## 2.4 Upper Rondout Creek Geology


*Figure 1 Aerial view of the Peekamoose Gorge looking northeast. The headwater reaches of Rondout Creek occupy a deeply incised cut into the sandstones along the southern escarpment of the Catskills. The gorge is believed to be the spillway of an ice age lake that used to occupy the Esopus Creek valley.*

### Introduction

Streams are essentially incisions in the landscape – channels to convey the water delivered to the watershed and sediment from the eroding landscape. The geology (the earth material) of the landscape helps determine the nature of the streams that form, influences the stream's water quality and the way the landscape erodes. Geology of the landscape through which the stream flows influences the bedrock-lined reaches of Peekamoose gorge and the bouldery step pools, giving way to gravel-rich riffle-pool reaches in the valley bottom upstream of the Rondout reservoir. The ice ages left behind a fluvial legacy of boulder-dominated reaches in the upper portion of the watershed. In the Catskill Mountains, geology is a primary control on water quality. Jill Schneiderman, a professor of geology at Vassar College, notes in her book **The Earth Around Us: Maintaining a Livable Planet** that the bedrock and glacial sediments of the Catskills provide excellent filtration for maintaining high water quality (Schneiderman, 2003). However the geology also periodically degrades this same resource. Where the stream erodes into very fine-grained (silt and clay) glacial deposits the water becomes brown with the suspended sediment. This section of the Plan presents basic background information on Catskill and Upper Rondout Creek geology and discusses some of its important implications with respect to stream management. The intent is to describe in general terms the geologic setting and history of the watershed. References are provided for the reader interested in obtaining more detail on the geology of this region.

Streams and glaciers sculpted these mountains out of rock that formed from ancient rivers. That is essentially the geologic story of the Catskill Mountains. These mountains and their river valleys are the ongoing result of water interacting with landscape geology under the force of gravity over millions of years. Knowing the geology of the landscape and stream corridor helps stream managers understand important conditions that control the stream's work (moving water and sediment out of the watershed) as well as significantly influencing water quality.

The nature of the bedrock – its composition and structure – determines how the stream valleys form and what the sediment is like. Upper Rondout Creek drains the southern front of the Catskill Mountains. These mountains are composed of sedimentary rock. Broken bits of this rock, formed from layers of ancient river sediment, are the source of almost all of the stream sediment you see today - from clay to boulders. Much of this sediment that the stream is currently conveying was deposited during the most recent ice ages of 12,000 – 25,000 years ago, when the Catskills were mostly occupied by ice or the meltwater streams and lakes that followed the ice's retreat. Rondout Creek and all the streams that feed it water and sediment have inherited this geologic framework.

## Bedrock Geology

The bedrock geology of the Catskill Mountains and Upper Rondout Creek watershed exerts considerable control on the character of its valley slopes and streams (Fig. 2). Sedimentary rock, primarily composed of alternating layers of sandstone and siltstone/shales, creates the characteristic Catskill stepped topography. Sandstones form the cliffs while the more easily erodible siltstones/shales tend to form slopes. The mountaintops tend to be formed of conglomerate (a gravelly sandstone). 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 (Isachsen et al, 2000) that drained the ancient high peaks of the Taconic mountain range. Titus (1998) has compared it to the Bangladesh river complex draining the Himalayas. The sandstone and conglomerate are made up of river channel sand and gravel, while the siltstones and shales are overbank and shallow freshwater silts and clays.

