in lake basins that were not filled completely with glaciolacustrine sediment. Typically, these basins were large, and at least 100 feet eep. Deltas and lacustrine-fan deposits are generally separated by extensive areas of lake-bottom sediment, with a large part of the basin being covered by the lake-bottom plain. Lake Pequest illustrates this setting.

The second setting includes deposits in lake basins that are nearly or completely filled with glaciolacustrine sediment. Typically, these basins are small and/or narrow, and topset beds may have been extensively aggraded as deposition in the basin became largely dominated by glaciofluvial sedimentation. Deltas and lacustrine-fan deposits commonly coalesce, and delta plains commonly form the floor of an entire lake basin. Lacustrine-fan deposits may also lie beneath younger deltaic and lake-bottom deposits. Typically, these fans lie on till or bedrock at the bottom of the former lake basin; well records show that they do not form continuous sheets across the basin floor. The Paulins Kill valley in the vicinity of Blairstown illustrates this setting.

GLACIAL HISTORY

The late Wisconsinan ice advance into Kittatinny Valley is obscure because glacial drift and striae that record this history have been eroded or were buried. If the ice sheet advanced in lobes as suggested by the lobate course of the terminal moraine, then its initial advance was marked by lobes of ice moving down the Kittatinny and Minisink valleys (fig. 3). Sevon and others (1975) suggested that ice from the Ontario basin first advanced southward into northeastern Pennsylvania and northwestern New Jersey. Later, ice from the Hudson-Wallkill lowland, which initially had lagged behind, overrode Ontario ice, and the ice flow turned to the southwest. In this scenario, the course of the terminal moraine in Minisink and Kittatinny Valleys was controlled by ice flowing from the Hudson-Wallkill lowland. Iternatively, Connally and Sirkin (1973) suggested that the Ogdensburg-Culvers Gap moraine (ice margin 7 on figure 3) represents or nearly represents the terminal late Wisconsinan position of the Hudson-Champlain lobe based on changes in ice flow noted by Salisbury (1902) in the vicinity of the moraine. Ridge (1983) proposed that a sublobe of ice from the Ontario basin overrode Kittatinny Mountain and flowed southward into Kittatinny Valley. Southwestward flow occurred only near the glacier margin where ice was thinner, and its flow was constrained by the southwesterly trend of the valley. Analyses of striae, drumlins, and the distribution of erratics in the upper part of Kittatinny Valley and adjacent Kittatinny Mountain partly support Ridge's view. These data further indicate that by the time the Oddensburg-Culvers Gap moraine was formed, ice flow in Kittatinny Valley had turned completely to the southwest with extensive lobation at the margin.

Boulders of nepheline syenite and Martinsburg hornfels, uncovered by a recent landslide in Minisink Valley north of the Blairstown quadrangle, may provide information on the advance history of the Kittatinny and Minisink Valley ice lobes. The boulders were derived from till that had covered a steeply dipping bedrock slope (Witte and Epstein, 2012). Previous investigations by Salisbury (1902), Ridge (1983), and Witte (1988, 1991) have shown that the boulders lie in Kittatinny Valley, and on Kittatinny Mountain northward of the Culvers Lake area (fig. 3). Based on their location in Minisink Valley, ice would have had to flow south 55° west across Kittatinny Mountain, from the outcrops in Kittatinny Valley. This direction is not consistent with the direction of ice flow reconstructed from striae, drumlins, and till provenance. Clearly, this find represents an anomaly that cannot be explained by the direction of regional ice flow during the late Wisconsinan maximum or during deglaciation, which has been firmly established by previous investigations. A possible explanation for the location of the syenite-bearing till may be that it represents the initial advance of late Wisconsinan ice into this area from the Hudson-Wallkill lowland. Later as the ice thickened and the Kittatinny Valley and Minisink Valley lobes coalesced, ice flow turned southward.

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 983), Cotter and others (1986), and Witte (1988, 1991, 1997a, 1997b) showed that the margin of the Kittatinny and Minisink Valley lobes retreated systematically with minimal stagnation. However, the chronology of deglaciation in this area is somewhat uncertain. This is due to scant radiocarbon dates because of a lack of organic material that can be used to date deglaciation, inadequacies of dating bog-bottom organic material and concretions, and use of sedimentation rates to extrapolate bog-bottom radiocarbon dates. Also, there are too few varve exposures to build a varve chronology.

