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 LAKE MASKENOZHA QUADRANGLE
SUSSEX COUNTY, NEW JERSEY AND PIKE COUNTY, PENNSYLVANIA
OPEN-FILE MAP OFM 101

INTRODUCTION

The Lake Maskenozha quadrangle is in the glaciated part of the Valley and Ridge Physiographic Province in Sussex County, New Jersey, and the Glaciated Low Plateau Section of the Appalachian Plateau Province in Pike County, Pennsylvania. Main geographic features are Minisink, and Wallpack Valleys, Wallpack Ridge and Kittatinny Mountain (fig. 1). The Delaware River, which separates New Jersey from Pennsylvania, flows southwest in Minisink Valley through the Delaware Water Gap National Recreational Area. A steep bluff cut in shale forms a nearly continuous scarp along the valley's west side. Toms Creek, Dingmans Creek, and a few smaller Delaware tributaries drain the Low Plateau area of the quadrangle. The highest point is 1,423 feet above sea level on a small hill near Lake Maskenozha, and the lowest point lies on the Delaware River, approximately 330 feet 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 radiocarbon years before present (yr BP), and postglacial stream sediment, hillslope deposits, wind-blown sand, and swamp and bog deposits laid down in late glacial and postglacial time. These materials may be as much as 200 feet (61 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, meltwater terrace, and deltaic deposits was laid down at and beyond the glacier's margin, in Minisink and Wallpack Valleys. These deposits typically form terraces that lie as much as 120 feet (37 m) above modern valley floors. The most extensive postglacial materials lie in Minisink Valley and consist of alluvium deposited by the Delaware River. Elsewhere, organic soil, consisting largely of humus and peat, is found in the many bogs and swamps that dot the landscape.

PREVIOUS INVESTIGATIONS

The geology of surficial deposits in Sussex County, New Jersey was first discussed by Cook (1877, 1878, 1880). He included detailed observations on recessional moraines, age, distribution and types of drift, and evidence of glacial lakes. Shortly thereafter, White (1882) described the glacial geology of Pike County, Pennsylvania, and a voluminous report by Salisbury (1902) detailed the glacial geology of New Jersey region by region. The terminal moraine (fig. 2) and all glacial deposits north of it were interpreted to be products of a single glaciation of Wisconsinan age. Salisbury also noted that "in the northwestern part of the state, several halting places of ice can be distinguished by the study of successive aggradation plains in the valleys." Crowl and Sevon (1980), Cotter and others (1986), and Stone and others (2002) indicated the youngest glacial deposits in Pennsylvania and New Jersey are of late Wisconsinan age. Crowl (1971) mapped part of the quadrangle, and included detailed observations on glacial drift and its history in Minisink Valley, and Sevon and others (1989) reported on the surficial geology of Pike County, Pennsylvania.

For detailed discussions on the glacial and postglacial history of northwestern New Jersey see Witte (1997, 2001a, 2001b, 2008) and Witte and Epstein (2004, 2012).

PHYSIOGRAPHY AND BEDROCK GEOLOGY

The Lake Maskenozha quadrangle lies entirely within the Delaware River drainage basin (fig. 1). The Delaware River, which is the master stream in this area, flows southwestward through Minisink Valley following the easily eroded Onondaga Limestone and Marcellus Shale. The western side of the valley is bordered by a 300- foot-high escarpment cut in the Mahantango Shale. Tributaries typically flow at right angles to the Delaware and are deeply incised, flowing over rock before entering the trunk valley. Most of the Delaware River's tributaries form a modified trellis drainage pattern following the southwest structure and cross joints of the local rock formations. In places this pattern is overprinted or replaced by a dendritic one that has formed over thick unconsolidated 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 falls along many of the Delaware's tributaries hint of multiple glaciations (Witte, 2001c, 2012).

Kittatinny Mountain is underlain by the Shawangunk Formation, which consists of quartz-pebble conglomerate, and quartzite, and the Bloomsburg Red Beds, which consist of red sandstone, and red shale (fig. 3). The mountain forms a very long ridge that extends southwestward from the Shawangunk Mountains in New York through New Jersey into Pennsylvania (inset map, fig. 1). In many places its steep southeast face forms a nearly continuous escarpment. In places the continuity of the mountain is broken by 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 high ridge area of the mountain is underlain by the Shawangunk Formation, whereas the hills and slopes to the west are underlain by Bloomsburg Red Beds, which in most places is covered by thick glacial drift. Relief here may be as much as 300 feet (91 m), and the surface is marked by rolling topography of gentle to moderate slopes chiefly formed on drumlins and ground moraine.

Wallpack Ridge, Wallpack Valley (local name for Flat Brook valley), and Minisink Valley are northwest of Kittatinny Mountain (fig. 1). Bedrock in this area (fig. 3) consists of Silurian and Devonian strata that dip northwest and form a southwest-trending homocline (Drake and others, 1996; Sevon and others, 1989). Wallpack Ridge (fig. 1) separates Minisink and Wallpack Valleys. It is underlain by thinly-bedded sandstone, siltstone, and some limestone with the highest parts of the ridge held up by sandstone of the Esopus Formation, which rises as much as 300 feet (91 m) above the adjacent valley floors. Minisink and Wallpack Valleys are narrow, deep, and trend southwest, following belts of weaker rock. High cliffs formed on the Mahantango Shale border the western side of Minisink Valley. The valleys were also the site of a planned 1960's hydroelectric and water storage project by the Army Corps of Engineers. A dam constructed at Tocks Island, six miles downstream from Wallpack Bend, would have flooded Minisink Valley upstream to Port Jervis, New York, and Wallpack Valley upstream to Layton. The resulting reservoir would have provided a storage capacity of 133.6 billion gallons (Corps of Engineers, 1967). This project has since been de-authorized by the U.S. Congress.

PREGLACIAL DRAINAGE

The overall drainage pattern of the study area has probably not substantially changed from the middle Pleistocene to the present. A report on the Culvers Gap River (Witte and Epstein, 2004), and a report on waterfalls and multiple glaciations in Minisink Valley (Witte, 2001c, 2012) indicated that major changes in drainage of the Delaware River in the Lake Maskenozha area would have had to occur during the early part of the Pleistocene or earlier during Late Tertiary time.

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, 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 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. Also, 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 lithology was largely dependent on the south-to-southwest direction of ice flow over narrow, southwest-trending belts of local sedimentary source rocks. Till (Qtk) is chiefly derived from limestone, shale, limey shale, and sandstone in Minisink Valley and atop Wallpack Ridge. Till (Qtq) on Kittatinny Mountain is chiefly derived from quartzite, quartz-pebble conglomerate, and red sandstone and shale that underlie the mountain.

Deposits of Glacial Meltwater Streams

Sediment carried by glacial meltwater streams was chiefly laid down at and beyond the glacier margin in valley-train deposits (Qv), outwash-fan deposits (Qf), and ice-contact deltas (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 glacial 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 its basal dirty-ice zone, and till and reworked outwash in upland areas. Debris carried to the margin of the ice sheet by direct glacial action is only a minor component.

Glaciofluvial sediments were laid down by meltwater streams in valley-train (Qv), outwash-fan (Qf), and meltwater-terrace deposits (Qmt). 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 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. 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 mouth of tributary valleys. These deposits were laid down beyond the glacier margin, and are graded to the surface of the valley-outwash deposits that lie in the trunk valley.

Glaciolacustrine sediments were laid down by meltwater streams in ice-contact and valley-outwash deltas (Qod), and lake-bottom deposits (Qlb); all 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, parallel-laminated sand and silt with clay drapes.

Typically, deltas consist of many individual lobes that prograde outward from the delta front across the lake floor, thinning and widening with distance (Gustavson, and others, 1975). Because proglacial lake basins in the Minisink and Wallpack Valleys were very narrow, they were filled with glaciolacustrine sediment and 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.

Lake-bottom deposits 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 of deposition. 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. Lake-bottom deposits grade laterally into bottomset beds of deltas.

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

POSTGLACIAL DEPOSITS

Wind-Blown Sediment

Thin, patchy sheets of wind-blown (shown by stippled pattern on map) sand occur along the eastern side of Minisink Valley on the lower parts of Wallpack Ridge. Thicker deposits, including dunes have been observed elsewhere in the valley (Witte, 2012). Eolian deposits were presumably laid down in early postglacial time (16 to 12 yr BP) when sparse vegetative cover and strong westerly winds created favorable conditions for the erosion of fine sand off deflated glacial outwash plains.

Hillslope Sediment

Thin deposits of shale-chip colluvium (Qsc) lie at the base of cliffs formed by the Mahantango Formation in Minisink Valley. The rubble, described in Sevon and others (1989), consists of angular, elongated, platy, prismatic and bladed clasts of the Mahantango Formation. Average clast length ranges from one to six inches. Larger clasts, up to boulder size, may be interspersed throughout the deposit. Typically, the rubble has very little matrix, although many of the clasts exhibit a thin coating of clay. The few beds having a substantial matrix component display a coarsening upwards of shale clasts, suggesting they were deposited as a slurry flow. Bedding is slope parallel, and averages one to four inches in thickness. However, in many places the homogeneity of the rubble obscures bedding. Most of the elongated fragments are oriented downslope. Bedding, sorting, and clast orientation of the rubble suggests that most of it, after it has fallen off the outcrop and accumulated at the top of the apron, moves downslope as a massive sheet flow. Bedding and grading show that this downslope transport is episodic and in some cases may have involved water.

Glacial erosion and the lithic and structural elements of the Mahantango Formation have produced very large volumes of shale-chip rubble in a short time. Glacial erosion over the course of at least three glaciations has cut back the west side of Minisink Valley and formed a very steep rock face that is as much as 300 feet (91 m) high. Mechanical weathering of the rock by frost shattering has formed an extensive apron of shale-chip rubble that has accumulated since Minisink Valley was deglaciated about 18,000 yr BP. The steep southeast-dipping cleavage of the Mahantango Formation, its thin, northwest-dipping beds of shale and siltstone, and its vertical joints form weak zones facilitating rapid fragmentation. The size of the rubble clasts is directly related to cleavage spacing, bedding thickness, and joint penetration (fig. 4).

