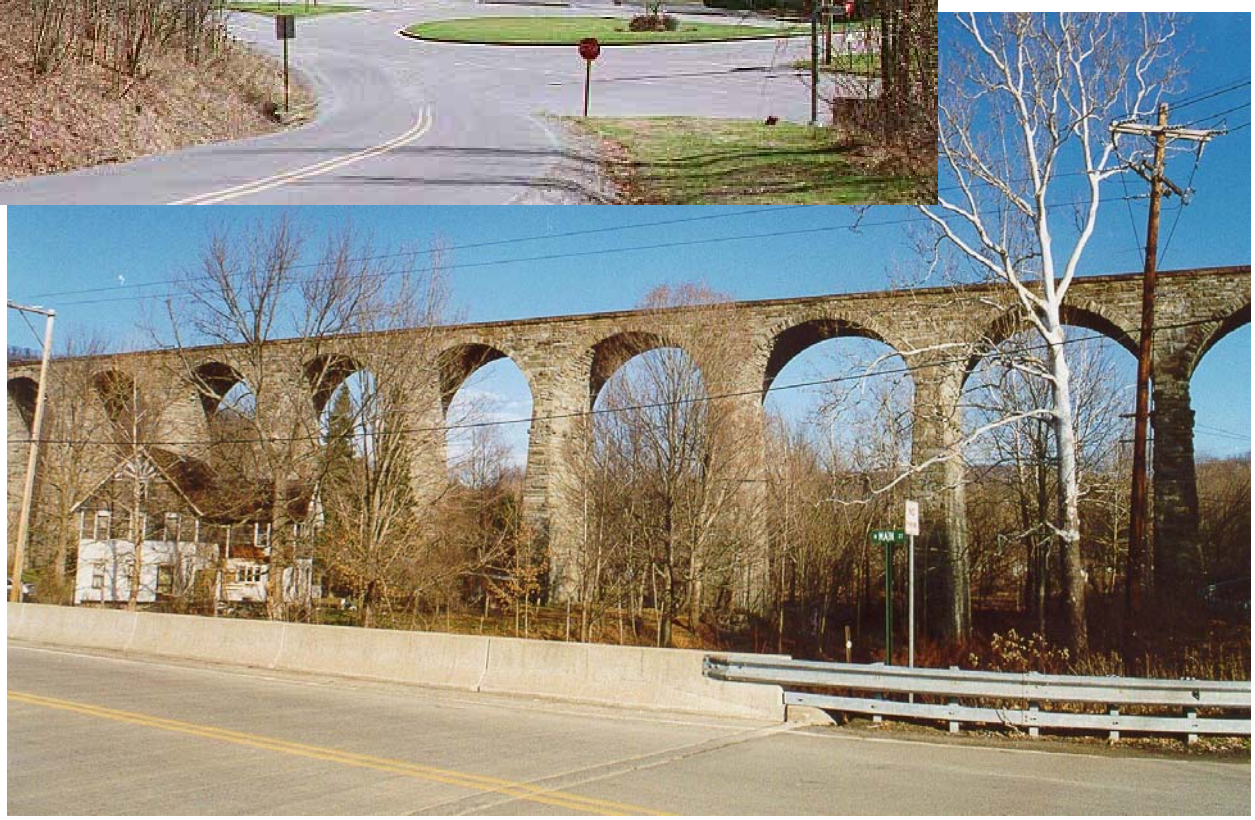
FROM TUNKHANNOCK TO STARRUCCA:
Bluestone, Glacial Lakes, and Great Bridges in the "Endless Mountains" of Northeastern Pennsylvania



67th Field Conference of Pennsylvania Geologists

October 3–5, 2002
Tunkhannock, PA

Hosts
Pennsylvania Geological Survey
Bloomsburg University
Excalibur Group, LLC
Susquehanna County Historical Society

Frontispiece- Group Photo of the 2001 Field Conference of Pennsylvania Geologists.
Stokes State Forest, New Jersey.

Guidebook for the
67th Annual Field Conference of Pennsylvania Geologists

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Bluestone, glacial lakes, and great bridges in the "Endless Mountains" of northeastern Pennsylvania

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Cover: The Tunkhannock and Starrucca Viaducts. (Photos by Jon D. Inners.)

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PREFACE

The "Endless Mountains" figure prominently in the title of this 67th Field Conference, but are virtually never mentioned in the guidebook. Why? The term is a geographical misnomer. According to Donehoo in his *A History of the Indian Villages and Place Names in Pennsylvania* (1928), it is derived from translation of the Delaware Indian word *kittatinny* ("endless") and referred specifically "to the mountain range which crosses the State from north-east to south-west, and which forms the northern boundary of the Cumberland Valley" (i.e., Blue Mountain in Pennsylvania). The original name is preserved in Kittatinny Mountain in New Jersey. Presumably, the "endless" described the fact that this ridge extends from horizon to horizon with scarcely a break. In Colonial documents, "Kittatinny," or Endless, gradually came to refer to the range of similar northeast-southwest aligned mountains that we now call the "Ridge and Valley province," or the folded Appalachians. On Lewis Evans' 1755 map, the designation "Endless Mountains" appears imprinted near modern Sunbury. Unfortunately, geographers and geologists never took up on the this perfectly reasonable geographic name for the fold belt, and it remained for a local tourism "booster" of the 1950's —Myron Shoemaker—to adapt the name to the plateau mountains of northeastern Pennsylvania, based on his reading of Evans' map (Robert Veleker, Bradford County Historical Society, 2001, personal communication). The rest, so to say is history, and the "Endless Mountains" are firmly established in the promotional and tourist literature of northeastern Pennsylvania, even receiving official sanction from the Commonwealth as the "Endless Mountains Heritage Region." But as noted above, we geologists and geographers have only ourselves to blame for not having the wit to apply the name where it should have been—and for leaving the magnificent mountains of central and east-central Pennsylvania with the lame designation, Ridge and Valley (or Valley and Ridge) province.

But as Juliet observed, "...a rose by any other name would smell as sweet," and the Endless Mountains, no matter what you call them, boast great scenic beauty, colorful human history, fascinating geology, and three of the most magnificent railroad bridges in Pennsylvania. New geologic work in the region, involving both surficial and bedrock mapping, has been funded though the STATEMAP portion of the National Geologic Mapping Act, a cooperative program between the U. S. Geological Survey and state surveys. Though these studies are now largely completed, much still needs to be done. Particularly needed are detailed studies of Catskill stratigraphy and paleoenvironments. Plenty of thesis topics are available here—and we look forward to some present or future "field trippers" putting their geologic talents to work in the "Endless Mountains."

So, as Jackie Gleason says on p. 156 of last year's guidebook, "And awaaaaayyyyyy we go!" We hope you have as much fun participating in this Field Conference as we had putting it together.

ACKNOWLEDGMENTS

The organizers and editors owe heartfelt thanks to the many individuals, businesses, and organizations that have made this 67th Field Conference possible. We are especially indebted to the geologists and historians who contributed STOP descriptions and articles to the guidebook, and to the foremen and workers who have volunteered to assist in organizing and leading conference participants at the various quarries and gravel pits. Businesses and individuals who generously allowed us to use sites on their properties for STOPS or to investigate private sites for related geologic investigations include Chet Grover, New Milford Sand and Gravel Co.; Robert Coleman and William MacDonald, Endless Mountain Stone Co; Ellis Arthur, Lynn Lenox, and Robert Barnes, State Aggregates, Inc.; Richard Masters and Robert Housel, Masters Ready Mixed Concrete Co.; and Ron Pickel, Norfolk Southern Corp. Jim McKenna, PaDEP, provided invaluable assistance during the early phases of preparation for this Conference. He would have been a major contributor to the final "product," but was seriously injured in an automobile in February of this year. (His recovery continues, but it's a slow process.) The late Rev. Garford Williams of Nicholson supplied much information on the Tunkhannock Viaduct and the DL&W Railroad. Betty Smith and Debra Adleman of the Susquehanna County Historical Society contributed both historic photos and newspaper articles on the gas wells at Salt Spring State Park, as well as numerous other historical "vignettes." Richard Howe and Brian Whelan helped in the preparation of roadlogs for both Conference and pre-Conference field trips. Gwendolyn Mott, Christopher Webster, and William Moore provided "yeoman-like" field assistance in 1997, 1998, and 2000, respectively. Mr. Joseph Skiscim, Ms. Barbara Hughes, and Ms. Erika Tilcher of Shadowbrook Inn and Resort were very helpful in setting up the food and lodging arrangements at the Conference headquarters. The editors especially thank Helen Delano and Jody Zipperer for their help at particularly important times in the preparation of the guidebook!

This Field Conference had its beginnings in an informal field trip run on June 5, 1999 (Inners et. al., 1999). The descriptions for STOPS 2, 3, 6, 7, 8, and 9 are taken partly from that 1999 guidebook.

SHADOWBROOK INN AND RESORT

Dawn view of Osterhout Mountain from in front of the motel at Shadowbrook. The flat in the foreground is alluvial terrace, the rising ground beyond is Late Wisconsinan till, and the upper slopes and summit of the mountain are bedrock (Catskill and Spechty Kopf).

The Field Conference of Pennsylvania had little choice in picking the headquarters for its 67th annual meeting. As two esteemed "Devonian sojourners" so aptly put it in the first article in this guidebook, the Endless Mountains is a region of "flat-topped hills and narrow, steep-walled valleys distant from urban centers." This part of the Commonwealth was one of the last to be settled and "even today, it seems remote…[and] most non-residents pass through on their way to somewhere else."

Shadowbrook Inn and Resort, however, is an oasis of civilization in this wilderness. It had its beginnings in 1962 as a dairy bar featuring homemade ice cream, milk, and other products made from the milk of Guernsey cows raised on an adjacent farm. Forty years later Shadowbrook has grown to include a large motel; an 18-hole golf course; a bowling alley; miniature golf course (which Gary Fleeger swears is the same one he played on as a kid in Butler County during the '60's); a swimming pool; racquetball courts; a fitness center; dining and conference facilities at the motel; and a separate restaurant right on US 6 (recently reopened as a Perkins). (And you can still get Shadowbrook's famous ice cream at a newly refurbished dairy bar.) If you can't find something to do in your "spare time" here, don't blame the Field Conference organizers or officers!

Most of the resort complex is located on an alluvial terrace enclosed within a meander bend of Tunkhannock Creek about two miles above its confluence with the North Branch Susquehanna River. Hills standing 400-500 feet above creek level border the outside of the meander on the west, north, and northeast, and rugged Osterhout Mountain (elevation 1880 feet A.T.) frames the horizon to the southeast, more than 1200 feet above the alluvial flat. Except for the very top of Osterhout Mountain (capped by Mississippian-Devonian Spechty Kopf Formation), all of the surrounding highlands are underlain by alternating gray sandstones and red shales and mudstones of the Late Devonian-age Catskill Formation. Bedding in these sedimentary rocks is generally subhorizontal. Late Wisconsinan till covers the lower slopes of all the hills, reaching 100 feet thick in pockets on Osterhout Mountain. A local thickening of this till cover forms the low hill on which the Perkins Restaurant is situated. Come to think of it, most of the geologic features we will see on the field trip can be observed within a five mile radius of Shadowbrook, so why are we traveling 200 miles over the next two days to see them? Maybe we could have planned this a little better!

LATE DEVONIAN STRATIGRAPHY IN NORTHEASTERN PENNSYLVANIA, *OR* DEVONIAN SUBDIVIDIN' AND CORRELATIN'

by
Donald L. Woodrow and Frank W. Fletcher
(Two Devonian Sojourners)

PARADIGM FOUND

Northeastern Pennsylvania is a region of rugged topography, with relief of 900 feet or more, flat-topped hills and narrow, steep-walled valleys far distant from urban centers. Only the Susquehanna and Delaware Rivers provide easy access. Forests cover most of the hills, and outcrops are scarce. Its ruggedness militates against farming and easy transportation. Historically, it was the last region of the Commonwealth to be settled by Europeans, and it was the last to receive electrical service. Even today, it seems remote, as most non-residents pass through on their way to somewhere else.

Geologists, too, have viewed the region as remote. In the 19th century, staff of Pennsylvania's Second Geological Survey worked the counties but only sketchily. In the 1930s and 1940s, Professor Bradford Willard of Lehigh University, examined rocks of the region but referred to them only sparely in *The Devonian of Pennsylvania* (1939). In the late 1950's and 1970's interest in the region revived somewhat as staff of the Pennsylvania Geological Survey prepared new 1:250,000 geologic maps of the state. Apparently, few graduate students in geology ventured into the region, with notable exceptions being (Woodrow, 1968; Rahmanian, 1977; and Loule, 1987).

However, the regional bedrock geology dataset is significant. In addition to scattered natural outcrops, the interstate and other highway upgrades provide major road cuts. Many small quarries exist and exploratory natural gas wells provide access to the subsurface. Results from various studies over the past 40 years have demonstrated that the Late Devonian of this region is made up of intertonguing marine and nonmarine strata. Deciphering the stratigraphy has been undertaken via two approaches. In one approach, stratigraphic units are defined and mapped based on their physical character and sequence (lithostratigraphy). In a second approach stratigraphic units are defined, interpreted, and mapped based 1) on their relationships within a framework of key beds and unconformities and paleontologic zones, 2) on rock-unit sequence, and 3) on physical characteristics. The second approach equates to modern-day sequence stratigraphy.

Lithostratigraphy, based on readily observable features, is a tried and true method in sedimentary geology. It is the foundation of most geologic mapping and the establishment of rock-unit sequence. In fold belts, lithostratigraphic units control topography, and geologic maps of them illustrate geologic structure. A prime example is provided by the Early Silurian Tuscarora Formation. Its quartz-rich sandstones form the backbone of numerous ridges in the fold belt, while the pattern of Tuscarora distribution shown on geologic maps outlines the regional structure.

Sequence stratigraphy and its antecedents are and have been widely used in sedimentary geology, but they are not as frequently employed in the making of geologic maps. Instead, they provide a strong basis for the interpreting the origin of rock sequences, basin analysis, paleogeographic and paleoclimatologic analysis, and establishing temporal relationships among rock masses at all scales. Examples of regions where sequence stratigraphy and related techniques have been applied with great success are the Appalachian Plateau, the Midwest and Great Plains, and the Gulf Coast. Litho-

Woodrow, D.L. and Fletcher, F.W., 2002, Late Devonian stratigraphy in northeastern Pennsylvania, *or*, Devonian subdividin' and correlatin', *in* Inners, J. D., and Fleeger, G. M., eds., From Tunkhannock to Starrucca: bluestone, glacial lakes, and great bridges in the "Endless Mountains" of northeastern Pennsylvania: Guidebook, 67th Annual Field Conference of Pennsylvania Geologists, Tunkhannock, PA, p. 1 - 7.

stratigraphy falls victim to facies variability over regions both large and small, whereas defining facies variability is the essence of sequence stratigraphy.

In the northern and northeastern boundary counties of Pennsylvania, both techniques have been applied. Results differ and the differences can be seen in the Geologic Map of Pennsylvania (Berg, Edmunds, Geyer, et al., 1980), the Pike County report of Sevon and Berg (1989) and geologic maps of three New York/Pennsylvania boundary regions: Bradford County. (Woodrow, 1968), Starrucca/Long Eddy 15-minute quadrangles (Woodrow and Fletcher, 1968, unpublished), and the Pennsylvania portions of the Milford and Port Jervis 15-minute quadrangles (Fletcher and Woodrow, 1970). (See Figure 1 for a chart of stratigraphic nomenclature.) The application of lithostratigraphy using rock subdivisions defined in the Lehigh and Susquehanna valleys resulted in large areas of New York/Pennsylvania boundary regions covered by a single geologic symbol on the 1980 Geologic Map of Pennsylvania. This simple map pattern implies homogeneity of rock sequence that is not observed in the field and which tells us little about local geologic structure. On the other hand, the three county maps based on sequence stratigraphy display symbols for several stratigraphic units, which more faithfully record the variations in rock types and rock structure.

AGE	BRADFORD COUNTY			STARRUCCA & POND EDDY QUADS.			PIKE COUNTY			
	Woodrow, 1968			PA Geologic Map, 1980	Woodrow and Fletcher, unpub	Wagner, 1963	Fletcher and Woodrow, 1970		Sevon and others, 1989	
Carboniferous	Pocono			Huntley	Pocono	Pocono				
				Mountain Fm.	Removed by erosion					
		Sunfish Fm.			Mt. Pleasant Fm	Mt. Pleasant Fm				
	Canadawa	Towanda Fm.	Luthers Mill			Elk Mountain Fm.				
	Group		Coquinite Mem.							
					Cherry Ridge Fm	Cherry Ridge Fm.				
		Dunkirk Fm.		Catskill Fm.						
	Java Gr.	Wiscoy Fm.	Fall Creek		Honesdale Fm.	Honesdale Fm.				
		Pipe Creek Fm.	Conglomerate Mem.							
	West	Nunda Fm.			Stockport Fm.	New Milford Fm.		Removed by erosion		
	Falls	Gardeau Fm.	Corning Mem.							
Upper	Group	Rhinestreet Fm.	Roricks Glen Mem.		Walton		Walton	Lackawaxen Fm.	Catskill	Lackawaxen Mem.
Devonian					Group		Group	Shohola Fm.	Group	
					(Undifferentiated	Delaware		Delaware		Delaware
	Naples	Undifferentiated below the			below the	River Flags		River Fm.		River Mem.
		Rhinestreet. Not exposed.)			Walton. Not					Towamensing Mem.
				Lock Haven Fm	exposed)	(Analomink?)				
						Trimmers Rock		Millrift Fm.	Trimmers	Millrift Mem.
	Genesee							Sloat Brook Fm.	Rock Gr.	Sloat Brook Mem.
		Tully Ls.		Tully Ls.	Tully equivalents	Tully equivalents		Sparrow Bush Fm.	Tully equivalents not recogni	

Figure 1. Stratigraphic nomenclature in the border counties of northeastern Pennsylvania, Bradford County to Pike County.

We field trippers might say: So what? How is this difference of approach not just an exercise in stratigraphic butterfly-collecting?

The most general answer is that the two approaches are attempts by the geologists involved to arrive at an understanding of the rock section simple enough to convey on a map. Making such maps is an important purpose of geology, some would say, **THE** purpose. Another response is that the two approaches were designed to meet different needs. Lithostratigraphy has as its goal the delimiting of rock masses. Time is not an issue. It is the method of choice where folded sedimentary rocks are involved, and it yields excellent geologic maps of those regions. However, it is a blunt instrument for geologic studies requiring knowledge of rock unit interrelationships and the placement of rock units in a time framework. Lithostratigraphers usually provide us with maps. Sequence stratigraphers may provide maps, but their products more often include correlation charts, facies diagrams, and computer-generated block diagrams of rock masses at depth, which may or may not be temporally constrained.

"THE NATURAL ORDER OF STRATA"

We have divided the rocks of the northeastern corner of Pennsylvania into six mappable units (from oldest to youngest): Walton Group, Stockport Formation, Honesdale Formation, Cherry Ridge Formation, and Mount Pleasant Formation.

Walton Group

The oldest rocks that are exposed in the region are assigned to the Walton Group. Fletcher (1963, 1964) defined the Walton Group for rocks that crop out in the vicinity of Walton, New York (Delaware County) and mapped the unit throughout the Catskill Mountains and into the Delaware River Valley adjacent to northeastern Pennsylvania. Strata of the Walton Group occur only in the subsurface throughout most of northeastern Pennsylvania, but they are exposed on the surface in the Milford and Port Jervis region.

White (1881) first studied the strata now assigned to the Walton Group and placed them in his New Milford Group. We, however, were unable to distinguish the various subdivisions of White's New Milford Group in the type region and could not trace any of these strata with certainty into the Starrucca region. An example of the problem inherent in using the term New Milford in a regional sense can be seen in White's tracing of the "New Milford lower sandstone" (a part of the lowest sequence of Catskill strata) from the type region northwestward to Deposit, New York and then southward along the Delaware River to the New York state line where it is, as White (1881, p. 69-70) stated "beneath the river bed." The problem that White faced in attempting to trace through this region an individual series of strata that occur near the base of a larger unit of red rocks and gray, cross-stratified sandstones is, as well samples from an exploratory gas well (Doyon No. 2) demonstrate, that the base of the red Catskill facies descends approximately 1,400 feet in the stratigraphic section along a line eastward and southward from the type region of the New Milford Group to the Delaware River. Willard (1939) recognized this facies change and made White's New Milford Group equivalent to his Shohola Formation. Unfortunately, this maneuver provides no solution to the mapping problem because the strata in question bear scant lithologic resemblance to those of the type Shohola Formation. In sum, the name New Milford is inapplicable for these strata because of miscorrelation, and, likewise, the name Shohola cannot be applied because of fundamental lithologic differences. Thus, we have extended the Walton Group into northeastern Pennsylvania from New York based on lithologic similarity and equivalent stratigraphic position.

Approximately 500 feet of strata assigned to the Walton Group are exposed in the Starrucca region. They consist of fine- to medium-grained, medium-gray (N5-6) to greenish-gray (5GY5/1-6/1) sandstones and siltstones and gray (N3-4), olive (5Y shades), and red (5R4/2) shales and sandstones. Crossbedding and parting lineations are common; ripple marks are rare. Fining-upward cycles with fine- to medium-grained, greenish-gray sandstones at the base and red shale or claystone at the top are common. Thin lenses of intrasparrudite are sometimes observed at the base of the lowest sandstone unit of the fining-upward cycle. Plant fossils are common in these strata throughout the region, and fragments of invertebrate fossils have been observed at one locality.

The upper boundary of the Walton Group is placed at the top of a thin sequence of dark-gray (N3-4) shales correlated with the Roricks Glen Member of the Rhinestreet Formation in adjacent New York (Rickard, 1964). The base of the Group is not exposed in this region, but it is placed (in the Doyon No. 2 well, at depth 810 feet) at the lower boundary of a sequence of red shales and greenish-gray sandstones. Given these boundaries, the Walton Group has a thickness of approximately 1,260 feet.

Stockport Formation

We proposed the name Stockport Formation for the strata that overlie the Walton Group (Woodrow and Fletcher, 1972, unpublished). The type section consists of a series of exposures on the south side of a gravel road that parallels Stockport Creek, Buckingham Township, Wayne County. The paucity of exposures throughout the region makes accurate determination of the thickness of the unit difficult, but it has been measured as 650 feet in the Heightman No. 1 well and 560 feet in the Hudson Realty No. 1 well. The lower boundary is placed at the top of the dark-gray shales of the Walton Group; the upper boundary is placed at the top of another series of dark-gray shales, which, based on their distinctive character and stratigraphic position, are believed to be equivalent to the Corning Member of the Gardeau Formation (Woodrow, 1968, Rickard, 1964). White (1881) referred these strata to the New Milford Group. Willard (1936, 1939) placed them in the Shohola Formation. We have rejected these interpretations based on arguments presented in the previous section.

The Stockport Formation is composed of greenish-gray (5GY5/1-6/1) very fine to medium-grained sandstones and red (5R4/2) claystones and siltstones. These rocks commonly occur in fining-upward cycles: sandstones grading upward into claystones. Like the basal sandstones of the fining-upward cycles of the Walton Group, those of the Stockport Formation sometimes contain lenses of intrasparrudite. Plant fossils are common, but no invertebrate fossils were observed during the field study. Evidence from both surface and subsurface samples indicates a change to non-red facies within the unit southward from the Heightman No. 1 well and westward from the Hudson Realty No. 1 well. These non-red strata are the equivalent of the Gardeau Formation, which occurs 35-50 miles west of Wayne County.

Honesdale Formation

First defined by White (1881, p. 66-68), the stratigraphic term Honesdale has been widely used in northeastern Pennsylvania by subsequent geologists and was adapted readily by Willard (1939, p. 288-291). White recognized a tripartite subdivision at the type section at Honesdale, Pennsylvania. Willard, however, concluded that these three subdivisions could not be mapped beyond the type region and recommended that the scheme be discarded (Willard, 1939, p. 288). We chose to retain the name Honesdale and assign to it 950 feet of strata which are informally divided into two parts: an upper member of red shales and medium- to coarse-grained, pebbly sandstones and a lower member similar in lithology and sequence to the underlying Stockport Formation. The upper member is 700 feet thick, and the lower member is approximately 250 feet thick. We were able to map these units separately across the southernmost two-thirds of the Starrucca 15-minute quadrangle, but they appear to be indistinguishable toward the northwest, illustrating the stratigraphic problems posed by the marked facies changes that occur from southeast to northwest across this region.

The lower member of the Honesdale Formation is composed of fine- to medium-grained, greenish-gray (5GY6/1) sandstones and red (5R4/2) shales and claystones, which occur in fining-upward cycles. In contrast, the upper member is made up of pebbly sandstones and numerous, thickly bedded red shales and claystones. These sandstones contain scattered pebbles of pink or white quartz. Intrasparrudites are rare in both members. Additionally, it appears that the sandstones of the Honesdale Formation are generally lighter in color than the sandstones of the units both beneath and above. This characteristic, which is enhanced on weathered surfaces, serves as a useful guide to identification. Another characteristic of the upper member is the brown-spotted appearance on weathered surfaces of the sandstones, caused by the presence of small limonitic patches. Parting lineations are generally rare but are best developed in the lower member.

Cherry Ridge Formation

White (1881) defined the Cherry Ridge Formation as a stratigraphic unit separated into five subdivisions: Cherry Ridge conglomerate (20-25 feet thick), Cherry Ridge shales (20-25 feet thick), Cherry Ridge sandstone (15 feet thick), Cherry Ridge limestone (5 feet thick), and Cherry Ridge red shale (100-110 feet thick). The formation is poorly exposed in northeastern Pennsylvania, and the thin subdivisions defined by White are not resolvable as mappable units because they are not unique in lithology or stratigraphic sequence. Willard (1939) arrived at this same conclusion and refused to subdivide the formation.

We chose to retain the Cherry Ridge Formation as a stratigraphic unit, but we have expanded it to include White's "Elk Mountain" gray shale (1881, p. 64). Our examination of the type section at Elk Mountain demonstrated that the rocks to which White referred are indistinguishable from those above and below the strata of the Cherry Ridge Formation. White himself seems to have been unsure about just what was contained in the unit, because after naming it as a gray shale he went on to say, "...it consists largely of gray, red, and spotted shales, with few sandstone layers" (White, 1881, p. 64). Willard (1939) attempted to resolve this inconsistency by redefining the Elk Mountain Formation as a sandstone unit, assigning to it the rocks exposed west of Honesdale, near Prompton, Pennsylvania. He stated further that the outstanding characteristic of these rocks is their well-developed cross-strata, but our studies elsewhere in Pennsylvania and in New York in similar Late Devonian rocks illustrates that no regionally mappable unit exists that possess cross-stratification unique enough to serve as the single most distinctive feature of the unit. Consequently, we have rejected the use of the term Elk Mountain Formation.

The Cherry Ridge Formation is characterized by fine- to medium-grained, greenish-gray (5GY5/1-7/1) sandstones and red (5R4/2) shales arranged in fining-upward cycles. Crossbedding and parting lineations are common and well developed. Whereas the gross attributes of the unit are comparable to the strata beneath it, the Cherry Ridge Formation includes thick beds of intrasparrudite (the "calcareous breccia" or "agglomerates" of White, 1881, and the "glomerates" of Willard, 1939). White's description of these rocks makes clear their lithologic character: "...an agglomeration of chips of slate or shale—fish bones and fragments—pieces of fossilized wood—and often a large quantity of sand—all connected together by lime (1881, p. 65)." We have found this distinctive rock type at several horizons in the Cherry Ridge Formation. Although examples of this intrasparrudite are seldom found *in situ*, large weathered blocks of intrasparrudite with a dark brown, pitted appearance are so characteristic of the float blocks of the unit that concentrations of these blocks in open fields and on hillsides can serve as useful mapping tools. Willard (1939, p. 285) evidently believed that this rock type comprised a single bed—"a useful key bed," as he put it—which he referred to as the "Dyberry glomerate"; however, our studies have demonstrated that this unit cannot be distinguished from similar rocks occurring throughout the Cherry Ridge Formation.

The Cherry Ridge Formation is approximately 1,100 feet thick in the Hudson Realty No. 1 well. Its base, which is transitional through 100 feet, is placed at the lower boundary of a section characterized by numerous beds of intrasparrudite. The upper boundary is placed sharply at the base of the conglomerate contained in the overlying Mount Pleasant Formation. Because exposures of the formation are so scattered and small, it is difficult to obtain accurate information concerning the unit's thickness away from the well. We estimate the total thickness of the Cherry Ridge Formation to approach 1800 feet in the vicinity of Mt. Ararat (Starrucca 15-minute quadrangle, Orson 7.5-minute quadrangle).

Mount Pleasant Formation

The youngest Upper Devonian rocks of the region are assigned to the Mount Pleasant Formation. White (1881, p. 58) referred to these rocks as "transition layers, Sub-Pocono" and included with them, as an informal unit, the Mount Pleasant Conglomerate. Willard (1936, 1939) renamed all of these strata the Mount Pleasant Red Shale and stated that the unit contains 500 feet of strata dominated by red shales and sandstones. We retained the name Mount Pleasant because it denotes a readily mappable sequence of distinctive rocks.

Red strata appear to make up almost 75 percent of the formation, and most of them are at least mildly calcareous. Although red siltstones and sandstones are present in the Mount Pleasant Formation, red shales and claystones are most common. The shales are typically silty and fissile, and the claystones are silty but lack clearly defined stratification. Small calcareous nodules, gray (N5) to pale red (10R6/2), are found in the claystones and shales. These nodules are notably absent from older units and, thus, comprise a useful feature for identifying the formation. Sandstones are fine- to coarse-grained, greenish-gray (5GY6/1), light gray (N6-7), and pale red (5R5/2-5YR5/2) and react readily to HCl. Although rare, conglomerates and conglomeratic sandstones, with both white and pink quartz pebbles, may also be found in the Mount Pleasant Formation. Thin lenses of intrasparrudite are present at the base of sandstones of fining-upward cycles, but make up a small part of the total sequence. The calcareous clasts of the intrasparrudites exhibit the same size, shape, and general appearance as the nodules found in the claystones and shales of the formation and may represent lag deposits.

The base of the Mount Pleasant Formation is only poorly exposed in this region; the upper boundary is exposed to the south of the region in the Honesdale 15-minute quadrangle. Conglomerates mark both boundaries and these, together with distinctive red soils, may be traced across a relatively broad outcrop belt.

RED BEDS, BLACK SHALES AND ANCIENT LANDS

The Upper Devonian rocks of northeastern Pennsylvania represent deposition chiefly in non-marine environments. See Woodrow and Fletcher (1968) for a more extensive description of the paleogeography of northeastern Pennsylvania during the Late Devonian. The most common characteristic of the strata are the fining-upward cycles: basal gray, cross bedded sandstones containing plant fossils and locally quartz pebbles and intrasparrudites lying directly above an erosion surface and grading upward to red sandstone, siltstone, and at the top of the cycle, claystone with bioturbated bedding. These features are reported to occur in fluvial deposits throughout the world. Only near the base of the Walton Formation, in the vicinity of obvious marine-to-non-marine facies changes have we observed marine invertebrate fossils. These consist of brachiopods, crinoids, and trilobites and typically occur in the gray sandstones.

Walton Formation. We have interpreted the rocks of the Walton Formation as indicative of non-marine deposition on a lowland alluvial plain. During most of this deposition basin subsidence did not keep up with sedimentary infilling and non-marine sediments built into the basin toward the west and northwest. Deposition of the fining-upward cycles was interrupted by deposition of the muds that form the dark-gray shales at the top of the formation. Geologic mapping in adjacent parts of New York by Sutton (1963) and Fletcher (1964), as well as interpretation of subsurface data, indicates that these dark shales are the eastern equivalents of an extensive sheet of dark-gray and black shales—the Roricks Glen Member of the Rhinestreet Formation (Rickard, 1964). Intercalations of these dark-gray strata in an otherwise repetitive sequence of red and greenish-gray rocks is similar to the pattern of Upper Devonian strata described by Woodrow (1968) in Bradford County. In that region dark-gray shales intercalated with fining-upward cycles are seen as the product of shoreline flooding and stream drowning. Dark-gray muds were deposited in drowned streams and over submerged parts of the alluvial plains and backshore lowlands. The striking similarity of the rock types in the two regions suggests a common origin for both. Moreover, the appearance of regionally extensive, dark-gray shales indicates an increase in subsidence sufficient to restrict and reverse basin-ward migration of the non-marine facies represented by the strata of the Walton Formation. During this time of restricted depositional basin, dark-gray muds were deposited over older, originally non-marine deposits. Finally, subsidence of the basin slowed and the non-marine sediments built back over the dark muds. Evidence from cross bedding measurements and the general direction of major facies changes indicate that basin filling took place from east to west across the region.

Stockport Formation. The rocks of the Stockport Formation demonstrate a continuation of the pattern established during the deposition of the Walton Formation. Like the Walton Formation the Stockport Formation consists of a thick series of repetitive fining-upward cycles marked by dark-gray shales at the top of the unit. Depositional events on the lowland alluvial plain appear to have been interrupted, as in the case of the older strata, by shoreline flooding and stream drowning during a period when the rate of basin subsidence was sufficient to halt for a time the basinward encroachment of non-marine facies.

Honesdale Formation. A change in the depositional framework is indicated at the boundary between the Stockport Formation and the Honesdale Formation, because the latter unit contains a greater volume of medium-grained sandstones than does the Stockport Formation and marks the appearance of conglomeratic lenses. Additionally, while fining-upward cycles are common in the Honesdale Formation, lenses of intrasparrudite are thicker than those of older units. The upper part of the Honesdale Formation marks a return to deposition of finer-grained sediments. Sandstone predominates in this formation, but red claystones and silty shales are more common than in older units. Indeed, the stratigraphic equivalents of the upper Honesdale rocks in the quadrangles south and southwest of this region appear to be the "Damascus Red shale" of Willard (1939).

Cherry Ridge Formation. Lithologic characteristics of the Cherry Ridge Formation suggest that these sediments were deposited on a higher part of the alluvial plain than the sediments of the older units. Here stream velocity was greater than in previous periods. The streams flowed sufficiently fast to erode, transport, and deposit the coarse fragments found in the intrasparrudites. These streams likely removed much of the finer-grained flood deposits in the interfluves during floods. At the same time conglomerates and conglomeratic sands were being formed to the southeast of the present-day Milford (Pike County) region, where very coarse sediments were deposited near the basin margin.

Mount Pleasant Formation. Lithologic evidence suggests that the rocks of the Mount Pleasant Formation were formed on an elevated region of the alluvial plain. They are strikingly unlike those of the underlying Cherry Ridge Formation, being dominantly red and typically calcareous. The water table of the depositional site must have been low much of the time in order to account for the thickness of red strata. The calcareous aspect of this unit may be explained by the low water table (and inferred aridity), which would yield upward percolation of ground water and deposits of calcareous materials in the upper part of the sediments. Further, in all of the units beneath the Mount Pleasant, directional indicators point to currents flowing westerly. Cross bedding down-dip azimuths measured in the Mount Pleasant strata exposed on the west and north flanks of the Lackawanna syncline indicate flow to the south and southeast. This evidence suggests that sediment transport during the deposition of the Mount Pleasant sediments was from the north, northwest, and southeast, into a region of relatively rapid subsidence at the present-day site of the Lackawanna syncline.

PALEOENVIRONMENTAL INTERPRETATION OF A MARGINAL-MARINE ENVIRONMENT: THE CATSKILL FORMATION (UPPER DEVONIAN) AT WYALUSING ROCKS, PA

by
Jennifer M. Elick

INTRODUCTION

Figure 2. Wyalusing Rocks, looking south down the valley of the North Branch Susquehanna River. The projecting rock strata (lowermost Catskill Formation) are part of the study interval. (Photo by J. D. Inners.)

Although renowned for its scenic qualities, the cliffs at Wyalusing Rocks (Figure 2) and the roadside exposures located along US 6 (Bradford County) contain many interesting sedimentary and biogenic structures and fossils. Here the Upper Devonian Catskill Formation records a transition of sea-level fluctuation that marks the onset of major environmental change related to the Acadian Orogeny. This interval may help to provide a better understanding of the paleoenvironmental stresses acting on Devonian organisms like fish (placoderms and crossopterygiian), plants (coastal and "upland" floodplain types), and invertebrates. By combining what we know about the lithofacies and paleontology of this and other Devonian deposits, a better understanding of the paleoecology of late Paleozoic marginal-marine environments can be established. Additionally, the interpretation of this and other similar environments at the same stratigraphic level may help differentiation of the undivided uppermost Devonian in northeastern Pennsylvania. *It should be noted that this is a report of preliminary findings from Wyalusing Rocks; some of the identifications of fish and trace fossils are considered tentative and may be subject to change.*

NOTE: The land east of US Route 6 and the land upon which Wyalusing Rocks is located are owned by the East Delaware Valley Native American Tribe. All fossil collection and research on this property must be arranged with the tribal council. The exposures at the overlook are very steep; special precautions should be taken when descending the overlook.

Elick, J.M., 2002, Paleoenvironmental interpretation of a marginal marine environment: the Catskill Formation (Upper Devonian) at Wyalusing Rocks, PA, *in* Inners, J. D., and Fleeger, G. M., eds., From Tunkhannock to Starrucca: bluestone, glacial lakes, and great bridges in the "Endless Mountains" of northeastern Pennsylvania: Guidebook, 67th Annual Field Conference of Pennsylvania Geologists, Tunkhannock, PA, p.8 - 14.

STRATIGRAPHIC POSITION OF THE STRATA AT WYALUSING ROCKS

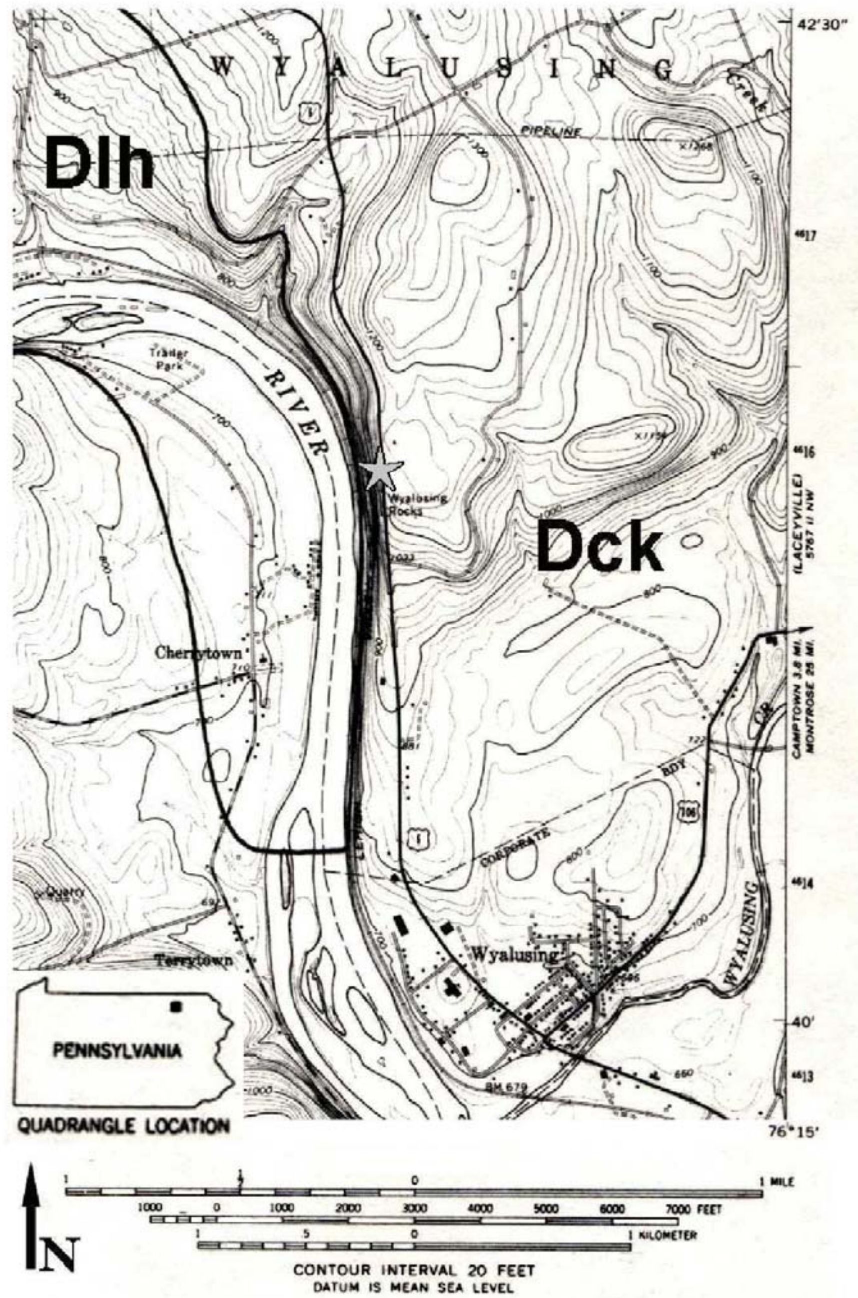


Figure 3. Location of Devonian deposits at Wyalusing Rocks (star). Dlh=Lock Haven Formation and Dck=Catskill Formation.

The Geological Map of Pennsylvania (Berg et al., 1980) and the preliminary geologic map of the Wyalusing quadrangle (Sevon, 1981) identify the exposures at Wyalusing Rocks as belonging to the Catskill Formation (Dck undivided) and the Lock Haven Formation (Dlh) (Figure 3). The Lock Haven, which stratigraphically underlies the Catskill, forms steep cliff exposures from water level to approximately 160 feet above the Susquehanna River. The lower part of the Catskill Formation forms the remaining steep cliff exposures to the top of the mountain.

The exposures at Wyalusing Rocks correspond to a description of Upper Devonian rocks labeled “Formation B” by Woodrow (1963), which places them stratigraphically at or near the base of the Catskill Formation (Frasnian-Famennian). This part of the Catskill Formation is situated in between gray-green marine facies and probably represents the interfingering relationship of marine- and continental-dominated facies (Figure 4).

FACIES DESCRIPTIONS AND INTERPRETATIONS

The gently south-dipping succession at Wyalusing Rocks is predominantly composed of interbedded sandstone and fine shale and siltstone deposits (Figure 5). Although the roadside exposures offer the safest, most complete sections of rock, exposures along the overlook provide a weathered profile that clearly reveals many sedimentary features that are not obvious along the road. There are 4 different facies that can be recognized at Wyalusing Rocks and in the northern part of the rock cut on US 6 directly to the east: (A) a levee/bar facies, (B) floodplain/overbank facies, (C) a channel sandstone facies, and (D) a marine to brackish water facies. The lithofacies described here are commonly laterally discontinuous and pinch out, producing a complex array of interfingering units. These facies and their components are described below:

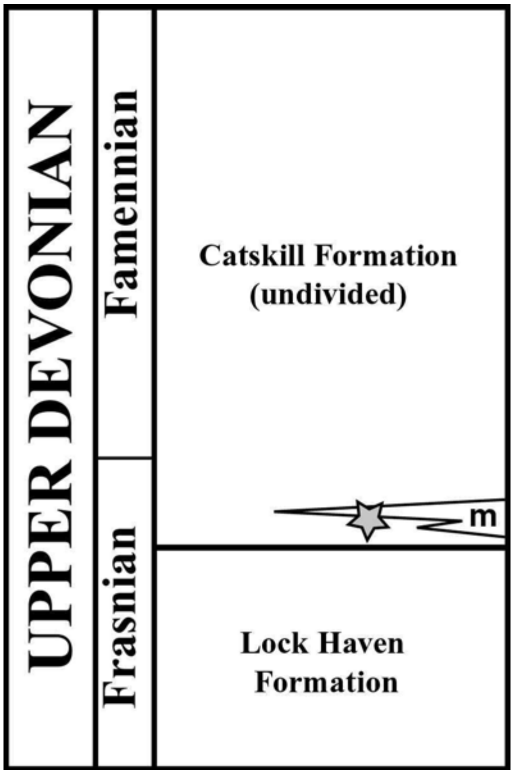


Figure 4. Upper Devonian rock units exposed in the study area. The star marks the position of interval of interest. The symbol "m" delineates a succession of marine deposits that overlies the study interval.

A. **Levee/bar facies.** This facies starts as thin to massive medium-grained light reddish- to olive-gray flaggy sandstone with interbedded thin layers of dark reddish-gray, platy shale and clay drapes. A tree stump of *Eospermatoperis* was found at the base of the facies with other greenish-gray, clay-lined and downward branching root traces. The sandstone may contain small ripple marks, planar laminations, and larger, hummocky dune-like features. Clay drapes between sandstone layers contain small arthropod crawling traces and vertical burrows, raindrop impressions, mudcracks and possible evaporite molds. A fossil zone composed of the placoderm *Bothriolepis*, occurs in this facies. Though most of the sandstone is medium-grained, there are some sandy, intraformational conglomerates that contain rip-up clasts, fish fragments, and transported carbonized plant fragments. The top of the levee/bar facies undulates and appears eroded by small channels.

B. **Floodplain/Overbank facies.** This facies may be up to 2.4 m thick and typically consists of a fining-upward succession of interbedded light-reddish-gray shaly sandstone and shaly siltstone that grade into a dark-reddish-gray, platy, silty shale. The lower, coarser part of this facies may contain small carbonate nodules, transported plant fragments, and fish fragments. Large fragments of *Archaeopteris* and other plants, small vertical burrows, and crossopterygiian fish fossils, including parts of the skull, jaw, and body scales, may be found at the base of this section. The upper, finer-grained, part of this facies contains interbedded platy shale and thin, laterally discontinuous layers of fine-grained sandstone. The sandstone contains small asymmetrical ripple marks, it fills mudcrack polygons, and it is sometimes mottled light greenish gray. Larger carbonate nodules and very fine root traces occur in the platy shale. Some of the overbank deposits exhibit structures that suggest lateral accretion. This facies is truncated by channel sandstone.

C. **Channel sandstone facies.** Although it forms the ledges along the overlook, the channel sandstones are generally the thinnest of the lithofacies. They are composed of laterally discontinuous, light-reddish- to olive-gray, medium-grained channel sandstone units. These channels are very broad and acutely concave, and several span the entire length of the exposure. A combination of small cross-strata, asymmetrical ripple sets, transported plant traces, and scour marks suggest a west to northwest current direction. Some of the channel sandstone units contained *in situ* clay-lined, downward-branching root traces. Bedding planes in this facies may contain *Rivularites* (a texture composed of fine pustules), imprints of mudcracks, and large crawling traces. Many of these features on the bedding plane are preserved by thin clay drapes. One particular very large but faint crawling trace (up to 16 cm wide and 284 cm long), which appears to have been produced by a large organism, crosscuts the ripple marks and *Rivularites* on the same bedding plane.

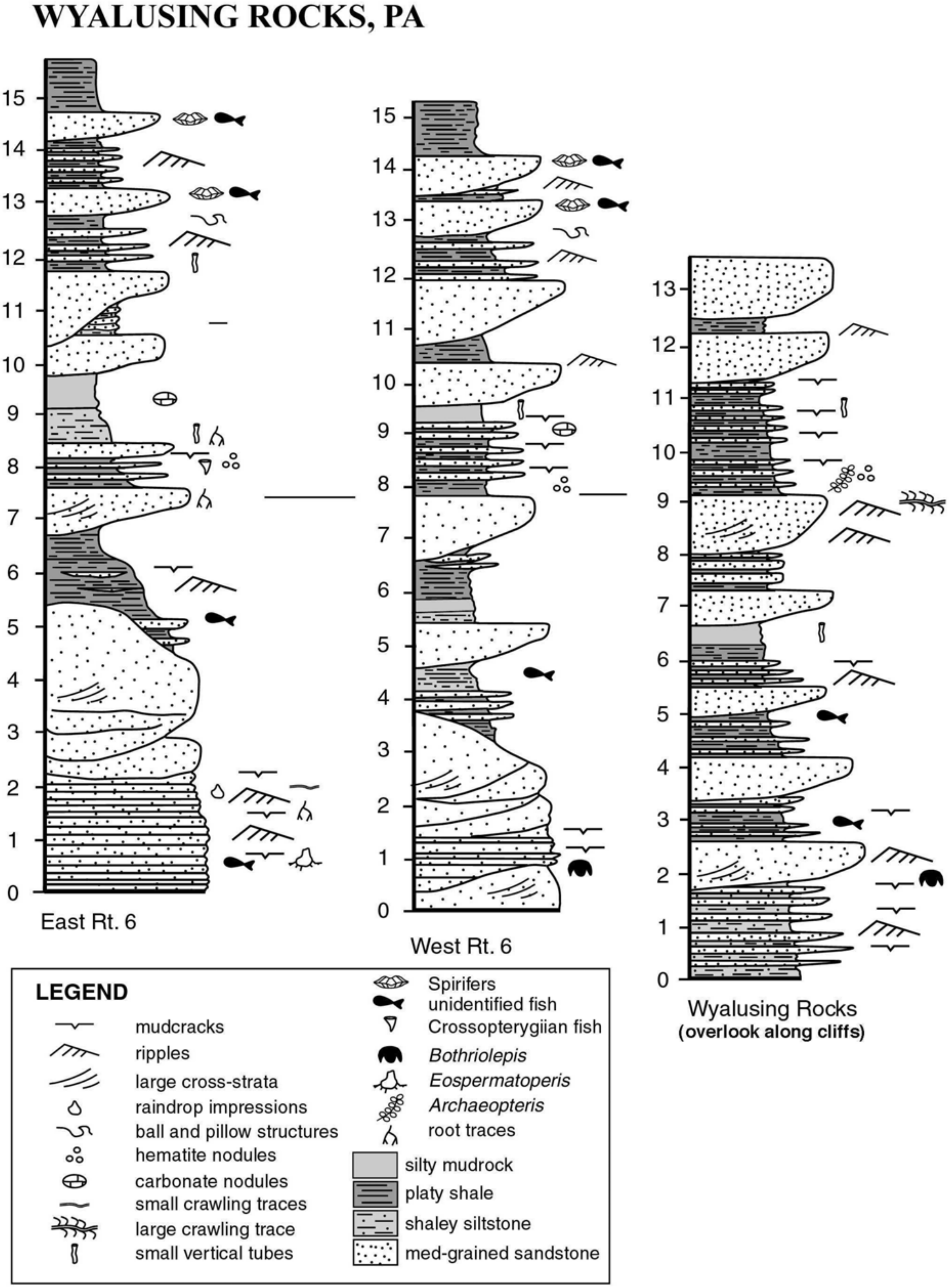


Figure 5. Stratigraphic sections of the Upper Devonian Catskill Formation at Wyalusing Rocks.

D. Marine/brackish water facies. This succession consists of interbedded light-olive-gray sandstone with bluish-gray to greenish-gray platy shale. At the base of the section, sandstone units are "clean," exhibiting planar lamination and scour marks while the bluish-gray shale is fissile and non-fossiliferous. The sandstone units at the top of the section contain fish and spirifer fragments, bluish-gray shale rip-up clasts (up to 3 cm long), and transported/ macerated carbonized plant fragments. Some of these sandstone units appear iron-stained and contain an exterior crust of gypsum. The greenish-gray shale at the top of the section contains some thin and discontinuous sandstone lenses, some of which contain ball-and-pillow structures. This shale appears bioturbated and does not contain obvious fossils.

PALEONTOLOGY

The combination of lithofacies descriptions and paleontology are essential in determining the interaction of organisms with each other and within their environment. In this section, a description of each of the organisms and trace fossils and a short discussion of their ecological niche and role in the community will be provided.

Fish. Based on preliminary identifications of fish fossils, there were two types of fish found at the interval of study: a placoderm, or armored fish, and a crossopterygiian, or lobe-finned fish. The placoderm, an antiarch called *Bothriolepis*, is identified based on the presence of jointed and serrated limbs, dorsal armored plates, and "egg" shape. The *Bothriolepis* fossils (7.0 cm long with 6.0 cm long limbs) were well articulated and found within a dark reddish-gray mudcracked shale and siltstone layer. *Bothriolepis* is a common Middle to Upper Devonian placoderm that is known on every continent in the world and is most often associated with freshwater deposits. It is commonly found in the same environments as lungfish and they probably shared the same habitats (Maisey, 1996).

The identification of the crossopterygiian fish is more problematic because the skeletal components of a head (thought to be maxilla), which contain large teeth similar to *Hyneria*, also contain a texture that resembles the bony material of a rhizodontid fish (D. Rowe, 2002, personal communication). Body scales found stratigraphically lower in the section, which have a rounded, rhomboid shape with concentric rings that contain bony ridges that radiate outward from the center of the scale, also suggest the presence of a rhizodont. Only a few skeletal components belonging to the crossopterygiian fish head were found, which consist of a massive dentary (4.5 cm wide with conical shaped teeth up to 0.8 cm long) and the maxilla with imbedded teeth (up to 3 cm long). The large size and shape of the teeth and jaw of this fish indicates that it was probably large, at least one meter in length, and was a fierce predator. This skeletal material was found in a dark-reddish-gray shaly siltstone in the lower part of the overbank deposits.

Plants. The sand-filled cast of a tree stump identified as *Eospermatoperis* was found in the levee/bar facies. *Eospermatoperis*, a coastal-margin tree, is identified by its bulbous base. Previous work by Driese at al. (1997) showed that it has a unique root system that allows it to live in waterlogged environments. The stump in this section was 50 cm high and 65 cm wide. The other fine root traces (up to 25 cm long) found in the levee/bar facies may belong to *Eospermatoperis*.

At the top of the floodplain succession, a frond of *Archaeopteris* was found. The occurrence of several large (up to 14 cm in diameter) in situ clay-filled root/tree casts in the overbank and channel facies may be from *Archaeopteris* trees. *Archaeopteris*, the first true tree, is common in Upper Devonian floodplain deposits from the Catskill Formation; it has also been found in some near-marine environments as transported plant material (Banks, 1985). Fine roots (up to 3.0 mm wide and 7 cm long) in the upper part of the overbank facies crosscut mudcracks.

Crawling traces. Several different size crawling traces were observed on the bedding planes of sandstone units. The finer traces (up to 3 mm wide) found in the levee/bar facies consist of grooved lobes that may have been produced by small arthropods. A very large trackway (up to 16 cm wide and 284 cm long) (Figure 6A) is located on the top of a sandstone bedding-plane. It crosscuts the trace *Rivularites*, interference ripples, and the traces of transported plant material. The trace consists of a central grooved-ridge with lobe-like impressions extending along the margins of the ridge. The lobe-like impressions appear slightly staggered and are very closely spaced, though they are not always obviously present. A number of different organisms could have produced this trace.

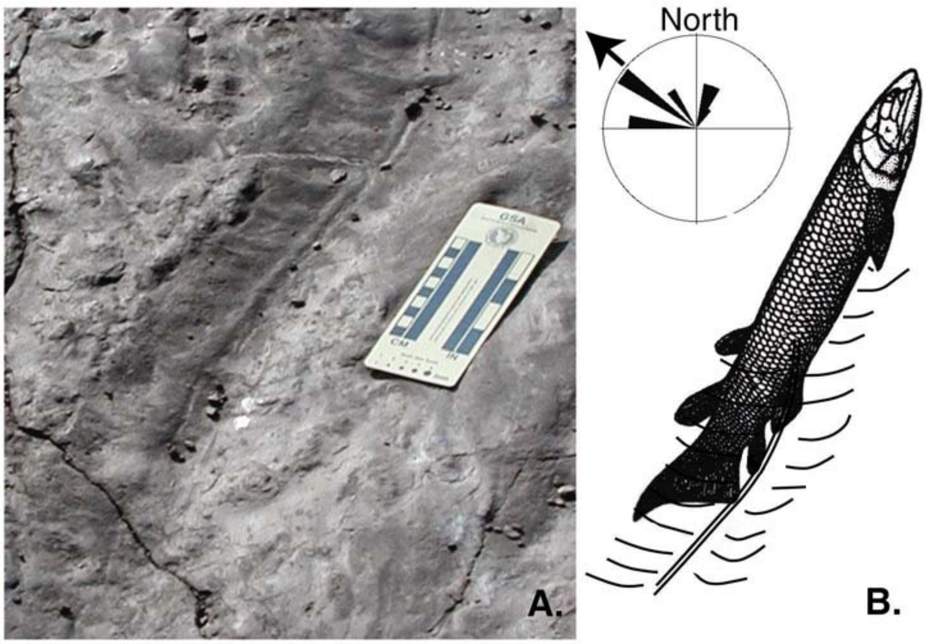


Figure 6. (A.) Crawling trace found on bedding plane of channel sandstone facies at Wyalusing Rocks. (B.) Sketch of a lobe-finned fish producing the crawling trace. A rose diagram in the upper left hand corner indicates the predominant paleocurrent direction, which is towards the northwest (N=14).

One potential trace-maker is a semi-buoyant lobe-finned fish (Figure 6B). The lobe-finned fish would have propelled itself through the shallow water and across the sandy substrate using strong pectoral fins, creating the lobe-like impressions. Its pelvic fins could have carved the groove that the anal fin or tail scraped through. Though the fossils of lobe-finned fish collected at Wyalusing Rocks were larger than the organism suspected of producing the trace, a smaller, juvenile fish, similar in size to the rhizodont described by Davis et al. (2001) may have been capable of making it.

Another possible trace-maker candidate is *Bothriolepis*, which could have used its armored limbs to push its body over the sand while its tail scraped the sediment producing the grooved ridge. Due to the support offered by its armored skeleton and the discovery of possible lung sacs (Denison, 1941), *Bothriolepis* was thought to be able to leave water and crawl around on land. Though not conclusive, *Bothriolepis* was suggested as a possible trackway producer of crawling traces described from Greenland (Friend et al., 1976). A potential problem with this theory is that *Bothriolepis* probably relied on its tail for much of its propulsion, and there is no strong evidence for this kind of movement in the production of the Wyalusing trace.

Other possible trace producers include large arthropods, plants, and large grazing gastropods. Though these candidates seem less likely, they cannot yet be ruled out.

Vertical burrows. Two types of vertical tube-like structures were observed. One is found in the overbank facies (4.0 mm in diameter) and resembles an invertebrate burrow. The other, located in the levee/bar facies is 1.0 cm wide, may have been produced by a slightly larger invertebrate.

DEPOSITIONAL ENVIRONMENT

Willard (1939) offered a facies map that delineated the early Chemungian shoreline that separated marine facies in the west from fluvial deposits derived from the east-southeast. The periodic high sedimentation rates associated with the onset of the Acadian Orogeny, in addition to changes in subsidence and sea level, probably controlled the migration of this shoreline. By the latter part of the Chemung stage, the lower part of the Catskill Formation was deposited. The increasing abundance of coarse-grained red deposits at this time, which indicate emergence, relative to the drab colored deposits of stratigraphically lower rocks, which indicate submergence, suggest a progressive progradation of the shoreline towards the west.

A thick succession of older, drab colored, fossiliferous sandstones and shale, north along US 6, represent a submerged part of the basin, possibly tidally influenced shelf sands and indicate a more easterly located shoreline. As sedimentation rate increased, the shoreline progressively moved westward, and the resulting deposits were subaerially exposed and influenced by freshwater. Coastal-margin plants like *Eospermatoperis* and burrowing invertebrates colonized the migrating levee/bar complex within the interdistributary region of the basin. The levee/bar facies recorded the periodic floods as well as the temporary episodes of landscape stabilization. Rapid sedimentation in this system allowed for the preservation of raindrop impressions, mudcracked surfaces, and the well-articulated death assemblage of placoderm *Bothriolepis*.

With increased sedimentation, streams flowing in a west-northwest direction transported fine-grained sediments across a laterally accreting floodplain. Rippled sands and thin layers of mud were often bioturbated by small invertebrates and colonized by large, water consuming plants like the "upland" forest-producing tree *Archaeopteris*. Prolonged exposure, resulting in thicker successions of mudcracked deposits, may have prevented these invertebrates from thriving in the upper part of the overbank facies; here too, smaller root traces, presumably produced by small stature plants, and carbonate nodules are also found. The climate, tropical wet and dry or desert (Woodrow, 1985), and the high sedimentation rate prevented well-developed soils from forming. At most, entisols to inceptisols were present along the floodplain.

Lobe-finned fish occupied low-sinuosity, shallow and broad freshwater streams with *Bothriolepis*. These sand-lined streams were probably cloudy from the abundant clay-rich sediment, and they may have contained branches of trees, some of which may have been shed by *Archaeopteris*. The lobe-finned predators may have used these branches as hiding places, while waiting for prey. When water levels lowered in the streams, the lobe-finned fish may have relied on their pectoral fins to move themselves to deeper parts of the stream, leaving large crawling traces (Figure 6B).

Eventually, the terrestrial environment experienced gradual flooding due to a shift in sea level. The drab colored shelf deposits returned, while bioturbation by marine invertebrates, spirifer brachiopods, and transported plant debris became common within the shallow shelf sediments once again.

CONCLUSION

Although this work was based entirely on one set of laterally extensive exposures, the many sedimentary features and fossils help to create an interesting environmental interpretation. The lack of good exposures and monotony of Upper Devonian-age rocks in northeastern Pennsylvania are some of the reasons why the Catskill Formation is undivided in this region. A better understanding of depositional environments like the one at Wyalusing Rocks may provide a useful way of differentiating mappable units in the formation. In addition, the interpretation of plant and animal interactions will help improve our understanding of the development of early terrestrial ecosystems.

ACKNOWLEDGMENTS

Great thanks to Jon Inners for suggesting that I look at the Devonian rocks in northeastern Pennsylvania in preparation for this field conference. I am also indebted to Doug Rowe for offering his help in preliminary identifications of some of the fish collected in the study interval. Special thanks to the East Delaware Valley Native American Tribe for access to their property.

OIL AND GAS PROSPECTS IN NORTHEASTERN PENNSYLVANIA

by
Kristin M. Carter and John A. Harper

INTRODUCTION

This paper summarizes our current knowledge of oil and gas exploration and production in northeastern Pennsylvania (Figure 7). Drilling for hydrocarbons in this region commenced as early as 1884 (Fuller and Alden, 1903). It has continued sporadically through today (several oil and gas operators are drilling, or considering drilling wells in this area even as we write). However, much of this region remains unexplored or underexplored as evidenced by the sparse nature of both dry holes and established oil and gas fields in the 17 counties in northeastern Pennsylvania (Figure 7 and Table 1). That this area of the state lies proximal to large market areas such as New York, New Jersey, New England, and Philadelphia should be enough to generate additional attention. What is surprising is that it hasn't!