Varves and radiocarbon dates in the Passaic, Hackensack, and Hudson valleys in eastern New Jersey and adjoining New York bracket the age of the terminal moraine to between 25 and 24 ka (ka = thousand years ago) and the retreat of ice from New Jersey to about 22 ka (Stanford and others, 2021). Basal organic material cored from a bog in the Blairstown quadrangle located on the east side of Jenny Jump Mountain approximately three miles north of the terminal moraine by D. H. Cadwell (written communication, 1996) yielded a radiocarbon age of 19,340 +/- 695 yr B.P. (GX-4279), which calibrates to 23.3 ka (with a one-sigma uncertainty range of 24.1-22.5 ka). This is a minimum age for the deglaciation of this area. Similarly, basal organic material from Francis Lake in the Tranquility quadrangle. two miles east of Johnsonburg and approximately eight miles north of the terminal moraine, yielded a radiocarbon age of 18,570 +/- 250 yr B.P. (SI-5273) (Cotter, 1983), which calibrates to 22.4 ka (with a one-sigma uncertainty range of 22.1-22.7 ka). This is also a minimum age for deglaciation in this area. Based on the morphosequence concept of Koteff and Pessl (1981), many ice-re-

cessional positions have been delineated in Kittatinny Valley (Ridge 1983; Witte 1988, 1997a). In addition, moraines and glacial-lake histories, based on the correlation of elevations of delta topset-foreset contacts, former glacial-lake water levels, and lake spillways, provide a firm basis for the reconstruction of the recessional history of the ice lobes. Recessional deposits are discussed in reference to deposition at the margin of the Kittatinny Valley lobe in the Paulins Kill, Beaver Brook, and Pequest valleys.

Paulins Kill Valley Meltwater deposits in the Paulins Kill valley consist of valley-train deposits, deltas,

ice-contact deposits, and meltwater-terrace deposits. They lie as much as 100 feet above the Paulins Kill, and most were laid down from ice-retreatal positions north of the quadrangle. Deltaic deposits form the bulk of the stratified sediment in the Paulins Kill valley. Rising to an elevation of 410 feet near Blairstown, these deposits were laid down in a small proglacial lake that was dammed downvalley in the Portland quadrangle by older outwash. Foreset bedding and lake-bottom deposits observed by the author and Ridge (1983), and well records (table 1), support the former existence of a glacial lake in this part of the Paulins Kill valley. During glacial retreat, the lake expanded up the valley at least as far as Blairstown. Sediment-laden meltwater from ice-retreatal positions north of the quadrangle (Witte and Epstein, 2012) filled in the lake basin. Based on morphosequence mapping, Ridge (1983) and Witte (1988) delineated 14 ice-retreatal positions in the Paulins Kill valley.

> Meltwater-terrace deposits that cover parts of the valley floor were formed at some later time. The timing of their formation is not clear because outwash from successive ice-retreatal positions up-valley (Witte, 1988) rise in elevation. Erosion may have been delayed until the margin of the Kittatinny Valley lobe retreated north of the Wallkill River-Paulins Kill drainage divide. At this time, Lake Wallkill was formed (Witte, 1997a). Outlet water from this lake continued to flow across the spillway at Augusta and erode meltwater deposits in the Paulins Kill valley until a lower spillway was uncovered in the Wallkill valley, and the lake drained into the Hudson valley. Alternatively, older outwash deposits down-valley were incised by meltwater streams emanating from distant ice-retreatal positions up-valley.

Meltwater deposits in the Beaver Brook valley and its tributary valleys of Honey Run and Muddy Run consist of deltaic deposits and meltwater-terrace deposits. The streams are flanked by low, discontinuous terraces that were formerly more extensive before they were eroded by later meltwater and postglacial stream action. Upstream these deposits reach an elevation of 450 feet, and downstream they drop to 380 feet. The downstream parts of the meltwater-terrace deposits appear to be deltaic based on foreset bedding observed in a few small sand and gravel pits. Similar to the depositional setting in the Paulins Kill valley, these deposits may have also been laid down in a glacial lake dammed by older outwash

thick wedge of glaciofluvial sand and gravel that extended from valley wall to Lake Pequest was a large and deep lake dammed down valley by the terminal

moraine near Townsbury in the Washington quadrangle. There are several sluiceways through the moraine that were probably cut by the lake's outlet waters. The highest of these lies at 565 feet above sea level, and it appears to have controlled the elevation of ice-contact deltas during the early period of the lake's history. At some time, this spillway was abandoned, and a lower one, apparently located along the course of the present-day Pequest River, became active. The timing of this event is not clear, although the elevation of deltas in the northern part of the basin near Johnsonburg (these lie at an elevation of 560 feet) suggests that the level of the lake had dropped by the time the glacier had retreated to a position

Lacustrine-fan deposits in the valley define two ice-retreatal positions of the Kittatinny Valley lobe. These are called the Post Island and Stevens Island margins. These positions have been traced westward by Ridge (1983) into the Paulins Kill valley, where they are tentatively correlated with it burg and Walnut Valley. Based on morphosequen Witte (1988, 1991) delineated 13 ice-retreatal posi-Summary of Deglaciation

histories in the Pequest and Paulins Kill valleys sh inny Valley lobe retreated in a systematic manner i chiefly by melting at its periphery. This style of retr of the late Wisconsinan deglaciation observed (Ridge, 1983; Cotter and others, 1986; Witte, 1988

