2.4 Geology of the Stony Clove Creek

The streams of a region reflect the climate, geology, and biology of that region. We know that areas that receive more precipitation and associated runoff than other areas typically have larger streams for a given watershed size. Likewise, the amount of forest cover in any particular watershed affects the amount of rain and snowfall that will run off the landscape to become streamflow, thereby affecting the shape and size, or *morphology*, of the stream channel. The streamside (or riparian) vegetation helps control the stream channel stability. Similarly, the geology of the Catskill Mountains exerts a clear influence on the landscape, valley and stream channel morphology. This section describes the basic geology of the Catskill Mountains, what we know about the geology of Stony Clove, and finally, how this affects the stream channel form and water quality of the basin.

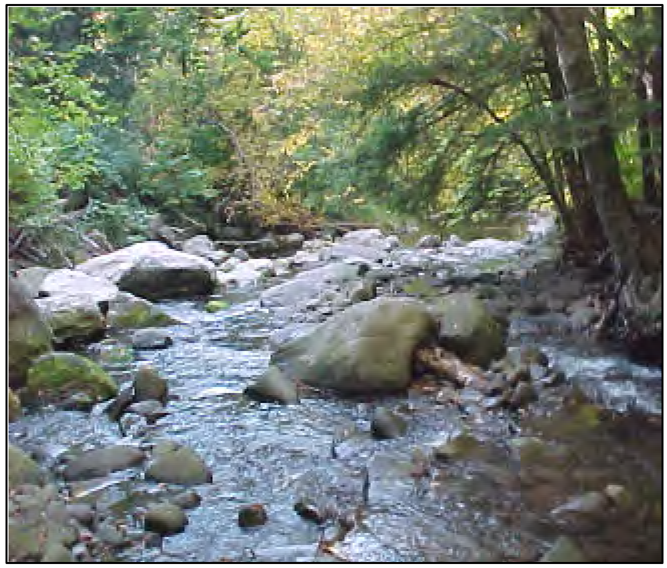

Figure 1 Geology and Streams: Water flows across the landscape and sculpts the watershed. The watershed geology helps determine the nature of the streams that form. As the gelogy changes so does the stream. A bouldery reach of Stony Clove Creek.

Catskill Mountain Geology

The Catskill Mountains are a dissected plateau of sedimentary rocks carved by streams and ice flow over millions of years. The mountains are at the northeastern extreme of the Alleghany plateau, a physiographic province (a land area with fairly uniform physical characteristics) that extends from Tennessee along the western border of the Appalachians (Rich, 1935). Rich (1935) provides a useful description of the escarpments that comprise this mountainous region: Northeastern Escarpment (Blackhead Range); Eastern Escarpment (Wall of Manitou); the Central Escarpment (Indian Head to Utsayantha); and the Southern Escarpment (Slide Mountain to Ashokan High Point) (Fig. 2). Stony Clove is located along the Central Escarpment, draining the south slopes of Plateau, Hunter, and West Kill Mountains. The geologic discussion that follows is for the Central Escarpment.

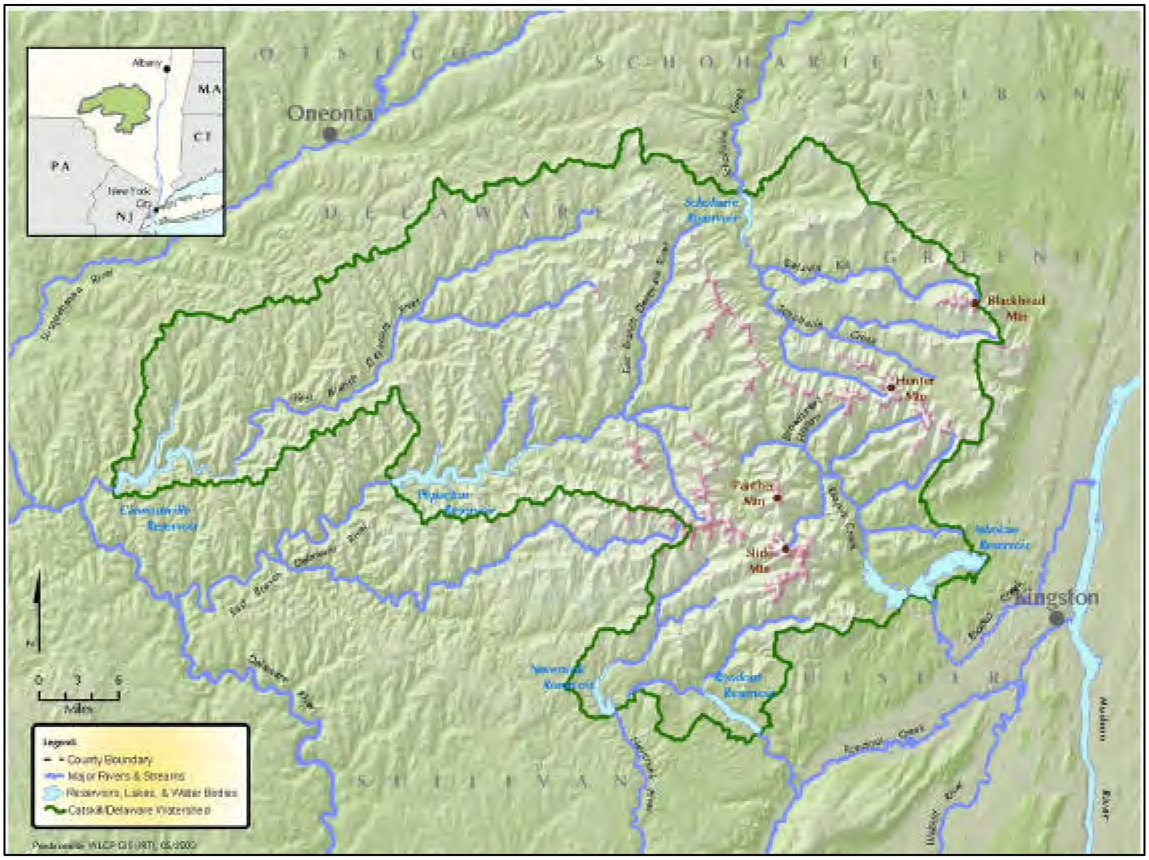

Figure 2 Catskill Mountain Region and the West of Hudson NYC Water Supply Watershed