Other slope deposits include thick talus (Qta), chiefly made up of blocks of conglomerate and quartzite. It forms an extensive apron of rock debris on the southeast face of Kittatinny Mountain and at the base of a few cliffs higher on the mountain.

Organic Deposits

Many swamp and bog deposits (Qs) are in the quadrangle. They formed in kettles and glacially scoured bedrock basins, in glacial lakes that persisted into the Holocene, in abandoned stream channels on alluvial plains, and in poorly drained areas on ground moraine. These deposits principally consist of peat, muck, marl, and minor 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 is underlain by calcareous marl (Waksman and others, 1943).

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

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

Stream-terrace deposits (Qst, Qst2, Qst3) include both channel and flood-plain sediment, and they lie 5 to 35 feet (2 to 11 m) above the modern flood plain and below meltwater-terrace deposits. They form two distinct sets (Witte, 2001b) in Minisink Valley; elsewhere, along the course of smaller streams, only one terrace (Qst) is mapped. The oldest and highest stream-terrace deposits in Minisink Valley (Qst3) lie 40 to 48 feet (12 to 15 m) above the modern river and typically consists of as much as 10 feet (3 m) of overbank fine sand and medium sand overlying glacial outwash. In places, this material has been eroded, exposing the underlying outwash. The Qst3 terraces are typically small and flank the younger Qst2 deposits. In some places they lie surrounded by Qst2 deposits. No dates are available for the Qst3 terrace, but based on the Holocene age of the Qst2 terrace, it is late Wisconsinan in age and it may mark a transition from glaciofluvial to postglacial fluvial environments.

The lower and younger (Qst2) terrace lies between 20 and 35 feet (6 to 11 m) above the river and consists of as much as 25 feet (8 m) of overbank fine sand and silt (fig. 5) 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 are Holocene age. They 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. In a few places the levee is well developed and forms a prominent ridge that is as much as 8 feet (2 m) high. Mostly, it is the highest point on a gently inclined surface that slopes away from the river to the valley wall. At the base of the valley wall the terrace is cut by a shallow channel that typically contains organic deposits. In many places, alluvial-channel scrolls are preserved, 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 (levee and backslope) on the terrace, and 2) parts of the terrace may have been lowered by fluvial erosion during floods. 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). However, without precise elevation control, these terrace subsets are difficult to correlate on a valley-wide scale. They are shown on the geologic map by scarp symbols.

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

GLACIAL HISTORY

Glacial Erosion

The distribution and differences in weathering characteristics of glacial drift in northwestern New Jersey (Salisbury, 1902; Witte and Stanford, 1995; Stone and others, 2002) show continental ice sheets covered the study area at least three times during the Pleistocene epoch. Each ice sheet modified the landscape by deeply scouring valleys, and wearing down and streamlining bedrock ridges, hills, and slopes. Both floors of Minisink and Wallpack Valleys, and part of Kittatinny Valley were deeply scoured by glacial erosion. Depressions in the buried-bedrock floor of Minisink Valley indicate that glacial scour exceeds 50 feet (15 m) and may be as much as 150 feet (46 m) (Witte and Stanford, 1995). Because of weathering, only erosional features of the late Wisconsinan glaciation are preserved. These include polished and plucked bedrock, striations, and streamlined bedrock forms called roche montonnées. The many unweathered and lightly weathered bedrock outcrops also show that preglacial saprolite and soil were removed by glacial erosion. However, saprolite observed by the author on the Poxono Island Formation downvalley in the Bushkill quadrangle shows that at least some preglacial materials were not completely eroded.

Glacial Advance and Changes in Direction of Regional Ice Flow

The late Wisconsinan advance of ice into the upper part of 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. Sevon and others (1975) speculated 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 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. Connally and Sirkin (1986) suggested that the Ogdensburg-Culvers Gap Moraine represents or nearly represents the terminal late Wisconsinan position of the Hudson-Champlain lobe based on changes in ice flow noted by Salisbury (1902) near 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 show that by the time the Ogdensburg-Culvers Gap Moraine was formed, ice flow in Kittatinny Valley had turned completely to the southwest with extensive lobation at the margin.

Style and Timing of Deglaciation

The recessional history of the Laurentide ice sheet is well documented for northwestern New Jersey and parts of eastern Pennsylvania. Epstein (1969), Ridge (1983), Cotter and others (1986), and Witte (1988, 1997) showed that the margin of the Kittatinny and Minisink Valley lobes retreated systematically with minimal stagnation. However, the age of the Terminal Moraine, timing of the late Wisconsinan maximum, and precise chronology of deglaciation are 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, varved lake-bottom exposures that can be used for chronology are scarce.

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 BP (I-2845), and a concretion sampled from sediments of Lake Passaic by Reimer (1984) that yielded a date of 20,180 +/- 500 yr BP (QC-1304) suggest that the age of the Terminal Moraine is about 22,000 to 20,000 yr BP. 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 BP (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 BP (SI-5273) (Cotter, 1983). Because the lake lies approximately 3 miles (4.8 km) 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 BP (I-4935) from sediments of Lake Hudson (cited in Stone and Borns, 1986) and an estimated age of 17,210 yr BP for the Wallkill moraine by Connally and Sirkin (1973) suggest that ice had retreated from New Jersey by 18,000 yr BP.

Based on the morphosequence concept (Koteff and Pessl, 1981), many ice-recessional positions have been delineated in Kittatinny Valley (Ridge 1983; Witte 1988, 1997). 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).

Minisink Valley

Meltwater deposits in Minisink Valley consist of valley-train, outwash-fan, and meltwater-terrace deposits. Valley-train deposits are remnants of an extensive outwash deposit laid down from the Dingmans Ferry ice margin (fig. 2, position 7). These outwash remnants form discontinuous, narrow terraces that lie 100 to 120 feet (30 to 37 m) above the Delaware River. They are attached to the valley wall, have even surfaces that slope gently downvalley and have steep-sided erosional escarpments that lie against the younger meltwater-terrace, stream-terrace and alluvial deposits that cover the lower parts of the valley floor. 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 and ripple 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 upstream at the Dingmans Ferry ice margin (fig. 2, position 7). Lake-bottom deposits in Minisink Valley north of Wallpack Bend (Witte and Epstein, 2012) show that a proglacial lake occupied the valley before outwash from the Dingmans Ferry position buried the lacustrine sediments. The valley floor is deeply scoured on both sides of Wallpack Bend and as the glacier margin retreated northward, a proglacial lake formed in the scoured depression. The lake's spillway was presumably across slightly older outwash downstream from Wallpack Bend. The extent of the glaciolacustrine sediment is uncertain. Records of wells in the valley (on file at the New Jersey Geological and Water Survey) show that it is discontinuous. It is shown here locally underlying the Dingmans Ferry valley-train deposit.

On the Pennsylvania side of Minisink Valley, large fan-shaped deposits of sand and gravel lie near Egypt Mills and Dingmans Ferry. They head in the small valleys now drained by Toms Creek, Hornbecks Creek, and Dingmans Creek. They reach an elevation of as much as 450 feet (137 m), and are graded to the surface of the valley-outwash deposits. Meltwater streams draining the upper reaches of the tributaries laid down these fans.

Meltwater-terrace deposits in Minisink Valley are chiefly strath terraces cut in valley-train deposits by meltwater streams emanating from ice-recessional positions north of the Dingmans Ferry ice margin (fig. 2, position 7). These deposits are as much as 15 feet (5 m) thick and consist largely of reworked sediment eroded from the adjacent or the upstream parts of valley-train deposits, and from till that covers the lower part of valley slopes. They range in elevation from 405 to 350 feet (123 to 107 m) above sea level and were formed during a period of fluvial incision following the lowering of local base level downvalley by erosion. The surface of some terraces dips towards the center of the valley. These are interpreted to be slip-off slopes that were formed by the rapid downcutting and the lateral migration of meltwater streams across the valley bottom as local base level was lowered by erosion downstream.

Wallpack Valley

Meltwater sediment in Wallpack Valley consists of valley-outwash deltas, and meltwater-terrace deposits. Valley-outwash delta deposits form collapsed and discontinuous terraces that cover large parts of Wallpack Valley's floor. They consist of cobble-pebble gravel, pebble gravel, and sand topset beds that overlie pebble gravel, pebbly sand, and sand foreset beds. In places foresets are interlayered with massive, coarse, sediment-grain-flow deposits, and flow till. Deposits are as much as 460 feet (140 m) above sea level and are collapsed in many places. Apparently, they were laid down in a proglacial lake that was dammed by higher deposits downvalley and/or laid down in ice-contact ponds within areas of stagnant ice. Topographic profiles of the outwash surface (fig. 4) indicate these deposits were laid down from the Dingmans Ferry ice margin (fig. 2, position 7).

Meltwater-terrace deposits in the valley are common. These deposits are mostly beveled outwash surfaces cut by meltwater streams emanating from ice margins farther up valley. In a few places downcutting and lateral erosion by meltwater streams is commonly exhibited by slip-off slopes that cut down into the higher valley-outwash deposits. These occur on the inside bend of channels and they represent a period of rapid erosion.

Summary of deglaciation in Minisink and Wallpack Valleys

Retreat of the glacier from the Sand Hill Church ice margin (fig. 2, position 4) 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 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 occupied Minisink Valley south of Wallpack Bend. Initially, the lake may have been dammed by outwash laid down from the Zion Church ice margin (fig. 2, position 3). The Dingmans Ferry Moraine, which is just upstream in the Cuvers Gap quadrangle (Witte and Epstein, 2004) marks the next ice-recessional position. It has been 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 Church and Dingmans Ferry may reflect rapid wasting and retreat of the ice margin. Alternatively, the glacier margin remained at the Dingmans Ferry margin long enough so that older heads-of-outwash downvalley were buried.