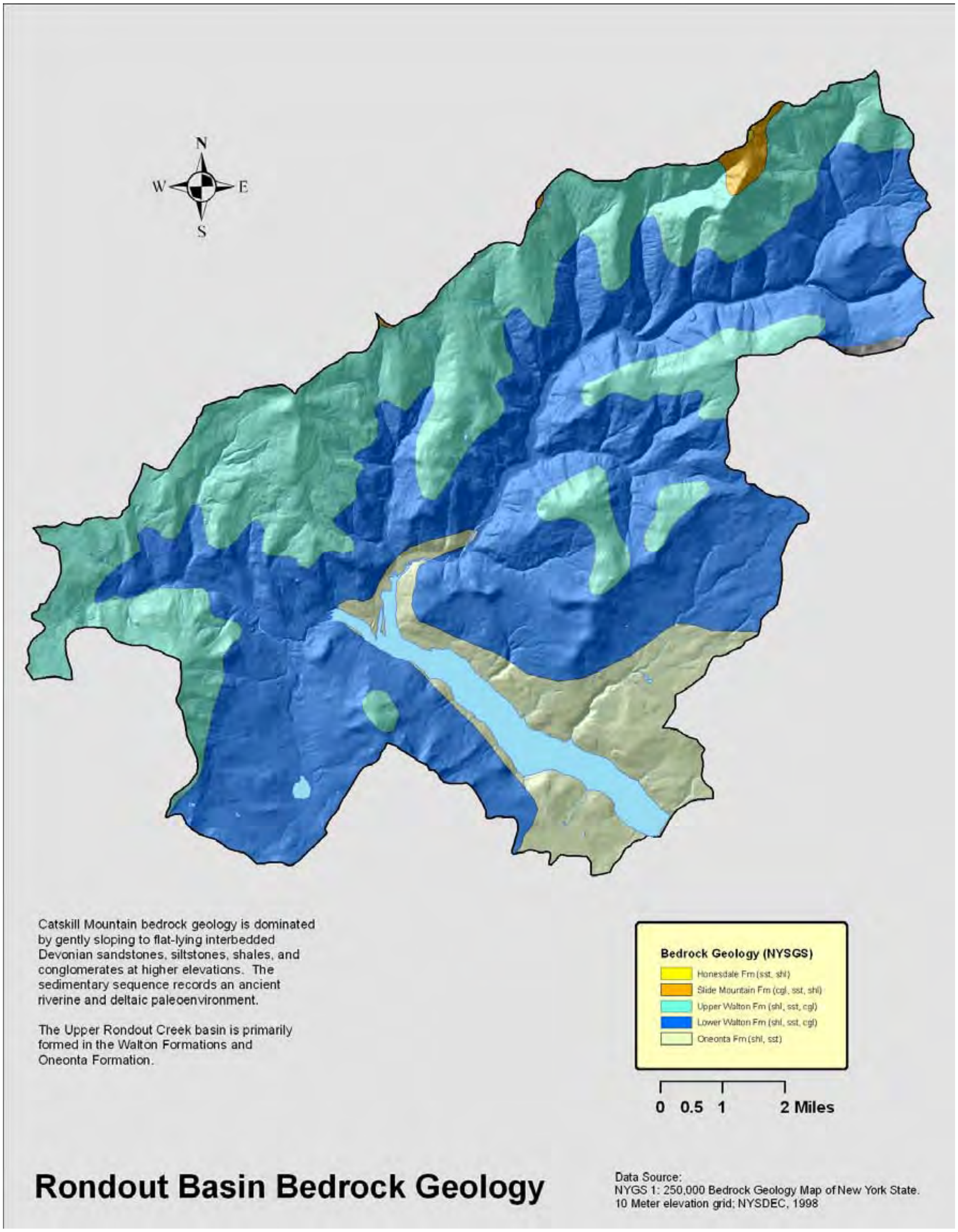


*Figure 2. Bedrock Geology of the Upper Rondout Creek Watershed*

The Catskill Delta deposits were buried beneath younger sediments, and then uplifted as a plateau. Prior to and during the uplift, intersecting sets of vertical fractures formed in the Catskill rock. The following eras eroded away the overlying rock, and streams incised multiple channels into the slowly rising plateau. The following two publications are recommended for further detail on Catskill bedrock geology: *Geology of New York: A simplified account* (Isachsen, et al, 2000) and *The Catskills: A Geological Guide* (Titus, 1998)

*Figure 3 Exposure of the Walton Formation's well-bedded sandstone along an upper reach of Rondout Creek.*

Fisher, et al. (1970) mapped the bedrock of the area as part of the New York State Geological Survey Map and Chart Series (Fig. 2). The mapped geologic formations that make up most of the watershed are the Upper and Lower Walton formations comprising sandstones, shales, and mudstones (Fig. 3). The uppermost rocks in the sequence are conglomeratic sandstones of the Slide Mountain Formation. The rocks comprising the lower elevations in the watershed are sandstones and shales of the Oneonta Formation.