Bedrock Geology

The bedrock of the central Catskill Mountains is sedimentary and composed of conglomerate, sandstone, siltstone, mudstone and shale. The sediments that form the middle-to-late Devonian (390 to 360 million years ago) bedrock are interpreted to be deposits of a vast deltaic river system, often called the "Catskill Delta" deposits (Isachson et al, 2000) (Fig. 3). The sandstone and conglomerate are made up of river channel deposits, while the siltstones and shales are overbank and shallow fresh water deposits. The "red beds", or mudstones, are often paleosols (ancient soils) that record the presence of Devonian forests. The repeating sequence of deposits shows continuous *aggradation* (building up) of the channels and floodplains of a complex *meandering* river system.

The "Catskill Delta" deposits were buried beneath other sediment, then uplifted as a plateau during the Alleghanian Orogeny (mountain building, 330 to 250 mya). When bedrock buried at great depth is subjected to stress (e.g. related to plate tectonics such as mountain building events) the rock can fold or fracture. In the case of the Catskill rock, intersecting sets of vertical fractures, called joints, formed during and after the Alleghanian Orogeny. The following eras eroded away the overlying rock, and streams cut multiple channels into the slowly rising plateau. The structure of the uplifted bedrock facilitated erosion and stream drainage development.

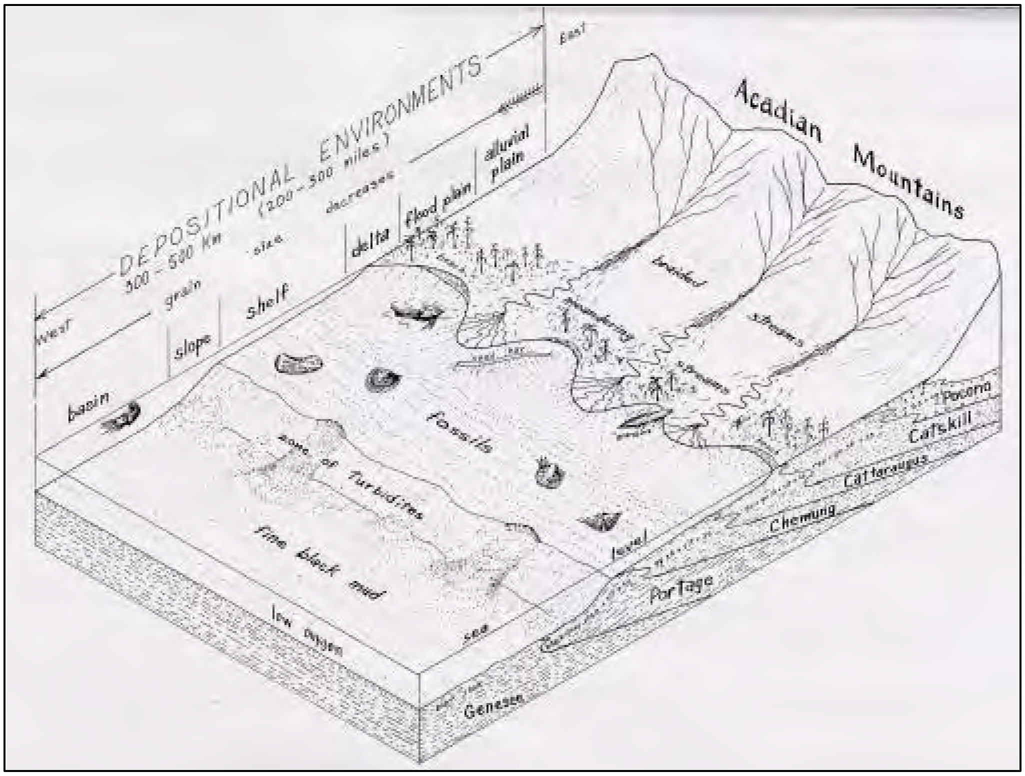

Figure 3 (After Isachsen, et al., 2000) Diagram of the depositional environments and sediments of the "Catskill Delta". The buried sediments were turned to rock and later lifted up during continental collisions. The lifted rock was exposed to the carving agents of time and water forming the Catskill Mountains.

Surficial Geology

The cyclic ice ages of the last 1.6 m.y. (Pleistocene Epoch) have left the latest indelible mark on the already incised landscape of the Catskills. Vast continental ice sheets and smaller local alpine and valley glaciers scoured the mountains. The last ice sheet reached maximum thickness (more than a mile thick) over the Catskills during the Wisconsinan Stage of the Pleistocene, about 21,750 years ago (Isachson, et al., 2000). As measured on the scale of geologic time, or even in terms of human evolution, this was a very recent event.

This was a period of accelerated erosion as the flowing ice sheet abraded and quarried the bedrock. Glacial erosion broke the rock down into an entrained mixture of fragments ranging in size from boulders to clay. This mixture of sediment was carried along by the ice and deposited as till (unsorted assemblage of glacial sediment) or as stratified “drift” if the sediment was subsequently sorted by melt-water streams. These glacial deposits filled in deep river ravines that drained the landscape before these most recent glaciers advanced over the mountains.