POSTGLACIAL HISTORY

The Lake Maskenozha quadrangle is estimated to have been deglaciated by 17,500 yr BP, 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 15,000 to 14,000 yr BP (estimated from Ozvath and Coates, 1986).

The postglacial landscape immediately following deglaciation was cold, wet, and windswept. This harsh climate and sparse vegetation enhanced erosion of the land by streams, and by mass wasting of material on slopes. Mechanical disintegration of exposed bedrock by frost shattering was extensive. In Minisink Valley, deposits of shale-chip colluvium mantle the lower part of the cliffs and steep slopes along the Delaware River. In areas of less relief, boulder fields formed at the base of slopes where rocks were transported by soil creep or where fine sediment was winnowed from till by groundwater seepage. Other fields 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 ka to 11 ka, 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 ka to 9.7 ka) 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 9.4 ka, 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 15 ka (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.

Later, there was renewed downcutting and extensive vertical and lateral accretion of overbank deposits. This interval was initiated by 1) isostatic rebound of the Earth's crust, which commenced about 14 ka (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 ^{14}C years, 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 4.1 ka. Stewart (1991) showed that the base of the Qst2 terrace may be as old as 11 ka 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 Mininsink Valley (Witte, 2011, 2012: Witte and Epstein, 2004, 2012) and radiocarbon dating of charcoal (fig. 5) 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 divide the Delaware Valleys postglacial fluvial history into 6 phases with a major climatically-driven incision event occurring during the middle Holocene (6 ka to 5 ka) followed by three additional phases of terrace and floodplain reworking. Their work further details the dynamic history of the Delaware River during the late 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, and ice-contact deltas (Qod) in Minisink and Wallpack Valleys. Sediment may be used as aggregate, subgrade fill, select fill, surface coverings, and decorative stone. Shale-chip colluvium (Qsc), which forms thick aprons along Minisink Valley's western side, makes excellent subgrade material. The location of all sand and gravel pits and quarries is shown on the surficial geologic map. All pits are currently inactive except for occasional local use. Till can be used for fill and subgrade material, and till stones can supply building stone. Humus and marl from swamp deposits (Qs) may be used for soil conditioning.

REFERENCES

Bitting, K. S., 2013, Terrace formation and floodplain sedimentation in the northern Delaware River valley, New Jersey, USA: Fluvial response to postglacial climatic, environmental, isostatic, and anthropogenic influences, unpublished Ph.D. thesis, Rutgers University, 146 p.

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

_____, 1986, Woodfordian ice margins, recessional events, and pollen stratigraphy of the mid-Hudson Valley, in Cadwell, D.H., (ed.), The Wisconsinan Stage of the First Geological District, Eastern New York: New York State Museum, Bull. no. 455, p. 50-69.

Cook, G.H., 1877, Exploration of the portion of New Jersey, which is covered by the glacial drift: N.J. Geological Survey Ann. Rept. of 1877, p. 9-22.

____, 1878, On the glacial and modified drift: N.J, Geological Survey Ann. Rept. of 1878, p. 8-23.

____, 1880, Glacial drift: N.J. Geological Survey Ann. Rept. of 1880, p. 16-97.

Corps of Engineers, U.S. Army, 1967, Tocks Island Reservoir, site geology: USA Engineering District, Corps of Engineers, Philadephia, PA, Design Memorandum No. 6.

Cotter, J. F. P., 1983, The timing of the deglaciation of northeastern Pennsylvania and northwestern New Jersey: Doctoral Dissertation, Lehigh University, Bethlehem, Pa., 159 p.

Cotter, J. F. P., Ridge, J. C., Evenson, E. B., Sevon, W. D., Sirkin, Les, and Stuckenrath, Robert, 1986, The Wisconsinan history of the Great Valley, Pennsylvania and New Jersey, and the age of the "Terminal Moraine", in Cadwell, D. H. (ed.), The Wisconsinan stage of the First Geological District, eastern New York: N.Y. State Museum Bulletin 455, p. 22-50.

Crowl, G.H., 1971, Pleistocene geology and unconsolidated deposits of the Delaware Valley, Matamoras to Shawnee on Delaware, Pennsylvania, Pennsylvania Geological Survey, 4th ser., General Geology Report 60, 40 p.

Crowl, G.H., and Sevon, W.D., 1980, Glacial border deposits of late Wisconsinan age in northeastern Pennsylvania, Pennsylvania Geological Survey, 4th ser., General Geology Report 71, 68 p.

Davis, D. K., 1989, Groundwater Resources of Pike County, Pennsylvania: U.S. Geological Survey Water Resources Report 65, 63 p., 2 pls. in pocket.

Drake, A. A., Jr., Volkert. R. A., Monteverde, D. H., Herman, G. C., Houghton, H. H., Parker, R. A., and Dalton, R. F., 1996, Bedrock geologic map of northern New Jersey: U.S. Geological Survey Misc. Inv. Ser. Map I-2540-A.

Epstein, J. B., 1969, Surficial Geology of the Stroudsburg Quadrangle, Pennsylvania-New Jersey: Pennsylvania Geological Survey, 4th series, Bulletin G57, 67 p., scale 1:24,000.

Gustavson, T.C., Ashley, G. M., and Boothroyd, J. C., 1975, Depositional sequences in glaciolacustrine deltas, in Jopling, A.V., and McDonald, B.C. (eds.), Glaciofluvial and Glaciolacustrine Sedimentation, Society of Economic Paleontologists and Mineralogists, Special Publication no. 23, p. 264-280.

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

Jepsen, Glenn, 1959, A New Jersey Mastodon: New Jersey State Museum Bulletin, no. 6, 20 p.

Koteff, Carl, and Larsen, F. D., 1989, Postglacial uplift in western New England: Geologic evidence for delayed rebound, in Gregersen, S., and Basham, P. W., (eds.), Earthquakes at North Atlantic passive margins: Neotectonics and Postglacial Rebound, p. 105-123.

Koteff, Carl, and Pessl, Fred, Jr., 1981, Systematic ice retreat in New England: U.S. Geological Survey Professional Paper 1179, 20 p.

Minard, J. P., 1961, End moraines on Kittatinny Mountain, Sussex County, New Jersey: U.S. Geological Survey Prof. Paper 424-C, p. C61-C64.

Munsell Color Company, 1975, Munsell soil color charts: a division of Kollmorgan Corp., (unnumbered text and illustrations).

Ozvath, D.L., and Coates, D.R., 1986, Woodfordian stratigraphy in the western Catskill Mountains, in Cadwell, D.H. (ed.), The Wisconsinan Stage of the First Geological District, Eastern New York: New York State Museum, Bull. no. 455, p. 109-120.

Reimer, G. E., 1984, The sedimentology and stratigraphy of the southern basin of glacial Lake Passaic, New Jersey: unpublished M.S. thesis, Rutgers University, New Brunswick, New Jersey, 205 p.

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

Salisbury, R. D., 1902, The glacial geology of New Jersey: N.J. Geological Survey Final Report, v. 5, 802 p.

Sevon, W.D., Crowl, G.H., and Berg, T.M., 1975, The Late Wisconsinan drift border in northeastern Pennsylvania: Guidebook for the 40th Annual Field Conference of Pennsylvania Geologists, 108 p.

Sevon, W.D., Berg, T.M., Schultz, L.D., and Crowl, G.H., 1989, Geology and mineral resources of Pike County, Pennsylvania: Pennsylvania Geological Survey, County Report 52, 141 p., 2 plates, scale, 1:50,000.

Stewart, Michael, 1991, Archaeology and environment in the upper Delaware, in Orr, D. G., and Campana, D. V. (eds.), The People of Minisink, Papers from the 1989 Delaware Water Gap Symposium: National Park Service, U.S. Department of the Interior, p. 79-115.

Stinchcomb, G. E., Driese, S. G., Nordt, L. C., and Allen, P. M., 2012, A mid to late Holocene history of floodplain and terrace reworking along the middle Delaware River valley, USA: Geomorphology 169-170, p. 123-141.

Stone, B. D., and Borns, H. W., 1986, Pleistocene glacial and interglacial stratigraphy of New England, Long Island, and adjacent Georges Bank and Gulf of Maine, in Sibrava, V., Bowen, D. Q., and Richmond, G. M. (eds.), Quaternary glaciations in the northern hemisphere: Quaternary Science Reviews, v. 5, p. 39-53.

Stone, B. D., Stanford, S. D., and Witte, R. W., 2002, Surficial geologic map of northern New Jersey: U.S. Geological Survey Misc.Inv. Ser. Map I-2540-C.

Wagner, D. P., 1994, Pedology and geomorphology of the Depew Recreation Area, in Inashima, P. Y. (ed.), Gemorphology, Remote Sensing, and Archealogical Monitoring at Depew Recreation Area, National Park Service, U.S. Department of the Interior, p. 1-36.

Waksman, S. A., Schulhoff, H., Hickman, C. A., Cordon, T. C., and Stevens, S. C., 1943, The peats of New Jersey and their utilization: N.J. Department of Conservation and Development Geologic Series Bulletin 55, Part B, 278 p.

White, I.C., 1882, The geology of Pike and Monroe Counties: Pennsylvania Geological Survey, 2nd Series, Report G6, 333 p.

Witte, R.W., 1988, The surficial geology and Woodfordian glaciation of a portion of the Kittatinny Valley and the New Jersey Highlands in Sussex County, New Jersey: unpublished M.S. thesis, Lehigh University, Bethlehem, Pa., 276 p.

______, 1997, Late Wisconsinan glacial history of the upper part of Kittatinny Valley, Sussex and Warren Counties, New Jersey, Northeastern Geology and Environmental Sciences, v. 19, no. 3, p.155 -169.

