

- 0.2 8.2 At traffic light, turn LEFT on PA 171/PA 92. To left, the shopping center and parking lot occupy the site of the extensive Erie Railroad yards and shops, for more than a century (1848-1960's) the "bread and butter" of Susquehanna. A commemorative wall, a high water tank, and one large brick building are about all that remain. With the demise of the Erie and its successor Erie-Lackawanna in the third quarter of the 20<sup>th</sup> century, Susquehanna fell on hard times. Construction of a new highway bridge in 1995 and recent refurbishing of several buildings in the downtown area may betoken better days ahead.
- 0.2 8.4 At 2<sup>nd</sup> traffic light continue straight ahead on PA 171. PA 92 turns right just before the traffic light.
- 0.5 8.9 At the top of the hill is a view to the left across North Branch Susquehanna River to an 24 meter (80 ft.) cut in an abandoned gravel pit in the spectacular Lanesboro-Oakland esker. The esker extends intermittently for seven miles along the river (see map for STOP 6).
- 0.6 9.5 Continue straight ahead under the concrete Canawacta Viaduct, onto SR 1009. PA 171 turns to the right, going up the Canawacta valley.
- 0.1 9.6 Alluvial terraces on the left and under the road at most 6 meters (20 feet) above river level.
- 0.6 10.1 Bear RIGHT, continuing on SR 1009 and pass under the Starrucca Viaduct. Historical Marker to left under the viaduct reads: *STARRUCCA VIADUCT. Built in 1847-48 by the Erie Railroad, it is the oldest stone railroad bridge in use today. Viaduct is 1040 feet long, 100 feet high, and 25 feet wide at the top. We will stop at a park at the other end of the viaduct on the way back this afternoon.*
- 0.5 10.6 Cross the D&H Rail Trail and Starrucca Creek. The abandoned railroad grade is the Jefferson Branch of the Erie—now the D&H Rail-Trail.
- 0.8 11.4 Start ascending hillside. To both sides of the road for the next mile are slump benches that in places have sag ponds on their tops. Humans have raised the level of the ponds with small dams and increased the likelihood of future movement. To the right, Starrucca Creek is undercutting the slope composed of varves overlain by till and the entire slope is slumping (see map, Figure 26).
- 0.4 11.8 Sag pond on right.
- 0.5 12.3 Cross the D&H Rail Trail, passing by the Lunch Stop and way to Stop 4 to left, and immediately cross Starrucca Creek. On the right the Village of Brandt (formerly Harmony Center) was once a thriving community with numerous industries in the 19th century. It was named for Henry Brandt (1808-1886), notable local entrepreneur. The village cemetery is on a knob of sand and gravel (ice-contact stratified drift).
- 0.4 12.7 To right immediately before the next bridge over Starrucca Creek is a pond that probably marks where clay was excavated for the making of bricks at the old Brandt Brick Works. Clay for bricks here was obtained from the varved clays and silts of Glacial Lake Great Bend. Young (1995) cites this area as the source of clay for the manufacture of bricks used in the Starrucca Viaduct. The higher ground above the pond is a series of hummocky slump benches in the varved lake sediments and overlying till. This will be Stop 3, later this morning, slump exposures of the varves upstream of here.
- 0.1 12.8 Cross Starrucca Creek, to right are the slumps we will be walking along to get to the varve outcrops.
- 0.1 12.9 Alluvial terraces to right, slump benches to left.
- 0.2 13.1 Cross Sarrucca Creek, to left are the stone abutments of a bridge on the former Jefferson Branch of the Erie/D&H Railroad. To right on stream bank are ledges of Lock Haven Formation sandstone.
- 0.2 13.3 On right is the old Steven's Point (Grover's) quarry that provided dimension-stone for the Starrucca Viaduct. It exposes two fluvial fining upward cycles in the lower-most Catskill Formation.
- 0.1 13.4 Village of Stevens Point. To left is Stop 2.
- 0.1 13.5 Cross Starrucca Creek, continuing straight ahead on
- 0.1 13.6 To left is a "beautiful" large sandstone block, stone wall built by the WPA during the Depression. It is a retaining wall for ice-contact stratified drift that has been undercut by Starrucca Creek. From about this point to Stop 1 we will be in the south to north trending part of the Starrucca Valley and underneath the water level of Glacial Lake Starracca. At this point the lake would have been about 170 meters deep (560 ft.) and would have drained through a saddle about 3 km (2 mi.) southwest (right) of here at an elevation of 1700 feet.
- 0.6 14.2 Broad alluvial terraces on the right side of the road.
- 0.8 15.0 On right are large sandstone blocks transported from bedrock ledges upslope as part of a bouldery colluvium from intense periglacial activity after ice recession.
- 0.9 15.9 On right, intersection with Melrose road.
- 2.0 17.9 Enter Wayne County where the route number changes to SR 4309.
- 0.7 18.6 Enter borough of Starrucca.
- 0.2 18.8 Turn LEFT and cross Starrucca Creek, staying on SR 4039. To the left just after the bridge is the Italianate mansion of Major Elisha Strong (1818-1895), the leading citizen of Starrucca in the post-Civil War era. Among the industries he operated after coming here in 1862 were a tannery and a sawmill (Sampson, 1972).

- 0.1 18.9 Bear LEFT, staying on SR 4039, at the Post Office. Immediately to left behind the buildings of the Priory of Ephesus nuns, is an exposure of ice-contact stratified drift. With the ice front at this point, Glacial Lake Starrucca would be draining through a sluice about 6.5 km (4 mi.) to the south at the head of the drainage basin at an elevation of 1800 feet. The lake would have been about 120 meters (400 ft.) deep here.
- 0.8 19.7 Turn RIGHT just beyond a couple of barns onto Buck Road (T671) and cross Starrucca Creek yet again. Only one vehicle on the bridge at a time.
- 0.2 20.0 Ascend hill and just after leveling off, go by falls on the left.
- 0.1 20.1 Continue on and turn around in side road on the right. Then park vehicles along the right side of the road. Walk back down the road to the falls.

## Stop 1 Bucks Falls Post-glacial Gorge

Leaders: Duane D. Braun and Jon D. Inners

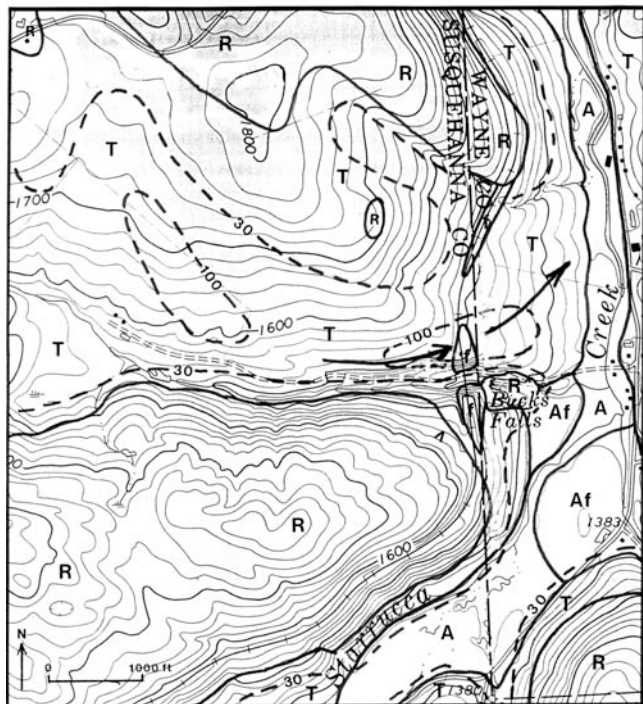


Figure 21. Surficial deposit map of the Bucks Falls area. Curved arrows - preglacial valley buried by till. A - Alluvium, Af - alluvial fan, F - fill, R - Bedrock, T - Till. Thickness contours at 30 and 100 feet. (From Braun, 2004c)



Figure 22. Bucks Falls and present gorge. (Photo by W.S. Young)

## Origin of the Falls

Bucks Falls is located where an east-draining tributary joins the north draining Starrucca valley (Figure 21). Such east to west trending valleys are transverse to glacier flow and become partly buried by glacial deposits that form a "till shadow" on the north side of the valley (Figure 4, Quaternary History article). This produces an asymmetric valley, gentler on the north side and steeper on the south side (Figure 21). As the stream cuts down into the till-fill, it soon encounters the sloping bedrock surface under the south side of the valley. The incising stream then migrates down the bedrock-till contact in a "one-sided gorge" having bedrock on its south side and till on its north side (Figure 4). At some point the stream starts cutting more vertically and forms a "double-sided" bedrock gorge (Figure 22).

Bucks Falls differs from other sites where a post-glacial bedrock gorge has been cut along-side a preglacial valley buried by till. Bucks Falls present gorge has an abandoned gorge on one side (south) and the beginning of a new gorge on its other side (north) (Figure 23).