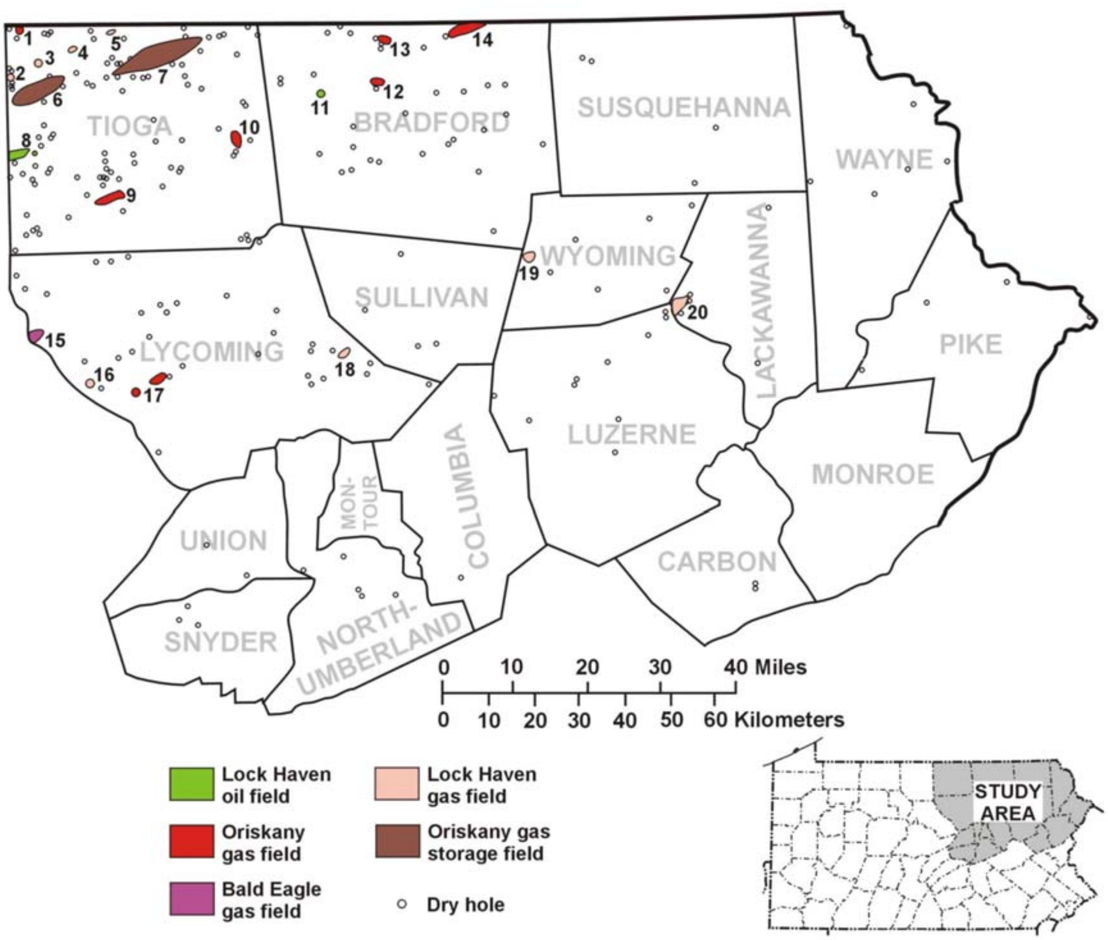


Figure 7. Map of northeastern Pennsylvania showing locations of producing oil and gas fields and exploratory dry holes (all available data as of June, 2002 - see Table 1).

Carter, K.M. and Harper , J.A., 2002, Oil and gas prospects in northeastern Pennsylvania, *in* Inners, J. D., and Fleeger, G. M., eds., From Tunkhannock to Starrucca: bluestone, glacial lakes, and great bridges in the "Endless Mountains" of northeastern Pennsylvania: Guidebook, 67th Annual Field Conference of Pennsylvania Geologists, Tunkhannock, PA, p. 15 - 31.

Table 1. Summary of basic data on the producing oil and gas fields in northeastern Pennsylvania (see Figure 7 for locations).

Map Number	Field Name	Year Discovered	Producing Formation	Current Status	Product	Number of Producing Wells	Well Completion Date(s)	Initial Production (per day)[2]	Average Annual Production (per day)[2,3]
1	Brookfield[1]	1938	Oriskany	Abandoned	Gas	1	1938	2,000 Mcf Nat	6,800
2	Potter Brook	1905	Lock Haven	Abandoned	Gas	4	1905	Unknown	---
3	Westfield	1895	Lock Haven	Abandoned	Gas	2	1895-1900[4]	Unknown	---
4	Knoxville	1917	Lock Haven	Abandoned	Gas	?	1917-1925	6,000 Mcf Nat	---
5	Elkland	1895	Lock Haven	Abandoned	Oil & Gas	2	1895-1933	Unknown	---
6	Sabinsville	1935	Oriskany	Gas Storage	Gas	22	1935-1938	14,000 Mcf Nat	59,500
7	Tioga	1930	Oriskany	Gas Storage	Gas	48	1931-1935	25,000 Mcf Nat	25,800
8	Gaines	1897	Lock Haven	Abandoned	Oil	130[5]	1900-1940[4]	10 Bbl Nat	10-40
9	South Wellsboro	1982	Oriskany	Inactive	Gas	2	1981-1983	531 Mcf Nat	18.5
10	Mainesburg	1990	Oriskany	Active	Gas	2	1990-1992	15,000 Mcf Nat	0-2,030
11	Brace Creek	1987	Lock Haven	Active	Oil	1	1987	3 Bbl Af	1-5.6
12	Peas Hill	1995	Oriskany	Active	Gas	2	1995-1996	Not Reported	---
13	Wilawana	1995	Oriskany	Active	Gas	2	1995-1996	Not Reported	---
14	Stagecoach[1]	1991	Oriskany	Active	Gas	7	1991-1994	Not Reported	3.8-1,192
15	Grugan	1982	Bald Eagle	Active	Gas	3	1982-1988	20,000 Mcf Nat[5]	0.2-2,107
16	Tiadaghton	1991	Lock Haven	Abandoned	Gas	1	1991	2,000 Mcf Af	---
17	Salladasburg	1976	Oriskany	Abandoned	Gas	4	1976-1978	1,100 Mcf Af	1.3-10
18	Shrewsbury	1969	Lock Haven	Abandoned	Gas	2	1969-1977	86 Mcf Af	---
19	Lovelton	1965	Lock Haven	Abandoned	Gas	4	1965-1971	30 Mcf Nat	---
20	Harveys Lake	1956	Trimmers Rock	Abandoned	Gas	7	1956-1958	300 Mcf Nat	100

[1]Field is partially in the State of New York.
[2]Gas reported in thousands of cubic feet (Mcf); oil reported in barrels per day (Bbl); Nat ≡ natural open flow; Af ≡ after treatment open flow.
[3]Based on available annual production data.
[4]One or more completion dates were unknown.
[5]Estimated.

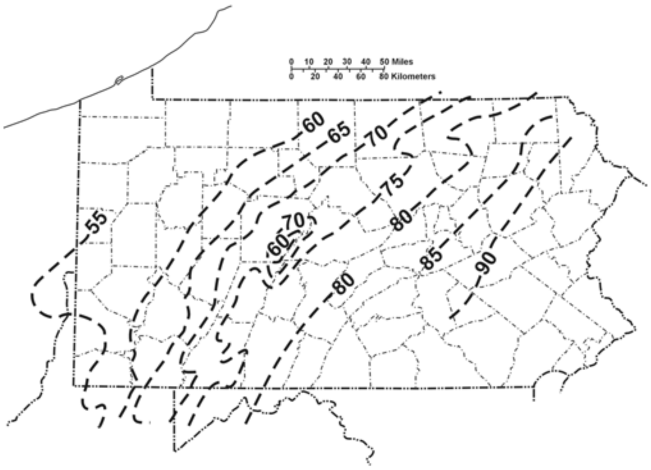


Figure 8. Carbon ratio map of Pennsylvania (based on Thom, 1934).

Petroleum exploration historically has been very limited in northeastern Pennsylvania. Initially, this resulted from the carbon-ratio theory, which predicts the absence of hydrocarbons east of Potter County. The carbon ratio theory assumes that commercially producible quantities of oil and gas will occur only where heat and pressure has had a limited effect on the alteration of reservoir rocks, as established by the percentage of fixed carbon in coals occurring in the area (Thom, 1934). Producers generally considered areas having carbon ratios of 65 or more to be unproductive (Figure 8 and Table 2) and so avoided spending resources looking for hydrocarbons in "known" barren areas. Later, other factors stayed the drillers' hands – factors such as the complexity of geologic structures (particularly in the fold belt south of the Appalachian Plateau) and the quality of the potential reservoirs (low porosity and permeability).

During the first half of the 1900s, a few forward-thinking (or, perhaps, foolhardy) drillers began exploring for oil and gas in areas previously considered too mature for hydrocarbon production. The discovery of gas in the Oriskany Sandstone in Wayne-Dundee field, Schuyler County, New York early in 1930 spurred others to go far afield in search of buried treasure. Discovery of Oriskany gas in the Tioga field, Tioga County, Pennsylvania later that year led to a spate of exploratory drilling throughout north-central Pennsylvania (Harper and Patchen, 1996). However, after a few years and fewer discoveries, the excitement died down. Tioga was as far east as anyone could find anything of value until the latter half of the 20th century.

Accordingly, this paper summarizes past oil and gas exploration and production in northeastern Pennsylvania, and identifies and discusses those geologic strata that may warrant further study and exploration. We present a discussion of the geological, production, and historical details of drilling activities in the study area, and conclude with an assessment of future prospects for oil and gas in the area.

Table 2. The relation of the percentage of fixed carbon in coals to the potential for finding oil and/or natural gas in rocks in the same area (based on Thom, 1934)

Carbon Ratio (Percentage of Fixed Carbon In Coal	**Oil and gas Production Potential**
<50	Fields of heavy coastal plain oils and unconsolidated Tertiary or other formations
50 –55	Principal fields of medium oils of Ohio-Indiana and mid-Continent fields.
55-60	Principal fields of light oils and gas of the Appalachian fields
60-65	Commercial pools rare but oil exceptionally high grade when found. Gas wells common but usually isolated rather than in pools.
65-70	Usually only shows or small pockets. No commercial production.
>70	No oil or gas with rare exceptions.

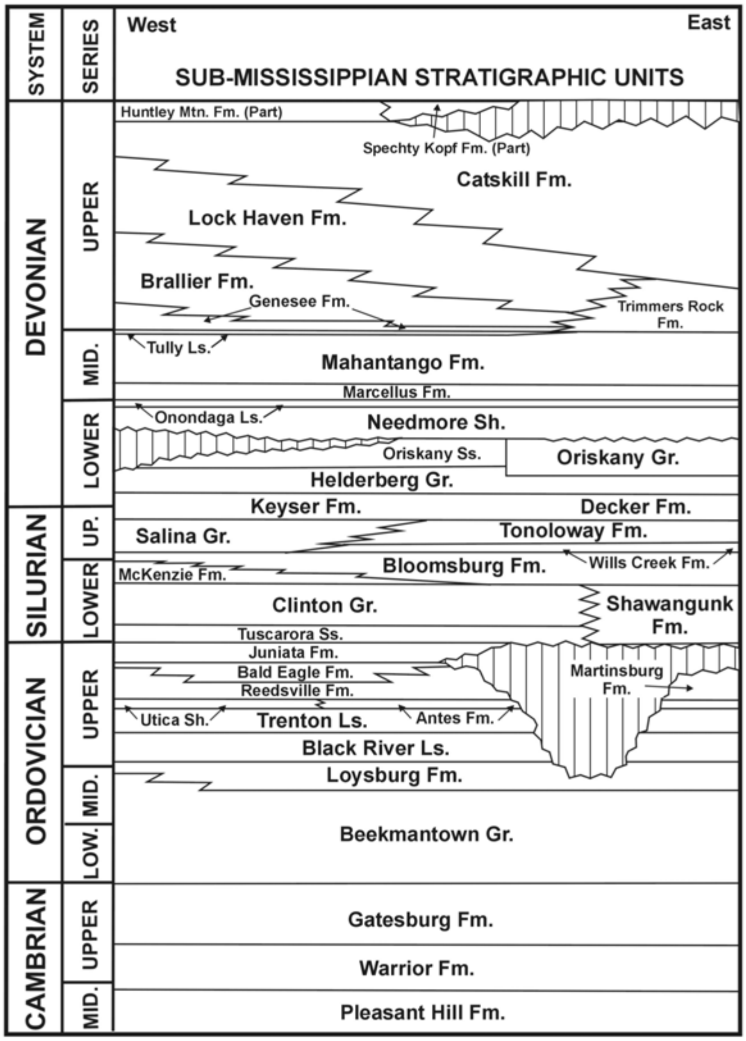


Figure 9. Stratigraphic correlation chart of sub-Mississippian formations in northeastern Pennsylvania (modified from Berg and others, 1983).

DRILLING HISTORY

With one exception, oil and gas production in northeastern Pennsylvania historically has been limited to Devonian strata (Figure 9). In particular, the Upper Devonian Lock Haven Formation has produced both gas and oil; the Lower Devonian Oriskany Sandstone produces gas only. Gas also occurs in the fractured sandstones of the Upper Ordovician Bald Eagle Formation in one small, three-well field. In many cases, discoveries were unexpected and occurred while test drilling for deeper Cambrian-Ordovician rocks. We discuss the lithology, reservoir characteristics, and production areas for these rocks in greater detail below.

Lock Haven Formation

The Upper Devonian Lock Haven Formation (formerly called "Chemung") was tested in Tioga County as early as 1884, with a few minor successes (mostly non-commercial). It wasn't until the completion of the Atwell #1 Fee well at Gaines in 1898, however, that this formation proved to be economically viable. Success in the Gaines field spurred additional drilling in the Lock Haven Formation in various areas in northeastern Pennsylvania through the early 1990s, with only a few, minor successes (Figure 7; Table 1).

Lithology and Reservoir Characteristics: The Lock Haven Formation lies beneath the Catskill Formation throughout most of the study area. In north-central Pennsylvania the Lock Haven lies on the Brallier Formation, whereas in the northeasternmost counties it lies on, or is replaced by, the Trimmers Rock Formation (Figure 9). The Lock Haven Formation generally consists of fine- to very fine-grained sandstones and silty shales that correlate in part to the Bradford and Elk Group sandstones (Speechley, Bradford, Kane, Elk, etc.) of western Pennsylvania (Fuller and Alden, 1903; Lytle, 1950; Grow, 1964; Cornell, 1971; Donaldson et al., 1996). These formations were deposited in shallow waters associated with a large alluvial coastal plain situated to the west of the eroding Acadian highlands in late Devonian time (Dott and Batten, 1988). Fuller and Alden (1903) interpreted the Lock Haven Formation in northwestern Tioga County as having been deposited in a shallow bay environment influenced by current action. Laughrey and others (in press) interpreted the Lock Haven in the Council Run field of Centre and Clinton Counties (southwest of the study area) as slope turbidites in the lower part, grading upward in a series of parasequences consisting of marine shelf deposits, delta-front lobes, and shoreface deposits. Although Laughrey and others (in press) found no evidence for equivalent delta-plain and alluvial facies, they suggested this was probably due to sedimentary bypass or to destruction of the facies during erosion by transgressions at the beginnings of each parasequence. Kehn and others (1966) found much of the lower portion of what they called the Catskill Formation in Lackawanna County to be generally similar in nature to the Lock Haven. Zagorski and others (2000) agreed, finding the limited data available supported a shoreline, strike-parallel mode of deposition. We believe this portion of Kehn and others' (1966) Catskill is, in fact, Lock Haven.

The primary porosity of the Lock Haven Formation was exhausted through the processes of compaction, cementation, and mineral replacement. Secondary porosity subsequently developed through diagenetic dissolution of cements, unstable grains, and minerals. In some areas, the occurrence of fractures further augmented secondary porosity. The average porosity of the Lock Haven formation in the Council Run field is nine percent, but Donaldson and others (1996) suggested that, where fractures are present, porosity might be as much as 50 percent. No such data exist for the Lock Haven in the eastern part of the study area.

Stratigraphic and diagenetic traps account for the majority of Lock Haven gas occurrences (Grow, 1964; Cornell, 1971; Donaldson et al., 1996; Harper, Tatlock and Wolfe, 1999). However, the occurrence of oil and gas in the Gaines field of Tioga County provides a good example of how geologic structure (in this case, shallowly dipping beds associated with a syncline) can impact the distribution of hydrocarbons (Fuller and Alden, 1903). The producing sandstones of the Lock Haven Formation in the Council Run field range from about 30 to 60 feet in thickness, and the reported average thickness of the pay zone is 23 feet (Donaldson et al., 1996). Production from the Lock Haven in Harvey Lake field in Lackawanna County came mostly from a thick section of fractured silty shales and interbedded sandstones ranging in thickness from a few inches to 22 feet (Zagorski et al., 2000).

Oil Fields: Oil is a rare commodity in northeastern Pennsylvania. In fact, it is an anomaly where it exists because the geochemistry of the region indicates overmaturity – any oil generated in the available source rocks should have been cracked to gas long ago (C. D. Laughrey, 2002, oral communication).

Only three known oil fields occur in northeastern Pennsylvania – the Elkland, Gaines, and Brace Creek fields (#5, #8, and #11, respectively, on Figure 7 and Table 1). All three produced from Upper Devonian strata. No information exists concerning Elkland, beyond what is in Table 1. Brace Creek field, located in northwestern Bradford County (Figure 7), is the only field in the study area to have produced oil from the Lock Haven Formation in recent years. Mark Resources Corporation discovered this field in 1987 when they drilled to test the Lower Devonian Oriskany Sandstone for gas, and instead, found oil in the Lock Haven Formation between 774 and 785 feet (Harper and Cozart, 1992). The test well was plugged back to the Lock Haven, and produced three barrels of oil per day (Bopd) after treatment. Available production data for this well indicate it produced at least 310 barrels of oil.

The Gaines field is situated in west-central Tioga County and east-central Potter County (#8 in Figure 7) on the northwestern flank of the Marshlands anticline. This oil field, the largest in northeastern Pennsylvania, was discovered in 1898 when the Atwell #1 Fee well came in at 10 Bopd (Table 2). During 1899 and 1900, numerous wells drilled in the field discovered two discrete pools producing from sandstones separated by about 200 vertical feet. The westernmost pool, called Watrous, occupies about 280 acres and produced from the Atwell sand about 700 feet below the lowest red beds of the Catskill Formation. Wells in the pool initially produced up to 40 Bopd (Fuller and Alden, 1903), averaging about 25 Bopd (Fettke, 1950). The eastern pool, called Manhattan, is about 170 acres in size and produced from the Blossburg sand about 500 feet below the Catskill. Manhattan wells ranged from just a few barrels to 2,100 Bopd from one well. Operators completed more than 125 wells in the Gaines field between 1898 and 1991. This field is now abandoned, and many of the wells have been identified for plugging by the Pennsylvania Department of Environmental Protection (PADEP).

Of the two producing sandstones in the Gaines field, the Blossburg sand consists of a series of alternating shaly sandstones, shales, shaly limestones, and thin limestones (Lytle, 1950). Fuller and Alden (1903) reported that the oil apparently came from open joints and bedding planes, but this may have been just a reiteration of the old "crevice" concept of early oil drillers. Lytle (1950) described the Atwell sand as a uniformly fine-grained and very dark-chocolate-brown sandstone having an average porosity of 19 percent and average permeability of 75 millidarcies (mD). It ranges from 25 to 35 feet in thickness, with about 12 feet having an average of 45 percent oil saturation. The crude oil had an API gravity of 44.3^{o}, making it a good, light oil.

No production information exists for the Manhattan pool, but Fettke (1950) estimated the Watrous pool produced about 500,000 barrels up to 1942 when water flooding was first tried in the field. At that time, about 80 wells produced about 10 Bopd. The water flood experiment involved eight injection wells and seven producing wells on 25 acres of the pool (Lytle, 1955). The project was unsuccessful, possibly because of the high paraffin content of the oil or because fresh water invaded the reservoir through old, unplugged wells watering out extensive areas prior to water flooding (Fettke, 1950).

Gas Fields: Seven Upper Devonian gas fields are located in northeastern Pennsylvania (Figure 7). These fields were discovered as early as 1895 and as recently as 1991. Table 1 summarizes the basic data for these fields. Where reported, initial production ranged from 30 to 6,000 thousand cubic feet of gas per day (Mcfgpd). Each of these seven fields currently is abandoned.

Perhaps the most interesting and important of these seven is the Harvey Lake field located in western Lackawanna County (#20 in Figure 7 and Table 1). This field represents the easternmost hydrocarbon production in Pennsylvania. Transcontinental Production Company discovered this field in 1956 while drilling a test well along the northeastern limb of the White Deer anticline (Figure 10) (Grow, 1964; Kehn et al., 1966; Cornell, 1971). They drilled the #1 Lawrence Richards well to test the Oriskany Sandstone as a potential gas storage reservoir close to northeastern markets, but instead found gas in the Catskill and Lock Haven Formations (Grow, 1964). The Richards well had shows of gas in several zones ranging from 1,200 to 3,200 feet (Figure 11). After finding nothing in the Oriskany, the well was plugged back to 3,600 feet.
It encountered a large flow, estimated at 10,000 Mcfgpd at 2,814 feet, but this blew down quickly. The flow eventually was gauged at 310 Mcfgpd after a month. Various companies drilled 14 wells in this field between 1956 and 1992, which makes it more frequently drilled than any other Upper Devonian gas field in northeastern Pennsylvania (Table 2). Only seven of the wells

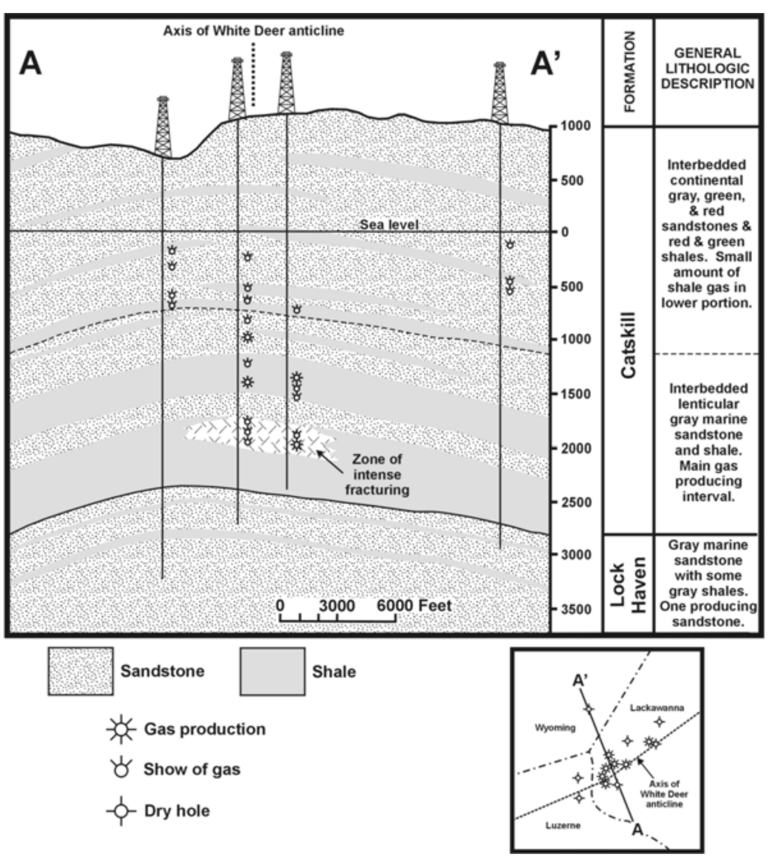


Figure 10. Cross section of Harvey Lake field in Lackawanna County, showing structure, general lithology, and zones having gas shows and production. See Figure 1 (#20) for general location. Modified from Grow (1964) and Zagorski et al. (2000).

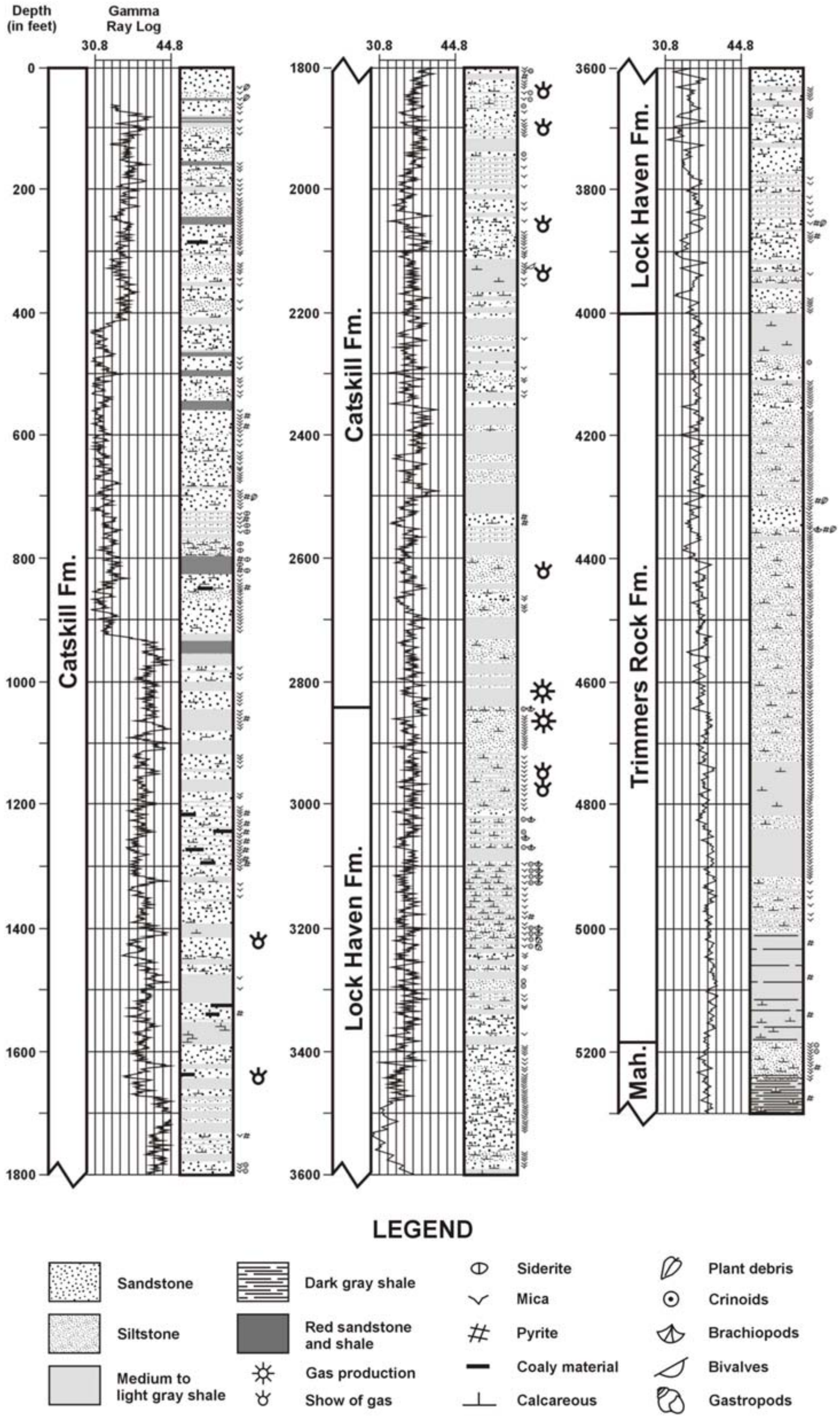


Figure 11. Diagram of Upper Devonian portion of Transcontinental Production Company #1 Richards well in Harvey Lake field, Lackawanna County, showing gamma ray log curve and lithology. Lithology generalized from Kehn et al. (1966).

produced gas, with open flows ranging from 70 to 6,675 Mcfgpd (Grow, 1964), and rock pressures ranging from 209 to 1,525 pounds per square inch (PSI) (Zagorski et al., 2000). Production was limited – the field produced a total of 151 million cubic feet (Mmcf) in the two years the wells were on line. The gas was dry – more than 96 percent methane, one or two percent each of ethane, propane, and nitrogen, and a heating value of 1,011 British thermal units (Btu) (Grow, 1964; Zagorski et al., 2000).

Harvey Lake field was purchased and reconditioned for gas storage in 1960. After limited use as a storage reservoir, the natural fracturing in the rocks, combined with a gas injection pressure that exceeded the natural pressure in the reservoir, caused a fatal accident involving a nursing home. This resulted in the storage field being deactivated, and in the Pennsylvania Department of Mines (now PADEP) enacting laws and regulations governing the safe storage of natural gas in underground reservoirs.

Oriskany Sandstone

The first concerted deep drilling activity to take place in Pennsylvania occurred in Tioga County in 1930 with the exploration of the Lower Devonian Oriskany Sandstone (Garrett, 1931; Finn, 1949; Harper and Cozart, 1992). On September 10, 1930 Allegany Gas Company drilled the #1 Palmer well to a depth of 4,010 feet and the well flowed 22,000 Mcfgpd (Gaddess, 1931), discovering the Tioga field (Figure 7). Subsequent Oriskany fields were discovered and developed between 1935 and 1995 (Figure 7, Table 1).

Stratigraphic note: Reference to the "Oriskany Sandstone" in the subsurface of Pennsylvania is based on drillers' terminology used for all Middle and/or Lower Devonian-age quartzose sandstones in the Appalachian basin, generally without distinction. The "true" Oriskany Sandstone of New York and northwestern Pennsylvania is just one such sandstone. An updip sandstone pinch-out against the "Oriskany no-sand area" of northwestern Pennsylvania separates typical Oriskany Sandstone from the age-equivalent Ridgeley Sandstone of western and south-central Pennsylvania. The "Oriskany no-sand area" constitutes an area of either nondeposition of sand or uplift and erosion, whereby any sand that was deposited subsequently was removed (Harper and Cozart, 1992; Harper and Patchen, 1996). The use of "Oriskany" nomenclature has been adopted herein to be consistent with this driller's convention.

Lithology and Reservoir Characteristics: The Oriskany Sandstone typically is a pure, medium- to coarse-grained, monocrystalline quartz sandstone containing well-sorted, well-rounded, and tightly cemented grains (Fettke, 1931; Gaddess, 1931; Finn, 1949; Diecchio, 1985; Harper and Patchen, 1996). Quartz and calcite comprise the most common cementing materials in the formation, but minor proportions of pyrite, dolomite, and other minerals have also been observed (Harper and Patchen, 1996). The sandstone originated in a marine setting fairly early in the Devonian when an emergent landmass in central Pennsylvania and New York was uplifted and eroded (Torrey, 1931; Harper and Patchen, 1996), creating a shallowing-upward sequence. The lithology of the upper portion of the Oriskany tends to be coarser and have less carbonate cement than the lower portion (Harper and Patchen, 1996). The Oriskany Sandstone in the study area ranges from about 10 to 60 feet thick, with the average thickness of the pay zone in Tioga County ranging from seven to eight feet (Harper and Patchen, 1996).

The Oriskany exhibits both intergranular and fracture porosity. Intergranular porosity developed along the northern and western extent of the Oriskany depositional basin in association with pre- and/or post-Oriskany unconformities (Finn, 1949; Diecchio, 1985; Harper and Patchen, 1996; Patchen and Harper, 1996; Harper, Kelley, and Linn, 1999). In this area, the event(s) responsible for the unconformities apparently enhanced natural formation porosity through dissolution of carbonate cements and feldspar grains, with the unconformities themselves creating an updip permeability barrier that aided in the stratigraphic trapping of gas (Diecchio, 1985). In the central and western portion of the basin, secondary porosity developed via fracturing during Early Devonian deformation associated with plastic deformation in the underlying Salina Group salt beds (Bradley and Pepper, 1938; Harper, 1989). Fracturing facilitated the migration of overpressured fluids, including hydrocarbons, downward from overlying Middle Devonian shales (Torrey, 1931; Harper and Patchen, 1996). Although gas production in the Tioga field resulted from both intergranular and fracture porosity (Diecchio, 1985), Fettke (1931) surmised that Oriskany fracture porosity may have been considerably reduced due to the secondary quartz growth he observed in the fracture spaces. Alternatively, the secondary quartz growths may be propping open the fractures (C. D. Laughrey, 2002, written communication). Reported porosities in the sandstone range from approximately four to ten percent (Gaddess, 1931, Fettke, 1931; Hamilton, 1937; Fettke, 1938; Harper and Patchen, 1996).

Structural traps (primarily faulted anticlines) provide the dominant control mechanism for the occurrence of gas in the Oriskany Sandstone in northeastern Pennsylvania. However, as discussed above, stratigraphic traps (porosity pinch-outs) also play an important part in the trapping and accumulation of gas in the Oriskany in the northwesternmost fields in this area (Finn, 1949; Diecchio, 1985; Harper and Patchen, 1996; Patchen and Harper, 1996; Harper, Kelley, and Linn, 1999).

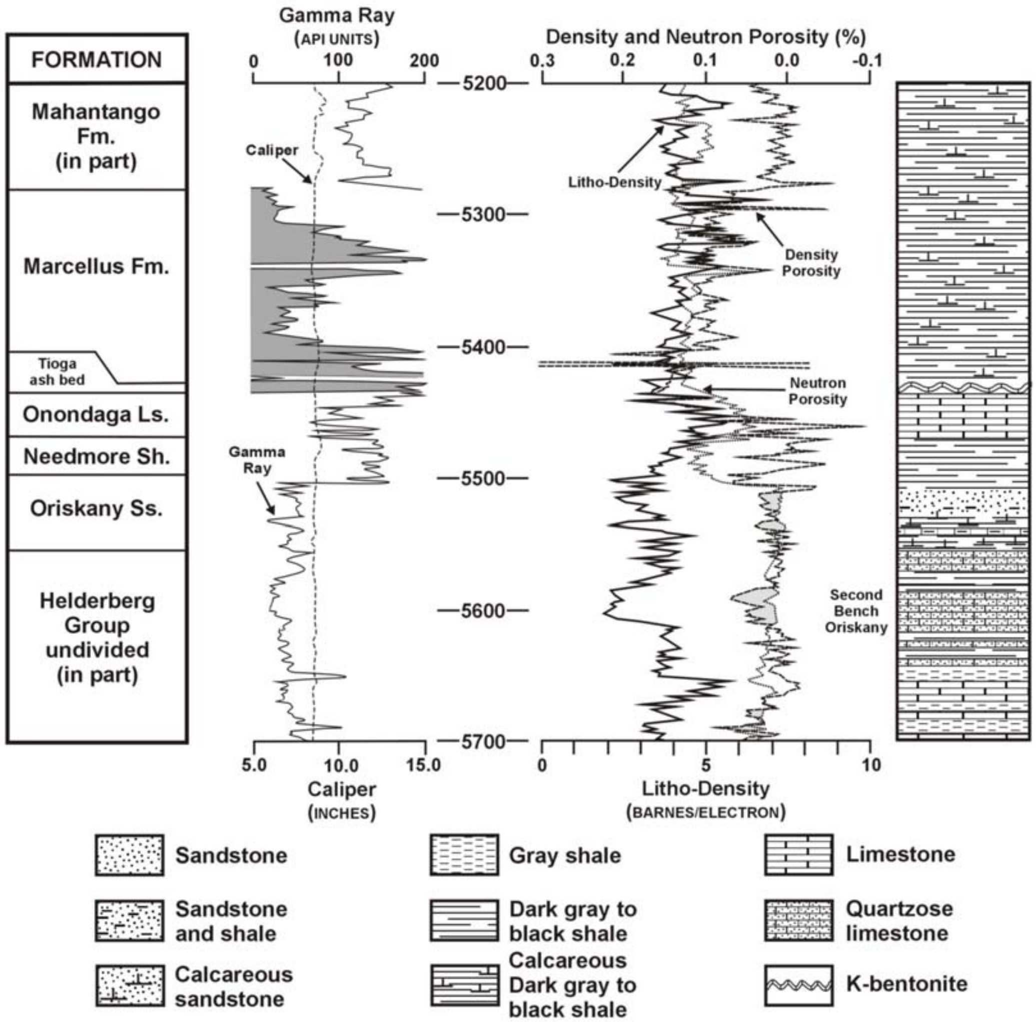


Figure 12. Composite diagram of Lower Devonian Oriskany Sandstone and adjacent formations in northern Bradford County, showing “second bench Oriskany” (Helderberg) that is one of the main targets of drillers in that area. Light shading between neutron and density log curves indicates porosity. Lithology generalized from several Bradford County wells.

Fields: Nine Oriskany fields occur in northeastern Pennsylvania (Figure 7, Table 1). The two largest, Tioga field and Sabinsville field (#7 and #6, respectively, on Figure 7), were also the first discovered. Both are now being used for gas storage. They are discussed in more detail below. Brookfield field, located in northwestern Tioga County (#1), extends to the north into New York (Figure 7). It has a total of four producing wells, of which three are in New York. Salladasburg field in Lycoming County (#17) was drilled on the Tombs Run anticline in 1976 (Figure 1) (Harper, 1981). Of the six wells drilled in the area, four produced gas in limited quantities; the field was abandoned in the 1980s. South Wellsboro and Mainesburg fields in Tioga County (#9 and #10, respectively) are small two-well fields that haven’t generated much interest since their discovery. Both lie on anticlines, but the Oriskany in these fields does not exhibit the good porosity found to the northwest. South Wellsboro currently is inactive.

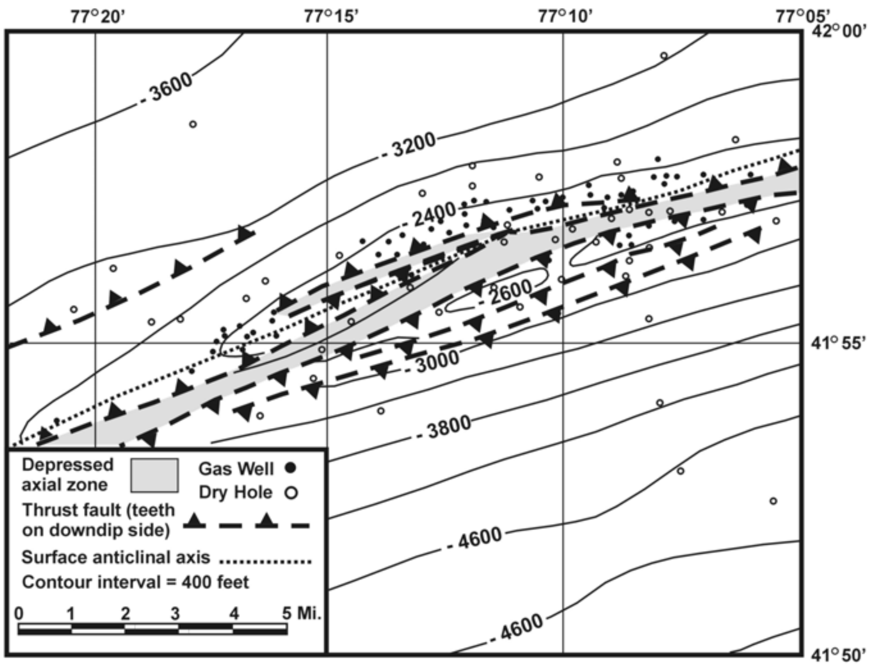


Figure 13. Structure map of Tioga gas field on Sabinsville anticline in Tioga County (modified from Gwinn, 1964). Notice that production (and, later, gas storage) occurs on overthrusts flanking depressed anticlinal axis.

Three Oriskany fields located in Bradford County offer proof that, with proper exploratory efforts, gas can be found well northeast of the established production "limits" of an older era. Stagecoach field (#14 in Figure 7), located in northeastern Bradford County, is an extension of well-established production to the north in New York. The Pennsylvania portion of the field was discovered in 1991 and has a total of seven producing wells. Wilawana and Peas Hill fields (#13 and #12, respectively) in north-central Bradford County were discovered in 1995. Each has two producing wells. The Oriskany Sandstone in this area purportedly is divided into separate sand zones by a zone of limestone. Drillers call the lower sandstone "second bench Oriskany", which is actually a sandy facies of the underlying Helderberg Group limestones (Figure 12).

The Tioga field occurs along the axis of the Sabinsville anticline in north-central Tioga County (Garrett, 1931; Fettke, 1938). Allegany Gas Company discovered this field when the #1 Palmer well came in at 25,000 Mcfgpd in September 1930 (Gaddess, 1931). Subsequent drilling delineated the existence of three pools separated by faults flanking a depressed axis (Figure 13). By 1935, two of the pools had been converted to gas storage fields, and in 1940, the third pool was also converted to storage (Lytle and others, 1961). Of 120 wells drilled in the Tioga field area between 1931 and 2000 only 48 actually produced gas. The 26 wells drilled off the anticline were reported as dry. The remaining wells were drilled as storage wells.

Sabinsville field also occurs along the axis of the Sabinsville anticline (Fettke, 1938). This field was discovered in 1935 and subsequently was converted to storage in 1951 (Lytle and others, 1961). Of the 59 wells drilled in the Sabinsville field between 1934 and 1986, only 22 actually produced gas; there were only three dry holes. The remaining wells were drilled as gas storage wells in the 1950's and 1960's.

Bald Eagle Formation

The Upper Ordovician Bald Eagle Formation has experienced only limited production in the Appalachian Basin. In fact, the only field discovered in the basin to date is the Grugan gas field (#15 in Figure 7), which consists of just three producing wells, only one of which is in the study area.

Lithology and Reservoir Characteristics: The Bald Eagle Formation (= Oswego Sandstone of New York) consists of shales and siltstones interbedded with very fine- to coarse-grained sandstones and conglomerates. Laughrey and Harper (1996) interpreted it to have been deposited in paralic and fluvial environments along the foreland of the Taconic orogenic belt. The formation is on the order of 1,000 feet thick in south-central Pennsylvania, but thins rapidly to the northeast and east through the study area

(Laughrey and Harper, 1996). In Grugan field, which lies primarily in Clinton County west of the study area, the reported thickness of the pay zone ranges from 28 to 130 feet and averages 74 feet (Laughrey and Harper, 1996).

Both intergranular and fracture porosity occur in the Bald Eagle in Grugan field. The sandstone matrix of the formation is very tight and exhibits low natural porosity (Harper and Cozart, 1992; Laughrey and Harper, 1996; Harper, Kelley, and Linn, 1999). A combination of infilling with authigenic cements and compaction of the sediments upon burial reduced most of this porosity. Secondary intergranular porosity formed through grain and cement dissolution; however, measured intergranular porosities for this formation remain low, ranging from two to eight percent (Laughrey and Harper, 1996). Networks of subvertical to vertical fractures having measured porosities of up to 30 percent represent the main contributor to porosity, and therefore, production, in the Bald Eagle Formation. Such fracture porosity developed when a combination of saline brines and a methane emulsion migrated upward from deeper horizons during the Alleghanian deformation to cause natural hydraulic fracturing of this formation (Lacazette, 1991; Laughrey and Harper, 1996; Harper, Kelley, and Linn, 1999).

Structural traps control the occurrence of hydrocarbons in the Bald Eagle Formation. However, additional mechanisms facilitate this sealing effect, including: 1) the naturally tight nature of the formation; 2) observed partial fracture filling with secondary minerals; and 3) the presence of shale in the overlying Juniata Formation (Laughrey and Harper, 1996).

Fields: Grugan field is situated on the northwestern edge of the Hyner anticline in Clinton and Lycoming Counties. Texaco discovered the field in 1982 when they experienced a large gas show at 12,900 feet in the #1 State Forest Tract 285 test well in Clinton County while drilling to Cambrian targets at 19,365 feet. When the well failed to find gas in the deeper strata, Texaco plugged it back and completed it in the Bald Eagle at 13,500 feet. Once the casing was perforated and the mud cleaned up with acid, the well provided a large flow, estimated at about 20,000 Mcfgpd. Grugan field has produced an astonishing 6.6 billion cubic feet of gas (Bcf) since being drilled, making it one of the most productive small fields in the basin. Attempts to find additional Bald Eagle fields throughout the area have, thus far, failed.

FUTURE PROSPECTS

Future prospects for oil and gas in northeastern Pennsylvania are promising because potential hydrocarbon source and reservoir rocks exist and the lithology and geologic structure in the area afford numerous opportunities for the trapping of hydrocarbons. In addition, exploration activity may be stimulated by the fact that certain Devonian formations are amenable to the storage of natural gas, and that the area is strategically located with respect to major market areas (Cornell, 1971).

Devonian

Catskill and Lock Haven Formations: Exploration for, and development of, gas fields in north-central Pennsylvania throughout the last two decades of the 20^{th} century suggests the Lock Haven Formation and, possibly, the Catskill as well, have potential for further hydrocarbon production. Discovery of gas in Lackawanna County in 1956 (Harvey Lake field), and oil in Bradford County in 1987 (Brace Creek field), came as quite a surprise to everyone. Geochemistry had largely predicted the absence of heavier hydrocarbons throughout the area, and the intense deformation and inherent high temperatures associated with development of the Lackawanna syncline suggested that not even the lighter hydrocarbons would have been retained.

Known reservoir sandstones in western and north-central Pennsylvania equivalent to the Catskill and Lock Haven sandstones in the study area provide additional insight into the potential productivity or the Upper Devonian in northeastern Pennsylvania. For example, many of the Catskill and Lock Haven sandstones are lithologically similar to the productive Bradford Group sandstones of western Pennsylvania (Harper, Tatlock, and Wolfe, 1999) with which they are partially equivalent. Further, production data for the Lock Haven sandstones of Centre and Clinton Counties suggest that as much as 30 Bcf could be produced from the Lock Haven in Bradford and Lycoming Counties alone (Donaldson and others, 1996). For these reasons, the Lock Haven Formation should be further evaluated as an oil and gas reservoir.

Oriskany Sandstone: The Oriskany Sandstone first produced gas in northeastern Pennsylvania in 1930 despite deep drilling throughout much of the state in prior years. From that time until the later decades of the 20th century, exploration for Oriskany reservoirs was directed to the west. Yet additional exploration throughout the mid-1990s documented the potential of this formation farther east, in Bradford County. Currently, four active fields produce gas from the Oriskany, with average annual productions as high as 2 Mmcf. The relative success of the Oriskany Sandstone as both a producing and storage reservoir results from its porosity characteristics and the trapping mechanisms responsible for the accumulation of hydrocarbons in the formation (Lytle and others, 1971; Harper and Patchen, 1996; Patchen and Harper, 1996). Traditional Oriskany drilling locations have targeted surface expressions of anticlines, but future exploration activities would benefit from using seismic exploration techniques to evaluate more obscure, subsurface structures (Briggs and Tatlock, 1999).

Silurian

Tuscarora Sandstone: The Tuscarora sandstone is a fine-grained to conglomeratic, quartz-cemented, quartzose sandstone that includes minor amounts of feldspar, chlorite, and illite. Fractures largely control porosity in the Tuscarora, and structural traps are the dominant mechanism by which natural gases accumulated in this formation (Avary, 1996; Briggs and Tatlock, 1999; Harper, Kelley, and Linn, 1999). Although gas was first discovered in the Tuscarora of Pennsylvania in Fayette County in 1964, the first established production occurred with completion of the Amoco/UGI #1 Texasgulf well in Centre County in 1977 (Harper, Kelley, and Linn, 1999). This well flowed an estimated 20,000 Mcfgpd and marked the discovery of the Devils Elbow field (Harper, 1981). Additional drilling in Centre County established the Runville and Black Moshannon gas fields in 1980 and 1982, respectively. Although the quantity of gas observed in these fields typically is large, the high levels of non-hydrocarbon gases it contains limits the quality of Tuscarora gas (Harper and Cozart, 1992; Harper, Kelley, and Linn, 1999). Pennsylvania wells generally have relatively high nitrogen contents, lowering the heating values to about 850 Btu; in West Virginia, some Tuscarora wells produce carbon dioxide. The presence of both of these gases indicates the high degree of thermal maturation characteristic of Paleozoic strata where the Tuscarora is producing (C. D. Laughrey, 2002, written communication).

The best Tuscarora sandstone prospects will exhibit one or more of the following characteristics: 1) the presence of intergranular and fracture porosity, and moldic porosity along feldspar-rich laminae; 2) low amounts of non-hydrocarbon gases in the mix; 3) structural traps that are not so complex as to be irresolvable using remote sensing techniques; and 4) stratigraphic traps where the formation grades from coarser units (e.g., Shawangunk Formation in eastern Pennsylvania) into finer grained, tighter (lower permeability) units (e.g., Medina Group sandstones in northwestern Pennsylvania) (Avary, 1996; Harper and Cozart, 1992; Lytle et al., 1971; Cornell, 1971).

Ordovician and Cambrian

Bald Eagle Formation: To date, Grugan field in Clinton and Lycoming Counties is the extent of Bald Eagle production in the Appalachian basin. The extent to which the following issues can be determined will affect future prospects for this formation: 1) the timing of fracturing, structural trap development, and migration of gas to the reservoir rock; 2) the role of Alleghanian deformation and/or basement faulting on structural trap and reservoir development; and 3) the nature of an anomalous seismic reflector observed at the base of the Bald Eagle Formation in the Grugan field (Laughrey and Harper, 1996).

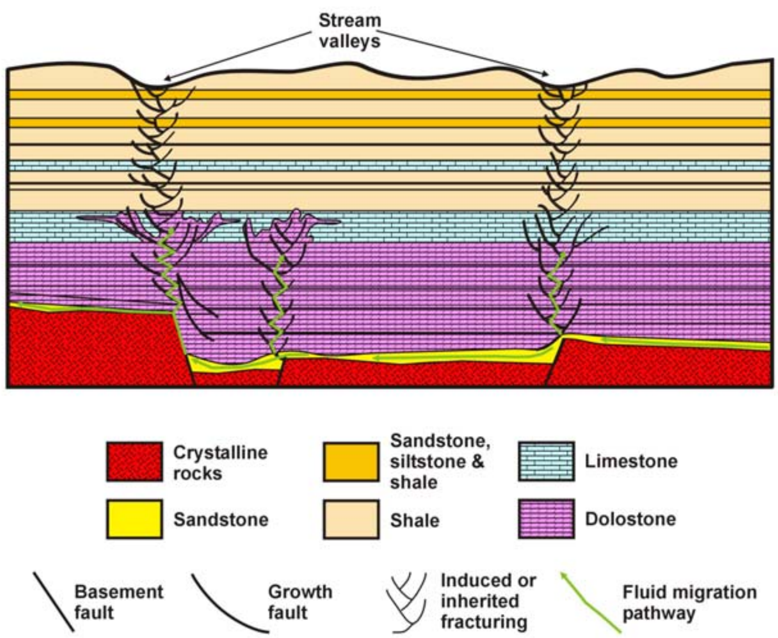


Figure 14. Diagram illustrating two scenarios for development of gas reservoirs in Trenton and Black River Limestones in Appalachian basin. Deposition of sedimentary cover over eroded and faulted basement (Rome trough) resulted in offset beds and growth faults in Lower Paleozoic stratigraphic section. Combination of overburden weight and intermittent movement of basement induced series of fractures in brittle sedimentary cover above basement faults (stream valleys and other linear features reflect fracturing at surface). Fluid migration through porous basal Paleozoic sandstones allowed magnesian-rich fluids to dolomitize Trenton and Black River Limestones, at least in northern part of basin (New York and Ontario) (left side of diagram). In south (West Virginia), fracturing associated with Rome Trough appears to be sole factor accounting for gas production from Trenton and Black River section (right side of diagram).

Trenton and Black River Limestones: (Stratigraphic note: The names Trenton and Black River generally are considered group or stage names in Pennsylvania. However, because most of the established formation names, such as Benner, Salona, and Linden Hall, refer to facies that occur in various parts of the section in areas outside the type localities, we prefer to use the drillers' terminology.) The oil and gas industry has paid a great deal of attention to the Trenton and Black River Limestones during the last few years. Recent discoveries of natural gas in great quantities in New York, Ohio, and West Virginia have revitalized the exploratory efforts of a number of companies and drawn attention from across the country. Production occurs associated with faulting and fracturing in the limestones, typically associated with basement faulting. There are at least two scenarios associated with production (Figure 14). In the first scenario, typified by Trenton and Black River production in New York and Ontario, hot magnesian-rich hydrothermal brines penetrated the limestone along faults and fractures propagating upward from the basement and dolomitized the limestone. Dolostones tend to have more porosity than limestones, and the porosity tends to be concentrated in large openings or vugs (Figure 15A). Hydrothermal dolomite within these vugs crystallizes as "saddle dolomite", a form of the mineral in which the crystal lattice is twisted, giving the crystals a curved shape (Figure 15B). In thin section, "saddle dolomite" has classic spearhead geometry (Figure 15C) and curved crystal faces (Figure 15D). In the second scenario, typified by Trenton and Black River reservoirs in West Virginia, production comes from intense fracturing related to the Rome trough, but is not associated with dolomitization (Figure 14).

Of the approximately 80 wells drilled in Pennsylvania that penetrated at least to the top of the Trenton, including two or three drilled in 2002, none has ever found more than a show of gas. Figure 16

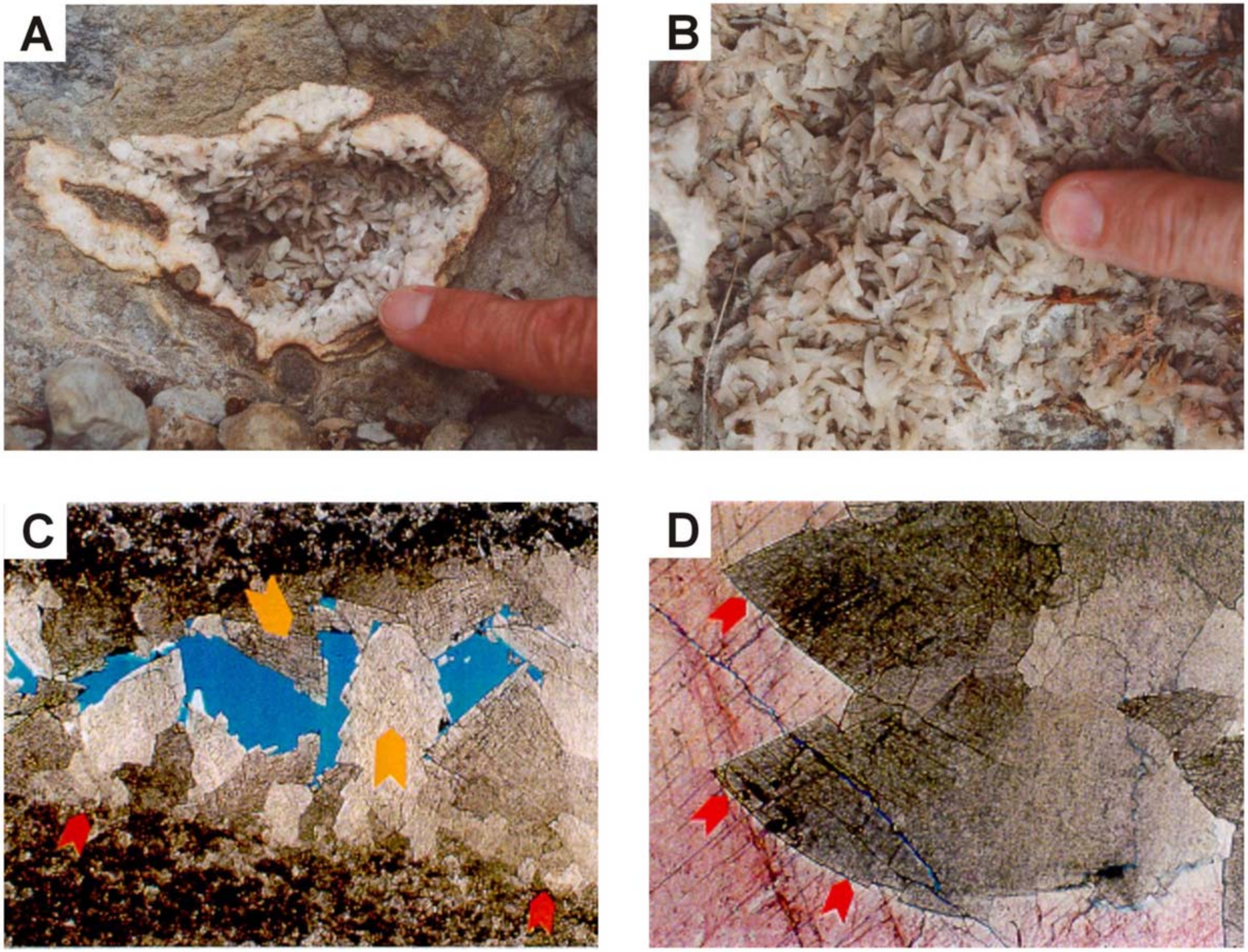


Figure 15. Photographs of dolostone from hydrothermally dolomitized limestone: A – Dolomitization of limestone typically results in vugs or cavities in rock. This vug is lined with crystalline dolomite; B – Closer examination shows dolomite crystals to be "saddle dolomite," known to occur as result of intrusion of hydrothermal brines; C – Photomicrograph of hydrothermally altered dolostone shows large pore space (blue) being occluded by dolomite crystals exhibiting classic "spearhead" geometry (yellow arrows); and D – Photomicrograph showing curved crystal faces of "saddle dolomite" (at red arrows). Photomicrographs (C and D) from Davies (2000).

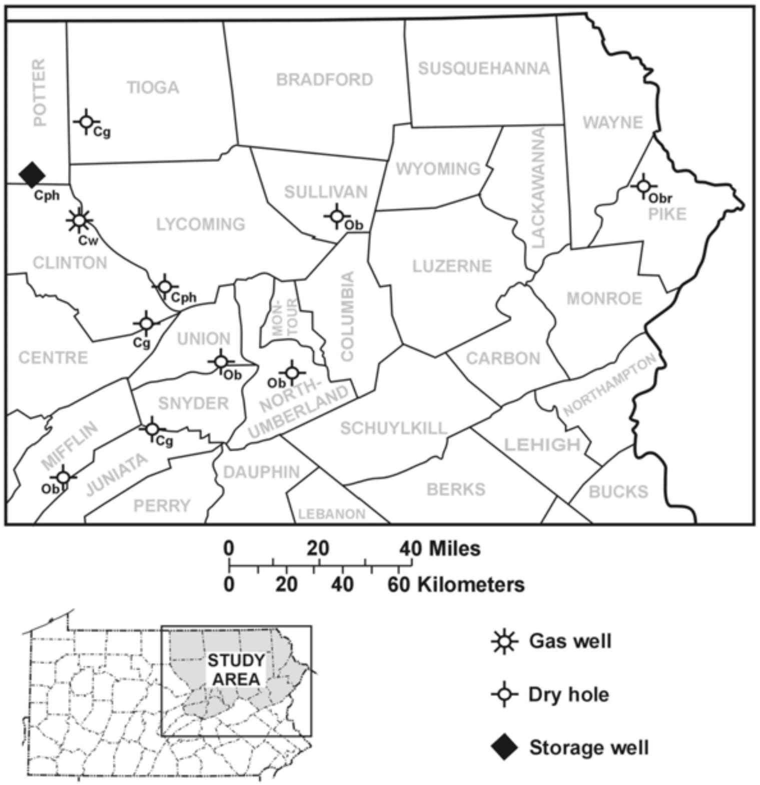


Figure 16. Map of northeastern Pennsylvania showing the locations of wells that penetrated at least to top of Trenton Limestone, and formations at total depth (TD) for each. Well symbols indicate most recent status of the wells. TD formations: Obr – Black River Limestone. Ob – Beekmantown Group. Cg – Gatesburg Formation. Cw – Warrior Formation. Cph – Pleasant Hill Formation.

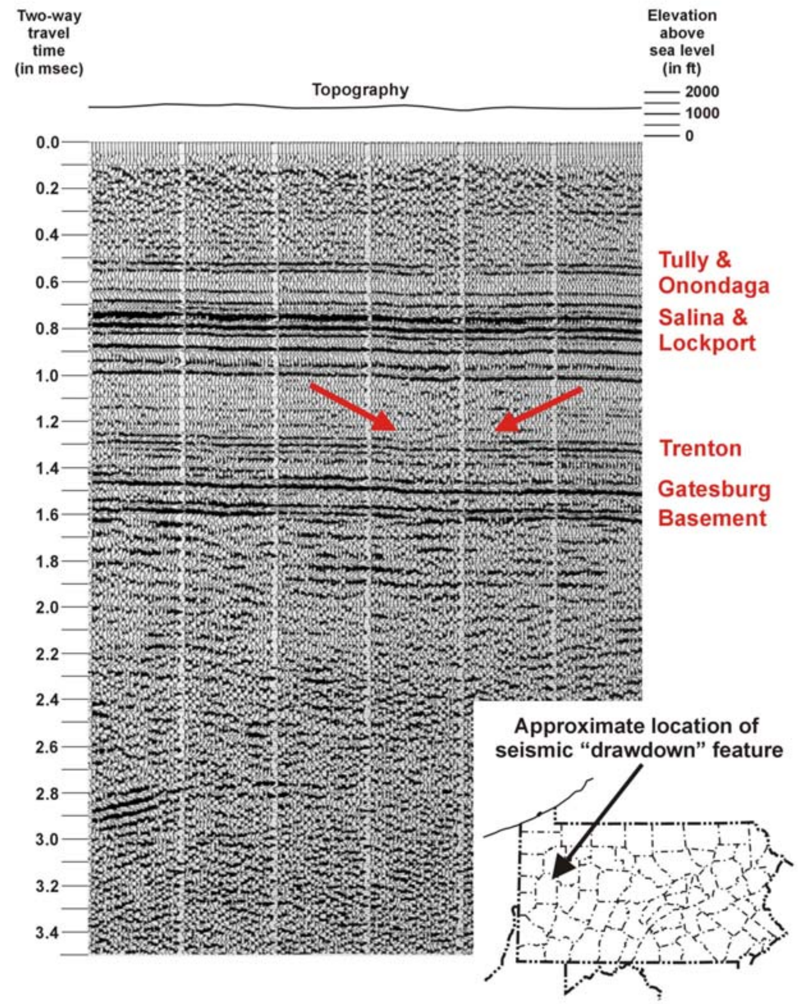


Figure 17. Interpreted seismic survey line through Venango and Butler Counties, Pennsylvania, showing potential location to explore for Trenton and Black River reservoirs. Line shows "drawdown" feature (at arrow) at level of Trenton reflectors. "Drawdown" features have proven to be highly productive drilling targets in Ontario and other places.

shows those wells within, or closely adjacent to, the study area. Until recently, exploration focused on that old standby, the anticline. The current Trenton/Black River play focuses on targets that are very restricted geographically – essentially planar in geometry. As such, seismic surveys (both 2D and 3D) and other geophysical surveying techniques are absolutely required for finding the basement faults (Rome Trough and cross-strike faulting) that create potential reservoirs. One of the types of seismic features the industry is looking for is a "drawdown" in the seismic reflectors (Figure 17), indicating a potential rift associated with dolomitized Trenton and Black River limestones.