_____, 2001a, Late Wisconsinan end moraines in northwestern New Jersey: observations on their distribution, morphology, and composition, in Inners, J.D. and Fleeger, G. M. (eds.) 66th Field Conference of Pennsylvania Geologists 2001: A Delaware River Odyssey, p. 81-98.

_____, 2001b, Late Wisconsinan deglaciation and postglacial history of Minisink Valley, Delaware Water Gap to Port Jervis, New York, in Inners, J. D. and Fleeger, G. M. (eds.), 66th Field Conference of Pennsylvania Geologists 2001: A Delaware River Odyssey, p. 99-118.

_____, 2001c, Raymondskill Falls, in Inners, J. D. and Fleeger, G. M. (eds.), Guidebook for the 66th Field Conference of Pennsylvania Geologists: 2001: A Delaware River Odyssey, p. 271-283.

_____, 2008, Surficial Geologic Map of the Branchville Quadrangle, Sussex County, New Jersey: New Jersey Geological Survey Geologic Map Series, GMS 08-2, scale: 1 to 24,000, 2 plates.

_____, 2012, Surficial Geologic Map of the Milford Quadrangle, Sussex County, New Jersey and Part of Pike County, Pennsylvania: New Jersey Geological Survey Open-file Map OFM 96, scale: 1 to 24,000.

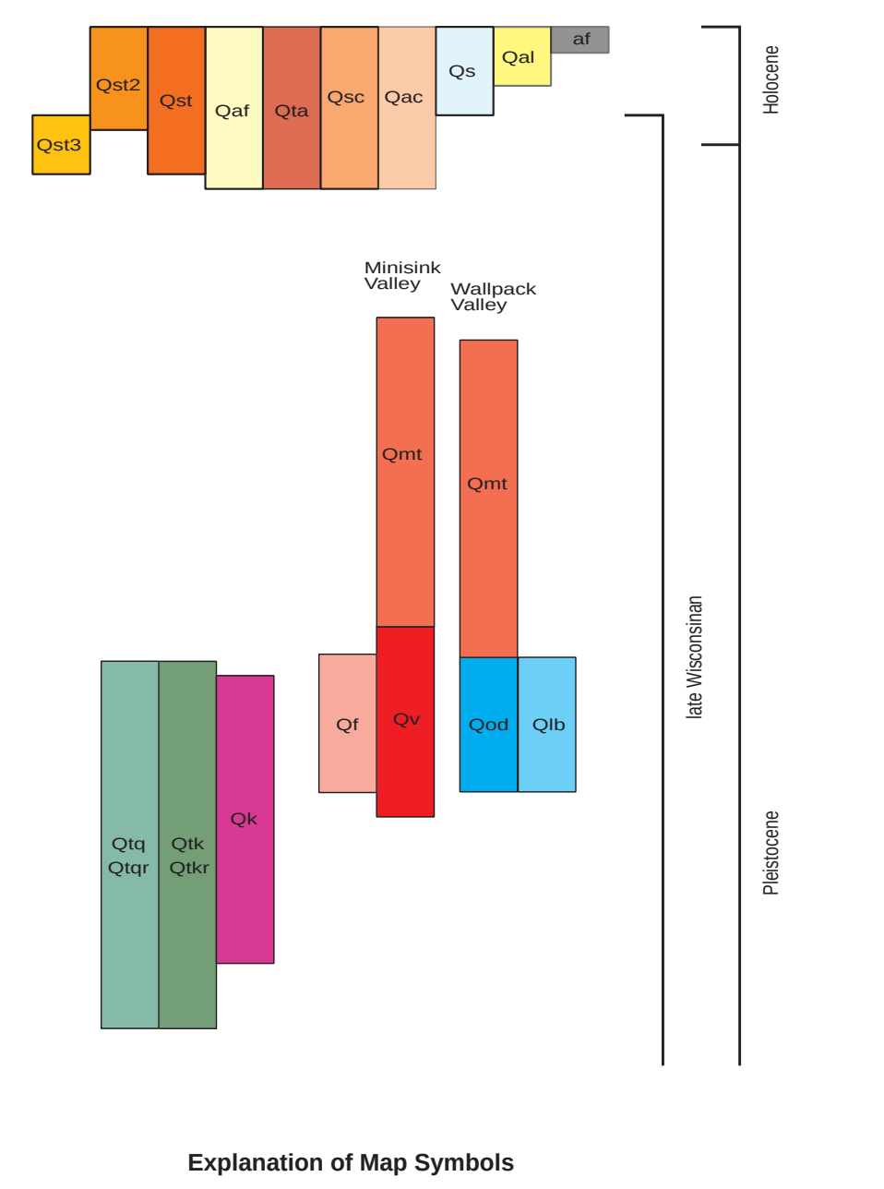
Witte, R. W. and Epstein, Jack, B., 2004, Surficial Geologic Map of the Culvers Gap Quadrangle, Sussex County, New Jersey, New Jersey Geological Survey Geologic Map Series., GMS 04-1, scale: 1 to 24,000.

Witte, R. W, and Epstein, Jack, B., 2012, Surficial Geologic Map of the Flatbrookville Quadrangle, Sussex County, New Jersey and Pike County, Pennsylvania: N.J. Geological Survey Geologic Map Series GMS 12-1, scale 1:24,000.

Witte, R. W., and Evenson, E.B., 1989, Debris sources of morphosequences deposited at the margin of the Kittatinny Valley lobe during the Woodfordian deglaciation of Sussex County, New Jersey, in Geological Society of America, Abstracts with Programs, v. 21, p. 76.

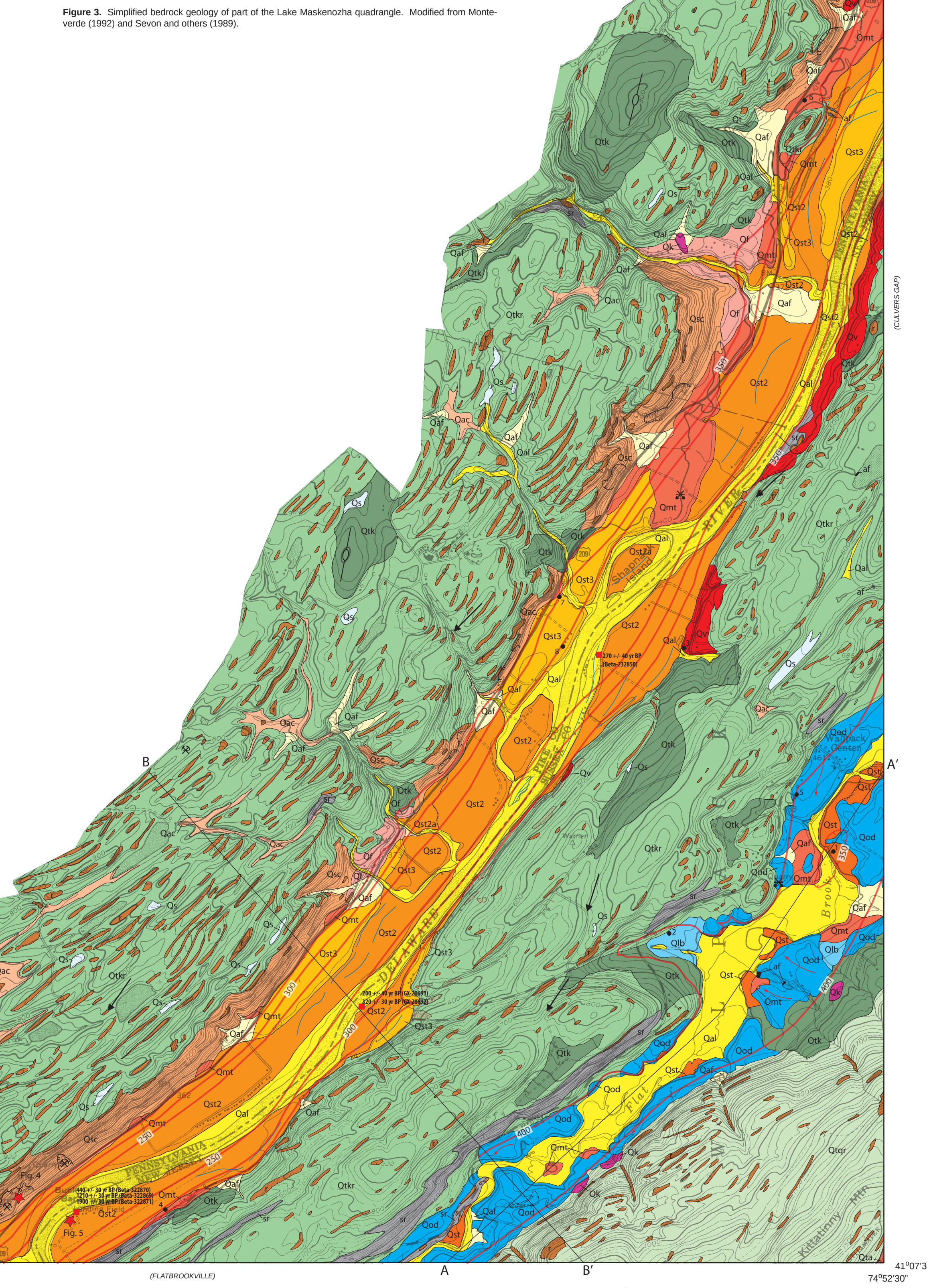
Witte, R. W., and Stanford, S. D., 1995, Surficial geology and earth material resources of Warren County, New Jersey: N.J. Geological Survey Open-file Map OFM 15-C, scale 1:48,000.