After ice retreated from the quadrangle, meltwater from Lake Wallkill continued to flow down the Paulins Kill valley until a lower spillway was uncovered in the mid-Wallkill valley, and the lake drained into Hudson valley. This occurred around 19 ka based on the varve chronology in the Hudson valley (Stanford and others,

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Meltwater deposits in the Pequest valley include ice-contact deltas, lacustrine-fan deposits, and lake-bottom deposits laid down in Lake Pequest. The history of the lake was described earlier by Salisbury (1902), Ridge (1983), and Witte (1988). Table 1. Records of selected wells in the Blairstown quadrangle. The listed wells were drilled for private and public water supply, and exploration. Wells listed with a NJDEP permit number are from the files of the Bureau of Water Allocation, N. J. Department of Environmental Protection. All other records are from exploratory borings that are on file at the New Jersey Geological and Water Survey. The location of wells with NJDEP permit numbers are based on block and lot maps or drillers' descriptions of distances from road intersections and they are generally accurate to 500 feet of the actual location. Exploratory borings were located in the field.

The delineation of ice-recessional positions and Lake dates (Cotter, 1983), the latest date of deglaciation for the Blairstown quadrangle is 22 ka.

Following deglaciation, cold and wet conditions, and sparse vegetative cover enhanced the erosion of hillslope material by solifluction, soil creep, and slope wash. Some of this material lies in small colluvial fills in first-order drainage basins. Mechanical disintegration of rock outcrops by freeze-thaw provided additional sediment, some of which now lies in aprons of talus at the base of cliffs on Jenny Jump Mountain. A few small boulder fields were formed where boulders, transported downslope by creep, accumulated at the base of hillslopes and in first-order drainage basins. These fields, and other concentrations of boulders that were formed by glacial transport and meltwater erosion, were further modified by freeze-thaw and their stones reoriented to form crudely shaped stone circles. Gradually as climatic conditions warmed, vegetation spread, and was succeeded by types that further limited erosion. Between 16 and 14 ka, lacustrine sedimentation, which had been dominated by clastic material, became enriched in organic material (Cotter, 1983). This transition represents a warming of the climate such that subaquatic vegetation could be sustained and marks a change in terrestrial vegetation from herb (tundra) to spruce and hemlock parkland, and eventually to spruce and hemlock forests. Oak and mixed hardwood forests started to populate

Stream-terrace deposition presumably started in the quadrangle when meltwater was cut off from the stream valleys, and stream discharge diminished substantially. This promoted an interval of lateral erosion across the valley floor as the larger streams began to meander. Sometime later, a period of incision ensued, and the streams cut down to their present levels. Based on the alluvial stratigraphy in Minisink Valley (Witte, 1997b), it appears that the onset of isostatic rebound, which is estimated to have begun in this region at 17 ka (Koteff and Larsen, 1989), and the onset of warmer climate that allowed deeper-rooted and more extensive forest to grow and so reduced sediment load in the drainage basin, may have initiated

the landscape around 11 ka (Cotter, 1983).

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north of the quadrangle.

| n ice contact deltas near Haines- ence mapping, Ridge (1983) and | |
|---|---|
| ositions in the Pequest valley. | 1 |
| If the interpretation of glacial lake | 2 |
| show that the margin of the Kittater in a northeasterly direction, and | 3 |
| treat is consistent with the pattern delsewhere in Kittatinny Valley 88, 1997a). Based on the Francis | 4 |

number by driller in land surface

gallons per

21-8006 20

21-6639 20

21-7030 30

21-6151 15

21-5875 20

21-8054 5

21-8208 6

21-4839 4

21-6652 none

21-5632 40

21-8123 8

21-7154 6

24-22804 8

24-17592 40

24-19455 20

24-19136 7

24-16964 5

24-14963 60

24-11998 5

24-20092 7

21-7768 20

reported

21-7760 artesian 0-55

21-7718 10

POSTGLACIAL HISTORY

Shallow, rimless depressions formed in stream-terrace deposits that lie on the floor of Lake Pequest in the Bear Swamp area (fig. 8) suggest that the lake may have drained before the climate warmed. These basins, shown by a blue crosshatch pattern on the map, are characteristic of thermokarst. Possibly they may have originated as thaw basins within a larger area of permafrost, or they may be fossil impressions of ground ice.

