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

INTRODUCTION

The Bushkill PA-NJ 7.5' quadrangle lies in the glaciated part of the Valley and Ridge physiographic province in Warren County, New Jersey, and Pike and Monroe Counties, Pennsylvania. The New Jersey part was mapped under COGEOMAP and STATEMAP, both cooperative Federal and State geological mapping programs. The Pennsylvania part in Minisink Valley was mapped under the National Park Service Geologic Resources Inventory Program. Discussion of surficial geology elsewhere in the quadrangle is limited to deglaciation of the lower part of the Bush Kill valley (informally named here the Echo Lake lowland) and is meant to provide a more detailed deglaciation framework for the Minisink Valley ice lobe. Geologic interpretations there are based on Witte (2001a and 2001b), Crowl (1971), and unpublished field notes by the author.

Main geographic features are Kittatinny Mountain and Wallpack Ridge, Kittatinny and Minisink Valleys, and the Echo Lake lowland (fig. 1). The Delaware River, which separates New Jersey from Pennsylvania, flows southwest in Minisink Valley through the Delaware Water Gap National Recreational Area. Bush Kill is the largest tributary, draining southeastward off the Pocono Plateau into the Delaware River just upstream from the quadrangle at Wallpack Bend. The highest point is approximately 1,563 feet (476 m) above sea level on Kittatinny Mountain, and the lowest point lies on the Delaware River, approximately 297 feet (91 m) above sea level.

Surficial materials in the quadrangle consist of till and meltwater sediment deposited during the late Wisconsinan glaciation about 22,000 to 17,000 yr B.P., and postglacial stream sediment, slope deposits, wind-blown sand, and swamp and bog deposits laid down in late glacial and postglacial time. These materials may be as much as 250 feet (72 m) thick, lie on bedrock, and form the parent material on which soils form. The glacial deposits are correlative with the Olean Drift of northeastern Pennsylvania (Crowl and Sevon, 1980). Till typically lies on bedrock and in many places it is interspersed with numerous glacially-eroded bedrock outcrops. Thicker till forms drumlins, ground moraine, and aprons on north-facing hillslopes. Recessional moraines are absent. Glacial outwash, consisting of valley train, outwash fan, and meltwater terrace deposits, was laid down at and beyond the glacier's margin, in Minisink Valley. These deposits typically form terraces that lie as much as 120 feet (37 m) above the modern valley floor. Their ice-contact heads-of-outwash mark ice recessional positions of the Minisink Valley ice lobe (Witte, 2001b). The most extensive postglacial materials lie in Minisink Valley and consist of alluvium deposited by the Delaware River. Elsewhere, organic soil, largely humus and peat, is found in the many bogs and swamps that dot the land.

PREVIOUS INVESTIGATIONS

Cook (1877, 1878, 1880) discussed the geology of surficial deposits in Sussex and Warren Counties, New Jersey, in a series of Annual Reports of the State Geologist. He included detailed observations on the terminal moraine, recessional moraines, ages of drift, distribution and kinds of drift in Kittatinny Valley, and evidence of glacial lakes. Shortly thereafter, White (1882) described the glacial geology of Pike and Monroe Counties, Pennsylvania, and a voluminous report by Salisbury (1902) detailed the glacial geology of New Jersey region by region. The terminal moraine (fig. 2) and all surficial deposits north of it were interpreted to be products of a single glaciation of Wisconsinan age. Salisbury also noted that "in the northwestern part of the state, several halting places of ice can be distinguished by the study of successive aggradation plains in the valleys." In Pennsylvania, Leverett (1934) also assigned a Wisconsinan age to the terminal moraine and the glacial drift north of it. Crowl and Sevon (1980) and Cotter and others (1986) also indicated the youngest glacial deposits in eastern Pennsylvania and northwestern New Jersey are late Wisconsinan age. Crowl (1971), Sevon and others (1989), and Stone and others (2002) produced surficial geologic maps of parts of the Bushkill quadrangle, and Witte (1997, 2001b) described the glacial history for the upper part of Kittatinny and Minisink Valleys.

For detailed discussions on the glacial and postglacial history of northwestern New Jersey and Minisink Valley see Witte (1997, 2001b, 2012, 2013, 2014) and Witte and Epstein (2004, 2012).

PHYSIOGRAPHY AND BEDROCK GEOLOGY

The Bushkill quadrangle lies entirely within the Delaware River drainage basin (fig. 1). The Delaware River, the master stream in this area, flows southwestward from Port Jervis, New York, to Wallpack Bend following the easily eroded Onondaga Limestone and Marcellus Shale that underlies Minisink Valley. At Wallpack Bend, the river follows a large s-shaped bend that cuts through Wallpack Ridge. Downstream, it enters a deep narrow valley underlain by shale and sandstone of the Bloomsburg Red Beds and dolomite of the Poxono Island Formation (fig. 3). The river continues to Delaware Water Gap where it crosses the resistant Shawangunk Formation and enters Kittatinny Valley.

The overall drainage pattern of the study area has probably not changed substantially from the middle Pleistocene to the present. The history of the Culvers Gap River (Witte and Epstein, 2004), and a report on waterfalls and multiple glaciations in Minisink Valley (Witte and Wright, 2001, and Witte, 2012) indicated that major changes in drainage of the Delaware River in the Minisinik Valley area would have had to occur during the early part of the Pleistocene or earlier during Late Tertiary time. The low position of Illinoian outwash in the Delaware River valley (Stone and others, 2002) downstream from the late Wisconsinan terminal moraine shows that the Delaware River and its larger tributaries have occupied nearly the same course for at least the last 150,000 years. In contrast, pre-Illinoian glacial outwash, which is estimated to be older than 800,000 years (Stone and others, 2002), lies 80 to 120 feet (24 – 37 m) above the floor of the Delaware River valley and only in areas that have been protected from fluvial and slope erosion.

Wallpack Bend may have been the product of an earlier glaciation (Witte and Epstein, 2012), when glacial lake discharge carved a new route through Wallpack Ridge, resulting in the abandonment of the Delaware River's course through the Echo Lake lowland.

The Delaware River's tributaries typically flow at oblique angles to the course of the main river, are deeply incised, and flow over bedrock before entering Minisink Valley. Drainage typically forms a modified trellis pattern that is constrained by the orientation and density of strike-parallel and cross-joints of the local rock formations. This pattern in places is overprinted or replaced by a dendritic one that has formed over thick glacial deposits of late Wisconsinan age. Waterfalls are common, mostly the products of knickpoint retreat due to glacial widening and deepening of Minisink Valley. Multiple knickpoints, and abandoned, notched, waterfalls along many of the Delaware's tributaries hint of multiple glaciations (Sevon and Inners, 2001, Witte and Wright, 2001, and Witte, 2012).

Minisink Valley was also the former site of a planned hydroelectric and water storage project by the Army Corps of Engineers. The deauthorized dam was to be constructed at Tocks Island (fig. 1), where it would have flooded Minisink Valley upstream to Port Jervis, New York, and Wallpack Valley upstream to Layton, New Jersey. The reservoir would have provided a storage capacity of 133.6 billion gallons (Corps of Engineers, 1967).

Wallpack Ridge (fig. 1) separates Minisink Valley and the Echo Lake lowland. It is held up by thinly bedded, northwest-dipping Silurian and Devonian sandstone, siltstone, and limestone (fig. 3) that rises as much as 900 feet (274 m) above the adjacent valley floors.

Kittatinny Valley is a broad northeast to southwest trending lowland underlain by Lower Paleozoic dolomite, slate, and greywacke. Only slate and greywacke of the Martinsburg Formation underlie the valley In the Bushkill quadrangle (fig. 3). Topography consists of undulant hills of moderate to steep slopes and many strike-parallel ridges streamlined by glacial erosion. Bedrock is deeply buried in some places beneath drumlins.

Kittatinny Mountain is underlain by quartz-pebble conglomerate and quartzite of the Shawangunk Formation, and red sandstone and red shale of the Bloomsburg Red Beds (fig. 3). The mountain forms a very long ridge that extends southwestward from the Shawangunk Mountains in New York into Pennsylvania (inset map, fig. 1). Its steep southeast face forms a nearly continuous escarpment. The mountain's continuity is broken by a few wind gaps. The largest of these is Culvers Gap (fig. 1), which marks the former site of a large river that abandoned its course some time during the late Tertiary (Witte and Epstein, 2004). Topography is rugged on the mountain, chiefly consisting of uneven, narrow- to broad-crested, strike-parallel ridges. Rock outcrops are very abundant and they exhibit extensive glacial scour and plucking. The Shawangunk Formation underlies the high ridge area of the mountain, whereas the Bloomsburg Red Beds underlie the hills and slopes to the west, which in many places are covered by thin till.

GLACIAL DEPOSITS

Till

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

Till is typically a compact silt to silty sand containing as much as 20-percent pebbles, cobbles, and boulders. Clasts are subangular to subrounded, faceted, and striated, and measured clast fabrics indicate a preferred long-axes orientation that is parallel to the regional direction of glacier flow. Presumably, this sediment 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, and boulders, all interlayered with lenses of sorted sand, gravel, and silt. Overall, clasts are more angular, and their fabrics lack a preferred orientation or have a weak orientation oblique to regional glacial flow (Witte, 1988). This sediment appears to be ablation till and flowtill, and it has not been mapped separately because of its scant distribution and poor exposure. In addition, cryoturbation and bioturbation have altered the upper few feet of till, masking its original character by making it less compact, reorienting stone fabrics, and sorting clasts.

Till in the quadrangle has been divided lithologically into two types and they are informally called here lowland (Qtk) and upland (Qtq) till. Their composition was largely dependent on the south-to-southwest direction of ice flow over narrow, southwest-trending belts of local sedimentary source rocks. Lowland till (Qtk) is chiefly derived from limestone, shale, limey shale, and sandstone in Minisink Valley and atop Wallpack Ridge. Upland till (Qtq) on Kittatinny Mountain is chiefly derived from quartzite, quartz pebble conglomerate, and red sandstone and shale that underlie the mountain. Due to the southward movement of the late Wisconsinan ice sheet across the mountain (Witte, 1997), this till (Qtq) also lies in a narrow belt along the mountain's base in Kittatinny Valley, a position that overlies the slate and greywacke of the Martinsburg Formation.

Drumlins

Drumlins are ice-molded, elongated hills of till deposited at the ice-sheet's base. They occur in the quadrangle in Kittatinny Valley as part of an extensive belt of thick till along the western edge of Kittatinny Valley that extends from the Delaware River northeastward to Culvers Lake (Witte and Epstein, 2004; Witte, 1988; Ridge, 1983). Well records (table 1, plate 2) show that till in this area is typically greater than 100 feet (30 m) thick, showing that some of the drumlins do not have a rock core. Drumlin axes indicate southwestward ice flow, in a direction that is slightly oblique (more southward) to the areas strongly developed northeast to southwest topographic grain.

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

Glaciofluvial sediment was laid down by meltwater streams in valley train (Qv), outwash fan (Qf), and meltwater terrace deposits (Qmt). Delta topset beds of unit Qod are also glaciofluvial, but they are discussed in the following section on glaciolacustrine sediments. Glaciofluvial sediment includes cobbles, pebbles, sand, and minor boulders laid down in stream channels and sand, silt, and pebbly sand in minor overbank deposits. Sediment laid down near the glacier margin in valley train deposits and delta topset beds typically includes thickly bedded, imbricated, planar coarse gravel and sand, and minor channel fill deposits that consist largely of cross stratified pebbly sand and sand. Downstream the overall grain size of the outwash decreases, sand is more abundant, and crossbedded and graded beds are more common. Outwash fan deposits consist of gently inclined beds of planar to cross bedded sand and gravel that form large fan-shaped deposits (similar to alluvial fans) at the mouths 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. They were mostly deposited by meltwater streams, but in places have a non-meltwater component.

Glaciolacustrine sediments were deposited by meltwater streams in ice contact and valley outwash deltas (Qod), and lake bottom deposits (Qlb). Because proglacial lake basins in Minisink Valley were very narrow, they were filled with glaciolacustrine sediment and then covered by a thick wedge of glaciofluvial sand and gravel from valley wall to valley wall. In a few places, outwash was laid down over and around stagnant ice. 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 bedded and parallel-bedded 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.