Correlation of Map Units



Explanation of Map Symbols

- Contacts, dashed where inferred.
- Striation, measurement at tip of arrow.
- Drumlin, denotes long axis.
- Small meltwater channel.
- Large kettle in glacial outwash or moraine. Smaller kettles on moraines are not shown. Tics point downslope.
- Fluvial scarp, line lies at base of scarp. Tics point upslope.
- Alluvial channel scroll.
- Inactive sand and gravel pit.
- Inactive quarry.
- Boundary of large sand and gravel pit.
- Boundary of large shale pit.
- Thin sheet of eolian sand.
- 350 Approximate elevation of bedrock surface beneath thick valley fill. Based on well records, location of rock outcrop, and data in adjoining quads (Witte and Epstein, 2004; 2012). Contour interval 50 feet.
- ● 8 Well or boring with log in Table 1.
- ■ 270 +/- 40 yr BP (Beta-232850) Radiocarbon date on charcoal sampled from stream-terrace deposits with error and lab identification. Depths of samples: Beta-322870 (51.5",130.8 cm), Beta-322869 (58.0", 147.3 cm), Beta-322871 (81.5", 207.0 cm), Beta-232850 (72.8", 185 cm), GX-20691(20.9", 53 cm), GX-20692 (63.4", 161 cm).
- ★ Location of photographs in Figures 4 and 5.



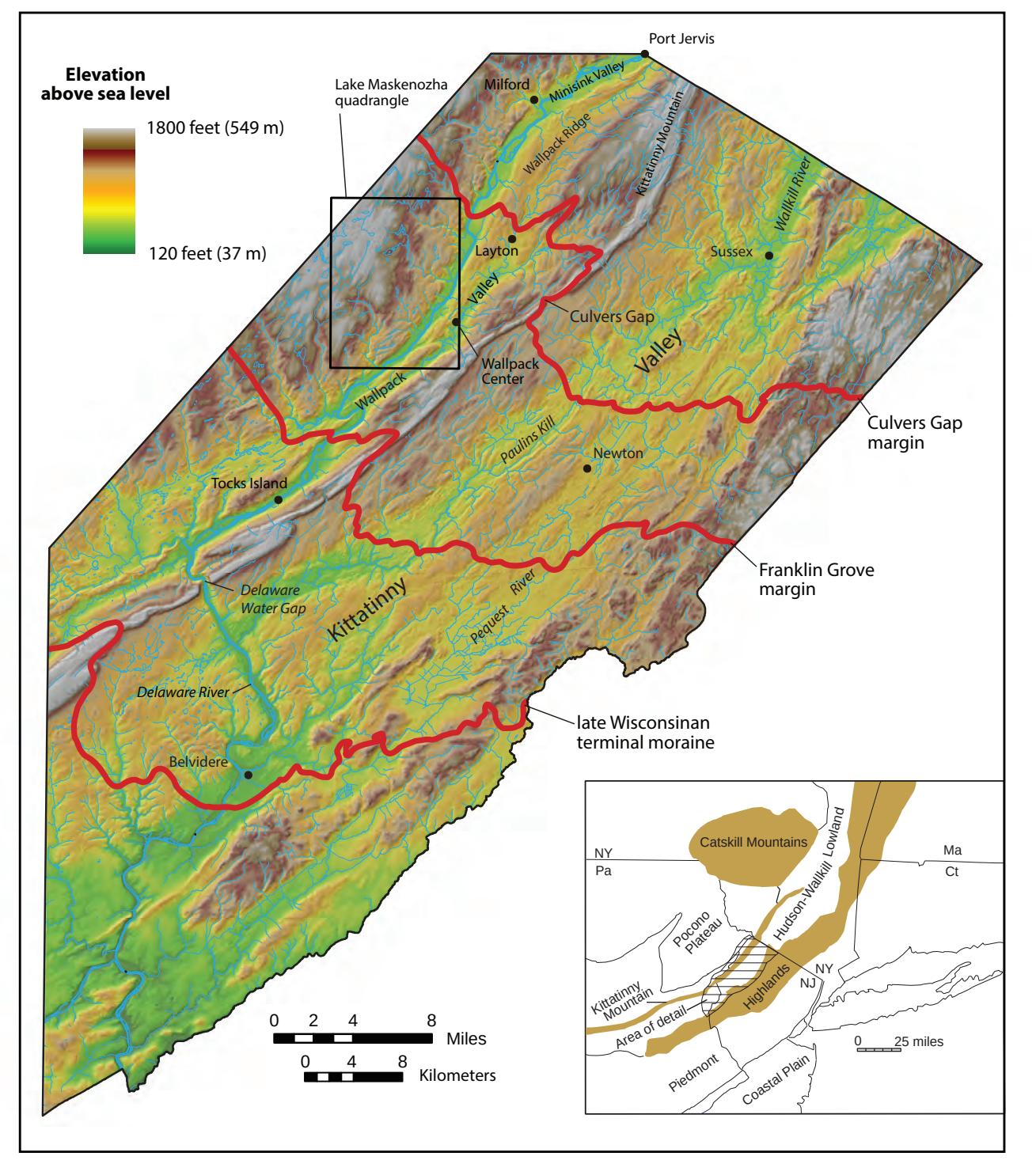


Figure 1. Physiography of northwestern New Jersey and northeastern Pennsylvania and location of the Lake Maskenozha 7.5 minute topographic quadrangle. Minisink Valley is a local geographic name for the Delaware River valley from Delaware Water Gap to Port Jervis, New York and Wallpack Valley is a local geographic name for the Flat Brook valley.

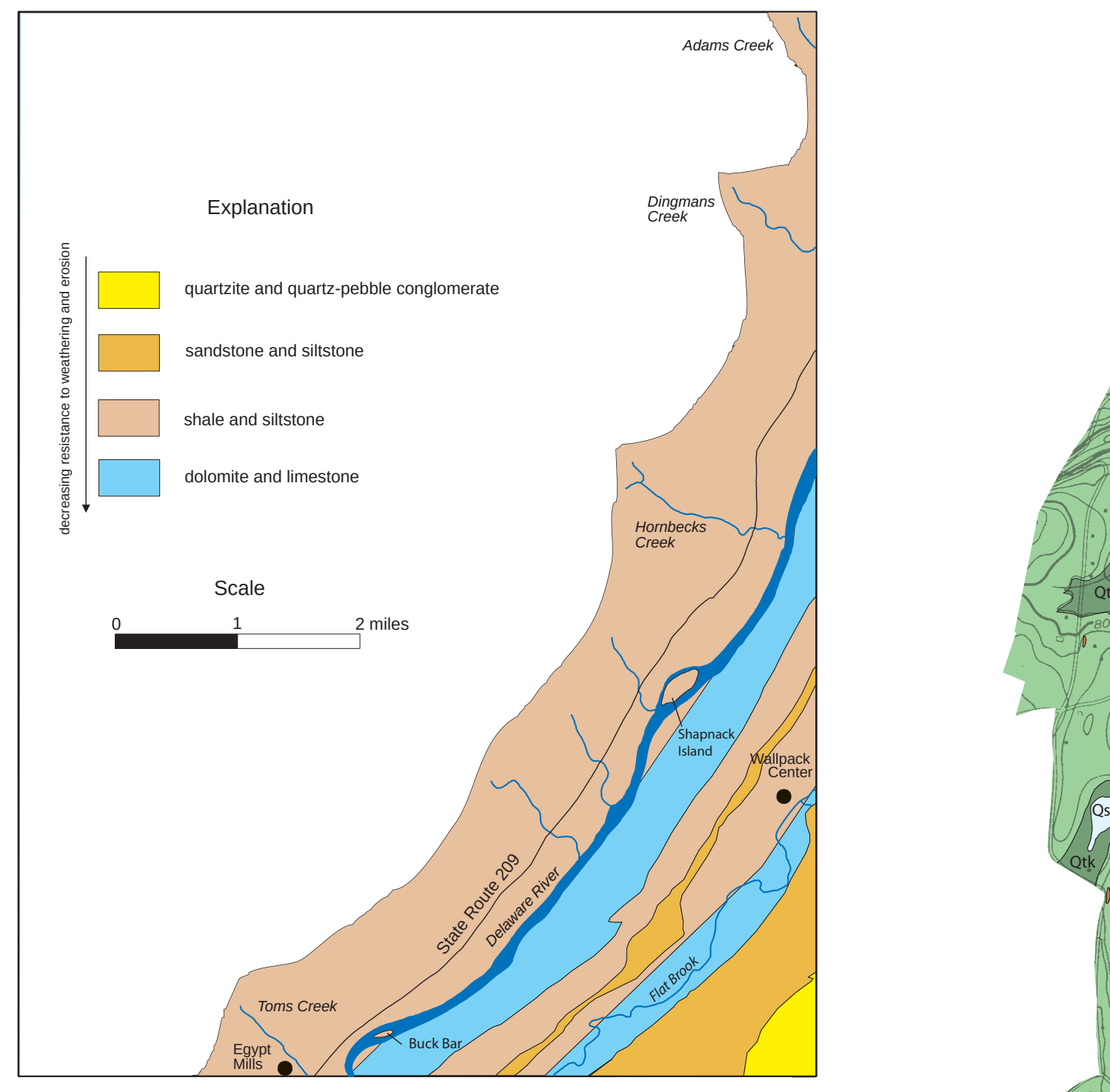


Figure 3. Simplified bedrock geology of part of the Lake Maskenozha quadrangle. Modified from Monteverde (1992) and Sevon and others (1989).