At Bucks Falls the valley buried by till curves northeast as it enters the Starrucca valley (arrow on Figure 21). At this site the stream is cutting into a northeast trending bedrock ridge or nose rather than just running beside the south bedrock side of the valley. As the stream cuts a gorge in the northeast trending bedrock nose, upstream of the nose, the stream is still just migrating down the bedrock-till contact. This migration permits the stream to carve a channel in the till (alluvium area (A) along present channel on Figure 24) that eventually captures the channel that leads directly to the falls (rc, Figure 23 and 24). This happens because the channel in the till curves around to the north and exposes bedrock that is lower (future channel, fc, on Figure 23 and 24) than at the upstream entry to the "nose

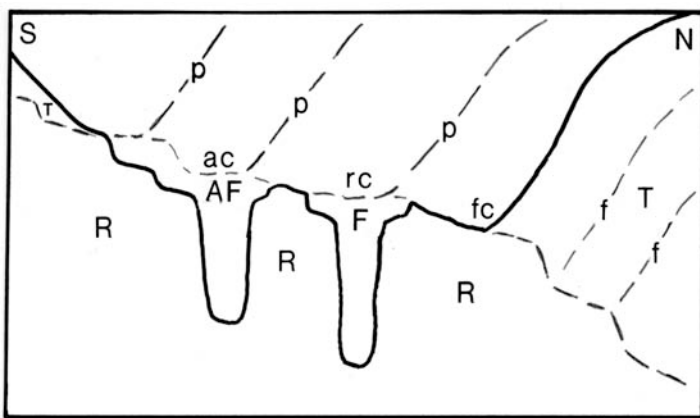


Figure 23. Cross-section sketch of Bucks Falls showing the abandoned falls gorge (AF), the present falls gorge (F), and the future channel and gorge (fc). p - past north slopes of till, f - future north slopes of till, T - Till,

gorge”(rc on Figure 23 and 24). Once the stream is in this more northerly curved channel, during high flow periods it starts spilling over at the bedrock–till contact and begins cutting a new bedrock gorge at that point (future channel, fc, Figure 23 and 24). This process will shortly cause abandonment of the present falls and is the same process that caused the gorge and falls upslope (AF and ac on Figures 23 and 24) to be abandoned in prehistoric times. Humans have built a road up the developing gorge (fc, Figure 23 and 24) and diverted the stream back to its direct course towards the Falls (rc, Figure 23 and 24) thereby temporarily blocking the natural process.

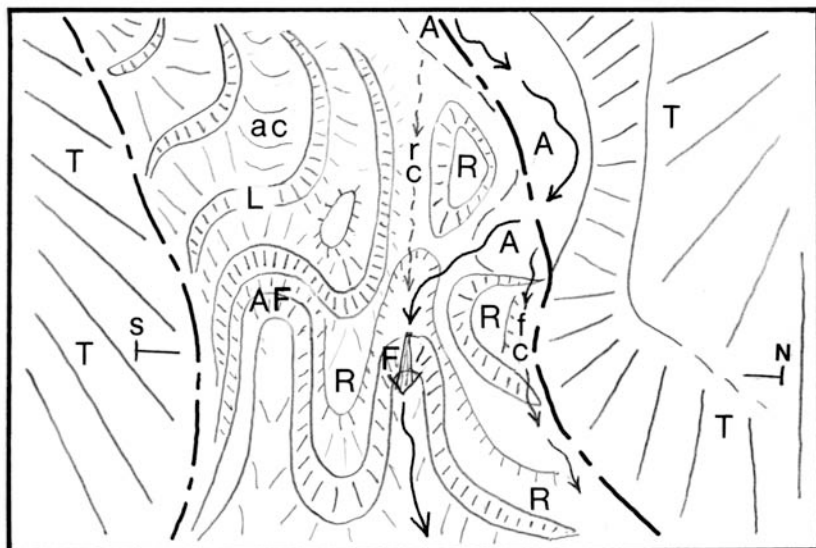


Figure 24. Sketch map of the Buck Falls area showing the present channel (long wavy arrows), the long abandoned channel ac and falls gorge (AF), the recently abandoned channel (rc), and the future channel (fc). Bold short and long dashed line is the bedrock - till contact. L - Bedrock ledge symbol of short tick marks between two parallel lines, A - Alluvium, R - Bedrock, T - Till

### “Industrial” History of the Falls

Bucks Falls has a rich history, dating back to the early part of the 19th century (Sampson, 1972). It was here, in 1818, that Henry Sampson, one of the earliest settlers in the Starrucca valley, constructed what may have been the first gristmill in extreme northeastern Pennsylvania.

The next notable “industrial intrusion” on the area around Bucks Falls was in 1870, when the Jefferson Branch of the Erie Railroad was completed from Carbondale through Starrucca to Binghamton (Sampson, 1972). Built as a vital link in the intricate late-19th-century railroad network that carried Lackawanna anthracite to markets in New York and New England, the Jefferson Branch was utilized by trains of both the Erie (later the Erie-Lackawanna) and the Delaware and Hudson (D&H) Railroads. The railroad crossed the valley of Bucks Creek on a high wooden trestle that was reportedly a fire hazard due to sparks from the coal-burning steam engines (some of which were probably built at Susquehanna Depot). In 1888 the Jefferson Branch was double-tracked, and the wooden structure was replaced with a much stronger steel trestle. (The line returned to single track in the 1950’s). The railroad operated over this trestle (strengthened twice over the years, about 1900 and again in 1968) (Sampson, 1972) until it ceased operation in 1981. A year or two later, the trestle was torn down (W. Young, 2002, personal communication). All that remains now are the ruins of the pier foundations, the large ones built of cherty, gray limestone (Onondaga or Helderberg?) and greenish sandstone (Catskill) (Figure 25). (Small pier-footings low on the slope near the stream are concrete.) The old Jefferson Branch Railroad grade from Simpson in the Lackawanna Valley north to the New York State line is now

the D&H Rail-Trail administered by the Rail-Trail Council of Northeast Pennsylvania.

Early in the 20th century, probably about the time of World War I, Bucks Falls was again developed as a power source. I. L. Buck and his sons (on whose farm the falls is located) installed a water-powered turbine-generator to provide electricity for farm lighting and other uses (Sampson, 1972). To maintain sufficient water flow during the dry summer months, a low dam was built at the crest of the falls. Water held back during the daylight hours was released for generation of electricity in the evening. (This is just the reverse of what is done in today's pumped-storage operations!) A 12-14-inch pipe (a piece of which is embedded in loose rocks below the falls) carried the water from the crest to the turbine house located on the north side of the stream about 75 feet below the falls. The stone foundation of this housing can still be seen.



Figure 25. View north across the valley of Bucks Creek, showing the stone pier-foundations of the Erie/D&H railroad-trestle (wood 1870; steel, 1888) that once crossed the valley just upstream of Bucks Falls. The fields on the north side of the valley are underlain by a thick "till shadow"

Leave Stop 1 and retrace route to SR 4039.

- 0.4 20.5 Turn LEFT onto SR 4039.
- 0.7 21.2 Borough of Starrucca.
- 0.2 21.4 Turn right, staying on SR 4039, across from Post Office.
- 0.1 21.5 Cross Starrucca Creek and turn LEFT at stop sign immediately after the bridge, staying on SR 4039.
- 0.8 22.3 Enter Susquehanna County. You are now on SR 1009.
- 1.9 24.0 Village of Melrose.
- 1.6 25.6 Broad alluvial terraces on both sides of the road.
- 1.3 26.5 WPA Stonewall on right.
- 0.2 26.7 Enter village of Stevens Point, cross Starrucca Creek, and immediately pull over and park along the right side of the road. Once the glacier retreated to here, Glacial Lake Starrucca drained and was replaced by the lower (about 365 meter (1200 ft.) elevation), much more extensive and longer-lived Glacial Lake Great Bend.

## **STOP 2. Sequence of Deposits from Glacial Readvance into Glacial Lake Great Bend.**

Leaders: Duane Braun and Jon Inners

This natural cut-bank on Starrucca Creek at Stevens Point is a splendid exposure of a Late Wisconsinian-age readvance sequence, cut by at least two post-depositional faults. The cut-bank is approximately 15 meters (50 feet) high and contains, glacial till at the base, succeeded upward by cobbly gravel, "sand with swallow holes," and more cobbly gravel. From here to STOP 4 the Starrucca Creek valley runs east to west, transverse to glacial flow, so the valley was deeply buried by glacial deposits (Figure 26) as first noted by White (1881). Thickness contours on Figure 26 (dashed lines) show the deposits to be greater than 50 meters (150 feet) in thickness in the tributary on the north and east side of the Starrucca valley. As the glacier retreated just north of the valley, the valley became the easternmost arm of Glacial Lake Great Bend. Post glacial incision of the creek has caused extensive slumping of the valley sides (hachured arcuate lines on Figure 26) due to the presence of clayey lake