The most important surficial-material resource in the quadrangle is sand and gravel. Most of the sand and gravel are mined from deltas and lacustrine-fan deposits in the Pequest and Paulins Kill valleys. It is used as aggregate, subgrade fill, select fill, surface coverings, and decorative stone. Weathered slate that has been principally derived from frost riving makes an excellent subgrade material. although most of this material is too thin and discontinuous to be of economic importance. Till may be used for fill and subgrade material, and large cobbles and small boulders may supply building stone. Humus from swamp and bog deposits (Qs) may be used as a soil conditioner. It was formerly mined in the Pequest valley. The location of all pits and quarries are shown on the map. Most of these are inactive except for occasional use by the landowner.

Deltaic and lacustrine-fan sand and gravel deposits are permeable and may be aguifers in valley bottoms where they are more than 50 feet thick. Lacustrine-fan gravel that is overlain by low-permeability lake-bottom clay and silt, particularly in the Pequest valley, may be a confined aquifer. Elsewhere, the sand and gravel aquifers are mostly unconfined.

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sand and gravel brown soil and rock mixture sand, clay, and gravel overburden ractured limestone 21-5881 30 sand, clay, and gravel clay and hardpan clay and gravel

orange clay and brown shale

blue and brown slate

sand and heavy gravel

soft brown shale

sand and gravel

gravel, blue and grav clav

sand, gravel, and clay

clay and boulders

clay and sand

broken sandstone

clay and hardpan

ractured limestone

sand, clay, and limey gravel

hardpan, gravel, and sand

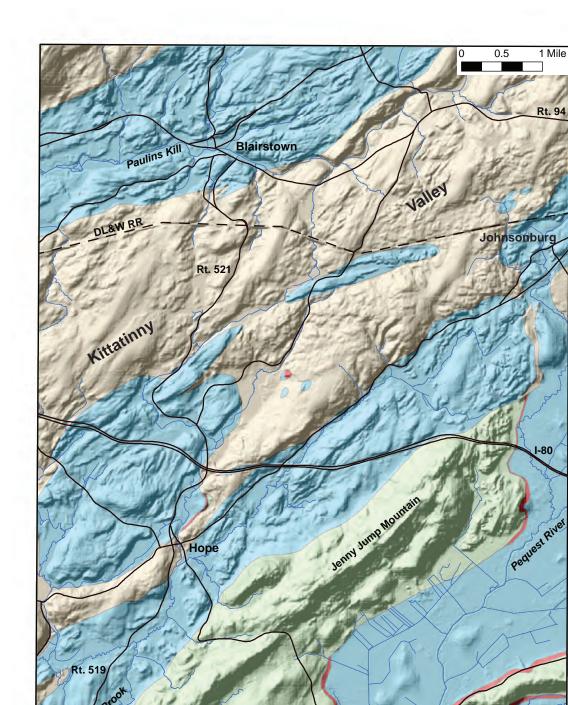
very fine sand

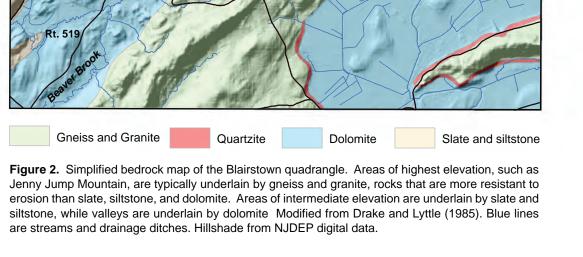
CORRELATION OF MAP UNITS

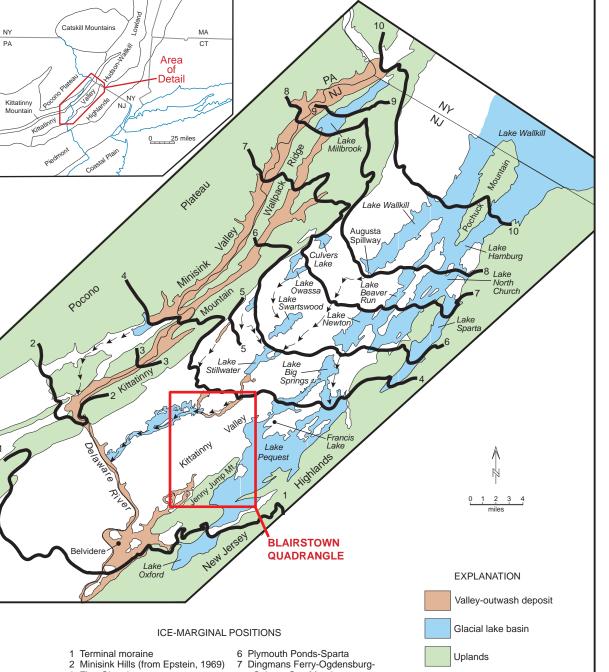
VERTICAL EXAGGERATION 10X

clay, boulders, and large gravel

rotten limestone and orange clay







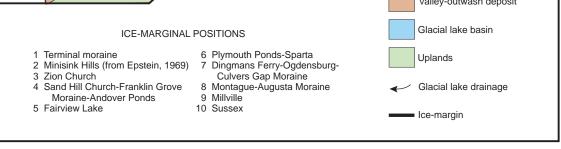
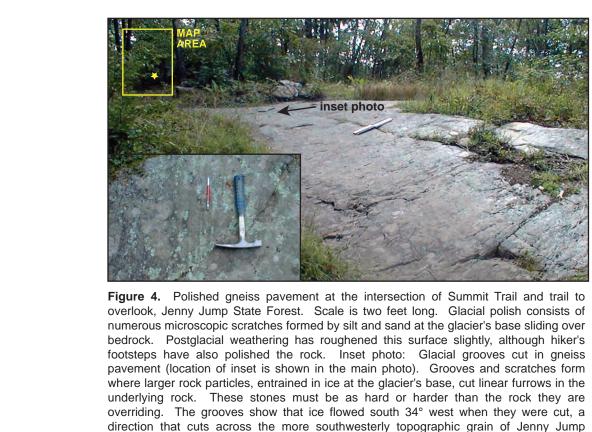


Figure 3. Late Wisconsinan terminal and recessional ice margins of the Kittatinny and Minisink Valley ice lobes,

and location of large glacial lakes, extensive valley-outwash deposits, and the Blairstown quadrangle. Modified

from data in Crowl (1971), Epstein (1969), Minard (1961), Ridge (1983), Witte (1997), and Stanford and others

Figure 1. Color-shaded relief map of the Blairstown quadrangle. Area of figure 8 outlined in red. Blue lines are streams and drainage ditches. Hillshade from NJDEP digital data.