Most of the stream valleys draining the Southern 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 4 Imbricated stream sediment*

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 plate 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 4).

Imbricated streambeds are thus generally more stable or "locked up," and all other things being equal, generally require a larger flow to mobilize the bed material than nonimbricated beds. However this same plate shape can also, under the right conditions, act like an airplane wing and be lifted by the streamflow more readily than would a spherical particle of similar weight. Once this occurs for even a few particles, the imbrication is compromised and significant portions of the streambed become mobile.

**Surficial Geology**

Surficial geology is concerned with the material covering bedrock. In the Catskills this surface material is principally soils and glacial deposits. The focus here is on a brief introduction to the glacial geology of the watershed and stream corridor. The Ulster County and Sullivan County Soil Surveys are excellent sources for examining the soils of the Upper Esopus Creek corridor (Tornes, 1979; Seifried, 1989).

Ice ages of the last 1.6 million years (Pleistocene Epoch) have left the latest mark on the Catskill landscape. Vast continental ice sheets and smaller local mountain glaciers scoured the mountains and left thick deposits of scoured sediment in the valleys. The last ice sheet (the "Laurentide Ice Sheet") reached maximum thickness over the Catskills about 22,000 years ago (Isachsen, et al., 2000) and had fully retreated by 12,000 years ago (Fig. 5). As measured on the scale of geologic time this was a very recent event.


*Figure 5 (a) map of Laurentide ice sheet. (b) Photo of Greenland ice sheet in mountainous terrain.*

The most recent ice ages – the time that spanned the last 30,000 years or so – had giant continental-sized ice sheets flowing across the northern landscape (Fig. 5a). The ice sheet covering Greenland (Fig. 5b) is a modern day analog to those Pleistocene conditions. Continental glaciers scoured and moved vast amounts of sediment across the landscape. Once the ice sheet started melting back into the Hudson River valley and to the north, smaller alpine glaciers formed in the mountains and further sculpted the landscape. The glaciers left a legacy that still profoundly influences hill slope and stream channel stability and water quality (Figs. 6-7, below).

Figure 6  Glacial till deposit on a hillslope, with clay particles being entrained by stream flow at the toe of the slope, Sundown Creek

*Figure 7  turbid runoff from a glacial till hillslope,  headed toward Sundown Creek*

This was a period of accelerated erosion in the Catskills as the flowing ice sheet bulldozed sediment and "quarried" bedrock.  Glacial erosion broke the rock down into an entrained mixture of fragments ranging in size from boulders to clay.  This mixture of saturated sediment was carried along by 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 once drained the landscape prior to the last glacier's advance over the mountains.

As the climate warmed and ice thinned, the landscape was deglaciated – lobes of the continental ice sheet melted back from the central Catskills in periodic stages (Dineen, 1986).  As the ice sheet pulled back (and occasionally re-advanced as distinct "lobes" of flowing ice) alpine glaciers formed on some of the newly exposed peaks (e.g. Hunter and Panther Mountains).  Meltwater from the decaying ice left a complex array of stream (outwash plain) and ice-contact (kame) sand and gravel deposits. Pro-glacial lakes (large and small) formed where mountains, recessional moraines (deposits at former glacial margins) and ice impounded water and filled valley floors with thick deposits of layered silt and clay.  Locally, "fossil" deltas from meltwater streams pouring into these meltwater impoundments are further evidence for the complex deglaciation of the region (Rich, 1935).  As climate fluctuated during the period of deglaciation, temporary re-advances of ice from ice sheet 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.   After the ice fully retreated north, rainfall-runoff returned as the predominant sculptor of the landscape.