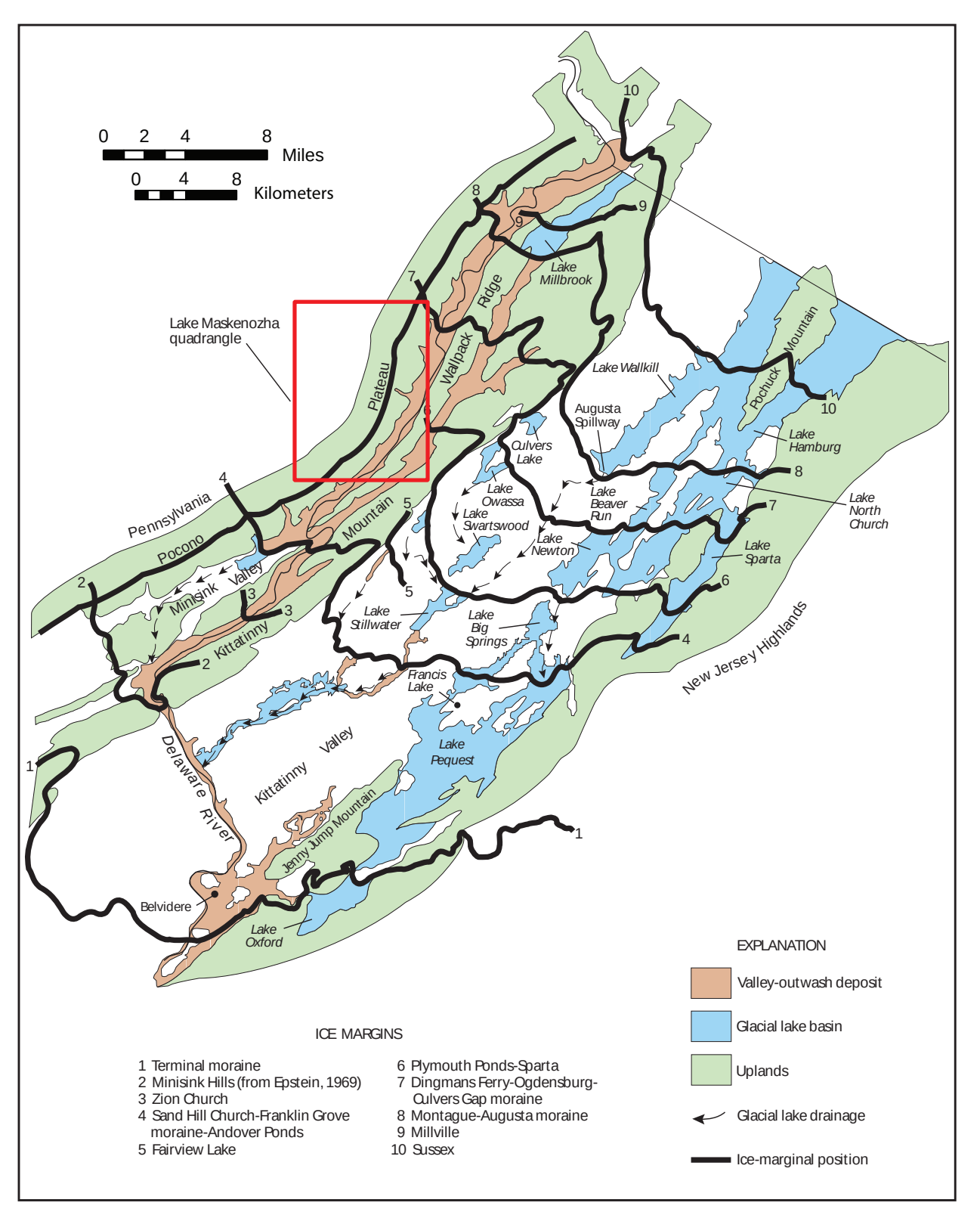


Figure 2. Late Wisconsinan ice margins of the Kittatinny and Minisink Valley ice lobes, and the location of large glacial lakes, extensive valley-outwash deposits, and the Lake Maskenozha 7.5 minute topographic quadrangle. Modified from data by Crowl (1971), Minard (1961), Epstein (1969), Ridge (1983), and Witte (1997, 2001b).

Base from U.S. Geological Survey, 1942
Culture Revised, 1954

SCALE 1:24000

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

QUADRANGLE LOCATION

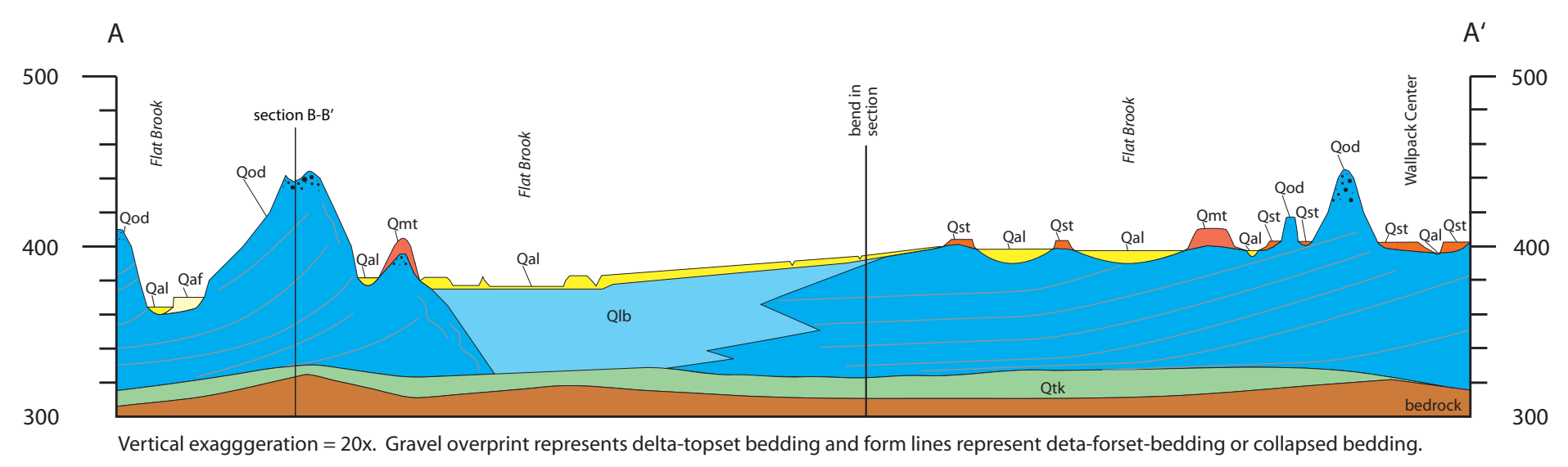
Surficial geology mapped by R.W. Witte, 1991-1995 and 2005-2007. Mapping in Delaware Water Gap National Recreation Area (DEWA) was completed as part of the National Park Service Geologic Resources Inventory Program. Research supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program, under USGS award number 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, New Jersey Geological and Water Survey.

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

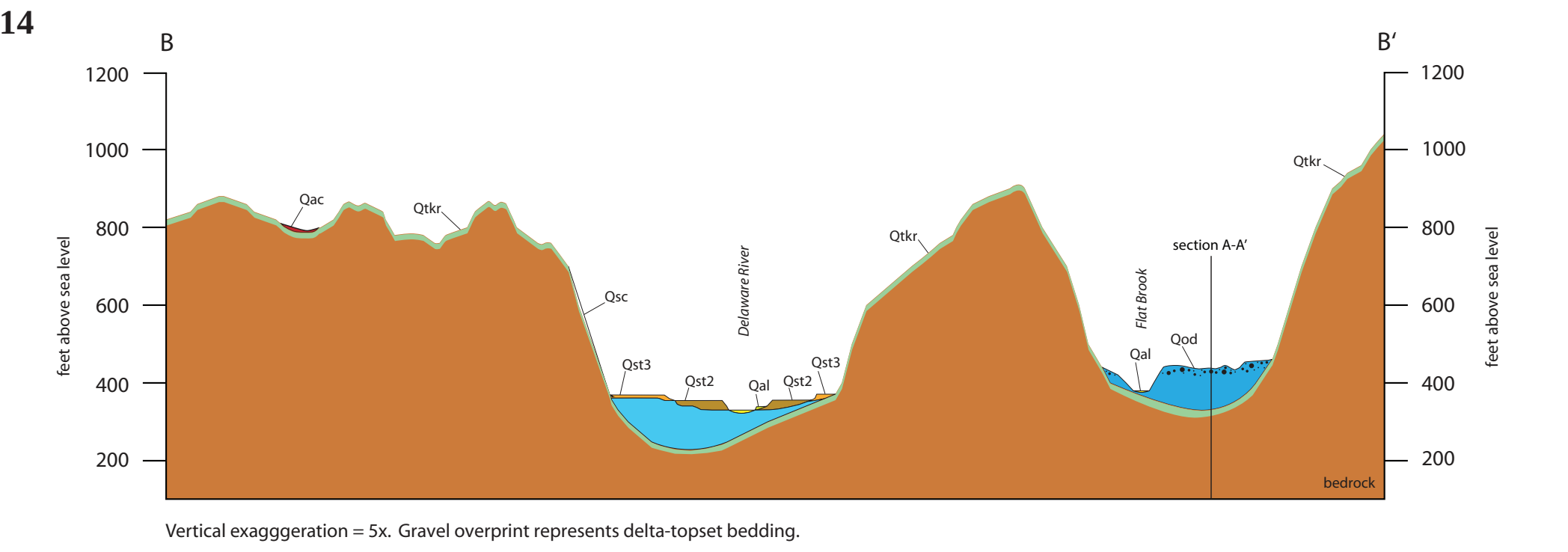
BY

RON W. WITTE

2014



Vertical exaggeration = 20x. Gravel overprint represents delta-topset bedding and form lines represent delta-foreset bedding or collapsed bedding.



Vertical exaggeration = 5x. Gravel overprint represents delta-topset bedding.

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 Lake Maskenozha 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 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 largely 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.

Qst **Qst2** **Qst3** **Stream-terrace deposits (Holocene and late Wisconsinan)** -- Stratified, well- to moderately-sorted, massive to laminated, and minor cross-bedded fine sand, and silt 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.