In 1971, Texaco drilled a well on State Forest Lands in Pike County. Description of the well cuttings (Figure 18) suggested that the well had an essentially normal Trenton section, but only 40 feet of Black River between (picked at between 13,750 and 13,790 feet) before encountering dolostones thought to be Beekmantown. The geophysical logs (Figure 18), however, indicate otherwise. The base of the Trenton Limestone (identified by the signature of the Millbrig and Deicke K-bentonites) occurs

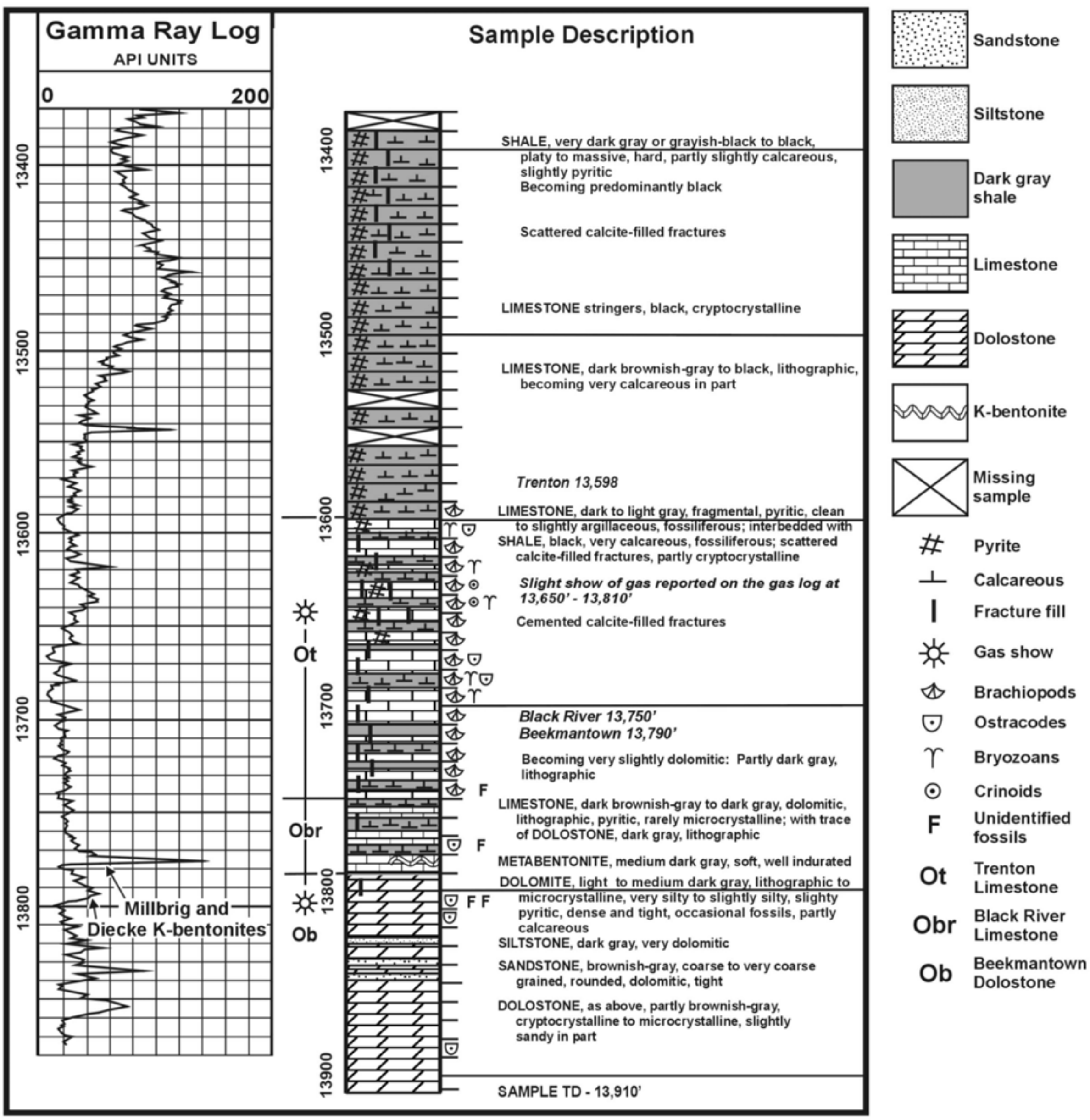


Figure 18. Gamma ray log and sample description of Utica Shale and Trenton and Black River Limestones in Texaco #C-1 PA Department of Forest and Waters Tract 163 well in Pike County (see Figure 16 for location). Notice that sample description and gamma ray log depths do not correspond owing to differences in datum elevations.

between 13,775 and 13,800 feet, indicating that the Black River section on the sample description is actually lower Trenton. The section below this has been dolomitized, but unless the Black River Limestone has been completely eroded or faulted out in this area (highly unlikely), the dolostone must represent Black River rather than Beekmantown. Unfortunately, Texaco ceased drilling approximately 120 feet into the dolostone, so there is not enough logged section for accurate correlation with other wells. The Pike County well had gas shows from 13,650 to 13,810 feet. This was probably the result of increased porosity, which in turn was probably due to faulting or fracturing of the limestone.

We fully expect more Trenton and Black River wells to be permitted and drilled in the near future in Pennsylvania.

Beekmantown and Cambrian Formations: Although Lower Ordovician and Cambrian formations have been explored in the study area (Figure 16), there really aren't enough wells to obtain an accurate evaluation of these deeper rocks. Exploration of the Lower Ordovician Beekmantown Group in Pennsylvania has been limited. Only a few, mostly dry, wells have been completed in the Beekmantown over the past five decades. A few wells in northwestern Pennsylvania produced from the Beekmantown, but not enough data have been obtained from these wells to evaluate them.

Cambrian formations in central and eastern Pennsylvania typically have attracted only the major oil companies and those large independents with the capital to drill 15,000- or 20,000-feet deep wells. The Gatesburg Formation has been a highly successful target in central and western Ohio, and produced some gas and condensate in a few wells in Crawford County in northwestern Pennsylvania. Gatesburg and other Cambrian Formations could be viable targets in northeastern Pennsylvania. However, the depth of the formation, the structural complexities of the "Eastern Overthrust Belt", and other factors may discourage all but the most strong-hearted explorationists (Harper, 1981; Harper and Cozart, 1992). The potential certainly exists if the structural features (stacked imbricate thrust sheets) associated with Gatesburg and deeper formations can be resolved using appropriate geophysical techniques prior to drilling.

QUATERNARY HISTORY OF THE TUNKHANNOCK-GREAT BEND REGION

by
Duane D. Braun

OVERVIEW

During the Quaternary, the Tunkhannock-Great Bend region was affected by a climate that alternated between cold, glacial-periglacial conditions and warm, humid-temperate interglacial conditions. About ten such alternations have affected northeastern Pennsylvania during the last one million years (Braun, 1989, 1994, 1997). There is evidence for four different glacial advances across the region in that there are three different aged glacial limits mapped farther to the southwest (Figure 19) (Braun, 1994; Sevon and Braun, 1997) with a fourth limit now being separated out (Braun, 1999, and ongoing work). The farthest to the southwest and oldest glacial limit is considered to be of pre-Illinoian-G age (850 Ka) or even 2-Ma age (Stanford, 1997). The next distinct glacial limit is considered to be of either late Illinoian (150 Ka) or pre-Illinoian-B (450 Ka) age and is only about 10 miles beyond the most recent, Late-Wisconsinan age (20Ka) glacial limit. Other glacial advances have approached the area and caused severe periglacial activity (Braun, 1989, 1994, 1999).

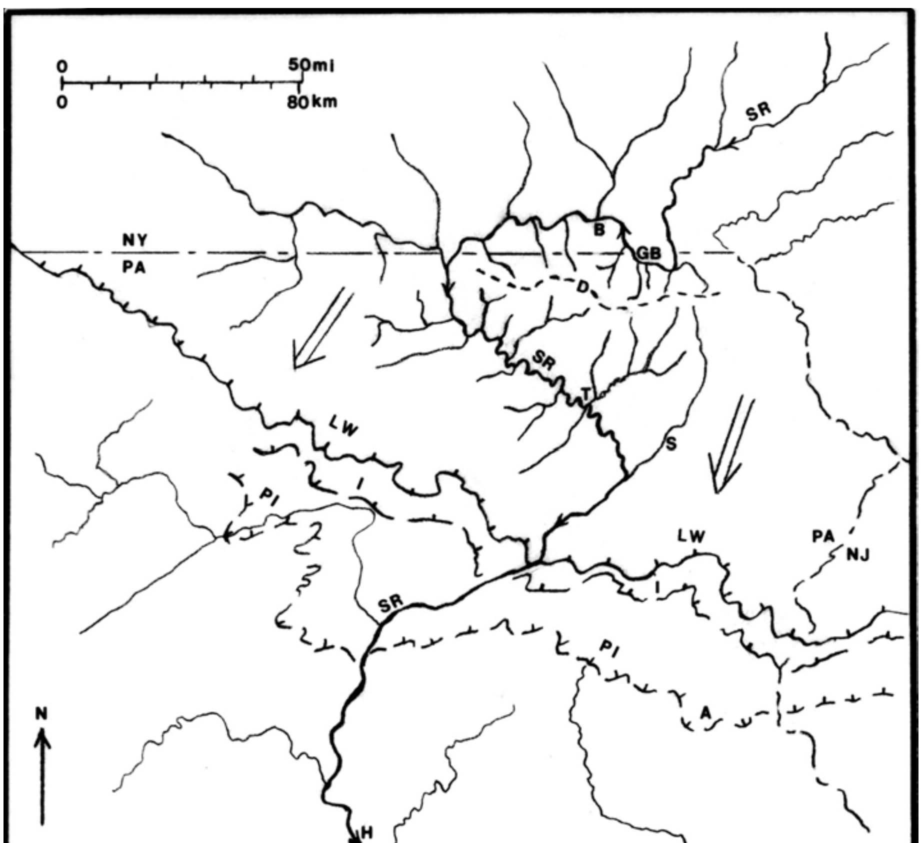


Figure 19. Location map showing drainage patterns, regional ice flow direction, and glacial limits. Double sided arrows = regional ice flow direction. Hachured lines are glacial limits: LW = Late Wisconsinan, I = Illinoian or older, PI = pre-Illinoian-G or older. Dashed line labeled D is the regional east–west divide: SR = Susquehanna River, B = Binghamton, GB = Great Bend, S = Scranton, T= Tunkhannock

Braun, D.D., 2002, Quaternary history of the Tunkhannock-Great Bend Region, *in* Inners, J. D., and Fleeger, G. M., eds., From Tunkhannock to Starrucca: bluestone, glacial lakes, and great bridges in the “Endless Mountains” of northeastern Pennsylvania: Guidebook, 67th Annual Field Conference of Pennsylvania Geologists, Tunkhannock, PA, p. 32 - 38.

Each glacial advance across the Tunkhannock-Great Bend region would have accomplished some erosion. The older glacial termini are parallel to the Late Wisconsinan terminus (Figure 19) and glacial striations in the area covered by the older glaciations are in the same direction as striations within the Late Wisconsinan limit (Braun, 1994). This indicates that the older glaciers moved across the region in about the same direction as the Late Wisconsinan ice and that they should have eroded and deposited in a pattern generally like that of the Late Wisconsinan. Preglacial valleys oriented near parallel to the ice flow would be significantly scoured and partly back filled in each glaciation. Valleys oriented transverse to ice flow would be the least scoured and the most back-filled, sometimes becoming completely buried. The meltwater sluiceways discussed below were probably initiated by the earliest glaciation and enlarged by each succeeding glaciation.

Only Late Wisconsinan-age deposits and constructional landforms have been observed in the Tunkhannock-Great Bend region and elsewhere within the Late Wisconsinan limit in northeastern Pennsylvania (Braun, ongoing mapping). The last glacial advance was quite effective in removing older glacial deposits, presumably of similar thicknesses to those of Late Wisconsinan age, from the landscape. The clasts in the till are dominated by fresh clasts of the local bedrock. This suggests considerable erosion of the bedrock during this last glaciation. Older deposits may still exist under the Late Wisconsinan deposits where glacial scour was minimal, such as in valleys transverse to ice flow.

The total duration of Late-Wisconsinan ice cover is on the order of 6000 years at the northern boundary of Pennsylvania and 1000 years at the terminus in northeastern Pennsylvania. The Late-Wisconsinan ice advanced across the Buffalo, New York area at 24.5 Ka (all dates in C_{14} years) (Muller and Calkin, 1993) and probably entered Pennsylvania at about 23 Ka. The glacier reached its terminal position at about 21 to 20 Ka in adjacent states (Cotter, 1983; Cotter et al., 1985; Lowell, 1991) and probably also in Pennsylvania. Retreat from the terminal position started around 19 Ka (Cotter, 1983; Cotter et al., 1985) and reached the Finger Lakes at about 16 Ka (Muller and Calkin, 1993). A reasonable estimate for the ice recession to reach the northern edge of Pennsylvania is about 17 Ka. This means that it took about 2000 years for the ice to retreat the 70 miles (along a S20^{o}W flowline) from the terminal moraine through Tunkhannock to the New York line. If the ice retreated at a steady rate (assuming no significant readvances) it would have taken about 30 years to recede one mile. At that rate, the ice would have crossed a single 7.5-minute quadrangle in about 250 years and retreated from Tunkhannock to Great Bend in about 800 to 1000 years.

Much of the glacial deposition occurred as the ice was receding, so the bulk of glacial material in northeastern Pennsylvania was deposited in about 2000 years. In any particular 7.5-minute quadrangle, the materials were deposited within 200 to 300 years. Ongoing mapping by Braun of the glacial deposits in northeastern Pennsylvania suggests that several (5 to 15) short-lived still-stands of the glacier occurred as it receded across an individual quadrangle. During each still-stand the ice deposited a belt of thicker material, usually expressed in each valley as a till knob damming the valley. A series of such knobs formed “beaded valleys” that have a series of narrower and wider segments (Figure 20). From the time estimates above, each of these belts of thick till or valley damming knobs should have taken on the order of 15 to 60 years to form. Coates and King (1973) and Coates (1981), working within and just north of the Great Bend area, also described till knobs that partly block many small tributary valleys and impound lakes and swamps. From well data, primarily in New York, till thickness in the valleys averaged 60 feet, was often over 100 feet especially under knobs, and was in a few places 250 feet. Similar thicknesses of till are shown by thickness contours (isochores) on the 7.5-minute quadrangles mapped by Braun in northeastern Pennsylvania.

Thick till masses were also deposited in the lee of bedrock hills, such as Elk Mountain (Day-l Roadlog), and in valleys transverse to ice flow. Coates (1966) noted that the valleys transverse to ice flow are usually asymmetric with a steep south side and gentler north side underlain by a mass of thick till that he called a “till shadow” (Figure 21). In a typical example, the till shadow partly to completely

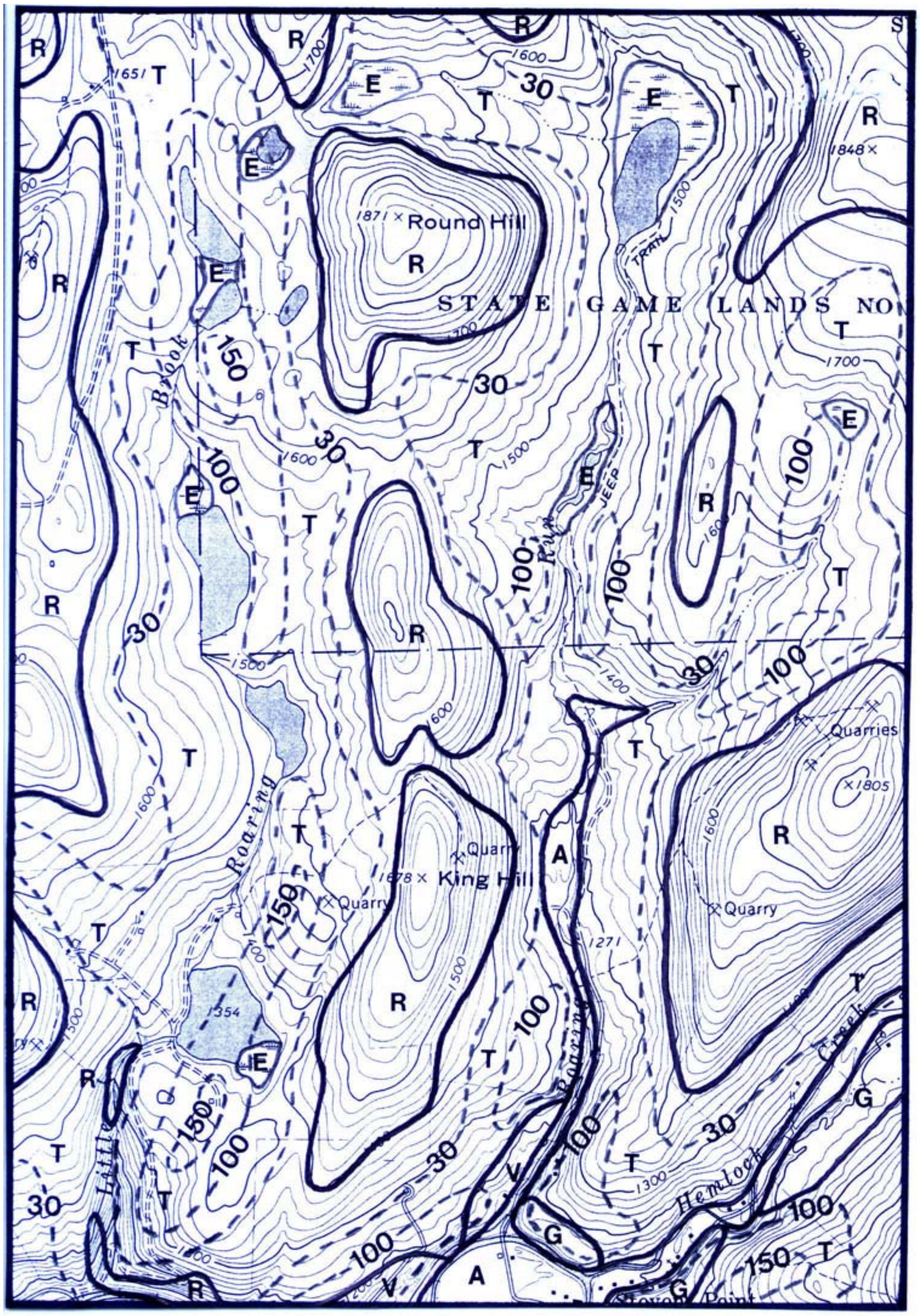


Figure 20. Till knobs forming "beaded valleys", north-central Susquehanna 7.5-minute quadrangle immediately north of STOP 2. Glacial deposit thickness contours (isochores) at 30, 100, and 150 feet. A= alluvium, E = wetlands, G = ice-contact stratified drift, R = bedrock at or within 6 feet of the surface, T = till, V = till underlain by varved sediments.

buries the center of the preglacial valley cut in bedrock. The postglacial stream often incises into the south bedrock side of the valley and has started to cut a bedrock gorge that typically contains a series of waterfalls. Often the gorge is "one-sided" with bedrock ledges on its south side and till on its north side. Many examples of such gorges are noted on both Day-1 and Day-2 Roadlogs. Sometimes the burial of the transverse valley is so deep that the post-glacial stream is diverted to an adjacent valley. This is the case at Salt Springs State Park (STOP 10).

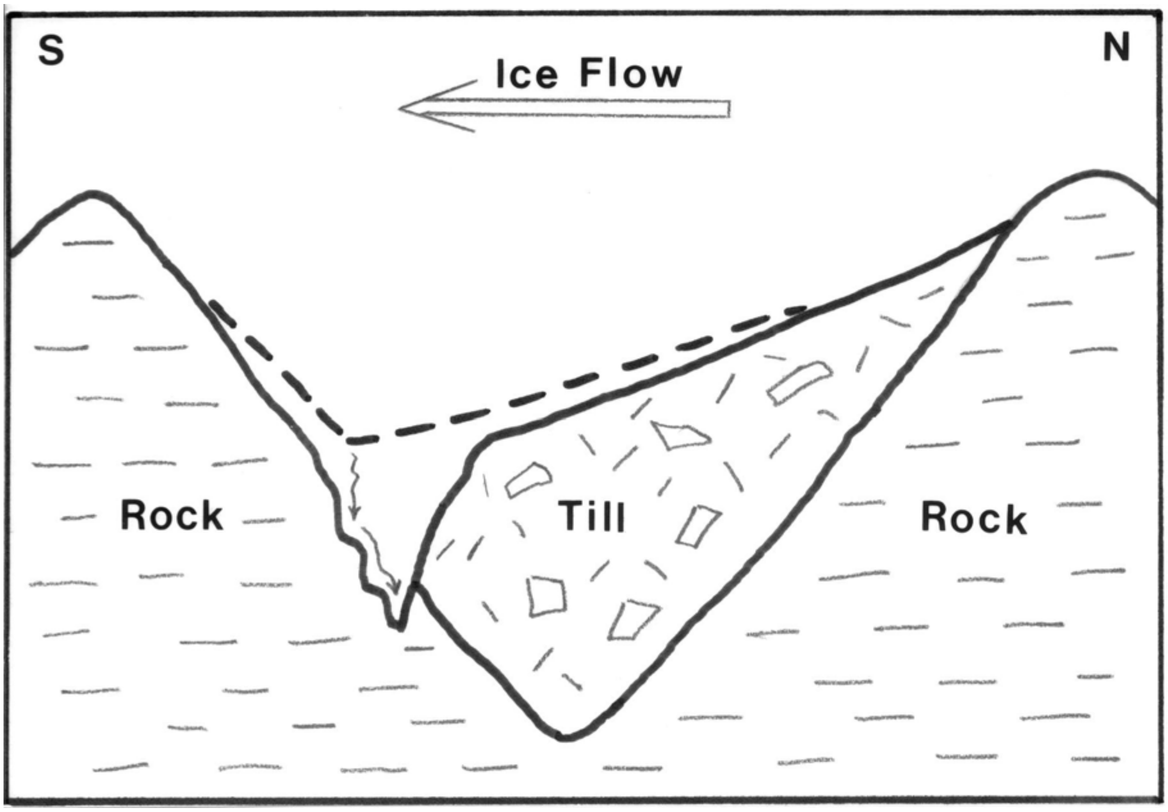


Figure 21. Cross-section sketch of an asymmetric valley transverse to ice flow showing a “till shadow” on the north side of the valley and postglacial stream incision along the south side of the valley. Dashed line shows the till surface upon glacial recession. The incising stream often has a “one-sided” bedrock gorge on the south side of the valley that often develops into a double-sided bedrock gorge as incision continues.

As the glacier continued its recession north of Pennsylvania, cold periglacial climatic conditions prevailed in the area for several thousand years. At that time, the exposed sandstone ledges were frost-riven and shattered (Peltier, 1949; Harrison, 1966) and the blocks transported downslope by various processes collectively known as gelifluction (Coates and King, 1973; Coates, 1981; Braun, 1997). These processes resulted in a boulder colluvium mantle often extending 500 feet, and in places, as much as 1000 feet, downslope of individual sandstone ledges. A few exposures show Late Wisconsinan till or ice-contact gravel under the boulder colluvium. The glacial till deposits themselves have been “mobilized” on the slopes by gelifluction (Braun, 1994, 1997). On the upper to middle parts of the slopes, the upper 2 to 3 feet of material is colluvium derived from till. The material often shows a well-developed downslope fabric (tabular clasts near parallel to the ground surface). On the lower parts of the hillslopes the “colluviated till” is often 5 or more feet thick.

Itter (1938) noted that the amount of erosion in postglacial times has been comparatively slight because the depositional features originating near the close of the Pleistocene have not been significantly altered. In the latest Pleistocene, after 13,000 BP (Dalton et al., 1997), forest vegetation became well established in the area. This acted to reduce erosion and sediment load of tributary streams while trunk streams continued to incise into the glacial deposits. In the Holocene the only areas of sediment deposition have been on the floodplains of the larger streams in the region, such as the North Branch Susquehanna. Those deposits are primarily overbank deposits that drape the lower portions of the outwash terraces. Small-scale climatic changes during the Holocene are reflected in changes in the rate of that overbank sedimentation.

THE EFFECT OF THE COURSE OF THE NORTH BRANCH SUSQUEHANNA RIVER ON DEGLACIATION OF THE AREA

The convoluted course of the North Branch Susquehanna River caused meltwater to be ponded in front of the ice in places while in other places the meltwater could freely drain away from the ice. From its New York State headwaters the river flows southwest to Pennsylvania where it makes a near 180^0 "Great Bend" to re-enter New York State flowing northwest (see Figure 19). The river then flows west until it makes a more than 90^0 bend to re-enter Pennsylvania and flow southeast in a series of large incised meanders past Tunkhannock to the Wyoming Valley. Between Tunkhannock and Great Bend is an east-west trending regional divide separating streams draining north to Great Bend and New York State from those draining south to the incised meander reach. The northerly draining tributaries on the west side of the incised meander reach and north of the east-west divide contained proglacial lakes during deglaciation.

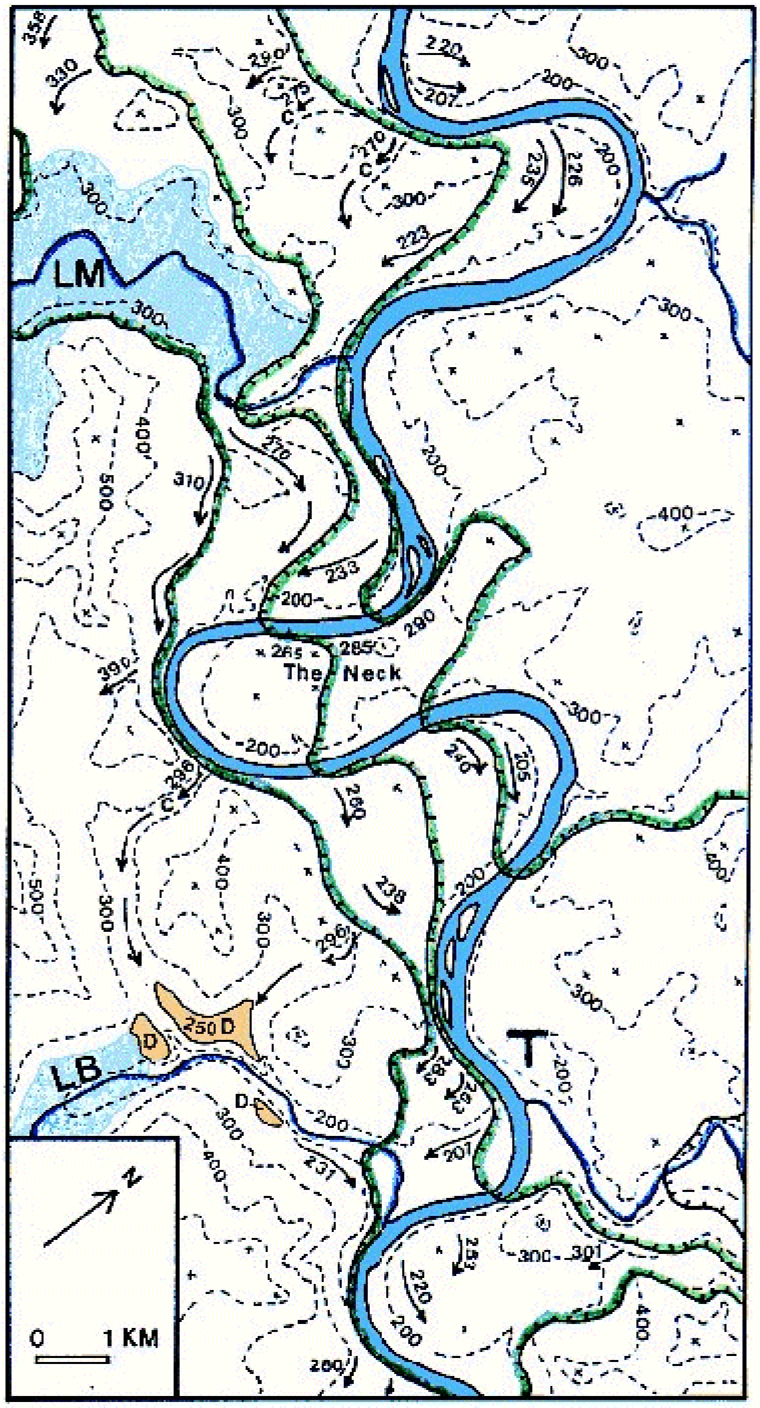


Figure 22. Map showing the incised meander reach of the Susquehanna River near Tunkhannock (T). Lines with hachures are successive ice margins that forced meltwater drainage through a series of sluiceways (arrows) on the southwest side of the valley. C = Deep col to west side of delta, D = Bowman valley delta, LB = Glacial Lake Bowman, LM = Glacial Lake Mehoopany. Elevations of topographic contours and sluiceways are in meters.

Deglaciation of the Tunkhannock area

The southeast trending incised meander reach of the North Branch Susquehanna River was parallel to the edge of glacier as it retreated from the area. When the ice front reached the river valley, ice marginal meltwater drainage cut a series of channels and incises cols on the southwest side of the valley (Figure 22). Additional drainage came from ice-dammed lakes in tributaries that enter the southwest side of the Susquehanna valley. Before the ice front reached the Susquehanna valley, those lakes only had outlets near their headwaters and had high elevation water levels. As the ice retreated into the Susquehanna valley, those lake levels dropped several hundred feet and sent large quantities of water along the southwest side of the Susquehanna valley.

This ice-marginal drainage built large deltas in the mouths of the dammed tributary valleys. The largest of these deltas was built into Glacial Lake Bowman near where the Bowman Creek valley enters the Susquehanna valley just south of Tunkhannock. (D on Figure 22). The delta was fed by two different meltwater sluiceways (Figure 22). The western sluiceway has an especially deeply incised col (C on Figure 22) that carried flow from Glacial Lake Mehoopany when that lake's level dropped about 600 feet as ice retreated to the Susquehanna valley. STOP 11 will examine the bottomset beds of the delta, and STOP 12 will examine the topset beds of the delta.

Once the ice front of the glacier retreated northeast of the Susquehanna valley, meltwater built a series of outwash terraces on the floor of the valley. Both White (1883) and Peltier (1949) noted several terrace levels in the Tunkhannock area. The current mapping (Braun, in progress) generally agrees with the terrace levels observed by previous workers but revises the elevation and interpretation of some of those levels. White's 200- and 150-feet terraces are ice-marginal channels. Peltier's 100-feet-level kame terrace under the town of Tunkhannock is actually the main outwash terrace found at a number of sites along the river in the area and should properly be called the "Olean" terrace. Peltier's 75-feet-high Olean terrace is actually the next to highest glacial outwash terrace and is more properly related to ice margin positions farther north than those that produced the 100-feet-high terrace. Peltier's 45- to 50-feet terrace is present in the mouths of tributary valleys. This terrace is probably related to the latest glacial to postglacial downcutting of the river rather than the Valley Heads ice margin in New York State. Peltier's lowest 25- to 30-feet-high terrace and White's lowest 30- to 35-feet terrace are both related to the post-glacial incision of the river.

Shaw (1989) proposed that catastrophic-scale subglacial meltwater floods (17,000,000 cubic feet per second) carved the drumlins and Finger Lake valleys in central New York State and then came down the Susquehanna valley. A flood of that size would require water depths in excess of 500 feet above the Susquehanna valley. Braun (1990) noted a number of features in the Susquehanna valley from Bloomsburg to Tunkhannock that show flood levels were never more than a few tens of feet above the surface of the highest outwash deposits. Two miles south of the town of Tunkhannock is an extensive area of knob and kettle morainic topography that lies just 40 feet or so above the 100 feet terrace surface. This means that only a flood 40 feet deep could have come down the river, less than 10 percent of the depth of Shaw's proposed flood

Deglaciation of the Great Bend Area

As the glacier retreated from the Tunkhannock to Great Bend, meltwater was free to drain away from the ice down south-draining valleys until it reached the regional east-west divide near New Milford. Once the ice retreated north of the divide, a series of proglacial lakes developed in each of the north-draining valleys. As the ice continued retreating north of Great Bend, the individual lakes combined into the regional Glacial Lake Great Bend when the Susquehanna valley opened up in the Great Bend area (Figure 23). This proglacial lake extended for 25 miles along the Susquehanna valley and up all the tributary valleys. The outlet was through New Milford and down Martins Creek to Nicholson, the New Milford sluiceway (Harrison, 1966). The meltwater carved a 600 feet deep notch through the east-west divide (STOP 7).

The five ice margins shown on Figure 23 represent different phases in the development of Glacial Lake Great Bend and its deposits. Ice margin 1 was when the ice was right at the entrance to the New Milford sluiceway and meltwater was still draining freely to the south. As the ice receded up Salt Lick Creek valley from margin 1 to margin 2, it deposited the sand and gravel deposits at STOP 8. Margin 2 is marked by a hanging delta (D on Figure 23) on the west side of the valley that is graded to the level of the lake. Margin, 3, is marked by a hanging delta and a sluiceway channel that extends from the next valley to the east and is graded to the level of the lake. Margin 4 was where the ice first started to "open up" the Susquehanna valley and permitted expansion of Glacial Lake Great Bend into valleys to either side of the sluiceway valley. This expansion process continued until the lake reached its maximum size at ice margin 5. Once the ice receded north of margin 5, the lake would have drained as meltwater freely flowed westward down the Susquehanna Valley at Binghamton, New York.

Outcrops of varved sediments exist in tributary valleys adjacent to the Susquehanna valley throughout the area of Glacial Lake Great Bend. The varves in the Susquehanna valley appear to be below present river level. All the varves are between a basal till unit and thick overlying till and ice-contact stratified drift units. This indicates that there was a significant readvance of the glacier across the entire Great Bend area to near the east-west divide before the glacier finally retreated entirely from the region.

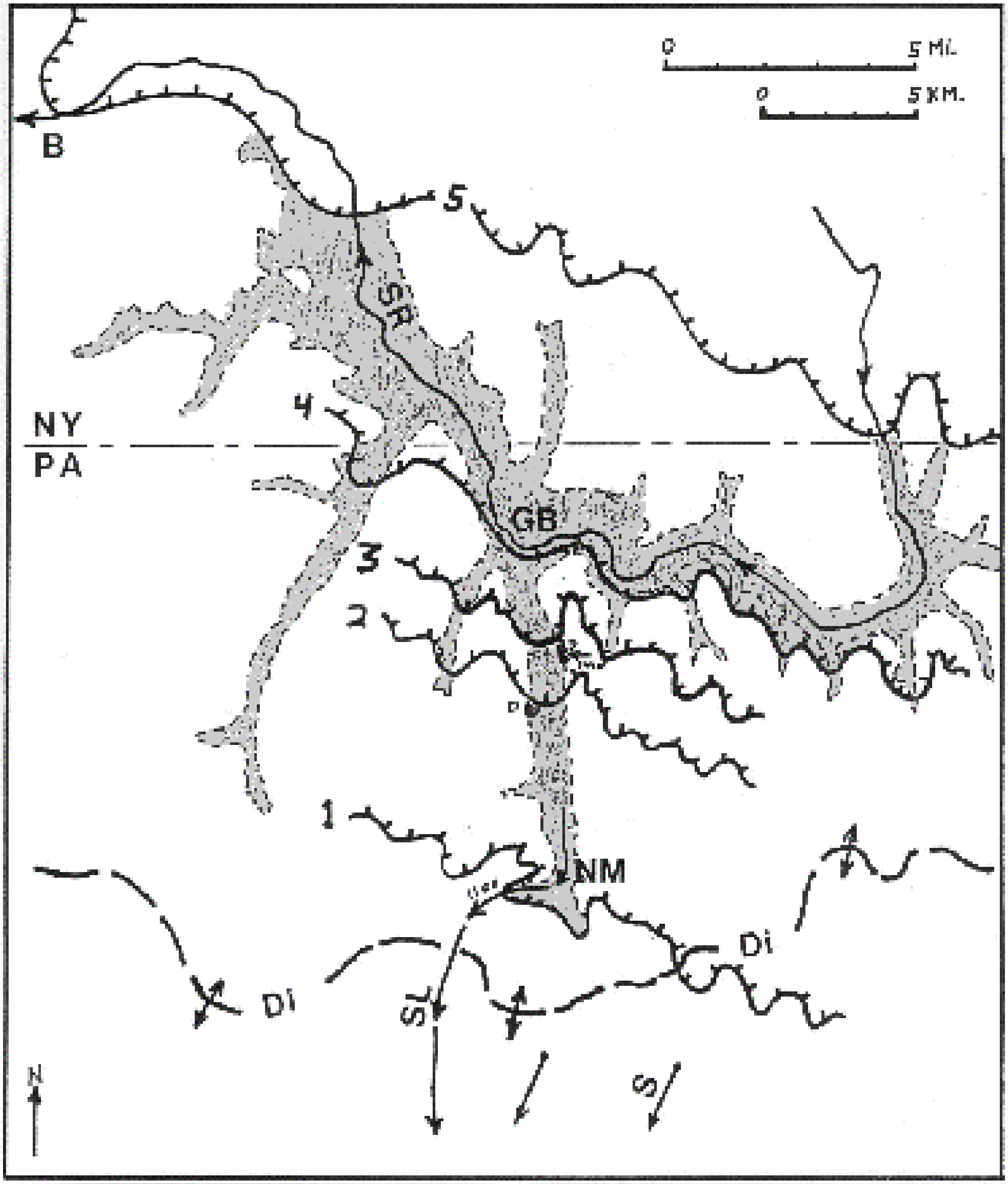


Figure 23. Map showing Glacial Lake Great Bend at its greatest extent. The five hachured lines are successive ice margins of the retreating glacier that mark different phases in the development of the lake. B = Binghamton, Di = east-west trending drainage divide, GB = Great Bend (borough), NM = New Milford, S = glacial striations, SL = New Milford sluiceway, SR = Susquehanna River, small D's = hanging deltas.

BUCKS (STARRUCCA) FALLS

by
Duane D. Braun and Jon D. Inners

INTRODUCTION

Figure 24. Bucks Falls and its downstream gorge. Note the high, vertical wall on the south side of the gorge and the rock rubble on the north side. (Photo by W. S. Young.)

Bucks, or Starrucca, Falls is a 25-foot-high waterfall (Figure 24) located on "Bucks Creek," an important, but officially unnamed, tributary stream that enters Starrucca Creek from the west about a mile below the main residential area of the borough of Starrucca (Figure 25). Bucks Creek rises in several branches, the main one of which flows out of a large, swampy man-made impoundment about three miles to the west. Its total drainage area is approximately 5 mi^2. The falls lies just east of the Wayne-Susquehanna County line, 0.25 mile above the confluence of Bucks Creek with the Starrucca and just a short distance upstream of the edge of the master stream's broad floodplain.

Although Bucks Falls is but one of many waterfalls in northeastern Pennsylvania formed by postglacial stream processes, it possesses somewhat more intrinsic geologic interest due to its relationship to local glacial deposition and its complex erosional history. The falls and its immediate vicinity also witnessed the playing out of several interesting industrial and railroad vignettes over the past two centuries—traces of which have now all but vanished from the landscape.

The falls is located on Star Spring Farm, owned by Mr. Robert Buck and Mr. Kirk Rhone. **Please obtain permission from the owners, who reside along SR 4039 directly to the east, before entering upon the property.**

BEDROCK GEOLOGY

Bucks Falls cascades over a subhorizontal ledge of thick-bedded, crossbedded, light gray, greenish-gray weathered, mostly fine- to medium-grained, quartzose sandstone in the lower part of the Late-Devonian-age Catskill Formation (Figure 26). In the middle of the exposed section are several 2-inch to 12-inch bands of "vuggy," yellow-brown weathered, medium- to coarse-grained, calcareous sandstone. Based on mapping by Inners (2002), the sandstone occurs in the lower part of the Lanesboro Member, about 350 feet above the base of the formation. Woodrow and Fletcher (1968) assign the rocks at the falls to their Honesdale Formation (see also this guidebook, p. 1 - 7).

As is typical of the sandstones throughout the "Endless Mountains," two sets of subvertical joints are well developed—a roughly "north-south" set (averaging N3^{o}E at the falls) and an "east-west" set (averaging N86^{o}W). In most cases the joints are smooth, relatively planar, and continuous and are spaced 3 to 12 feet apart. In the gorge downstream of the falls, especially on the north side, sandstone blocks bounded by these fractures have sloughed off the main ledge into the gorge (see Figure 24), at one point forming a crude "rock city" with narrow "streets" 0.5 to 2 feet wide.

Braun, D.D. and Inners, J.D., 2002, Bucks (Starrucca) Falls, *in* Inners, J. D., and Fleeger, G. M., eds., From Tunkhannock to Starrucca: bluestone, glacial lakes, and great bridges in the "Endless Mountains" of northeastern Pennsylvania: Guidebook, 67th Annual Field Conference of Pennsylvania Geologists, Tunkhannock, PA, p. 39 - 43.

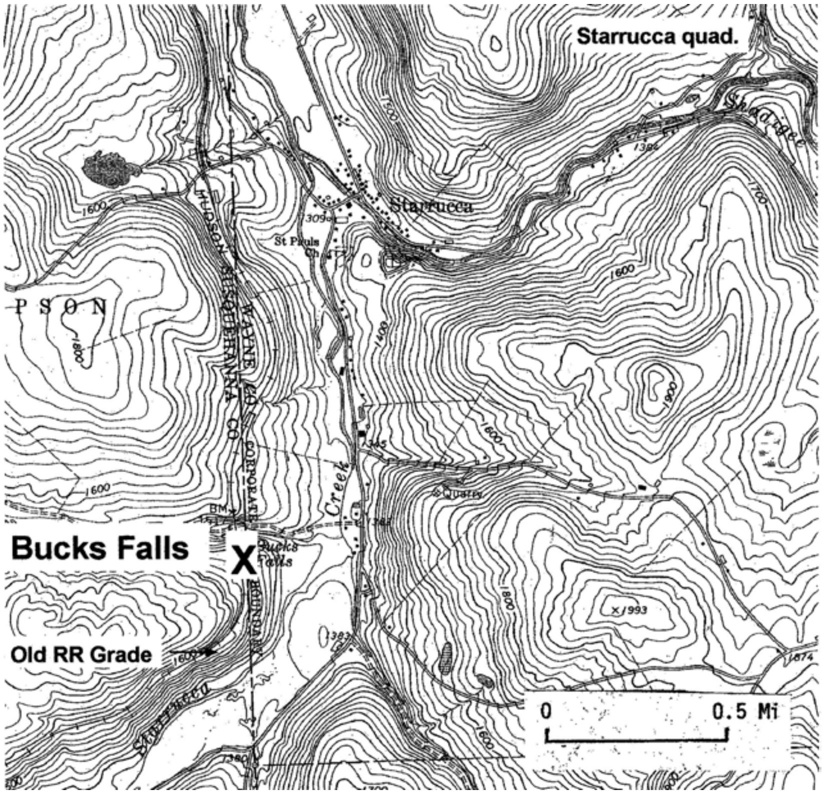


Figure 25. Location map of Bucks (Starrucca) Falls, Susquehanna and Wayne Counties, PA.

The gorge formed by retreat of the falls is about 30 feet deep. Upstream of the falls Bucks Creek is incised 6 to 8 feet into strongly crossbedded sandstone.

ORIGIN OF THE FALLS

Bucks Falls differs from other sites where a postglacial gorge has been cut alongside a preglacial valley buried by till. The present gorge of Bucks Falls has an abandoned gorge (with a “dry waterfall”) on one side (south) and the beginning of a new gorge on its other side (north) (Figure 27). The falls is located where an east-draining tributary (Bucks Creek) joins the north-draining Starrucca valley (see Figure 25). 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 27; see Braun, this guidebook, p. 32 - 38). This produces an asymmetric valley, gentler on the north side and steeper on the south side (Figure 28). 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 27). At some point the stream starts cutting more vertically and forms a “double-sided” bedrock gorge (Figures 27 and 29).

At Bucks Falls the valley buried by till curves northeast as it enters the Starrucca valley (arrows on Figure 28). 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 this bedrock nose, it is still just migrating down the bedrock-till contact upstream of the nose. This migration permits the stream to carve a channel in the till (alluvium area, A, along the present channel on Figure 29) that eventually captures the channel that leads

Figure 26. Low (A.) and high (B.) stages of flow over subhorizontal Catskill sandstone ledges at Bucks Falls. (Photos by W. S. Young.)

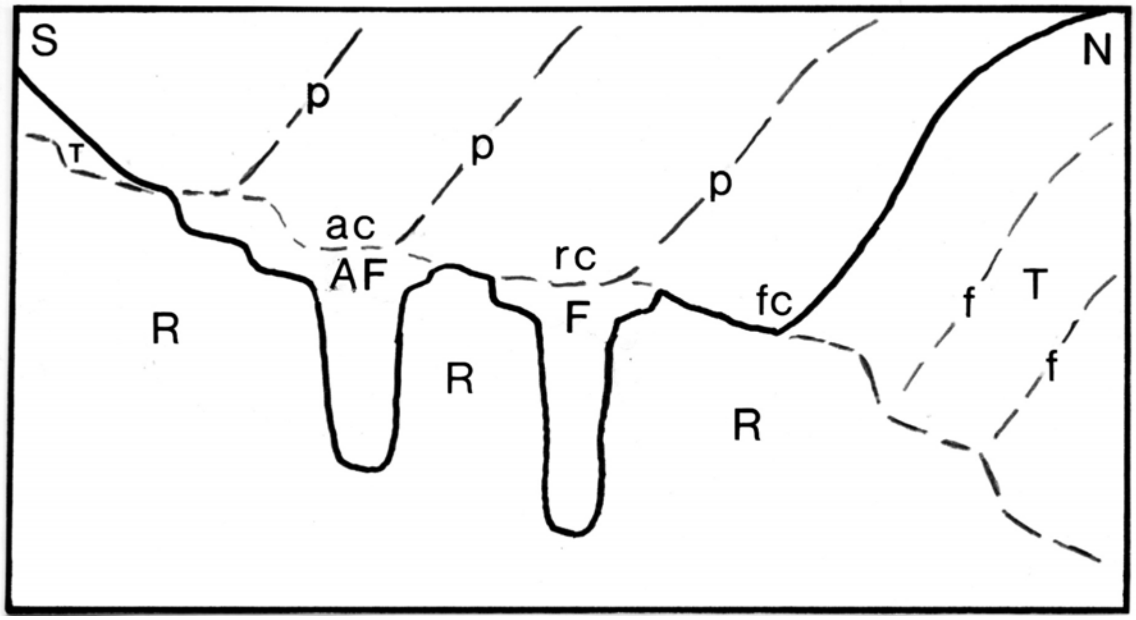


Figure 27. Cross-section sketch of Bucks Falls, showing the abandoned falls gorge (AF), the present falls gorge (F), and the future channel and gorge (fc). p = past north slopes of till, f = future north slopes of till, T = Till, R = bedrock.

directly to the falls (rc, Figure 29). This happens because the channel in the till curves around to the north and exposes bedrock that is lower (future channel, fc, on Figure 27 and 29) than at the upstream entry to the "nose gorge" (rc on Figure 27 and 29). 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 27 and 29). 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 27 and 29) to be abandoned in prehistoric times. Humans have built a road up the developing gorge (fc, Figure 29) and diverted the stream back to its direct course towards the falls (rc, Figure 29) thereby temporarily blocking the natural process. (The stream has already started to cut a new channel—up to 5 feet deep—along the south side of the road just north of the falls. At some time in the recent past a low dike has been emplaced at the upstream end of this channel to protect the road.)

"INDUSTRIAL" HISTORY

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 stone

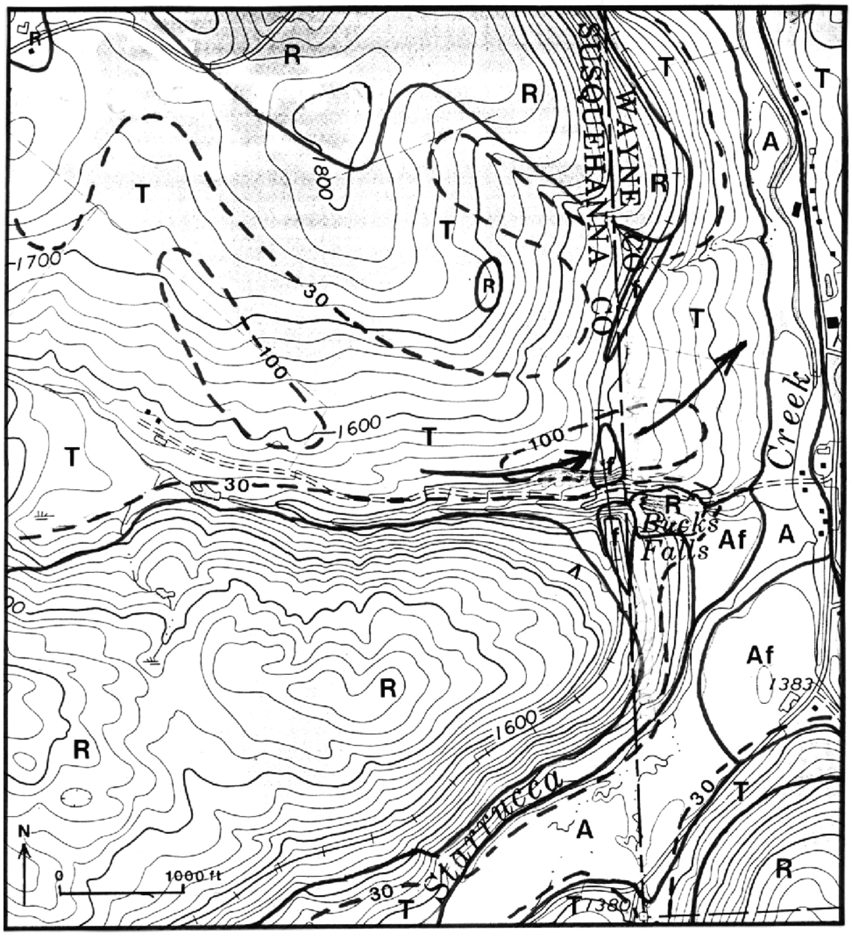


Figure 28. Map of surficial deposits in the Bucks Falls area, showing the gentler north side of the stream valley leading to the falls (underlain by a "till shadow") and the steeper south side (underlain by bedrock). Curved arrows = preglacial valley axis buried by till, A =- alluvium, Af = alluvial fan, f = fill, R = bedrock, T = till. Isochores of surficial deposits at 30 and 100 feet. (From Braun, 2001c)

ones built of cherty, gray limestone (Onondaga or Helderberg?) and greenish sandstone (Catskill) (Figure 30). (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 Starrucca Viaduct 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.

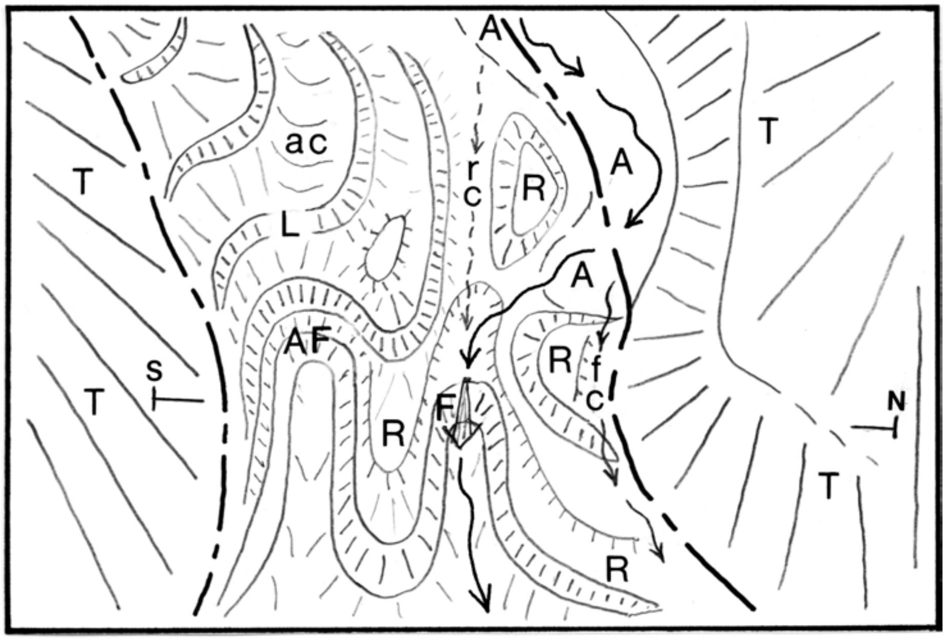


Figure 29. Sketch map of the Bucks Falls area, showing the present channel (long wavy arrows), the long abandoned channel ac and falls gorge (AF), the recently abandoned channel (rc), and the future channel (fc). Bold short and long dashed line is the bedrock - till contact. L = bedrock ledge symbol of short tick marks between two parallel lines, A = alluvium, T = till, R = bedrock.

Figure 30. 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 the falls.

THE GREAT BEND AND HALSTEAD PARK ARCHAEOLOGICAL SITES

by
Donald M. Thieme

This article describes two late Quaternary terraces at the apex of the Great Bend of the Susquehanna River. US 11 crosses the river at the bend apex, just downstream of the mouth of Salt Lick Creek (Figure 31). The Salt Lick Creek valley was the location of a large proglacial lake (see Braun, this guidebook p. 32). The US 11 bridge was replaced this past year (2001), and studies mandated by federal law provided an opportunity to examine deposits on both sides of the river as well as to recover prehistoric artifacts from Holocene stratigraphic contexts.

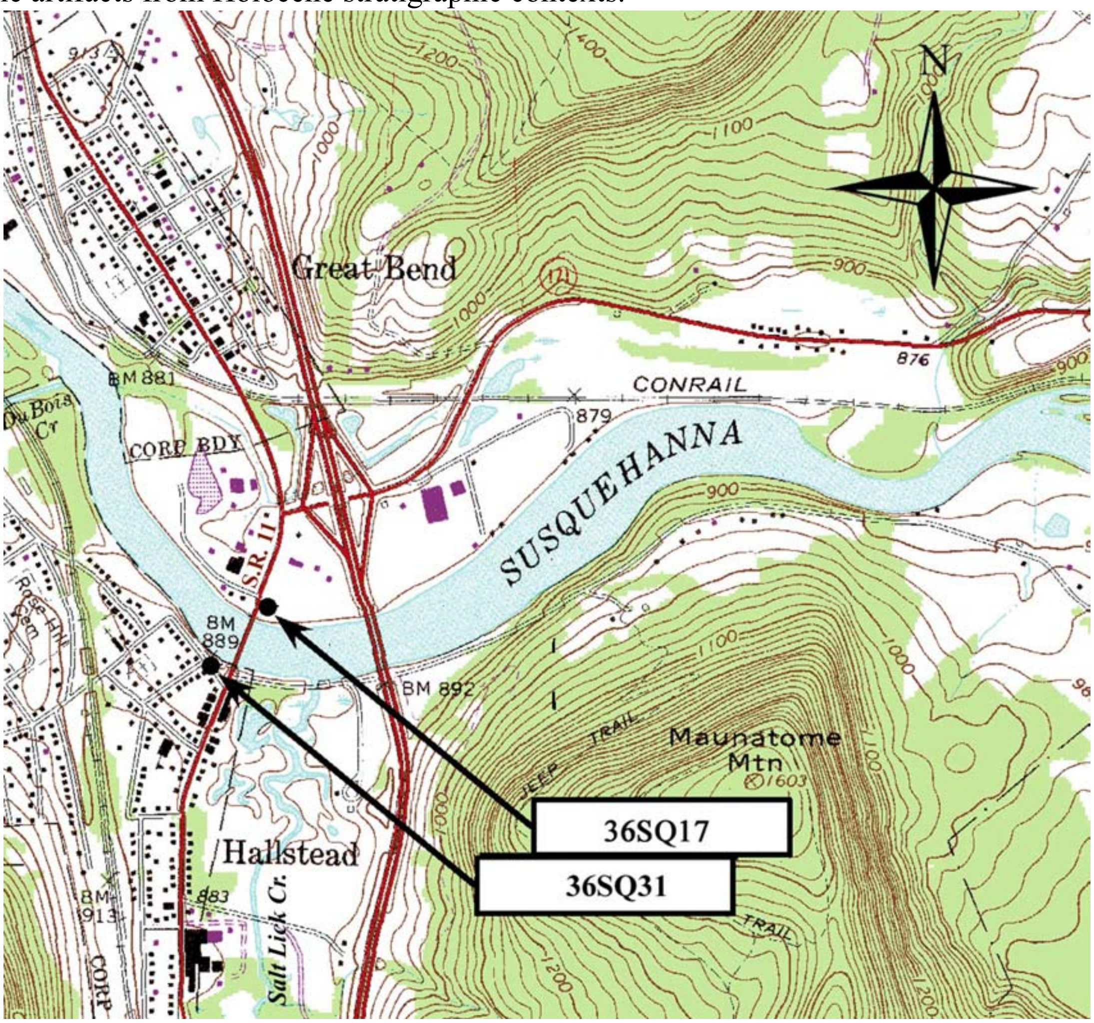


Figure 31. Great Bend of the Susquehanna River showing the location of Great Bend (36SQ17) and Halstead Park (36SQ31) sites.

T-1 AND THE GREAT BEND ARCHAELOGICAL SITE (36SQ17)

On the right bank of the river, there is a Holocene T-1 surface from three to five meters above river grade (Figure 32). A T-1 terrace at this same height above river grade occurs thirty kilometers upriver at the proposed crossing of the Millennium Pipeline near Windsor, New York (Thieme et al.,

Thieme, D.T., 2002, The Great Bend and Halstead Park archeological sites, *in* Inners, J. D., and Fleeger, G. M., eds., From Tunkhannock to Starrucca: bluestone, glacial lakes, and great bridges in the “Endless Mountains” of northeastern Pennsylvania: Guidebook, 67th Annual Field Conference of Pennsylvania Geologists, Tunkhannock, PA, p. 44 - 48.

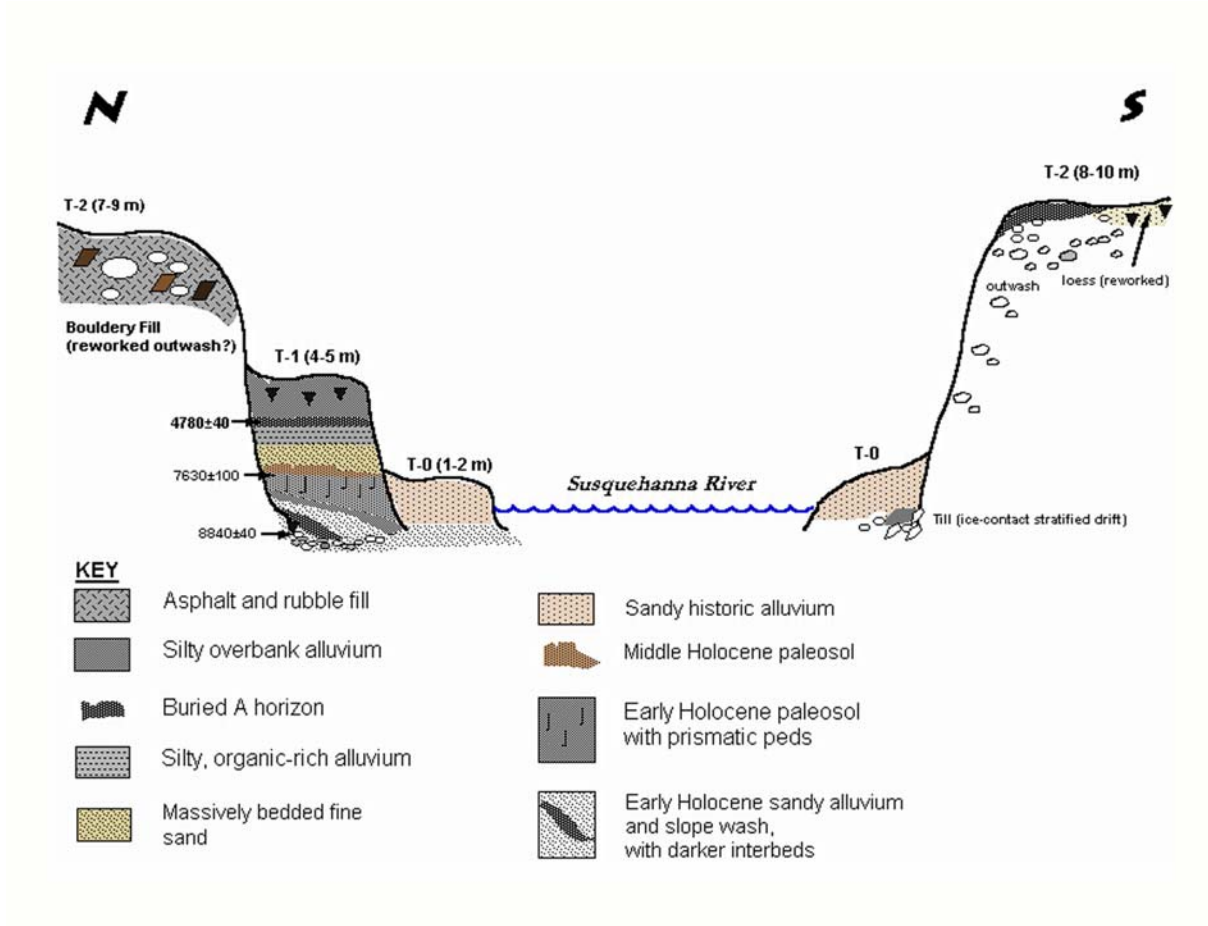


Figure 32. Schematic cross-section of the Susquehanna River valley at Great Bend showing the T-0, T-1, and T-2 surfaces.

1998). Discontinuous segments of the T-1 are also mapped further upstream in New York state by both Scully and Arnold (1979, 1981) and Dineen (1993). In Pennsylvania, the T-1 has recently been mapped for the reaches from Athens downstream to Northumberland (Thieme, 2002).

The T-1 at Great Bend houses a stratified archaeological site. The site is recorded in the Pennsylvania Archaeological Site Survey files as "36" (for the state of Pennsylvania), "SQ" (for Susquehanna County), "17" (the site number). The Great Bend site is only the seventeenth archaeological site to be recorded in Susquehanna County. The PennDOT archaeologist, Ms. Jamie McIntyre, suspected from the outset that prehistoric artifacts might be found deeply buried in this alluvial terrace. At the request of Ms. McIntyre and the state historic preservation office, geomorphological studies were performed in conjunction with the archaeological excavations.

Three geomorphological test trenches were used to describe the terrace stratigraphy. A 9- x-5-m excavation block was then excavated by hand to the base of the Holocene deposits. Wooden shoring was used to make the excavation safe. The stratigraphy within the excavation block generally conformed to a framework of "allostratigraphic" units (Autin, 1992; NACSN, 1983) based on the profile described in one of the test trenches, Trench 99-2 (Figure 33). The four allostratigraphic units were numbered sequentially beginning at an unconformable contact with upper Pleistocene outwash approximately 4.5 m below the land surface. Radiocarbon dates for the basal Holocene sediments range from 8,320∀50 B.P. to 11,160∀40 B.P., with the younger dates representing charred material directly associated with an assemblage of Early Archaic lithic artifacts.

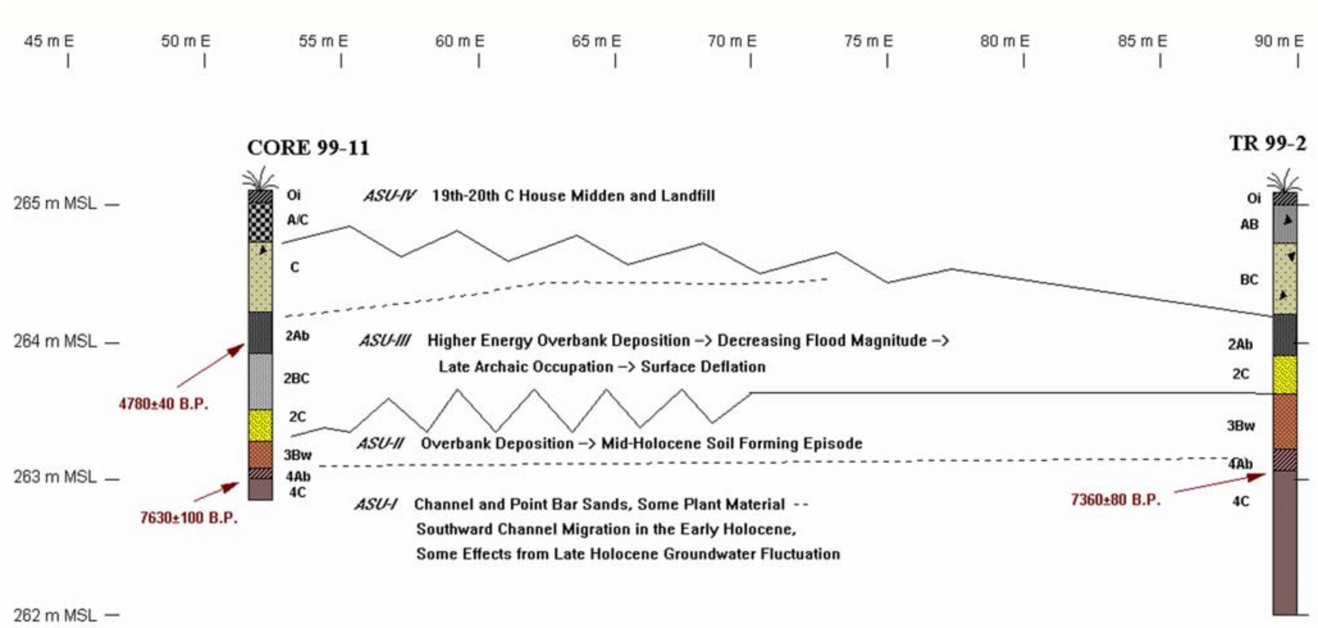


Figure 33. Allostratigraphic framework for site 36SQ17, Great Bend of the Susquehanna River.