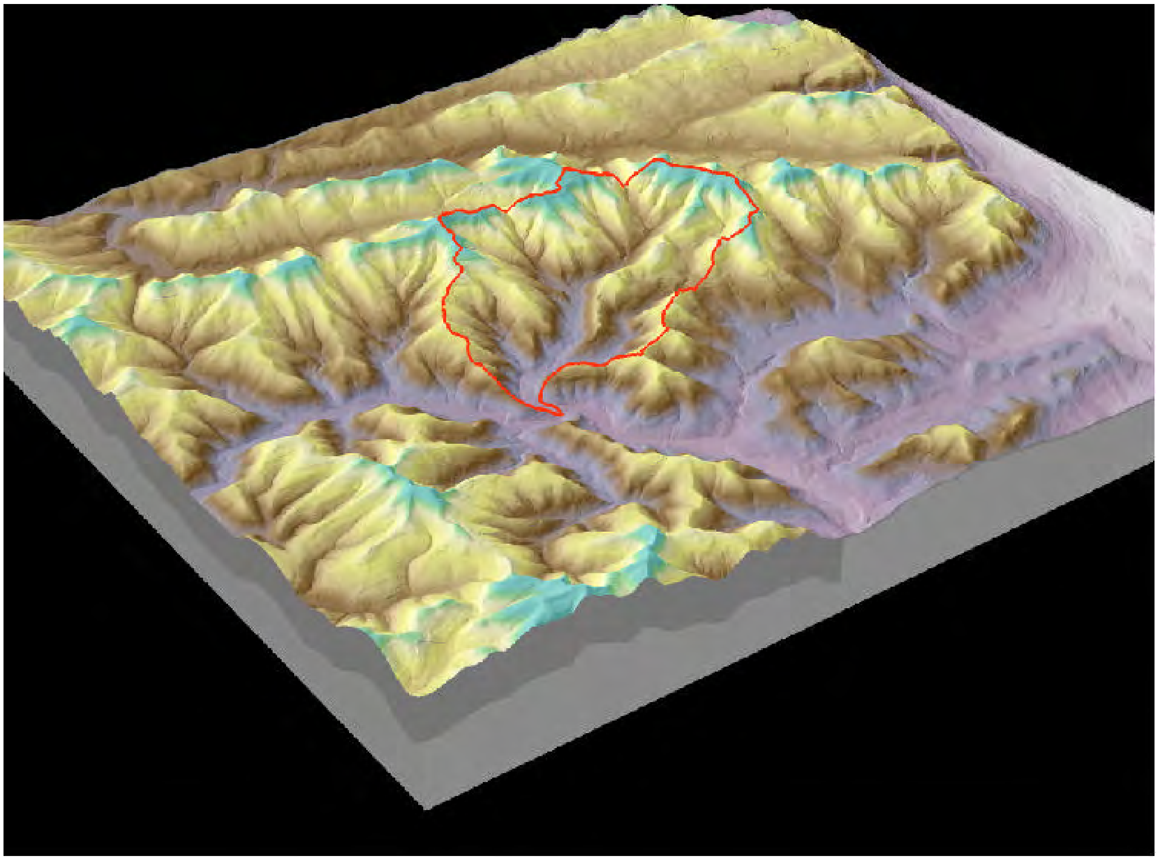

Figure 4 Block Diagram of Central Catskill Mountains depicting stream and glacially carved landscape. Stony Clove watershed is outlined in red.

As the climate warmed and ice thinned, the landscape was deglaciated – lobes of the continental ice sheet melted back from the central Catskills, and from alpine glaciers that formed on some of the newly exposed peaks (e.g. Hunter and West Kill Mountains). Meltwater along side the decaying ice left a complex array of meltwater and ice-contact deposits, along with lake clay where moraines (deposits at glacial margins) and ice impounded water, forming glacial lakes that filled the valley floors (Fig. 5). As climate fluctuated during the period of deglaciation, temporary re-advances of ice from lobes or alpine glaciers would leave till and other meltwater deposits on top of the earlier glacial material, resulting in the complex lateral and vertical distribution of glacial deposits observed today. For more detail on the glacial geology of the Catskills the reader is referred to Rich (1935), Cadwell (1986), and Titus (1996).