Lake bottom deposits (Qlb) include 1) glacial varves and 2) subaqueous-flow deposits. Glacial varves consist of stacked annual layers that consist chiefly of a lower "summer" layer of silt that grades upward into a thinner "winter" layer of very fine silt and clay. Most of these materials were deposited from suspension. However, the summer layer may contain sand and silt carried by density currents. Each summer and winter couplet represents one year. However, in places couplets may represent diurnal layers, especially in areas next to deltaic deposits. 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 gravity flows. Near deltas, lake-bottom deposits interfinger with deltaic bottomset beds.

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

POSTGLACIAL DEPOSITS

Wind Blown Sediment

Wind-blown sands are deflationary deposits blown off nearby glacial outwash during the close of the late Wisconsinan. Sand dunes and sheet sands have been identified upstream (Witte and Epstein, 2004; Witte, 2001b, 2012) in Minisink Valley and along the northwest flank of Wallpack Ridge. Thermoluminescent dating of eoilan material in the Milford quadrangle (Bitting, 2013) shows time of deposition between 13,000 and 14,000 years ago; a time well after deglaciation and prior to the colonization of extensive, deep-rooted vegetation in Minisink Valley. Mappable bodies of wind-blown sand have not been recognized in the quadrangle. It is too thin and scant in distribution to show at 1:24,000 scale. Also, most of this material has been mixed with underlying material and is now part of the pedogenic soil.

Slope Sediment

Slope deposits include thick talus (Qta), which chiefly consists of frost-shattered joint-blocks of conglomerate and quartzite of the Shawangunk Formation. This material forms an extensive apron of rock debris on the southeast face of Kittatinny Mountain and at the base of a few cliffs and steep slopes higher on the mountain.

Organic Deposits

Swamp and bog deposits (Qs) are found throughout the quadrangle. They formed in kettles and glacially scoured bedrock basins, in glacial lakes that persisted into the Holocene, in abandoned stream channels on alluvial plains, and in poorly drained areas on ground moraine. These deposits principally consist of peat, muck, and minor clastic detritus. Peat deposits on Kittatinny Mountain, in Minisink Valley are typically of woody origin, or consist of mixed wood and sedge peat (Waksman and others, 1943). In few areas where limestone and dolomite crop out, peat may be underlain by calcareous marl (Waksman and others, 1943).

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

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

Stream terrace deposits (Qst2, Qst2a, Qst3) include both channel and flood plain sediment, and they lie 15 to 45 feet (5 to 14 m) above the modern flood plain and below meltwater-terrace deposits. They form two distinct sets (Witte, 2001b) in Minisink Valley. The lower and younger (Qst2) terrace lies between 20 and 35 feet (6 to 11 m) above the river (measured at height above base flow) and consists of as much as 30 feet (9 m) of overbank fine sand and silt overlying cobble pebble gravel and sand. The underlying gravel and sand are channel-bar and point-bar deposits, and in places, strath terraces of a postglacial river. The Qst2 deposits typically form broad terraces that cover large parts of the valley's floor and flank the present course of the Delaware River. The highest parts of the terrace lie next to the Delaware River, on a levee. The levee in a few places is a low ridge that is as much as 6 feet (2 m) high. Mostly, the levee is represented by the highest point on a gently inclined surface that slopes away from the river to the valley wall. At the base of the valley wall, the terrace is cut by a shallow channel that typically contains organic deposits. Alluvial-channel scrolls are preserved in many places, especially where the terrace lies on the inside of a large river bend. The 15 foot (5 m) range in elevation of the terrace throughout Minisink valley is due to: 1) as much as 8 feet (2 m) of constructional relief on the terrace, and 2) parts of the terrace may have been lowered by erosion. The differing levels may also be related to local riparian conditions and channel morphology of the postglacial Delaware River.

The Qst2 deposits may also consist of two distinct terraces as shown by Wagner (1994), and Stinchcomb, and others (2012). A lower terrace, mapped as Qst2a, lies 15 to 20 feet (5 to 6 m) above the modern river. It has also been observed elsewhere in Minisink Valley (Witte, 2012, 2013 and 2014). However, without precise elevation control, these terrace subsets were difficult to correlate on a valley-wide scale. Recent analyses of detailed topographic maps (5-contour interval, scale 1:4800, and high-resolution digital elevation models created from LiDAR (fig. 4) show that the Qst2a terrace is a distinct surface that may be traced through Minisink Valley. This terrace may represent a renewed period of downcutting or lateral erosion during the middle to latter part of the Holocene that may be climatically driven (Stinchcomb and others, 2012).

The oldest stream-terrace deposits in Minisink Valley (Qst3) lie 40 to 48 feet (12 to 15 m) above the modern river and typically consist of as much as 10 feet (3 m) of overbank fine sand and medium sand overlying glacial outwash. This material is eroded in places, exposing the underlying sand and gravel. The Qst3 terraces are typically small and flank the younger Qst2 deposits. In places, they lie 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 in age, and it may mark a transition from glaciofluvial to a postglacial fluvial environment.

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

GLACIAL HISTORY

Glacial Erosion

The distribution and differences in weathering characteristics of glacial drift in northwestern New Jersey (Salisbury, 1902; Stone and others, 2002) show that continental ice sheets covered northern New Jersey at least three times during the Pleistocene epoch. From oldest to youngest these glaciations are the pre-Illinoian (> 780 ka), Illinoian (150 ka), and late Wisconsinan (24 ka). The action of each ice sheet modified the landscape by deeply scouring valleys, and wearing down and streamlining bedrock ridges, hills, and slopes. Smaller features of glacial ersoion include polished and striated bedrock, plucked bedrock, and streamlined bedrock forms called roche moutonnées provide evidence of glacial erosion. All these features are late Wisconsinan age because weathering has removed the older ones.

Glacial erosion has also removed nearly all of the pre-late Wisconsinan saprolite and soil. However, a deeply weathered outcrop of the Poxono Island Formation observed near Zion Church in Minisink Valley shows that not all preglacial materials were eroded by the last glaciation.

The bedrock floor of Minisink Valley was deeply scoured by the late Wisconsinan and Illinoian ice sheets. Ice flowing parallel to the valley's axis eroded the valley's rock floor by as much as 150 feet (46 m). Subsequently, valley fill consisting of glacial meltwater sediment and alluvium that is as much as 250 feet (76 m) thick has been deposited.

Glacial Advance and Changes in Direction of Regional Ice Flow

The late Wisconsinan advance of Laurentide ice sheet into Minisink and Kittatinny Valleys is obscure because glacial drift and striae that record this history were eroded or buried. If the ice sheet advanced in lobes as suggested by the course of its terminal moraine (fig. 2), then its initial advance consisted of ice lobes moving down Kittatinny and Minisink Valleys. Striae, drumlins, and the distribution of erratics in Kittatinny Valley and on Kittatinny Mountain (Witte, 1997) show that ice flowed southward over Kittatinny Mountain during the late Wisconsinan glacial maximum. Southwestward ice flow occurred only near the ice sheet's margin where ice was thinner, its flow highly constrained by the area's northeast to southwest topographic grain. During deglaciation, the edge of the ice sheet further thinned, and by the time the Ogdensburg-Culvers Gap Moraine was deposited (fig. 2), ice flow had turned more to the southwest with extensive lobation at the glacier's margin (Witte, 1997).

Style and Timing of Deglaciation

Most ideas about deglaciation during the middle to latter part of the 20th Century involved models of stagnation. A common view was that uplands became deglaciated first leaving large residual masses of ice on the valley floors. Meltwater, derived from melting stagnant ice, deposited sediment over and around residual ice blocks left in the valley. Upon their melting, kames, kame terraces, and kettles formed. In addition, after residual ice masses melted, outwash from distant sources upvalley formed an extensive outwash plain, covering the lower parts of the valley floor. Crowl (1971) surmised that stratified glacial deposits in Minisink Valley and the Echo Lake lowland were chiefly products of glacial stagnation. This was based on 1) the many kames and kame terraces he identified, 2) the existence of collapsed outwash that indicated deposition around and over stagnant ice, 3) kettles, and 4) highly variable surface textures.

Based on the sequence concept by Jahns (1941), which was later codified into the morphologic sequence concept by Koteff and Pessl (1981), 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 and 1997) showed that the margin of the Kittatinny and Minisink Valley lobes retreated systematically with minimal stagnation. 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. However, regionally the Minisink lobe retreated more rapidly (Witte, 1997).

The age of the Terminal Moraine, timing of the late Wisconsinan maximum, and precise chronology of deglaciation are uncertain. Scant radiocarbon dates because of a lack of organic material, inadequacies of dating bog bottom material and concretions, and use of sedimentation rates to extrapolate bog bottom radiocarbon dates make the determination of a glacial chronology highly speculative. In addition, varved lake bottom exposures that can be used for chronology (Ridge and others, 2012) are scarce because they lie beneath swamp and bog deposits and alluvium.

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

Kittatinny Valley lobe

Yards Creek

Glacial recessional deposits are not found in the small part of Kittatinny Valley that lies in the Bushkill quadrangle. During deglaciation, glacial meltwater streams carried sand and gravel down the steep reaches of Yards Creek and Stony Brook to the Paulins Kill valley where it was deposited in outwash fans (Qf) and glacial deltas (Qod).

Minisink Valley lobe

Kittatinny Mountain

Meltwater deposits are absent due to the mountain's rugged topography and because most drainages have steep, northwest draining courses that prohibit deposition. Deep ravines cut down in the mountain's long northwesterly slope may have been cut by glacial meltwater especially in areas where outwash fans (Qf) lie at the mouths of these drainages in Minisink Valley.

Minisink Valley

Meltwater deposits in Minisink Valley consist of valley train (Qv), outwash fan (Qf), and meltwater terrace deposits (Qmt). Qv deposits consist of high-standing (as much as 120 feet (37 m) above the modern river), partially collapsed, cobbly terrace remnants just downstream from Zion Church near Tocks Island. Large parts of the deposit have been eroded by meltwater and the postglacial Delaware River. The outwash remnants form discontinuous, narrow terraces that are typically attached to the valley wall. They have a flat surface that slopes gently downvalley and have steep sided erosional escarpments that lie against the younger meltwater terrace, stream terrace and alluvial deposits that cover the lower parts of the valley floor. Sediment consists of cobble pebble gravel and pebble gravel and sand. Coarser beds are generally planar bedded and graded. Some sand beds show trough cross stratification. Based on projected longitudinal profiles of terraces in the valley (Witte, 2001b) and increase in grain size upstream, the outwash appears to have been laid down from an ice recessional position near Zion Church (fig. 2, position 2). Smaller remnants of Qv may be traced downstream to Shawnee Island. Deposits downstream at Minisink Hills (Stroudsburg quadrangle) may be on grade with the Zion Church outwash. Reconnaissance mapping suggests that this deposit may be a large outwash fan laid down at the mouth of the Marshalls Creek valley rather than a separate and slightly older Qv deposit. Upstream from Zion Church, a large outwash fan deposit is found at the mouth of Vancampens Brook. It appears to be graded to nearby meltwater terrace deposits of similar elevation. Remnants of high-standing outwash just downstream from Vancampens Brook may represent a stillstand equivalent to the Sand Hill margin farther west (fig. 4).

Well records and geologic borings in Minisink Valley (table 1, plate 2) show thinly layered silt and clay and sandy silt beneath sand and gravel. These materials are interpreted to be lakebottom deposits or deltaic bottomset beds laid down into a sediment-dammed glacial lake in Minisink Valley. Due to the narrow width of the valley these lacustrine materials were buried by thick deposits of glaciofluvial outwash.

Meltwater terrace deposits in Minisink Valley are chiefly strath terraces cut in aggraded valley train deposits by meltwater streams emanating from ice recessional positions upstream (fig. 2). These deposits are as much as 15 feet (5 m) thick and consist largely of reworked sediment eroded from adjacent or the upstream parts of valley train deposits and till that cover the lower part of valley slopes. They lie 50 to 80 feet (15 – 24 m) above the modern river and range in elevation between 350 and 405 feet (107 and 123 m) above sea level. They were formed during a period of fluvial incision related to the lowering of local base level downvalley as the glacial Delaware River adjusted to its longer course.