A soil or buried soil occurs at the upper bounding surface of each allostratigraphic unit (ASU). The lowest buried soil, the 4Bt horizon capping ASU-1, has moderately developed, medium sized soil "peds" which are shaped like prisms (Figure 34). In thin section, reddish-brown clay can be seen as a discontinuous coating (ferriargillan) on the surface of a large ped as well as dispersed throughout the soil matrix (Figure 35). Clasts of quartz and fragments of the local siltstone bedrock are rimmed with the same reddish brown clay. The same is true of a large oval soil pore which represents a passage trace, probably a worm or insect burrow.

ASU-II consists of a single soil horizon, the 3Bw. The upper part of this buried soil was truncated by a scour episode, and it is unconformably overlain by the much coarser flood sands at the base of ASU-III. The abrupt coarsening in the profile at the

Figure 34. 4Btx horizon showing moderate medium prismatic ped structure and continuous clay films.

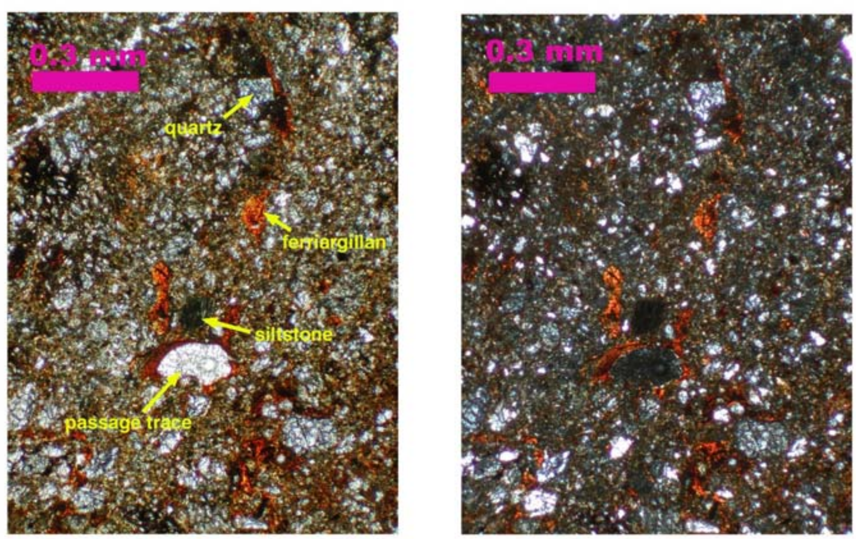


Figure 35. Thin-section photomicrographs in PPL (left) and XPL (right) of the 4Bt horizon in the Great Bend site (36SQ17) master stratigraphy

2C(b)/3Bw contact marks a new cycle of vertical accretion. Laboratory particle size analyses show the 2Cb horizon to be 84% sand compared to only 41% for the 3Bw horizon (Figure 36). The mean grain size for the 2Cb, 2.9 N (0.15 mm), is actually fine sand. Nonetheless, this is considerably coarser than the mean of 6.8 N (0.008 mm) for the 3Bw horizon.

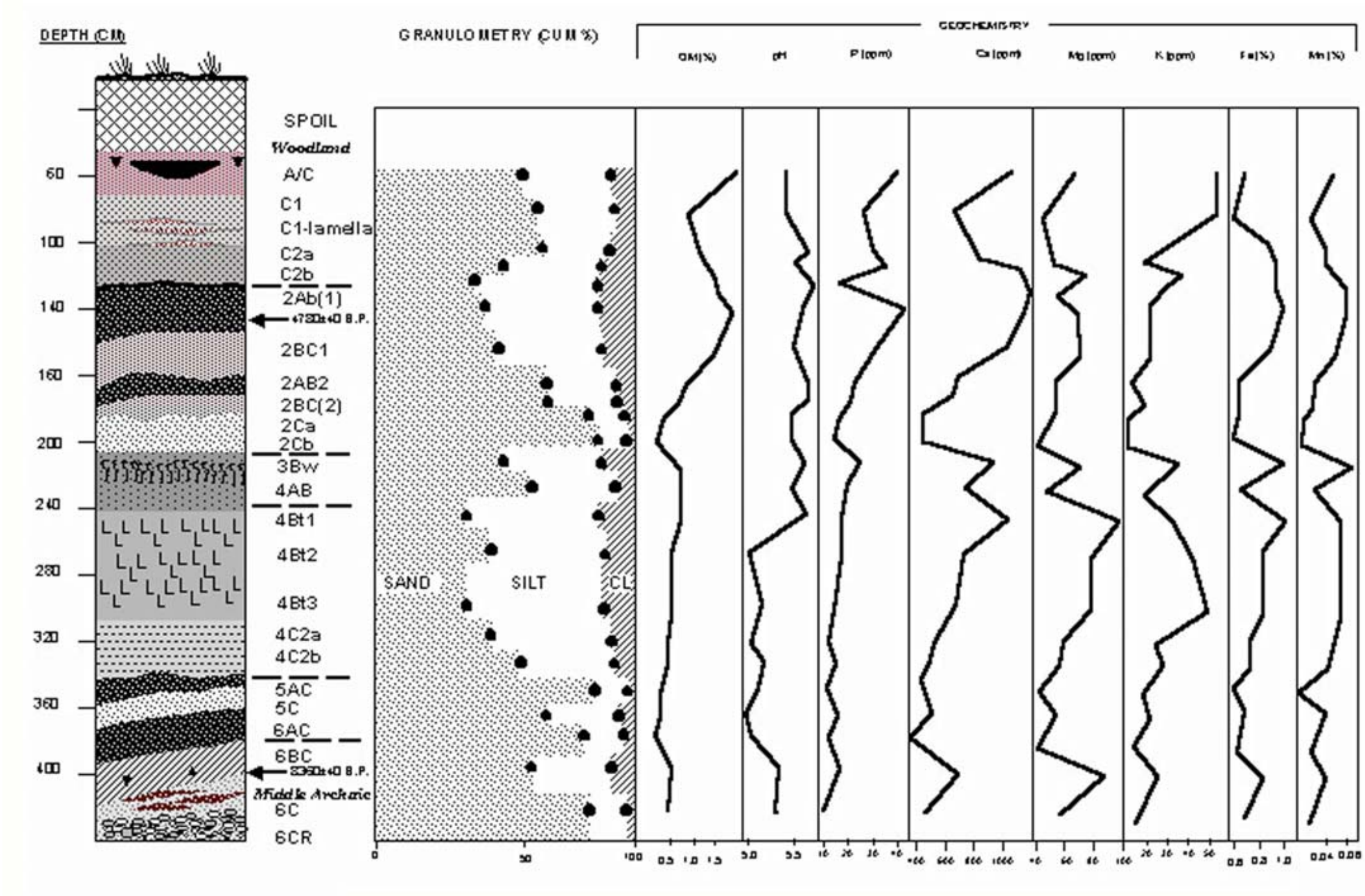


Figure36. Composite physical and chemical stratigraphy of the Great Bend site (36SQ17).

Increases in silt from the 4C2b (43%) to the 4Bt3 (64%), and from the 2Cb (13%) to the 2Ab (51%) typify fining-upward trends of vertical accretion on point bars of meandering streams (Allen, 1970, p. 140-143; Nichols, 1999, p. 116-118; Reineck and Singh, 1986, p. 267-274). Overbank deposition appears to have been much less common after the deposition of ASU-III, with both slope wash and refuse disposal contributing significantly to the uppermost 50-70 cm of the T-1 (ASU-IV). Several large Woodland (Owasco culture) pit features were found at the top of the C1 horizon, and subtle changes in the percent organic matter and sediment chemistry in the upper part of the profile are clearly related to late prehistoric as well as early historic human activities in the immediate vicinity of archaeological site 36SQ17.

T-2 AND THE HALLSTEAD PARK SITE (36SQ31)

On the left bank, diagonally across the river from the Great Bend archaeological site, a T-2 terrace stands approximately eight meters above river grade. Geomorphological investigations for the US 11 bridge replacement determined the T-2 to be composed of upper Pleistocene outwash with a thin cap of loess and/or colluvium (Thieme et al., 1999). The T-2 is flanked by a narrow (<3 m wide) floodplain (T-0), which consists of historic alluvium overlying glacial till.

Figure 37. View of the T-2 and the Hallstead Park archaeological site (36SQ31) from the old US 11 bridge over the Susquehanna River

A trench was excavated with a trackhoe on the sloping bank of the T-2 (Figure 37). This trench, Trench 1, was three meters wide and measured eight meters along its longer, north-south axis. Upper Pleistocene outwash gravel was encountered at depths raging from 0.3 to 0.9 m below surface (Figure 38). There appears to have been little or no alluvial deposition on this T-2 surface during the Holocene epoch.

Four auger borings were performed in the area west of Trench 1 in order to define the limits of the previously reported Hallstead Park archaeological site (36SQ31). Intact deposits containing prehistoric cultural material were identified in two of the borings. There is at least 60 cm of intact sandy loam sediment overlying the outwash gravel in this portion of the T-2. Excavations for the Pennsylvania American Water Line corridor by the Binghamton University Public Archaeology Facility (Wurst and Lain, 1996) recovered artifacts affiliated with the Middle Archaic through historic Iroquois cultures. Five radiocarbon dates were obtained, the earliest being 4290∀50 B.P. for Feature 21, which contained a Stanly Stemmed projectile point affiliated with the Middle Archaic culture.


Figure 38. View of Trench 1 on the T-2 looking north.

INDUSTRIES OF THE LOWER STARRUCCA VALLEY– LANESBORO TO STARRUCCA

by
William S. Young

The period for early settlement of the lower Starrucca Creek valley (Figure 39) was from about 1787 (Lanesboro area) to 1815 (Starrucca). The earliest activities were sawmilling and subsistence farming. Logs were floated down the Delaware and Susquehanna Rivers to Philadelphia and Maryland. Settlers clearing their land used the stone they removed for foundations and field walls; some of the wood they cleared was burned to make black salts, a crude potassium carbonate, which was sold in regional asheries to make potash for fertilizer and pearl ash for leavening.

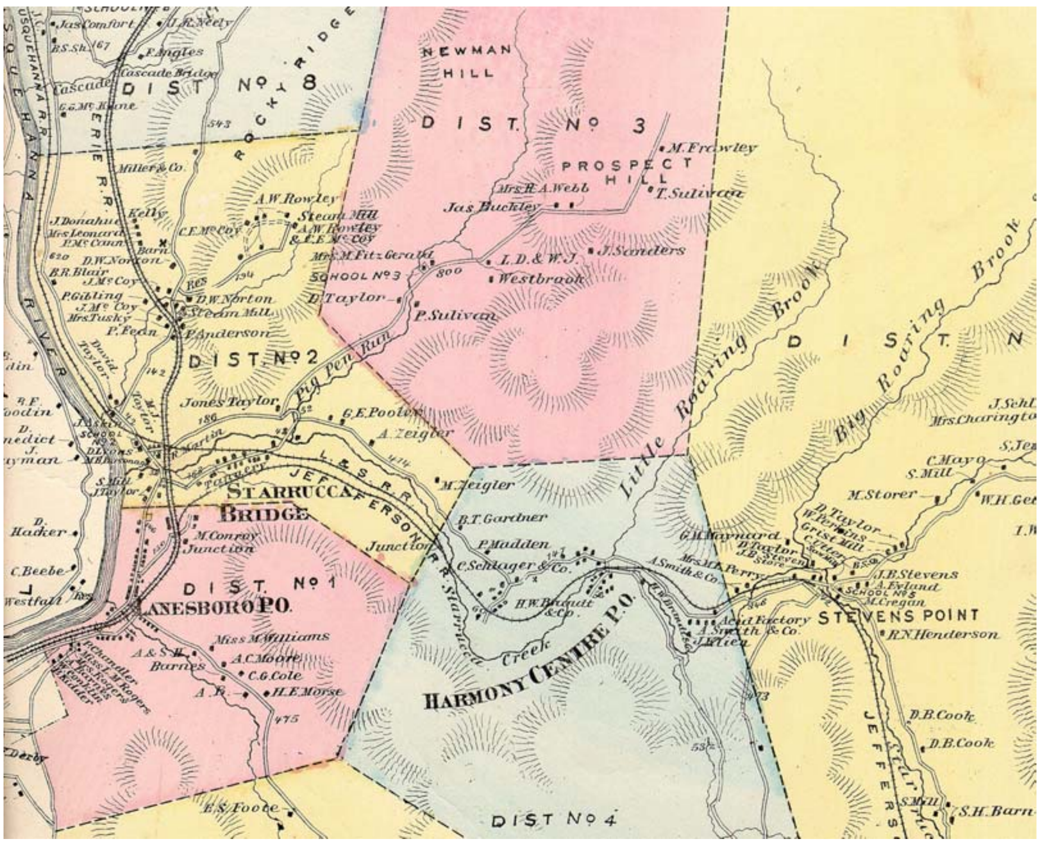


Figure 39. The Starrucca Creek valley as shown on the 1872 Beers Map of Harmony Township, Susquehanna County

The building of the New York & Erie Railroad, opened through Lanesboro in 1848, required much local stone and lumber and provided easy access to distant markets. By the 1840's tanneries had created the occupation of "bark peeler" and were beginning to use up the local hemlock. The bluestone industry did not develop substantially until the 1880's. In central Susquehanna County by the 1870's, dairy products were already being shipped away by rail in small lots. But comparatively little butter, cheese, or milk went from points along the Jefferson Branch rail line through the Starrucca Valley until some years after it began regular operation in 1871. The lower valley's first milk station, at Starrucca, was not opened until 1895. Express shipments of meat, poultry, and pelts also went out by rail. As the virgin pine and hemlock was largely cut over, industries dependent on hardwoods appeared, such as turning establishments and acid factories.

At Lanesboro—named for Martin Lane (d. 1825), an early miller—the earliest industries were a sawmill and a gristmill. Waterpower could be had from the North Branch Susquehanna River and Starrucca Creek. A prominent early resident was the controversial Timothy Pickering, Quartermaster

Young, W.S., 2002, Industries of the lower Starrucca Valley – Lanesboro to Starrucca, *in* Inners, J. D., and Fleeger, G. M., eds., From Tunkhannock to Starrucca: bluestone, glacial lakes, and great bridges in the "Endless Mountains" of northeastern Pennsylvania: Guidebook, 67th Annual Field Conference of Pennsylvania Geologists, Tunkhannock, PA, p. 49 - 50.

General of the Continental Army and a cabinet member under Washington and Adams. Pickering had long been interested in the development of northeastern Pennsylvania. He stayed only a few years before going back to his native Massachusetts to be elected to the U.S. Senate.

In a later time Lanesboro had two tanneries, the Barnes foundry and implement works, and a sash factory. Its last sawmill operated until the middle 20th century. Quarrying became extensive throughout the lower valley, especially around Lanesboro, Brandt, and Stevens Point.

Brandt, developed by Henry William Brandt (1808-1886) and Jacob Schlager (1816-1886), German immigrant tanners, was a beehive of industry. At various times it was the site of two tanneries, two chair factories, a large quarry, a pair of brick works, two steam sawmills, a chamois factory, a hat factory, the second wood-acid factory built in America, and an alcohol plant. Much of this activity was at the lower end of the community, at the place known as Schlager's. The material for bricks came from a 75-foot high glacial bank of reddish clay that jutted into the valley just upstream from Brandt. Brandt brick was widely used in nearby communities in New York and Pennsylvania. A celebrated furniture-maker, Jacob Schlager's nephew Gustav Stickley, began his career at Brandt. Henry Brandt, at his death in 1886, was said to be the county's wealthiest citizen.

Stevens Point was named for John B. Stevens, an Englishman who began farming, logging, and sawmilling there about 1850. The Point area also had other sawmills, a gristmill, a small chair factory, and a kindling-wood factory. It became a key location for the shipping of bluestone. A stone measuring 8 inches by 8.5 feet by 28.5 feet was shipped in 1897, but much of the dealing was in flagstone for curbs and sidewalks. A later industry at Stevens Point was an acid factory.

The Melrose area, farther up the valley between Stevens Point and Starrucca, had a large sawmill, with smaller sawmills and a small furniture factory and an acid factory nearby. A low falls at Melrose provided waterpower for the large mill.

Henry Sampson, a veteran of the Revolutionary War, built Starrucca's first gristmill and its first sawmill. Starrucca (Bucks) Falls, on a side creek south of the village, provided a source of waterpower, as did Starrucca, Shadigee, and Merrigan Creeks. The Starrucca area became a center for sawmilling. From 1844 to 1884 Starrucca's principal industry was a large tannery. The Italianate mansion of wealthy tannery owner Elisha P. Strong (1818-1895) still stands in the center of the village.

The first of two acid factories along the Shadigee near Starrucca opened in 1876. Its main product, distilled from the burning of hardwoods, was acetate of lime or "wood vinegar" (calcium acetate)—made from pyroligneous acid to which slake lime was added. This was mostly shipped to Europe and England for use in fabric dyes. Charcoal was an important byproduct, and various plants also produced acetone, methyl alcohol, acetic acid, formaldehyde, wood tar, and acetate of iron. During the heyday of acid factories in Pennsylvania and nearby parts of New York, the owners were small operators who banded together to form marketing companies and met openly to fix prices and limit production. When it closed in 1929, Starrucca's last acid factory had long outlived most others in the region.

Starrucca also had a ladder factory, a toy factory, a furniture factory, a wagon works, a factory that made sticks for umbrellas and parasols, and a roller-block factory. The roller blocks went mostly to Europe, where they were used to print calico and wallpaper. Crossley Lumber, which ran mills in Susquehanna County for close to 100 years, began with a woodturning business at Starrucca.

Note: The writer has two books in progress on local railroads and industries—*Susquehanna Hill: a railroad microcosm* and *Ararat: the life of a mountain railroad*.

THE LANDSCAPE AND THE RAILROADS

by
Jon D. Inners

INTRODUCTION

Susquehanna County may be but one of the numerous areas in Pennsylvania that are instructive of the influence of topography on transportation routes and history, but it is a particularly interesting one. The most important physiographic feature that had an effect on the construction of early railroads in this part of northeastern Pennsylvania is the high east-west divide that runs from west of Montrose in central Susquehanna County to Ararat and adjacent Wayne County (see Braun, this guidebook, p. 32 - 38). We will cross this divide in the east on Day 1 of the Conference Field Trip and in the west on Day 2. Our first crossing will be just east of the route of the Jefferson Branch of the Erie Railroad (1870), and our second will be along the route of Delaware, Lackawanna and Western (DL&W) Railroad through the New Milford (Summit) sluiceway (1851 and 1915). Why one of these still carries a viable railroad and the other is a rail-trail is mainly a function of the physiographic history of the two routes.

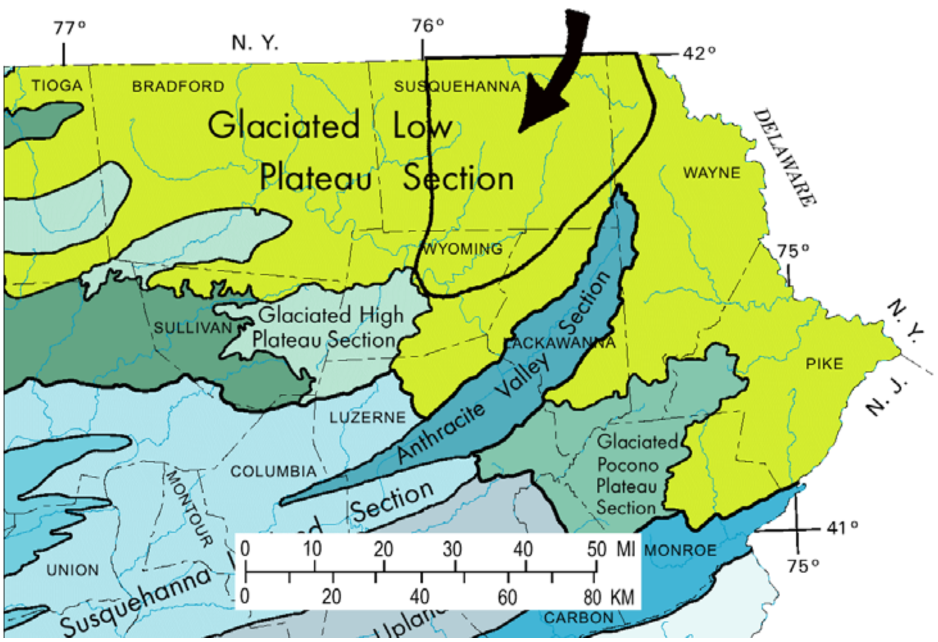


Figure 40. Physiographic map of northeastern Pennsylvania, showing Conference Field Trip area (outlined, with arrow) (Sevon, 1996).

PHYSIOGRAPHY

The field trip area (northern Wyoming and eastern Susquehanna Counties) is situated entirely within the Glaciated Low Plateau section of the Appalachian Plateaus province, as defined by the Pennsylvania Geological Survey (Figure 40). This region of rounded hills and moderately deep valleys lies northeast of the latest glacial border and extends from the Delaware River in Pike County westward and northwestward to the glaciated highlands which interfinger with the low plateau in Tioga, Bradford, Sullivan, and western Wyoming Counties. The low plateau is underlain by nearly flat-lying (mostly very slightly south-dipping) to gently folded sedimentary rocks (sandstones, siltstones, mudstones, and shales of the Late-Devonian-age Catskill Formation) that have been eroded over many millions of years into rolling hills and incised valleys—mainly by running water, but within the last million years or so also by glacial ice. The several episodes of glaciation, particularly the most recent one, are responsible for some of the more varied features of the landscape—such as the many ponds and lakes in Susquehanna County, the broad, gravel-choked valley of Tunkhannock Creek, the hummocky terraces that border Starrucca, Salt Lick, Snake, etc., Creeks, and (most pertinent to the field trip) the deeply scoured divide between Salt Lick Creek and Martins Creek at Summit.

Inners, J.D., 2002, The landscape and the railroads, *in* Inners, J. D., and Fleeger, G. M., eds., From Tunkhannock to Starrucca: bluestone, glacial lakes, and great bridges in the "Endless Mountains" of northeastern Pennsylvania: Guidebook, 67th Annual Field Conference of Pennsylvania Geologists, Tunkhannock, PA, p. 51 - 54.

Most hilltops in the plateau county of northeastern Pennsylvania are at elevations of 1300 to 1800 feet A.T. (Above Tide), with the valley floors 400 to 1200 feet lower. The highest points in Susquehanna County are in the southeast—on adjacent Elk Hill (North Knob, 2693 feet, and South Knob, 2602 feet) and East Mountain (2366 feet, north end, and 2312 feet, south end). Another significant belt of high hills lies along the east-west divide between streams that flow south mainly into Tunkhannock Creek and those that flow north into the North Branch Susquehanna River. This divide—with many hilltops at 1800 feet or higher—extends through Bridgewater, New Milford, Jackson,

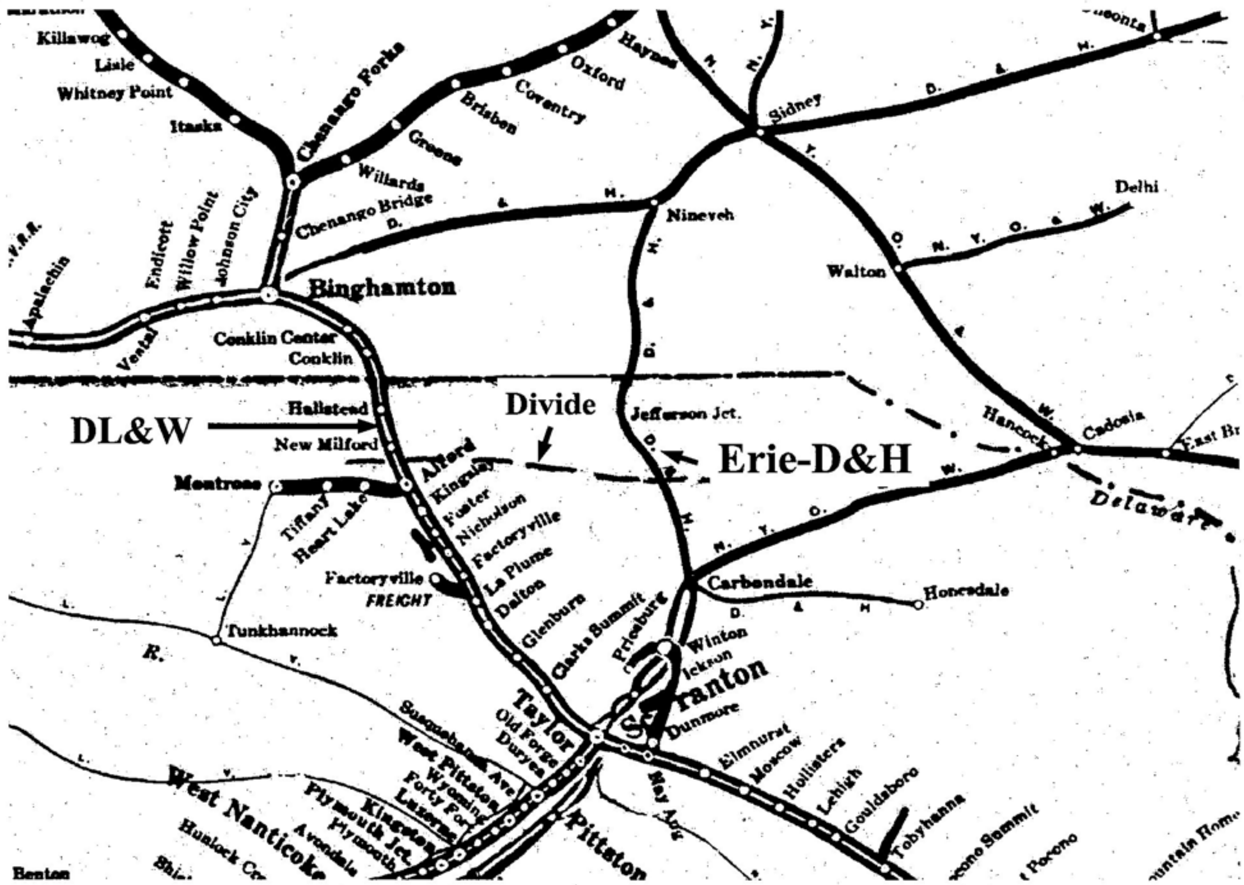


Figure 41. Generalized map showing the routes of the old DL&W and Erie-D&H (Jefferson Branch) Railroads across the east-west divide in Susquehanna County (not to scale) (slightly modified from Taber and Taber, 1980, front end paper).

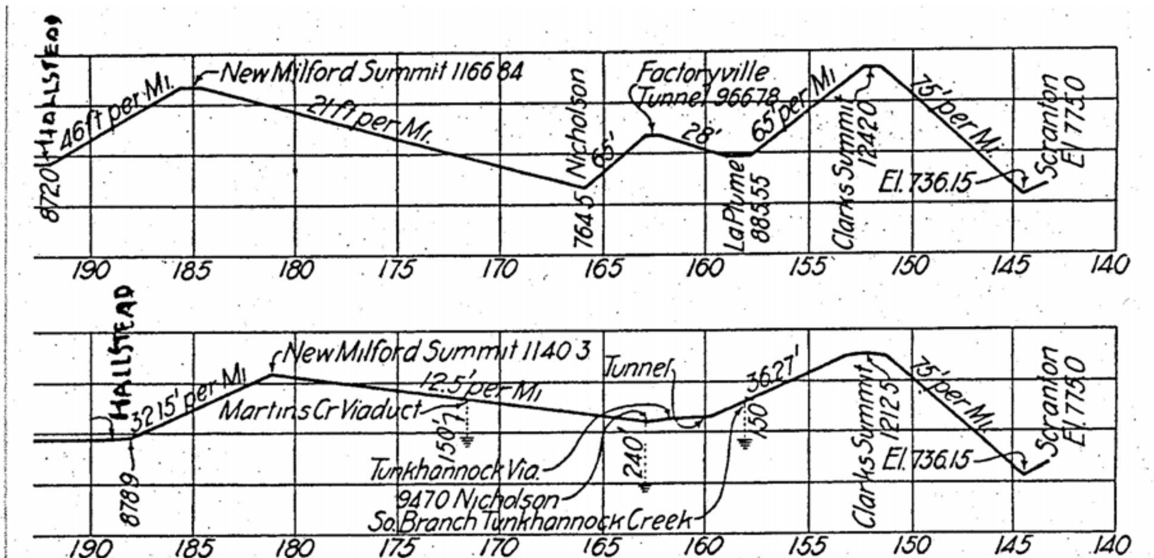
Thompson, and Ararat Townships . The two principal north-south railroad routes through Susquehanna County, the DL&W in the central part of the county and the Jefferson Branch of the Erie in the east, both had to contend with this divide (Figure 41), but—as we shall see—the vagaries of geologic history made it much easier for the former.

RAILROAD HISTORY

The original railroad from Scranton and Clarks Summit north to Hallstead, PA, and on to Binghamton, NY, the Leggets Gap Railroad (later the Lackawanna and Western) was completed through the New Milford (Summit) sluiceway in 1851. The railroad crossed the main east-west divide at Summit at an elevation of 1150 feet (STOP 7). In 1853 the Lackawanna and Western Railroad was combined with the Cobb's Gap Railroad to form the Delaware, Lackawanna and Western Railroad (DL&W, or simply, the Lackawanna), allowing for the potential of a continuous rail link from New York City to the Great Lakes. The DL&W soon became one of the major haulers of Pennsylvania anthracite—and built up an important passenger service as well. Later route changes north of Scranton before the end of the century mainly involved the construction (1854)—and later addition of a second bore (1883)—of a tunnel through "Roberts Hill" (now Tunnel Hill) between Factoryville and Nicholson.

A competing route to the DL&W's for carrying Lackawanna Valley anthracite to the Great Lakes was that of the Jefferson Branch of the Erie Railroad, which ran from Carbondale at the north end of the valley through Starrucca and on to Binghamton. Completed in 1870 this route crossed the main east-west divide at Ararat 12 miles farther to the east-southeast at an elevation 2023 feet—nearly 900 feet higher that at Summit. Clearly this gave the DL&W a decided advantage over the Erie in transporting anthracite out of the Lackawanna basin.

Nicholson (764.5 feet) was the low point on the original DL&W route between Scranton and Binghamton. Because of the comparatively steep grades coming out of Nicholson in both directions, "pusher engines" were necessary to move heavy freights going in both directions out of town. As the 20th century dawned, new management of the DL&W began to plan for major changes to the entire route from New York to Buffalo—including the section passing north through Nicholson and the New Milford sluiceway.



Comparison of the old and new grades west of Scranton. The old route had a .9% grade eastbound out of Hallstead and two 1.25% grades east of Nicholson whereas the new line was limited to only .6%. Westbound coal trains had only a .2% grade once they got past Clarks Summit instead of the .55% grade out of LaPlume and the nineteen miles of .4% grade the fireman had to shovel against from Nicholson.

Figure 42. Old (1854) and new (1915) grades of the DL&W Railroad over the Summit divide (Taber and Taber, 1980, p. 42).

On the ascendancy of William H. Truesdale to the presidency of the company in 1899, the DL&W entered upon its great period of expansion. The Summit Cutoff, one of Truesdale's most ambitious projects, was designed to increase the speed, capacity, safety, and economic efficiency of transporting freight—especially anthracite—northward and westward from the Lackawanna Valley (Braun et al., 1999). The new route shortened the railroad distance from Clarks Summit in Lackawanna County (just outside Scranton) to Hallstead in Susquehanna County from 43.3 miles to 39.6 miles, reduced the curvature, gradients, and "rise and fall", and eliminated all grade crossings (Figure 42).

Instead of following stream valleys and rising over several divides as did the old route, the new route ran along at a higher level, cutting into the faces of the hills and vaulting the valleys on deep fills and high viaducts. Major engineered structures on the "Cutoff" included (from south to north) a new Nicholson Tunnel, the Tunkhannock Viaduct (STOP 6), and the Martins Creek Viaduct. Both old and new routes following the glacial sluiceway from Nicholson to Hallstead, the old staying on the east side of the valley as far as New Milford, while the new—at a significantly higher level for all but the last few miles south of Hallstead—crossed the valley several times.

As the 21st century dawns, freight trains still rumble through the Summit Cutoff—but the days of "Phoebe Snow" and elegant passenger service between Scranton and Buffalo are becoming a distant memory. The DL&W, or Lackawanna, as "The Road of Anthracite" had a double meaning up until America's entrance into World War I—for the railroad was not only one of the major haulers of hard coal, but also powered its steam locomotives with anthracite. Well into the era of diesel locomotives millions of tons of anthracite moved northward and westward to heat homes in Upstate New York and fuel the vast iron-and-steel works of the Great Lakes region. By the 1950's, however, the Lackawanna and its main competitors were carrying more bituminous coal than anthracite (Young, 1968). Now, thirty years after the Knox Mine Disaster and the beginning of the precipitous decline of coal mining in the Northern Field, very little anthracite moves north along the Cutoff. The last daytime passenger service—the *Phoebe Snow*—was in November 1966, and the last Scranton-Buffalo-Chicago passenger trains ran in 1968 (Young, 1968).

The ownership of the original Lackawanna right-of-way has gone through numerous changes since the mid-century end of the era of steam. When the DL&W merged with the Erie in 1960, the trackage became part of the Erie-Lackawanna system. Then in the mid-1970's, the Erie-Lackawanna was absorbed into Conrail. Finally, with the recent acquisition of Conrail routes by to other railroads, the Summit route was taken over by the Delaware & Hudson (D&H), now a wholly owned subsidiary of the Canadian Pacific.

In comparison with the competing Jefferson Branch, however, the Summit route has fared very well indeed. The Jefferson Branch, originally built by the Erie with Delaware and Hudson money (Young, 2002, personal communication), was acquired by the D&H Railroad on the merger of the Erie and the Lackawanna. About twenty years later, the line was discontinued—and it is now a rail-trail. Certainly one of the major reasons for its abandonment was the competitive disadvantage imposed by route's high gradients over the Ararat summit.

Despite the decline of the original anthracite railroads over the past forty years, their great engineering works are still capable of inspiring wonder and awe. A modern observer of the Tunkhannock Viaduct needs little imagination to appreciate Theodore Drieser's description from August 1915:

> We were coming around a curve near Nicholson, Pennsylvania, approaching a stream which traverses this great valley, when across it from ridge's edge to ridge's edge suddenly appeared a great white stone or concrete viaduct or bridge…a thing so colossal and impressive that we instantly stopped the car so that we might remain and gaze at it…Those arches! How beautiful they were! How symmetrically planned! And the smaller arches above, how delicate and lightsomely graceful! It is rather odd to stand in the presence of so great a thing in the making and realize that you are looking at one of the true wonders of the world. (*A Hoosier Holiday*, quoted in Young, 1967).

Though the "glory days" of the Summit Cutoff are gone, the great viaducts at Nicholson and Kingsley may well stand until the next glaciation again sends the Susquehanna River coursing through the New Milford sluiceway.

THE MARTINS CREEK VIADUCT

by
Jon D. Inners

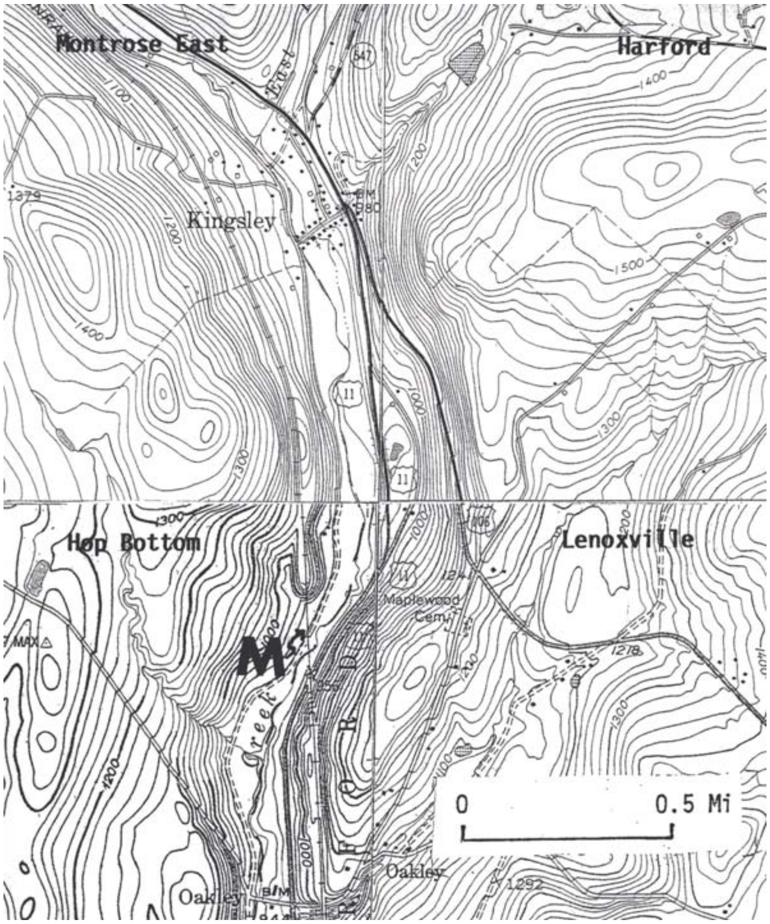


Figure 43. Location map of the Martins Creek Viaduct (M).

The Martins Creek Viaduct crosses the creek of that name about one mile south of Kingsley (Figure 43) and eight miles north of Nicholson. Approximately 1600 feet long, 125 feet high, and "three-tracks" wide, it is basically a smaller version of the reinforced-concrete Tunkhannock Viaduct (STOP 6) and has the same Beaux-Arts design (Figures 44 and 45). As described in Ray (1913), the viaduct consists of two 50-foot and two 100-foot semicircular arches and seven 150-foot three-centered arches each with small spandrel arches. It reportedly stands 88 feet above the old 1850's grade, which passed beneath the same arch as present-day US 11. Martins Creek flows through the third 150-foot arch from the south end. The contractors, F. M. Talbot Company of New York, completed the structure nearly a year before the rest of the "Cutoff" was ready, and to celebrate held an "aerial dance" atop the bridge—complete with flags, bunting, and appropriate dignitaries—on September 3, 1914 (Young, 1967).

The viaduct is oriented almost exactly north-south and crosses the New Milford (Summit) sluiceway (here trending N25°E to S25°W) at an acute angle. Just downstream is a marked constriction where the Martins Creek valley, 600 feet wide at Kingsley, narrows down to 250 feet wide and then broadens again to more than 400 feet wide. The south abutment of the viaduct is set into the steep bedrock slope on the east side of the valley, while the north end merges into a high fill that extends about 900 feet south from the gentler, till-covered west side. High rock cuts in sandstones and shales of the Catskill Formation occur just beyond the ends of the valley crossing, the cut on the north side being particularly spectacular.

The 1850's grade continued along the east side all along the length of Martins Creek and through the Summit divide (STOP 7) to New Milford, a total distance of about 11 miles. According to Taber and Taber (1980), the tracks of the old grade beneath the viaduct were removed during the winter of 1915-16 and the highway that was to become US 11 constructed on the old roadbed.

Inners, J.D., 2002, The Martins Creek Viaduct, *in* Inners, J. D., and Fleeger, G. M., eds., From Tunkhannock to Starrucca: bluestone, glacial lakes, and great bridges in the "Endless Mountains" of northeastern Pennsylvania: Guidebook, 67th Annual Field Conference of Pennsylvania Geologists, Tunkhannock, PA, p. 55 - 56.

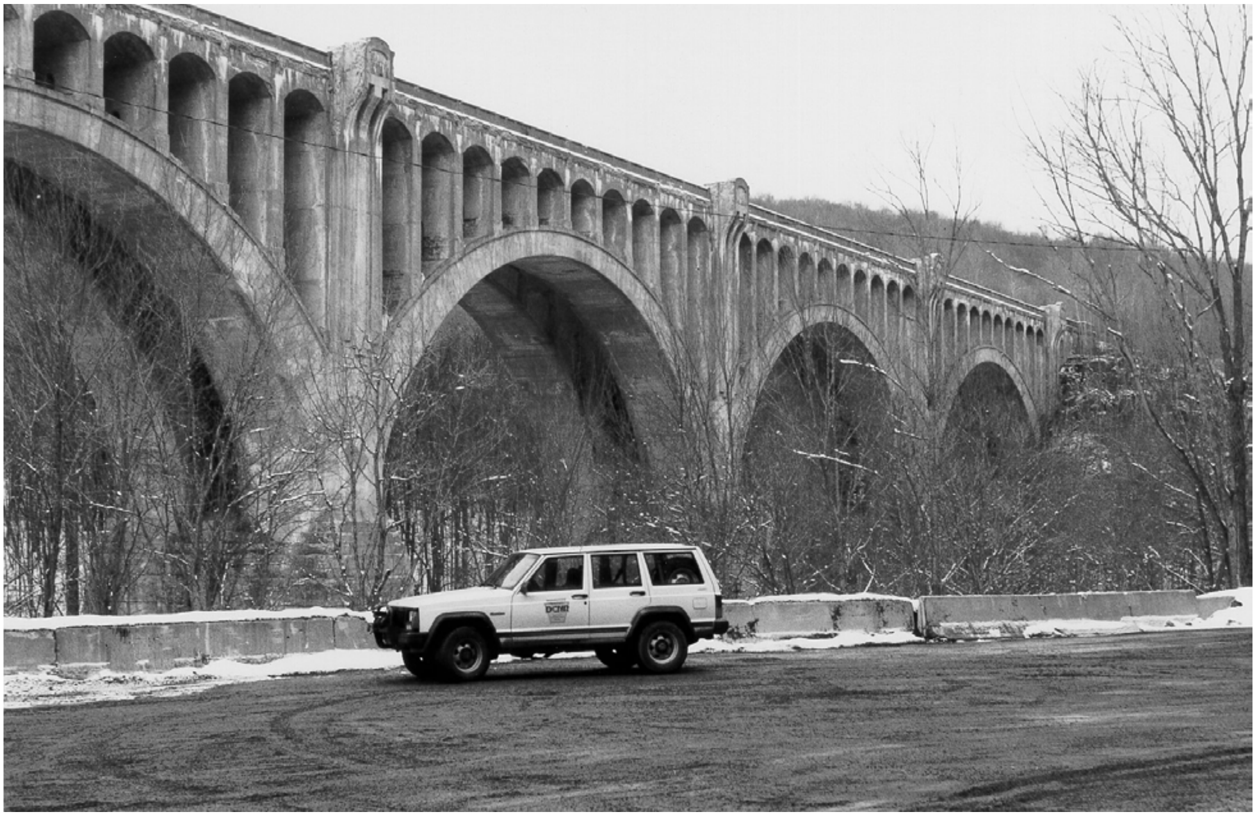


Figure 44. The Martins Creek Viaduct, looking northwest from the adjacent PennDOT storage area on US 11.


Figure 45. A view of the Martins Creek Viaduct from a point upstream on Martins Creek.

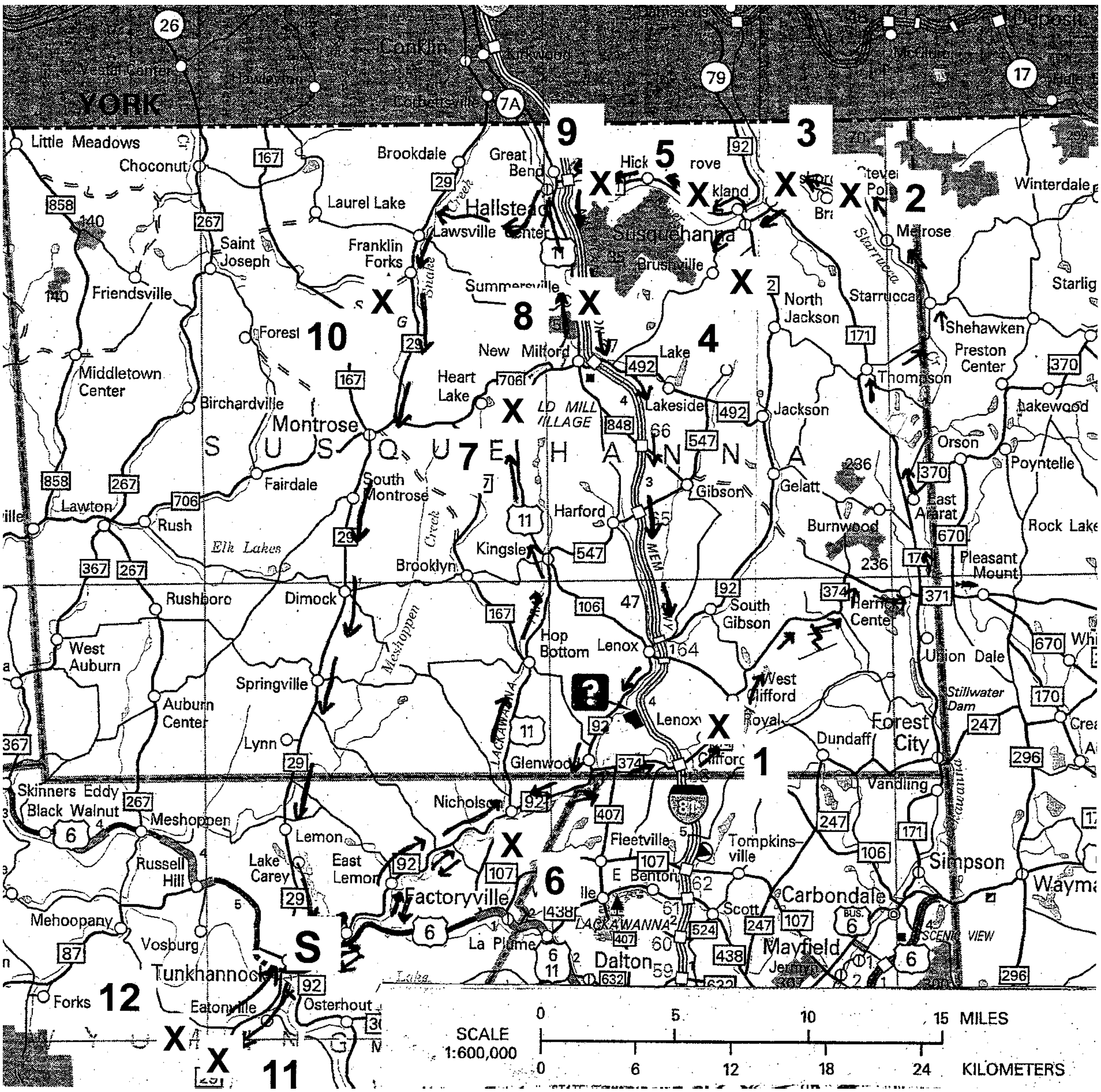


Figure 46. Field trip route and STOP locations. short arrows = Day-1 route, long arrows = Day-2 route, S = Shadowbrook Inn and Resort.

ROADLOG AND STOP DESCRIPTIONS

DAY 1

Miles Int.	Miles Cum.	Description
0.0	0.0	Leave parking lot at Shadowbrook Inn and Resort, proceeding toward EAST exit.
0.2	0.2	East exit of Shadowbrook; turn left on US 6-PA 92.
0.2	0.4	Cross Tunkhannock Creek.
0.1	0.5	To right is Osterhout Mountain (summit elev. 1900 feet A.T.), capped by the Spechty Kopf Formation of Late Devonian-Early Mississippian age (Berg and Dodge, 1981).
0.1	0.6	Esker on right paralleling road.
0.4	1.0	To left is a cut in gray Catskill sandstone.
0.3	1.3	Turn left on PA 92.
1.0	2.3	To left is a small post-glacial bedrock gorge with a waterfall cascade over a sandstone ledge in the Catskill Formation. Just to the right of the gorge is the preglacial valley now buried by more than 100 feet of till.
1.3	3.6	Cut to left exposes gray sandstone over red mudstone in the Catskill Formation.
0.4	4.0	To right is the wide floodplain of Tunkhannock Creek.
0.2	4.2	To left is a large colluviated block of pitted grayish-red, calcareous sandstone from Catskill ledges higher on the hill.
0.4	4.6	To left are flat-lying ledges of Catskill sandstone at base of a deforested hill. The deforestation is from the F-3 tornado of June 2, 1998, that traveled from left to right across the valley and through the village of East Lemon. (See mile 75.3 of Day-2 Roadlog for further discussion of this event.)
0.1	4.7	Descend the high outwash terrace that East Lemon is built on and cross tornado track.
0.7	5.4	To left adjacent to red building is a partly reclaimed gravel pit in glacial outwash.
0.1	5.5	Cross broad terraces of Tunkhannock Creek. To right are Holocene alluvial terraces and to left are forested outwash terraces.
0.3	5.8	Ascend riser onto high outwash terrace.
0.2	6.0	To right is a small cemetery; relatively easy digging in the outwash.
0.5	6.5	To left is a high cut in complexly interbedded and channelized, gray and grayish-red sandstone and shale and grayish-red mudstone of the Catskill Formation. At the west end a thick pod of calcareous breccia/agglomerate occurs at the base of a crossbedded channel-sandstone. Along the power line to right is an excellent view of high and low terraces along Tunkhannock Creek (Figure 47). The high-terrace riser is particularly impressive.
0.7	7.2	Cross valley of Monroe Creek, incised through the Tunkhannock Creek terraces.
0.3	7.5	To left is a cut exposing gray and grayish-red Catskill strata that exhibit several features typical of the formation, including sandstone channel cutouts, calcareous breccia/agglomerate lenses, and calcareous nodules in red mudstone (paleosol concretions).
0.5	8.0	To right are broad, low alluvial terraces of Tunkhannock Creek.
0.1	8.1	To left is a stone farmhouse with a bedrock gorge and waterfall cascade behind it. The preglacial valley buried by more than 100 feet of till is immediately to the right of the waterfall.

0.2	8.3	To left is a cut in gray Catskill sandstone.
0.2	8.5	To left is another cut in gray Catskill sandstone.
0.5	9.0	Cross low alluvial terraces (cornfield).
0.1	9.1	To left is a cut showing disturbed Catskill ledges and large colluviated sandstone blocks.
0.3	9.4	To left is a cut in red and olive-green Catskill sandstone and shale (at bend in road).
0.3	9.7	Enter borough of Nicholson.
0.2	9.9	Cross Horton Brook.
0.2	10.1	To left is an un-reinforced bluestone or flagstone wall that soil creep is now beginning to tilt towards the road and topple parts of it.
0.2	10.3	This part of Nicholson is built on the high outwash terrace of Tunkhannock Creek that stands about 100 feet above present creek level.
0.3	10.6	Descend riser to lower outwash terrace. Ahead is the great reinforced-concrete Tunkhannock Viaduct, commonly known as the Nicholson Bridge (see STOP 6). The structure was built by the Delaware, Lackawanna and Western Railroad (DL&W) in 1912-1915.
0.1	10.7	Cross Martin(s), originally Martens, Creek.
0.1	10.8	Ahead to left are ruins of some of the coal pockets of the old DL&W Railroad.
0.1	10.9	On left is the dangerous, complex intersection with US 11. Continue straight ahead on PA 92.
0.1	11.0	Pass under Tunkhannock Viaduct.
0.4	11.4	To right is a good view of outwash and alluvial terraces along Tunkhannock Creek. On the opposite side of the creek about 0.3 mile south of the this spot, a small sand pit exposes a beautiful cross section of intensely deformed ice-contact deposits in a kame terrace (see STOP 6, Figure 97).
0.3	11.7	To left are cuts in Catskill flaggy sandstone and colluvium at Kay's Pennsylvania Fieldstone Co.
0.9	12.6	Cross Willow Brook.
0.4	13.0	Ascend onto outwash terrace. To left is bouldery till.
0.4	13.4	To right is Tunkhannock Creek.
0.9	14.3	Enter Susquehanna County.

Figure 47. View (looking east) of high (main glacial outwash) and low (alluvial) terraces along Tunkhannock Creek at mile 6.5.

0.4	14.7	Turn right at intersection with PA 374 East. To right is a bluestone storage yard.
0.1	14.8	Cross Tunkhannock Creek.
0.3	15.1	On right is a bluestone cutting operation. The stone is trucked in from nearby quarries.
0.4	15.5	Intersection with PA 407. Continue straight on PA 374.
0.7	16.2	Cross East Branch Tunkhannock Creek. This east trending valley is much narrower than the Tunkhannock Creek valley we were traveling in before. The valley is transverse to ice flow and has been partly in-filled by glacial deposits, primarily till. Along the north side of the valley there is often more than 100 feet of till forming what has been termed a "till shadow" in the lee of features transverse to ice flow.
1.1	17.3	To right are low cuts in flat-lying Catskill sandstone and several large colluviated sandstone blocks.
0.2	17.5	To left is the Rock Creek Public Golf Course.
0.7	18.2	Pass under I-81.
0.2	18.4	Good cut through Catskill sandstone.
0.3	18.7	To right are rock cuts and natural ledges of Catskill sandstone on hillside.
0.3	19.0	To right, behind sheltering pine trees, is a small picturesque waterfall over Catskill sandstone.
0.6	19.6	Village of Lenoxville.
0.2	19.8	Enter Clifford Township. Cut in Catskill sandstone to right.
0.5	20.3	Cross East Branch Tunkhannock Creek, then immediately turn left at entrance to Clifford Quarry of State Aggregates, Inc.

STOP 1. CLIFFORD QUARRY OF STATE AGGREGATES, INC.
Leaders: Jon D. Inners, Michael G. Slenker, and Richard H. Howe.

Granted that the expression "breathe-taking" is relative to the eye and mind of the beholder, it does not take a great leap of imaginative to apply this adjective to the Clifford quarry of State Aggregates, Inc. Located on a glacially sculpted, N25°E-trending hill just north of the East Branch Tunkhannock Creek between Lenoxville and Royal, Susquehanna County, the quarry—with its 5-bench, 300-foot-high highwall—is one of the largest in northeastern Pennsylvania (Figures 48 and 49). It had its beginnings on the Bennett farm in 1954 as a PennDOT quarry supplying aggregate for a large job on US 11. In 1959 John Keelor purchased the farm and built the existing plant along with an asphalt batch plant and a construction division. In 1975 Donald Stabler purchased the property, and it has been operating as State Aggregates to this day. Current superintendent of operations is Mr. Ellis Arthur.
Geology. The quarry is mining in the Late Devonian-age Catskill Formation. The area just to the east (Clifford quadrangle) has most recently been mapped by Kochanov (2001), who did not subdivide the formation below the Duncannon Member. (The Duncannon forms the outer slope of the mountain range on the northwest rim of the Lackawanna basin.). The rock is mostly thick-bedded, crossbedded, medium-gray (N5) to light-gray (N7), fine-to medium-grained sandstone. Most of the thick sandstone units are channel-form, and many have clearly erosional contacts with underlying beds. Discontinuous, gray-shale-chip conglomerate deposits occur near the bases of many of the thick channel sandstones, and a few pods of gray shale —up to 10 feet or more in length and several feet thick—are found in the thick sandstone beds. As will be seen in our walk along Level 3 (see below), reddish-brown weathering pods of "agglomerate"/calcareous breccia, some 10 feet or more across and several feet thick, occur near the base of numerous sandstone units. The only significant "red rock" (interbedded sandstone, siltstone, and mudstone) is a 12-to-18-foot-thick band on Level 4 (or 4½) of the quarry (see below). The only fossils known from the quarry are the fairly abundant, commonly coalified, impressions of vascular-

plant trunks and stems. Locally these plant remains are concentrated in "log jams" (*"Pflanssenhacksel"*) at the base of sandstone channels.

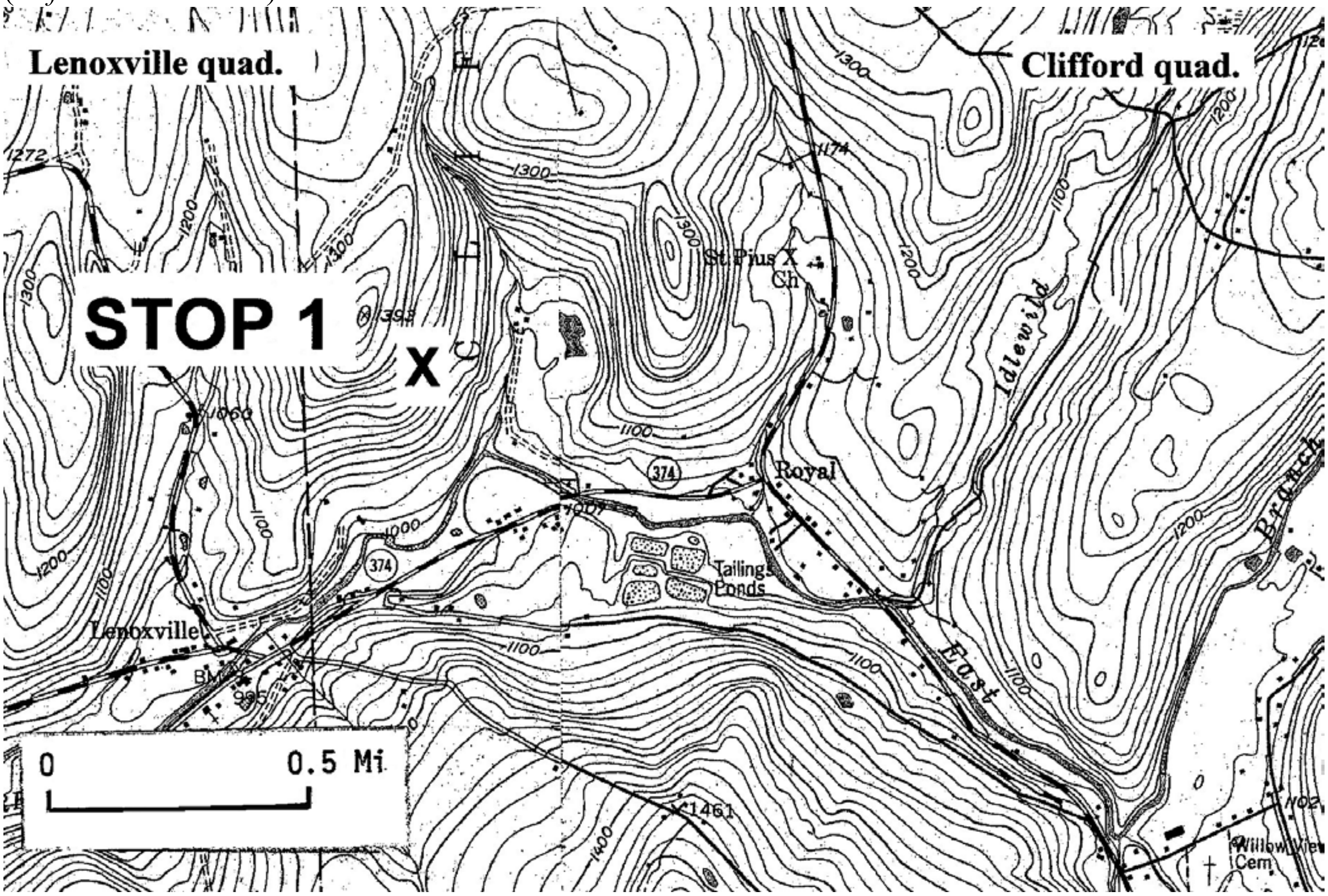


Figure 48. Location map for STOP 1 (Clifford quarry).

Bedding in the quarry dips 5^o or less to the southeast. The dominant structures evident, however, are the two well-developed joint sets, one striking a little east of north (typically N5-10^{o}E) (Figure 50) and the other roughly east-west (N85E-N85^{o}W). (We will see these two joint sets at practically every bedrock exposure in Susquehanna County!) The "north-south" set is usually the more planar and continuous of the two; it is also commonly quartz mineralized. The quarry is laid out with the "north-south" and "east-west" highwalls parallel to these joints (see Figure 49). This allows for easier extraction of the stone and also provides a straighter, cleaner highwall much less prone to rockfall.

Quarry operation. The Clifford Quarry has a total height of 300 feet and covers an area of about 25 acres. As presently configured, it has 6 lifts (highwalls of 50 feet), five benches, and a floor (Figure 49). The hardest and best stone, which easily meets state specifications for concrete and blacktop aggregate, comes from the bottom 3 lifts; the upper three lifts tend to produce softer stone, with more deleterious shale. Much of the stone from the upper lifts goes to 2RC and 2A material. Blasting is generally done once a week, less often in slack times (Figure 51). Typically 45 or 50 holes are drilled to a depth of 50 feet. Much of each hole is filled with fuel oil and nitrate with 3 or 4 sticks of waterproof dynamite in the bottom few feet. It takes 3 or 4 days to drill the blast holes, and about a week to clean up after a shot (Figure 52). Blasting contractor is Edward M. Arnold of Douglasville, PA.

Figure 49. Detailed map of the Clifford quarry, showing benches and Stops #1, #2, and #3 of tour.

Generally, the Clifford Quarry is an excellent location for aggregate stone since its many massive sandstone beds have relatively small amounts of deleterious red or gray claystone, shale, and sedimentary agglomerate/calcareous breccia when compared to most of the Catskill Formation. A high percentage of the stone meets PennDOT's sodium sulfate and Los Angles abrasion test requirements. Occasionally, as a particular claystone or shale bed thickens, the mine plan has to be altered to isolate the area and send the material to the stripping pile. The occasional thin beds of the deleterious material are much softer by nature and most of the softer material is "scalped" off at the primary crusher and ends up in the 2A modified which is not used in ready-mix concrete or hot mix asphalt. This, in effect, beneficiates the aggregate sizes which are used in concrete and asphalt as proportionally more of the

Figure 50. Dominant, smooth "north-south" joints in Clifford quarry.

"harder" sandstone and less of the "softer" deleterious stone end up in the aggregate. The thick bed of red shale/sandstone noted above is isolated and blasted separately and shipped to the stripping pile.

States Aggregates produces a wide range of product types and sizes, mainly for construction use. In addition to the various coarse aggregate types (Table 1), sand size material resulting from the crushing operations is marketed as fine aggregate (Table 2). Some of the red sandstone is sold as a red decorative landscape stone; however, the sales of this product are low. Material produced for the wearing courses of concrete and bituminous pavement meets the highest skid-resistance requirements (E).

Expansion of the quarry is closely limited on the north side, but considerable room is available to the west. Naturally all future expansion must maintain roughly the present configuration of highwalls and "levels" in order to comply with state mine-safety requirements.

Figure 51. Blast at Clifford quarry on July 25, 2002. Note rock fragments at edge of blast cloud. (Photo by Gary M. Fleeger.)

TOUR OF THE QUARRY

The buses will make three stops in the quarry (see Figure 49). Participants should get out of the buses at each of them, but DO NOT venture near the highwall. Stop #2 involves a walk along the face for several hundred yards. HARD HATS MUST BE WORN!