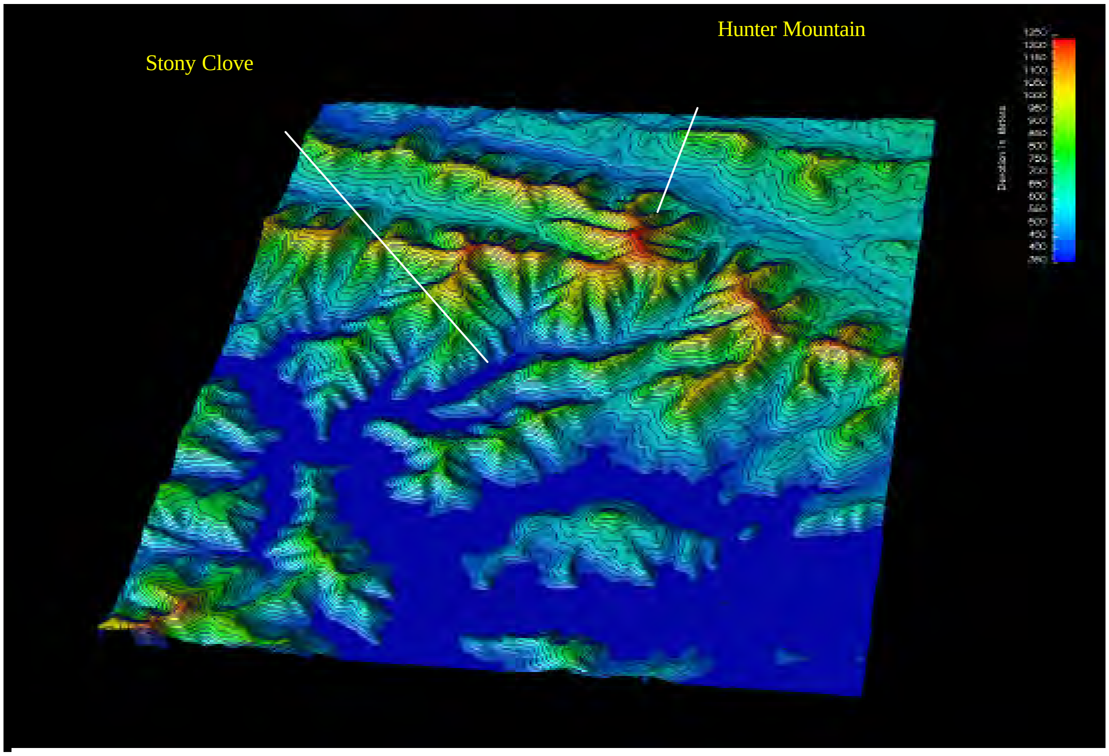

Figure 5 Model of glacial Lake Shandaken filling the Esopus Creek Valley. Water elevation is based on mapped lake deltas (created by Dominique Thongs, NYCDEP)

After the ice fully retreated north, rainfall-runoff returned as the predominant sculptor of the landscape. The Holocene (the last 12,000 years or so) has been a period of reclamation of the mountain landscape by forests and animals that together exert control on the stream valley and channel *geomorphology*. People then repopulated the landscape, and in the last 300 years humans have had the most dramatic effects on stream system morphology and stability.

Stony Clove Geology

The geology of Stony Clove has been included in several comprehensive investigations of Catskill bedrock and glacial geology (Rich, 1935; Cadwell, 1986; Willis and Bridge, 1988) as well as the subject of investigations by NYCDEP (Rubin, 1996). The following discussion is an abbreviated account of Stony Clove geology based on available information.

Stony Clove Bedrock Geology

The bedrock geology of Stony Clove exerts considerable control on the character of its mountains and streams. The sedimentary rock, composed of alternating layers of sandstone and siltstone/shales, creates the characteristic Catskill stepped topography. Rickard (1975) mapped the bedrock of the area as part of the New York State Geological Survey Map and Chart Series (Fig. 6). The lower portion of the Stony Clove valley, below approximately 1400 ft, is mapped as the Oneonta Formation, which is principally sandstones and siltstones/mudstones (Fig. 7). Most of the residents who draw their household water supply from wells in the valley are probably tapping groundwater in the fractured bedrock of the Oneonta Formation.