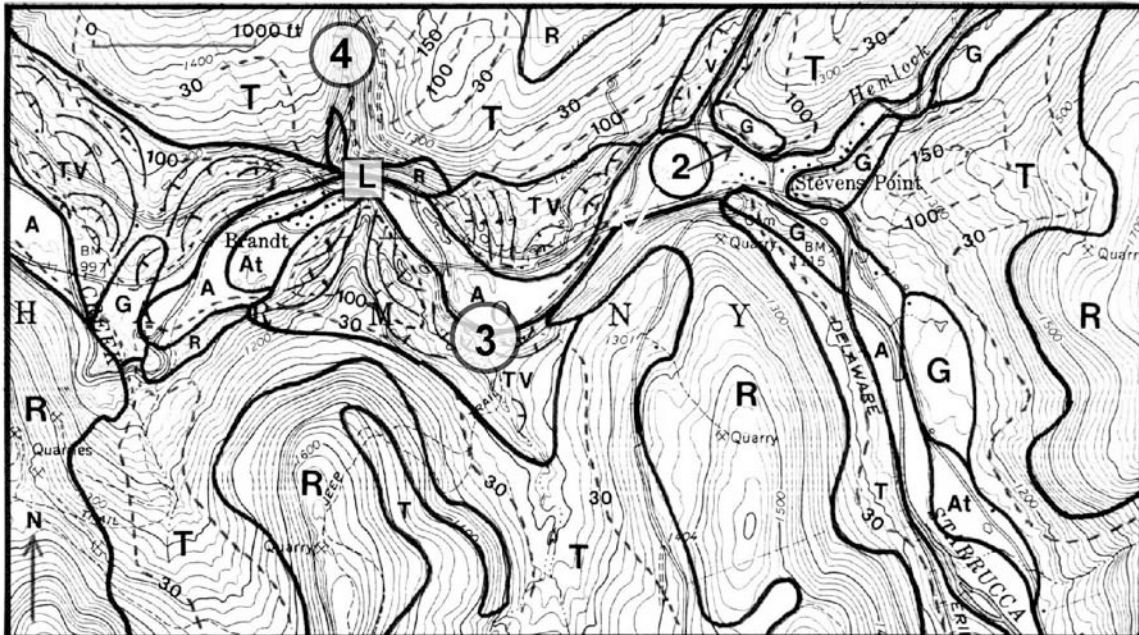


Figure 26. Map of glacial deposits in the Stevens Point-Brandt area (Braun, 2004d). Circled numbers are STOPS 1 to 4. L = Lunch Stop A = alluvium, At = alluvial terrace, G = ice contact stratified drift, R = bedrock, T = till, TV = till over varved sediments. Isochores of surficial deposits at 30, 100, and 150 feet. Hachured arcuate lines are slump headwalls. (From Braun, 2004 c)

sediments (varves). The slumping has produced a number of exposures of the ice-contact stratified drift, till, and varved deposits that fill the valley. This site is one of the larger and more readily accessible exposures of the glacial deposits in the area.

The outcrop shows compact till overlain by cobbly sand and gravel that is in turn overlain by lake sands with clay drapes (ice-proximal varves) that are capped by fluvial gravels (Figures 27 and 28). The till is best exposed at the south end, where a slight undercut has exposed several large (1 meter x 0.2 meter) blocks of tan, very fine grained, sandy silt that probably represent blocks of older lake bed sediments ripped up by readvance of the glacier. Striated pebbles and cobbles are common here. The gravels directly above the till are crudely bedded and poorly sorted, with a sandy matrix between the large clasts. Although it looks almost as though this unit was “dumped” into its present location, imbrication of the pebbles and cobbles indicate that it was deposited by flow from the north. All of these textural characteristics are consistent with deposition of these gravels below lake level on a sublacustrine fan fed by an ice tunnel. The “sand with swallow holes” (Figure 29) unit actually consists of interbanded rippled fine sand (tan) and silty clay (red) that was deposited in a late stage of Glacial Lake Great Bend. The sandy bands are 1.0 to 5.0 cm thick, while the clayey bands are 1.0 to 2.0 cm thick. The upper few feet of the deposit appear to be all sand. The gravels capping the lake sediments have a near planar top surface and have weakly expressed imbrication that shows flow was from the south, the direction of flow of the present Starrucca Creek. This indicates that the upper gravels are fluvial and are on a strath terrace cut into the glacial deposits in late glacial or early post-glacial time.

The right, or east, side of the outcrop has been down-dropped to the south along two steeply inclined faults (Figures 27 and 28). Inners et. al. (1999) interpreted the faults as collapse from the melting of underlying dead ice. On close examination, it can be seen that the fault on the left is “overturned” and dips north—thus having a reverse-fault orientation. It was thought that the fault started as a south-dipping normal fault on initial melting of the ice, but was then overturned as melting and slumping progressed. Braun (2004) recognized that the faulting cuts the post-glacial fluvial gravel and then traced slump benches along the north side of Hemlock Creek, which enters Starrucca Creek at the east end of the outcrop, directly to the faults. One is seeing the cross-section view of slumps that are rotating into Hemlock Creek. The slumping suggests there are varves not far below creek level at this site. The Stevens Point cut-bank exposure only shows the lake sediments from the final recession of the ice from the area and not the lower set of lake sediments that causes all the slumping

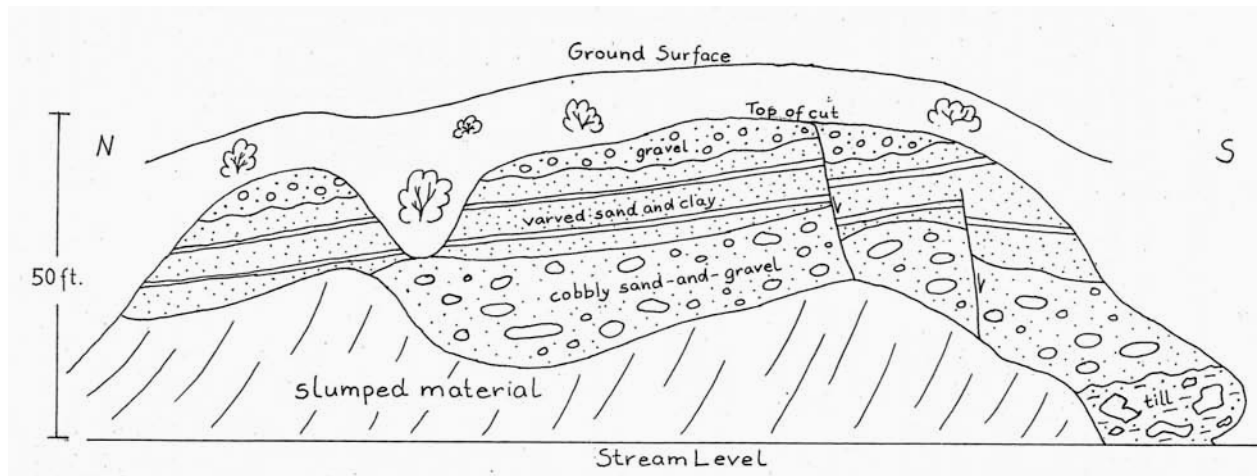


Figure 27. Starrucca Creek cut-bank exposure at Stevens Point showing till overlain by cobbly sand and gravel that is in turn overlain by lake sands with clay drapes (ice-proximal varves) that are capped by fluvial gravels. (Sketch by Mott and Inners)



Figure 28. Faulted sub-lacustrine fan gravels are overlain by sandy lake sediments that are in turn capped by fluvial gravel. Note that the fault on the right dips north. Both faults cut through all the units.

down-valley to the east. The lake sediments under-lying the till are well exposed at the next stop (STOP 3). The lower lake sediments are true silt-clay couplet varves once used in making bricks at the village of Brandt downstream from here (Figure 26).

Throughout the 40 km-wide area of Glacial Lake Great Bend the lower varved sediments are exposed under thick glacial till deposits. This indicates that there was a regional readvance of the glacier across Glacial Lake Great Bend. At Stevens Point and a few other sites a thin upper sequence of sandy lake sediments marks the short-lived lake phase from the ice very rapidly and permanently retreating north of Pennsylvania.

Another possible interpretation of this sequence, since there are no absolute dates available, is that it represents the original advance of the late Wisconsin glacier. The varves below stream level here would be the initial glacial advance across Glacial Lake Great Bend. The till would represent both the advance and retreat of the late Wisconsin glacier, a 10,000 calendar year period. The overlying



Figure 29. Close-up photograph of the upper lake sediments here expressed as rippled sand strata with clay drapes. Swallow holes mark fine-sand beds.

gravels and clay draped sands would record the final recession of the glacier and the short-lived recessional Glacial Lake Great Bend. This interpretation is thought to be unlikely because the lower varve sequence would have to survive 10,000 years of glacial scour. While the overall trend of the Starrucca valley here and to the west of here is transverse to ice flow, tributary valleys oriented sub-parallel to ice flow should have funneled ice into the Starrucca valley downstream of this site. That part of the Starrucca valley is where the varves are the thickest as at STOP 3 (Figure 26).

Leave STOP 2, continuing ahead on SR 1009.

0.2 26.9 On left is the dimension-stone quarry for the Starrucca Viaduct.

0.2 27.1 Cross Starrucca Creek. To the right are a series of slump benches but they are difficult to see from the road.

0.4 27.5 Cross Starrucca Creek and immediately pull over on the LEFT shoulder of the road for Stop 3.

### STOP 3: Glaciolacustrine varves along Starrucca Creek near Stevens Point

Jack Ridge, Dept. of Geology, Tufts University, Medford, MA 02155 jack.ridge@tufts.edu

About 3-8 km east of where Starrucca Creek enters the Susquehanna River the Starrucca Valley (Susquehanna, Pa 7.5-minute quadrangle) has sections of glaciolacustrine varves overlain by till (Braun, 2004d). The steep incision of the valley and high clay content of the varves has triggered slumps along almost every varve embankment. Slumping has produced irregular mounded topography on both sides of the valley for a distance of about 5 km (Figure 26) and exposures of the varves are not common, especially in undisturbed sections. Varves occur up to an elevation of at least 1100 ft and represent deposition either: 1) in an extension of Glacial Lake Great Bend into the Starrucca Valley or 2) in local lakes in the Starrucca Valley impounded by ice in the Susquehanna Valley to the west. The relatively low consolidation of the sediment suggests, but does not confirm, that the varves were likely deposited just prior to a readvance that occurred during late Wisconsinan ice recession. One would expect varves to be more consolidated if they were deposited in a lake overrun by much thicker ice of the initial late Wisconsinan advance to the Terminal Moraine. Varves above till at other localities and deposited during the final recession of ice are sandier than the varves beneath till and are often overlain by recessional stratified sand and gravel deposits (Braun, 2002).