Glacial geology sets the geologic framework for most of the Upper Rondout Creek stream system, controlling such characteristics as depth of *alluvium* (water worked sediments), presence of non-alluvial boundary conditions (bedrock, till and glacial lake sediments), sediment supply and stream channel slope and geometry.  For example,

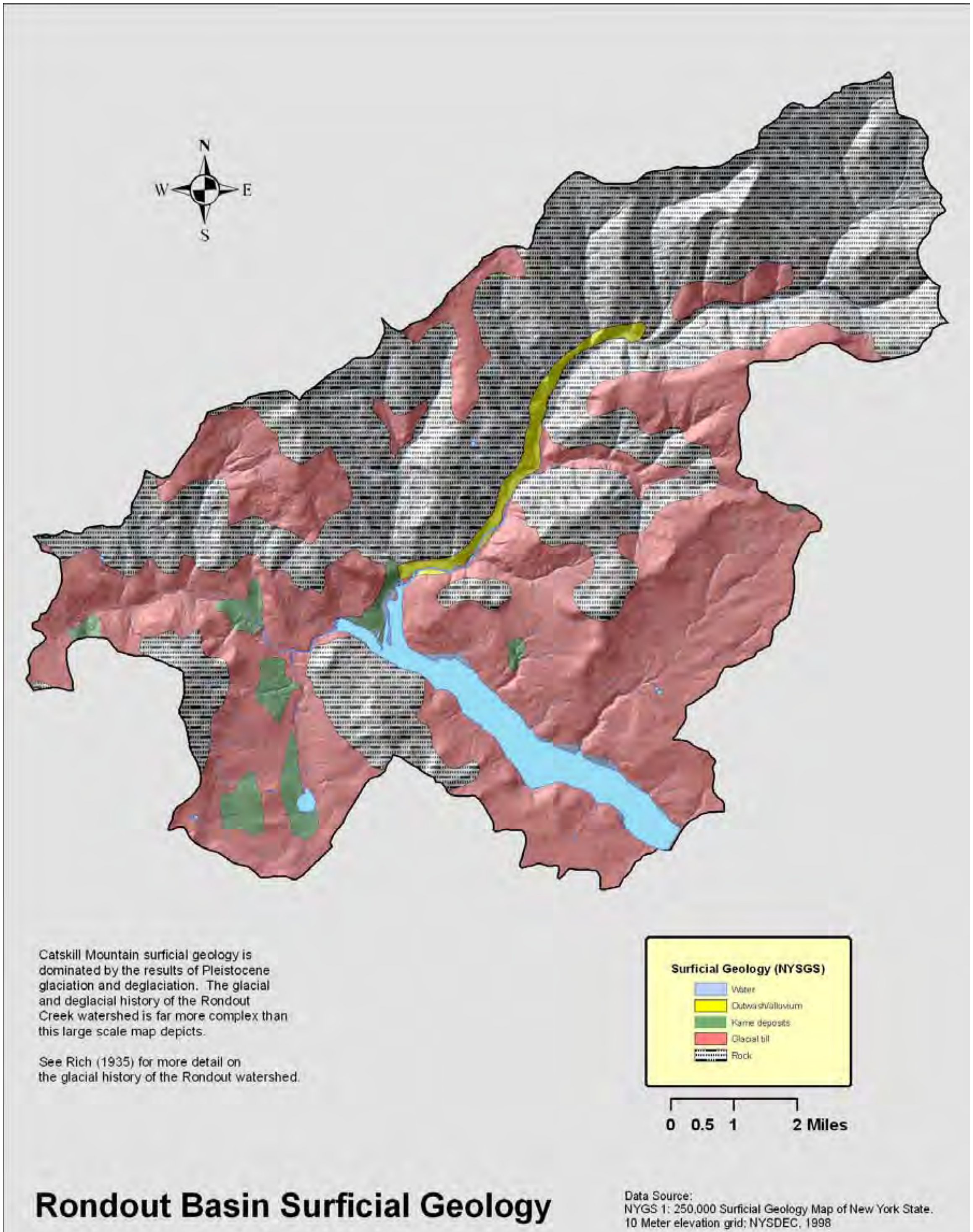


*Figure 8  Surficial Geology of the Rondout Basin as mapped at 1:250,000 Scale*

glacial depositional features that partially fill river valleys, such as recessional moraines or kame terraces along the valley wall, influence valley slope and cause valley constriction, both of which limit the lateral extension of the river channel in its floodplain. Also, locally complex *stratigraphy* of glacial till, glacial lake deposits and unconsolidated *fluvial* deposits in the stream bank profile significantly influences erosional process. Most dramatically, the deep, bedrock-lined Peekamoose gorge is the legacy of a powerful ice age stream that was the outlet of a vast pro-glacial lake in the adjacent Esopus valley.