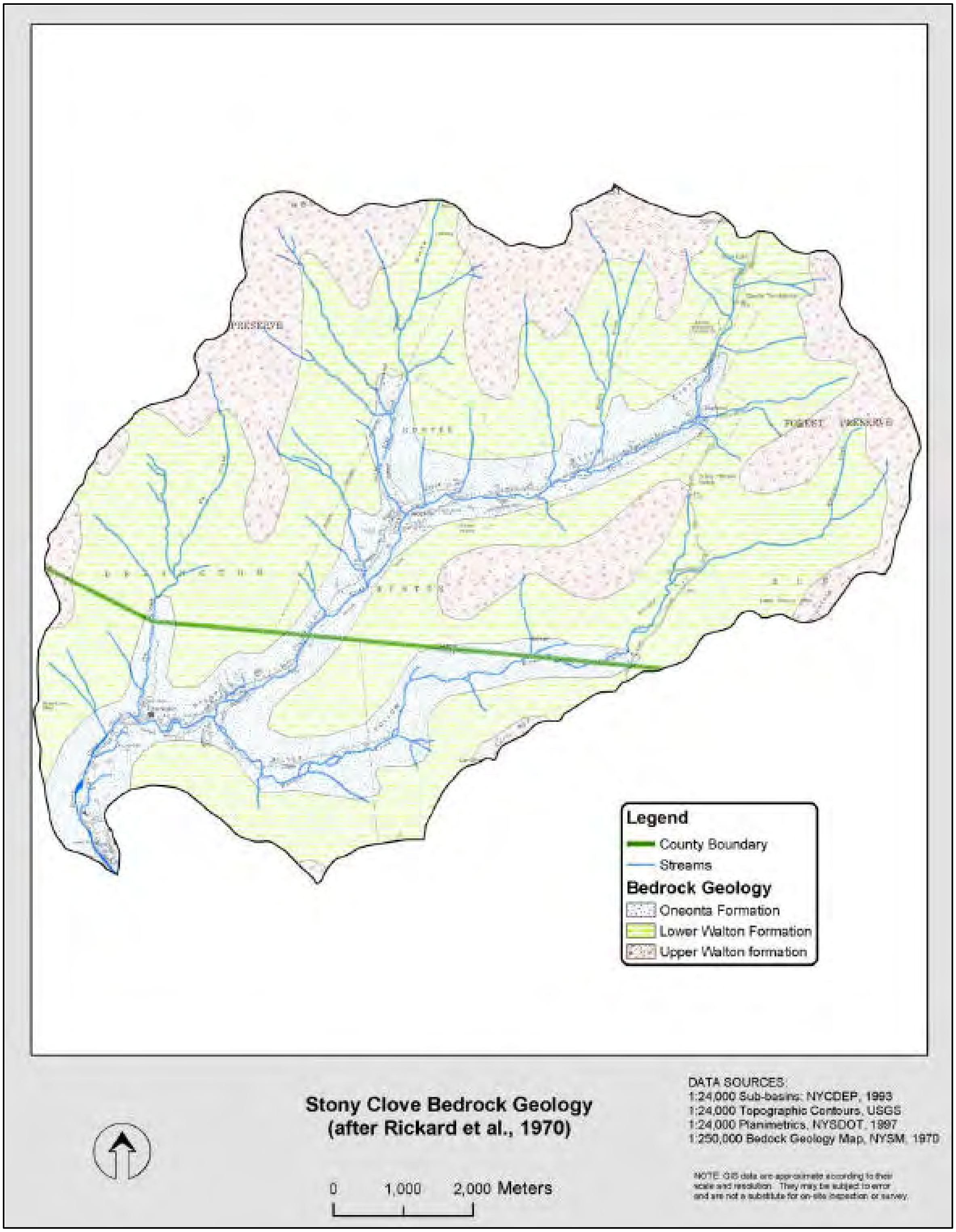

Figure 6 Bedrock Geology Map of Stony Clove Creek Watershed

The overlying Lower Walton Formation makes up most of the valley floor (above 1400 ft.) and walls, while the ridges are capped with the Upper Walton Formation. The Walton Formations consist of greater than 1,000 ft. of red beds (shales and musdstones), gray sandstones and small amounts of gray shale (Fletcher, 1967). The uppermost beds are conglomeratic sandstones that grade upward into the overlying Slide Mountain Formation that is comprised of a yellowish-gray conglomerate.

Figure 7. Outcrop of Oneonta Formation with river channel sandstones over mudstone laver

Most of the stream valleys draining the Central Escarpment are oriented NE-SW, bisecting the two predominant bedrock fracture orientations. This orientation is principally based on pre-glacial erosion of the landscape, which was controlled by the fractured bedrock. The orientation of stream valleys is important, influencing the microclimate, average depth of snowpack and local hydrological regime in many ways.

Figure 8 Example of imbricated Catskill stream sediments

Modern stream deposits in the Catskill Mountains are principally derived from erosion of the well-bedded sedimentary Catskill bedrock. As a result, stream clasts (sediment particles and classes) have a low spherocity ("roundness"), typically forming platy or disk-like particle shapes. This platy shape affects the stability of the streambed in a number of ways. First, it allows the particles to *imbricate*, or stack up at an angle, forming an overlapping pattern like fish scales or roof shingles (Fig, 8). Imbricated streambeds are thus generally more "locked up", and all other things being equal, generally require a larger flow to mobilize bed material than nonimbricated beds. However this same platy shape can also, under the right conditions, act like a airplane wing and be lifted by the streamflow across it more readily than would a spherical particle of similar weight.

Stony Clove Glacial Geology

Glacial geology sets the framework for the Stony Clove stream system, controlling such characteristics as depth of *alluvium* (water worked sediments), sediment supply and stream channel slope and geometry. Understanding the glacial geology of Stony Clove can help identify causes of stream erosion and water quality problems as well as assist in prioritizing where future stabilization/restoration actions will be most useful.

Rich (1935) and Cadwell (1986) are the primary published sources of information on the surficial geology (deposits and landforms) of the Stony Clove watershed. During the first quarter of the twentieth century John Rich examined the glacial geology of the Catskill Mountains in great detail (Rich, 1935). His detailed information and interpretation on glacial landforms and distribution of glacial deposits in the Stony Clove watershed has been mapped (Fig. 9). In 1996 DEP mapped surficial geology of the Stony Clove Creek sub-basin along stream corridors with the primary goal to identify sources and types of sediments contributing to stream turbidity (Fig. 10). In addition, observations of erosion and clay exposures were made during the 2001 watershed assessment.

What's in a name?

The name Stony Clove evokes the geology that forms it. During the ice age the Catskill Mountains were flooded by ice sheets and smaller glaciers flowing down mountain flanks. The notch between Hunter and Plateau Mountains was carved by ice and torrents of water draining a vast glacial lake in the Schoharie Valley. Anyone who has walked in land that once hosted glaciers can see the erosive power of flowing ice. The bare rock is plucked and carried along scratching and plucking more rock beneath. Over thousands of years thousands of tons of rock are eroded and carried along in the ice or meltwater streams. When the ice melted back from its work in the Stony Clove valley, the streams that returned carved through the thick layer of stone left behind.

The result: one very stony stream.

Glacial geology of Stony Clove is the combination of the Pleistocene ice sheet overflowing the central escarpment and through the Stony Clove gap and of alpine glaciers flowing down from Hunter, West Kill, and Plateau. Interpreting glacial geologic evidence in the Stony Clove watershed is complicated by the complex regional and local ice flow conditions, and the masks of subsequent erosion and current forest cover. The following interpretation is largely based on Rich's work.

During the maximum advance stage of the continental ice sheet the ice completely flowed over the Catskill Mountains. As the climate warmed, the ice front retreated northward and the Catskills slowly emerged in successive steps with the ice margin occupying the main valleys as lobes of flowing ice. During this time alpine glaciers formed and flowed down from the peaks. Rich mapped a number of *moraine* loops that marked the former boundaries of local glaciers that occupied the tributary valleys of the Stony Clove Watershed (Fig. 9). Excellent examples are in the Hollow Tree Brook valley with accompanying over-steepened valley walls and cirques eroded by glacial ice. With respect to the modern fluvial setting, continental and local glacial landforms, such as *kame terraces* and moraine features can determine valley floor confinement and its cross-sectional configuration.