In June 2003 Duane Braun encouraged me and my students to study a varve section on the south side of the Starrucca Valley about 2 km west-southwest of Stevens Point. It was hoped that the section would yield a varve stratigraphy that could eventually be used for regional correlation, especially with sections in the Hudson Valley near Haverstraw, NY (Antevs, 1928) and in northern New Jersey (Reeds, 1926). Samples for paleomagnetic measurements would also be collected. The Starrucca Creek exposure is about 3-4 m high and continues below stream level. The section has very clayey varve summer layers making it difficult to recognize annual layers at the outcrop. For this reason, and to create an archive, the outcrop was sampled in nine overlapping 2-ft sections of 3-in ID schedule 40 PVC pipe. The pipe sections were beveled on their lower outside edge, greased inside with Vaseline,

and driven into the outcrop with a homemade drop-weight core driver (Figure 31). The cores were then dug out of the outcrop and sealed with duct tape for transport.

In the lab, split cores were scraped with a razorblade and allowed to dry very slowly to create the maximum contrast between clayey sediment that remains moist and dark, and silty to fine sandy beds that dry faster and become lighter. Varves become much easier to recognize under these semi-dry conditions as compared to the very moist conditions at the outcrop that tend to mask annual layering. Successive overlapping digital images (640 x 480 pixels) of each core were collected for measurement of varve thickness on a computer using a specially written script program (Shuai Yuan, Dept. of Computer Science, Tufts Univ.) to go along with image analysis software downloaded from the internet (UTHASCA Image Tool 3.0). Additional high-resolution (2048 x 1536 pixels) digital images of selected varves were collected for producing detailed gray-scale (total RGB) scans (25 pixel width average) again using a script program (Shuai Yuan) written for Image Tool 3.0.

Unfortunately the Starrucca Creek section did not have a continuous varve sequence and was interrupted by nine low angle faults related to slumping. In overlapping cores it was possible to eliminate four of the fault gaps but the section is still divided into six disjointed varve sequences, the longest of which is 36 years, with a total of 73 different years found in the cores (Figure 32). Varves range from about 1-12 cm thick. Superposition of the fault-bounded sequences does not necessarily give their relative ages because it was discovered in some cores with overlapping varves that older varves had been thrust over younger units by mass movement. The varve sequences shown on Figure 31 are shown with arbitrary gaps between them and with their relative positions at the outcrop, which may be different than their true relative ages. Attempts at both visual matching and computer matching using both parametric and non-parametric statistics did not reveal any distinctive matches between varves 1-36 at Starrucca Creek and varve records in the Hudson Valley or northern New Jersey. Bedding at the outcrop dipped as much as 15°. Because of the rotation of the sediment about a horizontal axis, possible rotation about a vertical axis, and other deformation during slumping, paleomagnetic sampling was not attempted.



Figure 31. Jack Ridge, Jonathan Nichols, and Duane Braun (left to right) collecting core samples of the Starrucca Creek varve section using a homemade drop-weight core driver.

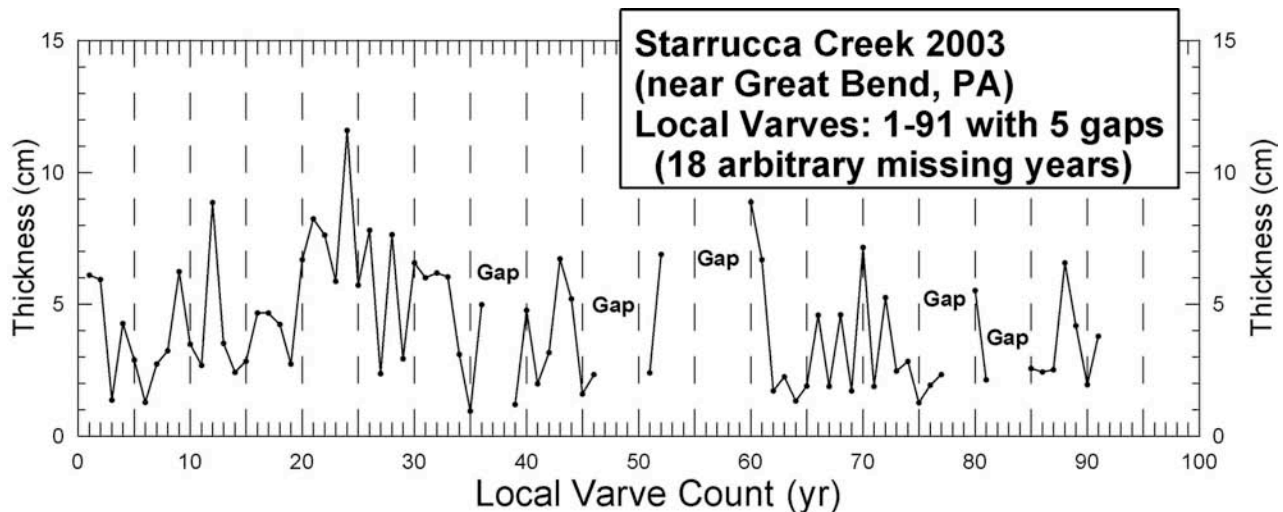


Figure 32. Varve measurements at the Starrucca Creek varve section. The section is split into 6 disjointed varve sequences separated by 5 fault gaps. Sequences are shown here in their relative position at the outcrop from bottom (1) to top (91)

Except for their very clayey character in some summer layers, the Starrucca varves have features typical of glacial varves seen elsewhere in the northeast (Figures 33A to 33F at end of this article). The clayey character of the varves is probably related to the soft sedimentary rock units, especially red shale, in the area. Varves in the Starrucca Valley are typical ice-proximal glaciolacustrine varves dominated by sediment transported by glacial meltwater as opposed to sediment derived from runoff erosion of a paraglacial landscape. Winter (non-melt season) layers can be more than 1 cm thick and are composed of nearly pure dark reddish brown clay. The thickness of winter layers correlates well with the thickness of summer layers suggesting that clay layer thickness is related to total sediment input during the summer. The presence of these pure clay beds is critical to recognizing annual layers in the varves. The winter layers are probably composed of clay that rapidly flocculated over a few weeks at the end of the summer season when bottom currents slowed down or came to a stop as meltwater and sediment entered the lake at greatly reduced rates. Cold water, high concentrations of suspended clay, and possibly high dissolve ion concentrations may have promoted rapid flocculation. Floccules have been recognized in the winter layers of glaciolacustrine varves elsewhere (Genesee clay and Glens Falls clay) using scanning electron microscopy (O'Brien and Pietraszek-Mattner, 1998). Summer (melting season) layers are tan to reddish tan or olive gray and have many clayey silt to fine sand units that are micrograded. In the summer layers of two couplets there are thin massive reddish brown gritty clay units that contain granules and appear to represent distal mudflows that were probably generated by slope failure along the steep sides of the valley. Throughout the summer layers it is possible to find the sinusoidal trails of nematodes on silt and fine sand partings.