Understanding the glacial geology in detail beyond the general level can help identify causes of stream erosion and water quality problems as well as assist in prioritizing where future stream stabilization or restoration actions may be most useful.

For more detail on the glacial geology of the Catskills the reader is referred to Rich (1935), Cadwell (1986), Dineen (1986) and for a popularized account Titus (1996). Figure presents the glacial geology for the Rondout basin as mapped by Cadwell (1987) and in more detail by Rich (1935).

**Hydrogeology**

Though groundwater is not the primary subject of this Plan, its constructive role in maintaining base flow to the stream and cold water springs for thermal refugia, and its destructive role in hill slope failures should be addressed.

*Figure 9 Stratified deposits in high bank, leading to groundwater piping, mass wasting and debris torrent along Greenville Road*

Where the valley floor stratigraphy includes buried impermeable layers of glacial lake silt and clay and/or glacial till, groundwater circulating through the upper permeable coarse-grained alluvium is often perched and discharges as springs or base flow to the stream. Following periods of excess rainfall not only does the stream flow increase to or near flood stage, but the water table also increases and can flood basements. Much of the "flood" damage to basements in the stream corridor is due to excess groundwater in these shallow groundwater systems and not directly from stream flooding. These conditions also have implications for the effectiveness of household septic systems, and for their effect on local water quality. Groundwater flow through the complex glacial stratigraphy on hill slopes is a major factor in massive hill slope failures that impact stream channel conditions and water quality (Fig. 9). The combination of stream erosion at the toe of the hill slope, fluctuating groundwater levels, differential seepage from the slopes and saturated sediment can result in very long-lasting, deep-seated slope failures. While more common in the adjacent Esopus Creek watershed there are instances of these mass failures throughout the Rondout watershed.

**Stream Channel Geology**

Developing an effective Plan that incorporates geologic boundary conditions requires an additional step beyond describing the geologic setting. Additional analysis is needed to characterize the surficial geology that forms the stream channel boundary by some of its sedimentologic conditions, specifically grain size distribution, cohesiveness, and consolidation.

The upper Rondout Creek and its tributaries flow across a landscape characterized by *sedimentological heterogeneity* as a result of the complex distribution of glacial deposits and landforms. Stream channel stability and water quality vary in part as a function of this heterogeneity. By classifying the surficial geology along the stream corridor into mappable units that describe the potential for bed and bank erosion and entrainment of the stream channel material, recommendations for management of stream reaches can better reflect local geological considerations.

Rubin (1996) began this effort in the Stony Clove basin by classifying the glacial deposits into three sedimentologic units and mapping their distribution along the Stony Clove mainstem and tributary channels (GCSWCD, 2004). The following 3 key sedimentologic units that influence water quality and stream stability were proposed by Rubin (with some modification for this report).

**Unconsolidated Deposits**

This general term is applied to all unconsolidated deposits regardless of whether they were deposited directly as post-glacial stream deposits, glacial *outwash* (proglacial fluvial sediments), reworked outwash, *kame terrace* deposits, *melt-out till, moraine* deposits or reworked *lodgement till* (see Fig. 6, above). The unit is composed of sand, gravel, cobbles, boulders and a small clay/silt fraction. The unconsolidated deposits are present in valley centers and are the predominant stream channel boundary material observed below Stony Cabin Brook. 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 some aquatic habitat and diversity.

**Lacustrine silt/clay**

This reddish or pinkish brown, finely-layered, silty-clay deposit may form channel margin boundaries in isolated settings of the Upper Rondout drainage. It was deposited *subaqueously* (from streams discharging into meltwater impoundments) as a sediment blanket draped over underlying till or bedrock. When present, it is commonly exposed along the toe of the stream bank, sometimes in the channel bottom (often beneath a thin cover of coarse alluvium), and less frequently as long and/or large banks. This unit is far more common in the adjacent Esopus Creek watershed which hosted large valley-filling lakes.