SIZE AND GRADING REQUIREMENTS FOR COARSE AGGREGATES
(Based on Laboratory Sieve Tests, Square Openings)

AASHTO NUMBER	TOTAL PERCENT PASSING													
	100 mm (4")	90 mm (3 1/2")	63 mm (2 1/2")	50 mm (2")	37.5 mm (1 1/2")	25.0 mm (1")	19.0 mm (3/4")	12.5 mm (1/2")	9.5 mm (3/8")	4.75 mm (No. 4)	2.36 mm (No. 8)	1.18 mm (No. 16)	150 µm (No. 100)	75 µm (No. 200)
1	100	90-100	25-60		0-15		0-5							
3			100	90-100	35-70	0-15		0-5						
467				100	95-100		35-70		10-30	0-5				
5					100	90-100	20-55	0-10	0-5					
57					100	95-100		25-60		0-10	0-5			
67						100	90-100		20-55	0-10	0-5			
7							100	90-100	40-70	0-15	0-5			
8								100	85-100	10-30	0-10	0-5		
10									100	85-100			10-30	
2A**				100			52-100		36-70	24-50	16-38*	10-30		0-10
OGS**				100			52-100		36-65	8-40		0-12		0-5

* Applies only for bituminous mixtures.
** PaDOT Number

TABLE 3. Specifications for coarse aggregate (PA Department of Transportation, 2002).

FINE AGGREGATE
Grading and Quality Requirements

	Cement Concrete Sand	Bituminous Concrete Sand Type B				Mortar Sand
Sieve Size	Type A	#1	#2	#3	Filler	Type C
9.5 mm (3/8-inch)	100	100	—	100	—	—
4.75 mm (No. 4)	95-100	95-100	100	80-100	—	100
2.36 mm (No. 8)	70-100	70-100	95-100	65-100	—	95-100
1.18 mm (No. 16)	45-85	40-80	85-100	40-80	—	—
600 µm (No. 30)	25-65	20-65	65-90	20-65	100	—
300 µm (No. 50)	10-30	7-40	30-60	7-40	95-100	—
150 µm (No. 100)	0-10	2-20	5-25	2-20	90-100	0-25
75 µm (No. 200)	—	0-10	0-5	0-10	70-100	0-10
Material Finer Than 75 µm (No. 200) Sieve Max. Percent Passing	3	—	—	—	—	—
Strength Ratio Min. Percent	95	—	—	—	—	95
Soundness Test Max. Loss Percent	10	15	15	15	—	10
Fineness Modulus	2.30 to 3.15	—	—	—	—	1.6 to 2.5

TABLE 4. Specifications for fine aggregate (PA Department of Transportation, 2002).

Stop #1—Level 1: Lower Beds

The lower beds in this quarry tend to be the most massive and contain mostly sandstone. The upper benches, although still containing mostly sandstone, have more deleterious beds. Selective quarrying, however, allows many of these upper beds to be used by themselves for material meeting PennDOT standards. The quarry plan is to alternate production on various benches. Notice the dual joint pattern on this level (and on the higher levels as well). An effort is made to drill and blast parallel to these joints, which are vertical and (luckily and ideally) approximately 90 degrees from each other. This helps in the breakage of the rock and tends to leave a face that is flat, vertical, safe and stable. Note some of the larger

Figure 52. Fragmented rock on Level 1 resulting from blast of July 25, 2002.

rocks, which will need to be broken by the portable hydraulic breaker, are very close to cube shaped.

The 50-foot-high west wall on this level is essentially a single, remarkably smooth, vertical N5^{o}E joint. The sandstone face contains a few lenticular agglomerate zones 1-3 feet thick and at least one pod of gray shale 1 foot thick by 4 feet wide. The north wall, parallel to the "east-west" joint set is much less smooth, but exposes many of the vertical "east-west joints" that are often 6 feet or more apart.

Stop #2—Level 3: Walk along the Highwall

Figure 53. Lenticular gray shale bed (1 foot thick and at least 25 feet wide) in massive channel-sandstone at intersection of two joints (Stop #2, Level 3).

As we walk along the west wall of the third level (looking at the 4th face), note how some of the beds tend to thin and thicken, due in part to numerous channel cutouts. Lenticular gray shale and agglomerate beds are common, these soft zones accounting for most of the rough places along the highwall. A 3-D view of a 1-foot-thick by several-10's-of-feet-wide shale bed can be seen at the south end of the traverse (Figure 53). Near the middle is another shale pod 2 feet thick by 30 feet wide and strongly contorted. This pod occurs below an incised channel. A large ball of pyritic sandstone occurs on the joint face just above its north end. (Most of these gray shale and agglomerate pockets will end up in the 2A-modified material.) Near the north end of the traverse, the highwall exposes several stacked paleo-stream channels (Figure 54).

Stop #3—Level 4: Red Stripping

This level exposes the only significant "red bed" in the quarry (Figure 55). The interval is approximately 15 feet thick and consists of interbedded sandstone, siltstone, mudstone, and shale—with a few thin bands of greenish-gray sandstone. Observable in loose blocks of red rock are mudcracks, current ripples, abundant horizontal burrow, some vertical burrows, and plant fossils (in greenish-gray sandstone). Thin calcite veins

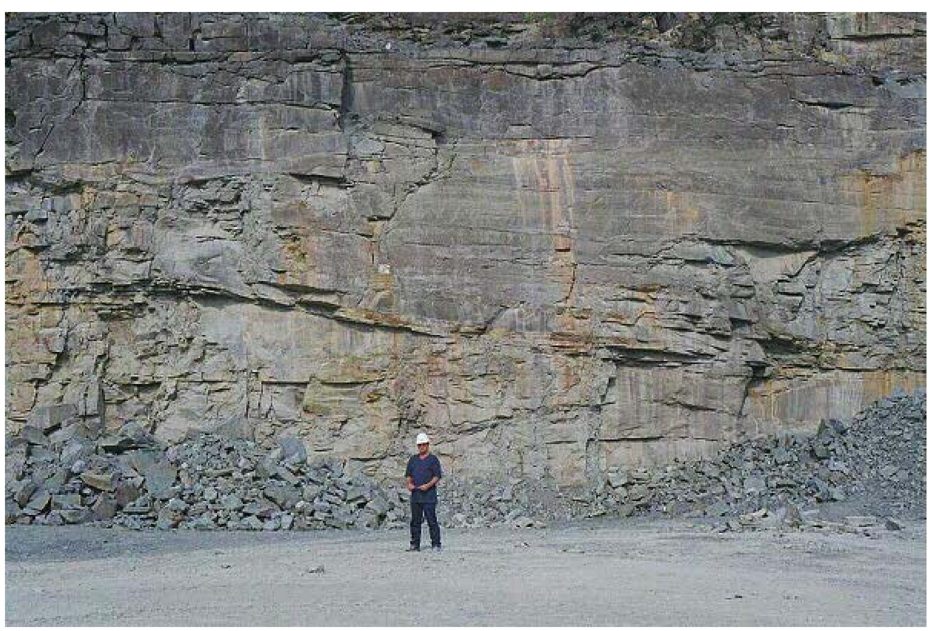


Figure 54. Stacked paleo-channel deposits at north end of Level 3 (Stop #2).

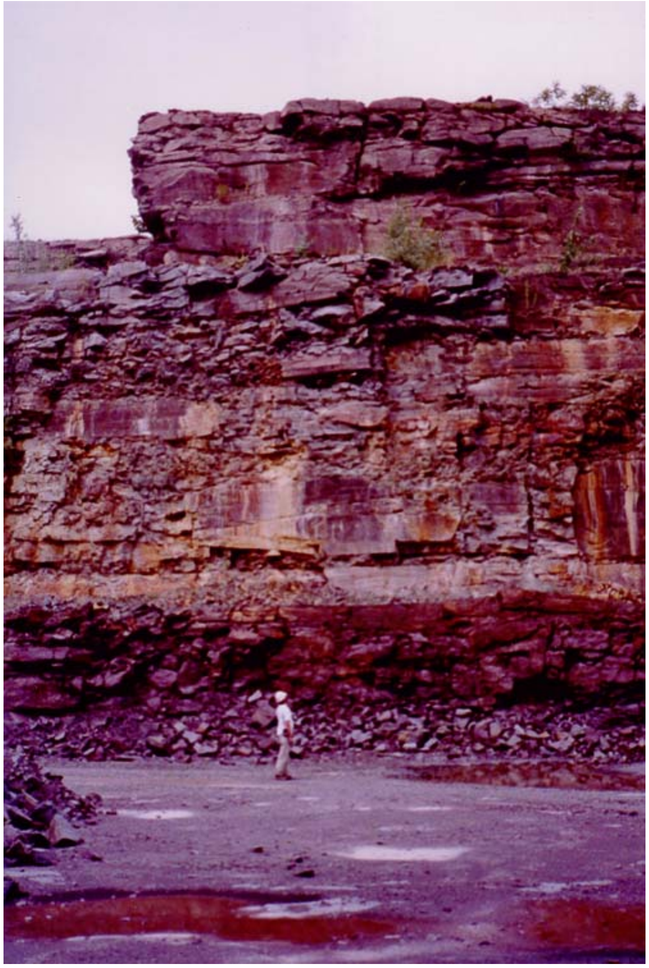


Figure 55. “Red bed” on Level 4 (Stop #3).

fill some fractures, and a few fragments have white gypsum coatings (also to be seen at STOP 4). Nearly all of this material goes to the stripping pile, since only 1 percent of red rock (even sandstone) is allowed in the high-quality aggregate. (This includes gray-green sandstone with red streaks and pods.) According to Mr. Arthur, PennDOT says that Susquehanna County has no red sandstone that qualifies as an aggregate source.

The abundance of channel sandstone and paucity of red overbank deposits in the Clifford quarry may be due to geographic circumstances that allowed a large meandering river channel to occupy roughly the same thalweg for many thousands of years as subsidence of the basin progressed. During his years as a well driller, Mr. Arthur observed that red beds were much more commonly encountered in the hills surrounding the quarry.

		Leave STOP 1, turning left on PA 374 at entrance to quarry.
0.4	20.7	Stop sign at intersection with PA 106. Turn left on PA 374 East/PA 106 West.
0.8	21.5	On right is a bison “ranch.”
0.3	21.8	Village of West Clifford.
0.2	22.0	Turn right, following PA 374 East.
0.6	22.6	Ahead is a good view of Elk Mountain (called Elk Hill on the Clifford 7.5’ topographic quadrangle), capped by the sandstone of the Catskill Formation (Elk Mountain sandstone of Willard, 1939), and not the Pocono Formation as shown on the next-to-the-latest Geologic Map of Pennsylvania (Gray and Shepps, 1960).
0.9	23.5	Stop sign. Turn right, following PA 374 and signs to Elk Mountain Ski Area.
0.1	23.6	Lake Idlewild to left.
0.4	24.0	Ahead are East Mountain (left) and Elk Mountain (right), the latter noted previously at mile 22.6. Each of these mountains have two “summit knobs”—East Mountain, 2366 feet (north knob) and 2312 feet (south knob); Elk Mountain, 2602 feet (South Knob) and 2680+ feet (North Knob) (Figure 56), the last being the highest elevation in northeastern Pennsylvania. The exceptional height of Elk Mountain is a topographic oddity. It is not on the up-plunge nose of the Lackawanna synclinorium (Northern Anthracite field) or presently on the regional drainage divide between Tunkhannock Creek and the Lackawanna River, two situations where one would expect exceptional height. The Elk Mountain sandstone caprock is not exceptionally resistant. In fact, the sandstone caprock on North Knob is only about 10 feet thick and is underlain by 16 feet of mostly red mudstone and shale (Figure 57).

Figure 56. View of Elk Mountain looking east from about mile 23.8. Welch (Welsh) Church is in the left mid-distance.

Figure 57. Section exposed at top of North Knob of Elk Mountain near the ski lift, showing gray sandstone bed (mostly eroded away) overlying interbedded grayish-red shale, mudstone, and sandstone.

Such a feature can generate a lot of untestable geomorphologic speculation involving ancient erosion surfaces and such. Braun's favored and testable hypothesis for the exceptional height of Elk Mountain is that the mountain marks the axis of a secondary syncline on the flank of the Lackawanna synclinorium. The highly resistant Pottsville conglomerate would have capped the mountain a few hundred feet above the present mountaintop and would have been geologically recently eroded from the mountain. Anticlinal areas to either side of the mountain would have had the Pottsville eroded earlier and then been eroded down more. Careful mapping of the subtle regional fold structure in the area should provide a test of this hypothesis. It is worth noting, however, that Kochanov (2001) mapped no discernable "structure" in the vicinity of Elk Mountain.

On the southwest side of Elk Mountain (the side you are seeing) is a thick till shadow, in places greater than 200 feet thick. On the northeast side of the mountain, where the ski area is located, is essentially ice-scoured bare bedrock.

1.9 25.9 Crest of high pass (elevation ~1840 feet) between East Mountain and Elk Mountain. On the skyline ahead is Mount Ararat, the up-plunge nose of the Lackawanna synclinorium—also capped by Catskill sandstone.

1.0 26.9 Entrance to Elk Mountain Ski Area to right.

1.2 28.1 Stop sign. Turn left, staying on PA 374 East.

1.0 29.1 Village of Dimock Corners.

0.4 29.5 Stop sign. Turn right, staying on PA 374 East. You are now crossing the drainage divide between Tunkhannock Creek and the Lackawanna River. The divide is 700 feet lower than Elk Mountain.

2.0 31.5 Ahead to right are mountains that mark the extreme north end of the synclinal Northern Anthracite field. The mountains (Catskill-Spechty Kopf-Pottsville Formations) rimming either side of the coal basin merge to form a narrow, synclinal range of hills (Catskill Formation) that extends north-south along the border of Susquehanna and Wayne Counties.

0.2 31.7 Deep cut through Catskill sandstone.

0.1 31.8 Cross former Jefferson Branch of the Erie/D&H Railroads, now the "D&H Rail Trail" maintained by the Northeastern Pennsylvania Rail-Trail Alliance out of Forest City (see Inners, this guidebook p. 51 - 54).

0.1 31.9 Village of Herrick Center.

0.1 32.0 Cross West Branch Lackawanna River.

0.4 32.4 Stop sign. Turn left on PA 171 North at Herrick Corner.

0.5 32.9 To right is the synclinal range of hills that marks the northward extension of the Northern Anthracite field, culminating a few miles ahead in Mount Ararat and Sugarloaf Mountain.

0.2 33.1 To left is a low cut in the Catskill Formation.

0.2 33.3 To left is a rare roadcut in grayish red shale and mudstone of the Catskill Formation. As is getting rather monotonously obvious by this time, most artificial cuts in the Catskill (except for very large ones such as we will see later today along I-81) expose only gray sandstone. I. C. White (1881, p. 29) notes, however, that "it is the universal testimony of the farmers that the '*red shale soils*' are generally stronger and richer than any others."

0.5 33.8 To right is a group of large Catskill sandstone blocks.

1.4 35.2 The high hills ahead and to right are Mt. Ararat (2656 feet, south) and Sugarloaf Mountain (2536 feet, north), both summits just over the border in Wayne County (Figure 58).

Figure 58. View of Sugarloaf Mountain (left) and Mt. Ararat from the west along the field trip route. The ridgeline is capped by sandstones of the Catskill Formation, gently folded along the axis of the Lackawanna syncline.

0.2	35.4	Enter Ararat Township.
0.6	36.0	Intersection with PA 370 in village of East Ararat. Continue ahead on PA 171. The gently rolling hills in this area are at an elevation of about 2000 feet, the height of most of the ridge crests in the Ridge and Valley province.
2.9	38.9	This broad hilltop marks the regional divide between south (Lackawanna River) and north (Starrucca Creek) draining tributaries to the North Branch Susquehanna River. During glacier recession, all the north-draining valleys contained proglacial lakes that drained southward across the divide. More on this tomorrow at STOP 7.
0.5	39.4	On right is a beaver pond.
1.1	40.5	On right is the first of several cuts in the Catskill sandstone as road descends hill.
1.0	41.5	Borough of Thompson. Valley to left was the outlet for Glacial Lake Starrucca.
0.2	41.7	On right is a concrete milldam.
0.2	41.9	Stop sign. Continue straight, now on SR 1005. (PA 171 turns left.)
0.5	42.4	Descend underneath the 1800-foot elevation surface of Glacial Lake Starrucca, a proglacial lake dammed by the glacier until it retreated north, downstream, to near the location of STOP 2 at mile 51.5.
0.9	43.3	Cross Starrucca Creek.
0.1	43.4	To right is a cut in flaggy Catskill sandstone.
0.4	43.8	Floodplain of Starrucca Creek begins to broaden out to left.
0.3	44.1	To left is a good view of the wide floodplain of Starrucca Creek.
0.1	44.2	Enter Wayne County. Road is now SR 4039.
0.4	44.6	To left is an alluvial fan deposited on the floor of the Starrucca valley from a tributary entering the valley on the right.

0.3	44.9	To left is the Buck Farm. The road leads back to Bucks Falls, another postglacial bedrock gorge beside a preglacial valley buried by glacial till (see Braun and Inners, this guidebook, p. 39 - 43).
0.7	45.6	Borough of Starrucca.
0.1	45.7	To right is the Glover Farm, boyhood home of Albert D. Glover, coal geologist with the Pennsylvania Geological Survey from 1962-1996. The farm was recently sold to an order of Roman Catholic nuns, the Priory of Ephesus, who now reside there.
0.1	45.8	Turn right, staying on SR 4039, across from Post Office.
0.1	45.9	Cross Starrucca Creek. To the right just before 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). At stop sign immediately after the bridge, turn left—still on SR 4039.
0.9	46.8	Enter Susquehanna County. You are now on SR 1009.
0.6	47.4	To right is Simrell Farm. The main part of the large frame house nearer the road dates from about 1840, while the interesting fieldstone house farther back was built in the 1930's.
1.3	48.7	Village of Melrose.
1.6	50.3	Broad alluvial terraces on both sides of the road.
0.8	51.1	To right is a "beautiful" large sandstone block stone wall built by the WPA during the Depression;, Starrucca Creek is to left.
0.1	51.2	Village of Stevens Point. Once the glacier retreated to here, Glacial Lake Starrucca drained and was replaced by the lower (about 1200 feet elevation), much more extensive and longer-lived Glacial Lake Great Bend.
0.1	51.3	Cross Starrucca Creek.
0.2	51.5	Pull into large parking area to right along old railroad grade. Disembark.

STOP 2. OLD STEVENS POINT (GROVER'S) QUARRY AND ICE-CONTACT-STRATIFIED DRIFT BESIDE STARRUCCA CREEK.

Leaders: Jon D. Inners and Duane D. Braun.

This STOP consists of two very different exposures (Figure 59). Site A is a bedrock dimension-stone quarry on SR 1009 and the old Jefferson Branch Railroad grade from which stone was first removed in the late 1840's for the construction of the Starrucca Viaduct (STOP 3). Site B is a spectacular faulted kame/strath-terrace deposit along Starrucca Creek about 1000 feet northeast of the quarry. We will divide into two groups, each of which will spend about equal time at the two sites.

SITE A: THE QUARRY

Extending west along the road for more than 500 feet and continuing along the bank of Starrucca Creek for another 250 feet is the intermittently exposed highwall of a large quarry in the basal sandstone beds of the Catskill Formation. At the eastern end of the site directly across from the parking area is part of the old dimension-stone quarry used for the Starrucca Viaduct (Stone, 1932). Further west along the road, the New Milford Sand and Gravel Co. (see STOP 8) has recently reactivated part of the old quarry, but apparently little work has been done here in the past year or so. On the bank of the Starrucca, the old highwall has been largely covered over by rubble from the newer quarry.

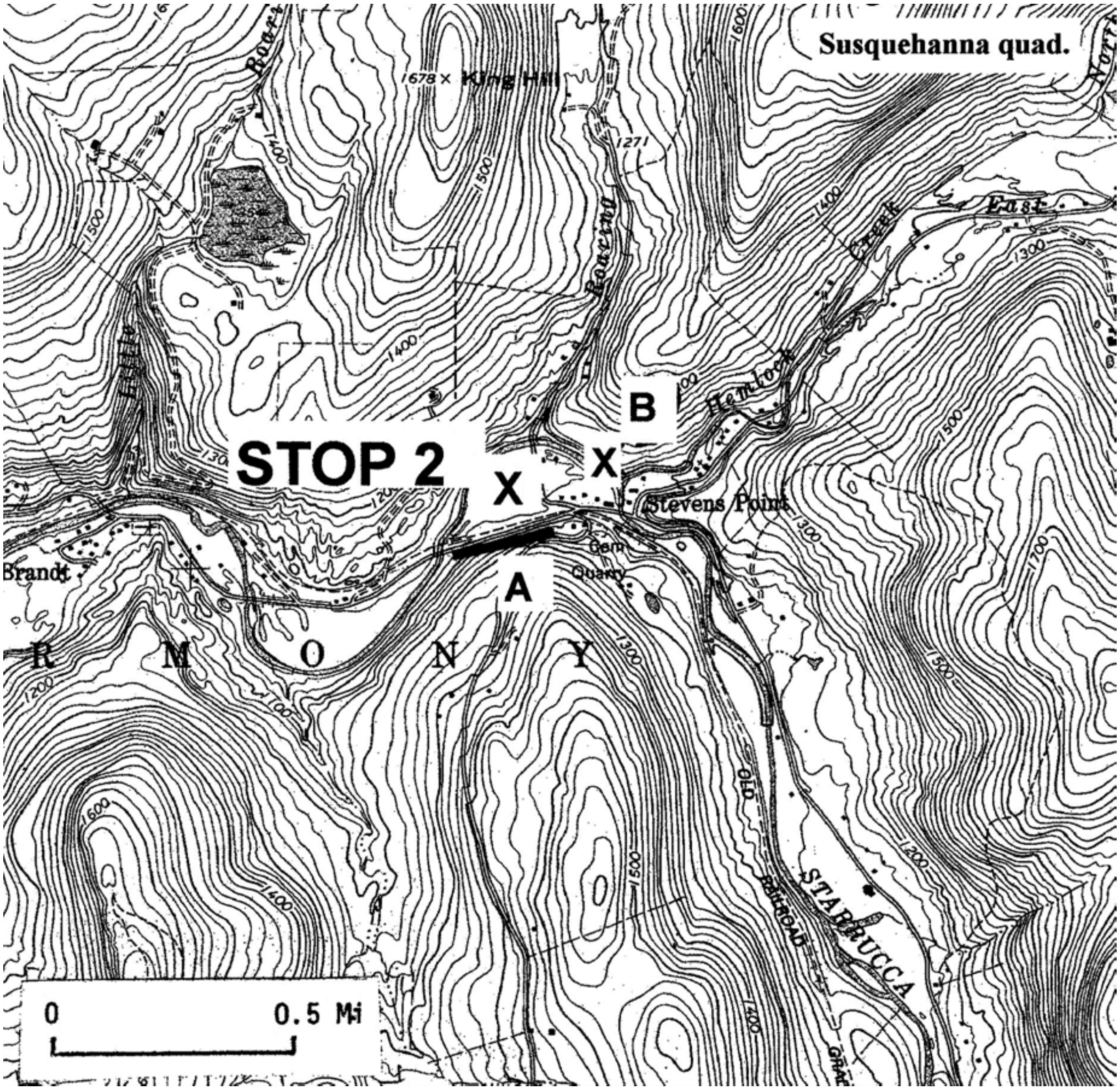


Figure 59. Location map for STOP 2, showing Sites A and B.

Geology. The rocks exposed in the Stevens Point quarry consist of the lowermost beds of the Late Devonian-age Catskill Formation—the informally named Great Bend Member of McElroy (2002). The contact with the underlying Lock Haven Formation may be exposed at the very base of the quarry on SR 1009. Uppermost Lock Haven strata—as mapped by Inners (2002)—definitely crop out along the road just east of the bridge across Starrucca Creek (2 feet of greenish-gray shaly siltstone with a thin bed of very fine-grained sandstone at the top) and along the bank of the creek at a local swimming hole (medium- to thick-bedded, light-olive-gray weathered, fine-grained sandstone).

The section in at Site A consists of two fining-upward sequences, the lower one about 22 feet thick cropping out along the road in the old, eastern part of the quarry and the upper one about 50 feet thick occurring mainly higher on the hill in the newer part (Figure 60). Except for 3 feet of grayish-red siltstone and sandstone near the top of the lower cycle, the rocks are all various shades of gray—fresh colors ranging from medium light gray (N6) in the sandstones to medium dark gray (N4) in the shales and siltstones. The massive, 10-foot-thick, basal sandstone (Figure 61) was apparently the source of stone for the Starrucca Viaduct. At several places, the old hand-held star-drill marks can still be clearly seen (Figure 62). The upper sandstone sequence is much thicker. It is planar bedded to crossbedded in

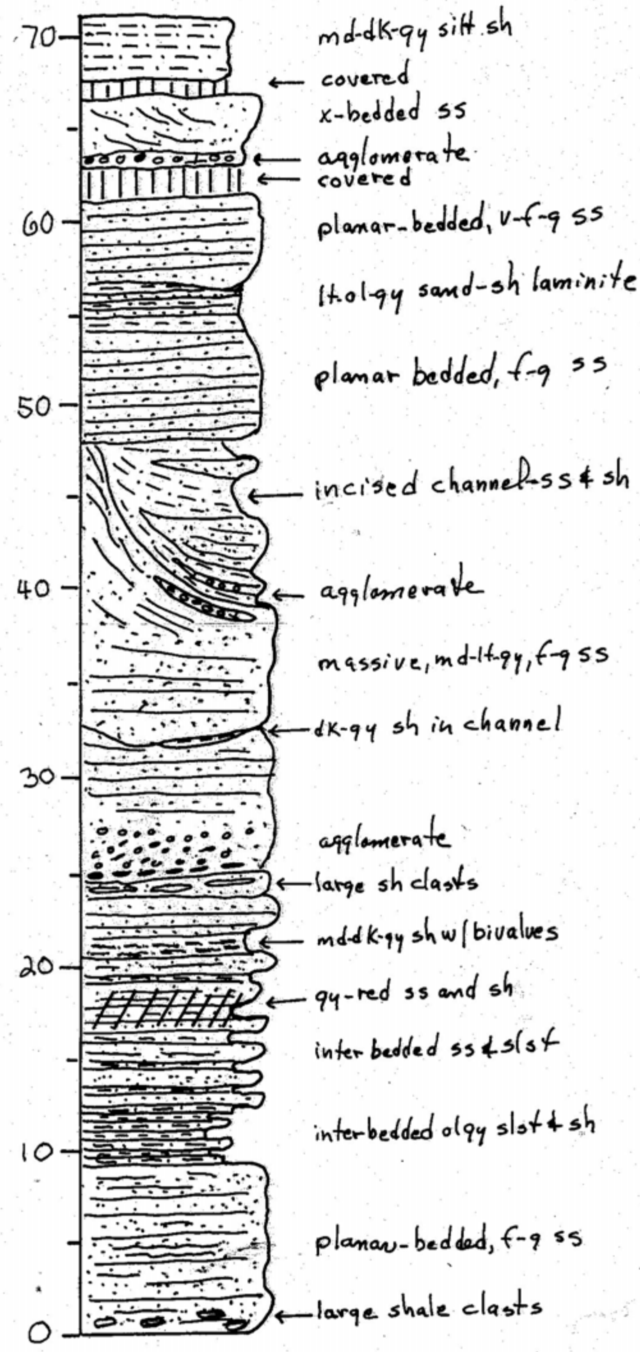


Figure 60. Generalized geologic section at Site A. Scale is in feet.

the lower 25 feet, with a deeply incised channel filled mostly with gray clay shale—but also containing lenticular sandstone and "agglomerate" beds (Figures 60 and 63). Two 5-foot-thick beds of well-jointed, planar-bedded sandstone separated by about 2 feet of light-olive-gray sand-silt laminite occur above the sandstone with the incised channel. The most interesting unit in the quarry, however, is found near the top of the finer grained interval separating the lower, "Starrucca-Viaduct" sandstone from the upper, channeled sandstone. This is a ±4-inch thick bed of medium-dark-gray (N4), silty clay shale containing abundant, small nuculoid bivalves (up to about ¾ inch in maximum size) (see Figure 60). Although collecting these fossils from the outcrop face is difficult, there are many large blocks of this shale lying about on the floor of the newer quarry from which they can easily be obtained.

Based on readings on a smooth bedding surface at the east end of the quarry, bedding strikes N42°E and dips 2° to the southeast. Parting-step lineation on this same surface indicates upper-flow-regime flow directed N56°W-S56°E. Joints in the sandstone beds form the same two subvertical sets seen at STOP 1. The sharpest, "smoothest" set trends on average N8°E, while the other set—generally not as smooth and cleanly "cut"—trends approximately N81°W. When they are continuous, relatively smooth, and widely spaced (as here), such fractures greatly facilitate quarrying.

Figure 61. Massive 10-foot-thick basal sandstone of lower fining-upward cycle at Site A—source of dimension stone used for the Starrucca Viaduct.

Some notes on stratigraphic nomenclature. I. C. White (1881, p. 96-97) assigned all of the beds exposed here to the Catskill Formation. Specifically, he assigned the quarry beds to his “New Milford lower sandstone”—the same beds occurring at the bottom of the New Milford Sand and Gravel Co. quarry at Tingley (McElroy, 2002; see STOP 8)—and beds immediately beneath to the “New Milford red shale” (although there is no red shale in the unit locally). White (1881) places the “New Milford lower sandstone” more than 200 feet above the base of the Catskill (p. 73). Willard (1939, p. 295-297) also called the lower beds of the Catskill New Milford, basically recognizing the same subunits as White. He noted (p. 297) that the New Milford (as studied by Mr. D. S. Harding of Susquehanna) consists of an alternation of marine and freshwater beds—the only indication of the marine beds being the invertebrate fossils contained therein. Recent geologic mapping in northeastern Susquehanna County has redefined the base of the Catskill to coincide with the base of the “New Milford lower sandstone,” while recognizing that the lower ±200 feet of the Catskill (the previously mentioned Great Bend Member) consists of just such marine-nonmarine alternations (McElroy, 2002; Inners, 2002). Woodrow and Fletcher (1968; this guidebook) assign these beds to their Walton Formation.

History. Young (1995, p. 9-11; 2002, personal communication) sites this as being the "main quarry" for the Starrucca Viaduct, opened in 1847 by Messrs. Baird and Collins "4 miles up the Starrucca Creek" at what became Stevens Point. A railroad from the quarry ran down the valley, crossed the creek several times, and—a mile from the viaduct—ascended “the north hillside" to bring stone to the construction site across a trestle 33 feet (and later, 66 feet) above the creek. Most of the stone used in 1848 came from this quarry (Young, 1995, p. 11).

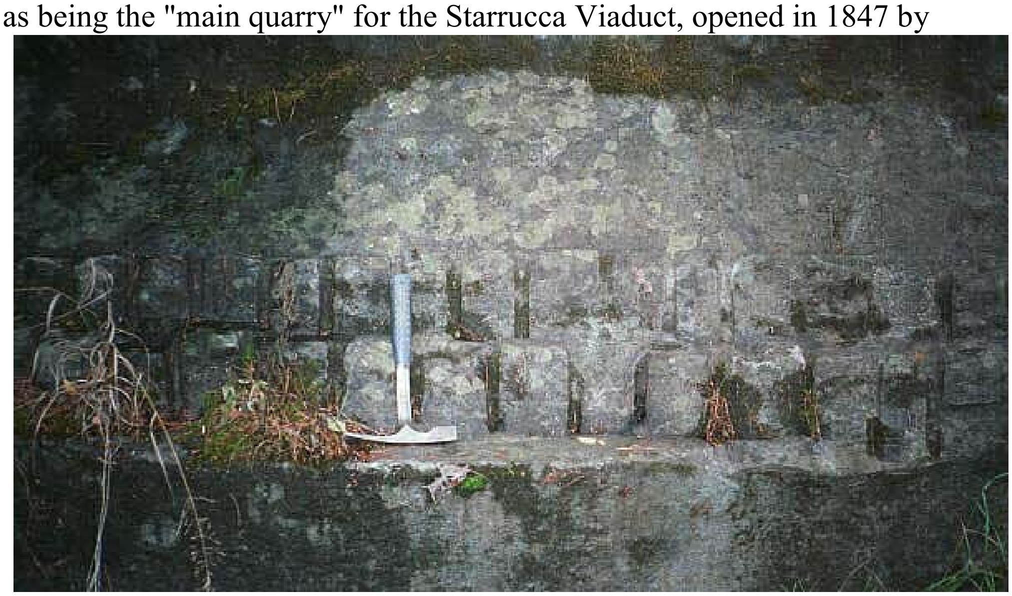


Figure 62. Star-drill marks in massive, basal sandstone at STOP 2, Site A. Hammer is 11 inches long.

Figure 63. Channel cutout in massive sandstone of upper cycle in new quarry at Site A. Staff is 5 feet long.

I. C. White (1881, p. 97) is apparently also referring to this site when he notes that the “New Milford lower sandstone” was quarried just below Stevens Point and used in constructing piers of bridges along the Jefferson Branch Railroad. (He observed the olive-shale clasts that occur at the base of the upper sandstone in the quarry.) The abutments of the Jefferson Branch bridge which crosses Starrucca Creek less than 1000 feet west of here is built of bluish- to greenish-gray, fine-grained sandstone that likely came from this nearby source. The only mention that White makes concerning the source of stone for the viaduct is that sandstone outcropping 150 feet above the base of the New Milford group (about the same as the Stevens Point stone) and occurring on a high knob just east of Starrucca Creek at Lanesboro was extensively quarried and used in constructing the "great viaduct" across the Starrucca valley (p. 102).

SITE B: THE KAME

This natural cut-bank on Starrucca Creek is a splendid example of Late Wisconsinan-age ice-contact stratified drift, complete with at least two (possibly three) post-depositional faults. The cut is approximately 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 3 the Starrucca Creek valley runs east to west, transverse to glacial flow, so the valley was deeply buried by glacial deposits (Figure 64) as first noted by White (1881). Thickness contours on Figure 64 (dashed lines) show the deposits to be greater than 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. Postglacial incision of the creek has caused extensive slumping of the valley sides (hachured arcuate lines on Figure 64) due to the presence of clayey lake sediments (varves). The slumping has produced a number of exposures of the ice-contact stratified drift, till, and varved deposits that fill the valley.

Site B is one of the larger and more readily accessable exposures of the glacial deposits. The outcrop shows 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 65 and 66). The till is exposed at the south end, where a slight undercut has exposed several large (3 ft x 0.5 ft) blocks of tan, very fine-grained, sandy silt that probably represent blocks of older lake bed sediments ripped up by a 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

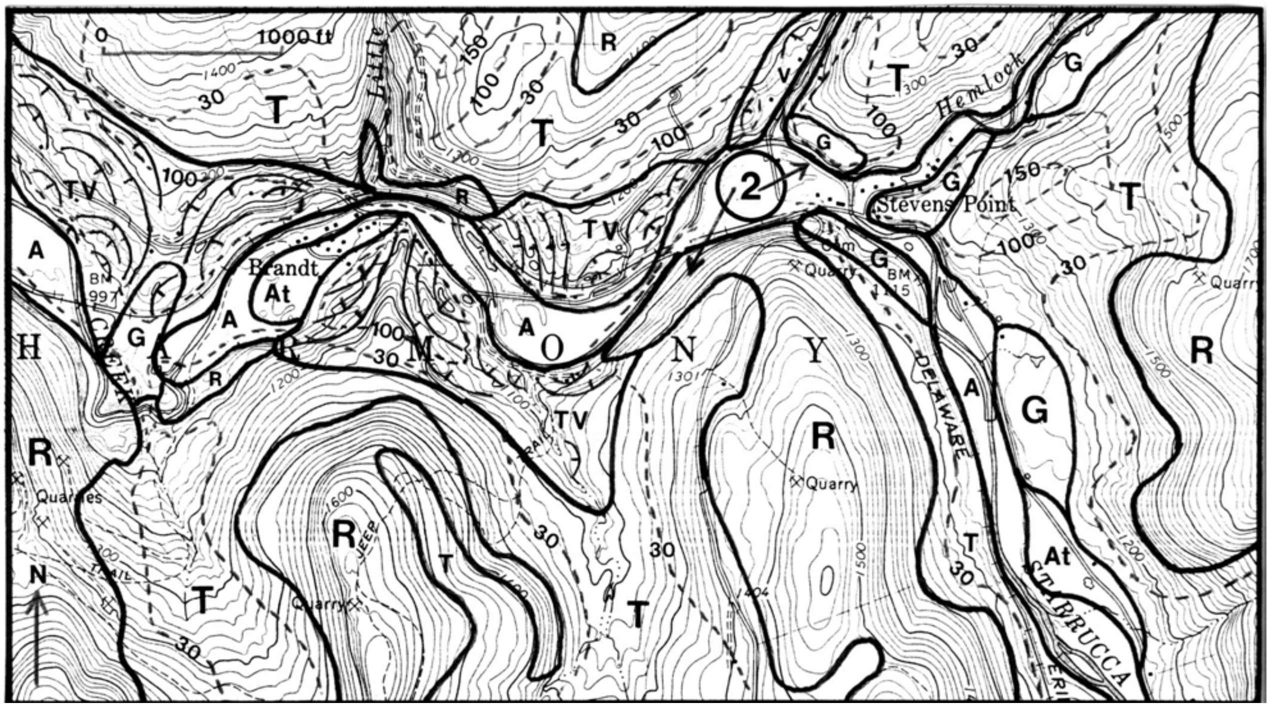


Figure 64. Map of glacial deposits in the Stevens Point-Brandt area (Braun, 2001d). Arrows directed outward from circled "2" point to Sites A (left) and B (right). A = alluvium, At = alluvial terrace, G = ice contact stratified drift, R = bedrock, T = till, TV = till over varved sediments. Isochores of surficial deposits at 30, 100, and 150 feet. Hachured arcuate lines are slump headwalls.

cobbles indicate that it was deposited by flow from the north. All of this 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 67) 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 0.25 to 2 inches thick, while the clayey bands are 0.25 to 0.5 inches 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 either late glacial or early postglacial time.

The right, or east, side of the outcrop has been down-dropped to the south along two steeply inclined faults (Figures 65 and 66). The most obvious explanation of the faults is collapse from the melting of underlying dead ice (Inners). Melting of the ice deprived the deposit of support, and the layers slipped past each other until a stable configuration was achieved. On close examination, it can be seen that the fault on the left is "overturned" and dips north—thus having a reverse-fault orientation. As in the kame in Figure 97 (STOP 6), the fault evidently started as a south-dipping normal fault on initial melting of the ice, but was then overturned as melting and slumping progressed. (The upper gravels would, therefore, be late glacial in age.) Alternatively, since the faulting cuts the postglacial gravel, it may have been caused by slumping of the eastern part of the outcrop into the valley of Hemlock Creek, which enters the main valley at the east end of the outcrop (Braun). In this case, the upper gravels could be clearly postglacial.

The Stevens Point 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 downstream from here (Figure 64). The lower lake sediments are under the till that is exposed at Stevens Point and below

Figure 65. Faulted ice-contact stratified drift (kame terrace) at Site B. Sub-lacustrine fan gravels are overlain by sandy lake sediments that are in turn capped by fluvial gravel. Note that the fault on the left dips north. Both faults cut through all the units.

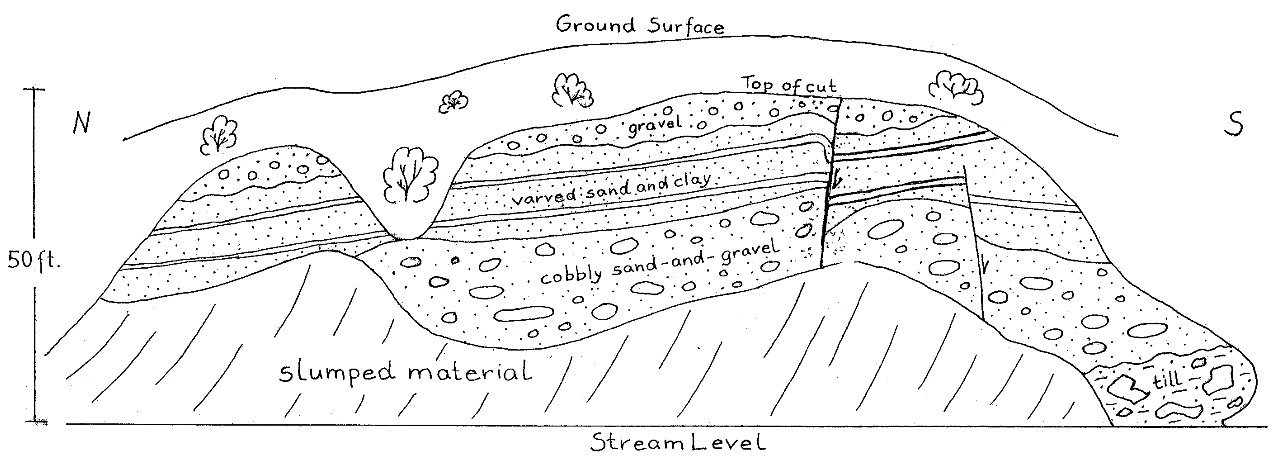


Figure 66. Starrucca Creek cut-bank exposure at Stevens Point (Site B), showing till overlain by cobbly sand and gravel that is in turn overlain by lake sands with clay drapes (ice-proximal varves) that are capped by fluvial gravels. (Sketch by Mott and Inners)

present stream level there. The lower lake sediments are true silt-clay couplet varves once used in making bricks at the village of Brandt downstream from here (Figure 64; see Young, this guidebook, p. 49 - 50). An exposure on the south bank of Starrucca Creek (mile 52.1), mid-way between here and Brandt, shows at least 100 varve couplets and maybe as many as 300 couplets. Throughout the 25-mile-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.

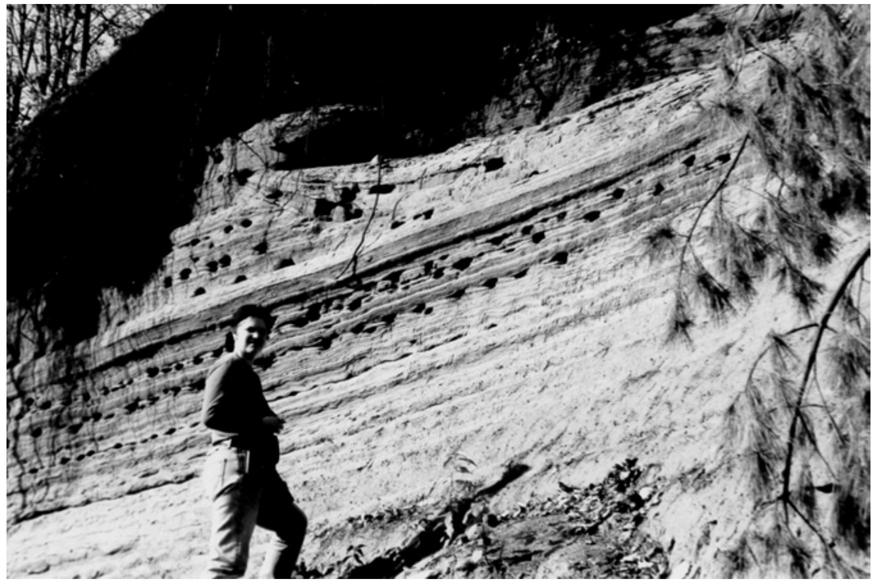


Figure 67. Close-up photograph of the upper lake sediments here expressed as rippled sand strata with clay drapes. Swallow holes mark fine-sand beds.

		Leave STOP 2, continuing ahead on SR 1009.
0.2	51.7	Cross Starrucca Creek. To right are the stone abutments of a bridge on the former Jefferson Branch of the Erie/D&H Railroad. To left are ledges of well-jointed Lock Haven sandstone, presumably just below—or above—the contacts!
0.1	51.8	To right is a shallow cut in late Wisconsinan till and gravel. For the next three miles the slopes above the road are a series of slump benches or steps developed in the varved sediments of Glacial Lake Great Bend. Some of the slumps have sag ponds at their heads.
0.3	52.1	Cross Starrucca Creek. To left on the south side of the creek is a high, intricately slumped cut in varved sediment overlain by till .
0.1	52.2	To left immediately after the bridge 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.
0.2	52.4	To left is the Village of Brandt (formerly Harmony Center), a thriving community with numerous industries in the 19th century. It was named for Henry Brandt (1808-1886), notable local entrepreneur —and not for Joseph Brant (1743-1807), the great Mohawk war "captain" of the American Revolution, as stated in Donehoo (1928). The village cemetery is on a knob of sand and gravel (ice-contact stratified drift).
0.1	52.5	Cross Starrucca Creek and then D&H Rail Trail.
0.4	52.9	To both sides of the road are sag ponds on the tops of slump benches. Humans have raised the level of the ponds with small dams and increased the likelihood of future movement.
1.4	54.3	Cross Starrucca Creek and the D&H Rail Trail to enter the borough of Lanesboro. Lanesboro (Lanesville until 1829) is named for Martin Lane who settled there on the

		old homestead of Thomas Pickering (see Young, this guidebook, p. 49 - 50) in 1818 (Blackman, 1873).
0.4	54.7	Historical Marker to right 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.*
0.1	54.8	Pass under Starrucca Viaduct.
0.1	54.9	Stop sign. Turn right onto SR 1015 and cross Starrucca Creek.
0.1	55.0	Turn right onto Depot Street, following signs for Luciana Park. Proceed into parking area directly ahead after passing under Starrucca Viaduct. (The abandoned railroad grade under the viaduct is the Lackawanna and Susquehanna Railroad—now the D&H Rail-Trail.) Disembark in parking lot at Luciana Park.

STOP 3 AND LUNCH. Starrucca Viaduct.

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

Figure 68. The Starrucca Viaduct at Lanesboro, Susquehanna County, looking northwest from "The Hole," a large "bluestone" quarry (elev. 1450 feet A.T.) on Taylor Hill.

Completed in 1848, the stone-arch Starrucca Viaduct (Figure 68) is the oldest of the three historic viaducts of Pennsylvania, the others being the wrought-iron Kinzua (1882, rebuilt of steel in 1900), and the concrete-arch Tunkhannock (1915) (STOP 6) (Mott et al., 1998). Only the Starrucca and Tunkhannock structures still carry trains, the Kinzua having been closed for structural weaknesses just this past June. Originally built by the New York and Erie (later simply the Erie) Railroad, the bridge eventually fell under the ownership of Conrail in the 1970's and is presently owned by the Norfolk Southern Railroad. Although the Kinzua Viaduct has been abandoned and the Tunkhannock is suffering steady deterioration of its concrete, the Starrucca Viaduct stands as beautiful and potentially useful as when it was built more than 150 years ago.

Site Geology. The Starrucca Viaduct is located on the glaciated Allegheny Plateau at the confluence of Starrucca Creek and the North Branch Susquehanna River in the borough of Lanesboro (Figure 69). Elevation of the valley floor at the viaduct site is about 900 feet, with rounded hills on all sides standing more than 800 higher. Bedrock outcropping on the higher slopes and summits of the adjacent hills consists of interbedded deltaic sandstones and silty shales of the Catskill Formation, while fossiliferous, marine sandstones and shales of the subjacent Lock Haven Formation underlie the lower hillslopes and valley bottoms. Bedding is subhorizontal in these Late Devonian rocks, this part of Susquehanna County lying north and east of the region affected by Alleghanian folding (Faill, unpublished map).

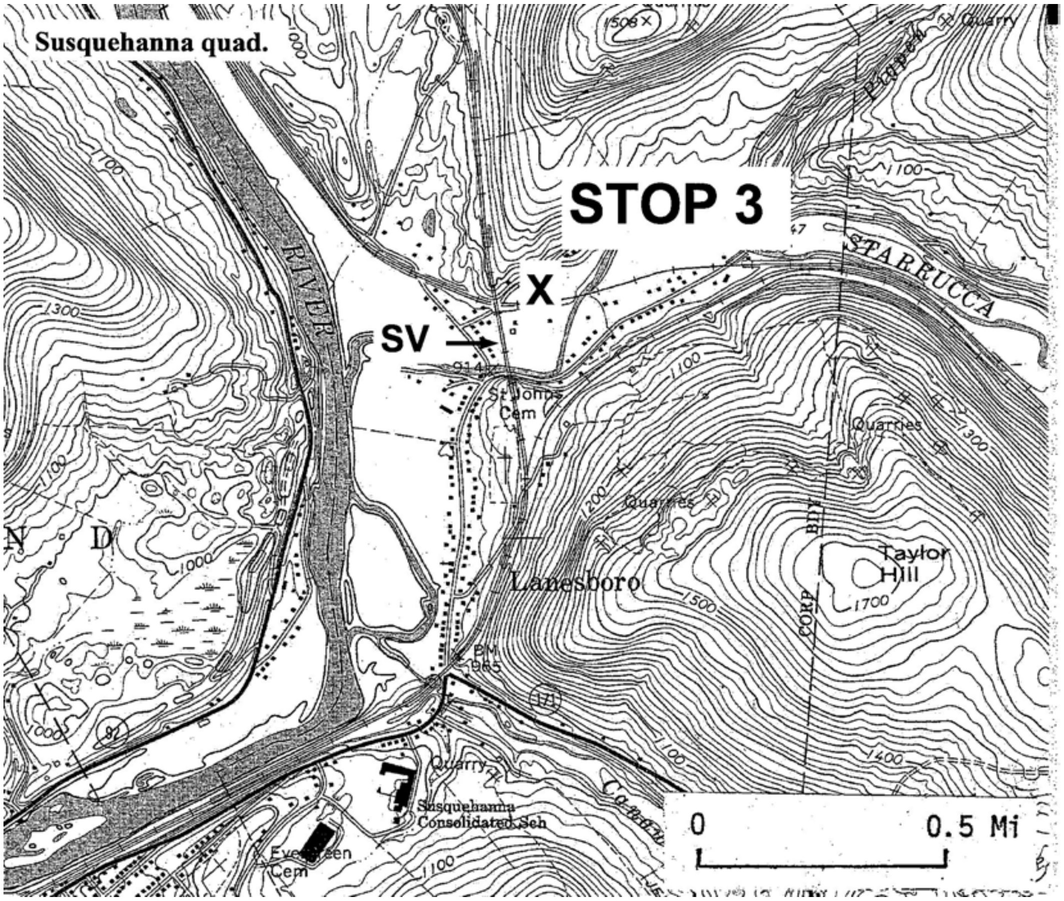


Figure 69. Location map for STOP 3. SV = Starrucca Viaduct.

Glacial deposits in the area are entirely of Late Wisconsinan age and consist of silty clay till on the uplands and complexly interstratified till, outwash and ice-contact gravel, and lacustrine sediments in the North Branch and Starrucca Creek valleys (Braun, 2001d; Braun, this guidebook, p. 32 - 38). Particularly good exposures of these mixed deposits up the Starrucca can be seen in the faulted kame terrace at Stevens Point (STOP 2) and in the deeply eroded stream bank just upstream of Brandt (Day-1 Roadlog, mile 52.1). In the North Branch valley, a once continuous esker can clearly be traced through gravel pits north of Lanesboro to just west of Oakland (STOP 5). Thickness of glacial (and postglacial fluvial) deposits beneath the viaduct is at least 9 feet (the maximum depth of the pier foundations) and may be considerably more.

The stone of the Viaduct. Ralph Stone (1932) in his classic *Building stones of Pennsylvania*, provides as good a description of the Starrucca Viaduct as anyone:

> The high arch stone viaduct of the Erie Railroad at Lanesboro is built of [Catskill] bluestone which has weathered to greenish gray and rusty color. The stone was quarried at Stevens Point [STOP 2A] and dressed to joint-face and rock-face …[coursed] ashlar [Figure 70]. The blocks are all sizes up to 6 feet by 10 inches, 3 feet by 20 inches, and some may be up to 24 inches thick. They are sound and it looks as if it would stand for centuries.

Note that the drill marks on the sandstone blocks are identical to those seen on the quarry wall at Stevens Point. A few blocks have numbers carved in them that date from the time of quarrying (for example, a block in the second pier from the south along SR 1009 contains a weathered, upside-down "3"). Such numbers may have indicated the workman or work crew responsible for quarrying certain individual blocks or "skids" of stone.

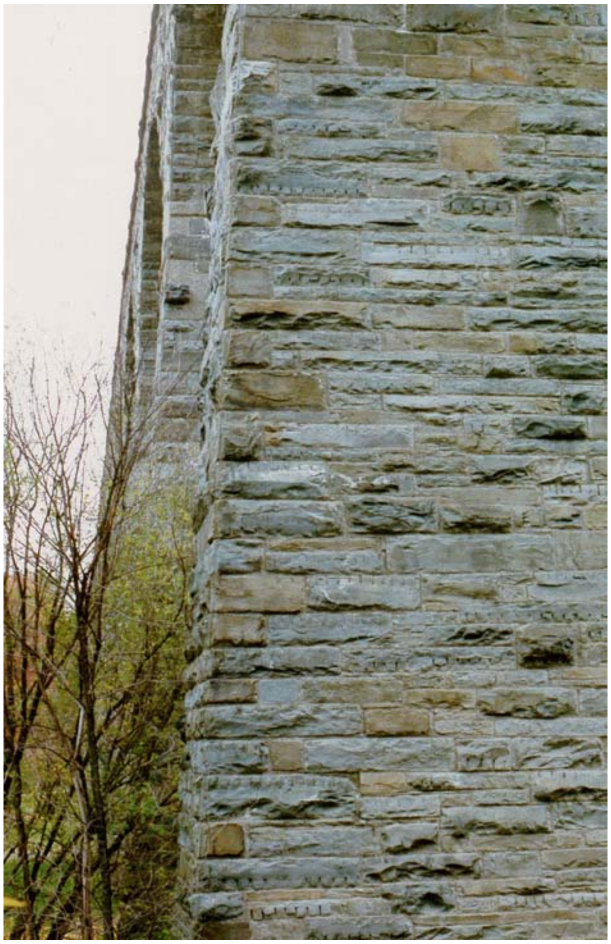


Figure 70. Coursed-ashlar stonework on one of the piers of the Starrucca Viaduct. All of the stone is gray sandstone from local quarries in the Catskill Formation. The smooth blocks are “joint face” and the rough blocks are “rock face.” Note the star-drill marks in the latter (see STOP 2, Figure 62).

History and engineering. The New York and Erie Railroad was designed to connect New York with the Great Lakes Region. Although ground was broken for the railroad in 1835, it was not until 1846 that construction really got under way. The final route passed up the Delaware River from Port Jervis to Deposit, NY, cut across the Delaware-Susquehanna divide at Gulf Summit, and then followed the North Branch Susquehanna River down into Pennsylvania—through Lanesboro (Figure 71), Susquehanna Depot (now Susquehanna) and Great Bend—and back into New York. Plans to run the railroad directly through the newly opened Northern Anthracite field at Carbondale and Slocum Hollow (now Scranton) were stymied by the Delaware and Hudson Canal interests, who wanted to maintain their short-lived monopoly on coal transportation (Young, 1995).

The viaduct was designed by Julius Adams (1812-1865), a New Englander, and built mainly under the supervision of James Kirkwood (1807-1877), a New Yorker (who had been born in Scotland) and brother-in-law of Adams. It was constructed over a two-year period (1847-48) and was the most ambitious and expensive railroad bridge built up to that time (Figures 72 and 73). Stone was obtained from quarries two miles north of Lanesboro (1847 and late 1848) and at Stevens Point (STOP 2) in the Starrucca Creek valley. Rosendale cement (from limestone quarries in Ulster County, NY) was used for concrete in the pier footings and for mortar in the viaduct. (This use of concrete footings is one of the earliest uses of structural concrete known). Brick for supporting arches within

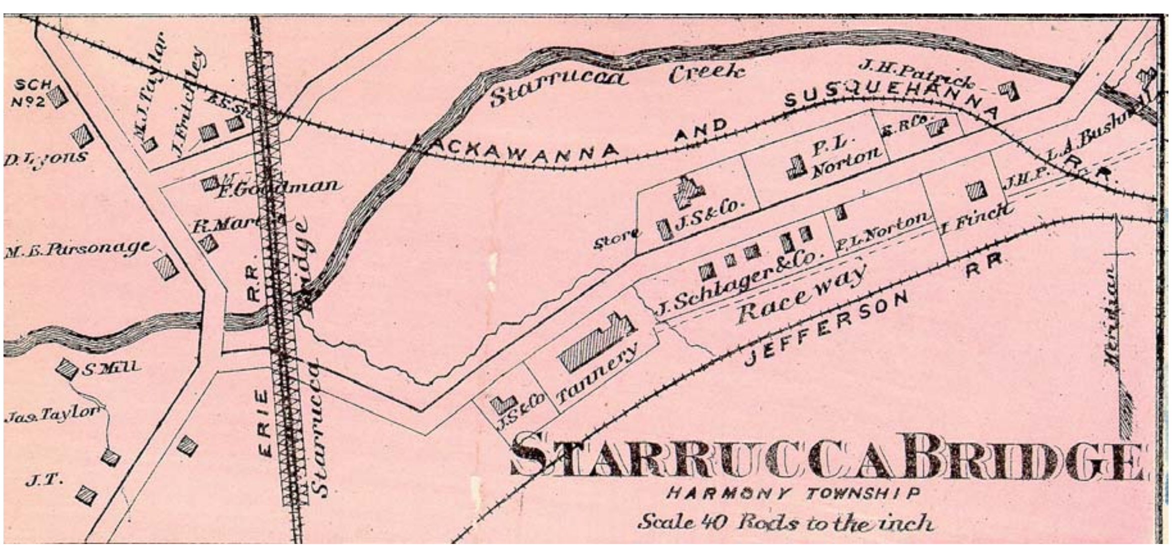


Figure 71. Detail of the area around the Starrucca Viaduct at Lanesboro as shown on the Beers Map of 1872.

Figure 72. *Starrucca Viaduct, Pennsylvania*, by Jasper Francis Cropsey (1823-1900). Oil on canvas (1865). The view depicted on this Hudson River School painting is looking northeast from behind the borough of Susquehanna Depot. The bridge over Canawacta Creek to the right was actually a wooden covered bridge. (W. S. Young, 2002, personal communication.) (Postcard used with the permission of the Toledo Museum of Art.)

Figure 73. Early 20th-century view of the Viaduct, looking east. The tracks in the foreground are those of the Lackawanna and Susquehanna Railroad, now the D&H Rail-Trail. (Postcard issued by Susquehanna County Library)

the hollow spandrels was made on site from clay found nearby—probably at Brandt where a thick deposit of lacustrine clay was utilized for brick making about 30 years later (Young, 1995). Wrought-iron T-rails for the broad-gage railroad were manufactured at the new Lackawanna iron works 40 miles to the south, the first large order for T-rail in the country and a contract which marked the industrial birth of the city of Scranton (Perry, 1994).

The foundations of the viaduct were dug only 6 to 9 feet deep, where Adams encountered "a course hard gravel, pervious to water" (Young, 1995)—apparently a cobbly outwash gravel. The shallow foundations of the piers were a cause of concern in later years, but Adam's rather daring decision has stood the test of time.

ENGINEERING STATISTICS
OF THE STARRUCCA VIADUCT
(Young, 1995; Historic American Engineering Record)

Construction material - dimension stone (sandstone)
Elevation of railroad grade - ~1000 feet*
Length - 1040 feet
Height - 100 feet
Width of deck - 26 feet

Number of arches - 17
Depth of pier footings - 6 to 9 feet
Pier centers - 58 feet
Height of piers -65.67 feet
Arch radia - 25.5 feet
Work force - ~800 men
*North abutment 12 feet higher than south abutment.

		Leave STOP 3, returning to SR 1015 and turning left.
0.1	55.1	Continue around to right at stop sign after crossing Starrucca Creek. You are back on SR 1009.
0.6	55.7	Intersection with PA 171 at high, concrete Canawacta Bridge. Continue straight on PA 171 North.
0.4	56.1	To left is a cut exposing interbedded gray shale and sandstone of the Lock Haven Formation.
0.1	56.2	At the top of the hill is a view to the right across North Branch Susquehanna River to a 50-foot high cut in an abandoned gravel pit in the spectacular Lanesboro-Oakland esker (see Fairchild, 1925). The esker extends intermittently for seven miles along the river (see STOP 5).
0.1	56.3	Enter borough of Susquehanna, incorporated as Susquehanna Depot in 1853.
0.5	56.8	Traffic light. Continue straight ahead following PA 171 North/PA 92 South. The shopping center and parking lot to right 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 (Figure 74). A commemorative wall, a high water tank, and one large

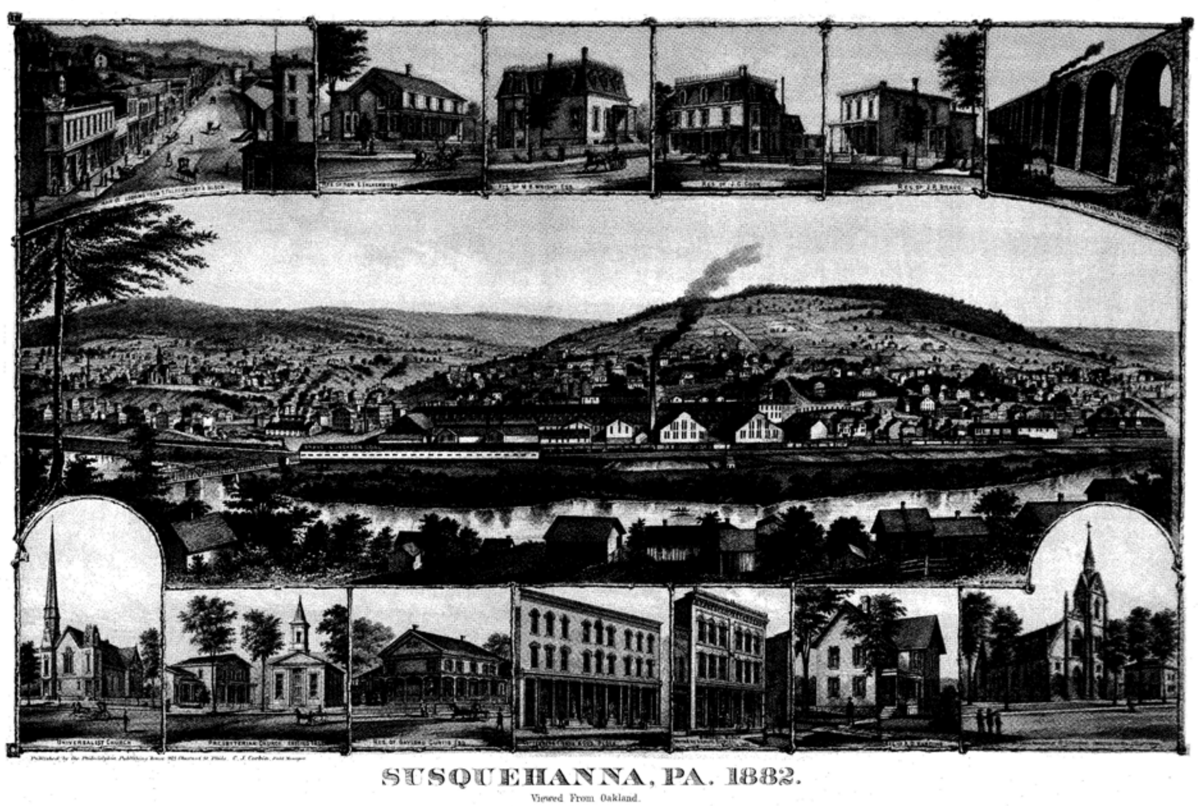


Figure 74. Views of old Susquehanna, c. 1882. Note particularly the great Erie Railroad shops along the river in the center picture. The truss bridge at the extreme left (or a newer one at the same spot) was in use until 1995.

brick building are about all that remain. With the demise of the Erie and its successor Erie-Lackawanna in the third quarter of the 20th 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.