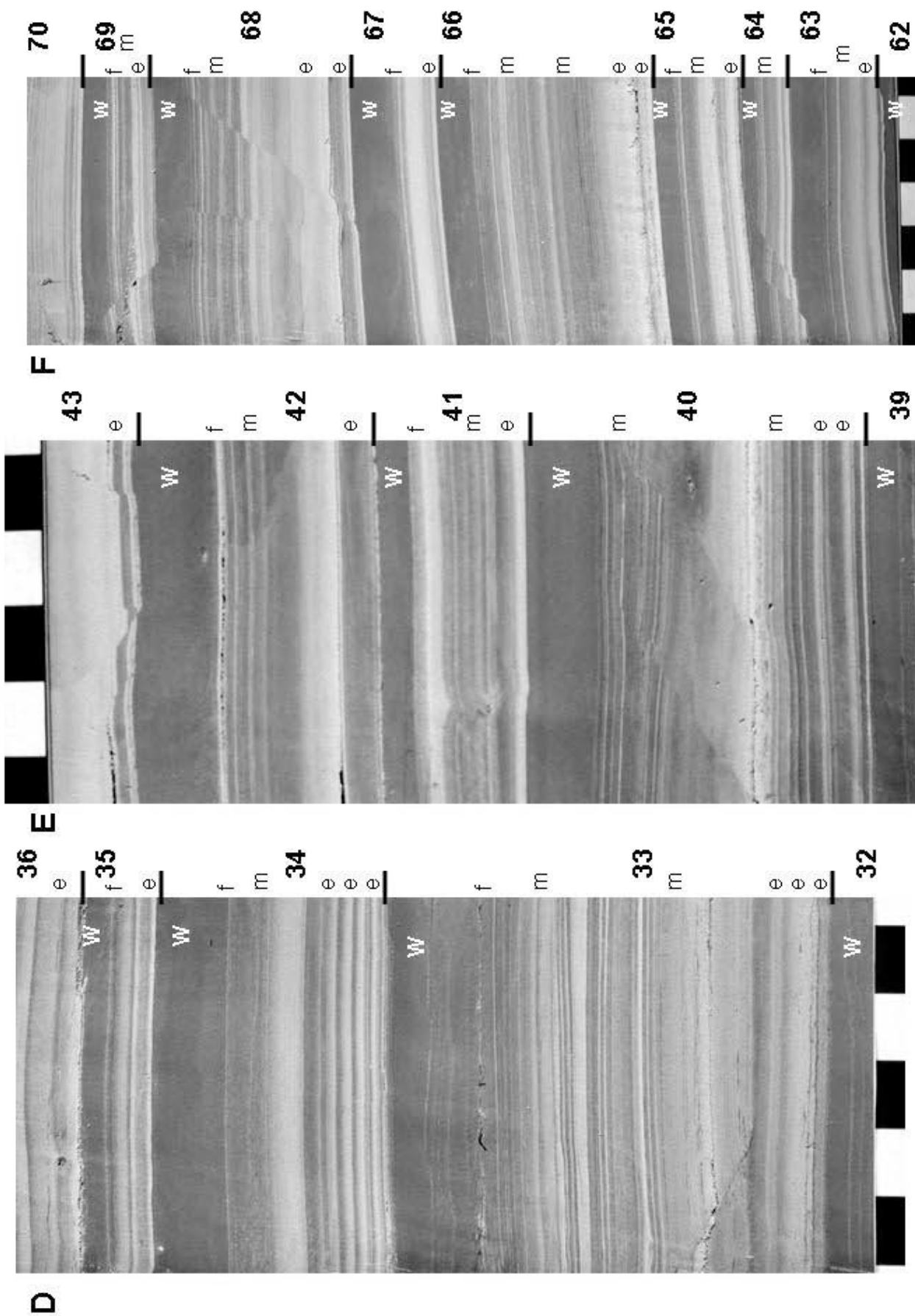
Summer layers in the Starrucca varves typically start with the coarsest and often the thickest graded unit of the summer that can sometimes overlie the preceding winter along a lightly-scoured contact. This unit appears to represent the spring melt in the form of a sudden burst of sediment carried by a very energetic current, possibly in combination with spring overturning triggered by the warming of surface water to 4°C. Following this unit other summer layers are generally thinner and usually become progressively finer upwards suggesting progressively lower sediment input and less energetic bottom currents over the course of the summer. A reduction of meltwater and sediment input over the summer may be a reflection of the depletion of snow after the early part of the melt season. Glacial ice would be the dominant source of meltwater by mid to late summer when the sun angle begins to decrease.

Analysis of high-resolution gray-scale scans of the summer stratigraphy of individual varves (Figures 34A to 34E at the end of this article) shows the complexity of the micrograded units in the summer layers of the Starrucca varves. Because they occur in packages of highly repetitive units the micrograded units are interpreted to represent diurnal cycles in sedimentation as daytime sunlight

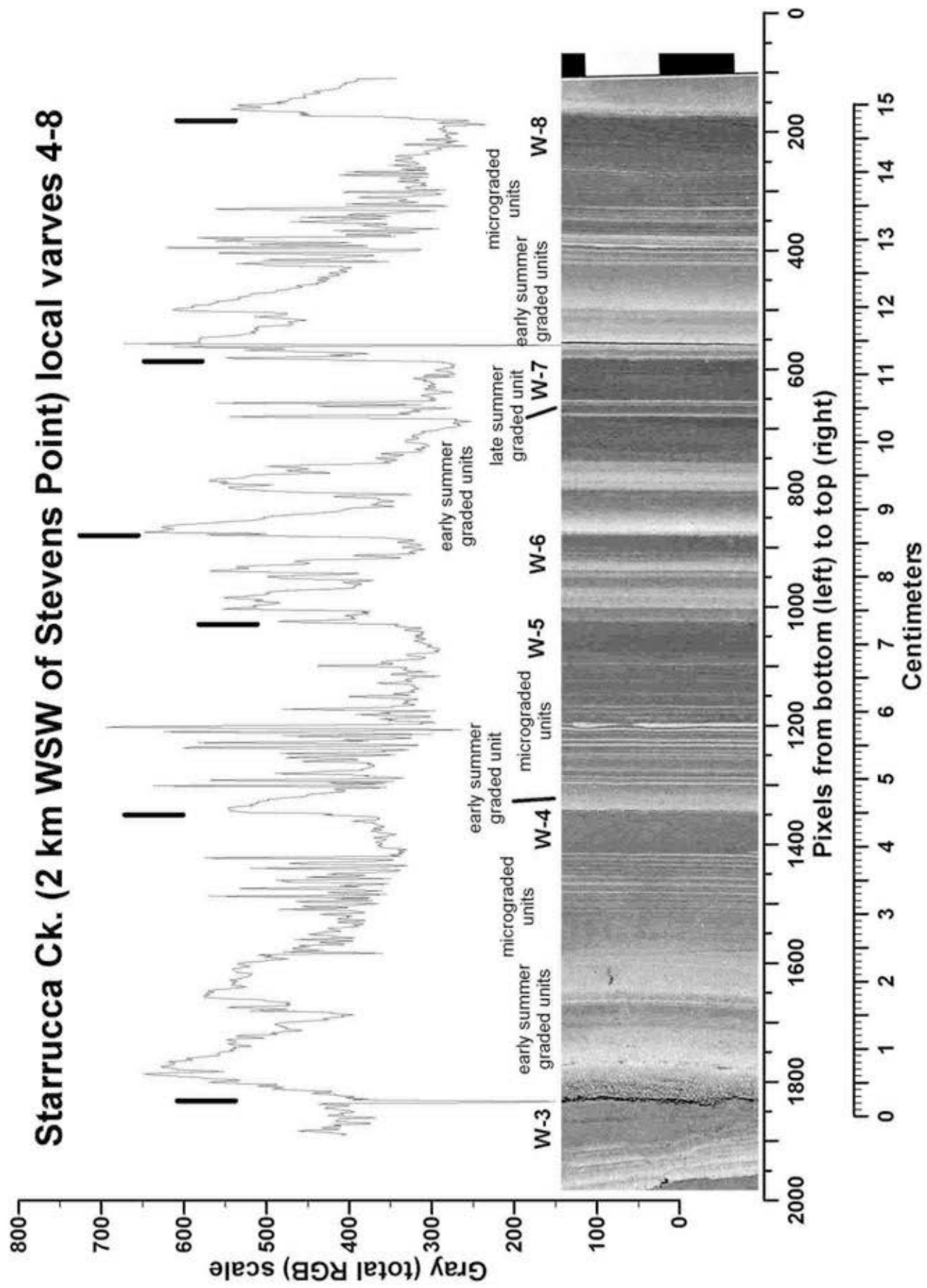
triggered melting and rapid sediment delivery to the lake and nighttime conditions reduced melting. In the thick varves analyzed with gray-scale scans there are 109, 108, and 78 individual summer units (varves 26, 28, and 43 respectively). Because it is likely that not all days of the summer, especially cloudy and cool days, are represented by micrograded units these numbers may represent the minimum number of melting days in the summer. Weaknesses of this technique and estimate are difficulties in obtaining accurate summer unit counts and the fact that it targets the thickest varves, the only varves for which a detailed analysis is currently possible. Analysis of only thick varves skews the data toward years with the highest summer sediment input, which may be the warmest and sunniest summers in the varve record.

The micrograded units that dominate the summer layer become clayey near the top of the summer layer where they may grade into the winter layer (Figures 33 and 34). However, in at least half the varves, especially higher in the section, the final unit of the summer layer is a bed coarser and often thicker than summer units immediately below it. This unit usually occurs just before winter clay deposition but occasionally just after the beginning of winter clay deposition and splits the winter bed. The origin of this prominent summer-ending unit is not known but the most reasonable explanation appears to be a late summer or fall overturning event triggered by the cooling and sinking of the lake's clay-laden epilimnion. The absence of this unit at the end of some summers would suggest that fall overturning either does not occur, which is unlikely, or that fall overturning does not always generate an aggressive current.