The fine, uniform grain size results in a very cohesive deposit that exhibits unique hydraulic and mechanical erosion characteristics. While the silts are easily entrained under high runoff events, many of the clay-rich deposits are resistant to hydraulic erosion. Susceptibility to erosion is largely dependent upon whether the layered silt/clay has been mechanically disturbed by geotechnical failures or human disturbance. The silt/clay unit tends to erode mechanically by slumping along rotational faults, subsequently losing its layered structure and cohesive strength. Within the silt and clay layers, strata of sand sometimes occur, creating the potential for piping and associated mechanical failures. When saturated, it tends to be extremely soft and in this physically- and chemically-weakened condition is susceptible to creep and erosion.

Clear stream water contacting lake clays often results in an entire stream becoming turbid downstream of the contact, and the size and chemistry of the clay particles allow them to remain in suspension for long periods of time.

**Lodgement Till**

This is an over-consolidated (very dense), clay-rich, reddish brown deposit that is prevalent in the Upper Rondout Creek watershed (Fig. 6, above). This hard-packed silty clay with embedded pebbles, cobbles and boulders forms a number of steep banks in the upper 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 some mountain sides. It is typically exposed in stream channels where streams have scoured into valley wall deposits or where they have breached morainal ridges.

Lodgement till's relatively competent nature, especially compared to disturbed lacustrine sediment, 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 and freeze/thaw cycles. This failed material is subsequently entrained by streamflows. Under conditions of high stream velocities and discharges, lodgement till is a contributor of suspended sediment. However, where the stream (particularly in tributary valleys) is against the valley wall and the hill slope composed of lodgment till is saturated, long-lasting exposures can be chronic sources of suspended sediment into the stream well-after a storm event. Rain water and overland runoff contacting exposed banks can also readily entrain sediment from these units.

## Bedrock Control

The presence of bedrock sills and banks is an additional geologic unit equally important in characterizing geology for stream corridor management. These hydraulic controls can represent natural limits to changes in the stream channel system caused by incision or lateral migration.  Lengthy stretches of the upper half of the Upper Rondout drainage have significant bedrock (and talus) control (Fig 10).