Sand Hill Delta: Local Geology

Crowl (1971) suspected that the flat-topped deposit that made up the Sand Hill (fig. 5) is a delta. However, because good exposures of foreset bedding were not available and the margins of the deposit exhibited ice-contact topography, he mapped the deposit as a kame that was laid down between ice blocks in the Werry Lake depression and Bush Kill valley. A sand and gravel pit shows that Crowl's initial suspicions were correct and why the hill is so appropriately named Sand Hill. Materials exposed along the pit's high, steep walls show that the Sand Hill delta consists of about ten feet of gravelly topset beds overlying about fifty-five feet of sandy foreset beds (fig. 6). Topset beds, which in many places have been partly stripped, consist of planar-bedded, framework-supported, cobble-pebble gravel. Elongated clasts exhibit imbrication that show a paleo-stream flow of south to southeast. Larger cobbles are as much as eight inches in diameter, and many of the gravelly beds contain larger clasts at their base. The gravel is largely derived from local sources, and consists of gray shale, siltstone, and sandstone with secondary amounts of white quartz-pebble conglomerate, red sandstone, and limestone.

Foreset beds (fig. 6) consist chiefly of fine to medium sand with a few thin beds of pebbly sand. Dropstones are common. Individual beds are typically less than two inches thick and dip less than eleven degrees in a northeast to southeast direction. Sedimentary structures consist of stacked sets of climbing ripple-drift sequences of Type A and B ripples capped by silt drapes. These rhythmic sets of sandy foresets are typically deposited on the middle part of the delta slope by underflow currents that flowed down the delta front along distributary channels. The Sand Hill section represents a subaqueous environment where sedimentation was rapid (possibly on a diurnal or hourly scale). These structures also reflect rapid changes in current velocity along the prograding delta front. The clay drapes were probably seasonally deposited, laid down during the winter months when meltwater production was minimal.

The thick mid-delta component represented here is probably a function of the small size of the lake basin and that the delta was chiefly built by meltwater from Bush Kill valley. Pebble provenance, and direction of paleo-flow determined by the dip of foreset bedding, and gravel imbrication support a westerly meltwater source. A slight rise in elevation of the delta plain in a northwest direction (510 to 520 feet; 155 to 158 m) also supports a Bush Kill source.

A second pit that lies about 1000 feet (305 m) northwest of the first one shows similar materials with the exception that the lower part of the pit contains a core of very coarse gravel. Bedding here dips about 12 degrees to the northwest. This material does not look collapsed. Perhaps these coarse gravel beds were deposited at the mouth of a subglacial tunnel prior to their burial by the sandy foresets.

Summary of Deglaciation in Echo Lake Lowland

Meltwater deposits in the Echo Lake lowland delineate two ice-retreat positions, one near Echo Lake, the other near Sand Hill (fig. 5). The Echo Lake morphosequence consists of an extensive outwash plain that has its ice-contact head located just northeast of Echo Lake. Reaching an elevation of about 535 feet (163 m), the Echo Lake sequence continues downvalley about four miles to Marshalls Creek, where it lies at an elevation of about 490 feet (149 m). Several lakes and many smaller kettles show that the Echo Lake outwash was deposited over and around small stagnant ice blocks. Because the floor of the Echo Lake lowland slopes northward, glaciolacustrine deposits probably lie beneath the valley train. Higher standing deposits downvalley from Echo Lake (fig. 5) are outwash fan deposits laid down by meltwater entering the lowland at the mouths of tributaries. There are a few kames between Meadow Lake and Oak Grove. These deposits are small mounds of sand and gravel that lie above the Echo Lake outwash. They predate the outwash, and represent places where depressions in the glacier's stagnant margin were filled with sand and gravel. The Echo Lake margin has been tentatively correlated with the Zion Church margin in Minisink Valley (fig. 5).

Retreat from the Echo Lake margin to the Sand Hill margin resulted in the formation of a small proglacial lake between the Echo Lake outwash and the glacier's margin. Collapsed topography on the northeast side of the Sand Hill delta places the Sand Hill margin near the modern location of Bush Kill. Later meltwater and postglacial drainage has eroded part of the Sand Hill delta, especially where Bush Kill enters the Echo Lake lowland. Sand Hill Lake drained over a rock-floored spillway (elv. 495 feet, (151 m)) near Middle Smithfield Church. The lake may have also drained out through a series of ice block depressions now marked by Echo and Coolbaugh Lakes. Since this spillway elevation is estimated at 505 feet (154m), lake drainage along this path was probably short-lived. Downstream from Coolbaugh Lake, the lake's outlet waters cut an erosional channel in the Echo Lake outwash.

Retreat from the Sand Hill margin resulted in meltwater draining Bush Kill valley to flow northeastward, directly to Minisink Valley. Outwash fan deposits and meltwater-terrace deposits behind the Sand Hill delta mark the lowering of local-base level control in the lowland and eventual opening of meltwater through-drainage to the Minisink as ice retreated out of the Echo Lake Lowland.

The northeast, stepward style of ice retreat suggested for the Echo Lake lowland is similar to that suggested for Minisink Valley by Witte (2001b) where the longitudinal profiles of valley-train terraces and their downstream continuation from their ice-contact heads show that large masses of residual ice did not cover the valley floor. Collapsed topography and kettles do indicate deposition against and over stagnant ice. However, these landforms are common components of stagnation-zone retreat, and there is no need to invoke regional or valley ice-tongue stagnation to explain deglaciation.

Summary of Deglaciation in Minisink Valley

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

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

POSTGLACIAL HISTORY

The Bushkill quadrangle is estimated to have been deglaciated by 18,000 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. The harsh climate and sparse vegetation enhanced erosion of the land by streams and mass wasting. Mechanical disintegration of exposed bedrock by frost shattering was extensive. On Kittatinny Mountain, thick deposits of talus (Qta) are found along the mountain's southeast face and elsewhere at the base of cliffs and steep rocky slopes.

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 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 nearly goes back 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 BP, the regional pollen sequence records the transition to a dense, closed boreal forest that consisted largely of spruce and fir blanketing the uplands. This was followed by a period (11, 000 to 9,700 yr BP) when pine became the dominant forest component. These changes in pollen spectra and percentages record the continued warming during the latter part of the Pleistocene and the transition from ice age to a temperate climate. About 9,400 yrs. B.P., oak and other hardwoods began to populate the landscape, eventually displacing the conifers and marking the transition from a boreal forest to a mixed-hardwoods temperate forest. Throughout the Holocene the many shallow lakes and ponds remaining 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 4.4 mi. (7.1 km) east of the quadrangle, show the presence of these large mammals in northwestern New Jersey during the close of the ice age.

The distribution of Qst3 and Qst2 terraces reflects two phases of postglacial fluvial evolution in Minisink Valley (Witte, 2001b). Stream-terrace deposition presumably started when the ice sheet retreated from the Delaware River drainage basin about 15ka (estimated from Ozvath and Coates, 1986), and stream discharge diminished substantially. This promoted an interval of minor incision and 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. It forms the highest flood plain deposits in the valley and it lies on elevated gravelly strath terraces that represent the former position of the Delaware River in early postglacial time. Dating the terrace is problematic due to scant organic material available for radiocarbon dating and in many places this higher terrace is covered by middle to late Holocene overbank sediment deposited during infrequent megafloods.

Following the above, there was renewed downcutting and extensive vertical and lateral accretion of overbank deposits. This interval was initiated by 1) rebound of the Earth's crust due to melting of the Laurentide ice sheet which commenced about 14,000 yr B.P. (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. Throughout the Holocene, these flood-plain materials sequentially built up to heights as much as 35 feet (11 m) above the modern river. Stepped strath terraces that lie buried beneath Qst3 and Qst2 overbank deposits mark incision phases of the Delaware River from late Pleistocene (< 14 ka) to modern time. Radiocarbon dating of a log found beneath thick Qst2 sediment at Bushkill Boat Access (GX-22942, 4,105 +/- 90 yr B.P., collected by Mr. John Wright, National Park Service) and lying on channel gravel similar in elevation to the modern river show that the Delaware River had cut down to its modern level by at least 4,100 years ago. Stewart (1991) showed that the base of the Qst2 terrace may be as old as 11,000 yr B.P. and Stinchcomb and others (2012) report a date of 9.3 ka near the base of Qst2 near Buck Bar. These dates show that the Delaware River may have cut down to or near its modern base level by the beginning of the Holocene. Mapping of postglacial terraces in Minisink Valley (Witte, 2012, 2013, 2014; Witte and Epstein, 2004, 2012) and radiocarbon dating of charcoal collected by the author suggest that even though the Delaware River had cut down to its modern base level by the early Holocene, subsequent evolution of the valleys terrace-floodplains by lateral erosion and vertical accretion was and is still ongoing. Stinchcomb and others (2012) further divided the Delaware Valley's postglacial fluvial history into 6 phases with a major climatically-driven incision event occurring during the middle Holocene (6-5 ka) followed by three additional phases of terrace and floodplain reworking. The development of Qst2a (fig. 7), based on its lower terrace height above the modern floodplain, appears to be a late Holocene event that further details the dynamic history of the Delaware River during the Holocene.

SURFICIAL ECONOMIC RESOURCES

The most important natural resource in the quadrangle, other than groundwater, is stratified sand and gravel, most of which lies in valley-train deposits (Qv), meltwater-terrace deposits (Qmt), and ice-contact deltas (Qod) in Minisink Valley and the Echo Lake lowland. This sediment may be used as aggregate, subgrade fill, select fill, surface coverings, and decorative stone. The location of sand and gravel pits and quarries is shown on plate 1. All pits are currently inactive except for occasional local use. Till (Qtk, Qtq) may be used for fill and subgrade material, and larger till clasts may be used as building stone. Humus and marl from swamp deposits (Qs) have been locally extracted and used as a soil conditioner.

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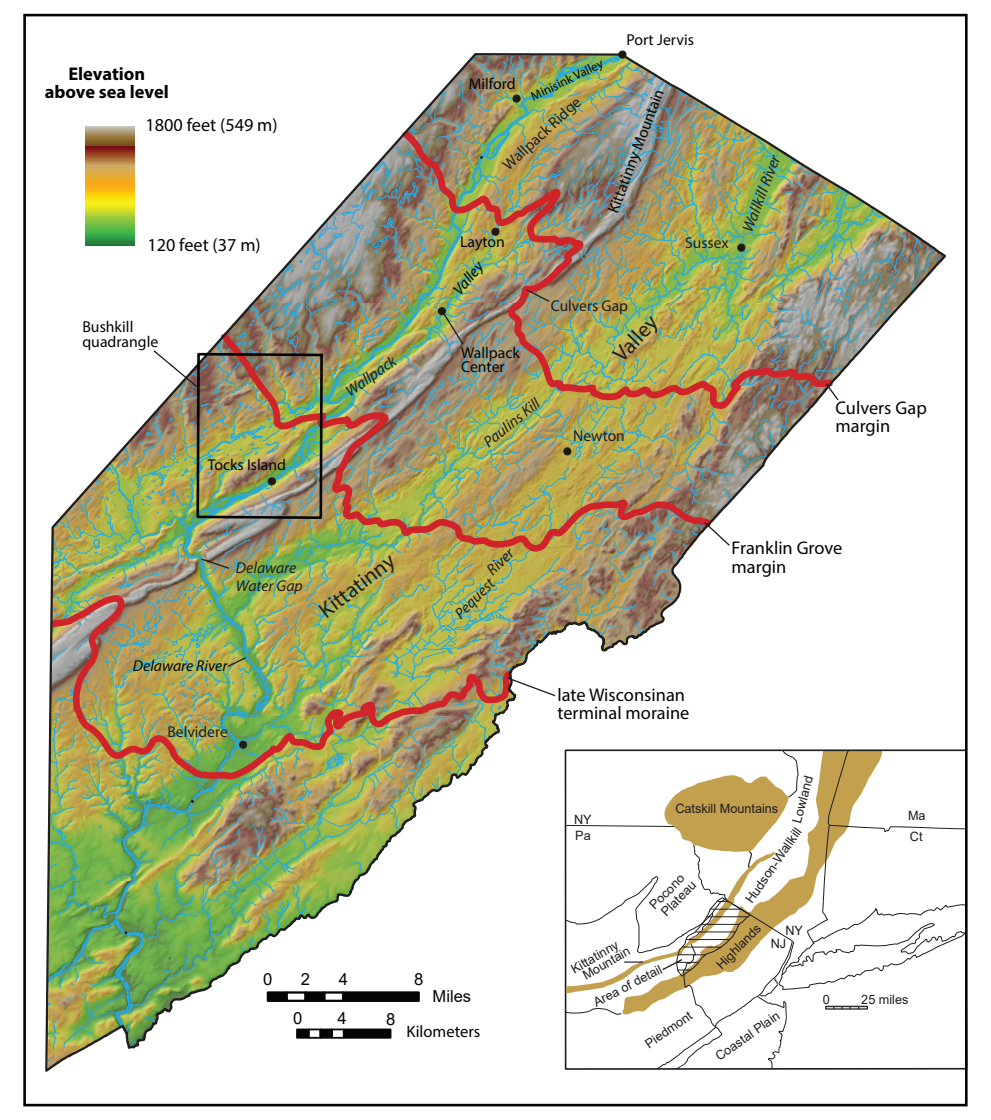


Figure 1. Physiography of northwestern New Jersey and part of northeastern Pennsylvania and location of the Bushkill PA-NJ quadrangle. Minisink Valley is a local geographic name for the Delaware River valley from Delaware Water Gap to Port Jervis, New York.