Qsc **Shale-chip colluvium (Holocene and late Wisconsinan)** -- Thin to thickly bedded, noncompact, poorly sorted light yellowish-brown (10YR 6/4) to brownish-yellow (10YR 7/6) or light olive-brown (2.5Y 5/2) framework supported, shale-chip gravel, containing as much as 80 percent unweathered to lightly weathered angular to subangular shale chips, and minor tabular pebbles and cobbles of siltstone, and sandstone. Interstitial material consists of silty sand. Forms aprons below cliffs and some steep slopes on the west side of Minisink Valley; as much as 20 feet (6 m) thick. Beds dip as much as 25° toward valley. In places the distal (downslope) beds are interlayered with wind-blown sand and alluvium. Graded to glacial and postglacial stream terraces in valley.

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. Based on well records (table 1), 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. In Minisink Valley forms shingled sets of outwash terraces.

Qf **Outwash-fan deposits (uncorrelated) (late Wisconsinan)** -- Stratified, well- to moderately-sorted sand, cobble-pebble gravel, and minor silt deposited by meltwater streams in fan-shaped deposits at the mouth of large tributaries in Minisink Valley. As much as 60 feet (18m) 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 (8m) thick. Overlies and grades into foreset beds that dip 20° to 35° basinward and consist of well- to moderately-sorted, rhythmically-bedded cobble-pebble and pebble gravel and sand. These beds grade downward and outward into ripple cross-laminated and parallel-laminated, sand, silt and pebble gravel that dip less than 20°. Lower foreset beds grade into gently inclined prodelta bottomset beds of rhythmically-bedded, ripple cross-laminated to graded fine sand and silt with minor clay drapes. Thickness may be as much as 100 feet (30m). Qod deposits were laid down in narrow sediment-dammed proglacial lakes in Paulins Kill and Wallpack Valleys. Deposits are extensively kettled, and in long, narrow lake basins, topset beds are extensively aggraded in their upstream sections.

Qlb **Glacial lake-bottom deposits (late Wisconsinan)** -- Parallel-laminated, irregularly to rhythmically-bedded silt, clay, and very fine sand; 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 (30m) thick. In subsurface only, thick deposits beneath Qs deposits and modern lakes in glacial Lake Owassa basin, Kittatinny Valley. Thin deposits presumed to be in subsurface in Paulins Kill, Wallpack, and Minisink Valleys.

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 (6m) 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 (15m) thick. Attitude of bedding is highly variable.

Non-stratified Materials

Till (late Wisconsinan) -- Scattered patches of noncompact to slightly compact, bouldery "upper till" overlying a blanket-like compact "lower till" deposited chiefly on bedrock and 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, 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 (15m) thick. Locally overlain by thin, discontinuous, non-compact, poorly sorted and layered, sand and minor silty sand, similar in color to lower till, that contains as much as 35 percent gravel, and minor thin beds of well- to moderately-sorted sand and pebbly sand. Clasts chiefly consist of unweathered quartz-pebble conglomerate, quartzite, red sandstone, and red shale. Matrix is a varied mixture of quartz, rock fragments, silt, minor feldspar, and clay. Till derived chiefly from quartzite, quartz-pebble conglomerate, and red sandstone 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.

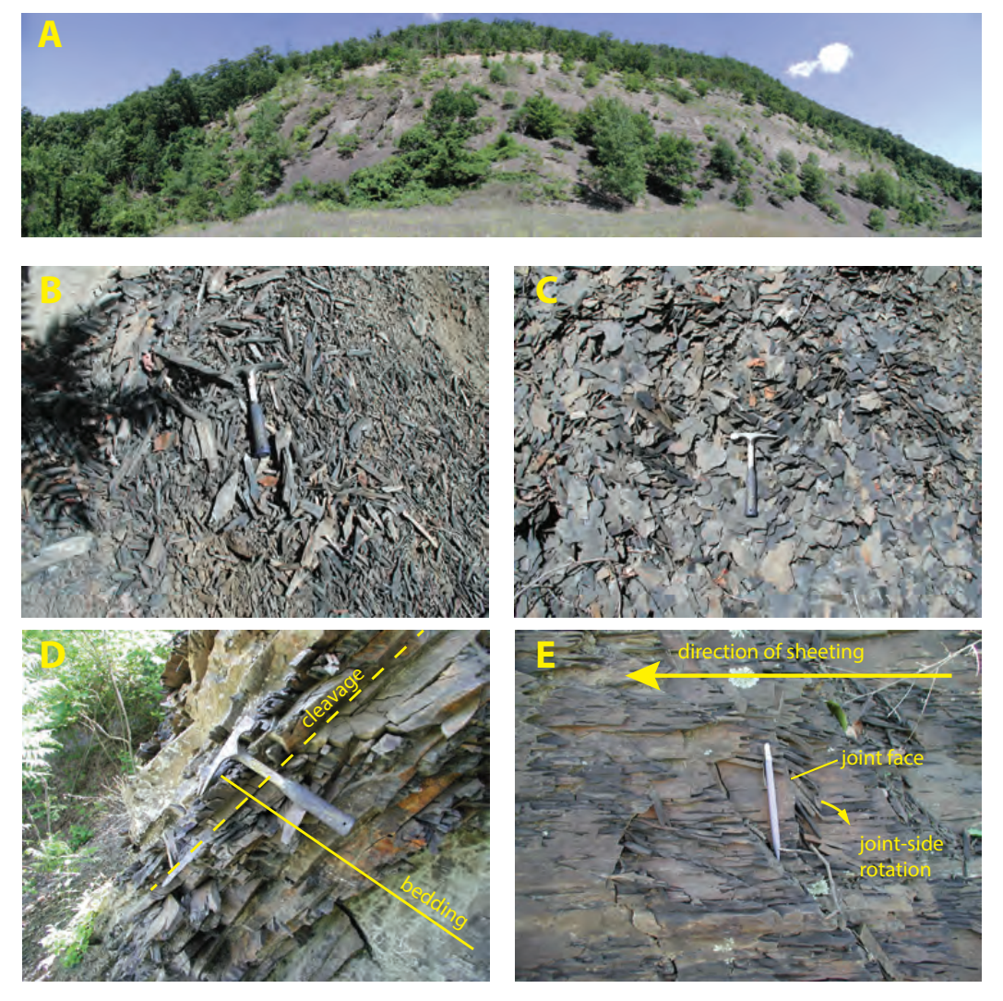


Figure 4. Toms Creek shale pit (inset A). The top of the pit scarp lies about 300 feet (91 m) above Route 209 (Minisink Valley floor). About 400,000 cubic yards of shale-chip rubble were mined from this pit. The rubble, well described in Sevon and others (1989), consists of angular, elongated, platy, prismatic and bladed clasts of the Mahantango Formation (inset B and C). Average clast length varies between one and six inches. Larger clasts, up to boulder size, may be interspersed throughout the deposit. Typically, the rubble has very little matrix, although many of the clasts exhibit a thin coating of clay. The few beds having a substantial matrix component displayed a coarsening upwards of shale clasts, suggesting it was deposited as a slurry flow. Bedding is slope parallel, and averages between one to four inches thick. However, in many places the homogeneity of the rubble makes it difficult to discern bedding. Most of the elongated fragments are oriented down slope.

Shale-chip rubble is the product of intense frost shattering along the cliff face. The size and shape of the fragments and rate of fragmentation is controlled by the attitude and spacing of cleavage, joints, and bedding and grain size. Bedding (N64°E 32°NW) and cleavage (N70°E 54°SE) largely control the shape of the fragments (inset D). In places where cleavage is closely spaced and bedding is thin, fragments will be bladed to prismatic. In places where cleavage is more widely spaced, platy fragments are more common. Grain size also controls size and shape of fragments. The finer-grained shale and siltstone beds form thinner fragments, while the coarser, sandstone beds form thicker fragments. The subvertical, nonpenatrative, cross-strike joints found throughout the Mahantango Formation hasten rubble formation by providing additional surface area and access to cleavage partings. This results in the disintegration of rock by cross-cliff sheeting, a step-like removal of rock away from the joint face (inset E). Shallow joints result in the weathering of thinner sheets, while deeper joints result in the weathering of larger sheets. At times, large joint blocks also become dislodged from the cliff. Several of these may be seen throughout the pit, either partially buried in the excavated rubble or lying on the modern rubble apron, which formed after the pit was abandoned. Up close, rock fragments are loosened individually or in small aggregates. Typically, there is a joint-side downward rotation of the fragment (inset E). Eventually, the tilted fragment dislodges and falls to the apron's surface. Another form of small-scale fragmentation includes flaking, a process where small rock chips and flakes on the exposed cleavage face become dislodged. This type of fragmentation occurs around shallow surface fractures, many of which were glacially formed. Bedding, sorting, and clast orientation of the rubble suggests that most of this material, after it has fallen off the outcrop and accumulated at the top of the apron, moves downslope as a massive sheetflow. Bedding and grading show that this downslope transport is episodic and in some cases may have involved water.