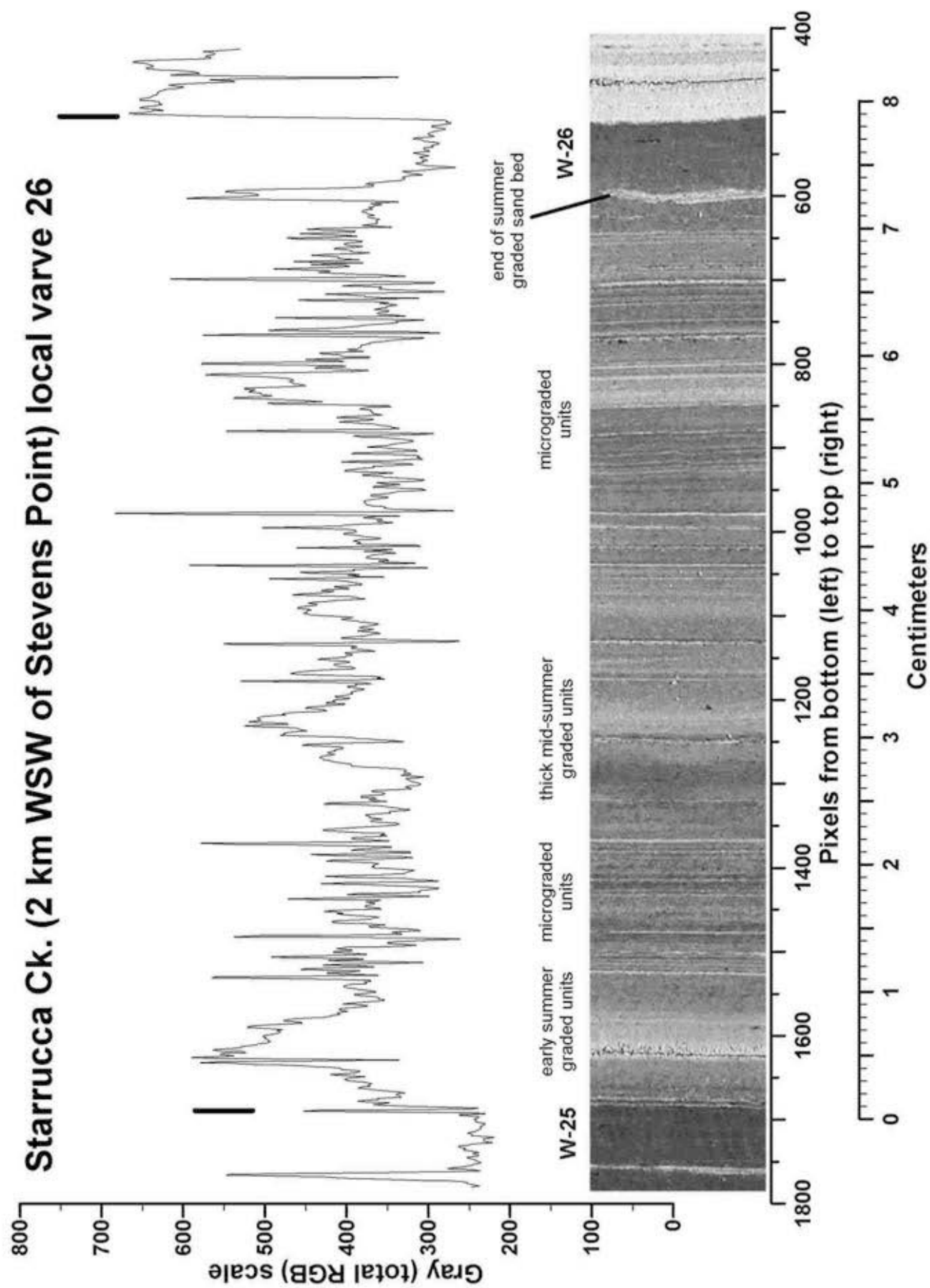




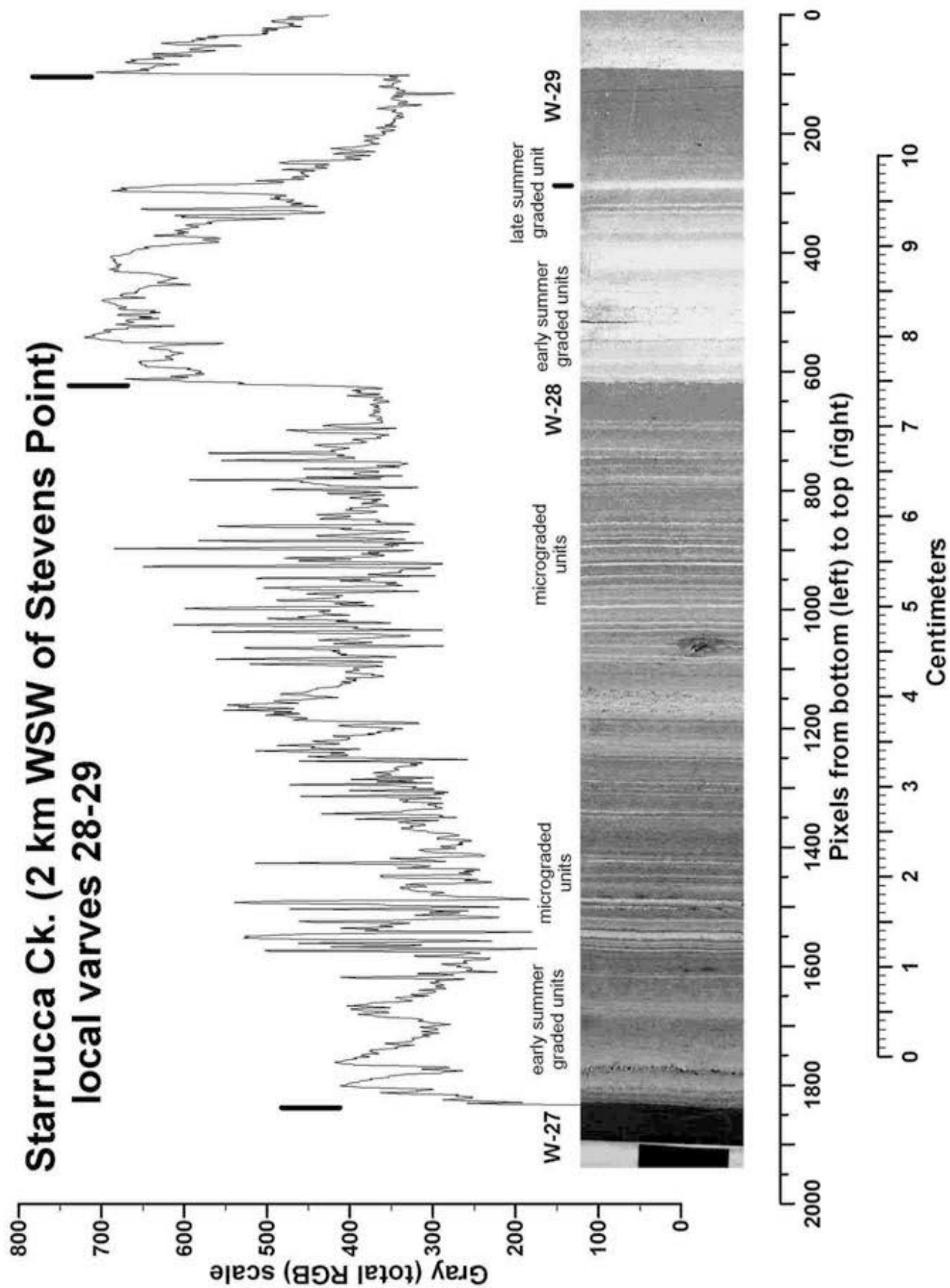
**Figures 33 D-F.** High resolution digital images of selected varves (varve numbers to right of images) from the Starrucca Creek outcrop. Scale bars are centimeters. Symbols: W = winter bed, e = early summer graded unit(s), m = micrograded unit(s), f = summer ending graded unit(s)



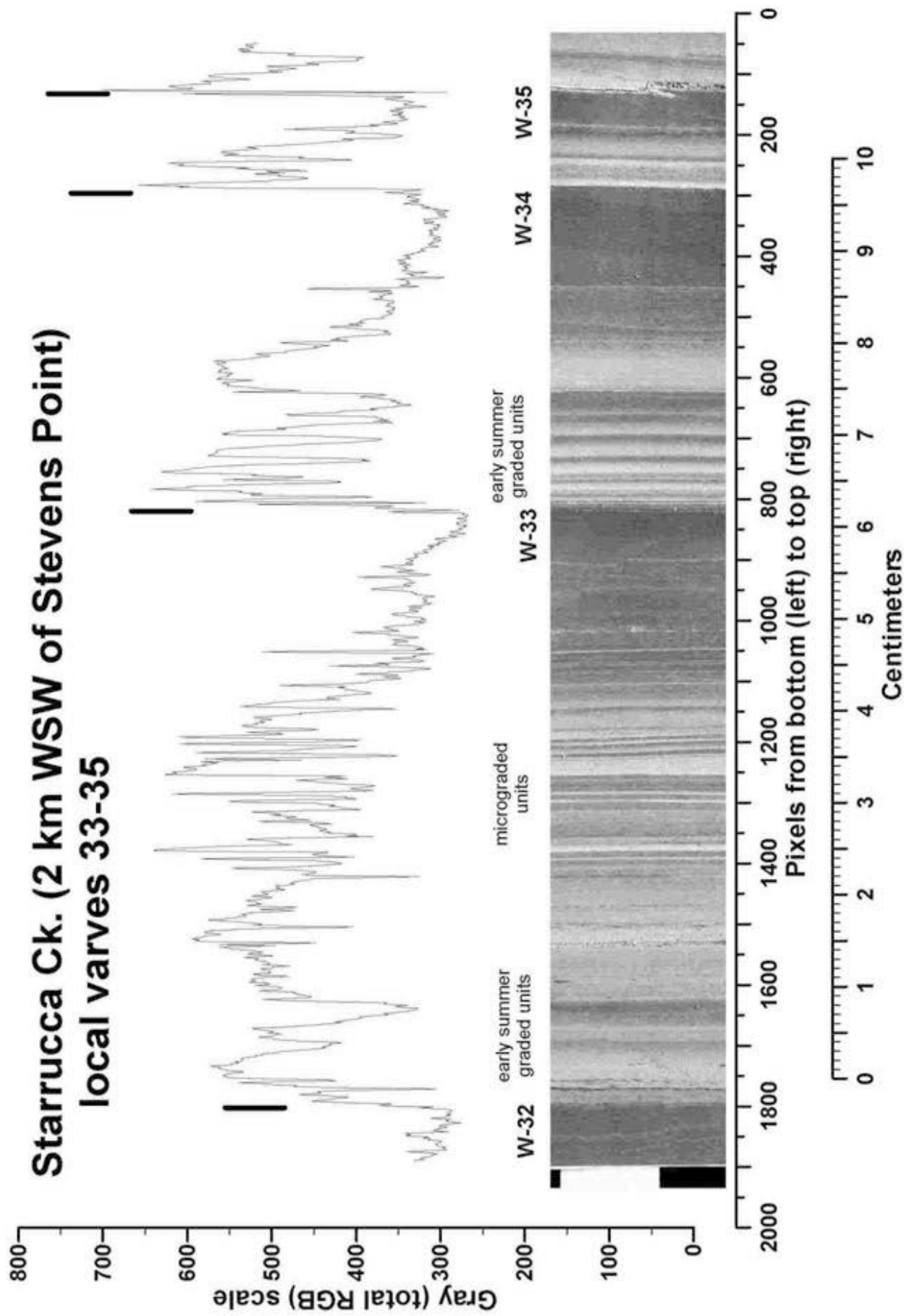
**Figure 34A.** Gray-scale (total RGB) scan and enhanced digital image of Starrucca varves 4-8.