overlook, Jenny Jump State Forest. Scale is two feet long. Glacial polish consists of numerous microscopic scratches formed by silt and sand at the glacier's base sliding over bedrock. Postglacial weathering has roughened this surface slightly, although hiker's footsteps have also polished the rock. Inset photo: Glacial grooves cut in gneiss pavement (location of inset is shown in the main photo). Grooves and scratches form where larger rock particles, entrained in ice at the glacier's base, cut linear furrows in the underlying rock. These stones must be as hard or harder than the rock they are overriding. The grooves show that ice flowed south 34° west when they were cut, a direction that cuts across the more southwesterly topographic grain of Jenny Jump Mountain. Yellow box shows location in quadrangle. Photograph by R. Witte.

Prepared in cooperation with the

EXPLANATION OF MAP SYMBOLS

Glacial-lake spillway--Number is elevation of its floor in feet

Bedrock surface contour--Approximately located. Number is

elevation of rock surface in feet above sea level. Contour

Elevation of bedrock surface determined by seismic

survey--In feet above sea level. Queried where anomalous

and not contoured. Surveys completed in 1992 by Jeff Wald-

ner, Dave Hall, and Don Jagel, N. J. Geological Survey, data

on file at N. J. Geological and Water Survey.

interval is 50 feet. Shown where rock surface is buried

above sea level. Arrow shows drainage direction.

Fluvial scarp--Line lies at base of scarp and tics

U.S. GEOLOGICAL SURVEY

NATIONAL COOPERATIVE GEOLOGIC MAPPING PROGRAM

Striation--Measurement at tip of arrow.

——— Drumlin--Line on crest, ellipse on summit.

Small meltwater channel

Shallow topographic basin

Inactive sand and gravel pit

beneath thick glacial sediment.

Well or boring--Log listed in table 1.

point upslope

Inactive quarry

Photograph location

Abandoned stream channel

Lake or pond

Excavation perimeter



Figure 5. Glacially-sculpted gneiss outcrop (roche moutonnee) located near the start of Summit Trail, Jenny Jump State Forest. Whaleback shape of outcrop is marked by heavy black line. Scale (upper right of photo) equals two feet. This erosional shape is produced by glacial abrasion (mostly on the sides and upper surface of the outcrop) and glacial plucking (mostly on the steep face on the down-ice side of outcrop). Nearly vertical jointing that trends oblique to the direction of ice flow (see figure 6) helps facilitate plucking. Yellow box shows location in quadrangle. Photograph by R. Witte.



Figure 6. Joint-block boulders formed along a glacially sculpted gneiss ridge. Photograph taken just to the right of figure 5. Scale in center equals two feet. Through multiple cylces of freeze and thaw, ice slowly widened fractures that cut the outcrop. Over time, joint blocks became detached from the main outcrop. Many of these now lie at the base of the outcrop where they have fallen and farther downslope where they have been transported by soil creep. Rock to the left of the scale is in place. Black box shows location in quadrangle. Photograph by R. Witte.