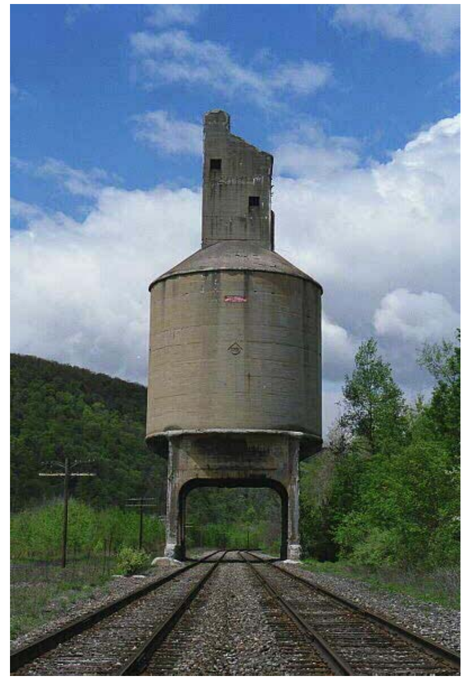


Figure 75. Erie-Railroad coal-loading facility on the north side of the North Branch Susquehanna River. This "tower" was designed and built by the Roberts & Schaefer Co. of Chicago. Installation of the inside machinery was superintended by Mr. Ira Reynolds of Susquehanna, who early this year celebrated his 100th birthday.

0.2 57.0 Traffic light at south end of bridge across North Branch Susquehanna River. Continue straight ahead on SR 1021. PA 171/PA 92 turns right to cross the new bridge.

0.6 57.6 The high concrete structure in the distance ahead to right is an abandoned coal-loading facility on the old Erie Railroad (Figure 75). For much of the first half of the 20th century, anthracite to power steam locomotives was dumped from here into the tenders of the Erie trains. After the steam era had passed, a large oil tank was installed to service the new diesel locomotives (William S. Young, 2002, personnel communication).

0.1 57.7 Enter Oakland Township.

0.3 58.0 To left at bend in road is a cut in uppermost Lock Haven sandstone and shale. To right below road level on Lewis Creek is a hemlock-lined, postglacial bedrock gorge cut into Lock Haven strata, with the old valley (buried by till) just to the west. At the head of the gorge is a beautiful waterfall over a single overhanging bed of sandstone (Figure 76).

1.2 59.2 Turn left at main office and entrance to Endless Mountain Stone Company's Susquehanna operation. At this point, Conference participants will be divided into two groups. Based on this division, the individual buses will proceed up hill to either A.) the main quarry, or B.) the processing shops. Groups will switch positions after about 45 minutes.

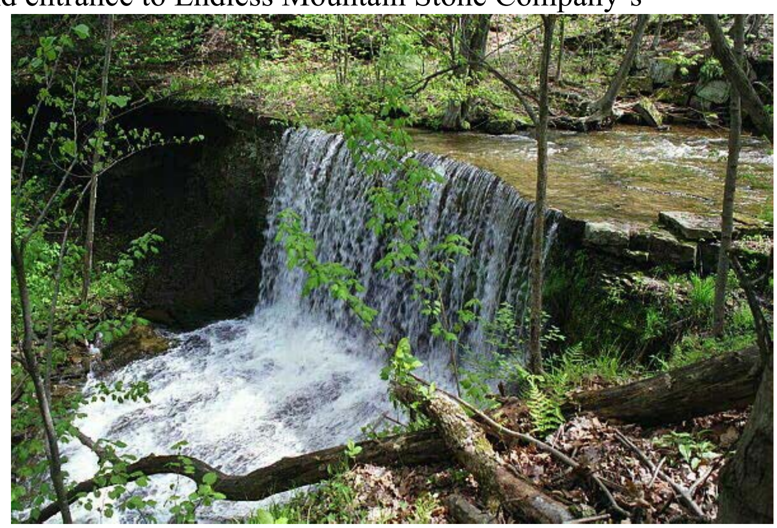


Figure 76. The falls on Lewis Creek near mile 58.0. The falls is about 15 feet high. Below the 1-foot-thick sandstone caprock is a thick bed of shale that has been scoured out to create a beautiful overhang—with a vegetated alcove directly behind the falls.

STOP 4. COLEMAN QUARRY AND PROCESSING SHOPS OF ENDLESS MOUNTAIN STONE COMPANY.

Leaders: Jon D. Inners and William N. MacDonald.

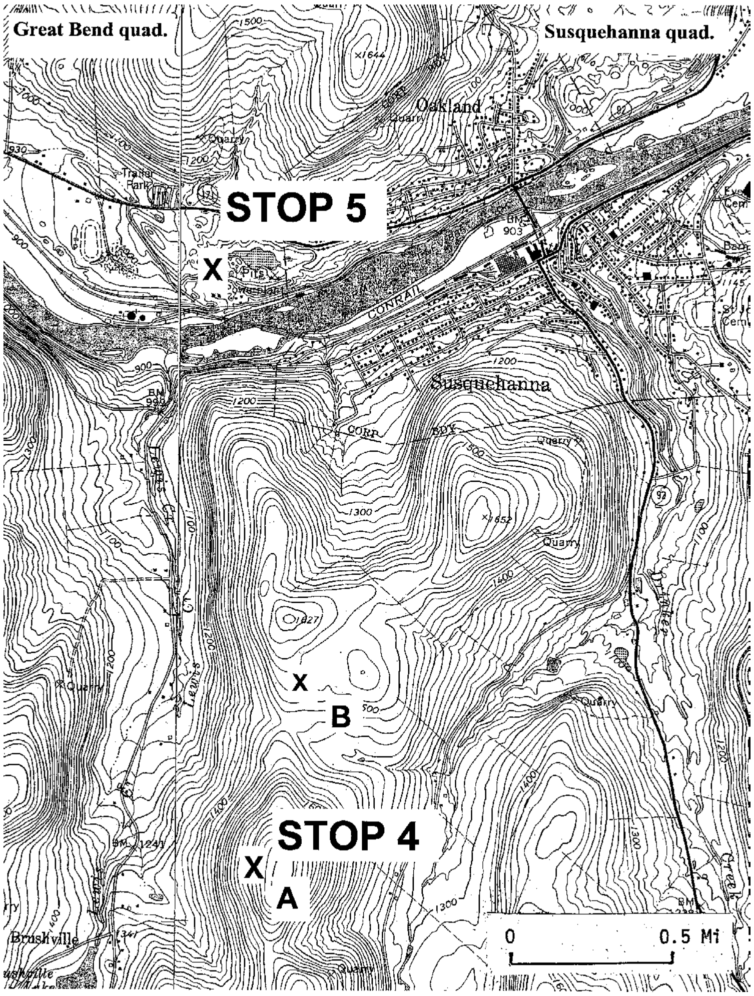


Figure 77. Location map for STOPS 4 and 5.

The Coleman quarry (A) and processing shops (B) of the Endless Mountain Stone Company are located high on the ridge between north-flowing Lewis (west) and Drinker (east) Creeks about a mile south-southwest of the borough of Susquehanna (Figure 77). Endless Mountain Stone Company is the largest "bluestone" producer in northeastern Pennsylvania and has been in operation for a quarter of a century. The company has fourteen quarry sites in northeastern Pennsylvania only five of which are presently active. Eight of these quarry sites are within a five-mile radius of the Coleman pit. The farthest is the Winterdale quarry near Shehawken in Wayne County. At current rates of production, it is projected that these quarries contain a supply of stone that will last 50 years. Bluestone products are shipped all over the United States, with about 1400-1600 tractor-trailer loads being sent out each year. Each truck carries 12-16 pallets at 1000-4500 lbs/pallet, massive dimension stone being the heaviest. Endless Mountain's largest customers include landscape and architectural firms, museums, and universities. All of the "bluestone" used at Princeton University comes from their quarries. It is used both inside and outside of buildings, for paving, and for chimney caps (Figure 78).

Site A—Coleman quarry. The Coleman quarry is situated on the west side of the ridge east of Lewis Creek at an elevation of about 1650 feet (41°55'12"N/75°37'16"W) (see Figure 77). This quarry is the largest and topographically highest of two active pits in this area. The other ("lower" quarry) is located about 400 feet down the hill to the west at an elevation of about 1500 feet.

Geology. Both the Coleman and the "lower" quarries are working stone in the medial part of the Catskill Formation (informal Lanesboro Member of Inners, 2002). A somewhat generalized measured section in the southern part of the quarry is shown in Figure 79. Approximately 90 feet of rock is exposed here, consisting of a complete fining-upward alluvial cycle (40 feet thick) in the lower


Figure 78. Bluestone chimney-caps made for Princeton University by Endless Mountain Stone Co.

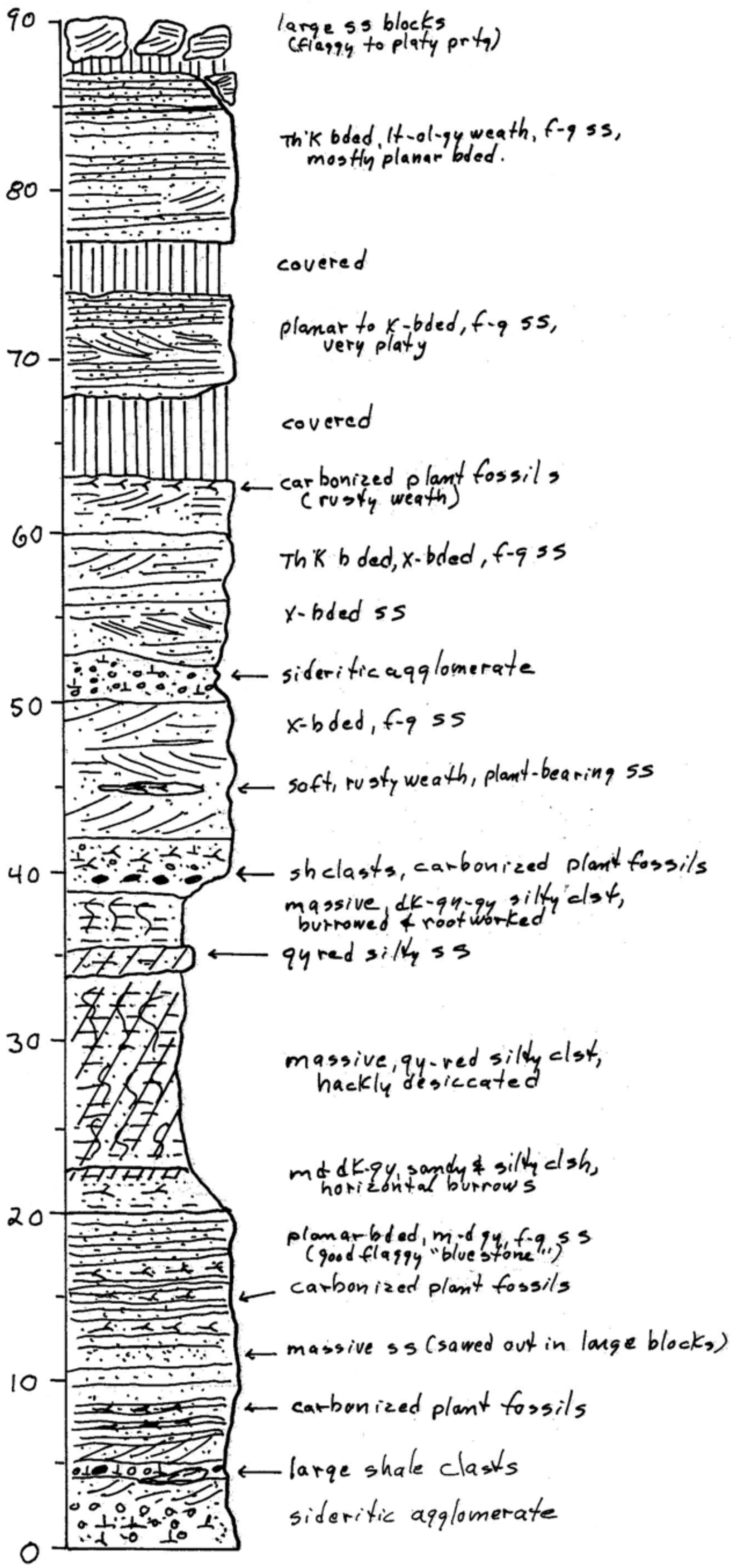


Figure 79. Generalized measured section of rocks exposed in the Coleman quarry (Site A). Scale is in feet.

part and a 50-foot-thick sandstone sequence in the upper part (Figure 80). The main quarried stone in the southern pit is a 10-foot-thick sandstone sequence between 10 and 20 feet of the measured section. The upper part of this sequence is good flaggy "bluestone," while the lower 3 feet is massive and is sawed out in large blocks. This lower sandstone sequence also yields stone suitable for both pattern and dimension stone in the northern part of the quarry. The 50-foot-thick upper sandstone (above 39 feet in the measured section) is typically crossbedded and contains inferior quality stone.

The best "flagstone" in the pit exhibits excellent parting-step lineation, a characteristic feature of planar sand beds formed by water currents undergoing upper-flow-regime flow (Allen, 1970). In the Coleman quarry, the flagstone beds presumably represent alluvial braid bars and belong to the type 3 deposits of Krajewski (1971) and Krajewski and Williams (1971). (See the latter for a detailed, but succinct, discussion of the flagstones of Susquehanna County.)

Though generally "anathema" to the quarry operator, sedimentary features of great interest to geologists are common in the section at Site A (see Figure 79). These include—besides parting step-lineation—crossbedding, sideritic agglomerate (Figure 81), large shale clasts, carbonized plant remains, vermiform horizontal burrows, and rootworked and desiccated claystone.

Figure 80. View of Coleman quarry (Site A), showing an alluvial fining-upward cycle overlain by the thick sandstone sequence at the base of the next cycle (Lanesboro Member of Catskill Formation).

Bedding in the Coleman quarry appears to dip very gently to the south. (Though clinometer readings of such low dips are highly questionable, a "best" reading of N85°W/2°SW was obtained here and an "average" reading of N80°E/2°SE in the "lower" quarry.) Joints in the Coleman quarry belong to the same two sets noted at STOPS 1 and 2: N10°E/90° and N83°W/90° (Figure 82). These fractures are generally spaced 3 to 10 feet apart and assist greatly in the quarrying out of large blocks of dimension stone for later cutting in the preparation shops (Site B).

Several interesting types of mineralization can be observed in the quarry. The "north-south" joint set is locally quartz mineralized. A few calcite-filled fractures also occur throughout the pit, and some planar joint surfaces have a thin coating of gypsum. Smooth bedding planes with pyrolusite dendrites are highly prized and are marketed as "fernstone."

State-mandated mine-safety requirements dictate that bluestone quarries be benched every 25-30 feet, with benches no less than 10 feet wide. There can be no overhangs on the highwalls. At the top of each bench, a berm must be constructed that is at least as high as the mid-axle of the largest mobile vehicle used. This berm can be constructed of boulders, trees, dirt, or guardrails.

Figure 81. Sawed face showing sideritic agglomerate near base of lower sandstone of measured section at Site A.

Site B—Processing Shops. The shops are located about 0.5 mile north-northeast of the Coleman quarry at an elevation of 1530 feet (41°55'40"N/75°37'04"W) (see Figure 77; Figure 83). The three buildings are mainly set aside for: 1) production of treads (i.e., stair steps, caps, and similar architectural stone); 2) production of pattern flagging and rock-face treads; and 3) specialty processing, i.e., thermaling, polishing, and specialty cutting.

Three types of products are prepared either in the quarry or in the processing shops, namely: irregular flagging, pattern flagging, and dimension stone.

Irregular flagging is prepared by the oldest method of quarrying stone. Tools used are hammers, wedges, wrecking bars, chisels, and skid steers. Most irregular flagging is "stand-up"—thin, rough, naturally weathered flagstone that requires minimal manual splitting (Figure 84). Much of this is used for "paving" construction sites; it is broken up when the job is done and worked into the ground surface. "Stand-up" is also used for erosion abatement. A second, better variety, of irregular flagging is "colonial," which constitutes much of the standard flagstone used in home-improvement projects (Figure 84).

Pattern flagging is the largest type of work being conducted in the bluestone industry today. Stone is processed in three colors, namely "full color" (rust and green), blue, and lilac (reddish). Tools used in preparation of pattern flagging are concrete, or block, saws, used in on-site cutting (Figure 85); re-cut saws, used in secondary cutting—often inside; and powered chipping-hammers or chisels and hammers, used to split the stone. On-site production of pattern stone is contracted out. Large cut blocks are sent to the pattern-processing shed for more precise work.

Dimension stone was an important item of bluestone production in the 19th and early 20th centuries and has had a marked revival in the last 15 years. Three methods are used for taking out large blocks: "plug and feathering," i.e., drilling holes at a regular spacing and splitting out the blocks along the line of drill holes (much as was done in the case of quarrying stone for the Starrucca Viaduct) (see STOPS 2 and 3); diamond wire saw; and belt (large "chain") saw. In the shops, dimension stone can be cut in circles and curves (see Figure 78) using a water-jet cutting process. The company can guarantee an accuracy of cuts to within 1/8 inch on dimensional patterns, treads, and cuts performed by saws.

The various buildings contain two automated thermaling lines, which burn a textured surface back onto the sawn face of the stone. This process is used mostly to produce treads, which vary from 1-6 inches thick by 6-24 inches wide by 24-120 inches in length.

The company currently has eight bridge (circular) saws. Seven can be programmed to run on automation, giving 24-hour production. Bridge saws vary in size with largest having a blade diameter of 11½ feet (Figure 86). This saw produces slabs that vary from ½ to 24 inches thick by 24-60 inches wide by 48-120 inches long.

Figure 82. Joints in lower part of lower sandstone sequence in northern part of Coleman quarry. The prominent, smooth fractures are the "north-south" set.

Figure 83. Processing shops of Endless Mountain Stone Co. (Site B).

Figure 84. On the left are skids of "stand-up" produced from naturally "flaggy" stone at the Coleman quarry. On the right is a skid of "colonial."

Figure 85. On-site cutting of sandstone blocks for production of “pattern flagging” at the “lower” quarry.

Scrap material from pattern, tread, and slab production is put through a tumbling process to round out the edges of the stone to give it a water-worn appearance. This creates a tumble product line and also leaves very little waste of quarried stone. The newest innovation is an automated polishing line. This gives the company the ability to provide mirror-finished bluestone material, such as countertops and tabletops.

Endless Mountain Stone’s operation is quite self-sufficient. Electricity for the processing shops is produced from the company’s own generators. To help with shipping, the company has added a pallet manufacturing line that assembles more than 12,000 pallets/year. Bundled firewood for home heating or campfires is made from the pallet scrap. During the winter, the processing sheds are heated by two big wood-burning stoves that burn scrap firewood. AND the sawdust is used by local farmers! Water is obtained mainly from several nearby mountain springs. The one drilled well on the property goes dry before the springs do.

		Leave STOP 4, returning to main office and proceeding right (north) on SR 1021 to intersection with PA 171/PA 92 in Susquehanna.
2.2	61.4	Traffic light. Turn left onto PA 171/PA 92 and the Susquehanna County Veterans Memorial Bridge (1995).
0.1	61.5	Bridge crosses old Erie Railroad tracks (now Norfolk Southern). To right is the site of the former Erie yards and shops and to left the former Erie Passenger Station, now a restaurant.
0.1	61.6	Cross North Branch Susquehanna River. Downstream to left is a low-head hydroelectric dam that impounds the river at this point. The river here is flowing westward at the apex of the Great Bend in the river (see Day-1 Roadlog map). Where we cross the river again at the town of Great Bend (mile 70.1) the river is turning northward to return to New York State in the Binghamton area.

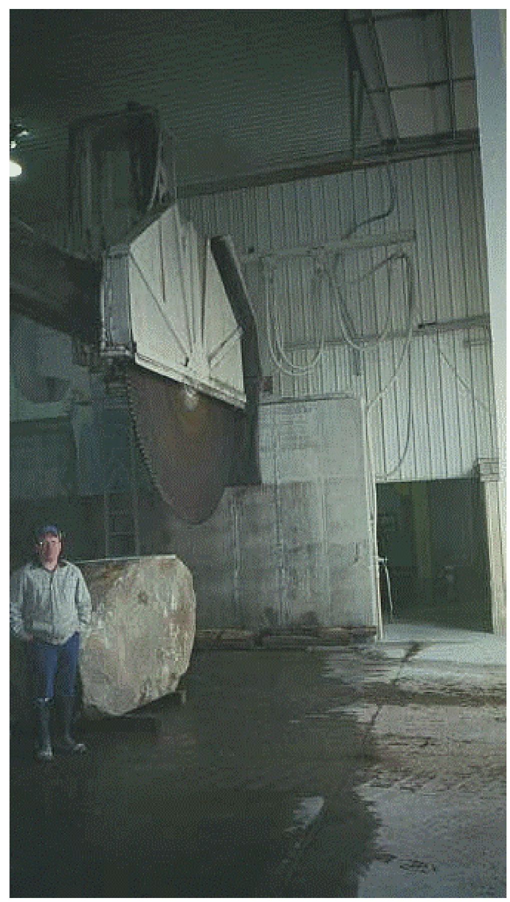


Figure 86. 11½-foot-diameter bridge saw used in cutting very large dimension-stone blocks.

0.1	61.7	Stop sign. Turn left, staying on PA 171 North.
0.9	62.6	Turn left onto access road to Red Oak pit of Masters Ready Mixed Concrete Co. Proceed back to pit. Disembark.

STOP 5. THE RED OAK SAND-AND-GRAVEL PIT AND THE LANESBORO-OAKLAND ESKER.

Leaders: Jonathan W. Harrington, Jon D. Inners, and Duane D. Braun.

Figure 87. The Red Oak sand-and-gravel pit of Masters Ready Mixed Concrete Co. (STOP 5). The mound-like cross section of the Lanesboro-Oakland esker shows clearly in this view to the west down the long axis of the deposit.

The Red Oak pit is located in Late Wisconsinan ice-contact stratified drift deposits on the north side of the North Branch Susquehanna River in Oakland Township, about 0.4 mile west of the borough of Oakland, Susquehanna County (41^{o}56'45"N/75^{o}37'24"W; see Figure 77). The mining of sand and gravel at this location has a long and varied history. During the 1920's, excavation was conducted by Madison Sand & Gravel Corporation of Hamilton, NY. This was a relatively small-scale excavation, removing material from the toe of the slope and trucking the product offsite via River Road, a narrow, dead-end secondary road. The operation ceased during the Depression.

In 1946, Richard Masters acquired the land and adjacent mineral rights. Mr. Masters is the owner of Masters Ready Mixed Concrete Co. of Kingsley, PA. At that time, the site was not reopened due partially to significant development constraints. The resource was held in reserve until the early 1990's when the economics of permitting and development were re-evaluated, and the permit process was initiated.

Figure 88. Segment of the Lanesboro-Oakland esker looking southwest, with the North Branch Susquehanna River valley to the left (Fairchild, 1925, Plate 33, Fig. 1). This is apparently the part of the esker just northeast of Oakland.

Geology. The deposit has long been recognized as part of the Lanesboro-Oakland esker, one of the largest such deposits in the region (Figure 87; Coates, 1981). The esker was first described by White in 1881 and named the Lanesboro esker by Fairchild in 1925 (Figure 88). White recognized that the feature was a type of glacial kame deposit. He noted that it was opposite the town of Susquehanna on the north side of the river and described it as long, sharp ridges 40 to 50 feet high "running generally parallel to the river" (Figure 88). Fairchild correctly identified the feature as an esker and named it after the town of Lanesboro that lies across the river to the

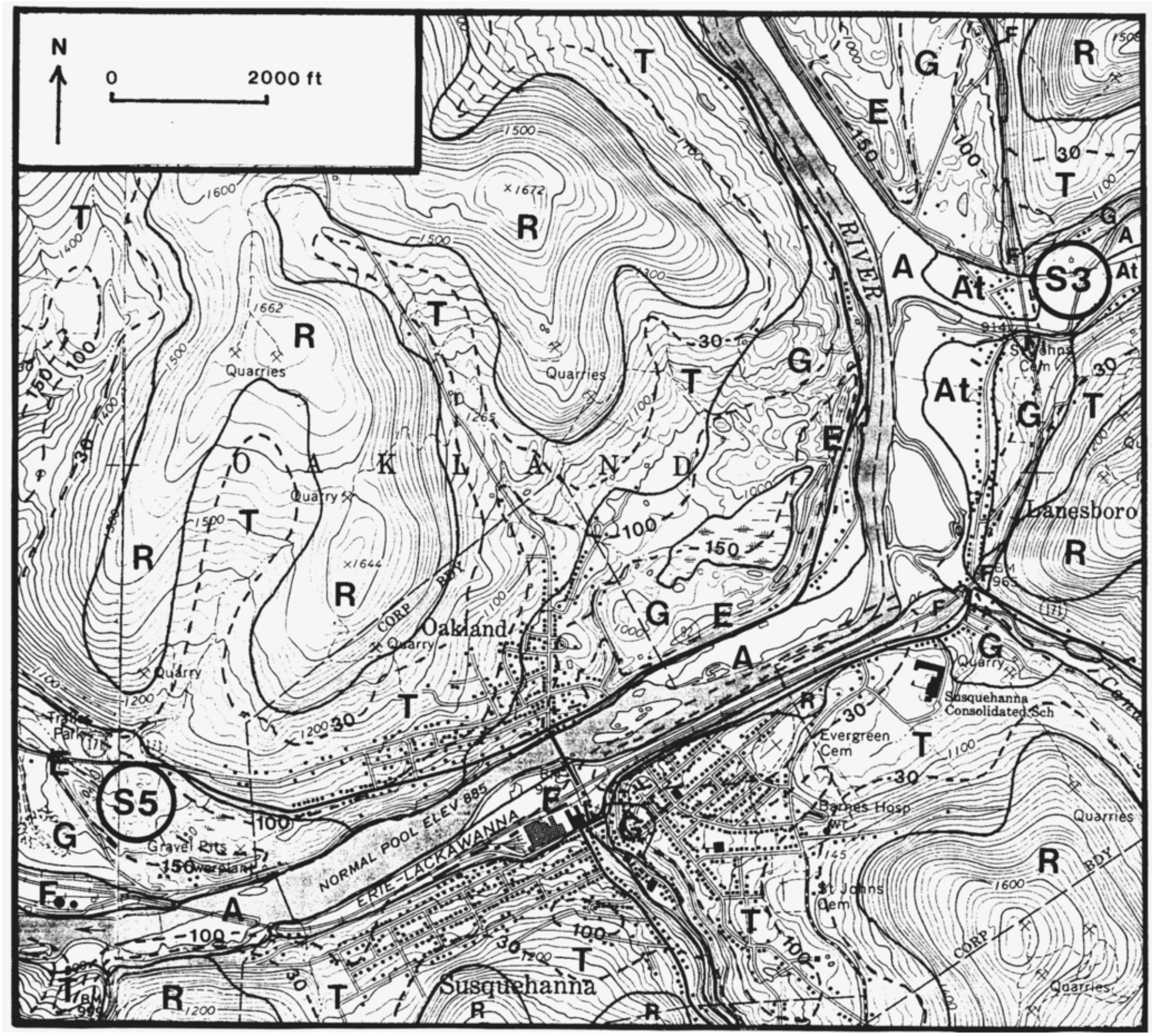


Figure 89. Map of surficial deposits in the area of the Lanesboro-Oakland esker, showing the three segments of the esker (E) and the other extensive and thick sand-and-gravel deposits (G) in the North Branch Susquehanna valley. A = alluvium, At = alluvial terrace, F = fill, GL = gravel underlain by varved sediments, R = rock, T = till, TL = till underlain by varves, W = wetland. Isochores of surficial deposits at 30, 100, and 150 feet. (From Braun, 2001)

east of the esker. Fairchild incorrectly identified the separate segment of the esker west of Oakland at STOP 5 as a drift dam, cut by two channels that held in a shallow lake in the Susquehanna valley upstream of the site. Harrison (1966) mapped an esker at STOP 5 with a knobby kame area on its north side and an outwash terrace on its south side, features confirmed by the recent mapping by Braun (2001d) (Figure 89).

The Lanesboro esker is more than four miles long and consists of three distinct segments, a western segment at STOP 5, a middle and longest segment opposite Susquehanna and Lanesboro, and a northern segment on the east side of the river north of Lanesboro (Figure 89). At each of these sites the esker is on top of and surrounded by much more extensive ice-contact sand and gravel deposits ("stratified drift"). Those other deposits show well-developed knob and kettle topography. (Between the esker and the bedrock valley wall, numerous small ponds are developed on isolated perched water tables within these fine-grained, ice-contact deposits.) The esker exceeds 100 feet in height, and its side slopes are steep.


Figure 90. Chaotic bedding in sandy and gravelly beds on the upper level. Note the relative scarcity of gravel in the deposit.

Exposures of sand and gravel within the Red Oak pit and at other nearby sites show the chaotic bedding (Figure 90), abrupt grain size changes (Figure 91), and collapse structures (Figure 92) typical of deposition in an ice-contact environment. The bulk of the deposit is sand, with gravel occurring mainly in thin discontinuous bands (see Figures 90 and 92). More than 90 percent of the pebble- and cobble-size clasts are locally derived, with exotic lithologies such as granite gneiss, pink quartzite, and gray pebbly quartzite being relatively rare. The sand fraction contains a high percentage of lithic fragments.


Figure 91. Poorly sorted cobble bed underlain and overlain by pebbly sand and gravel on "sublevel" at east end of pit. Note imbrication of the cobbles indicating current flow from the right (east).

Pit operation. In 1991 a series of test borings were drilled, and standard split-spoon sediment samples were recovered. This investigation indicated that over most of the property, useable sand-and-gravel deposits extended to a depth of over 75 feet and were underlain by till or flow till. Based on these borings, a process plant and mine layout were developed which took into account the specific site limitations. Its intent was to minimize the cost of production, while meeting state and local permit requirements. Material is excavated from the side of the esker and conveyed up to the processing plant, where individual aggregated products are separated. The office, scales, and stockpiles areas have all been developed on fine-grained lacustrine deposits that will not be excavated in the future. Material is readily transported offsite through access onto PA 171. Therefore, use of the lower secondary road is no longer required. Water for the wash plant comes from the adjacent pond. Secondary makeup water can be obtained directly from the Susquehanna. Fines from the washing plant are temporarily stored in settling basins along the mined-out toe of the deposit until the material is sold. Daily production is about 100 tons.

As soon as the mine was reactivated, it became evident that the deposit was more variable than subsurface borings had suggested. This has been an advantage in the material production. At present, five individual lifts have been developed. Each exposes material with differing grain size characteristics. This allows Red Oak Sand & Gravel to operate with a considerable range of flexibility without creating excess waste material. On a daily basis, material is screened at the process plant and gradations of individual products are recorded. If adjustments have to be made, the loader operator can then quickly alter the size and nature of material being fed to the conveyor.

When producing construction aggregate, two characteristics are of utmost importance—grain-size gradation and material soundness. The first is a function of several factors (e.g., the depositional characteristics of the material, excavation methods, and processing). Soundness is related almost exclusively to the mineralogy of the material. In this deposit, approximately 90 percent of the material is locally derived Upper Devonian graywacke.

Red Oak produces material mainly for its own use at the Masters Concrete plants at Kingsley and elsewhere in northeastern Pennsylvania, including work for road-construction projects. On a regular basis, PennDOT samples material from this pit and conducts a series of tests to evaluate the quality of the individual products and their anticipated performance. This includes grain-size distribution as well as a range of physical tests, including specific gravity, percentage absorption, crust count, Los Angeles Abrasion testing, loss in a sodium sulfate solution, etc. The material passes all such tests. It is acceptable for a full range of products, including Type A Fine Aggregate for Concrete Sand, #57 Type A Coarse Aggregate, and Type 6S Anti-Skid Material for road surfacing. Consequently, this mine should continue to provide quality construction materials to the northeastern Pennsylvania area for many years.

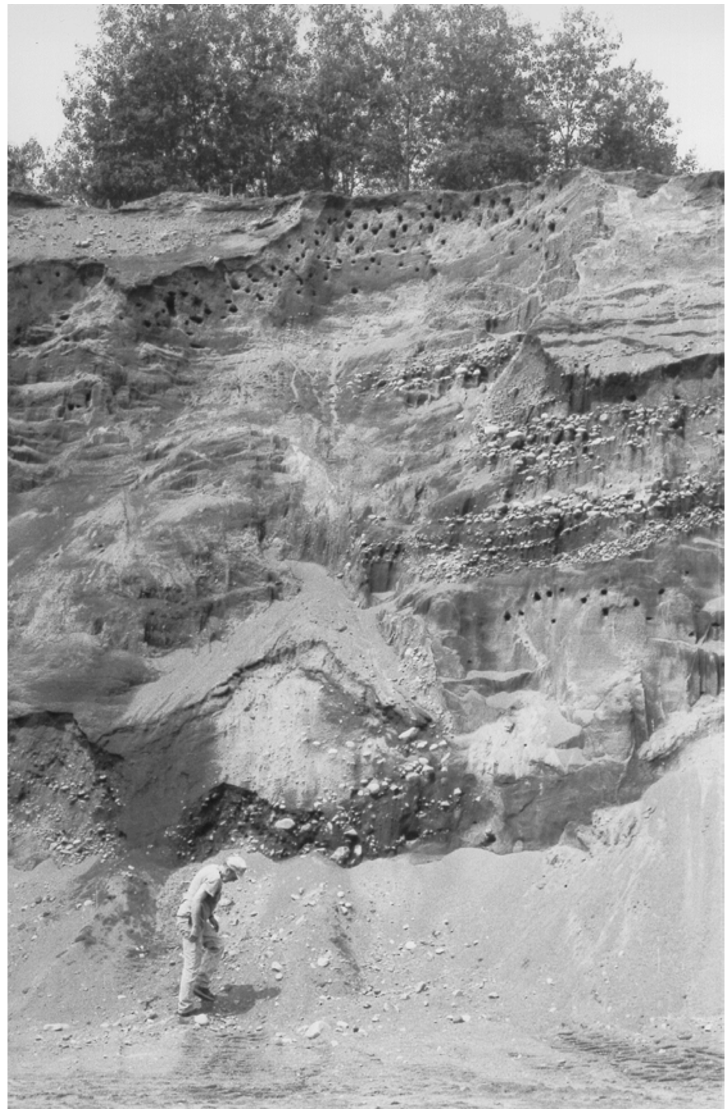


Figure 92. Rotated fault on upper level. The present configuration indicates a reverse fault with "upthrown" side on right. The fault actually originated as a normal fault with downthrown side on left. Continued deformation as more of the underlying ice melted resulted in overturning of the fault.

It is estimated by Braun (2001d) that the three esker sites noted above and a fourth north of the area shown on Figure 89 contain on the order of 50 million cubic yards of sand and gravel in areas not yet covered by housing.

		Leave STOP 5, returning on access road to pit entrance and turning left on PA 171.
0.2	62.8	Pass through Lanesboro-Oakland Esker. A small abandoned pit to right used to show a good cross section of the esker (Inners, et al., 1999). The esker at this point is composed of two types of material. The northern part is rather evenly stratified, coarse- to very coarse-grained sand containing bands of small to large pebbles. Occupying the southern part and cut into the sandy deposit is a channel filled with poorly sorted, poorly bedded, pebbly to cobbly gravel that has a matrix of coarse to very coarse sand and granules.
0.5	63.3	To left is the Aaronic Priesthood Restoration Site, a shrine of the Church of Jesus Christ of the Latter-day Saints. It was here on the homestead of his father-in-law, Isaac Hale, that Joseph Smith (1805-1844), the founder of Mormonism, translated

most of the book of Mormon in 1828-29 (from gold plates found in a drumlin in north-central New York). Several plaques and monuments at the site tell the story in considerable detail. Buried in the adjacent McCune Cemetery are Isaac Hale (1763-1839) and his wife, Mary (1766-1842), and Joseph and Emma Hale Smith's infant son, Alvin (d. June 15, 1828).

0.1	63.4	For the next two miles the valley trends transverse to glacier flow and the hillside to the right is a "lee" slope where a thick till shadow was deposited. Preglacial first-order tributary hollows cut into that slope are filled with more that 200 feet of till.
0.3	63.7	To left is Tower SR of the old Erie Railroad. The building was originally filled with manual switching and signaling elements ("Johnson bars," etc.). Most of this was replaced by more automated machinery in later years.
0.5	64.2	Enter Great Bend Township.
1.0	65.2	On right is a modernistic "Fallingwater-like" home with an ephemeral stream channel passing underneath the center portion of the house.
0.1	65.3	Village of Hickory Grove.
1.7	67.0	Village of Red Rock.
0.3	67.3	To right is a low cut in Lock Haven sandstone.
0.3	67.6	To left is a good view of the North Branch valley, with the postglacial Susquehanna cut through the bedrock spur of a preglacial incised meander loop (the old valley swings around to the south). Sheer sandstone cliffs (Lock Haven Formation) still descend down to the river on the far side, but on the north side construction of the Erie Railroad destroyed the "original beauty of this once interesting spot" (Blackman, 1873). In the days of early settlement this area was known as the "Painted Rocks" or the "Red Rock," because of Indian paintings on the ledges. (See STOP 9 for further discussion of this most interesting spot.)
1.0	68.6	To left is a cut in gray, fossiliferous Lock Haven sandstone and shale. At STOP 9, we will examine a much better exposure of these same strata along the old Erie (now Norfolk Southern) Railroad just to the south of this point.
0.1	68.7	Great Bend Township Municipal Building to left. Brant's Dairy Bar to right is also not named for Joseph Brant (see mile 52.4), but for the Brant family, which operates it. (They have excellent ice cream!)
1.2	69.9	Turn left onto ramp for I-81 South. Borough of Great Bend is ahead and to right.
0.1	70.0	Merge with I-81 South.
0.1	70.1	Cross North Branch Susquehanna River. Downstream to the right the river turns sharply to the north to enter New York State and complete the Great Bend of the North Branch Susquehanna River. I-81 South will now leave the North Branch valley and ascend the Salt Lick Creek valley.
0.3	70.4	To left is a low cut in Lock Haven gray sandstone and shale.
1.8	72.2	To left is an abandoned gravel pit that once showed delta foreset beds dipping towards I-81. The delta is "hanging" on the side of the valley with its top at about 1200 feet, the level of Glacial Lake Great Bend. The delta was fed by meltwater from the next valley to the east, Little Egypt valley. The meltwater incised a channel across a saddle in the divide between the valleys to reach the delta (Figure 93).
2.1	74.3	Pit to right (with a cell phone tower in it) is that of the New Milford Sand and Gravel Co. (STOP 8). It is developed in ice-contact stratified drift (below road level and mostly hidden by trees). Farther to right across the valley, the sandstone quarry (lowermost Catskill Formation) of the New Milford Sand and Gravel Co. is readily visible.

Figure 93. Notch cut by stream flowing westward from a high-level proglacial lake in Little Egypt Creek valley into an early phase of Glacial Lake Great Bend in Salt Lick Creek valley, about two miles south-southeast of Hallstead. In the middle distance is the Late Wisconsinan delta noted at mile 72.2 of the roadlog. Much of this delta was quarried away for aggregate or embankment material during construction of I-81 in the late 1960's or early '70's.

0.3	74.6	To left is a cut through Catskill gray sandstone and red shale.
1.7	76.3	To left is a cut through Catskill gray sandstone.
0.5	76.8	Exit 223 (New Milford-Lakeville). Continue on I-81 South.
2.1	78.9	Deep cuts in alluvial, fining-upward cycles of the Catskill Formation begin here and extend along both sides of I-81 for the next mile. This was the site of STOP 1 of the 36th Annual Field Conference of Pennsylvania Geologists (Krajewski and Williams, 1971). The sandstones at the base of the cycles exhibit thin zones typical of their type 3 (alluvial) flagstone deposits (p. 65-69).
0.2	79.1	Recrossing the regional east-to-west-trending divide between streams draining north or south to the North Branch Susquehanna River. We are now heading down south-draining valleys of the Tunkhannock Creek basin, where the glacial meltwater could freely drain away from the ice.
1.9	81.0	Exit 219 (Gibson). Continue on I-81 South.
2.4	83.4	Exit 217 (Harford) to PA 547. Continue on I-81 South.
2.2	85.6	To left is a low cut in well-jointed, gray Catskill sandstone.
2.4	88.0	The cut to left exposes parts of two fining-upward cycles (gray sandstone to red mudstone) in the Catskill Formation.
0.5	88.5	To left is a cut in thick-bedded, well-jointed, gray Catskill sandstone.
0.1	88.6	Exit 211 (Lenox). Bear right onto exit ramp.
0.3	88.9	Stop sign. Turn right onto PA 92.
0.1	89.0	Stop sign and blinking traffic light. Continue straight on PA 92.
0.8	89.8	To left in the fields is a hummocky or knob and kettle landscape developed on ice-contact stratified drift.
1.0	90.8	In the field to right are numerous large colluviated Catskill sandstone blocks.
0.6	91.4	To left are broad terraces along Tunkhannock Creek. The highest is an outwash terrace while the lower ones are alluvial terraces cut into the outwash.
0.6	92.0	To right is a low cut through sandstone overlain by bouldery till.
0.3	92.3	To right is another low cut through sandstone.
0.6	92.9	To right are many blocks of flaggy Catskill sandstone eroded out of the bouldery till. Those higher on the hillside are probably colluviated blocks from ledges higher on the slope.
1.0	93.9	Village of Glenwood.

0.5	94.4	Historical Marker to right reads: *GALISHA GROW. Father of the Homestead Act, opening western lands to free settlement in 1862. Speaker of the House 1861-1863. Returned to Congress 1893-1903. Retired to his home, which stood on this site, until his death in 1907.*
0.2	94.6	Intersection with PA 374. Continue straight ahead on PA 92, retracing route through Nicholson to Shadowbrook Inn and Resort. Note the large stockpile of flagstone to left just beyond the intersection.
2.6	97.2	Ahead to left, the Tunkhannock Viaduct can be seen in the far distance.
0.7	97.9	Directly ahead is an excellent view of the Tunkhannock Viaduct.
0.3	98.2	Intersection with US 11 in Nicholson. Continue straight on PA 92.
9.6	107.8	Intersection with US 6. Bear right on US 6 West/PA 92 South.
1.5	109.3	Turn right into main (west) exit of Shadowbrook.
0.2	109.5	Parking lot of Shadowbrook Inn and Resort. End of Day-1 field trip.

ROADLOG AND STOP DESCRIPTIONS

DAY 2

Miles Int.	Cum.	Description
0.0	0.0	Leave parking lot at Shadowbrook Inn and Resort, proceeding toward EAST exit.
0.2	0.2	East exit of Shadowbrook; turn left on US 6-PA 92.
1.1	1.3	Turn left on PA 92 and retrace route of DAY-1 Roadlog to Nicholson.
9.6	10.9	Bear left at complex intersection, following signs to US 11 North. BE CAREFUL!
0.1	11.0	Stop sign. Turn left on US 11 South.
0.2	11.2	Cross Tunkhannock Creek.
0.1	11.3	Turn right into parking area behind guide rails. Disembark.

STOP 6. TUNKHANNOCK VIADUCT.
Leaders: Jim T. Kovach, Jon D. Inners, and William S. Young.

By way of introduction, the Historical Marker on the opposite side of the highway reads:

> TUNKHANNOCK VIADUCT. This reinforced concrete structure was the largest of its kind ever built when it went into service in 1915 on the Delaware, Lackawanna & Western Railroad. The bridge, 2,375 feet long and rising 240 feet above Tunkhannock Creek, was the focal point of a 39.6-mile relocation between Clarks Summit and Hallstead. The novelist Theodore Dreiser called this viaduct "one of the true wonders of the World."

This short paragraph says quite a bit--and perhaps more than enough—as this most monumental of structures needs no explanation in order to take away the breathe of a first-time observer—or even to continually astound someone who sees it every day!

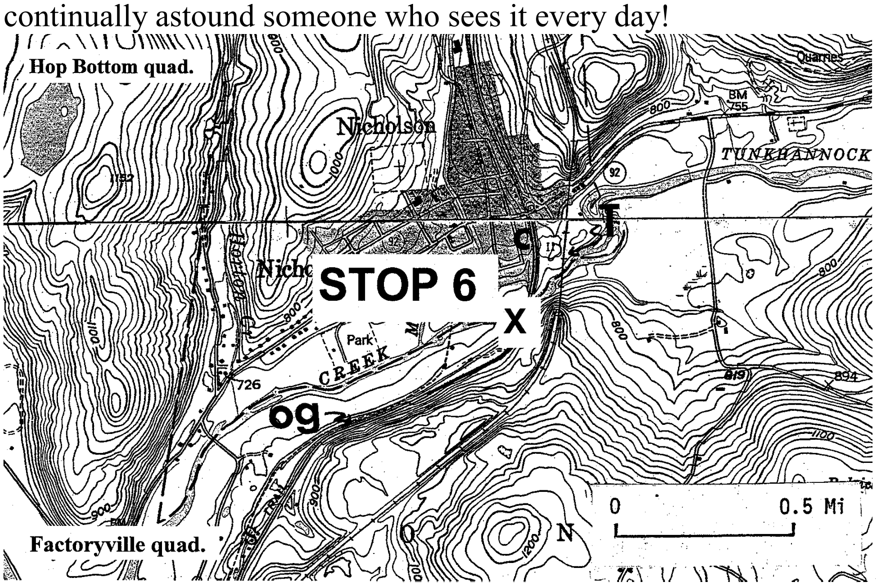


Figure 94. Location map for STOP 6. T = Tunkhannock Viaduct, C = coal docks, og = pre-1915 RR grade.

Geology. The Tunkhannock Viaduct, or "great white...bridge" of Dreiser, crosses the Tunkhannock Creek valley about 11 miles ("as the crow flies") above the juncture of that creek with the North Branch Susquehanna River at Tunkhannock (Figures 94 and 95). Width of the valley here is about 1300 feet, while the creek itself is only about 100 feet wide at normal flow. Surrounding hills to the north and south of Tunkhannock Creek reach elevations of 1200 to 1300 feet, with the stream level about 700 feet. Joining the creek from the north at Nicholson is Martins Creek, which occupies the southern 17 miles of a 24-mile long canyon extending to Hallstead on the North Branch Susquehanna River (see STOP 7).

Figure 95. The "Bridges of Tunkhannock Creek." View north from STOP 6, showing (left to right) the abutment of the old DL&W Railroad bridge (1850's, also used after 1915 for the original highway bridge), the new US 11 bridge (1990), and the Tunkhannock Viaduct (1915).

Bedrock over the entire area consists of interbedded gray sandstones and red shales, siltstones, and mudstones of the Late Devonian-age Catskill Formation (Figure 96). Extensive exposures of these rocks can be seen along US 11 and on the active railroad line north and south of the viaduct. The sandstones are typically crossbedded and locally contained lenticular beds of calcareous breccia/agglomerate and (rarely) pods of massive pyrite. Bedding is subhorizontal, but may locally attain dips as high as 12^{o}. Jointing is well developed in the sandstones, a smooth north-south set (occasionally with quartz mineralization) and a somewhat uneven east-west set being "ubiquitous." Although good flagstone is probably not as abundant as farther north in Susquehanna County, a few operators extract stone from quarries within sight of the viaduct. One of the historically important flagstone operations was Carlucci's quarry high on a hillside above the west bank of Martins Creek, about 2 miles north of Nicholson (in Lathrop Township, Susquehanna County). A small branch railroad was built to this quarry off the main DL&W line in 1900.

Late Wisconsinan glacial deposits (approximately 20,000 years old) exposed in the Nicholson area consist of silty glacial till in the hills and mixed outwash and ice-contact stratified drift in the valleys of Tunkhannock and Martins Creeks (Figure 96). At the site of the Tunkhannock Viaduct, glacial and glaciofluvial deposits are at least 50 feet deep across the entire valley and locally extend down to nearly 100 feet. Upstream and downstream of Nicholson, kettled outwash/kame terraces occur intermittently on either side of Tunkhannock Creek 20 to 30 feet above a continuous, relatively smooth alluvial terrace. An excellent exposure of folded and faulted ice-contact deposits in one of the higher terraces can be seen in an old sand pit on a farm (0.5 mile) east of Nicholson (Figure 97; 1 on Figure 96).

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 in does now. For Tunkhannock Creek—and Starrucca Creek at STOP 3—this period of very high flow was in the glacial epoch.) It is correctly called the "Tunkhannock Viaduct," because the engineering convention is to name such a structure for the stream it crosses; thus the "Starrucca Viaduct" (not Lanesboro) and the "Kinzua Viaduct," etc.

To conform to the lessened grades of the new "Cutoff" route north of Clarks Summit, the elevation of the crossing of Tunkhannock Creek on the new alignment was set at 947.0 feet (see Inners, this guidebook, p. 51-54; Braun et al., 1999). This necessitated a structure 240 feet above the floor of the valley. Since the DL&W had gained considerable experience with new reinforced concrete designs on previous projects (involving not only bridges, but company houses and breakers as well), choice of construction material for the bridge at Nicholson followed naturally. (See, for example, Janosov, 1986.) A. Burton Cohen designed the great viaduct in the monumental Beaux Arts style, which characterized many public buildings in the period between 1885 and 1930 (Young, 1968; McAlester and McAlester,

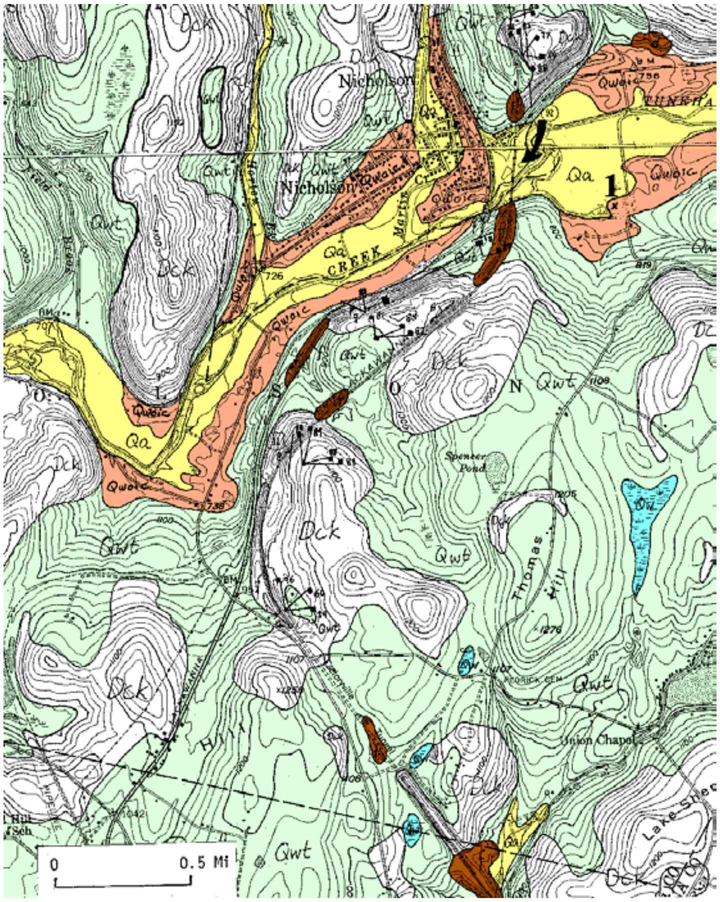


Figure 96. Geology of the region around the Tunkhannock Viaduct (large arrow) (surficial geology after Braun, manuscript map). f = artificial fill, d = quarry dump, Qw = wetland, Qa = alluvium, Qwoic = Wisconsinan outwash and ice-contact deposits (undifferentiated), Qwt = Wisconsinan till, Dck = Catskill Formation. Note the numerous deep cuts and fills—as well as the Nicholson (Factoryville) Tunnel —on the labeled Erie-Lackawanna grade (part of the "Summit Cutoff" of the old DL&W).

1984). George J. Ray and F. L. Wheaton supervised its construction (Engineering News, 1913), which began in May of 1912.

Construction of the pier foundations. A 49-ton Marion steam shovel with a 1¼-yard bucket was delivered by rail and commenced excavation of the upper portion of pier 6 in July 1912. It subsequently moved on to piers 5, 8, 9, and 10, excavating downward until groundwater was encountered. Spoils were delivered to narrow-gauge dump cars for movement away from the excavations. Approximately 2,000-feet of 3-foot gauge service tracks comprised of 60-pound rail and 6% slopes were constructed for the bridge project. While the steam-shovel excavation was in progress, a concrete plant with capacity of 40 cubic yards per hour, and the cableway, which commanded the full span of the valley, were installed.

The end abutments and piers 1 and 11 are located on the hillside where bedrock was only a *few* feet below grade and groundwater was not encountered. The foundations for piers 9 and 10 encountered bedrock approximately 20 to 30 feet below grade. The remaining piers (2, 3, 4, 5, 6, 7, and 8) required much deeper excavations to encounter bedrock. Most of the middle pier footings are founded on bedrock about 60 feet below creek level (but see below). These deeper excavations were accomplished through use of cofferdams constructed of interlocking steel-sheet piling.

The typical frame for each cofferdam consisted of a 43 x 49-foot base spliced together from 12 x 12-inch timber. Vertical posts were set-up on each base and a second rectangular frame comprised of 12 x 12-inch timber was built 16 feet above the base. This large box-shaped frame, known as a waling, was then completely surrounded by an outside frame of similar construction so that the interior and exterior walings were separated by a 6-inch space. A continuous row of 12-inch wide, 30-feet long, 45-pound Lackawanna steel sheet piling was driven between the exterior and interior walings. Driving was accomplished using Vulcan steam hammers suspended from derricks located adjacent to each excavation. The hammer continued to rotate around the structure, driving the piling about 2 to 3 feet with each pass. Care was taken to maintain a vertical line before internal excavation and bracing began.

The interior of the cofferdam was then excavated at an average rate of one foot per day by a Mead-Morrison one-yard, clamshell bucket suspended from one of the adjacent derricks. Deep excavation was aided by a Williams special one-yard, toothed clamshell bucket which provided excellent results in the compact, hard soil encountered. As excavation continued, the piles were driven to their full length (30 feet) and were braced with successive horizontal tiers of 12 x 12-inch longitudinal and traverse struts. Each horizontal tier was made from yellow pine with openings, measuring 7 x 10

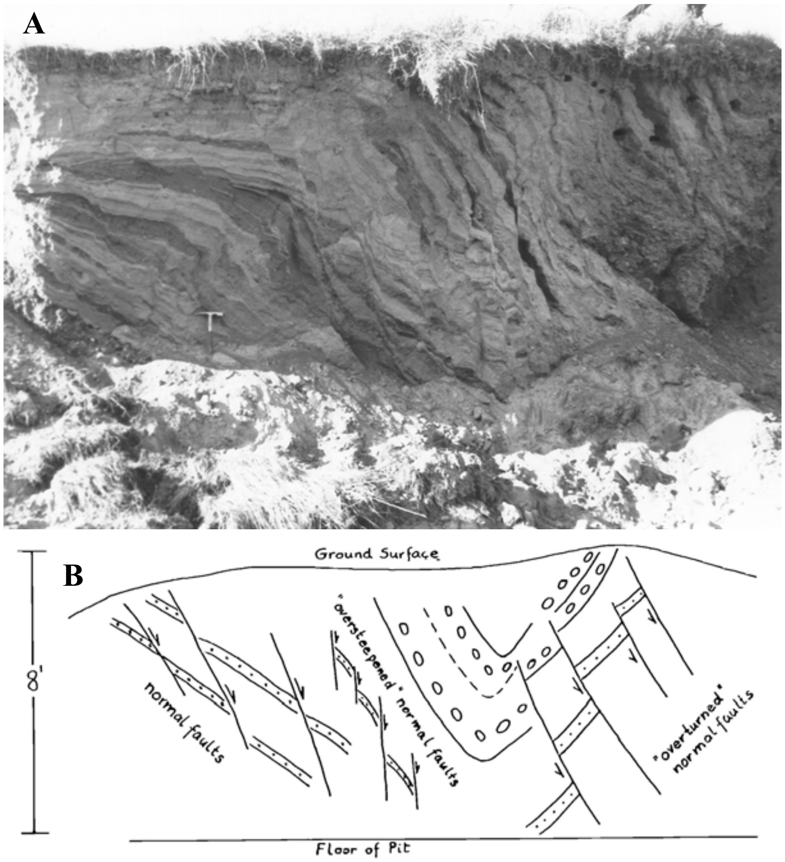


Figure 97. A. Faulted and folded ice-contact deposits in a kame terrace on the south side of Tunkhannock Creek, 0.5 mile east-southeast of Nicholson.
B. Diagrammatic cross section of intensely deformed ice-contact deposits pictured in the photo above.

feet, to provide clearance for excavating tools and concrete buckets. Successive tiers were spaced between 3 1/2 to 5 feet apart. Vertical braces were made from 12 x 12-inch posts. The entire structure was held together with slice boards, or fishplates, and ¾-inch connecting bolts.

Once the inner sheet piling was driven its full length, a second set of double walings were erected so that they were concentric with and 4 feet 8 inches outside of the inner wall. An outside set of pilings was then driven to a depth of 12 to 15 feet. The inside set of pilings was subsequently encountered in the glacial sediments. When encountered, they were usually undermined and rolled into the excavation. Large boulders were drilled and blasted to facilitate removal. Frequently a 2-inch pipe was driven into the hardpan or between boulders and one or two sticks of dynamite was used to loose the materials so that it could be removed by the clam-shell buckets. Considerable leakage occurred during the early stages of the excavation. This leakage usually diminished as the joints filled-up with sand.

Tunkhannock Creek was subject to flooding during the early phase of the project and, in turn, filled pits 3 and 4 located adjacent to the stream. Fortunately no great damage was done. The excavations were pumped out within a day or two. Most of the water entered through the bottom of the excavation. Two 8-inch centrifugal pumps and two 10-inch Emerson plunger pumps, supplied by a 150 horsepower boiler, were used to dewater pit 4, which was located adjacent to the stream. For general dewatering purposes, two of the pumps were sufficient to control groundwater infiltration. Upon completion of excavation activities, the interior sheeting lined with tarpaper and the cofferdams were completely filled with concrete using 2-yard capacity, Lockwood bottom-flap buckets. Once the pour began, work continued day and night without break to ensure a monolithic foundation. In pier 3, 2,400 yards of concrete were poured without interruption in one seven-day period.

Considerable groundwater infiltration was encountered during the excavation of pier 8. The problem was handled by constructing a wooden drain around the base of the cofferdam using 2 x 12 inch planks cleated together. Water was drained to a sump excavated into the bedrock floor and removed by an 8-inch centrifugal pump. Concrete was poured over the wooden drain, permanently entombing the wooden drain. As concrete was carried up, a full-size shaft was left open above the sump. This sump was later sealed with concrete when the pier was completed to the surface.

Once most of the foundation was prepared, mammoth towers were built at each end of the viaduct from which cement ran on an aerial tramway to dump their contents at the appropriate arch under construction. However, one pier—at the site of which quicksand was encountered at 60 feet—had to be extended down to 92 feet and was not completed until the spring of 1915. To complete this pier footing (No. 5), compressed air was used to keep the foundation forms from bulging, and workers had to be lowered through compressed air chambers to muck out the bottom (Young, 1967; Williams, [1990]). The foundation difficulties at this pier delayed completion of the viaduct for at least six months.

Construction statistics. Some important engineering statistics of the viaduct are as follows (Anonymous, 1976):

Construction material - reinforced concrete
Elevation of railroad grade - ~940 feet
Length - 2,375 feet
Height - 240 feet above stream level; over 300 feet above bedrock.
Spans **-** 12 (10 spans of 180 feet visible; 2 spans of 100 feet buried in approach fills.)
Materials - 163,000 cubic yds. concrete, 2,280,000 lbs. of reinforcing steel; 185,000 bbls. of cement.
Excavation of pier foundations - 48,000 cubic yds.
Depth of pier excavations - 60 to 138 feet
Workforce - 500 men

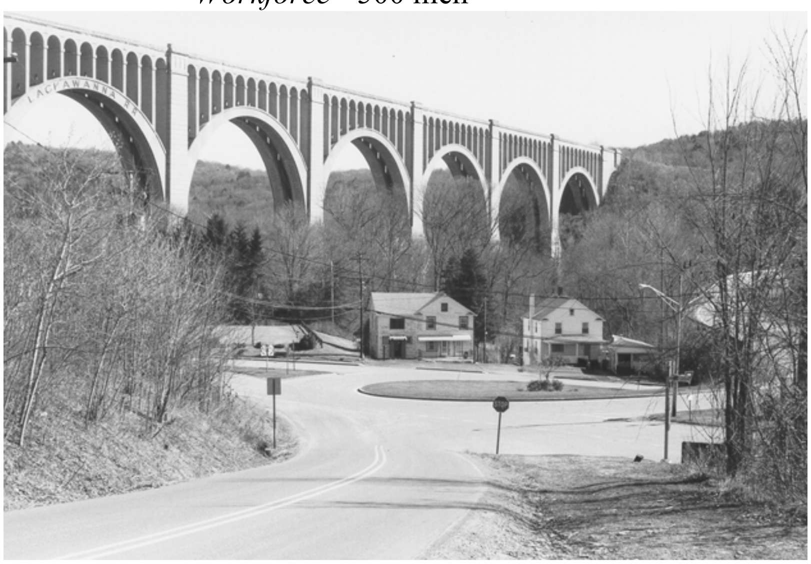


Figure 98. The "great bridge" towers over houses in the borough of Nicholson in this view looking south from SR 1025. To locals the viaduct will always be the "Nicholson Bridge."

It is finished! The "great bridge" was finally completed in late September 1915 (Figure 98). Festivities opening the Tunkhannock Viaduct and the "Cutoff" were held at the new Nicholson passenger station on November 6, 1915. (This new station was located not far from the north end of the viaduct. Only the tiled floor survives.) Dignitaries in attendance included Pennsylvania Governor Martin G. Brumbaugh, Lackawanna President William H. Truesdale, and Buffalo Mayor Louis P. Fuhrman, each of whom gave major speeches. The first train crossed the viaduct the next day (Young, 1968).

		Leave STOP 6, turning right on US 11 North back toward Nicholson.
0.3	11.6	Intersection with PA 92. Continue straight ahead on US 11 North.
0.1	11.7	Wood-frame DL&W Weigh House to left. This structure is along the old, pre-viaduct grade of the railroad. Today the site is a bluestone storage yard. You are now entering the mouth of Martins Creek, the glacial sluiceway outlet for Glacial Lake Great Bend.
0.4	12.1	Old quarry in Catskill sandstone to right, with much outcrop along road to north.
0.7	12.8	Enter Susquehanna County.
0.9	13.7	To right, behind the mobile homes, is a stonewall that is part of the old grade of the DL&W.
0.5	14.2	Martens Creek Antiques to right preserves the original spelling of Martins Creek, which was named for the large population of martens that once lived along its banks (Blackman, 1873).