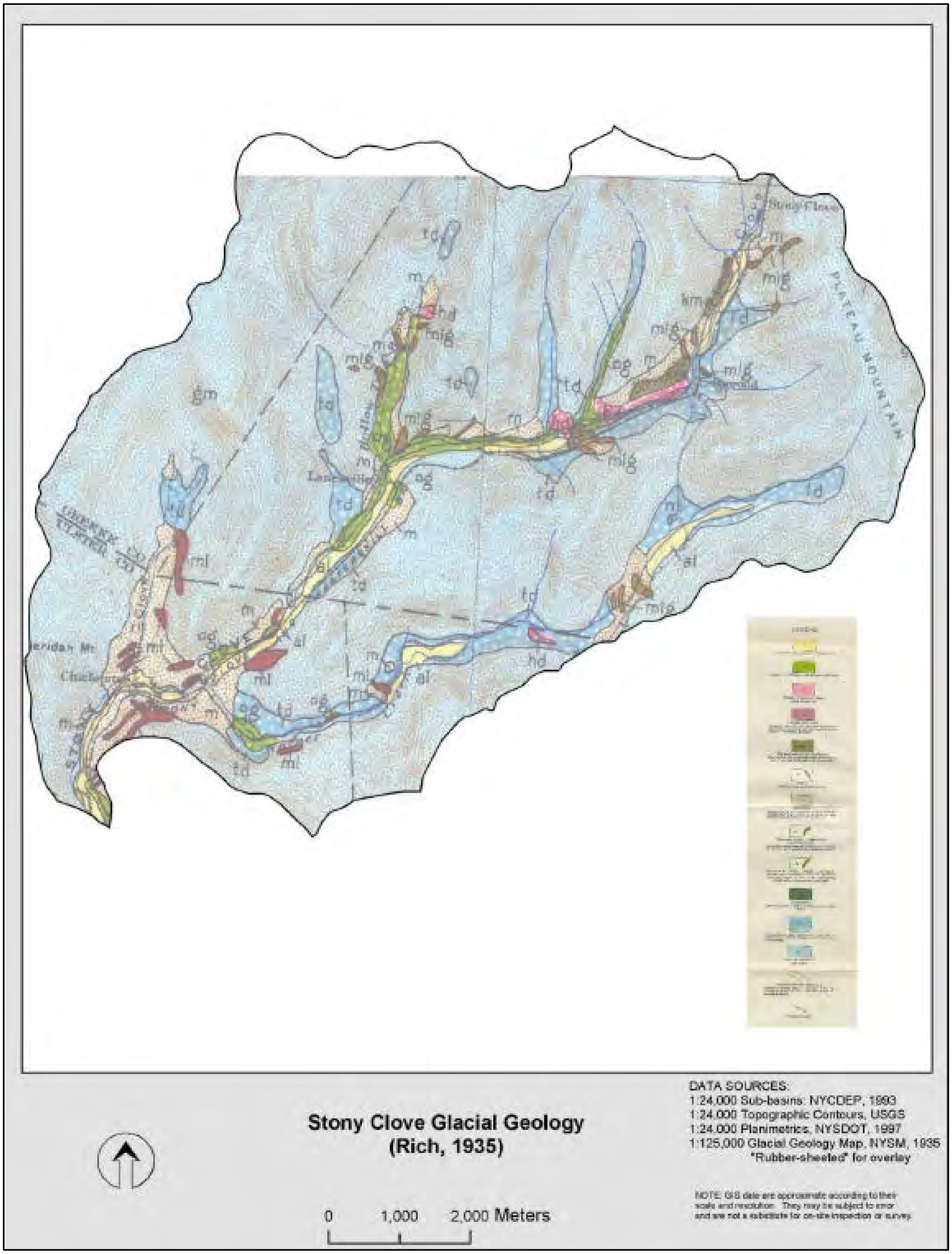

Figure 9 An excerpt of John Rich's 1935 map of Catskill glacial geology

Ice margins tend to retreat at a steady rate then hit a standstill for awhile. During one of the standstills a lobe of ice from the Hudson Valley blocked the Esopus Creek valley about two miles below Phoenicia. The Hudson valley ice lobe impounded meltwater from alpine glaciers on Hunter and other high peaks and the Schoharie valley ice lobe that flowed through the notches (Stony Clove, Deep notch, and Grand Gorge) of the Central Escarpment. During the maximum stage of the resulting lake (at an elevation of approximately 1830 ft) it is hypothesized that open water filled much of the Stony Clove basin, with the shore as far north as about a kilometer (3,281 ft.) below the notch. Rich referred to this prehistoric lake as Lake Peekamoose. As the ice retreated further up the Hudson Valley it eventually revealed a new way for water to flow out of the Esopus basin (from Peekamoose gorge into the Rondout Valley to Wagon Wheel Gap along the east side of Ashokan High Point). The lake level dropped as it drained through the new outlet. This new lake, leveling off at about 1320 ft, has been called Lake Shandaken (Figs. 5 & 9) (Rich, 1935).

The extent of the glacial lake at its two ice margin-controlled stages is interpreted from the location of former deltas (shelves and slopes of crudely layered, fine-course deposits) built out into the glacial lake at the mouths of meltwater streams. There is one very distinct delta in the Warner Creek valley that clearly flowed into a large water body. There are two other deltas in the upper reaches of Stony Clove (around Edgewood) that may be from Lake Peekamoose or may, as thought by Rich (1935), represent meltwater flowing into smaller lakes associated with alpine glacier meltwater impounded by a lobe of ice flowing up Stony Clove or by moraines. The presence and location of lake silts and clays throughout the basin is the result of these numerous large and small impoundments.