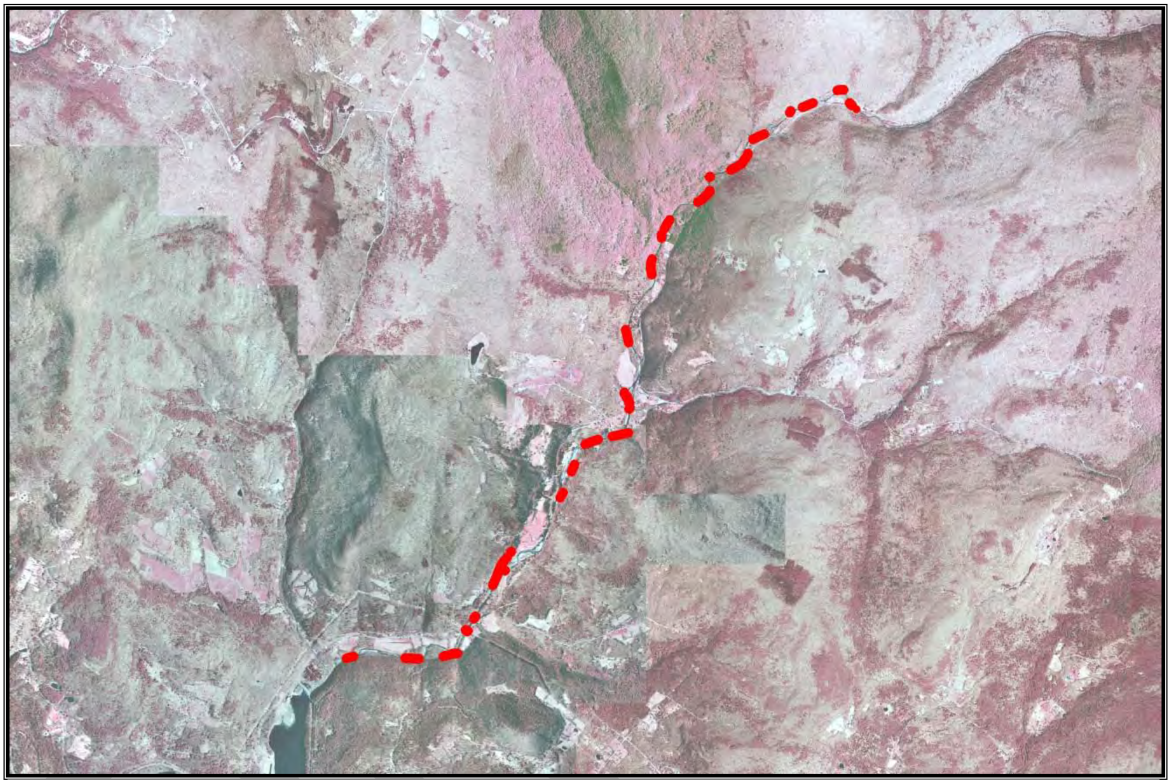

*Figure 10  Frequent vertical and lateral bedrock controls in the banks and bed of the Rondout Creek*

## Stream Management Implications

The inclusion of geology in stream management consideration for Upper Rondout Creek generally falls into four categories: fluvial erosion; hill slope erosion; water quality; and sediment supply.

## Fluvial erosion

There are different types or "styles" of stream bank erosion associated with the different geologic units the stream encounters.  The prediction, prevention and/or treatment of the eroding stream bank must factor in the stream bank material composition and the underlying mechanism of failure. Observations made during this planning process and previous similar projects throughout the watershed indicate the following:

- Pro-glacial lake sediment erodes easily during storm events once exposed; however, if the “soft” silt and clay unit is overlain by coarser fluvial sediment (sand-boulder sized material) it is typically a short-lived exposure and the stream bank tends to get armored by the draping of coarser sediment.

- Pro-glacial lake deposits that are undisturbed are much more resistant to erosion than those that have had their physical and chemical bonds weakened by mechanical action (including abrasion and displacement from hill slope failures).

- Glacial till tends to erode either as (a) mass slumping from saturated conditions or (b) translational fracture-bound failures forming high steep banks.

- The coarse-grained, non-cohesive fluvial sediment will erode easily if not protected by dense roots or revetment.

**Hill slope erosion**

Mass wasting, or geotechnical failure of the valley hill sides when proximal to stream channels, can result in chronic and excess fine and coarse sediment supply. This is a relatively common problem in the tributary valleys. Sediment entrainment occurs as a result of exposed glacial till or disturbed lake deposits to flood flows. In extreme situations, debris flows from these failures may block or cause the stream channel to adjust its planform. If the adjacent hill slope erosion is from a geotechnical failure in glacial till or pro-glacial lake sediment *and* the stream is actively eroding into the toe of the hill slope the problem is perpetuated by constantly activating the failure. Stream restoration or road construction/repair in these settings must first address whether the geotechnical failure can be resolved before dealing with the stream channel stabilization. Future construction or development activities in the Upper Rondout Creek tributary valleys should include geotechnical investigations and slope stability analyses to ensure that the proposed actions do not contribute to new slope failures or exacerbate existing failures.

**Water quality**

“Muddy” or turbid water that follows a storm event carries fine silt and clay particles initially deposited as glacial till or pro-glacial lake sediment. Fluvial and hill slope erosion of these fine sediment sources, along with re-suspension of fine sediment deposited in the stream bed are the primary cause of turbid water conditions.

**Sediment supply**

The mantle of glacial deposits over the landscape is the primary source material for all coarse and fine sediment that the stream system conveys. At any given time along any given reach of stream most of the sediment observed has been in the stream system for a “long time.” However, it is important to determine where sediment recruitment takes place. Which tributary streams deliver a proportionally larger amount of bed load material that Upper Rondout Creek has to process? Are there localized sources in the watershed that lead to localized aggradation? Further investigation of sediment dynamics in the Upper Rondout may provide answers to these questions, and support more effective management practices.