0.9	15.1	To right are cuts in Catskill sandstone.
0.4	15.5	To right is old channel of Martins Creek, cut-off by construction of US 11.
1.3	16.8	To right is another cut-off old channel of Martins Creek.
0.7	17.5	Intersection with PA 167 North in borough of Hop Bottom, named from the wild hops that grew along nearby Hop Bottom Creek two centuries ago (Blackman, 1873).
0.6	18.1	To right is a cut in Catskill sandstone.
0.3	18.4	To right behind a house is a 20 feet high cut in reddish-brown, silty-matrix, stony till.
0.4	18.8	To right is a cut in well-jointed Catskill sandstone.
0.7	19.5	To right is another cut in well-jointed Catskill sandstone.
0.9	20.4	Pass under Martins Creek Viaduct. Approximately 1600 feet long, 125 feet high, and "three-tracks" wide (wider than the Tunkhannock Viaduct), it is basically a smaller version of the reinforced-concrete Tunkhannock structure and has the same Beaux-Arts design (see Inners, this guidebook, p. 55-56).
0.1	20.5	To right, opposite the PennDOT storage area, is a long cut exposing one complete, 40-foot-thick, alluvial fining-upward cycle in the Catskill Formation and the base of another. Weathering has accentuated the crossbedding in calcareous sandstone units.
0.7	21.2	To right is a good stretch of the old DL&W grade.
0.2	21.4	From here for the next 7 miles US 11 runs on top of the old DL&W railroad bed. The old railroad bed is such a good base that when US 11 was concreted in the 1930's, it did not require major repair and resurfacing until 2000.
0.2	21.6	Intersection with PA 106 in borough of Kingsley.
0.2	21.8	To right are low ledges of flaggy, crossbedded, gray, fine- to medium-grained, micaceous and calcareous Catskill sandstone containing a large, calcareous breccia-shale ball 5 feet long and 3 feet thick. Channel cutouts occur at the south end and in the middle. Disrupted gray clay shale associated with a possible ball-and-pillow structure occurs beneath the south channel.
0.1	21.9	Intersection with PA 547 North. On the left side of the highway is a Historical Marker that reads: *Galusha Grow. Father of the Homestead Act, opening western lands to free settlement in 1862, lived at nearby Glenwood. Speaker of the House, 1861-1863, and member of Congress, 1893-1903. Died in 1907; buried in nearby Harford Cemetery at few miles from here.*
0.2	22.1	To right is a cut in well-jointed Catskill sandstone.
0.5	22.6	To right is a cut in beautiful flaggy Catskill sandstone. It is capped by several feet of gravel (ice-contact stratified drift).
0.3	22.9	The cut to right exposes gray, planar to crossbedded sandstone of the Catskill Formation. Channeling is evident at numerous places, and lenticular beds of gray, silty clay shale occur locally.
1.4	24.3	To right is another cut in crossbedded and channeled Catskill sandstone.
0.6	24.9	Dirt road to right leads to Alford Junction, where a branch railroad line to Montrose led off the new "Summit Cutoff" grade of the DL&W.
0.3	25.2	From this point to mile 30.0 are numerous cuts in well-jointed, flaggy Catskill sandstone. The prominent, smooth joints are the ubiquitous north-south set. On the opposite side of Martins Creek, north of Alford Junction, the new DL&W grade created a nearly continuous, 2-mile-long cut in Catskill sandstone and shale. These outcrops are where the incision of the Martins Creek valley by glacial meltwater has carved a deep, narrow sluiceway, the outlet to the long-lived, large

		Glacial Lake Great Bend. To left for the next several miles two long, narrow artificially dammed lakes occupy the floor of the sluiceway.
3.1	28.3	US 11 crosses what was once the regional east-to-west-trending divide between streams draining north and south to the North Branch Susquehanna River. The glacial sluiceway here is cut 700 feet deep through the divide. As the divide was cut down, it migrated two miles northward to its present position at STOP 7. Future glaciations will eventually deepen this sluiceway enough to capture the North Branch Susquehanna.
0.4	28.7	To left, beside a power line and hidden by trees on the hillside, is a 200-foot-high water fall "cascade" (a number of 5- to 15-foot-high waterfalls, one after the other) of a tributary that once drained north. The tributary has now been left "hanging" above the floor of the sluiceway and its drainage has been turned southward.
1.3	30.0	Turn left into south end of parking lot at the Summit Restaurant.

STOP 7. THE NEW MILFORD SLUICEWAY AND THE SUMMIT DIVIDE.
Leader: Duane D. Braun.

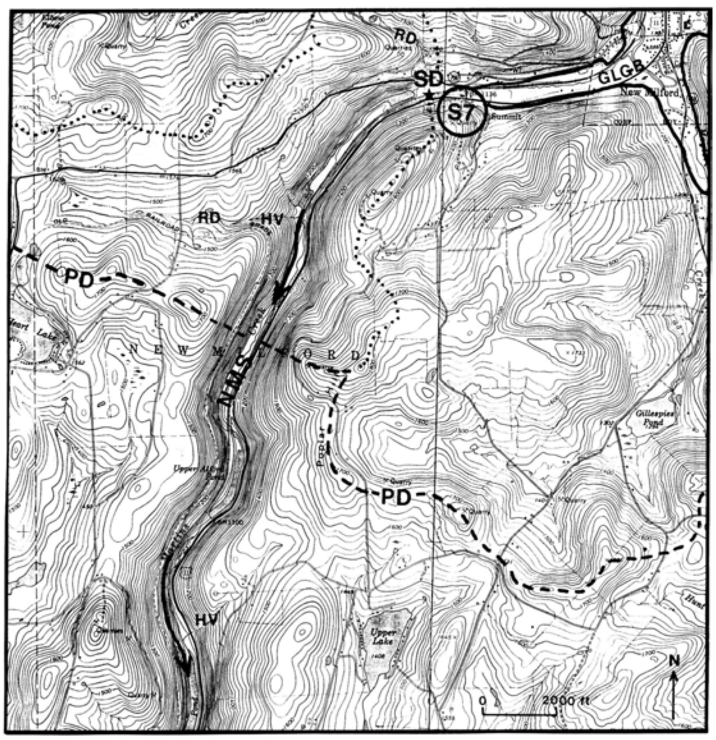


Figure 99. Map showing the New Milford sluiceway (NMS) cutting across the preglacial east-west divide (dashed line labeled PD). SD = Present Summit Divide, RD = Streams with reversed drainage, dotted line = area of reversed drainage, HV = hanging valleys, GLGB = Glacial Lake Great Bend.

The New Milford sluiceway is a deep breach in the drainage divide between streams heading north to the Susquehanna River in New York and streams heading south to the Susquehanna River in Pennsylvania (Figure 99; see Figure 23). As ice initially receded north of Tunkhannock, Pennsylvania, meltwater was free to drain southward and formed extensive outwash terraces along Tunkhannock Creek (as noted earlier on the Day-1 Roadlog). Once the ice receded north of the east-west trending divide, a series of proglacial lakes were impounded between the ice and the divide. Usually the lake in each individual north-trending valley would have had its own sluiceway. Thanks to the "Great Bend" in the overall course of the Susquehanna River, the New Milford sluice was positioned to receive drainage from 25 miles of ice front and 25 miles of adjacent valleys (see Figure 23). This permitted exceptionally deep cutting of the sluice. The 600 feet of cutting in the divide is a composite of all the ice and meltwater erosion from the 3 or 4 glaciations that have crossed the area. Other saddles along the divide that acted as only local proglacial lake sluiceways show incision on the order of 100 feet or so (look at the other saddles along the dashed line divide on Figure 99). As the sluiceway cut down the divide migrated north to its present position at Summit (SD on Figure 99; Figure 100). This migration of the divide reversed the drainage in the area between the old and present divide (area enclosed by dotted line on Figure 99). Two tributary streams that once drained northward (RD on Figure 99) now drain south. Small tributaries both north and south of the old divide were left as hanging valleys above the deeply incised floor of the sluiceway (HV on Figure 99). The stream that enters the sluiceway from the west just north of the old divide drops 300 feet down into the sluiceway in a chain of waterfalls.

There remains a 200-foot rise from the Susquehanna River at Great Bend to the present divide on the floor of the sluiceway at Summit. If during the next glaciation the ice has a significant stillstand just north of the town of Great Bend, the deposits from that stillstand may be thick enough to continue to block and permanently divert the Susquehanna River down the New Milford sluiceway. This is how the Susquehanna River was diverted out of its preglacial valley in the Bloomsburg area, blockage by 200 feet of frontal kame fan deposits marking the Late Illinoian (or older) terminus (Braun et al., 1984).

Figure 100. View northeast toward New Milford from PA 706 on the hillside west of the sluiceway and approximately on the Summit divide. Glacial Lake Great Bend filled the valley in the middle distance to a depth of about 50 feet.

		Leave STOP 7, turning left on US 11 North.
0.2	30.2	Intersection of US 11 with PA 706 West (to Montrose). Continue on US 11 North.
1.1	31.3	Intersection of US 11 with PA 429 East and PA 848 East in borough of New Milford. Continue on US 11 North. You are now descending beneath the water level of Glacial Lake Great Bend.
0.4	31.7	Cross Salt Lick Creek. To right is the turn-of-the-20th-century New Milford Library building.
0.9	32.6	To right behind the New Milford Township Authority Building is an occasionally active gravel pit in Late Wisconsinan ice-contact stratified drift (Figure 101).
0.3	32.9	Old US 11 (SR 1018) bears off to left here, crossing the active railroad grade on a concrete bridge inscribed "1915." Just to the southwest of the bridge, an abandoned railroad grade (also part of the 1912-1915 relocation) cuts through a large mass of late Wisconsinan ice-contact stratified drift that once rested against the west side of the valley.
0.4	33.3	To right is Salt Lick Creek.

Figure 101. Inclined (±25°SE) and faulted sand-and-gravel beds in Late Wisconsinan-age ice-contact stratified drift in the New Milford Municipal Authority pit at mile 32.6. Many pebbles and cobbles in this pit are coated with travertine.

0.2 33.5 Turn right into active gravel pit at Tingley (Summersville).

STOP 8. ICE-CONTACT DEPOSITS IN THE NEW MILFORD SAND & GRAVEL COMPANY PIT.

Leaders: Duane D. Braun, Jon D. Inners, and Brett Grover.

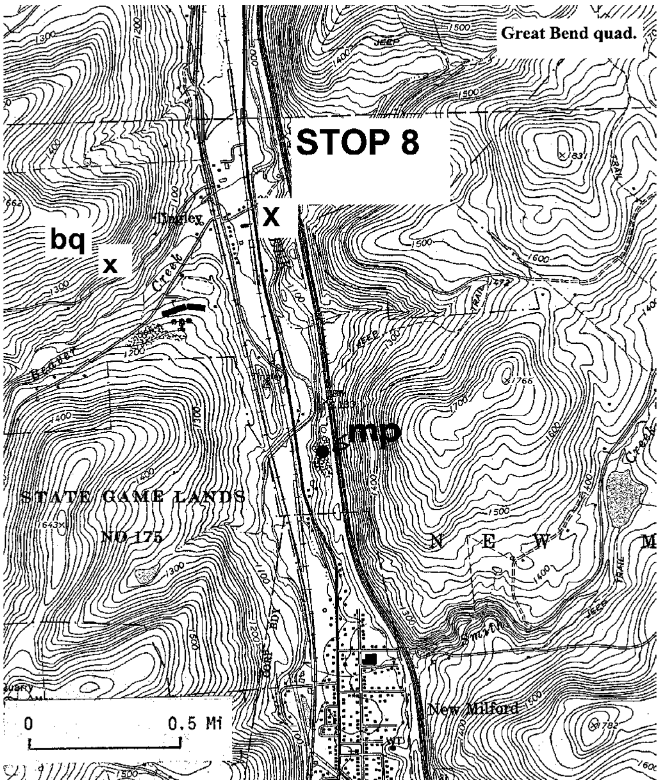


Figure 102. Location map for STOP 8. mp = New Milford Municipal Authority, bq = bedrock quarry of New Milford Sand & Gravel Co.

The sand and gravel deposit exploited here by the New Milford Sand and Gravel Company (Figure 102) is one of several Late Wisconsinan-age ice-contact kames or kame terraces along the edges of Salt Lick Creek valley between New Milford and Hallstead. On the way to this STOP, we passed another of these deposits on the east side of US 11 just outside New Milford at the New Milford Township Authority Building (mile 32.6, Figure 101). These materials were deposited along the bedrock valley wall on top of and against dead ice early in the history of Glacial Lake Great Bend. The short distance of transport and the highly variable conditions of meltwater sedimentation are shown by the poor sorting and chaotic bedding of the deposits. As the underlying and valleyward ice melted out, the drift was let down and partially collapsed onto the floor of the valley as shown by faults and melt-out structures in the coarse gravels. These deposits are within the area once covered by Glacial Lake Great Bend and were probably capped by a relatively thin sequence of glacial lake varves. Postglacial erosion has removed the lake sediments and much of the kames themselves.

The pit and its deposits. The entire section in the active New Milford pit is about 75 feet thick. It coarsens upward from rather evenly bedded sand and gravel—with distinct bands of dark gray to red silt—at the base (exposed next to Salt Lick Creek) to rather chaotic cobbly gravel in the upper few tens of feet (exposed on a high bank south of the crushing equipment). Two thin, discontinuous bands of red silt in the finer grained, lower part of the deposit may represent brief slack water episodes, while a thin, but relatively continuous "black band" between the two red layers may be an old soil horizon. In the high, west-facing cut south of the crushers the major exposed unit is a peculiar, subhorizontally bedded, fine-grained interval (with swallow holes) containing large, flat exotic blocks that were probably dumped directly off the glacier (Figure 103). The biggest "boulder" in the pit—a gray sandstone slab 15 feet in maximum dimension and at least 2.5 feet thick—is directly below this "fine grained" interval. The north-facing cut just to the south of this chaotic mass (beyond a badly slumped section) is composed mostly of well bedded, coarsening-upward cobbly gravel (Figure 104), which locally exhibits beautiful melt-out, collapse structures (Figure 105). Some of this is "open-work" gravel, i.e., it has very little sand matrix.

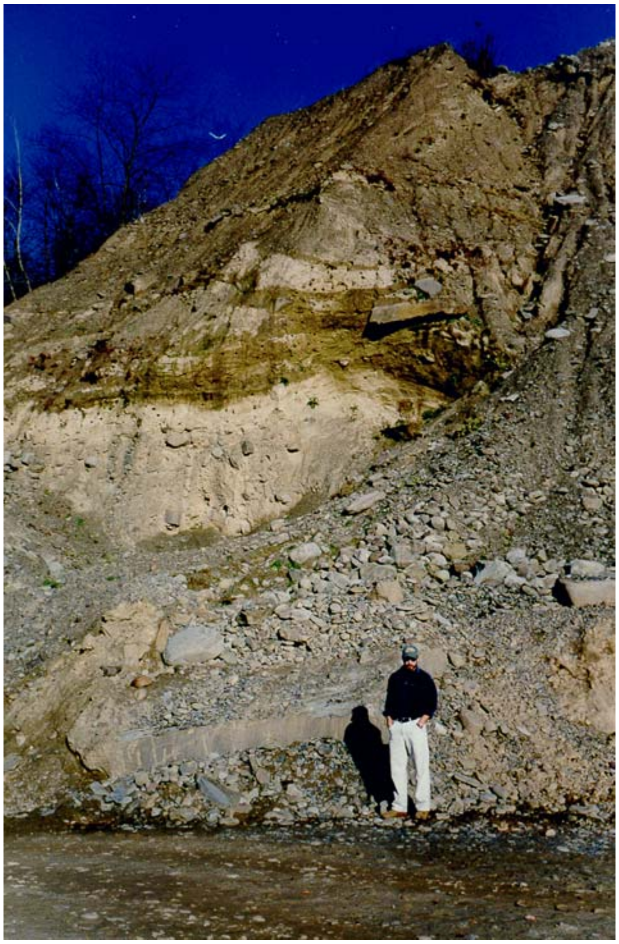


Figure 103. Fine-grained interval containing large, angular blocks on west facing wall at STOP 8.

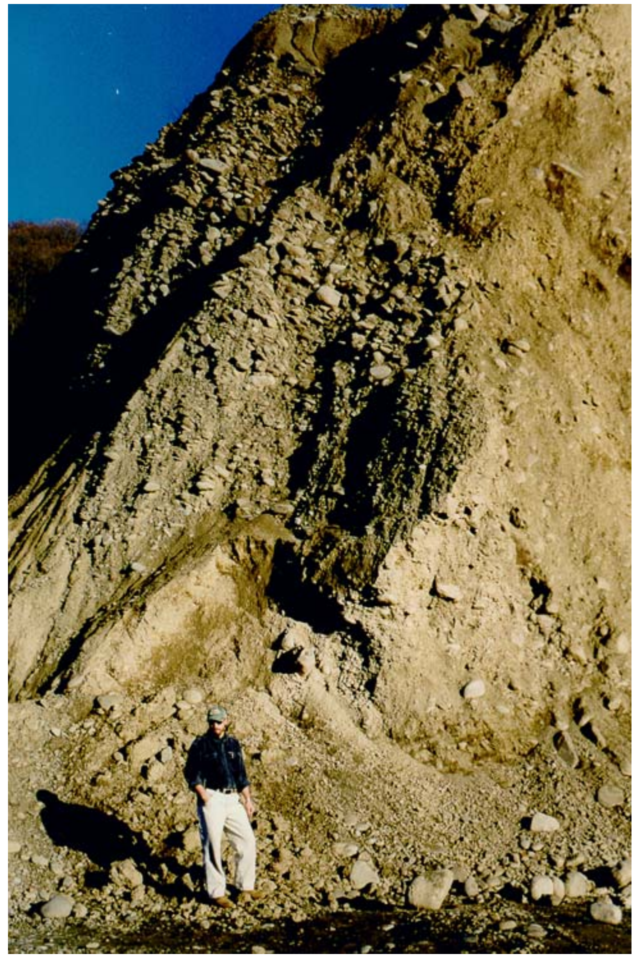


Figure 104. Coarsening-upward pebble-to-cobble gravel on north-facing wall in southern part of New Milford Sand & Gravel Co. pit.

Figure 105. Cobbly ice-contact stratified drift on north-facing wall at STOP 8, showing collapse features formed by melting of ice-blocks within and/or beneath the deposits.

Some interesting things to look for in this pit:

1). Dark brown, deeply weathered fossiliferous pebbles and cobbles derived from the Late Devonian-age Lock Haven Formation (the "Chemung" of I. C. White, 1881). These clasts originally contained calcareous brachiopod shells and crinoid disks, but the calcite has been leached out, leaving a "punky," fine-sand residue with fossil impressions. (Obviously, you want as little of this stuff in the aggregate as possible!)

2). Travertine (white, "bubbly" calcite) incrustations on pebbles and cobbles. This represents the calcite leached from calcareous clasts higher in the gravel mass and redeposited as water filters down toward the creek. (There is apparently not nearly as much of this here as in the New Milford Municipal Authority pit to the south.)

3.) "Granite" pebbles. (Some should be here, but they appear to be very rare.)

The New Milford Sand and Gravel Company produces PennDOT-approved coarse aggregate SLR E (i.e., excellent skid resistance level), type C fine aggregate, and antiskid (Barnes, 1997). These crushed stone products are made from a mixture of unconsolidated pit deposits and sandstone from a large quarry in the Late Devonian-age Catskill Formation on the other side of the Salt Lick Creek valley, 0.4 mile to the west (bq on Figure 102; Figure 106). The large, gray sandstone blocks scattered around the crushing area are from this quarry.

Figure 106. Quarry of the New Milford Sand & Gravel Co. in the Catskill Formation, 0.4 mile west of Tingley (41°54'03"N/ 75°44'27''W). The strata exposed here presumably occur at the base of the "New Milford lower sandstone" of I. C. White (1881). McElroy (2002) maps them at the base of his Great Bend Member, the contact with the Lock Haven Formation lying directly beneath the quarry rock.

Origin of the deposits. As the glacier receded north, down the Salt Lick Creek valley, a series of ice-contact sand and gravel masses (stratified drift) were deposited either in front of the ice or beside the ice. At this STOP on the east side of the valley, the sand and gravel was deposited as an ice-marginal kame terrace feature. The material was deposited on dead ice, as shown by the collapse features described below, with active ice beside it in the middle of the valley. The deposit is only found on the east side of the valley because it was fed by a sluiceway from the next valley to the east, the Little Egypt Creek valley (Figure 107). Both north and south of this site are three kame deltas that were built into the lengthening Glacial Lake Great Bend (Figure 107, KD). The northernmost delta, like at this site, was fed by a sluiceway from the adjacent Little Egypt valley.

The top of the deposit at this STOP is below the level of Glacial Lake Great Bend so it was once capped by a relatively thin sequence of glacial lake sediments from the final recession of the ice from the area. Postglacial erosion has removed the lake sediments and much of the kame. As noted in Braun (this guidebook, p. 32-38) and at STOP 2, within the area of Glacial Lake Great Bend, there is another glacial lake sediment unit observed under the glacial deposits that typically form the present ground surface. Opposite this site, Beaver Creek enters the west side of the Salt Lick valley. In that tributary valley, varved sediments were observed under thick till deposits (circled V on Figure 107). Presumably varves underlie the sand and gravel at this site but are below the present valley floor level and so do not cause slumping in this area.

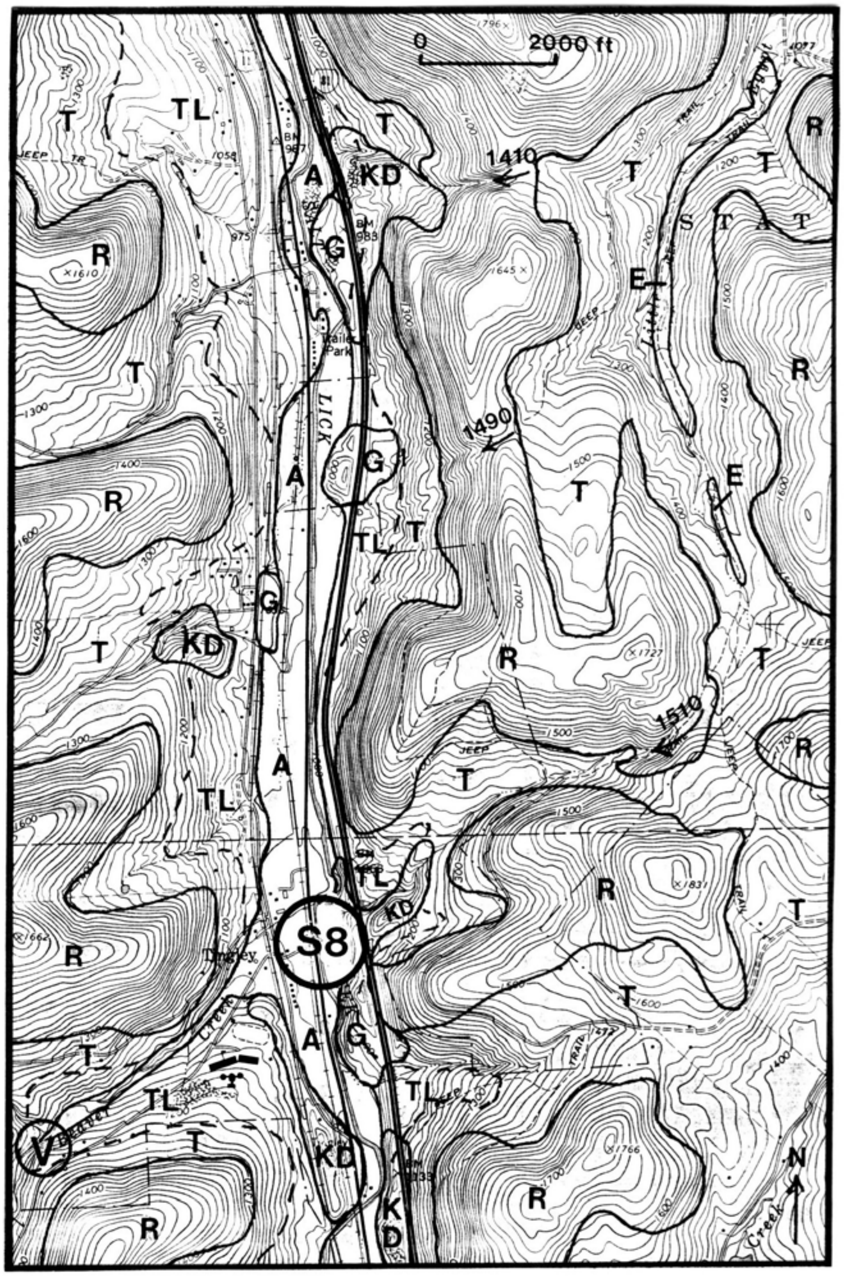


Figure 107. Map of surficial deposits around STOP 8. A = alluvium, E = esker, G = ice-contact gravel, KD = kame delta, R = bedrock, T = till, TL = till underlain by lake sediments, circled V = exposures of varved sediments overlain by till, Arrows with numbers = location and elevation of sluiceways from Little Egypt valley (from Braun, 2001b).

		Leave STOP 8, returning to US 11 and turning right (north).
0.3	33.8	To left are “mucky” fields that may mark the site of the “bottomless” Summersville swamp, which caused considerable trouble during railroad construction through here in 1912-1915.
0.5	34.3	To left on the hillside, partly hidden by trees, is another gravel pit in a “hanging delta” showing a foreset-topset contact at an elevation of about 1200 feet, the elevation of Glacial Lake Great Bend.

1.3 35.6 To right, on the hillside above I-81 is a distinct notch cut by the overflow from a proglacial lake in the Little Egypt Creek Valley into an early phase of Glacial Lake Great Bend (see Day-1 Roadlog, mile 72.2; Figure 93).

1.4 37.0 Borough of Hallstead, built on the high outwash terrace of the North Branch Susquehanna River. Originally part of Great Bend, which once occupied both sides of the river, Hallstead was renamed in honor of DL&W General Manager W. F. Hallstead at the turn of the 20th century.

0.3 37.3 On right is Humbie's Diner, where you can get "lost in the 50's" while enjoying hot cider and "humbeans."

0.3 37.6 Traffic light for construction of new bridge, continue straight.

0.1 37.7 Cross North Branch Susquehanna River where a new bridge is being constructed. To left the river turns sharply northward to complete the west side of the Great Bend of the river and to re-enter New York State. The new four-span concrete bridge nearing completion here is the seventh (or eighth if the temporary "Bailey-bridge" is included in the count) at this spot since 1814, Susquehanna County's oldest principal bridge crossing. Previous structures were completed in 1814, 1822, 1832, 1846, 1874, and 1926. The first four (wooded covered bridges) were destroyed by ice-jam floods. The fifth, originally a four-span wood truss, went through extensive changes over many years as individual spans were modified and replaced. The sixth, a 600-ton, steel, Platt-truss was toppled into the river on December 11, 2001, serving for 75 years "to the day" (Young, 2002).

0.1 37.8 To right between the north bank of the river and the McDonald's parking lot is the site of the Great Bend archeological site (see Thieme, this guidebook, p. 44-48), studied in 1999 as part of the engineering investigation for the new bridge.

0.1 37.9 To right is a Historical Marker that reads:
Joseph Smith, founder of Mormonism, once lived a few miles east of here prior to 1830. Much of the translation of the "Golden Plates" for the Book of Mormon is said to have been done there. Site is now owned by the Church of Latter Day Saints.
See also Day-1 Roadlog, mile 63.3.

0.1 38.0 Bear right onto PA 171 just before traffic light.

0.1 38.1 Pass under I-81.

0.2 38.3 Pass over Norfolk Southern Railroad tracks (the old Erie grade from the Starrucca Viaduct).

0.8 39.1 Turn right into parking area of the Great Bend Township Municipal Building. Disembark and walk south to railroad tracks, then east to high rock cut.

STOP 9. UPPERMOST PART OF LOCK HAVEN FORMATION AT THE "RED ROCK."

Leaders: Jon D. Inners, Donald L. Woodrow, and Thomas A. McElroy.

The vertical rock cut at this point on the north side of the Norfolk Southern (originally Erie) Railroad tracks at this point marks the northwestern end of a nearly continuous series of cuts that extend for more than a mile upstream along the river (Figure 108). (Another deep cut lies just to the east, but the discussion here concerns only the western cut.) Because the rock layers are about as close to flat lying as possible, virtually the same sequence of strata is exposed here as at the other end. Before the construction of the railroad, high cliffs bordered both sides of the river for much of this distance, the area being known to the early settlers as the "Painted Rocks," or "Red Rocks" because of Indian paintings on the cliffs (Blackman, 1873; White, 1881). Blackman (p. 52) notes: "The Erie Railroad, by their improvement, have cut away the rock on the north side, thus destroying the original beauty of this once interesting spot. White (p. 91-92) says that the paintings were on the cliffs on the south side. But more on the cliffs later.

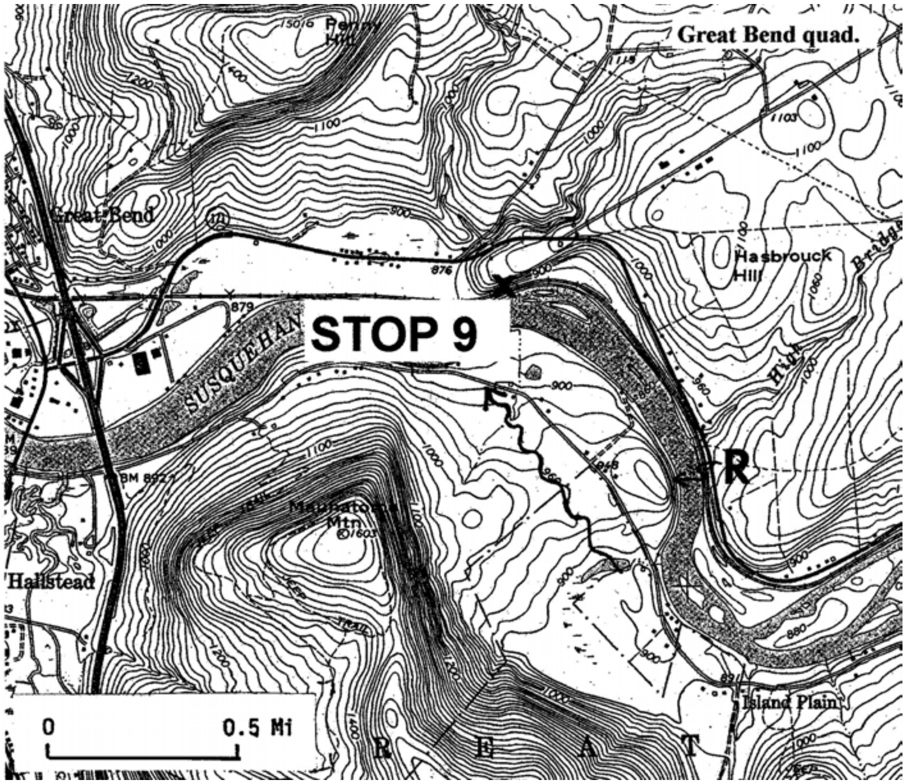


Figure 108. Location map for STOP 9. R = "Red Rock" cliffs; arrow = old channel of the Susquehanna River.

Geology. The 40-45 feet of interbedded gray, olive- and brown-weathering fossiliferous sandstone and silty shale (Figures 109) exposed here occur very near the top of the Late Devonian-age Lock Haven Formation, the mostly shallow-water marine phase of the Catskill Delta complex. The rock sequence in the cut consists of a lower 20-foot-thick shaly interval, containing a few widely spaced thick, continuous sandstone beds and several "ball-and-pillow" zones, as well as two distinct submarine-slide horizons; a medial 15± foot-thick interval of thinly interbedded sandstone and shale; and an upper 6-foot-thick interval of thick-bedded fossiliferous sandstone (Figure 110). At least 5 feet of interbedded fossiliferous sandstone and shale overlie the thick, upper sandstone in an old quarry above the cut. Both the sandstones and shales are medium gray to medium dark gray, and the sandstones commonly contain lenticular coquinite beds.

Fossils. Though the coquinite layers are clearly evident in the rock outcropping (Figure 111), they are not very common in the rubble at the base of the cut. (Layers like this are the source of the fossiliferous pebbles and cobbles seen in the New Milford Sand & Gravel Co. pit at STOP 8). Fossils that can be collected here are mostly the shells of marine brachiopods—especially of the genera *Cyrtosprifer* ("butterfly"-shaped shells) and *Ptychomaletoechia* (small, rounded-triangular, strongly ribbed shells)—and the disarticulated stem-plates of crinoids (round, wheel-like disks) (Figure 112).


Figure 109. Interbedded sandstones and shales of the upper part of the Lock Haven Formation along the Norfolk-Southern Railroad tracks at STOP 9.

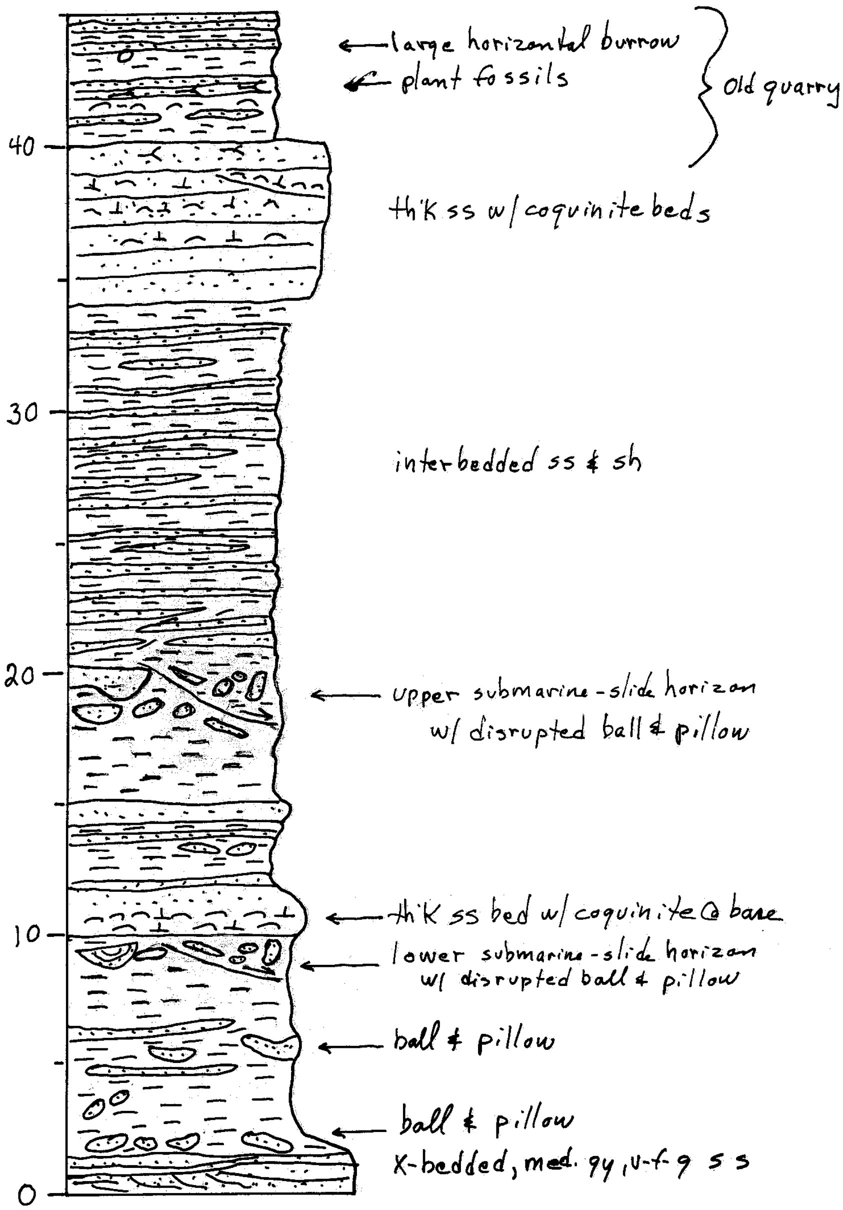


Figure 110. Generalized stratigraphic section of the rocks exposed at STOP 9.

It is probable that this uppermost part of the Lock Haven Formation was deposited under conditions generally unsuitable for marine invertebrates, due to presumed low salinity of the water and the rapid influx of muds and silts from the rivers and distributaries of the subaerial Catskill Delta. The lenticular bands of fossils accumulated when tidal and storm currents swept shells from areas of more normal marine salinity into channels and nearshore zones, where they were deposited as a "hash" of partially broken shells and other debris (Hoskins et al., 1983).

Ball-and-pillow structures and submarine slides. The ball-and-pillow structures are far and away the most significant and interesting aspect of this STOP. These rather chaotic balls and blobs represent parts of sandstone beds that have "foundered" into once soft and soupy mud beds below (Pettijohn, 1975; Sorauf, 1965; Howard and Lohrengel, 1969). Many of the "balls" and "pillows" occur in distinct groups (Figure 113 and 114) that appear to be more or less *in situ* (not laterally translated). Others are clearly part of two submarine slide zones—at about 10 feet and 20 feet above the base of the cut (see Figure 110; Figures 115, 116, 117, and 118). Both of these slide zones appear to have moved from west to east, with large "slabs" of sandstone piled up at the east end.

The long axes of several measured elongate "pillows" are aligned N80^{o}E-S80^{o}W, virtually the same orientation found by Sorauf (1965) found for 68 pillows in roughly equivalent "Chemung" rocks in Broome County, New York, just to the north. Sorauf (p. 562-563) postulated that such oriented pillows formed by foundering of sand beds in channels cut into the paleoslope, the elongation corresponding to the east-to-west sediment-transport direction generally recognized in these rocks. If this is the case, and it appears most reasonable, the west-to-east movement of the two submarine slides is puzzling. Perhaps there was a slight "roll" in the paleoslope in this area that allowed for localized "slumping" off to the east.

The two main "ball-and-pillow zones" can be traced for more than a mile in cuts along the railroad grade to the east. The occurrence of these structures in distinct horizons for relatively long distances along an outcrop or series of outcrops suggests that they mark an "event" of some significance.

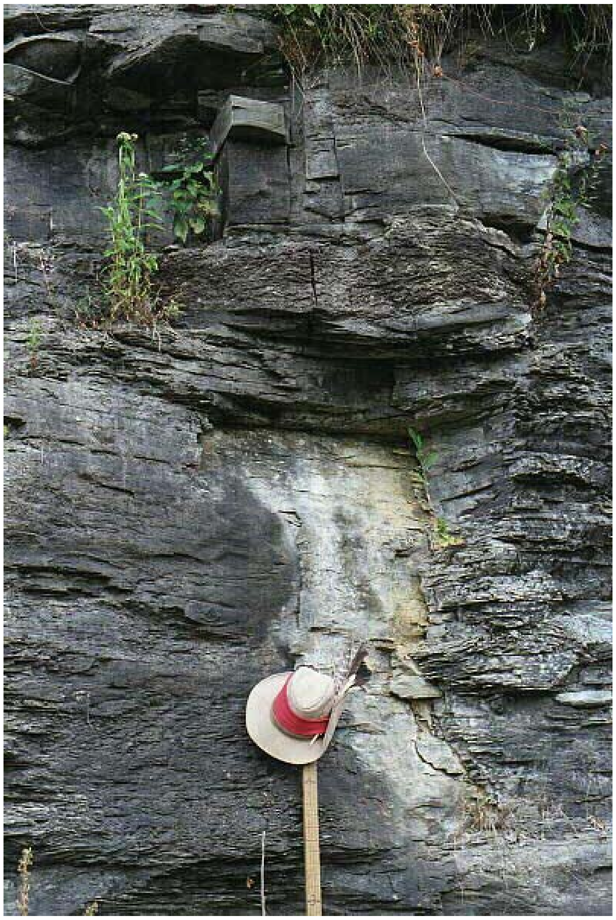


Figure 111. Calcareous brachiopod-crinoid coquinite bed at the base of the sandstone 11 feet above base of the section.

Perhaps an earthquake shook the sea floor and caused sandy layers to partially break up and sink irregularly into underlying muddy layers (Sorauf, 1965). Then again, perhaps an extremely rapid influx of sand due to coastal storms or delta floods overwhelmed the muddy layers, trapping an excess of water within the mud and creating an unstable "foundation" for the deposited sandy layers (Fletcher and Woodrow, 1970).

More on the cliffs. I. C. White (1881, p. 91) writes of the "Red Rock" area: "About two miles above Great Bend depot the Susquehanna River flows through a narrow gorge, only 100 yards wide, where it is hemmed in by vertical walls of outcropping sandstone." (He refers to the mile-long, north-flowing reach of the river from Island Plain on the south bank to the vicinity of STOP 9.) He later (p. 93) observes that this is "evidently a new cut, since the ancient channel of the stream may now be seen one half mile further south, filled with drift which silted it up during the Glacial Epoch..." The Great Bend topographic quadrangle map clearly shows this old channel—now filled with more than 100 feet of glacial drift. Diversion of the river to its present bedrock channel probably occurred at least as long ago as the Late Illinoian glaciation, about 150,000 years ago (D. Braun, 1999, personal communication). Till and gravel of this age almost certainly still exist buried beneath the Late Wisconsinan (20,000-year old) drift shown as the surficial deposit on the geologic map (Braun, 2001b).

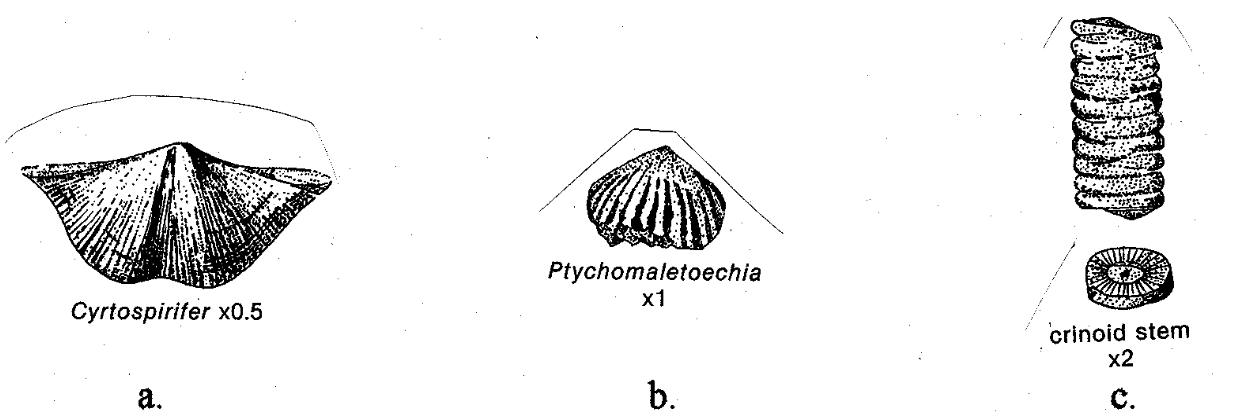


Figure 112. Some invertebrate fossils from the Lock Haven Formation. A. Cyrtospirifer; b. Ptychomaletoechia; c. crinoid stem.

Figure 113. Group of several pillows about 3 feet above the base near the west end.

Figure 114. Large, coarsely ribbed “pillow” and several small “balls” about 8 feet above the base in medial part of cut.

Figure 115. Upper submarine-slide horizon about 18 feet above the base of section. Note the peculiar elongate “flow” structure on the left (west) (see Figure 116), indicating “flow” toward the right (east). The slide zone appears to end in several nearly vertical sandstone blocks at the east end (see Figure 117).

Figure 116. Close-up of “flow” structure at west end of upper submarine slide horizon.

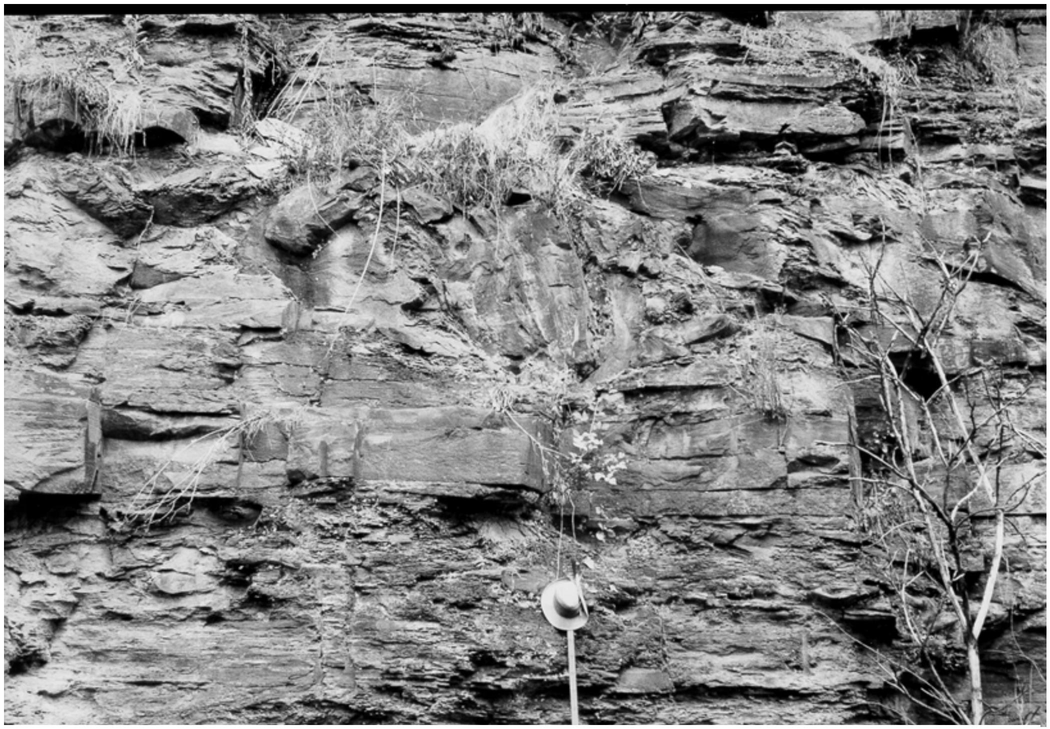


Figure 117. Close-up of subvertical sandstone blocks at east end of upper submarine slide horizon.

Figure 118. Lower submarine-slide horizon about 10 feet above the base of the section at the east end. Note the disrupted beds and translated “balls” and “pillows,” movement apparently being to the right (east) where several large “pillows” are piled up.

		Leave STOP 9, turning left on PA 171.
1.3	40.4	Traffic light. Turn left on US 11 South.
0.2	40.6	Cross North Branch Susquehanna River into Hallstead.
0.2	40.8	Traffic light. Turn right on Franklin Street.
0.2	41.0	Stop sign. Turn right on Pine Street.
0.1	41.1	At barrier, turn left on Church Street.
0.1	41.2	Pass under "new" DL&W grade at concrete bridge.
0.2	41.4	Turn left on Dubois Street (SR 1037).
0.6	42.0	To right is Dubois Creek. Note ledges of Lock Haven sandstone on bottom of creek.
0.2	42.2	Cross over Dubois Creek.
0.1	42.3	To right a small tributary valley enters the Dubois Creek valley. Once a township road went up the valley but it was abandoned because slumping on the Glacial Lake Great Bend sediments kept destroying the road.
0.2	42.5	To right is an outcrop of Lock Haven Formation.
0.3	42.8	To left is the Hallstead-Great Bend Rod & Gun Club. Upstream of the club and hidden by the forest are a series of slumps on the varved silts and clays of Glacial Lake Great Bend.
0.5	43.3	Stop sign. Turn right on SR 1022 and start ascending a tributary valley.
0.8	44.1	Rise above the water level of Glacial Lake Great Bend.
1.3	45.4	Directly ahead on the far hill is a big "bluestone" quarry. Note the huge waste dump draped down over the slope to the right of the quarry.
1.5	46.9	Cross Snake Creek. This north-draining valley also contained a large proglacial lake as the ice receded northward. Its downstream reaches were part of Glacial Lake Great Bend.
0.2	47.1	Stop sign. Turn left onto PA 29.
0.8	47.9	Village of Lawsville Center.
1.4	49.3	Village of Franklin Forks, bluestone wall on the right.
0.2	49.5	Turn right on SR 4008 and proceed up the Silver Creek valley. The valley has an asymmetric cross-profile with a much steeper south side. The valley is transverse to ice flow and has a thick "till shadow" on its north side (right) with the present creek on the steeper south side (left) of the valley, undercutting the bedrock.
1.0	50.5	Turn left at entrance to Salt Spring State Park. Cross Silver Creek about 0.1 mile from entrance. To right upstream, hidden in the vegetation, are a series of slumps on varved sediments. In places, varves are exposed at and below water level along the north bank. Proceed to parking lot and disembark.

STOP 10 AND LUNCH. SALT SPRING STATE PARK: THE SALT SPRING, FALL BROOK GORGE AND WATERFALLS, AND GAS WELL.

Leaders: Jon D. Inners, Duane D. Braun, Debra Adleman, and William E. Kochanov.

Salt Spring State Park, located a the junction of Fall Brook and Spring Creek, in Franklin Township (Figure 119), is a small, but neglected, gem of the Commonwealth's park system. With a rocky post-glacial gorge, three waterfalls, a historic salt spring, and the preserved site of an early 20th-century gas well, few larger state parks have as much intrinsic historical and geological interest as does this approximately 700-acre tract tucked away in the wilds of north-central Susquehanna County. The park is administered by Lackawanna State Park, 29 miles to the south-southeast, but operated and maintained on a day-to-day basis by a local volunteer group, the Friends of Salt Spring State Park.

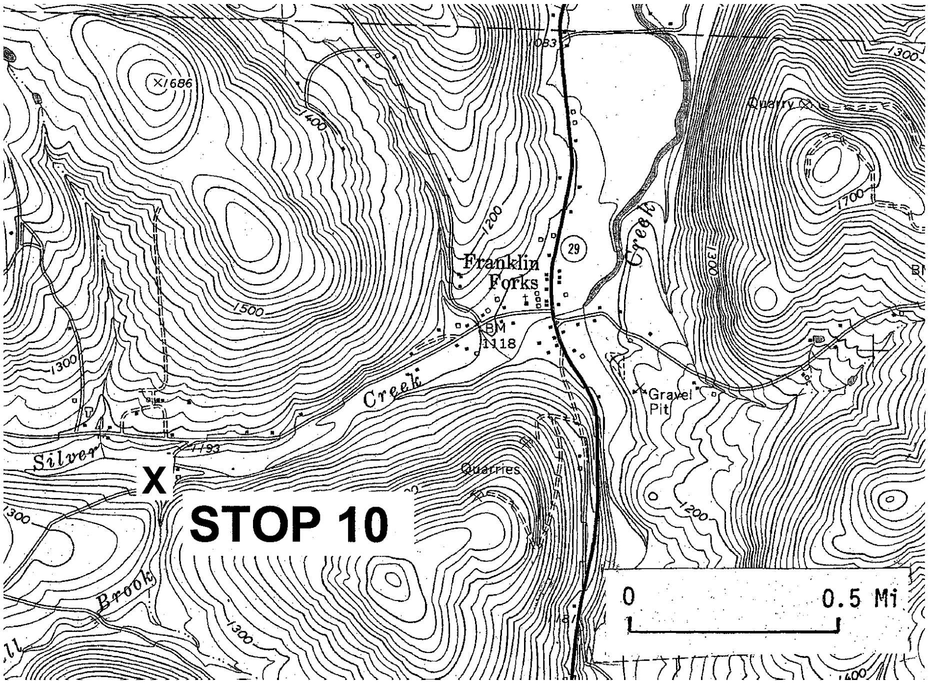


Figure 119. Location map of STOP 10 (Salt Spring State Park).

The park was part of a working dairy farm owned by the Wheaton family until it was sold to the Nature Conservancy in 1973. A year later it was turned over to the Commonwealth for incorporation into the state park system. The original house, built in the 1840's at the mouth of the Fall Brook gorge, is the Park Headquarters and education center and is currently being renovated by the Pennsylvania Conservation Corps. In the middle of the floodplain of Silver Creek is a newer house (circa 1880) that will be used as a rental residence.

GEOLOGY

Salt Spring State Park contains two features of significant geologic interest—the spring itself and the "postglacial" bedrock gorge (and its waterfalls).

The spring. The salt spring—those history is discussed in more detail below—is situated at the base of the bluff on the south side of Fall Brook about 300 feet east of the mouth of the gorge. Flow is generally very low, and in the summer the level in the pipe below the stone-lined basin of the spring is practically static, the only activity being the bubbling of very small quantities of natural gas. As should be expected, water from the spring is very high in chloride and sodium, but also extremely high in dissolved solids (Table 5A). In comparison, water from a nearby drinking-water well contains less than 20 percent as much chloride and sodium and about 13 percent as much dissolved solids (Table 5B). The methane bubbling from the well is an indication of the gaseous nature of the Upper Devonian sandstones at shallow depth (see below).

The gorge. The 80±-foot-deep gorge of Fall Brook (Figure 120) exposes a good local section of the Late Devonian-age Lock Haven Formation, which consists here of interbedded gray sandstone and shale that dip very gently to the south (Figures 121 and 122; Kochanov, 2002). The sandstones are typically thin to medium bedded, planar to crossbedded, medium light gray to medium gray, and well jointed. The shales are thin to thick bedded, medium gray to medium

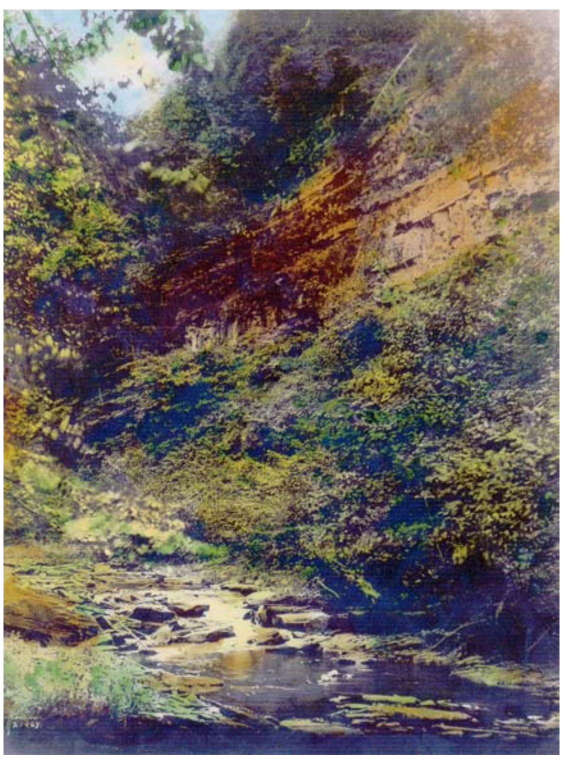


Figure 120. Vintage water-colored black-and-white photograph of the west wall of the Fall Brook gorge below the lower falls. This photo and those shown as Figures 129 and 130 were taken by John Horgan, Jr. (1859-1926), the great industrial photographer of the Pennsylvania Anthracite region (see Percival and Kulesa, 1995). (Photo from the collection of the Susquehanna County Historical Society.)

Table 5. Comparison of water analyses from the salt spring (A) to that from a nearby drinking-water well (B), Salt Spring State Park. (Samples collected 8/4/99 by Gary M. Fleeger and analyzed by PaDEP Bureau of Laboratories, 8/25/99.)

Sample ID	Description	Reported Results
A. 9201-001		
	sulfide	<0.1 mg/l
	chloride	4200.0 mg/l
	sodium	2330.0 mg/l
	TDS @ 105°C	8940 mg/l
B. 9201-002		
	sulfide	<0.1 mg/l
	chloride	671.0 mg/l
	sodium	428.0 mg/l
	TDS @ 105°C	1178 mg/l

TDS = Total Dissolved Solids

dark gray, and silty to sandy. Rippled bedding surfaces are common in the sandstones, and the shales are infrequently burrowed. Invertebrate fossils (brachiopods and crinoid fragments) are relatively rare, the only bed which was observed to contain abundant fossils being the "Mansfield iron-ore bed" (here containing very little iron) about 5 feet stratigraphically above the top of the lower falls (Figure 122). Though recognized in this area by I. C. White (1881), the Mansfield bed is always too lean to have offered 19th-century promoters any incentive to mine it (see Inners, 1999).

In contrast to the usual situation in Susquehanna County (and indeed in all of northeastern Pennsylvania), the dominant joints in the Lock Haven strata of the Fall Brook gorge belong to the "east-west" set—most striking about N85°W. These fractures are planar, vertical to subvertical, and spaced 4 to 12 inches apart (see Figure 125).

The three falls in the gorge are 11 feet (lower), 13 (middle) (Figure 123), and 7 (upper) (Figure 124) feet high, with a 3.5-foot-high mini-falls between the middle and upper falls. The dominant N85°W joint exerts a major influence on the configuration of the upper falls (Figure 125), and its effects are also evident in the crestline of the middle and lower falls (Figure 126).

The origin of the gorge and falls. Fall Brook starts in a broad, open valley and then enters a narrow, 80-foot-deep bedrock gorge where it cascades over three (and a half) waterfalls before joining Silver Creek (Figures 127 & 128). Such a steepening or knickpoint in a stream's longitudinal profile indicates a geologically recent drainage derangement. In this case the derangement was caused by glacial deposits burying the preglacial course of Fall Brook enough to force the stream to drain across a saddle in the divide between it and the adjacent Silver Creek valley (Figure 128). Fall Brook's original direction of flow started out northeasterly and then, at the saddle, turned southeasterly (bold arrows on Figure 127). The valleys of both Fall Brook and Silver Creek are transverse to ice flow and thick till shadows (explained more in Braun, this guidebook, p. 32-38) were deposited in both valleys (Figure 128). The till shadow in Fall Brook valley, in the lee of a high bedrock hill, got so thick that it formed a knob in the valley that was higher than the saddle in the divide just up-valley (Figures 127 & 128). Upon ice recession, the stream was forced to drain over the saddle to Silver Creek and cut the present bedrock gorge.

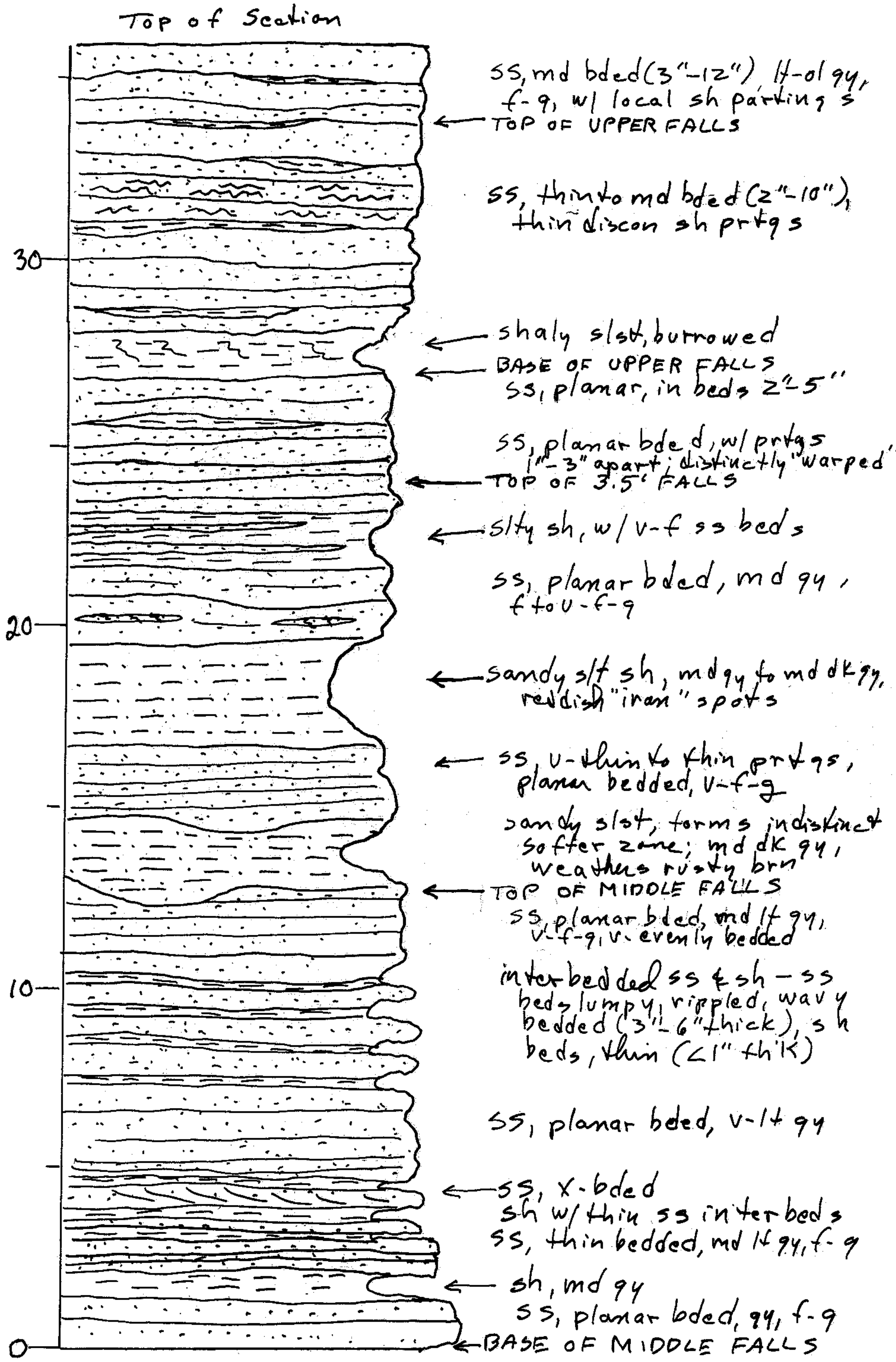


Figure 121. Generalized stratigraphic section of Lock Haven strata exposed in the Fall Brook gorge from the base of the middle falls to the top of the upper falls.

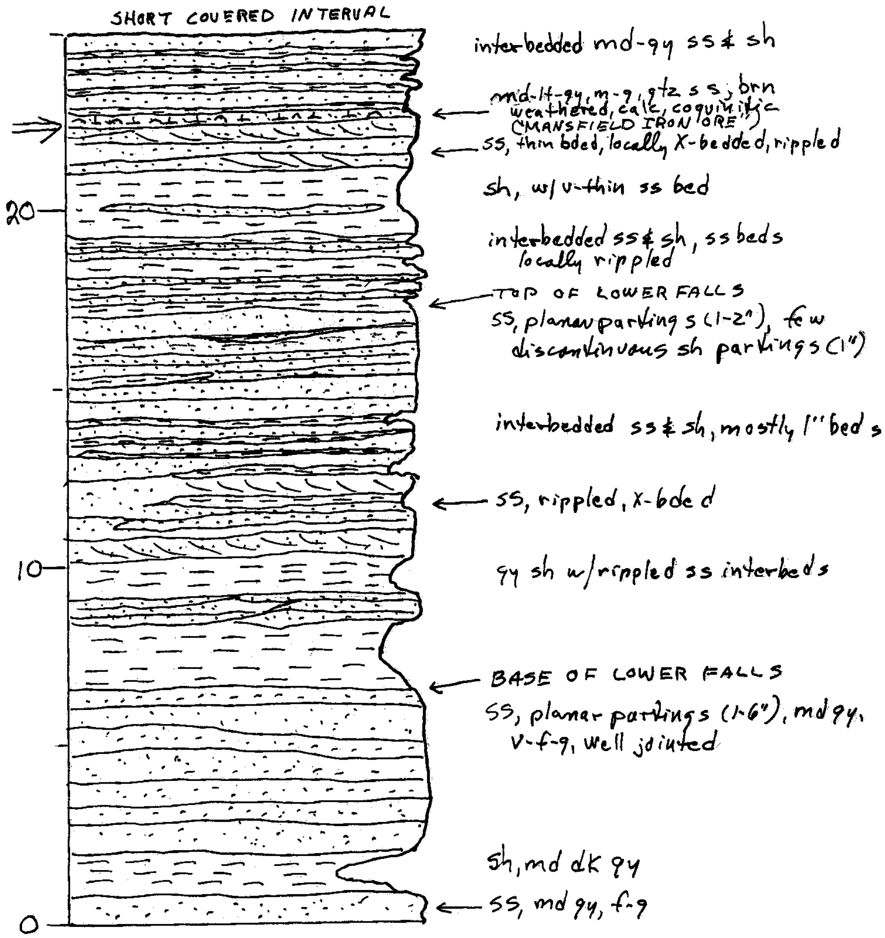


Figure 122. Generalized stratigraphic section of Lock Haven strata exposed from a little below the base to a little above the top of the lower falls.