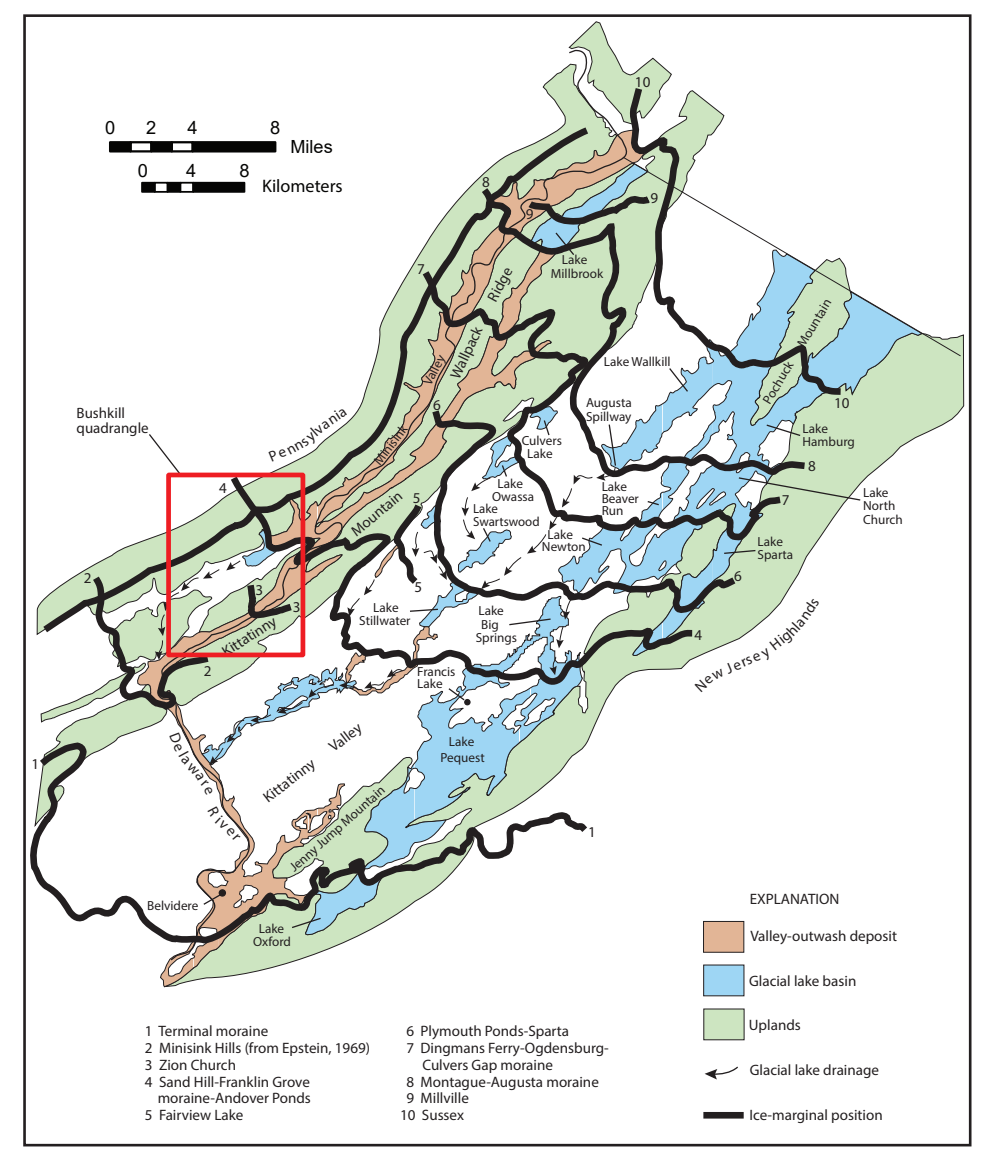


Figure 2. Late Wisconsinan ice margins of the Kittatinny and Minisink Valley ice lobes, and location of large glacial lakes, extensive valley-outwash deposits, and Bushkill PA-NJ quadrangle. Modified from data by Crowl (1971), Epstein (1969), Minard (1961), Ridge (1983), and Witte (1997).

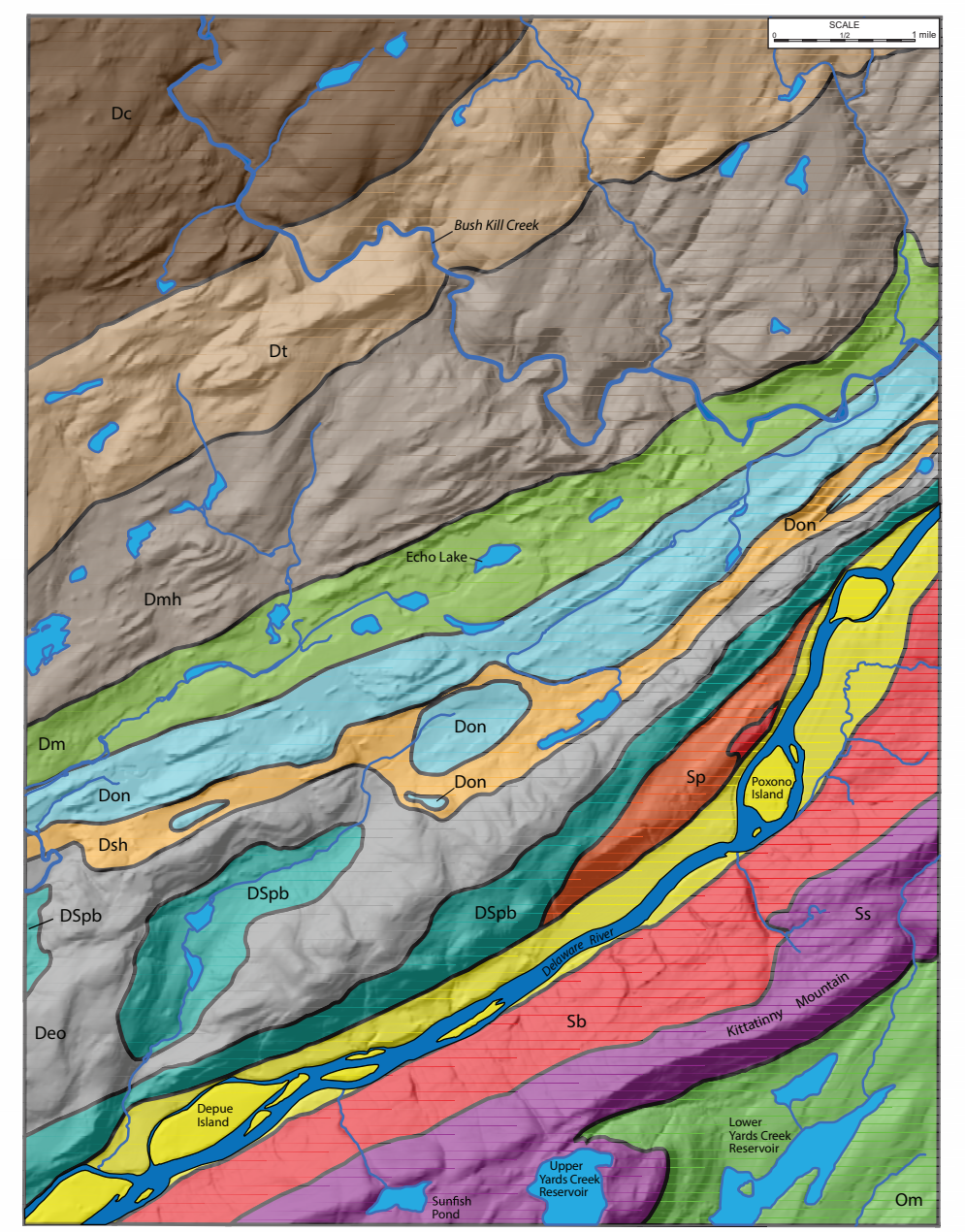


Figure 3. Bedrock geologic map of the Bushkill PA-NJ quadrangle (modified from Alvord and Drake, 1971). List of units: Om - Martinsburg Fm., Ss - Shawangunk Conglomerate, Sb - Bloomsburg Red Beds, Sp - Poxono Island Fm., DSpb - Port Ewen Shale, Minisink Limestone, New Scotland Fm., Coeymans Fm., Rondout and Decker Fms., and Bossardville Limestone, Deo - Esopus Fm. and Oriskany Fm., Dsh - Schohaire Fm., Don - Onondaga Limestone, Dm - Marcellus Shale, Dmh - Mahantango Fm., Dt - Trimmers Rock Fm., and Dc - Catskill Fm. Yellow area along the Delaware River represents alluvium and glacial outwash terraces. Base map derived from the Bushkill 7.5 minute digital elevation model (10m DEM), http://www.pasda.psu.edu/.

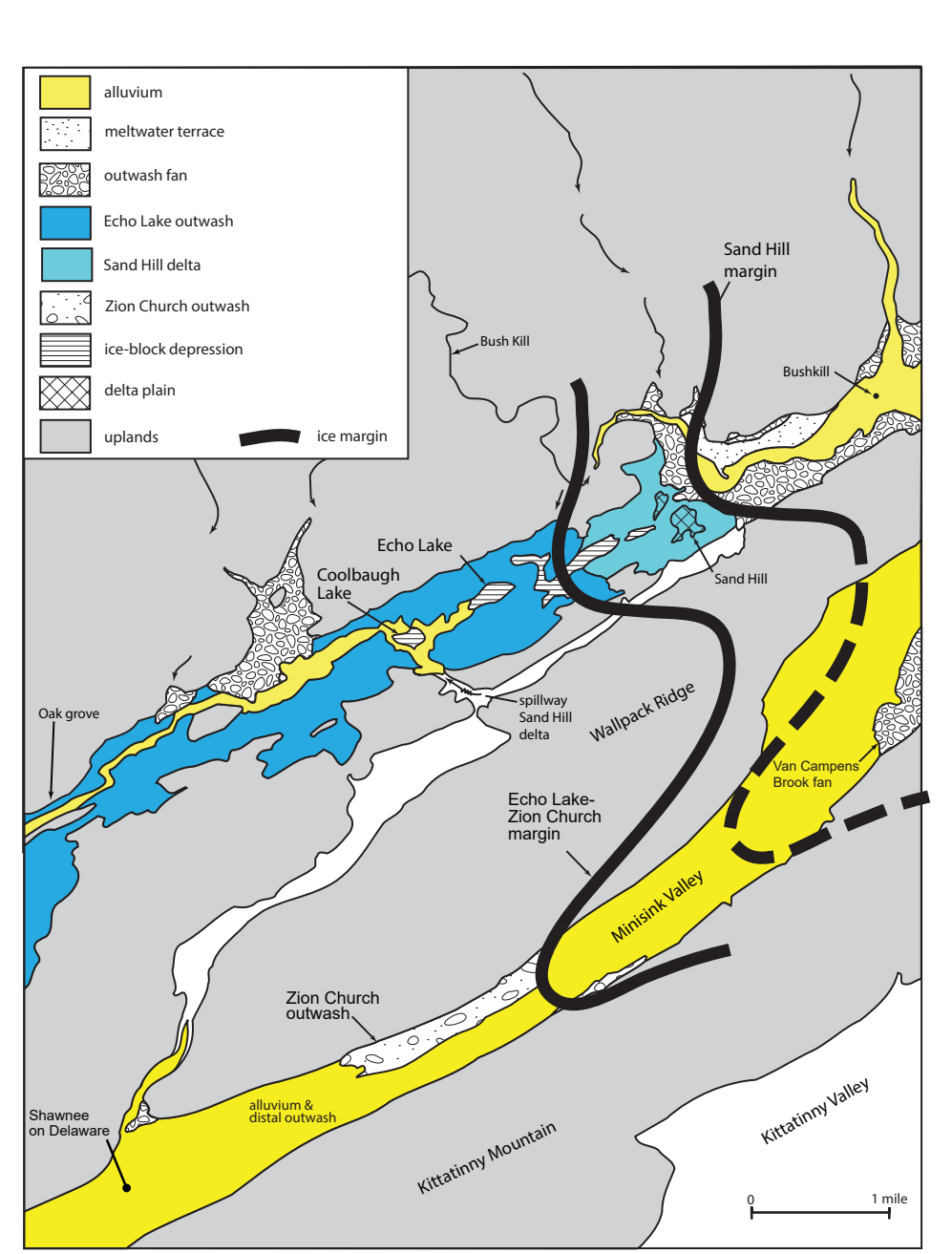


Figure 5. Surficial geology of the Echo Lake lowland and Minisink Valley, Bushkill PA –NJ quadrangle. Because the bedrock floor of the Echo Lake Lowland slopes northeast from Oak Grove, glacial retreat into the lowland resulted in the formation of a small proglacial lake. Two morphosequences, represented by the Echo Lake outwash and Sand Hill delta delineate two ice retreat positions. Following retreat from the Sand Hill margin through the Bush Kill valley to Minisink Valley, meltwater streams abandoned the Echo Lake Lowland and flowed directly to the Minisink. In Minisink Valley, the Zion Church outwash was laid down from an ice-retreatal position located about midvalley. It is correlated with the Echo Lake outwash. The Sand Hill equivalent deposits have not been recognized in Minisink Valley. Figure modified from Witte (2001a).