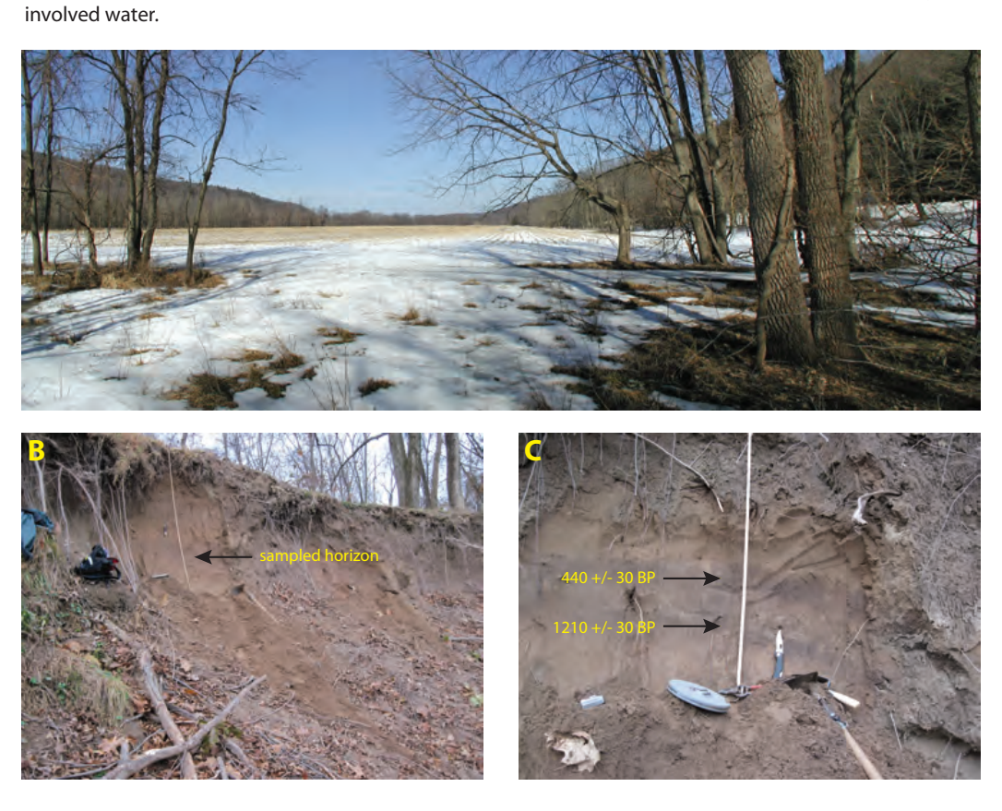


Figure 5. Buck Bar terrace (Qst2) looking upstream (inset A). Measured section (inset B and C) is just to the photo's left on a low bluff overlooking the Delaware River. Dates determined from charcoal fragments presumed to have been derived from an Amerind hearth. 440 +/- 30 BP (Beta-322870, depth = 58.5" (148.6 cm), 1,210 +/- 30 BP (Beta - 322869, depth = 51.5" (130.8 cm). Samples collected in thick paleosol (dark gray horizon) with knife tip at lower sample. Third sample collected just upstream from section yielded a date of 1,900 +/- 30 BP (Beta-322871, depth = 81.5" (207.0 cm). Paleosols are common in these overbank deposits representing periods of minimal sedimentation and landscape stability. Stewart (1991) has shown that some paleosols are chronosequences that are traceable throughout the Delaware Valley. Others have a decidedly more local origin. Work by Stinchcomb and others (2012) near this site show that lower paleosols have older dates of 9.3 ka and 6.7 ka indicating a nearly 10,000 year alluvial history has been preserved in this part of Minisink Valley.

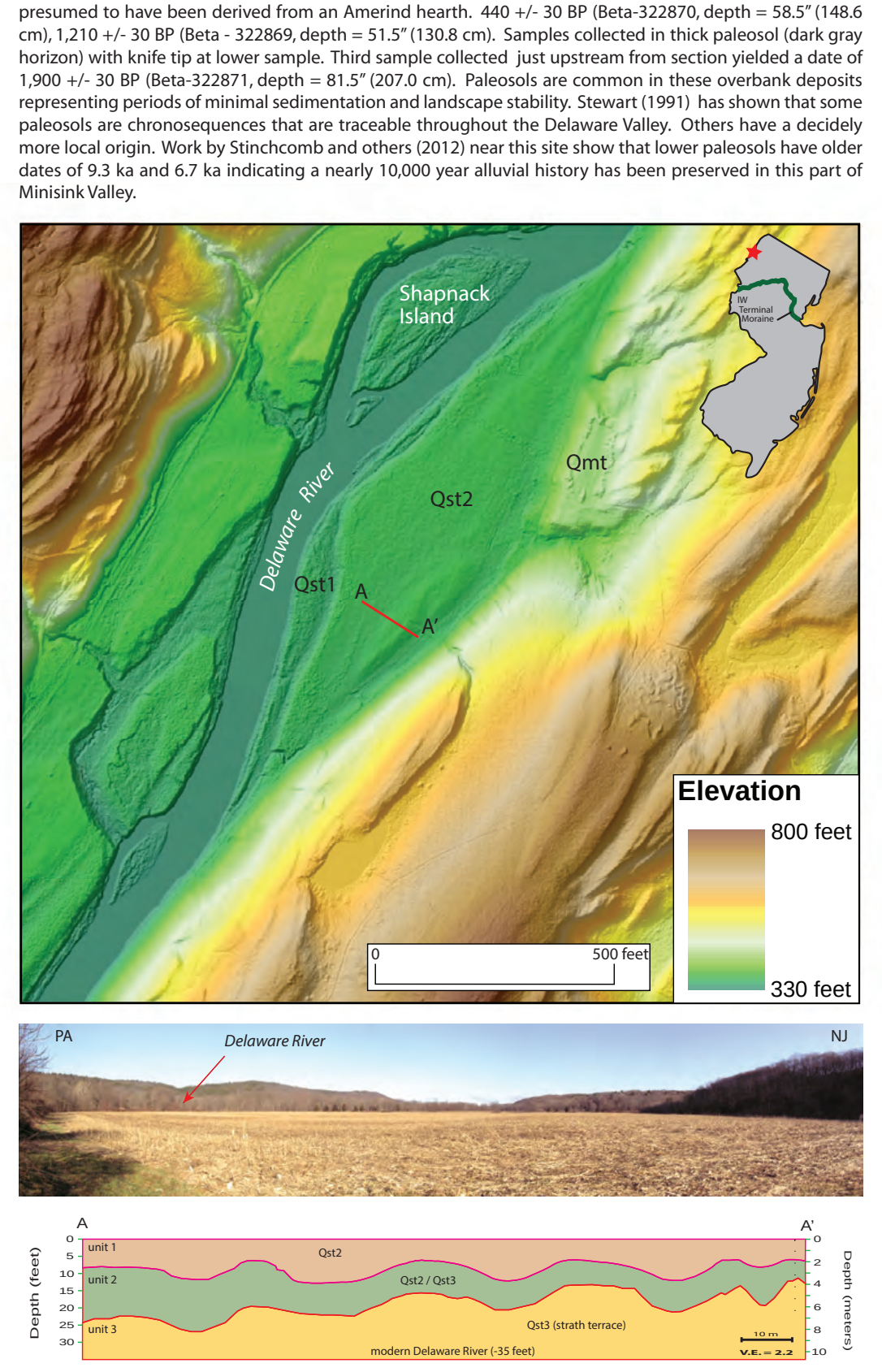


Figure 6. Color-shaded relief map (CSRM) of Minisink Valley in the vicinity of Shapnack Island, Delaware Water Gap National Recreation Area and location of profile A-A'. Panoramic view is looking upstream across the Qst2 surface near profile A-A'. CSRM constructed from PAMAP Program 3.2 ft. Digital Elevation model tiles (PAMAP Program, PA Department of Conservation and Natural Resources, Bureau of Topographic and Geologic Survey). Dark to light green areas (lowest to highest elevation) represent postglacial and glacial stream terraces laid down from Late Wisconsinan to modern time. The formation of postglacial terraces is related to incision of the postglacial Delaware River in response to isostatic rebound and large decreases in stream discharge and sediment load during the late Pleistocene and Holocene (Witte, 2001b). Because the valley is narrow most flood–plain sediment was deposited through vertical accretion (especially the upper part of the Qst2 terrace). Profile A-A' (modified from Bitting, 2013) represents a cross-sectional profile of postglacial stream deposits downstream from Shapnack Island. The profile was constructed from GPR data and Geoprobe borings taken along the profile line. Unit 3 is interpreted as a late glacial to early postglacial strath terrace developed on glacial outwash. It represents the former position of the Delaware River (10 to 20 feet above the modern river) during late Pleistocene time. These strath terraces are found elsewhere in Minisink Valley (Witte, 2001b) and they represent the former position of the Delaware River as it evolved into a modern river. Unit 2 is transitional, representing flood-plain deposition during the earlier stage of river incision. Unit 1 consists largely of vertically accreted flood deposits laid down during the middle to latter part of the Holocene when the river was at or near its present elevation. The profile surface has not been corrected for elevation changes. The elevation at A is about 6 feet lower than A'. The slightly elevated area along the profile (seen on the CSRM) is probably a terrace remnant formed by flood scour. GPR and boring data do not show a separate, older terrace.

Table 1. Records of selected wells in the Lake Maskenozha quadrangle, Sussex County, New Jersey, and Pike County, Pennsylvania. The wells listed were drilled for private and public water supply, and exploration. Wells listed with a NJDEP permit number are from the files of the Bureau of Water Allocation, Division of Water Supply and Geosciences, New Jersey Department of Environmental Protection. Wells noted in the table as "Pike Co." are from Davis (1989) and are preceded by an identification number that was used in the report. Location accuracy and some discharge measurements were unavailable for "Pike Co." wells. Accuracy in plotting well locations is listed as S, or F (100 or 500 feet of actual location). Locations are based on property maps, NJDEP atlas sheet coordinates, and driller's site maps. Key to driller's log for wells listed in Davis (1989); Qaoo - alluvium and Olean outwash, and Qoic - Olean ice-contact stratified sand and gravel.

Well number	NJDEP permit number or well id. (Davis, 1989)	Accuracy of well location	Discharge reported by drillers in gpm	Depth in feet	Driller's geologic log
1	21-235	S	20	0-59	Overburden (casing depth)
2	21-1045	F	25	0-120	Overburden (casing depth)
3	21-4960	S	4	0-2	Overburden
				2-12	Clay and boulders
				12-40	Sand and heavy gravel
				40-60	Clay (dry)
				60-100	Clay and water
				100-165	Clay
				165-167	Soft brown limestone
				167-171	Brown limestone
				171-197	Limestone
4	22-1261	F	3	0-137	Overburden (casing depth)
5	21-3696	F	15	0-65	Overburden (casing depth)
				65-186	Limestone
6	411 Pike Co.	F	10	0-229	Qoic
7	292 Pike Co.	F	-----	0-80	Qaoo
8	302 Pike Co.	F	-----	0-75	Qoic