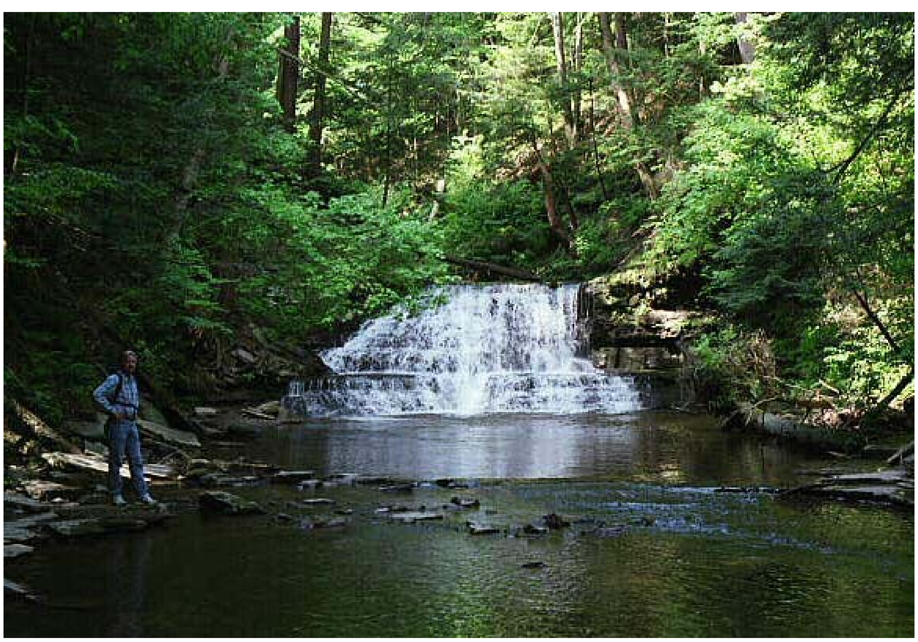


Figure 123. The middle falls in the Fall Brook gorge. "Devonian sojourner" Don Woodrow provides scale.

Figure 124. The upper falls in the Fall Brook gorge

Figure 125. "East-west" joints at the crest of the upper falls. Retreat of the falls is probably caused mainly by ice wedging in the joint fractures and subsequent "quarrying" out of the loosened blocks at times of very high stream flow.

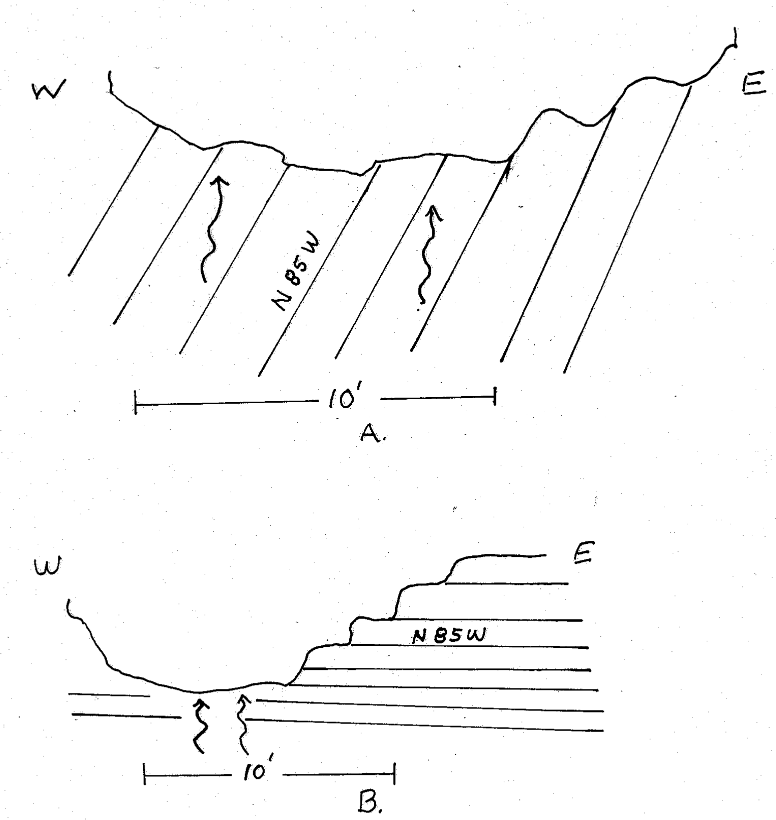


Figure 126. Generalized drawing showing relationship of N85°W joints to crestlines of middle (A) and lower (B) falls.

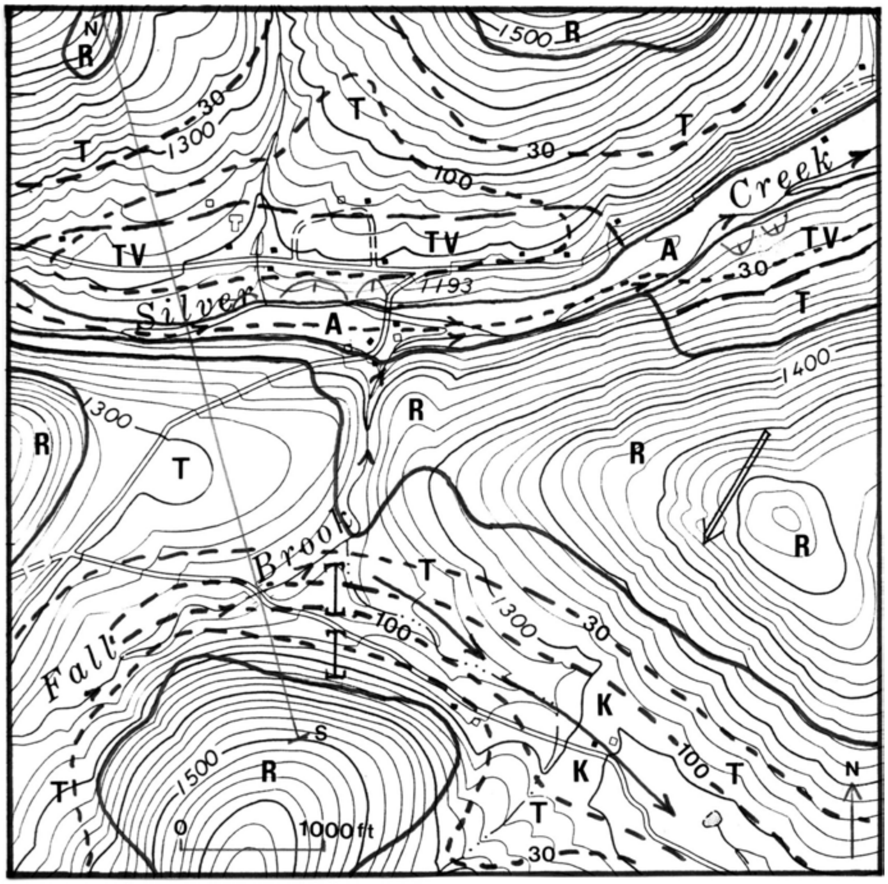


Figure 127. Surficial geology map of the Salt Spring State Park area, showing the now incised saddle that once separated Fall Brook from Silver Creek. The preglacial course of Fall Brook is shown by two bold arrows. Lines with brackets are seismic profiles. K = till knob that blocked Fall Brook's original course, A = alluvium, R = bedrock, T = till, TV = till and varved sediments, hachured arcs = slumps, double arrow = ice flow. Isochores of surficial deposits at 30 and 100 ft (Braun, 2001a)

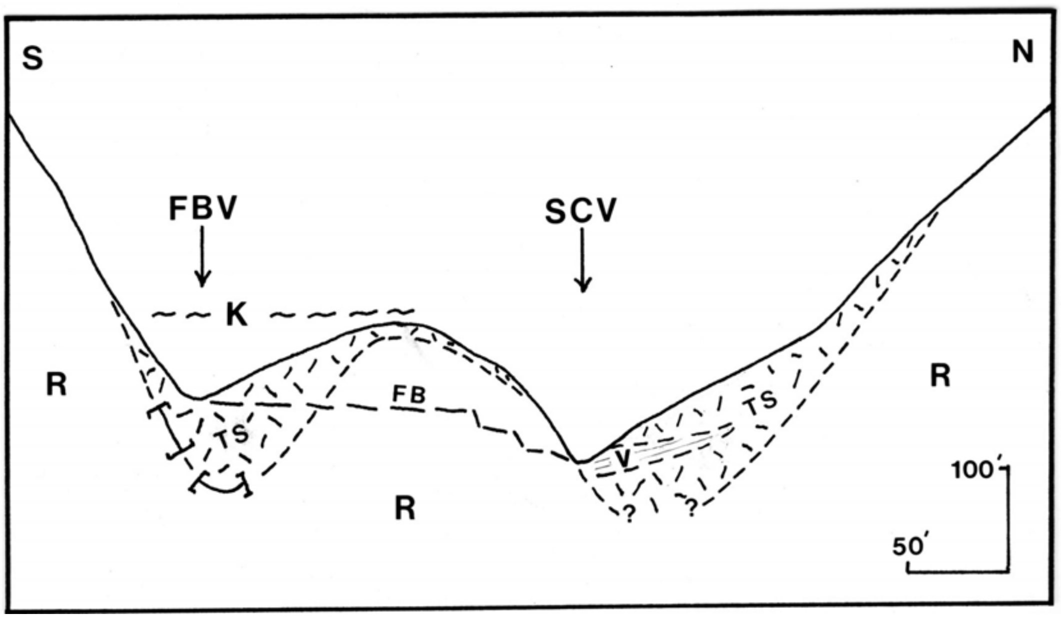


Figure 128. Composite cross section of the east-trending Fall Brook valley (FBV) and Silver Creek valley (SC), showing the till shadows in each valley. A till knob (K) to the east in Fall Brook valley, higher than a saddle in the divide between the two streams, diverted Fall Brook across the divide where it carved the present gorge (long dashes marked FB). Lines with brackets mark the seismic refraction profiles that determined bedrock floor of FBV. R = bedrock, V = varved sediments.

The presence of Fall Brook's buried preglacial valley was confirmed by seismic refraction profiling (Krauss, 2002). The profiles were done just south of the bedrock gorge (lines with brackets on Figure 127). The middle of the preglacial Fall Brook valley is buried by 100 feet of till (lines with brackets on Figure 128). Within a few hundred feet horizontally, the till thins to zero both north and south of the seismic profile lines.) The cross section in Figure 128 was drawn to best show the till shadows. (It runs a bit west of the actual seismic profile lines (Figure 127).) The seismic lines were projected onto the Figure 128 profile.

HISTORY

The salt spring and the nearby salt well. According to tradition, the Indians knew of several salt springs in what is now Susquehanna County, including the one in Salt Spring State Park. Most probably, the first white settlers to discover the "Franklin salt spring" were Abinoam Hinds and Isaac Perkins in about 1802. (The Indians were said to have kept carefully concealed the spring after they left the area, having turned the brook from its course and made it run over the site.) Some years later, probably in 1810, Judge Balthaser DeHaert and his brother started a boring near the spring. They encountered rock at about 20 feet and over the next several years continued to a depth of 300 feet. After this effort was given up, Nicholas Biddle renewed the boring and by about 1825 drilled it down to 500 feet. He abandoned the well at that point, and the less enterprising—or more sensible—settlers who bought the land turned to agricultural pursuits. The tool used by the DeHaerts and Biddle for boring was a hand-operated spring-pool—and it seems remarkable that they, or any of the early salt drillers, could obtain depths of many hundreds of feet with such primitive equipment.

Interlude: About 15 years after the abandonment of the old salt well, Daniel Keeler built a woolen mill on the west side of Fall Brook at the mouth of the gorge. This was a two-storey factory building, 24 feet by 50 feet, and was equipped with machinery for carding and fulling wool, and for making coarse cloths. Mill power was derived by means of a flume directly from the lower(?) falls to a waterwheel, which ran the machinery. The mill operated for about 10 years. Its stone ruins can still be seen just south of the Headquarters building near the site of the gas well (see below).

In January 1865, the "Susquehanna Salt Works Co." purchased the property and commenced deepening the old well, using a 15-horsepower steam engine and improved drill bits. As the initial step, they reamed the existing boring, which was 3¼ inch, to a diameter of 4½ inch, averaging about 10 feet in 24 hours for this operation. Eventually, they deepened the well to 650 feet and encountered several veins of fresh and salt water down to 380 feet, but no fresh water below that depth. The strongest vein of salt water was hit a few feet from the bottom of the well, from which about 20 tons of high-quality dairy salt were manufactured. But this production did not provide sufficient financial return to investors, and the project was abandoned.

In 1870, a new company, the "Susquehanna Salt and Mining Company," purchased the entire title and interest of the former company, and reportedly pushed the well down to a depth of 800 feet, where a "vein of brine of greater richness than any yet reached" was encountered. This brine could supposedly preserve meat "in its crude state."

The Franklin salt spring is one of several "mineral springs" in western Susquehanna County. Others are reliably reported to be located in Rush Township on Wyalusing Creek, 10 miles west of Montrose, where mineral "booths" were developed (probably in the 1850s'); on the Middle Branch of the Wyalusing in Forest Lake Township, on the old Jesse Birchard farm; and in Middletown Township, about ½ mile north of Middletown Center, on the Cahill farm, where a salt well was sunk in 1825 and deepened in 1828. (In 1865 a "wildcat" oil well—the so-called "Coryell well"—was sunk to a depth of 600 feet about 70 feet away, but found no petroleum.)

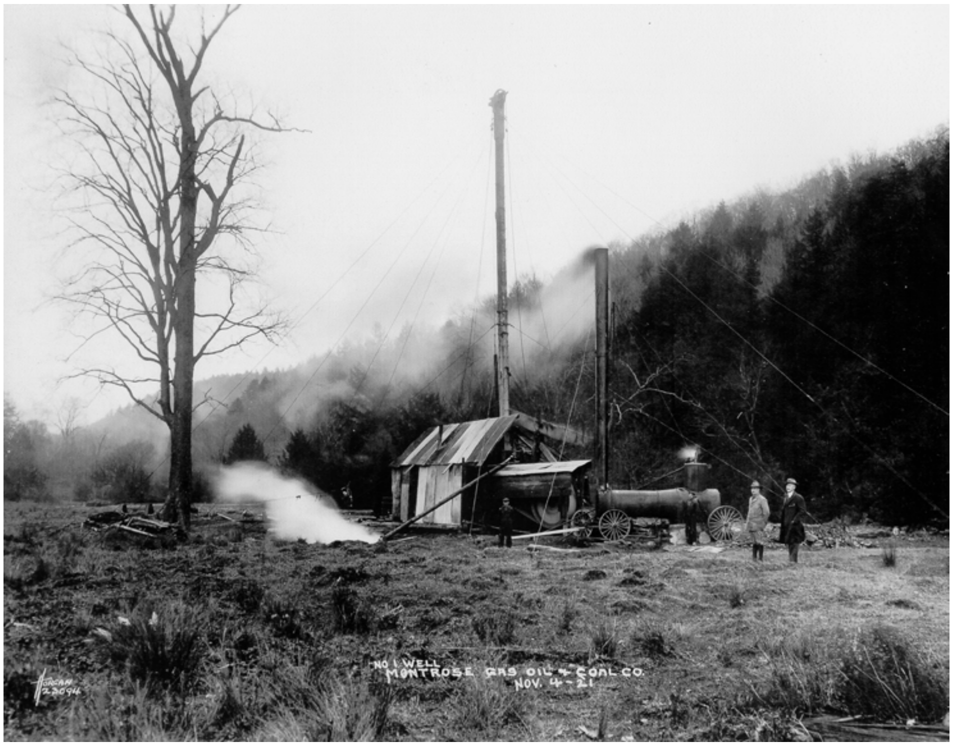


Figure 129. The No. 1 well of the Montrose Gas, Oil and Coal Company being drilled on the Wheaton farm (or somewhere nearby) in November 1921. (Horgan photograph from the collection of the Susquehanna County Historical Society.)

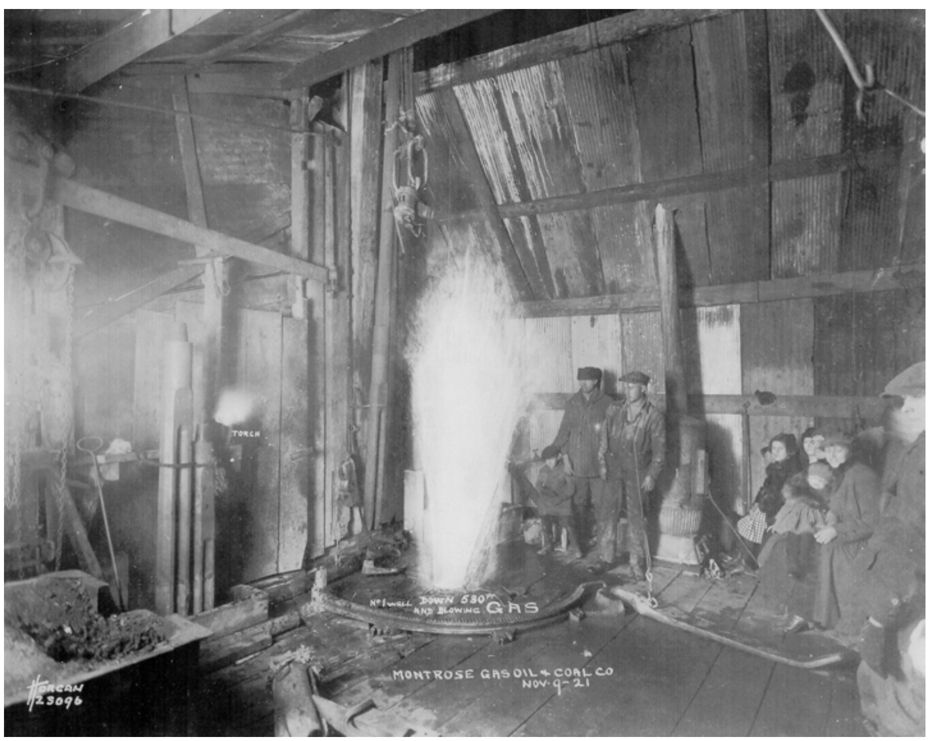


Figure 130. The No. 1 well, “down 530 feet and [reputedly] blowing gas.” This is a peculiar photo which may not be “telling the whole truth.” J. Harper (2002, personal communication) thinks that this is probably some sort of “staged” photograph: perhaps the negative was tampered with to provide the “incandescence” that is shooting out of the hole. (Horgan photograph from the collection of the Susquehanna County Historical Society.)

Montrose, where mineral "booths" were developed (probably in the 1850s'); on the Middle Branch of the Wyalusing in Forest Lake Township, on the old Jesse Birchard farm; and in Middletown Township, about ½ mile north of Middletown Center, on the Cahill farm, where a salt well was sunk in 1825 and deepened in 1828. (In 1865 a "wildcat" oil well—the so-called "Coryell well"—was sunk to a depth of 600 feet about 70 feet away, but found no petroleum.)

The gas wells. In 1901, unidentified interests drilled a test gas well "about 50 rods"(?) west of the salt spring (at the site of the stone ruins just south of the park headquarters) and reached a total depth of about 2000 feet. An "oiled sand" with a "marked flow of sand" was encountered at 900 feet (i.e., in the Lock Haven Formation). After a dispute with the drillers, the well was abandoned and plugged at 500 feet. But enough gas forced its way around the plug to supply the nearest house on Wheaton homestead (now the Park Headquarters building) with gas for more than 20 years. The gas was collected in a shed about 10 feet square built over the wellhead (the present stone ruin on the west bank of Fall Brook where it emerges from the gorge). The Wheatons' placed a large container over the wellhead to collect the gas seeping around the plug. A buried pipe then carried the gas to the house where it was used for lighting and cooking. The collecting tank was reportedly buoyant, "pressing like a balloon" against the nailed-down floorboards of the shed.

In 1920 the Montrose Gas, Oil and Coal Company was incorporated under the laws of the State of Delaware, with a capital stock of $300,000 divided into 30,000 common-stock shares at a par value of $10 each. The plan of the new company was to supply gas to Binghamton industries. By October of that year, the Montrose businessmen promoting the company, claimed to have leased the Wheaton farm, 1200 acres in the immediate vicinity, and 500 acres over the hills to the south—making 1700 acres in all. The Montrose Company drilled at least three wells over the next few years (Figures 129 and 130), but no more information on them has been gathered to this time. The fact that the company publicized statements that, though they were primarily seeking gas, they believed that there was "every indication also of oil and coal" on their leased lands strongly suggests an element of chicanery.

Two other interests were actively seeking or buying up leases in the area at the same time. A Harry L. Johnson, said to be from Tulsa, Oklahoma, and representing a "Mysterious Company," is reported to have stated "that in all his experience he never came across any section—and he claims to have been in the best oil and gas regions of the country—that 'looks more promising.'" And Mr. Thomas O'Brien of Binghamton—who filed his intentions in Harrisburg and Montrose to do business as the aptly named "Snake Creek Coal, Oil and Gas Company"—said that he had "analyses by chemists" that indicated the presence of coal on the more than 2000 acres of land that he owned or leased in the area. (He also claimed to have "two pieces of copper in lode form" taken from this land.) Clearly such promotions bordered on the criminal, but after all it was the beginning of the "Roaring Twenties"—and it would be another decade before "the chickens would come home to roost."

(The above historical sketch is based on Blackman, 1873, Stocker, 1887, and clippings from various 19th- and early 20th-century Montrose newspapers collected by Debra Adleman of the Susquehanna County Historical Society.)

		Leave STOP 10, returning to Park entrance. Turn right on SR 4008 and proceed back to PA 29.
1.0	51.5	Stop sign in Franklin Forks. Turn right on PA 29.
1.1	52.6	To right is the buried preglacial valley of Fall Brook, the stream that now flows over the falls at Salt Creek State Park.
2.7	55.3	Enter Bridgewater Township.
1.0	56.3	To right is an abandoned stone dam on Snake Creek.
0.1	56.4	To left, behind storage building "Mall" are cuts exposing 10's of feet of reddish-brown silty-matrix, stony till that is typical in the area.

0.4 56.8 To left is a cut in Catskill sandstone and a small bedrock gorge. On the right is another stone dam. The stream in its downcutting has just “caught” the west bedrock wall of the buried headwater valley of north-draining Snake Creek. To left beyond the bedrock outcrop is the preglacial floor of the valley now buried by more than 200 feet of till.

0.1 56.9 To left, Lake Montrose—its level raised by a man-made dam—occupies the till dammed basin at the head of Snake Creek.

0.3 57.2 Stop sign at intersection of PA 29, PA 167, and PA 706. Bear right (almost straight ahead), staying on PA 29.

0.5 57.7 Borough of Montrose, county seat of Susquehanna County. Named after a town in Scotland, Montrose was laid out in 1812. When Susquehanna County was split off of Luzerne County in 1810, it was named the county seat (Blackman, 1873). In the pre-Civil War era, Montrose was an important way station on the Underground Railroad, in part because Susquehanna County at the time had a sizable African-American population—many of whom were former slaves (Adleman, 1997). During the war, at least 14 men from the county served in Colonel Robert Gould Shaw’s 54th Massachusetts Volunteer Regiment (Colored). The heroic, but futile, frontal assault of the 54th on Fort Wagner outside Charleston, SC, on July 18, 1863, was celebrated in the movie *Glory* (Figure 131).

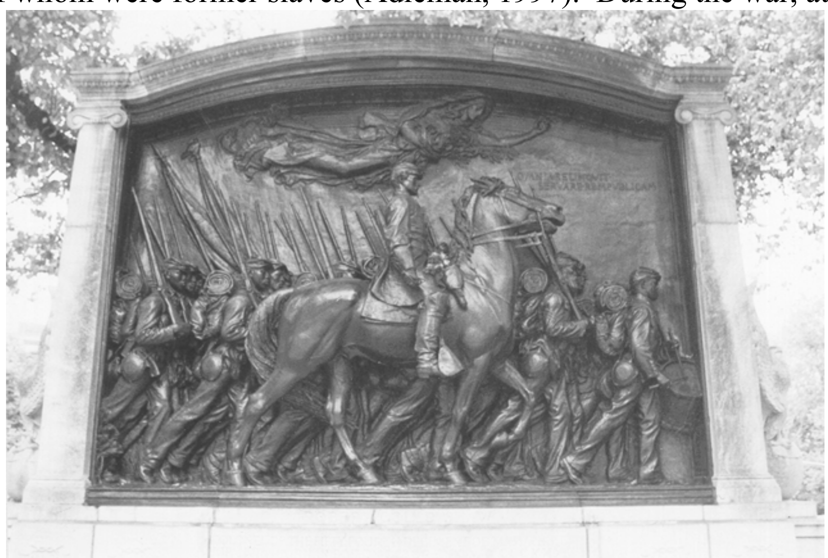


Figure 131. Detail of monument to the 54th Massachusetts Regiment on the Boston Common across from the State House, Boston, MA.

0.7 58.4 Traffic light. Turn left on PA 29 South, following signs to Tunkhannock. At the top of the hill to right is the Susquehanna County Court House, site of the sensational murder trial of Dr. Stephen Scher in the fall of 1997. Scher was convicted of killing Martin Dillon in a “hunting accident” twenty-one years earlier and was sentenced to life imprisonment. (He had married Dillon’s widow two years after the incident.) The Pennsylvania Superior Court overturned the verdict in April 1999, mainly on the basis of too much time having passed for a fair trial to be possible, and Scher was freed. In August of this year, however, the Pennsylvania Supreme Court overruled the lower court, and Scher was returned to prison. The defense is almost certain to make a final appeal to the U.S. Supreme Court.

1.7 60.1 To right are several low cuts in well-jointed gray Catskill sandstone. Farther to the right (west) the dump of an old quarry is visible on the hillside.

0.3 60.4 To right is yet another cut in well-jointed sandstone of the Catskill Formation.

0.7 61.1 Blinking traffic light in village of South Montrose; continue straight ahead.

1.5 62.6 To right is the “bluestone”-cutting operation of Delaware quarries. The “bluestone” is trucked in from their quarries in the area.

0.8	63.4	On right is a white hexagonal barn.
0.5	63.9	To right is a small new "bluestone" quarry.
0.2	64.1	On right is an unnamed artificial lake.
0.6	64.7	Blinking traffic light in village of Dimock.
3.1	67.8	Intersection in village of Springville.
0.6	68.4	Historical Marker to left reads: *Jonathan Jasper Wright (1840-1885). Jurist, educator, politician. The son of runaway slaves, Wright became the first black lawyer in Pennsylvania. He supported Frederick Douglass in advocating suffrage and legal equality for blacks. During Reconstruction in 1870, he was appointed South Carolina Supreme Court Justice, the first African-American United States Appellate Judge. Wright's boyhood home was here in Springville.* What the marker doesn't say is that at the end of Reconstruction in 1877 Wright was forced to resign from the South Carolina Supreme Court on an almost certainly trumped-up charge of "drunkenness." His reputation was further tarnished at the time by accusations of bribery brought against him by a patently corrupt former governor. Wright died of tuberculosis on February 19, 1885, and is buried in Charleston, South Carolina (Gergel and Gergel, 2000).
1.1	69.5	At the crest of the hill are massive outcrops of gray Catskill sandstone on both sides of road.
0.2	69.7	To left an artificial pond marks the headwaters of the North Branch Meshoppen Creek.
0.2	69.9	On left is another stone yard.
0.3	70.2	On right at top of hill is another cut in Catskill sandstone.
0.7	70.9	To right is another man-made lake impounded by an earthen dam.
1.2	72.1	Enter Wyoming County.
0.4	72.5	To right is a cut in well-jointed Catskill sandstone.
0.5	73.0	To right is a low cut exposing Catskill shale and sandstone.
0.3	73.3	Cross Meshoppen Creek.
0.3	73.6	To left along an abandoned Lehigh Railroad grade is an old sandstone quarry that exposes a 3-foot-thick, calcareous brachiopod-coquinite that D. Woodrow (2002, personnel communication) places in a stratigraphic position just above the Dunkirk Shale (New York State terminology). Willard (1939, p. 297-298) notes that this coquinite, which contains the Chemung "guide fossil" *Cyrtospirifer disjunctus*, may be the approximate correlative of the Luthers Mills coquinite of Bradford County.
0.4	74.0	Intersection in village of Lemon.
0.9	74.9	On right is Mud Pond, its level raised by a small artificial dam. The dam blocks a valley cut through a till knob that previously dammed the valley.
0.4	75.3	Enter the ¼-to-½-mile-wide track of the 1998 F-3 Lake Carey Tornado, with Lake Carey to left (Figure 132). The tornado, which struck on the 2nd of June, traveled from right to left (eastward), destroying or damaging 42 homes, killing two people, and leveling forests. You crossed the eastern end of the track at East Lemon on the first day of the field

Figure 132. Eastward track of the 1998 Lake Carey Tornado as seen from PA 29.

		trip (mile 4.6 of Day-1 Roadlog). The 38-mile-long track was aimed at the much larger town of Factoryville when the tornado lifted off the ground and dissipated.
0.2	75.5	To left is a better view of Lake Carey in area where the forest was leveled by the tornado. The lake is one of the largest lakes dammed by glacial deposits in the region.
0.3	75.8	Turn left onto SR 1003 and follow tornado track eastward.
0.3	76.1	Stop sign, continue straight ahead.
0.1	76.2	Start driving along a line of till knobs or a "morainic loop" across the valley that nearly divides Lake Carey into two separate lakes.
0.2	76.4	Cross causeway over the lake and immediately bear right and follow the east shore of the lake. Shortly you will leave the tornado track.
0.6	77.0	To right is the outlet to the lake with a 10 feet high human dam stabilizing the lake level. There is bedrock under the dam where the postglacial drainage from the lake "caught" the east bedrock wall of the buried valley. Beyond the dam, farther to the right, as much as 250 feet of till fills the preglacial valley
0.1	77.1	Bear right and head downslope. Shallow bedrock gorge to right.
0.1	77.2	Turn right onto SR 1001 and immediately cross bridge over outlet from lake. To left downslope, hidden by trees as usual, is a cascade of several waterfalls. For next 0.5 mile you are crossing the valley buried by the thick mass of till.
1.2	78.4	To left is yet another waterfall cascade beside yet another preglacial valley buried by till.
0.5	78.9	To right beside the road is a large rounded, rough textured boulder of phosphatic, "calcareous breccia" derived from the Catskill Formation. I. C. White (1881), in his report of the geology of Susquehanna and Wayne Counties, called such boulders "Nigger-Heads," a term that aptly describes their dark-brown to black weathering color, but is certainly politically incorrect by today's standards.
1.7	80.6	Bear sharply left at bottom of hill. Ahead and to right is Tunkhannock Creek.
0.2	80.8	To left is an abandoned gravel pit in ice-contact stratified drift.
0.1	80.9	To left is another gravel pit.
0.3	81.2	Stop sign, Turn right onto US 6.
0.1	81.3	Cross Tunkhannock Creek.
0.5	81.8	Turn right into main or west entrance to Shadowbrook Inn and Resort.
0.2	82.0	Parking lot of Shadowbrook. Disembark. Here's wishing those who depart here a safe trip home!

FOR THOSE WHO WANT TO GO ON THE LAST TWO STOPS (GRAVEL PITS IN A LARGE DELTA BUILT INTO GLACIAL LAKE BOWMAN), REASSEMBLE ON THE LEAD BUS. THE OPTIONAL TRIP WILL TAKE ANOTHER 1.5 HOURS.

		Leave Shadowbrook parking lot.
0.2	82.2	Turn right onto US 6.
0.4	82.6	Cross Tunkhannock Creek.
0.5	83.1	On right is an abandoned gravel pit in a kame composed of ice-contact stratified drift. It is now used as a bluestone storage yard.
0.1	83.2	Bear left across Tunkhannock Creek, staying on US 6.
0.2	83.4	Traffic light, continue straight ahead across terraces of Tunkhannock Creek.
0.2	83.6	To right is a distinct terrace-riser scarp separating two terrace levels.
0.3	83.9	Cross Tunkhannock Creek again.

0.1	84.0	Traffic light, turn left onto PA 29 South. US 6 continues ahead.
0.1	84.1	Begin crossing the North Branch Susquehanna River, now a much larger river than where we crossed earlier today at Great Bend. Along this reach of the river are a series of large incised meander bends. Some of those bends were seen on the optional pre-meeting trip to Wyalusing. Upstream to right, rock ledges are visible at low water on the south bank where the river is undercutting the mountain side.
0.5	84.6	To left is a broad outwash terrace that rises 60 feet above present river level.
0.4	85.0	Traffic light for Wal-Mart, continue straight ahead.
0.1	85.1	Descend outwash terrace riser to broad Holocene alluvial terraces developed where Bowman Creek cuts across the outwash terraces to enter the river to the right.
0.5	85.6	To right is an abandoned gravel pit at the mouth of a buried tributary valley. To the right of the pit and the partly disassembled house is a cascade of waterfalls on bedrock. We are now driving upstream in the northeast-draining Bowman Creek valley. The northeast-retreating glacier dammed a continuous series of proglacial lakes in this valley from its head at Ricketts Glen State Park to this point.
0.5	86.1	To right is a cut in Catskill sandstone.
0.1	86.2	Cross Bowman Creek.
1.0	87.2	Turn right onto SR 3003, beside the Sugar Hollow Diner.
0.1	87.3	Cross Bowman Creek and turn left onto Jadick Lane (T376).
0.2	87.5	Pull over onto broad shoulder on left side of road

STOP 11. BOTTOMSETS OF THE DELTA BUILT INTO GLACIAL LAKE BOWMAN.

Leader: Duane D. Braun

A large delta was built into the final phase of Glacial Lake Bowman when the edge of the glacier occupied the Susquehanna valley and just blocked the mouth of Bowman Creek. The delta is marked by two broad flat areas at 800 to 820 feet on the north side of Bowman Creek (Figure 133). The delta was fed by two sluiceways, Sugar Hollow on the northwest and Benson Hollow on the north. Broad terraces on the top of the delta graded to Sugar Hollow suggest that the delta was beginning to be incised while meltwater was still coming in from the west. Meltwater escaped eastward along the north flank of Miller Mountain and then down the southwest side of the Susquehanna valley. Two flat-topped remnants of that valley train remain on the flank of Miller Mountain. The more than 200 feet thick delta originally extended all the way across the Bowman Creek valley and dammed a postglacial lake in the Bowman valley. Postglacial incision of Bowman Creek and its tributaries carved the delta into its present two-part landform.

The overall stratigraphic sequence at the STOP is gravel overlain by sand that is in turn overlain by gravel capped by sandy silt. The lower gravel is interpreted to be an ice-contact, sub-lacustrine fan unit deposited when the ice-front was retreating past the site. The overlying rippled sands, with clay drapes that become more widely spaced upward in the sands, represents the progradation of the delta bottomsets and foresets across the site. The upper horizontally bedded gravel represents the topsets of the delta. The capping of sandy silt is windblown loess deposited when the delta top was beginning to be incised. Only the lower gravel and clay draped sand will be examined at this STOP (Figure 134). The upper gravel and loess will be examined at STOP 12.

The clay draped sands (Figure 135) are lake sediments that are near to or proximal to the sediment source. Some call such clay-draped sands proximal rhythmites. During the summer melt season several feet to even 10's of feet of sand are deposited. Then during the winter season the clay settles on top of the sand to form a thin clay drape. As the delta progrades across the site each season's sand layer gets thicker and the clay drapes get farther apart.

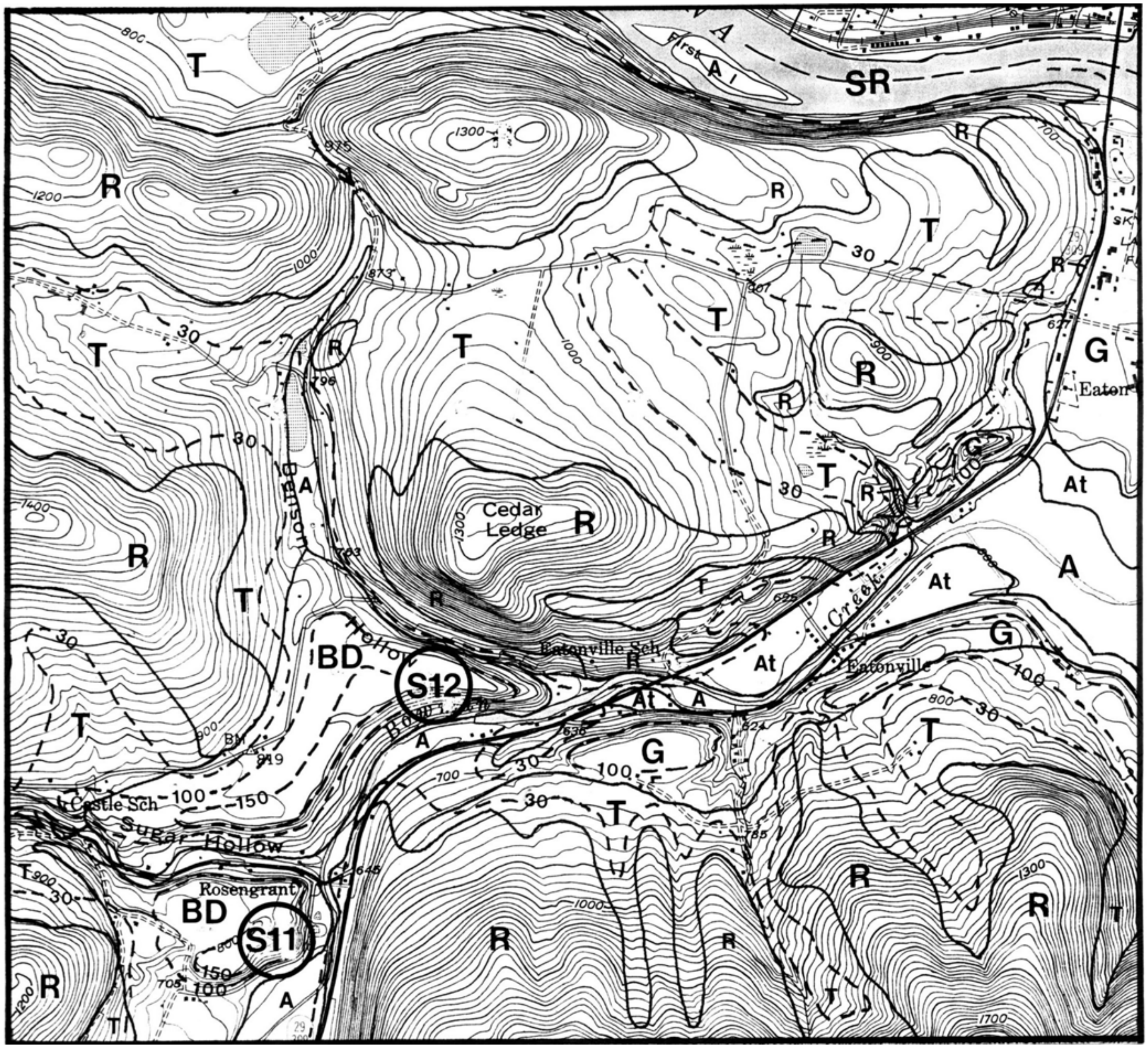


Figure 133. The Glacial Lake Bowman delta, marked by two broad flat areas at 800 to 820 feet on the north side of Bowman Creek (BD). G = outwash from delta or river (northeast G), A = alluvium, At = alluvial terrace, R = bedrock, T = till, SR = Susquehanna River. Isochores of surficial deposits at 30, 100, and 150 feet (Braun, 2002)

At this site the bedding is offset by faults (Figure 135 and 136) and tilted strongly to the west. The bedding should be tilted down towards the south in the direction that the delta was prograding into the lake. The faulting and westward tilt of the bedding has been caused by slumping of the outcrop, as Bowman Creek cut into the deposit in postglacial times.

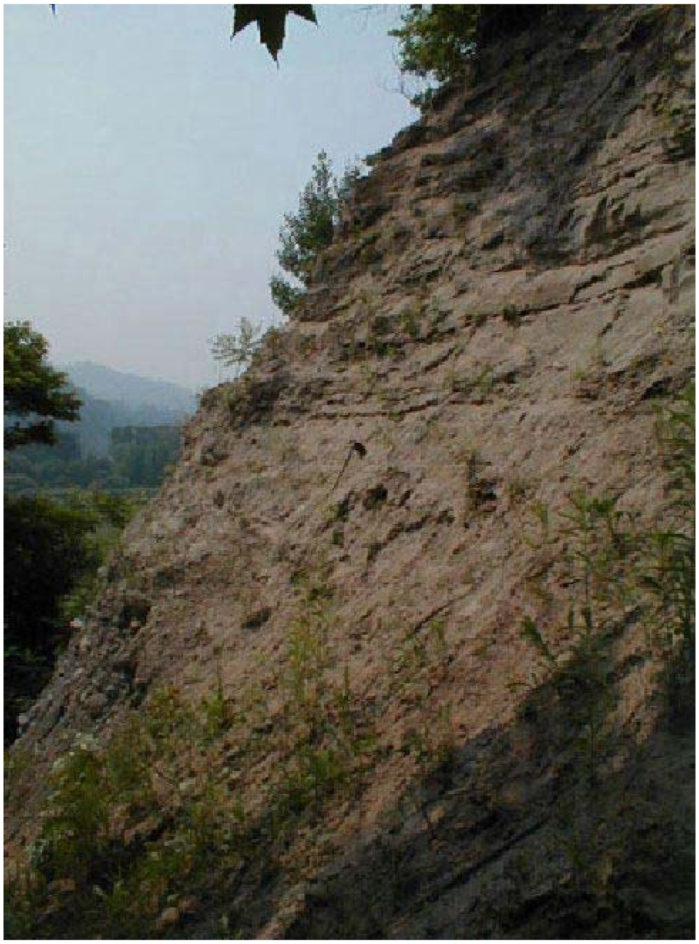


Figure 134. Photo of the outcrop face showing the lower sublacustrine gravel overlain by the sands with clay drapes. View to the south into the Bowman Creek valley. Trenching tool is 18 in long.

Figure 135. Close-up picture of the thin clay drapes (darker brown) and sand (lighter brown). The most distinct clay drapes are just above and below the scale. Also shown is a small-scale fault offset of the bedding caused by slumping of the outcrop.

Figure 136. Close-up of one of the offset clay drapes. Clay drape has a darker brown color as compared to the sands.

		Leave STOP 11, turning around and proceeding back the way you came.
0.2	87.7	Turn right and cross Bowman Creek.
0.1	87.8	Turn left onto PA 29.
1.0	88.8	Cross Bowman Creek and immediately turn sharply left onto Sand Bank Road that runs beside the creek. Another road at the intersection goes directly uphill.
0.5	89.3	On left across narrow valley are slide scars that expose sand and gravel of the delta. The stream valley the road follows runs along the contact between the bedrock hill on the right and the delta gravels on the left.
0.3	89.6	Turn left, continuing on Sand Bank Road and crossing the small stream.
0.3	89.9	Turn left into entrance to American Asphalt & Paving Co. Eatonville gravel pit.

STOP 12. TOP SURFACE AND TOPSETS OF THE DELTA BUILT INTO GLACIAL LAKE BOWMAN.
Leader: Duane D. Braun

At this STOP at the eastern end of the delta (see Figure 133), the topsets and loess cap are exposed. Most of the pit face is horizontally stratified pebble to cobble gravel with scattered boulders (Figure 137). At the top of the gravel is a boulder bed that may represent a lag left by the flood caused by the rapid, 600 feet lowering of Glacial Lake Mehoopany. That flood came down Sugar Hollow and out across the delta top. Above the boulder bed is a light brown layer of sandy silt that represents wind deposition of loess (Figure 138). There are a few pebbles in the loess probably caused by frost heaving from below during periglacial conditions.

Most of the gravel clasts are sedimentary rock from the region northeast of the site. A few percent of the clasts are sedimentary, metamorphic, and igneous rock from much farther north. The far traveled sedimentary material is gray chert from the Helderberg sequence in central New York. The far

Figure 137. West facing view of the pit face and top surface of the delta. The pile of boulders on the left has been mostly collected from a boulder bed at the top of the outcrop.

traveled metamorphic and igneous clasts are mostly quartzite, quartz-rich gneiss, and granite. The far-traveled erratic material is usually pebble sized though occasional cobbles are found.

The top of the pit stands at the highest level of the delta. To the west of the pit, there is a distinct step down to a lower level. This lower level represents the incision of the delta surface by meltwater from Sugar Hollow. As the glacier pulled back from the mouth of Bowman Creek a bit, lower channel ways along the southwest side of the Susquehanna valley would open up. This would permit incision of the delta surface and initial lowering of the lake level. This would also permit loess to be deposited on the highest part of the delta beside the active meltwater channel.

Figure 138. View of upper part of the pit face showing the top boulder bed and loess cap, 2 feet or so thick. Scraped off area at the center of the view best shows the light brown loess on top of the gray brown gravel. The tool head of the trenching tool beside the cleared area is 10 inches across.

		Leave STOP 12, turning right onto Sand Bank Road. Retrace route back to Shadowbrook Inn and Resort.
1.1	91.0	Turn left onto PA 29.
2.0	93.0	Finish crossing North Branch Susquehanna River.
0.1	93.1	Turn right onto US 6 East.
1.8	94.9	Turn left into entrance to Shadowbrook Inn and Resort.
0.2	95.1	Parking lot. Disembark. End of Day-2 Roadlog. Here's wishing you dedicated types a pleasant journey home—and don't forget to turn your lights on as you leave Shadowbrook!

POSTSCRIPT

And as a special treat for those of you who may have gotten the impression that there is no "structure" in the Endless Mountains except subhorizontal beds and "north-south" and "east-west" joints, we offer this concluding article.

THRUST-FAULT EXPOSURES IN THE ALLEGHENY PLATEAU BETWEEN WYALUSING AND WYSOX, PA

by
Norman M. Gillmeister

INTRODUCTION

Thrust faults have been described in the Allegheny Plateau section of northeastern Pennsylvania by Pohn and Purdy (1981) and Woodrow (1968). Excellent exposures in new roadcuts on US 6 at Wyalusing Rocks and east of Wysox indicate that thrust faults with relatively small net slip may be more common in the area than previously thought. The faults that can be observed in the exposures along US 6 are excellent examples of many of the structural features that are commonly associated with thrust systems and can serve as scale models for thrusts with large net slip.

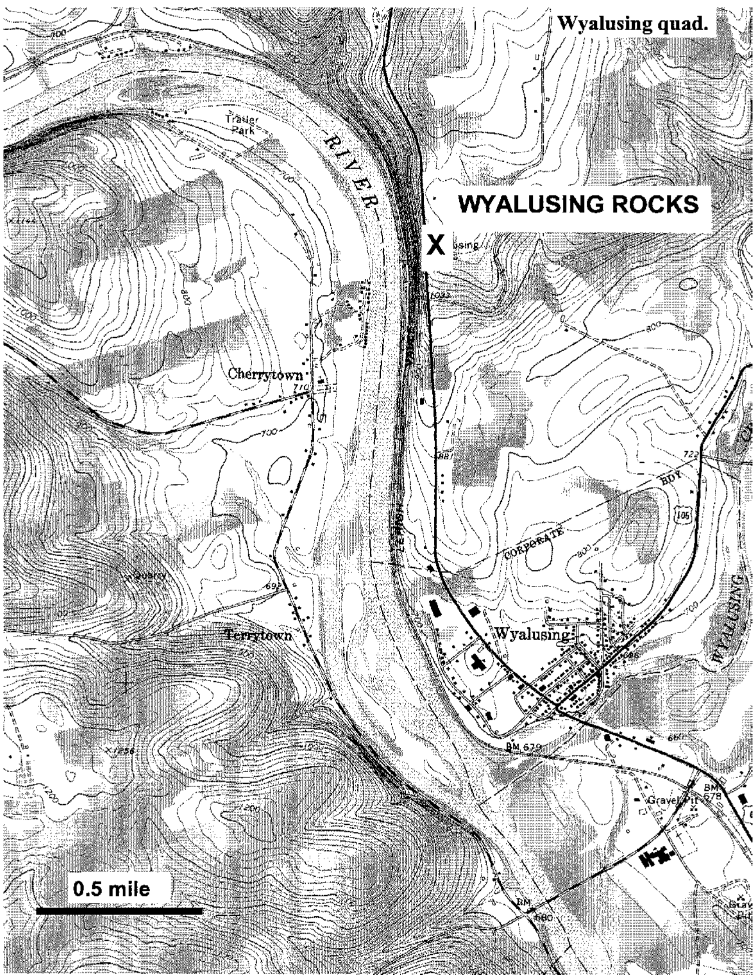


Figure 139. Location map for thrust-fault exposure on US 6 at Wyalusing Rocks.

FAULTS AT WYALUSING ROCKS

Two south-dipping thrusts faults cutting a thick marine interval in the lower Catskill Formation are exposed on the east side of US 6 about ¼ mile south of the parking area for the Wyalusing Rocks Scenic Overlook (Figure 139). Both faults are of small net slip and appear to have a flat-ramp-flat geometry, inasmuch as both probably propagate from a bedding parallel slip surface, then cut across bedding, and continue as an upper, bedding–parallel, slip surface. Bedding dips toward the Barclay syncline with an average orientation of E-W/10°S.

The lower slip surface is exposed to the north of the most northerly fault. The dip of that fault decreases as it cuts a coquinite bed near the base of the outcrop and becomes nearly parallel to bedding in a bed of gray shale below the coquinite. The shale horizon is tectonically disturbed for about 30 meters to the north of the fault exposure and probably represents a local décollement surface. The geometry of structures above the faults can be seen at the fault to the south. The dip of that fault decreases near the top of the outcrop and it then becomes parallel to bedding. There is a small fault-bend fold with angular (kink) geometry above the fault where it becomes bedding-parallel. These faults appear to be an example of a small fault duplex that transfers slip from a lower

Gillmeister, N.M., 2002, Thrust fault exposures in the Allegheny Plateau between Wyalusing and Wysox, PA, *in* Inners, J. D., and Fleeger, G. M., eds., From Tunkhannock to Starrucca: bluestone, glacial lakes, and great bridges in the "Endless Mountains" of northeastern Pennsylvania: Guidebook, 67th Annual Field Conference of Pennsylvania Geologists, Tunkhannock, PA, p. 135 - 138.

décollement, or sole thrust, in the gray shale horizon to an upper bedding-parallel roof thrust (see, for example, Suppe, 1985, or Davis and Reynolds, 2000, for an explanation of terminology).

Figure 140. View looking east at the northernmost fault in the roadcut at Wyalusing Rocks. The longer-stemmed arrow indicates the main thrust fault that cuts the coquinite bed at the base of the exposure. Note the listric nature of the fault. The short-stemmed arrow indicates the small synthetic thrust fault that envelops a triangular zone of deformed hanging wall rocks. The other dashed lines indicate small north-dipping (that is, antithetic) back thrusts. The third arrowhead points to a hammer that is 40 centimeters long. The lower back thrust has an orientation of N55°W/21°N near the hammerhead.

The faults differ in many respects. The southern fault has a larger net slip of about 1 meter and a fault zone that varies in thickness from 1 centimeter to about 30 centimeters. The average dip of the fault is 27°S and it strikes N80°W. Small drag folds with angular parallel geometry plunge to the east at low angles and indicate a transport direction to the north by their asymmetry. The northern fault has a net slip of about 0.5 meters and a steeper average dip of 38°S. Two small back thrusts occur in the hanging wall of that fault in a triangular zone of rocks that is bounded by a small, curved, synthetic thrust that separates this deformed wedge of rocks from the rest of the hanging wall rocks (Figure 140). The origin of back thrusts and minor folds is particularly well exposed near the coquinite bed (Figure 141).

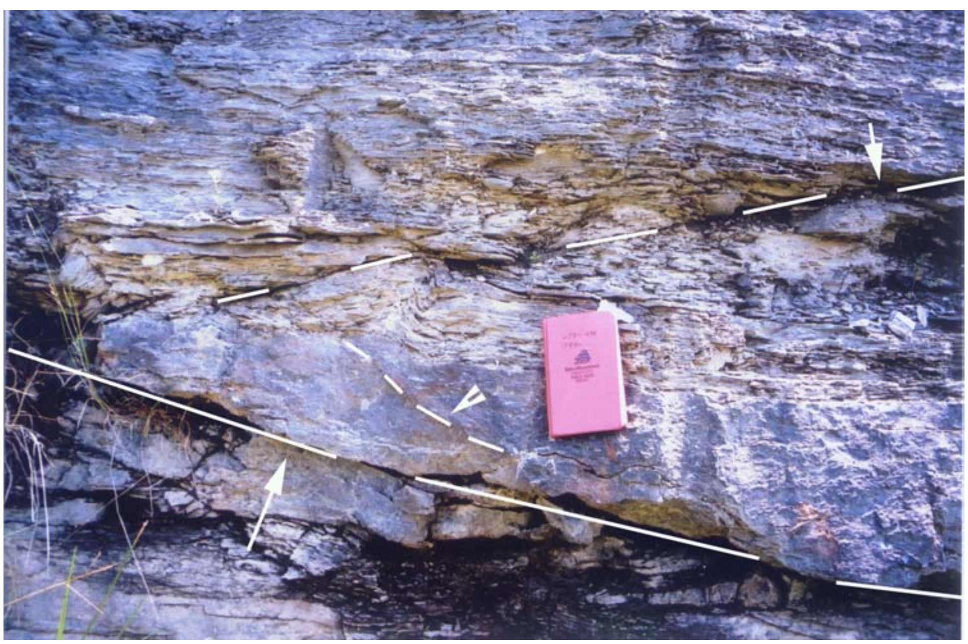


Figure 141. A detailed view of the lower part of Figure 140, showing a scale model of thin-skinned tectonics. The long-stemmed arrow indicates the south-dipping thrust fault, where it cuts the coquinite bed. The short-stemmed arrow indicates the north-dipping back thrust that originates at the larger fault. The third arrowhead points to a small synthetic thrust fault in the coquinite layer that has resulted in the formation of a "snakehead" structure. An asymmetric drag fold (steep limb to the south) has formed directly above the "snakehead". The notebook is 19 by 12 centimeters in size.

FAULTS NEAR WYSOX, PENNSYLVANIA

Conjugate thrust faults are well exposed in a high roadcut through the Lock Haven Formation (Wiscoy Formation of Woodrow, 1968) on the east side of US 6 about 2 miles east of Wysox, Pennsylvania (Figure 142). The locality appears to be

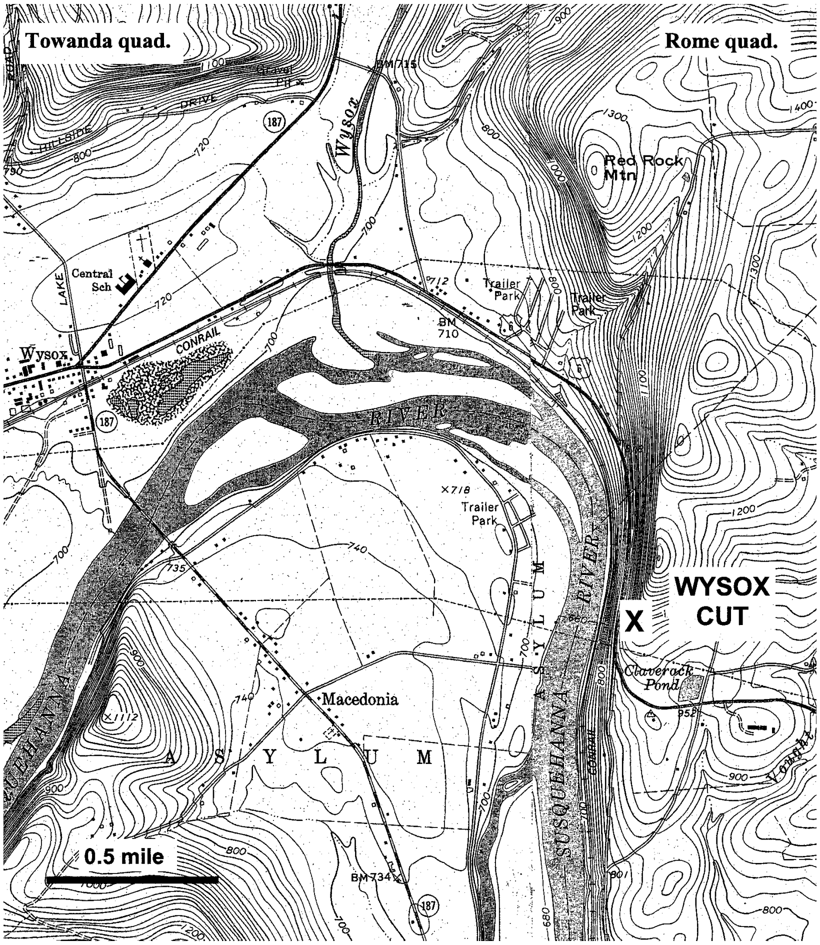


Figure 142. Location map for thrust-fault exposure on US 6 near Wysox.

at the hinge of the Towanda anticline inasmuch as bedding is essentially horizontal away from the immediate vicinity of faults. Two prominent south-dipping faults in association with a least three north-dipping antithetic thrusts represents a reasonably complex thrust system (Figure 143) that has the net effect of not only shortening the rocks horizontally, but also of displacing them upward by about 10 meters in the hinge zone of the anticline. The maximum compressional stress appears to have been oriented essentially N-S during formation of the faults.

South-dipping faults. The northernmost of these faults has an approximate orientation of N75° W?/ 28°S and a net slip of about 4 meters. The upper end of the fault ramp becomes a bedding-parallel slip surface in a dark gray shale bed. A prominent fault-bend fold is developed over the end of the fault ramp, forming a spectacular example of a classic "snakehead" or fault-bend fold structure (Figure 143). The footwall rocks are cut by a number of small, conjugate thrust faults with flat-ramp-flat geometry or curved fault surfaces.

The southern fault has a net slip of about 6 meters and appears to cut all rocks to the top of the roadcut, that is, about 100 meters above the level of the road. This fault may also be the one exposed along the railroad tracks below the highway.

Drag folds are present in both the footwall and hanging wall rocks and a brecciated zone up to 0.5 meters thick is present. Cracks in brecciated rocks are partially or completely sealed with quartz, pyrite, hematite and a brown-weathering carbonate with saddle-shaped crystals, presumably dolomite. The fault surface is irregular, but a slickensided surface is oriented at N55°W/44°S. Details of the fault zone are shown in Figure 144.

Exposures of the fault zone along the railroad tracks that parallel the east bank of the Susquehanna River are somewhat different in detail. There the thrust fault has a nearly E-W strike and the dip varies from 55°S to 32°S. The lowermost exposure of the fault consists of an upper fault gouge about 40 centimeters thick, followed by a sequence of intensely folded rocks at least 2 meters thick, with a second fault surface inferred to be present below that.

North-dipping faults. Two north-dipping thrust faults are exposed south of the larger, through-going, thrust fault described above. The lower of the north-dipping faults begins as a ramp, with a dip of about 10°N, in the hanging wall of the large fault (Figures 143 and 144), and then becomes bedding-parallel at the top of a prominent black shale unit. Net slip on the fault appears to be about 3 meters.

The upper fault forms by the coalescence of two small ramps, becomes bedding-parallel at the base of the black shale unit, and then continues as a ramp with an apparent dip of 15°N to the top of the roadcut. The combined slip of the two faults causes a pronounced local thickening of the black shale master bed. Net slip on the upper fault appears to be about 5 meters.

A third prominent north-dipping thrust is present toward the top of the roadcut, but is only visible from the west bank of the North Branch Susquehanna River (Figure 143).

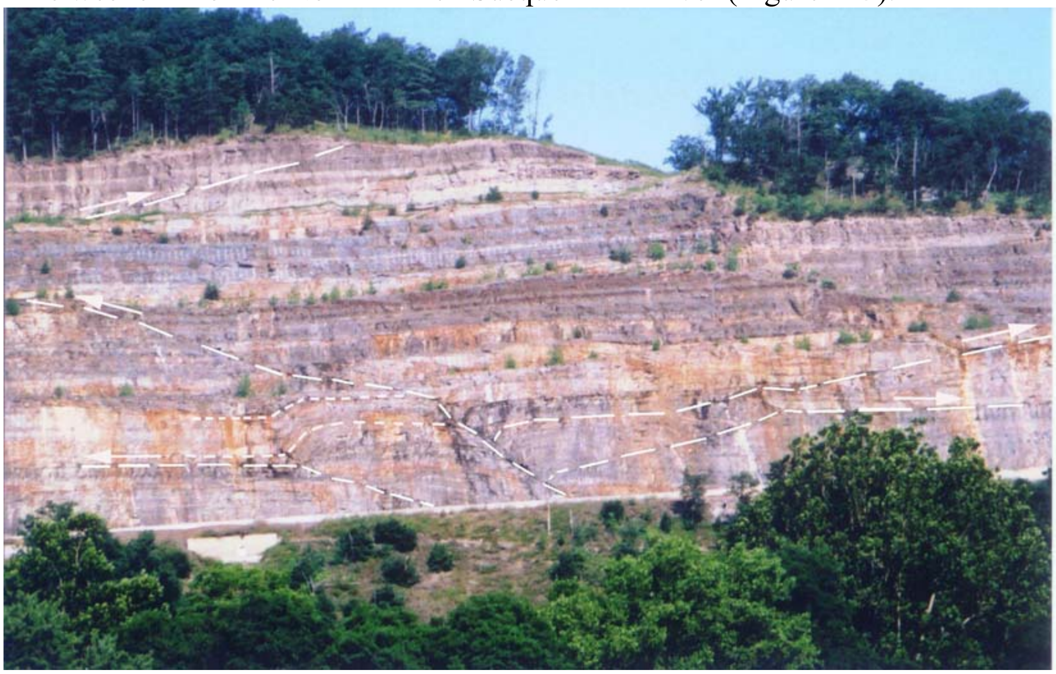


Figure 143. View of the US 6 roadcut near Wysox, looking east across the North Branch Susquehanna River. Longer white dashes locate two south-dipping and three north-dipping thrust faults. Shorter dashes outline bedding in the "snakehead" structure. Note that north-dipping faults are confined to hanging wall rocks of the larger south-dipping fault. The maximum vertical displacement of rocks between the conjugate fault sets is about 10 meters. The retaining wall along the road is the linear white feature in the lower part of the view.

Figure 144. View, looking east, of the most southerly thrust fault exposed along US 6. Fault surfaces are shown by bolder, solid lines. Dashed lines indicate the trace of bedding. Note the presence of drag folds in both footwall and hanging wall rocks and the absence of drag folding in immediately adjacent rocks. The north-dipping fault at the upper right is the lowest one shown in Figure 143. The fault features here are similar to those described by Pohn and Woodrow (1981) for the Bridge Street Fault in Towanda, Pennsylvania, which is located 4 miles due west of this site. The bold arrow points to a notebook 19 by 12 centimeters in size.

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