Prepared in cooperation with the
U.S. GEOLOGICAL SURVEY
NATIONAL GEOLOGIC MAPPING PROGRAM

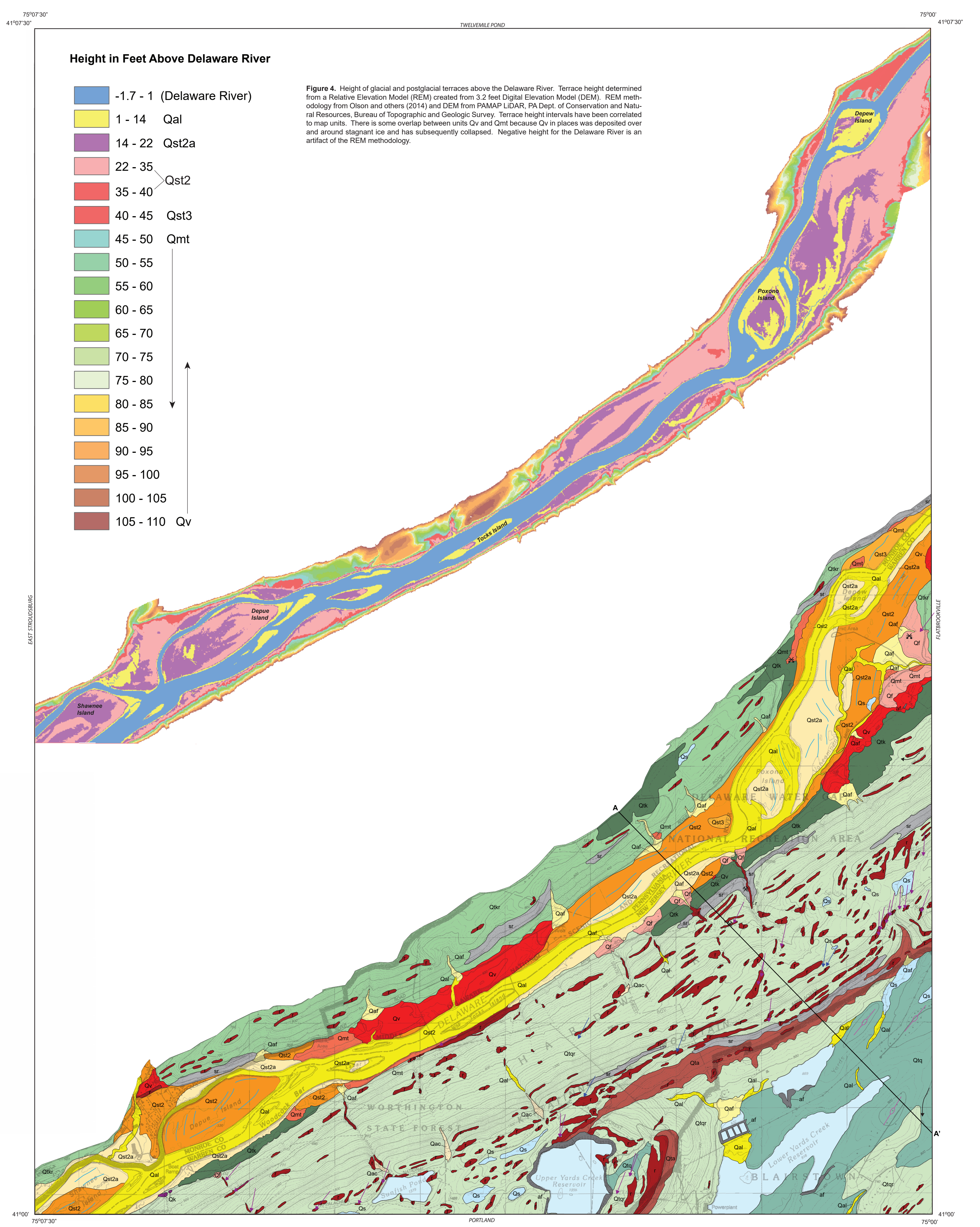


Figure 4. Height of glacial and postglacial terraces above the Delaware River. Terrace height determined from a Relative Elevation Model (REM) created from 3.2 feet Digital Elevation Model (DEM). REM methodology from Olson and others (2014) and DEM from PAMAP LiDAR, PA Dept. of Conservation and Natural Resources, Bureau of Topographic and Geologic Survey. Terrace height intervals have been correlated to map units. There is some overlap between units Qv and Qmt because Qv in places was deposited over and around stagnant ice, and has subsequently collapsed. Negative height for the Delaware River is an artifact of the REM methodology.

Base from U.S. Geological Survey
Compiled from aerial photographs taken 1991.
Field checked 1992. Map edited 1993

SCALE 1:24,000

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

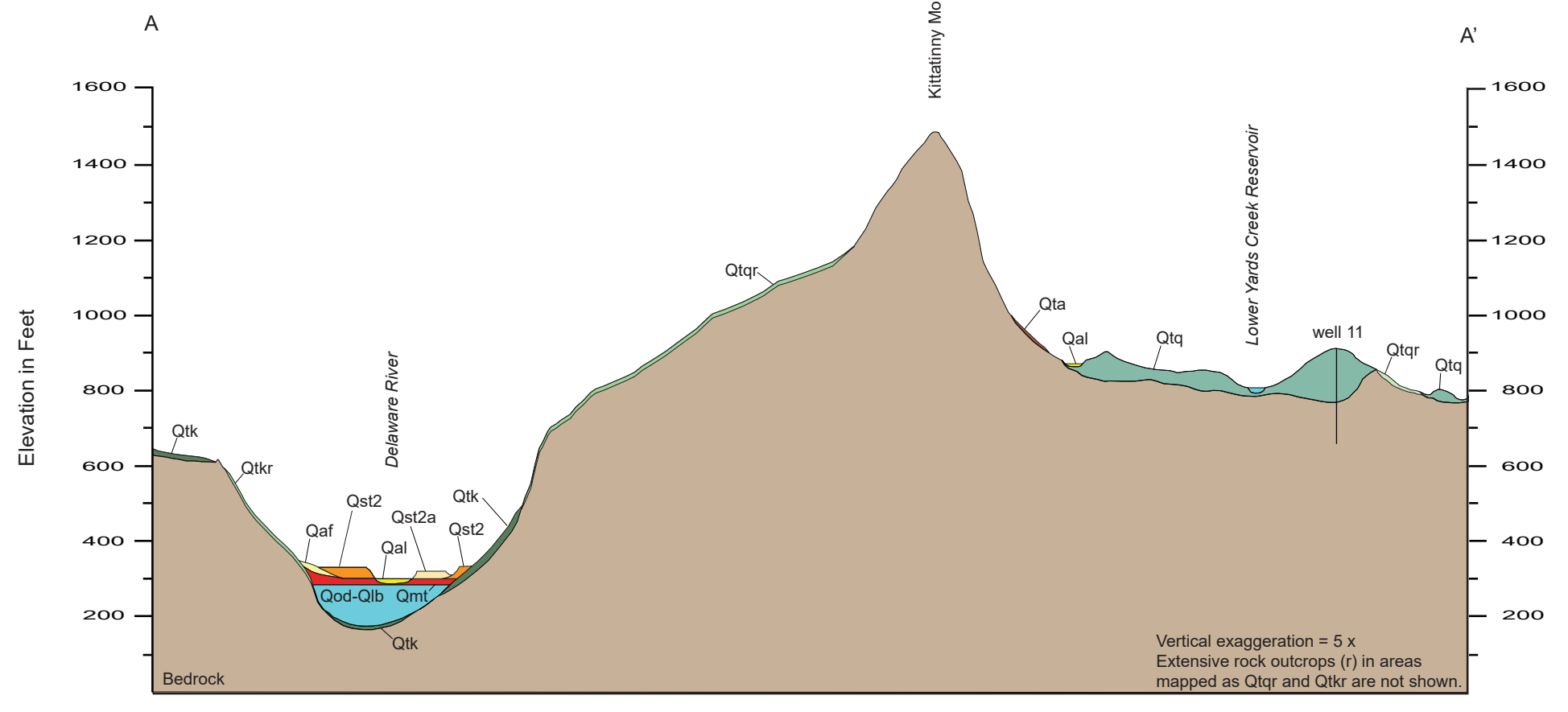
Surficial geology mapped by R.W. Witte, 1991-1995, 2007-2008, and 2014. Mapping in Delaware Water Gap National Recreation Area (DEWA) was completed as part of the National Park Service Geologic Resources Inventory Program. Research supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program, under USGS award number [illegible]. 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 R.W. Witte, New Jersey Geological and Water Survey.

SURFICIAL GEOLOGIC MAP OF PART OF THE BUSHKILL QUADRANGLE, WARREN COUNTY, NEW JERSEY AND MONROE COUNTY, PENNSYLVANIA

BY

RON W. WITTE

2017



SURFICIAL GEOLOGIC MAP OF PART OF THE BUSHKILL QUADRANGLE,
WARREN COUNTY, NEW JERSEY AND MONROE COUNTY, PENNSYLVANIA
PLATE 1 OF 2, OPEN-FILE MAP OFM 112

DESCRIPTION OF MAP UNITS

Industrial, commercial, and residential expansion in New Jersey and Pennsylvania have promoted the increased use of surficial geologic data for land-use planning, for identification, management and protection of groundwater resources, siting of solid waste disposal sites, locating and developing sources of geologic aggregate, and delineation of geologic hazards. Surficial deposits in the Bushkill quadrangle are lithologically diverse, cover most of the bedrock surface, and are found in many types of landscape settings. They include glacial drift of late Wisconsinan age, and alluvium, swamp and bog deposits, hillslope deposits, and wind-blown sediment laid down in postglacial time. Collectively, these deposits may be as much as 200 feet (61 m) thick and they form the parent material on which soils form. They are defined by their lithic characteristics, stratigraphic position, location on the landscape, and are further delineated by genetic and morphologic criteria. 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. The western edge of the mapped area in Pennsylvania is mostly coincident with the boundary of the Delaware Water Gap National Recreation Area.

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 (8m) thick. Not shown beneath roads, and railroads where it is less than 10 feet (3m) thick. Primarily used to raise the land surface, construct earthen dams, and form a soild base for roads and railways.

Qal **Alluvium (Holocene)** -- Stratified, moderately- to poorly-sorted sand, gravel, silt, and minor clay and organic material deposited by the Delaware River and its tributaries. Locally bouldery. As much as 25 feet (8m) thick. Includes planar- to cross-bedded gravel and sand, and cross-bedded and rippled sand in channel deposits, and massive and parallel-laminated fine sand, and silt in flood-plain deposits.

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.