DESCRIPTION OF MAP UNITS

Map units denote unconsolidated materials more than 5 feet thick. Color designations, based on Munsell Color Company (1975), were determined from naturally moist samples.

> Postglacial deposits ARTIFICIAL FILL--Rock waste, gravel, sand, silt, and manufactured materials emplaced by man. As much as 25 feet thick.

ALLUVIUM--Stratified, moderately to poorly sorted sand, gravel, silt, and minor clay and organic material. Locally bouldery. As much as 25 feet thick. Includes planar to cross-bedded gravel and sand in channel deposits, and cross-bedded and rippled sand, massive and parallel-laminated fine sand, and silt in flood-plain deposits. In places, overlain by and interlayered with thin organic material and colluvium. In the Pequest valley, alluvium is covered in most places by a thin veneer (< 2 feet) of peat and muck. This material is mapped separately as Qs where generally thicker

STREAM-TERRACE DEPOSITS--Stratified, well- to moderately sorted, massive to laminated, and minor cross-bedded fine sand, and silt in terraces flanking present or former stream courses. As much as 15 feet thick. Overlies planar to cross-bedded cobble-pebble gravel and pebbly sand as much as 20 feet thick.

than 5 feet.

Glacial deposits

SWAMP AND BOG DEPOSITS--Peat of reed, sedge, and woody origin, and muck underlain by laminated organic-rich silt and clay. As much as 25 feet thick. Locally interbedded with alluvium and thin colluvium. In areas underlain by dolomite, marl as much as 20 feet thick typically underlies the

TALUS--Angular boulders, as much as 15 feet long, cobbles, and smaller rock fragments that lie at the base of bedrock cliffs and steep hillslopes. As much as 20 feet thick. ALLUVIAL-FAN DEPOSITS--Stratified, moderately to poorly sorted,

brown to yellowish brown, gray sand, gravel, and silt in fan-shaped deposits: as much as 35 feet thick. Includes massive to planar-bedded sand and gravel and minor cross-bedded channel-fill sand. Bedding dips as much as 30° toward the trunk valley. Locally interlayered with unstratified, poorly sorted, sandy-silty to sandy gravel.

ALLUVIUM AND COLLUVIUM, UNDIFFERENTIATED--Stratified, poorly to moderately sorted, brown to yellowish-brown, gray sand, silt and minor

gravel; as much as 20 feet thick. Interlayered with or overlying massive to

crudely layered, poorly sorted sand, silt, and minor gravel. UNDIFFERENTIATED COLLUVIUM -- Poorly sorted, brown to yellowish prown, gray sand, silt and minor gravel derived from a mixture of weathered bedrock and till; as much as 10 feet thick.

MELTWATER-TERRACE DEPOSITS--Stratified, well- to moderately sorted sand, cobble-pebble to pebble gravel, and minor silt deposited by meltwater streams as terraces incised in valley-train and delta deposits. As much as 20 feet thick. Sediment and bedforms similar to the downstream, distal part of valley-outwash deposits. Includes bouldery lag deposits formed on till.

VALLEY-TRAIN DEPOSITS--Stratified, well- to moderately sorted sand, boulder-cobble to pebble gravel, and minor silt deposited by meltwater streams beyond the glacier margin. As much as 50 feet thick. The proximal part of the deposit consists of massive to horizontally bedded and imbricat ed 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 ding, and graded beds are more common. Overbank deposits of massive o laminated fine sand and silt are rare.

GLACIAL-LAKE DELTAS--Stratified, sand, gravel, and silt deposited by meltwater streams in proglacial lakes at and beyond the glacier margin. Includes well sorted sand and boulder-cobble to pebble gravel in glaciofluvial topset beds that are as much as 25 feet thick, with bedding similar to valley-train deposits. Topset beds overlie and grade 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. Foreset beds grade downward and outward into lower foreset beds consisting of ripple cross-laminated and parallel-laminated, sand, silt and pebble gravel that dip less than 20°. Lower foreset beds grade into gently inclined prodelta bottomset beds of rhythmically bedded, ripple cross-laminated to graded fine sand and silt with minor clay drapes. Thickness may be as much as 100 feet. In the Paulins Kill valley, fluvial topset beds may be as much as 65 feet thick and these deposits may have once filled the valley from wall

gravel and pebbly coarse sand in massive to plane-bedded backset beds that are flat-lying or dip gently upglacier, well to moderately sorted sand and gravel in massive to rhythmically bedded foreset beds that dip as much as 25° basinward and grade into ripple cross-laminated to parallel-laminated foreset beds of sand, fine gravel and silt. Foreset beds grade outward into or overlap gently inclined bottomset beds that consist of rhythmically bedded, ripple cross-laminated and parallel-laminated fine sand and silt with minor drapes of silty clay. GLACIAL LAKE-BOTTOM DEPOSITS--Parallel-laminated, irregularly to