Stony Clove Stream Channel Geology

While it is useful to develop a model of glacial history to explain the landscape and deposits, for the purpose of effective stream corridor management it helps to further characterize the surficial geology that hosts the stream channel by some of its sedimentologic conditions (specifically grain size distribution, cohesiveness, and consolidation). The Stony Clove Creek and its tributaries flow across a landscape characterized by geologic and geomorphic heterogeneity as a result of the complex distribution of glacial deposits and landforms. Stream channel stability varies in part as a function of this heterogeneity. By classifying the geology along the stream corridor into mappable units that describe the potential bed and bank erosion and entrainment of the stream channel material, recommendations for management of stream reaches can better reflect local geological considerations.

For effective stream management we will need to understand and characterize the sedimentologic heterogeneity in the Stony Clove. Rubin (1996) began this effort by classifying the glacial deposits into three sedimentologic units and mapping their distribution along the mainstem and tributary channels (Fig. 10). The result is a reconnaissance map of a specific geologic condition for the watershed stream channels. The following three key sedimentologic units that influence water quality and stream stability were proposed by Rubin (with some modification for this report).

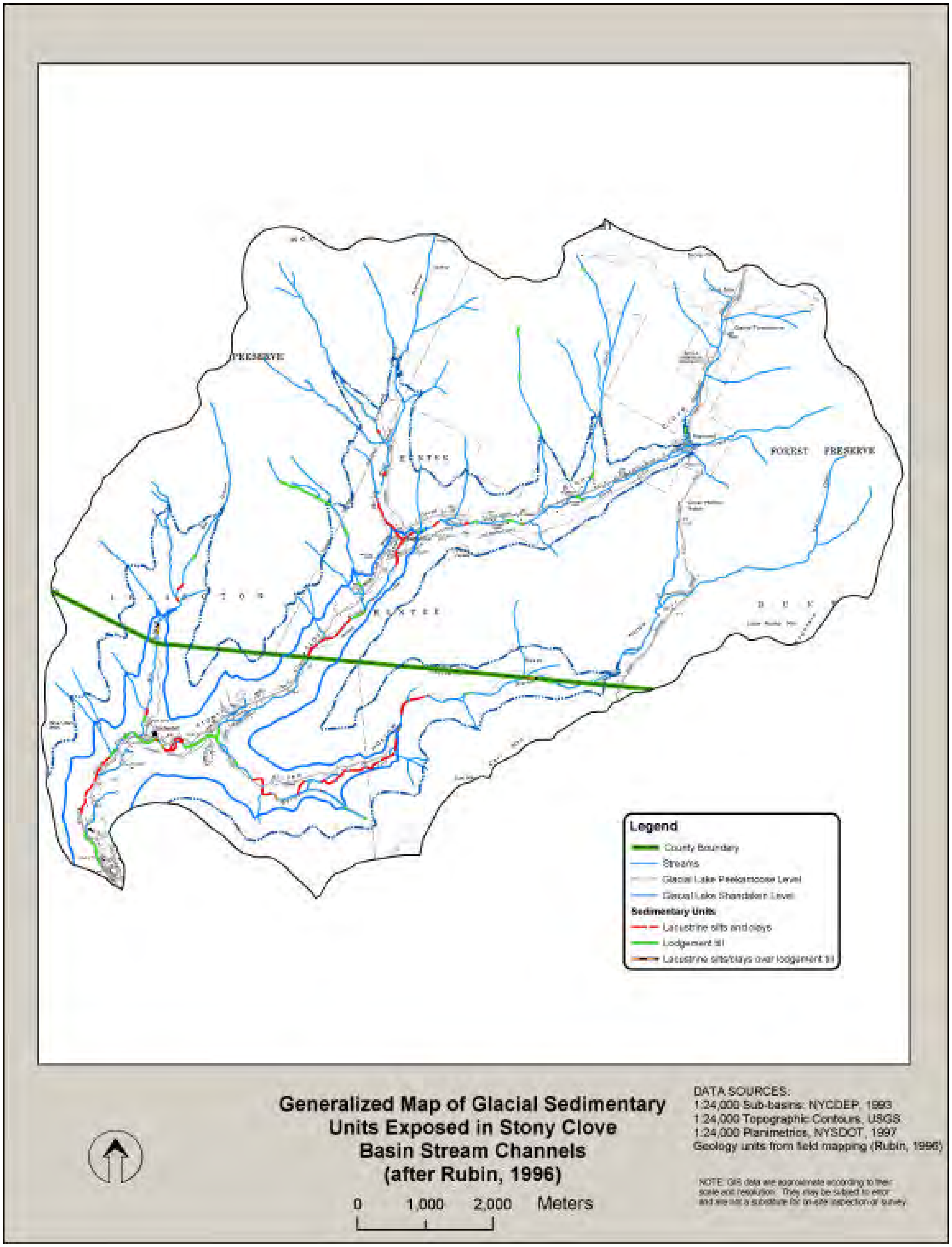

Figure 10 Stream Channel Corridor Sedimentologic Map

Sedimentologic Mapping Units

Unconsolidated Deposits. This general term is applied to all unsorted and unconsolidated deposits regardless of whether they were deposited directly as glacial outwash (proglacial fluvial sediments), reworked outwash, kame terrace deposits, melt-out till, moraine deposits or reworked lodgement till (Fig. 11). For mapping purposes, this unit incorporates finely stratified glaciolacustrine sand and pebble horizons sometimes interbedded with thin clay beds. The unit is composed of sand, pebbles, cobbles, boulders and a small clay/silt fraction. The unconsolidated deposits are present in valley centers, typically ranging from four to twelve ft. in thickness. With the exception of a thin, weathered mantle often capping it, this is the uppermost geologic unit most commonly forming stream banks. Boulders specific to this geologic unit naturally drop out as stream banks are eroded, providing fish habitat and limited channel armoring.