Qst2a
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 in terraces flanking present and late postglacial stream courses. As much as 20 feet (6 m) thick. Overlies glacial and postglacial fluvial, planar to cross-bedded pebbly sand and gravel; as much as 10 feet (3 m) thick. In Minisink Valley (Delaware River valley) deposits form two distinct terraces. The younger (Qst2) flanks recent and late postglacial stream courses and overlies early to late postglacial fluvial gravel and sand. It lies 20 to 35 feet (6 to 11 m) above the mean annual elevation of the Delaware River and chiefly consists of as much as 20 feet (6 m) of fine sand and silt overlying as much as 10 feet (6 m) of pebble gravel and sand. The older (Qst3) flanks late glacial and early postglacial stream courses and overlies glacial outwash and early postglacial fluvial sand and gravel. It lies 40 to 50 feet (12 to 15 m) above the river and consists of as much as 10 feet of fine sand and medium sand. Subscript "a" indicates elevation of terrace is slightly lower than similar nearby terraces. This lower substage has not been shown to be correlative throughout Minisink Valley at map scale. The lower elevation may be due to erosion or differences in local depositional conditions.

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

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

Glacial Deposits
Stratified Materials

Qv **Valley-train deposits (late Wisconsinan)** -- Stratified, well- to moderately-sorted sand, boulder-cobble to pebble gravel, and minor silt deposited by meltwater streams at and extending well beyond (greater than five miles (8 km)) the glacier's margin (fig. 1). 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 Minisink Valley forms shingled sets of outwash terraces. Based on well records (table 1, plate 2), may overlie glacial lake deposits previously laid down in sediment-dammed proglacial lakes. In places overlain by nonlayered, well-sorted, very fine sand and fine sand presumed to be eolian; as much as 5 feet (2 m) thick.

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

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

Qlb **Glacial lake-bottom deposits (late Wisconsinan)** -- Parallel-laminated, irregularly to rhythmically-bedded silt, clay, and very fine sand; and minor cross-laminated silt, fine sand, and minor clay deposited on the floor of glacial lakes chiefly by density currents and settling of fines. As much as 100 feet (30 m) thick. Qlb deposits were laid down in narrow sediment-dammed proglacial lakes in Minisink Valley. In subsurface only.

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

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

Non-stratified Materials

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

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

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

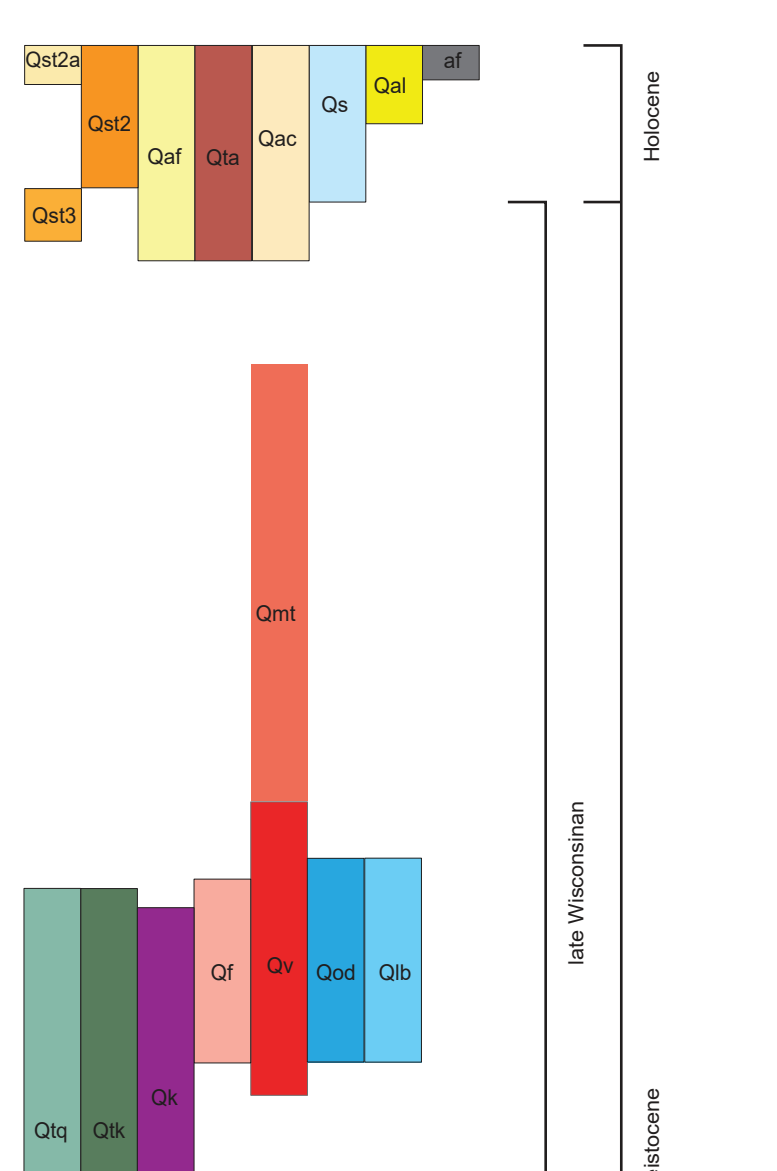
Qtkr and Qtqr denote areas of till generally less than 10 feet thick (3 m) with few to some bedrock outcrops.

Bedrock

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

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

CORRELATION OF MAP UNITS



EXPLANATION OF MAP SYMBOLS

Contacts, dashed where inferred.

Striation, measurement at tip of arrow.

Striation from Alvord and Drake, 1971.

Drumlin, line denotes long axis.

Small meltwater channel.

Alluvial channel scroll.

Inactive sand and gravel pit.

Inactive copper mine.

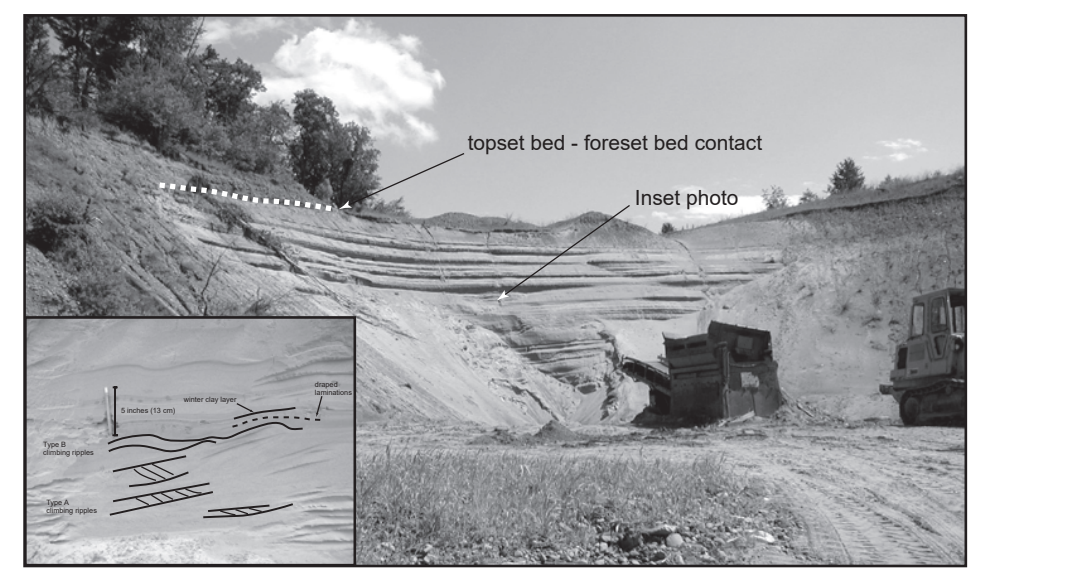


Figure 6. Sand Hill delta sand pit looking southward showing sandy foreset bedding. Approximate height of pit face is 60 feet (18 m). Inset photo shows climbing ripple sequences in foreset beds. This sequence is repeated many times throughout the pit and forms the bulk of the low-angle sandy foreset beds that make up this part of the Sand Hill delta. The winter-clay layer is often absent from the upper part of the sequence showing that the climbing ripple sequences were also deposited during the summer season. Photos modified from Witte (2001a).

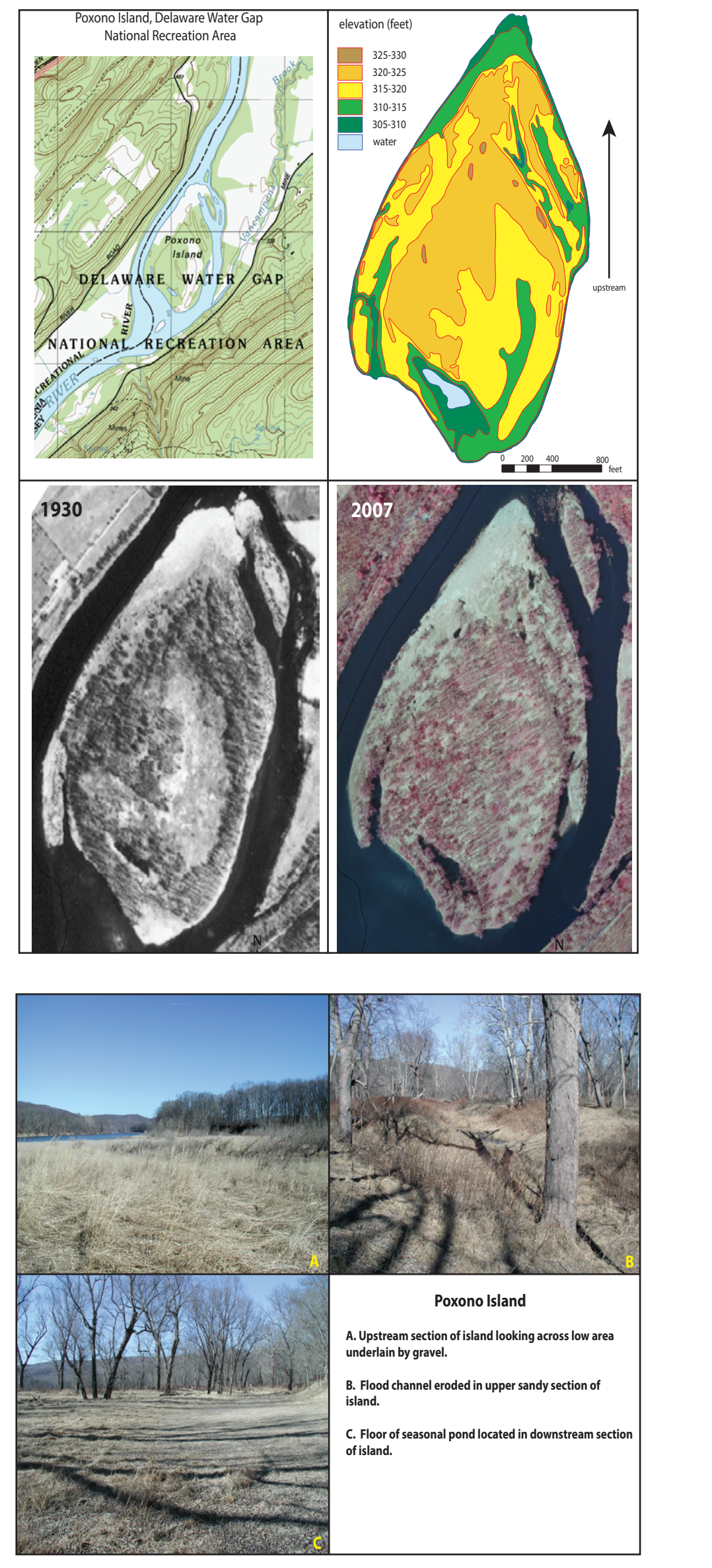


Figure 7. Poxono Island, at one time part of the mainland, formed after a channel was cut along the island's eastern side sometime during the middle to late Holocene. The color-contour map, aerial photos, and photos (a, b, and c) show extensive channelization of the island and transport of eroded sediment (sand), which resulted in downstream island growth. Upstream, gravel forms the island's nose. Some of this material appears to have been deposited by accretion, which indicates an upstream growth component. Elsewhere, the gravel was exposed by erosion of the island's upstream side. Poxono Island photos by R. Witte.