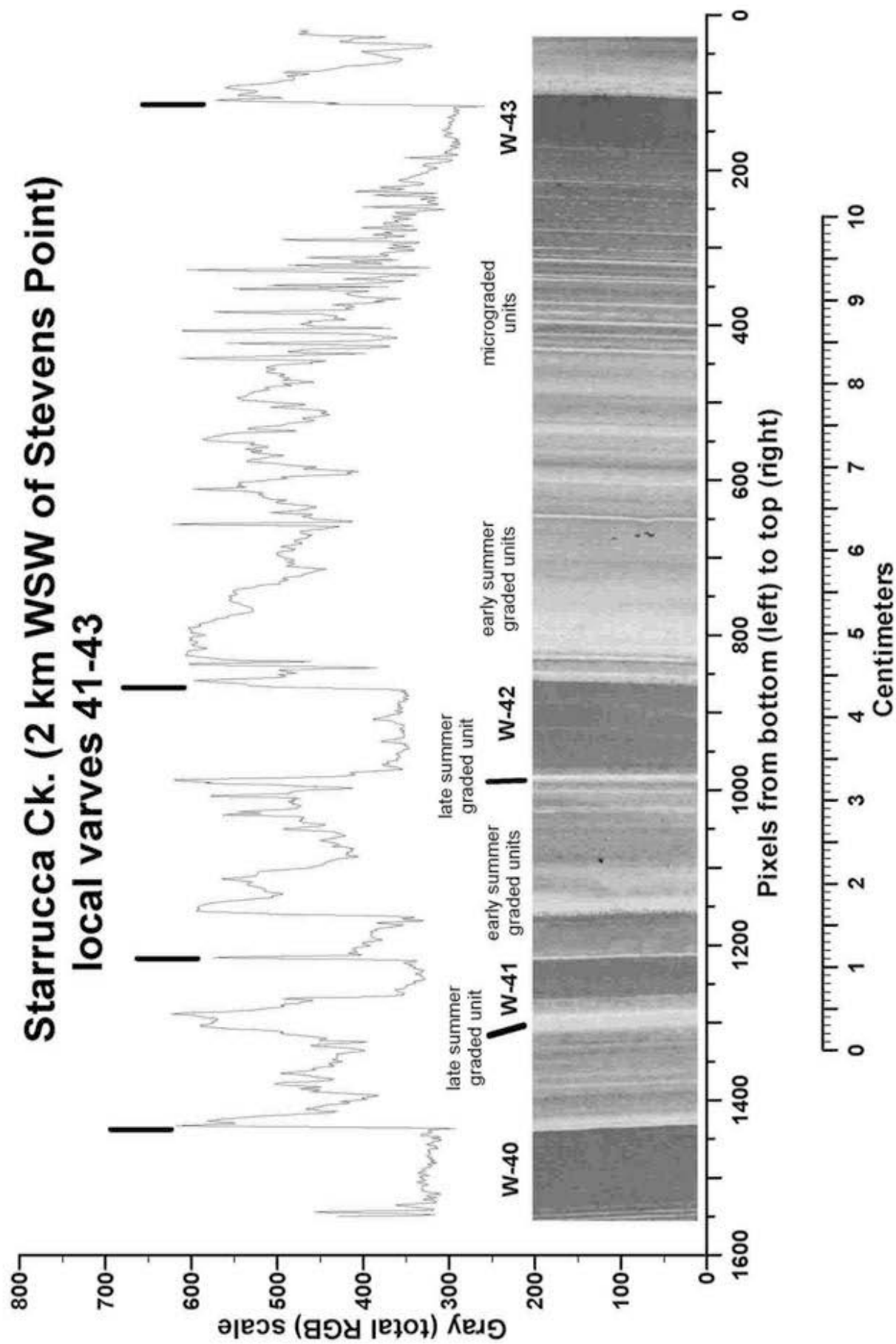
**Figure 34B.** Gray-scale (total RGB) scan and enhanced digital image of Starrucca varve 26.



**Figure 34C.** Gray-scale (total RGB) scan and enhanced digital image of Starrucca varves 28-29.



**Figure 34D.** Gray-scale (total RGB) scan and enhanced digital image of Starrucca varves 33-35.



**Figure 34E.** Gray-scale (total RGB) scan and enhanced digital image of Starrucca varves 41-43.

- Leave Stop 3, continuing straight ahead on SR 1009.
- 0.4 27.9 Cross Starrucca Creek and turn RIGHT onto the D&H Rail Trail and park along the right side of the roadway. LUNCH STOP and consolidation of people into vans or 4-wheel drive vehicles to go to Stop 4. If it has been raining the switch backs on the one-lane dead-end dirt road to Stop 4 are difficult to traverse even with 4-wheel drive.
- Leave the Lunch Stop and ascend the slope on King Hill Road to Stop 4.
- 0.3 28.2 On right going around the 2<sup>nd</sup> switchback is a sandstone ledge marking the buried ridgeline (see map, Figure 30).
- 0.6 28.8 Lake on right lies behind the till knob we have been climbing. Cross outlet to lake.
- 0.1 28.9 At junction with road to the right, turn around and head back downslope.
- 0.2 29.1 Park along the right side of the road and walk downslope to the exposure at Stop 4.

## **Stop 4 -Exposure in the core of a till knob**

Leader: Duane Braun

Glacial retreat from valleys in the moderate relief (300-500 m) Small Lakes part of the Glaciated section of the Appalachian Plateau in northeastern Pennsylvania was characterized by episodic deposition of till in a series of knobs that form “beaded valleys”. Individual valleys have a series of till knobs alternating with wetlands or lakes at a spacing of 0.2 to 5 kilometers (Figure 35). Outcrop and well data is limited for any individual knob, but a composite picture of a knob cross-section can be put together from the more than 1000 knobs mapped in region. The till knobs are typically 30 to 50 m thick. The knobs are cored by lodgement - deformation till with a thick wedge of ablation till (re-sedimented till) on their south sides, push structures in their interiors and north sides, and an overall veneer of “colluviated till” that thickens downslope on all sides (Figure 36). Glaciofluvial deposits are almost non-existent, usually showing as thin lenses on the flanks of the knobs.

The knobs are interpreted to be the periglacially and post-glacially modified remnants of recessional moraines. Individual till knobs were rapidly deposited in a few decades, possibly through layer by layer stacking of deformation till and till block melanges. The ice retreated systematically in stagnation-zone retreat mode, with active ice leaving till knobs and a 0.2 to 5 kilometer wide ice stagnation-zone leaving the lake basins (Figure 3, Quaternary History section). The till knobs can be connected from valley to valley, in lines perpendicular to ice flow, to delineate ice margin positions running across the region (Figure 35).

The slide scar exposure at STOP 4 is in the central core of the till knob, 20 to 25 meters (70 - 80 ft) below the top of the knob and 15 to 20 meters (50 - 70 ft) above the bedrock floor of the knob (Figure 36). The outcrop exposes what is interpreted to be lodgment till from its compactness, abraded clasts, platy structure, and clast fabric. Examination of the till and discussion of its mode of emplacement is one of the primary objectives of this stop. A second topic of discussion is how such a thick mass of till can be deposited rapidly during final ice recession or is the till knob a product slower deposition during the entire late Wisconsinan glacial advance and retreat? Or maybe the knob is a pre-Wisconsinan feature like some of the drumlins in New England or the cores of moraines in Ohio?? The till knob at this site is interpreted to be deposited during recession of the readvance across Glacial Lake Great Bend! The Stop 3 varve site is immediately south of this site and is overlain by till like that in this knob.