GLACIAL LACUSTRINE-FAN DEPOSITS--Stratified sand, gravel, and

silt deposited by meltwater streams in proglacial lakes at and beyond the

glacier margin. As much as 180 feet thick. Includes cobble to boulder

to wall in a similar way as valley-train deposits.

hythmically bedded silt, fine sand, and clay; and minor cross-laminated silt, fine sand, and minor clay deposited on the floor of glacial lake basins chiefly by density flows and settling of fines. As much as 100 feet thick. vic ICE-CONTACT DEPOSITS--Stratified, well to poorly sorted sand, boulder to pebble gravel, silt, and interbedded flowtill. As much as 50 feet thick. Attitude of bedding is highly variable, and beds are commonly collapsed.

NETCONG TILL Compact, unstratified, poorly sorted yellowish brown 10YR 5/4), light yellowish brown (2.5Y 6/4), pale brown (10YR 6/3) to brown (10YR 5/3) non-calcareous sand and silty sand that typically contains 10 to 20 percent gravel; as much as 80 feet thick. Locally overlain by thin, discontinuous, noncompact to slightly compact, poorly sorted, indistinctly layered yellowish brown (10YR 5/6), 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; as much as 10 feet thick. Clast consist of unweathered to lightly weathered gneiss and granite with minor marble, quartzite, sandstone, and carbonate rock. Matrix is a varied mixture of gneiss and granite fragments, guartz, feldspar mica, heavy minerals, and silt; minor constituents may include fragments of sandstone, siltstone, quartzite, carbonate rock, and clay. Near the limit of the late Wisconsinan glaciation weathered materials derived from preglacial surficial deposits and weathered rock are mixed with the less-weathered sediment. Qwtnr denotes areas of thin till typically less

than 10 feet thick, scattered bedrock outcrops, and minor thin colluvium.

KITTATINNY VALLEY TILL--Compact, unstratified, poorly sorted light blive-brown (2.5Y 5/4) to grayish brown (2.5Y 5/2), gray (5Y 5/1) to olive-gray (5Y 5/2) calcareous sandy silt and silty sand that typically contains 5 to 15 percent gravel; as much as 70 feet thick. Locally overlain by thin, discontinuous, noncompact to slightly compact, poorly sorted, indistinctly layered yellowish brown (10YR 5/6), 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; as much as 10 feet thick. Clasts chiefly are unweathered to lightly weathered slate, siltstone, sandstone, dolomite with minor limestone, chert, quartzite, and quartz-pebble conglomerate. Matrix is a varied mixture of nonweathered to lightly weathered quartz, rock fragments, and silt; minor constituents include feldspar and clay. On the northwest flank of Jenny Jump Mountain and the New Jersey Highlands, additional minor constituents include clasts of gneiss, and granite, and mica and heavy minerals in matrix. Qwtkr denotes areas of thin till typically less than 10 feet thick, a

TERMINAL MORAINE--Till as in units Qwtk and Qwtn, and minor poorly stratified sand, gravel, and silt, deposited at the terminus of the late Wisconsinan glacier. As much as 150 feet thick. Consists of poorly compact stony till, silty-sandy compact till, and minor lenses and layers of water-laid sand, gravel, and silt, in hummocky, bouldery, segmented ridges marking the former lobate glacier margin.