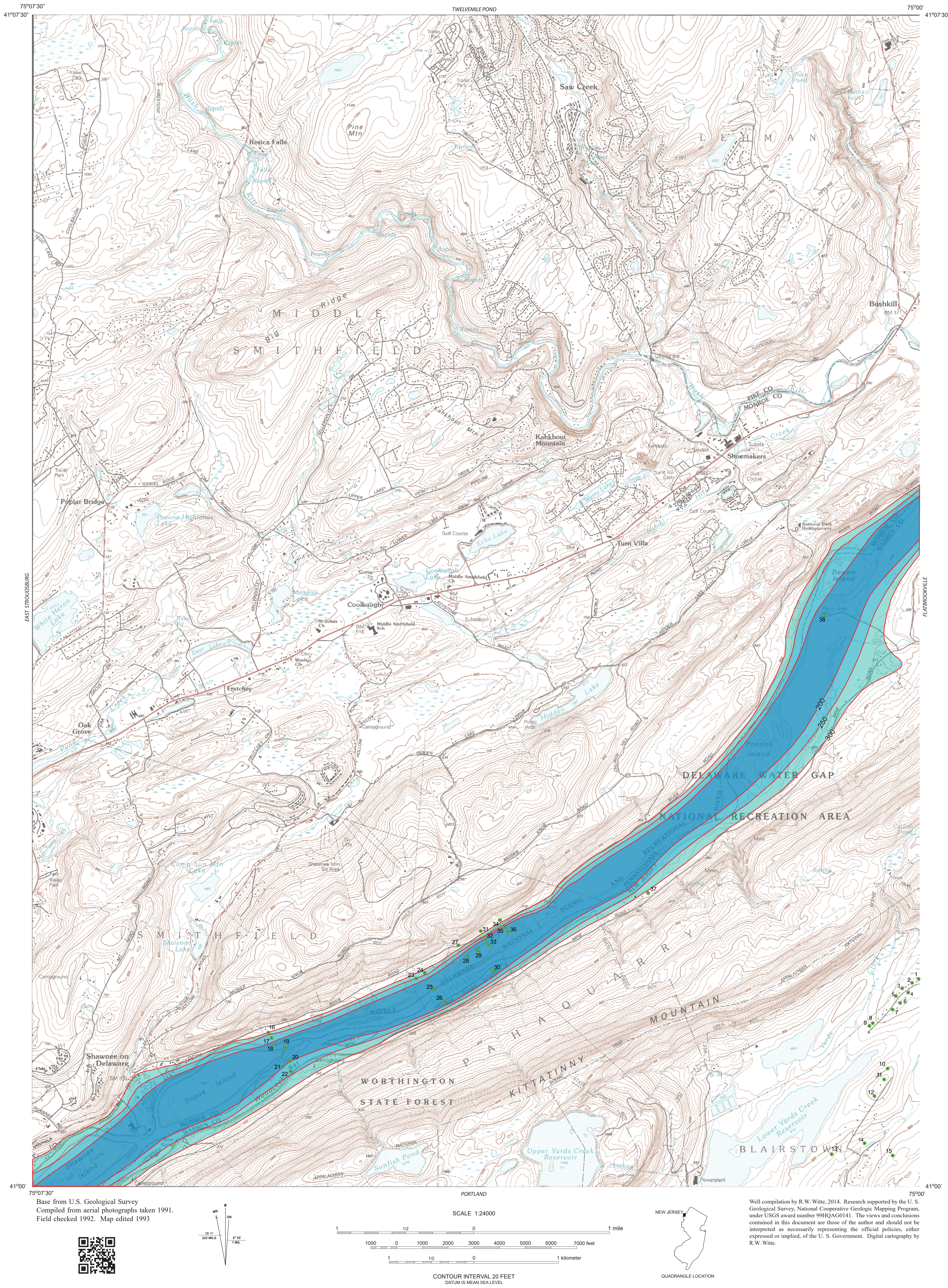
DEPARTMENT OF ENVIRONMENTAL PROTECTION
WATER RESOURCES MANAGEMENT
NEW JERSEY GEOLOGICAL AND WATER SURVEY

Prepared in cooperation with the
U.S. GEOLOGICAL SURVEY
NATIONAL GEOLOGIC MAPPING PROGRAM

SURFICIAL GEOLOGIC MAP OF PART OF THE BUSHKILL QUADRANGLE,
WARREN COUNTY, NEW JERSEY AND MONROE COUNTY, PENNSYLVANIA
PLATE 2 OF 2, OPEN-FILE MAP OFM 112

Table 1. Records of selected wells and borings in Minisink Valley and Kittatinny Valley, Bushkill quadrangle, Warrren County, New Jersey, and Monroe County, Pennsylvania. The wells listed were drilled for private and public water supply, and borings were drilled for exploration. Wells listed with a permit number beginning with "21-", E201210763, E200913109, and "P200911681" are from the files of the Bureau of Water Allocation, Division of Water Resources, New Jersey Department of Environmental Protection. The wells without a permit number are geologic borings from NJGWS permanent files on the Tocks Island Dam-site investigation. Borings listed with DP# id. are from test borings drilled for the Electric Power Company of New Jersey, Inc. by Sprague & Henwood, Inc., logged by Merideth Johnson, State Geologist. Borings listed with TI# id. are from test borings drilled for the Army Corps of Engineers for the Tocks Island dam investigation by Sprague & Henwood, Inc.

Map id.	Permit or Boring Number	Well Yield (gpm)	Depth in Feet	Driller's Log
1	21-04023	20	0-5	overburden, boulders
			5-30	clay and gravel
			30-100	sand, clay and gravel
			100-110	sand
			110-188	sand, clay and gravel
			188-190	big gravel
2	21-08252	10	0-55	clay and large gravel
			55-80	clay and fine gravel
			80-120	pink sandy hardpan
			120-160	soft pink sandstone
			160-170	brown slate
			170-273	slate
3	21-03197	1.5	0-180	overburden with gravel, sand and clay
			180-349	black shale
4	21-05931	5	0-209	boulders and gravel
			209-275	shale
5	21-03803	8	0-50	clay, gravel and boulders
			50-150	clay and gravel
			150-175	clay, boulders and gravel
			175-184	clay and gravel (water area)
			184-198	gray slate
6	21-09647	8	0-2	soil
			2-96	hardpan, gravel and clay
			96-300	black shale
7	21-09422	NA	0-35	gravel and clay
			35-38	boulders
			38-50	gravel and clay
			50-65	gravel, clay and boulders
			65-90	gravel, clay and small cobbles
			90-95	boulders
			95-104	gravel and clay
			104-108	boulders
			108-131	large gravel and clay
			131-173	clay with a little gravel
			173-180	large gravel
			180-700	blue shale
8	21-04151	10	0-5	overburden
			5-6	boulder
			6-35	clay and gravel
			35-110	clay, gravel and sand
			110-115	brown shale
			115-173	blue shale
9	21-09343	10	0-60	boulders with water and sand
			60-190	slate, water at 130' and 160'
10	21-09349	8	0-79	sand, clay and gravel
			79-86	large boulder
			86-107	stony hardpan
			107-373	slate rock
11	21-08569	15	0-146	gravel, clay and sand
			146-165	red sandstone
			165-248	slate
12	E201210763	NA	0-35	brown gravelly, sandy, silty clay
			35-422	blue slate
13	21-03939	10	0-75	sand, gravel and clay
14	21-09120	20	0-17	dirt and rock
			17-21	brown shale
			21-125	blue shale
15	E200913109	NA	0-35	brown gravelly, sandy, silty clay
			35-300	grey limestone
16	DP1	NA	@5	brown clayey silt
			@10	brown silty clay
			@15	brown medium-grained sand
			@20	brown clayey sand and gravel
			@25	brown sand, clay and gravel
			@30	mauve colored sandy clay
			@35	pinkish-gray clay with stone fragments
			@45	stiff gray clay with stone fragments
			@55	gray and yellow clay, coarse sand and stone fragments
			@61	yellow, medium-grained calcareous sandstone
			61-66	yellow, sandy calcitic shale
			66-71	yellow calcitic shale
			71-74	yellow to greenish-gray calcitic shale
17	DP2	NA	@5, 10	brown clayey silt
			@15	brown-gray clayey sand and gravel
			@25	gray gravel with little sand
			@30, 40, 50, 60	gray clay
			@65	soft buff and greenish-gray shale fragments with a few small pebbles
			@70	buff and gray clayey gravel and sand
			@80	soft buff and greenish-gray shale fragments with a few small pebbles
			@85	buff calcitic shale
			85-90	buff to greenish-gray calcitic shale
			90-95	greenish-gray shale with calcitic patches
18	DP3	NA	@5	brown clayey silt and sand
			@10, 20, 23	brownish-gray clay
			@32	tan to brown slightly clayey silt with some reddish-brown clay
			@42	brown and gray sand and gravel firmly cemented with clay
			@58	dark gray sand and gravel
19	DP4	NA	@10, 20	brownish-gray slightly clayey silt
			@30	brownish-gray silty clay
			@40	brownish-gray slightly clayey silt
			@50	brownish-gray clay
			@58	brownish-gray clayey silt
			@65	sand and gravel
			@68	chiefly gravel with some sand (pebbles up to 2 inches)
20	DP5	NA	@15, 20, 25, 30, 35	dark gray clayey silt
			@40	dark gray clayey silt with reddish-brown clay laminae
			@45, 50, 55, 60, 65	dark brownish-gray slightly clayey silt
			@66	clayey sand and gravel
			@69	dark brownish-gray very clayey, very tough coarse sand and gravel
21	DP6	NA	@10, 15	brownish-gray to gray clayey silt
			@20, 25,30, 35, 40	gray clayey silt with streaks of reddish-brown clay
			@45	slightly clayey sand and gravel
			@50	clayey sand and gravel
22	DP7	NA	@15, 20, 25, 30, 35, 40, 45	gray clayey silt and minor reddish-brown clay
			@ 48, 53	clayey sand and gravel
23	TI4	NA	@5	slightly clayey sandy silt
			@10-50	glacial till
			@55	silty very fine sand
			@60	compact glacial till
			@65	silty fine sand with some gravel
			@70	compact glacial till
			72-82	fine to medium grained dark gray limestone
24	TI1	NA	@5	weathered gravel with sand, silt and some clay
			@10, 15	yellowish-brown "dirty" sand and gravel
			@20	brown gravelly, silty sand
			@25	silt, some clay and sand
			@30	silt, sand, clay and gravel
			@ 35, 40	silty sand with some gravel
			@45	gravel, sand and silt
			@46, 50	silt and fine sand
			@55, 60	firm gravel, sand, silt and clay
			@65	silt and fine sand
			@68, 70, 75, 80, 85, 95	firm gravel, sand, silt and clay
			96-104	hard, gray limestone
25	TI3	NA	@5, @10	fine sandy silt
			@15, 20	clayey silt
			@25, 30, 35, 40	interbedded slightly clayey silt and fine sand
			@45, 50	interbedded slightly clayey silt and fine sand with some pebbles
			@55, 60	interbedded silt and gravelly sand
			@65, 70, 75	coarse glacial till very gravelly
			@80	silty medium to fine sand and gravel
			@85	glacial till
			@90	gravel
			@95	sand and gravel
			@100	gravel
			@105-160	glacial till
			164-174	dense fine-grained dolomitic limestone
			174-181	light sea-green limey shale with calcite lined vugs
26	TI2	NA	@5, 10	silty sand
			@15, 20	silty sand and gravel
			@25	coarse sand, slightly silty
			@30, 35	firm reddish silt
			@40, 45, 50, 55	firm silty gravel and sand with some clay
			@60	silty medium to fine sand
			@65	sandy silt with some clay and pebbles
			@70	boulders and gravel
			@75, 80, 85	silty sand with a few small pebbles
			@90, 95	reddish-brown sandy silty with some clay
			@100	interbedded silt and sand with some fine gravel
			@105, 110, 115	brown silty fine sand
			@120	silty sand and gravel
			@125	silty medium to fine sand
			@130	fine sandy silt with some clay
			@135 - 150	compact glacial till, some evidence of stratification
			@155	broken limestone fragments
			156-157	Bloomsburg red shale
			157-160	buff to greenish hard shale with calcite-lined solution cavities
			160-169	Bloomsburg Red Beds
27	TI6	NA	@5, 10	clayey silt
			@15-45	glacial till
			49-59	dark gray crystalline limestone
			59-69	calcareous shale
			69-140	limestone
			140-145	shaly limestone
			145-148	limestone
			148-152	shaly limestone with solution cavities
			152-155	limestone
			155-158	limestone with calcite seams
28	T17	NA	@5	brown clayey silt
			@10-50	glacial till
			@55, 60	fine brown sand with some silt and clay
			@65	glacial till
			@70-135	brown silty fine sand
			@140-145	very fine brown sand with red clay streaks
			@150-165	brown clayey silt
			@170-260	mostly silt, sand and gravel; refusal for many sampling intervals (coarse gravel ?)
			260-263	bluish gray dolomitic limestone
29	TI8	NA	0-11	brown silty sand and gravel
			@15-100	glacial till (loose)
			@105-125	glacial till (mostly compact sand)
			@130-150	silty sand
			@155	brown sandy silt with red clay layers
			@160-170	sandy silt
			@175	brown clayey silt with red clay layers
			@180, 185	silt and red clay
			@190	very fine sand and some silt
			@195	fine sand and some silt
			@200	glacial till (mostly sand, some pebbles)
			@205	cobbles and boulders
			@210	coarse sand and gravel
			239-243	limestone
30	TI9	NA	@1	sand, gravel, boulders
			@5, 10	silt, sand,and gravel
			@15-25	glacial till
			@30-60	sandy silt
			@65-119	silty clay to clayey silt, sparse red clay and fine sand layers
			119-130	compact glacial till
31	TI10	NA	@5	brown clayey silt
			@10	light gray clay, some silt and sand
			@15	brown clayey silt with some pebbles
			@20-50	coarse glacial till and cobbles
			@55	glacial till with clayey silty sand
			62-64	blackish gray limestone with streaks of calcite
32	TI11	NA	@5	clayey silt with weathered shale
			@10	loose till consisting of clay, silt, sand, and pebbles
			@15	clay and silt with cobbles
			@20-100	pinkish glacial till
			@105	glacial till (clay, silt, very coarse angular sand)
			@110-120	glacial till (clay, silt, very coarse angular sand)
			@125-130	glacial till (sand with some clay and silt)
			@135-155	silty sand with some clay
			@160	glacial till
			@165	silty sand and some gravel
			@170	clayey, silty sand
			@175-195	compact glacial till
			199-208	limestone
33	TI12	NA	@5	loose silty clay with red shale
			@10-15	glacial till consisting of silty clay with pebbles
			@20	clayey silt with very coarse shale particles
			@25-50	glacial till
			@55	glacial till consisting of very coarse particles and some cobbles
			@60-70	coarse sand and gravel
			@75-85	coarse sand and some clay
			@90-105	glacial till
			@110	brown clayey sand
			@115, 120	brown fine sand and some silt
			@125	brown fine sand
			@130	loose coarse sand
			@135	glacial till
			@140, 145	clayey sandy silt
			@150	gray silty sand
			@155, 160	clayey silt
			@165	clay
			@170	gray sand and some silt
			@175	clayey silt
			@180	fine sand, some clay and silt, occasional pebbles
			@190	fine silty sand and some clay
			@225, 230	glacial till
			@233	boulders
			252-253	blue limestone
34	TI13	NA	@5	brown silty clay, some sand and gravel
			@10, 15	brown clayey silt, some weathered shale fragments
			@25-50	glacial till
			@55	glacial till (mostly sand)
			@60, 65	glacial till
			@70	brown sand and silt
			74-76	black crystalline limestone
35	TI14	NA	@5-15	brown clayey silt
			@20	brown clayey silt with red clay streaks
			@25, 30	silty clay
			@35	sand and gravel
			@40	silty clay with pebbles
			@45-115	glacial till (heterogeneous mixture of clay, silt, coarse sand and pebbles.
			@120	silty sand with some clay
			@130, 135	glacial till (coarse angular sand, some silt and clay)
			@140-170	glacial till (coarse angular sand, some silt, clay and pebbles)
			@175	glacial till with fragments of green limestone
			177-179	green limestone
36	TI15	NA	@5	brown clayey silt with some shale fragments and gravel
			@10	clayey sand with some gravel
			@15-120	glacial till
			@125	cobbles (4" of quartzite and limestone)
			@135, 140	compact glacial till
			@150	fine sand and gravel
			@167	brown sand
			@172	silty sand
			@177	glacial till
			@182	glacial till changing to brown silty fine sand
			@187	glacial till
			@192	very compact silty sand
			@197	boulders
			201-203	green limestone
37	P200911681	100	0-48	overburden - sand and gravel
			48-182	limestone - red
38	21-10625	10	0-130	brown fine sand
			130-137	0.75" to 1.0" gravel (no water)
			137-305	hard red and gray sandstone