Figure 11 Unconsolidated deposit

Lacustrine silt/clay. This reddish or pinkish brown, finely-layered, silty-clay deposit floors significant portions of the mainstem Stony Clove and lower reaches of several tributaries. It was deposited *subaqueously* (from streams discharging onto the floor of one or two glacial lakes) as a sediment blanket draped over underlying till. Locally, it was also deposited in smaller impoundments associated with alpine glaciers and moraine dams. It is commonly exposed along the toe of the stream bank, sometimes in the channel *invert* (often beneath a poor armor), and less frequently as long and/or large banks. The fine, uniform grain size results in a very cohesive deposit that exhibits unique hydraulic and mechanical erosion characteristics. While the silts and clays are easily entrained under high runoff events it is somewhat resistant to hydraulic erosion. The silt/clay unit tends to erode mechanically by slumping along *rotational faults*, subsequently losing its layered structure and cohesive strength (Fig. 12). Within the silt and clay layers, strata of sand sometimes occur, creating the potential for *piping* and associated mechanical failures. Its extremely soft and, when saturated, physically weak character result in few large bank exposures. Where large exposures of lacustrine silt/clays are exposed and vegetative cover lost, revegetation is usually slow to occur due to the poor drainage characteristics of the soil. A metal probe or stick can often be sunk into this unit to depths of between three and five ft., thus enabling identification even when it is covered by a thin cobble armor. Elongate troughs, scour holes and even deep potholes reflect its entrainment potential. Clear stream water contacting lake clays often results in an entire stream becoming turbid within 50 ft. In the Stony Clove basin, and probably in other nearby basins once occupied by glacial lakes (e.g. Broadstreet Hollow, Woodland Valley, Bushnellsville Valley), this unit is the primary source for suspended sediment and turbidity problems.

Glacial Lake Clays and Stream Bank Erosion

Stream banks formed in clay deposits tend to fail by rotational failure which occurs in cohesive materials when a block of disturbed, bank material slides along a curved failure surface (fault). The block tends to rotate (appears to “slump”) back toward the bank as it slides, in a rotational slip.

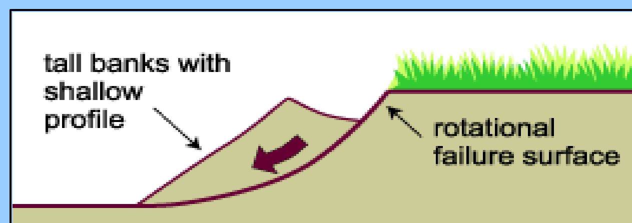

Figure 12 Rotational failure

Lodgement Till. This is an over-consolidated, clay-rich (pink to reddish-brown silty clay loam) till that floors the Stony Clove and its tributaries. It is also plastered against valley sidewalls as a result of extreme glacier ice pressure atop and against pre-existing clay-rich soils. This hard-packed silty clay loam with embedded pebbles, cobbles and boulders forms a number of steep banks in the drainage basin. Its dense, consolidated character is distinguished from the looser assemblage of mixed sediment sizes (silty sand-boulder) that comprises melt-out till found in moraines and along mountain sides. It is typically exposed in stream channels where overlying lake clay deposits have been erosionally removed, where streams have scoured into valley wall deposits or where they have breached morainal ridges. Its relatively competent nature, especially as compared to lake clay deposits, make it significantly more resistant to hydraulic erosion. It is however, susceptible to mechanical erosion by mass failure of fracture bound blocks during saturation/desaturation cycles (Fig. 13). A metal probe or stick can rarely be pushed into this unit more than 0.2 ft. Under conditions of high stream velocities and discharges, lodgement till is a contributor of sediment. Also, rain water and overland runoff contacting exposed banks readily entrains clay and silt-sized sediment fractions, resulting in *wet ravel*.

The presence of bedrock sills and banks is an additional geologic unit not mapped by Rubin but equally important in characterizing geology for stream corridor management. The locations of bedrock controls are included on Management Unit maps. These hydraulic controls can represent natural limits to changes in the stream channel system caused by incision or lateral migration. Examples include the falls at the Notch Inn and Edgewood, upstream of the Jansen Road bridge in Lanesville, and downstream of the NYS Route 214 bridge in Chichester, among others.

The variable character of the Stony Clove streams reflects the complex glacial history of the Stony Clove valley. The footprint of these glacial processes -the glacially modified landscape with its varying deposits of clay-rich or bouldery till, the silts, sands, gravels, and cobbles of meltwater streams and ice-contact deposits, and the glacial lake clays- can be tracked in the significant variation in floodplain topography, sediment supply (amount and size of material), channel boundary resistance (the "roughness" of the channel, and sediment resistance to moving in high stream flows) and rate of vegetative recovery of stream banks and hillslopes following catastrophic disturbance. In this way, the current architecture of the stream channel (its size, shape, bed form) is influenced to a large extent by the glacially and post-glacially deposited soils through which the stream runs, and in the adjacent hillslopes. Section 3.2 provides an overview of stream processes, including more detail on the role of bed material in stream channel morphology. The detailed management unit descriptions in Volume II Section 4 describe channel material characteristics reach by reach.

Figure 13 Erosion of lodgement till hillslope on Stony Clove Creek