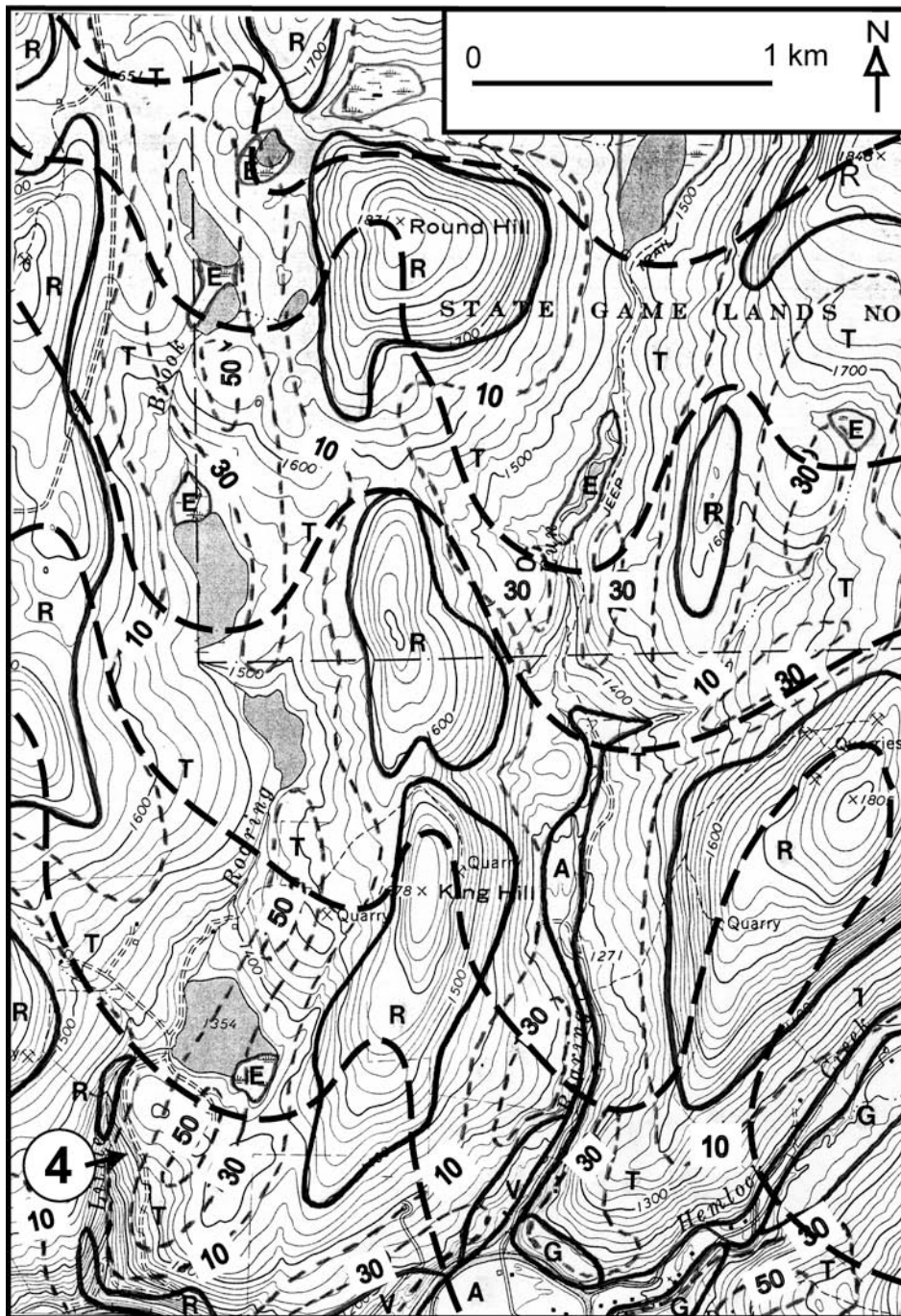


Figure 35. Glacial deposit pattern of bedrock ridges projecting through valleys mantled with thick till. Individual valleys have a “beaded” appearance from a series of till knobs and intervening lakes or wetlands spaced about one kilometer apart.

Heavy dashed lines are ice margin positions thought to be responsible for the deposition of the till knobs.

- A - Alluvium
- E - Wetlands
- G - ice-contact stratified drift
- R - Bedrock at or within 2 meters of the surface
- T - Till
- V - Till underlain by varves.

Glacial deposit thickness contours (isochores) at 10, 30, & 50 meters.

Topographic contour interval is 20 feet.

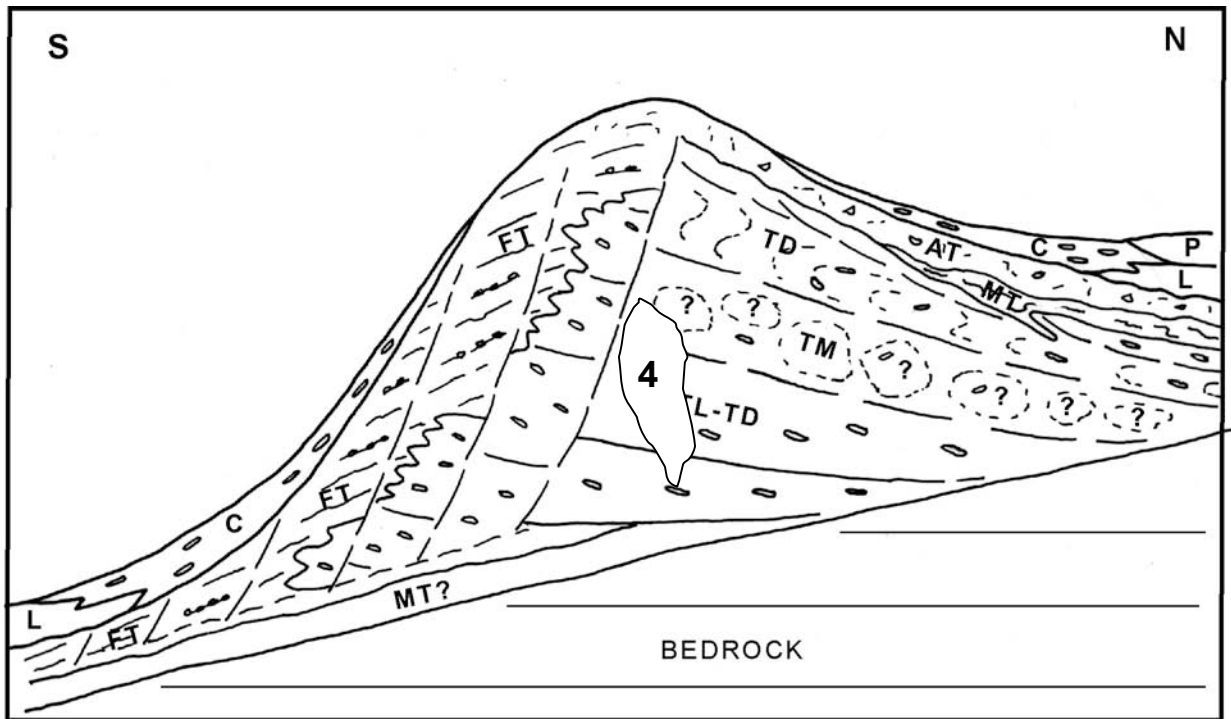


Figure 36. Cross-section sketch of a typical till knob showing the core of lodgement till (TL), deformation till (TD), and till melange (TM) flanked on the south by flowtill (FT) and on the north by meltout till (MT) and ablation till (AT). The entire knob is veneered by colluvium derived from till (C) that intertongues with lake sediments (L) and peat (P) in the lakes or wetlands to either side of the knob. Approximate position of the STOP 4 slide scar exposure is shown.

- Leave Stop 4, descending slope in low gear to preserve your brakes. You'll need them at the switch-backs though there are lots of trees along the road to stop you if you go off.
- 0.7 29.8 Lunch Stop on left, redistribute people if necessary.  
Turn RIGHT onto SR 1009 and retrace route to the Starrucca Viaduct.
- 0.2 30.0 To both sides of the road are the slump benches with sag ponds or wetlands.
- 1.5 31.5 Cross Starrucca Creek and the D&H Rail Trail to enter the borough of Lanesboro.
- 0.5 32.0 Pass under Starrucca Viaduct.
- 0.1 32.1 Turn RIGHT at stop sign onto SR 1015 and cross Starrucca Creek.
- 0.1 32.2 Turn RIGHT onto Depot Street, following signs for Luciana Park. Pass under the viaduct and over the railroad bed of the Jefferson Branch of the Erie railroad.
- 0.1 32.3 Turn RIGHT into Luciana Park. Proceed into parking area directly. Pit toilets farther ahead.

## STOP 5 Starrucca Viaduct.

Leaders: Jon D. Inners and William S. Young.

**The viaduct.** The structure is a "viaduct" because it vaults over a valley that is much wider than the stream that flows through it. (In geological terms, this generally means that the stream is "underfit" and that it at one time in its history had a much larger discharge than it does now. For Starrucca Creek here at STOP 5 and Tunkhannock Creek at STOP 11, this period of very high flow was in the glacial epoch. It is correctly called the "Starrucca Viaduct" (not Lanesboro) because the engineering convention is to name such a structure for the stream it crosses; thus the "Tunkhannock Viaduct," and the "Kinzua Viaduct," etc.

Completed in 1848, the stone-arch Starrucca Viaduct (Figure 37 and 38) is the oldest of the three great viaducts of Pennsylvania, the others being the wrought-iron Kinzua (1882, rebuilt of steel in 1900), and the concrete-arch Tunkhannock (1915) (STOP 11) (Mott et al., 1998). Only the Starrucca and Tunkhannock structures still carry trains, the Kinzua having been recently toppled by a tornado. Originally built by the New York and Erie (later simply the Erie) Railroad, the bridge eventually came under the ownership of Conrail in the 1970's and is presently owned by the Norfolk Southern Railroad.