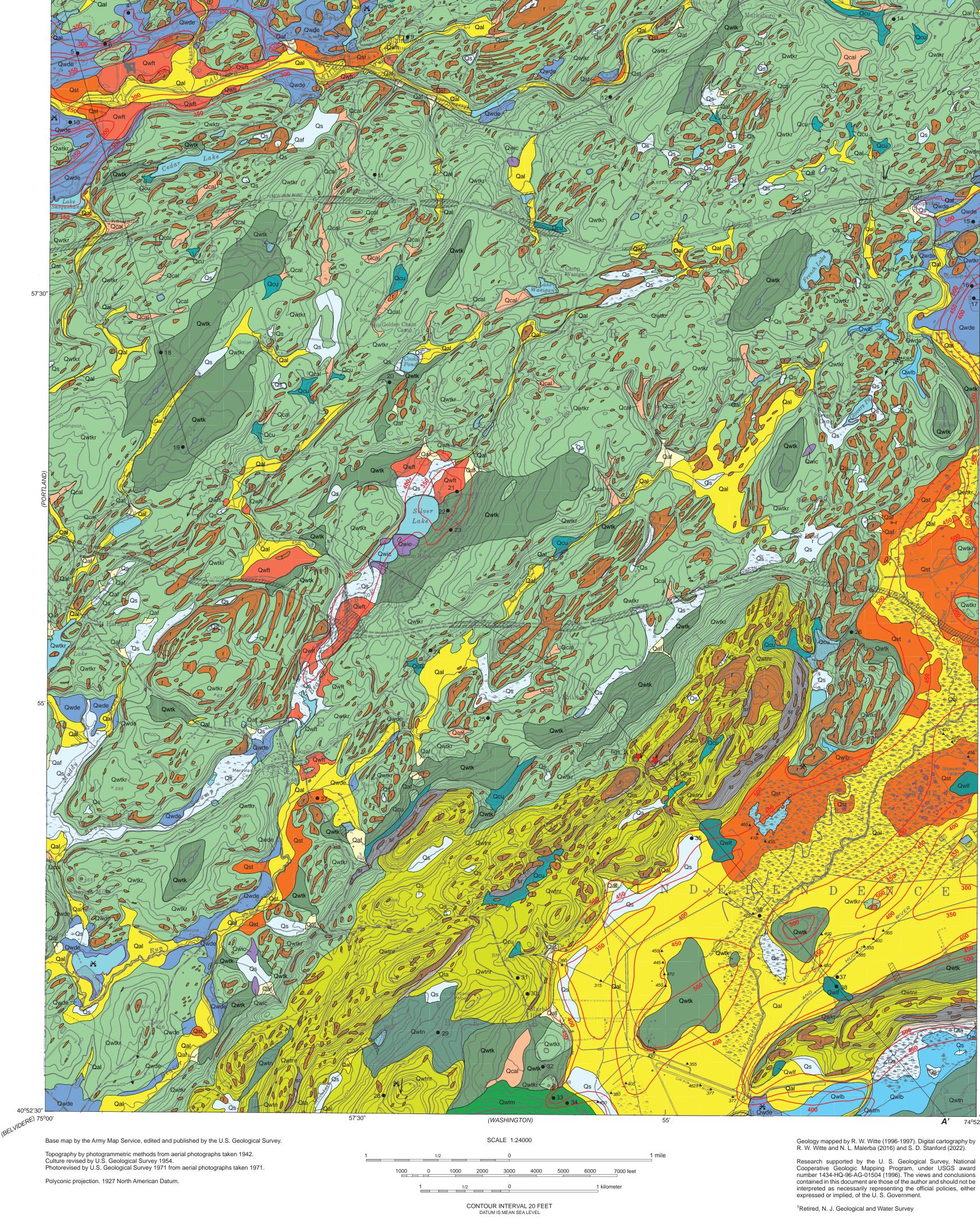
Bedrock Outcrop--Extensive outcroppings, minor frost-riven bedrock

rubble, and scattered erratics. Small bedrock outcrops are not labelled.

hillslopes and ridge crests, minor talus, scattered erratics, and a few small

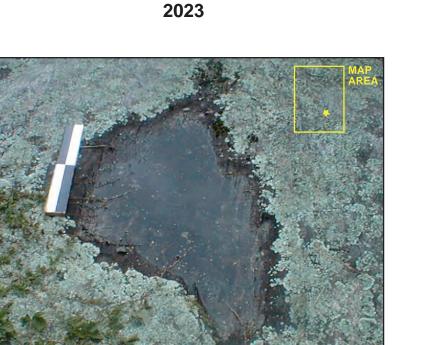
Scattered Bedrock Outcrop--Chiefly frost-riven bedrock rubble on steep

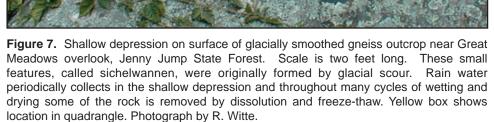
few bedrock outcrops, and minor thin colluvium.

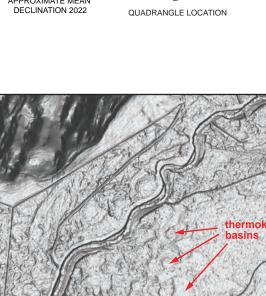


Bedrock









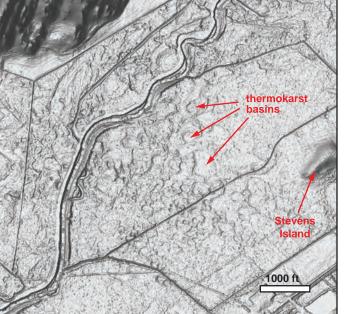


Figure 8. LiDAR hillshade image showing thermokarst basins on a postglacia stream terrace, and channels incised into the stream terrace, in Bear Swamp in the Pequest valley. Stevens Island is a lacustrine fan deposited in glacial Lake Pequest. Area of image shown on figure 1. Hillshade image from NJDEP