Base from U.S. Geological Survey
Compiled from aerial photographs taken 1991.
Field checked 1992. Map edited 1993

SCALE 1:24000

1 1/2 0 1 mile

1000 0 1000 2000 3000 4000 5000 6000 7000 feet

1 1/2 0 1 kilometer

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

Well compilation by R.W. Witte, 2014. 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. Digital cartography by R.W. Witte.

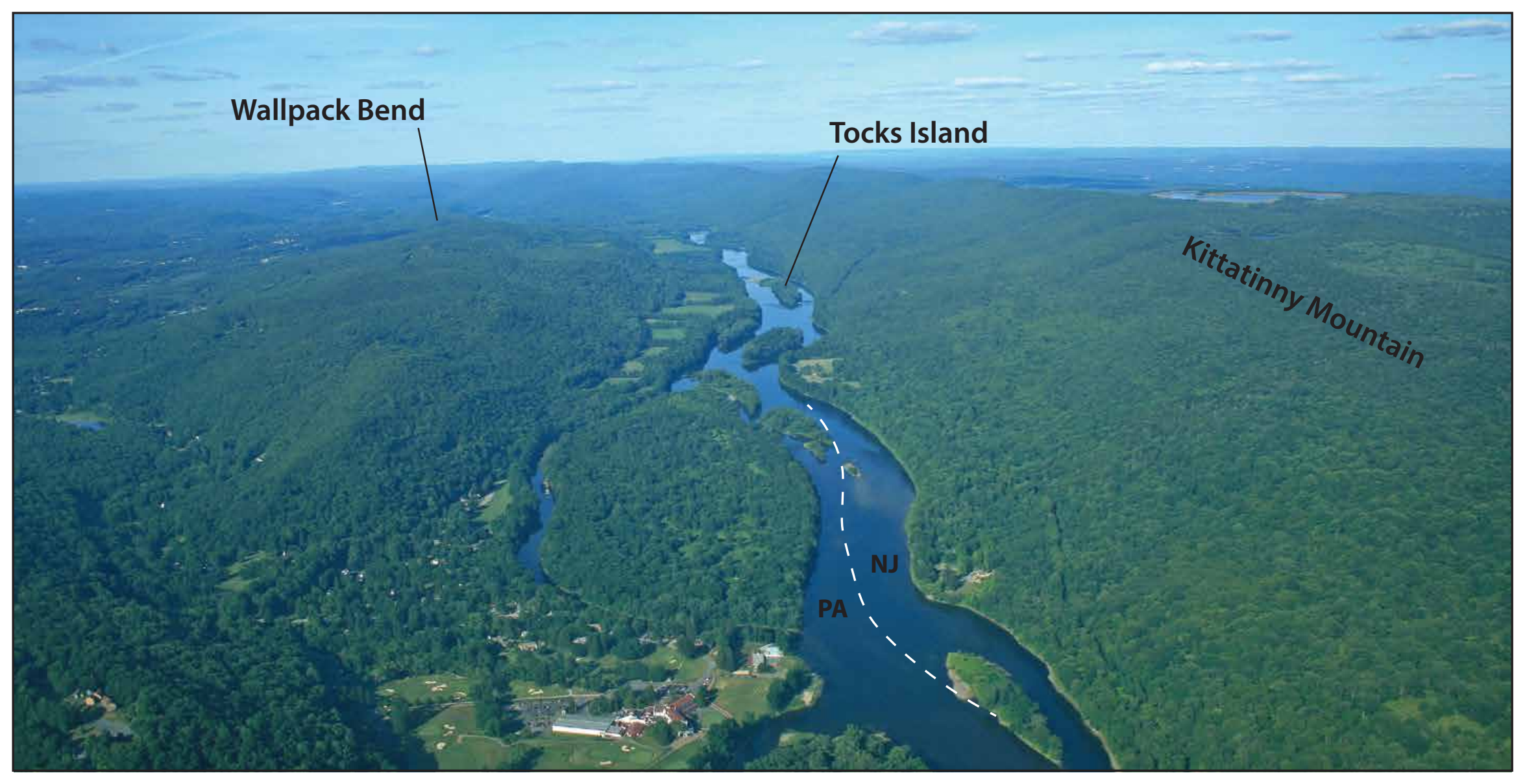
ELEVATION OF THE BURIED BEDROCK SURFACE FOR PART OF THE BUSHKILL QUADRANGLE, WARREN COUNTY, NEW JERSEY AND MONROE COUNTY, PENNSYLVANIA

BY

RON W. WITTE

2017

The Tocks Island Dam



Aerial view of Minisink Valley looking upstream from Shawnee on Delaware (building complex in foreground). Major public water supplies that depend in whole or part on the Delaware River include Philadelphia, New York City, and northern New Jersey. In the 1920s it became clear that water supply needs for these developing areas would quickly outpace current supplies. Most major water supply proposals called for the construction of dams or pumping stations on the upper Delaware. Tocks Island was not the most favorable dam location, but rather Wallpack Bend, which is located about six miles upstream. Two closely spaced events quickly changed the dam's location. The first when on August 12, 1955, Hurricane Connie dumped up to 12.5 inches of rain in the Delaware watershed and the second on August 18, 1955 when Hurricane Diane dumped an additional 11 inches of rain. These two storms caused widespread flooding, resulting in loss of life and extensive property and infrastructure damage. There was a subsequent outcry for flood control dams and the Delaware River was placed within the Army Corps of Engineers flood control mandate, paving the way for Federal involvement.

The Tocks Island part of the study was released in 1957 indicating that the construction of an earth-fill dam was feasible. In comparison to the Wallpack Bend site, reservoir capacity would be doubled and from this point, the Wallpack Bend was abandoned even though it was a more favorable site based on its geology. A dam at Tocks Island would have flooded Minisink Valley about 35 miles upstream to Port Jervis, New York, and Wallpack Valley upstream to Layton. The reservoir would have provided a storage capacity of 133.6 billion gallons (Corps of Engineers, 1967).

Extensive geologic investigations of the Tocks Island site began following Congressional authorization in 1962. The axis of the dam was to cross the valley above a southwest plunging asymmetric syncline (Depman and Parillo, 1969). The New Jersey dam abutment was to be anchored in the Bloomsburg Red Beds while the Pennsylvania abutment was to be anchored in thinly bedded Silurian and Devonian limestone, shale, and sandstone. The valley floor is underlain by as much as 200 feet (61 m) of unconsolidated material consisting of late Wisconsinan glacial sediment and postglacial alluvium. The glacial sediment stratigraphy was especially complex consisting of till, lacustrine silts and clays, and lacustrine and fluvial sand and gravel. Lacustrine sediments show the existence of a glacial lake in the valley, interpreted to be a sediment–dammed lake that formed during deglaciation. Additionally, the Zion Church ice-retreatal position has been mapped crossing the valley at Tocks Island, which explains the complex stratigraphy of till and outwash shown by the geologic borings.

Significant geologic problems of the dam site included 1) instability of glaciolacustrine silts and clays which have little shear strength and are prone to liquefaction, 2) excessive water flow through the coarser grained glacial outwash and alluvium, 3) cavern formation in some of the limestone formations, and 4) bedding plane faults in the Bloomsburg Red Beds which dip northwest into the valley.

Other problems included financial costs. From a 1962 estimate of $90 million, costs rose to $400 million by 1975, and were still climbing. Perhaps most important to the termination of the project was the extensive grass roots environmental opposition to the construction of a dam across the Delaware River. The Tocks Island dam project was finally deauthorized by the U.S. Congress in 2002. Text for caption modified from Harper (2002). Photo by R. Witte.

EXPLANATION OF MAP SYMBOLS

25 ●	Well or boring with log in Table 1.
250	Approximate elevation of bedrock surface beneath thick valley fill. Based on well records and geologic borings (Table 1), location of rock outcrop, and data in adjoining quadrangles (on file at New Jersey Geological and Water Survey, Trenton, New Jersey). Contour interval 50 feet.
	Elevation above sea level of glacially-scoured bedrock floor of the Delaware River valley.
🟩	251 - 300 feet
🟦	200 - 250 feet
🟦	< 200 feet

36 inch (91 cm) diameter calyx core along the Rock Cores Trail, Worthington State Forest, New Jersey. The core was drilled in the Bloomsburg Red Beds during the geological investigation of the Tocks Island dam site during the 1960s. Geologists were suspended in steel cages down the bore shafts in order to log the bore holes. Photo by R. Witte.

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